PEOPLE'S REPUBLIC OF BANGLADESH

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DATA COLLECTION SURVEY ON WATER RESOURCES DEVELOPMENT IN SOUTHERN CHATTOGRAM

FINAL REPORT

AUGUST 2022

JAPAN INTERNATIONAL COOPERATION AGENCY

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NKECJ CONSORTIUM

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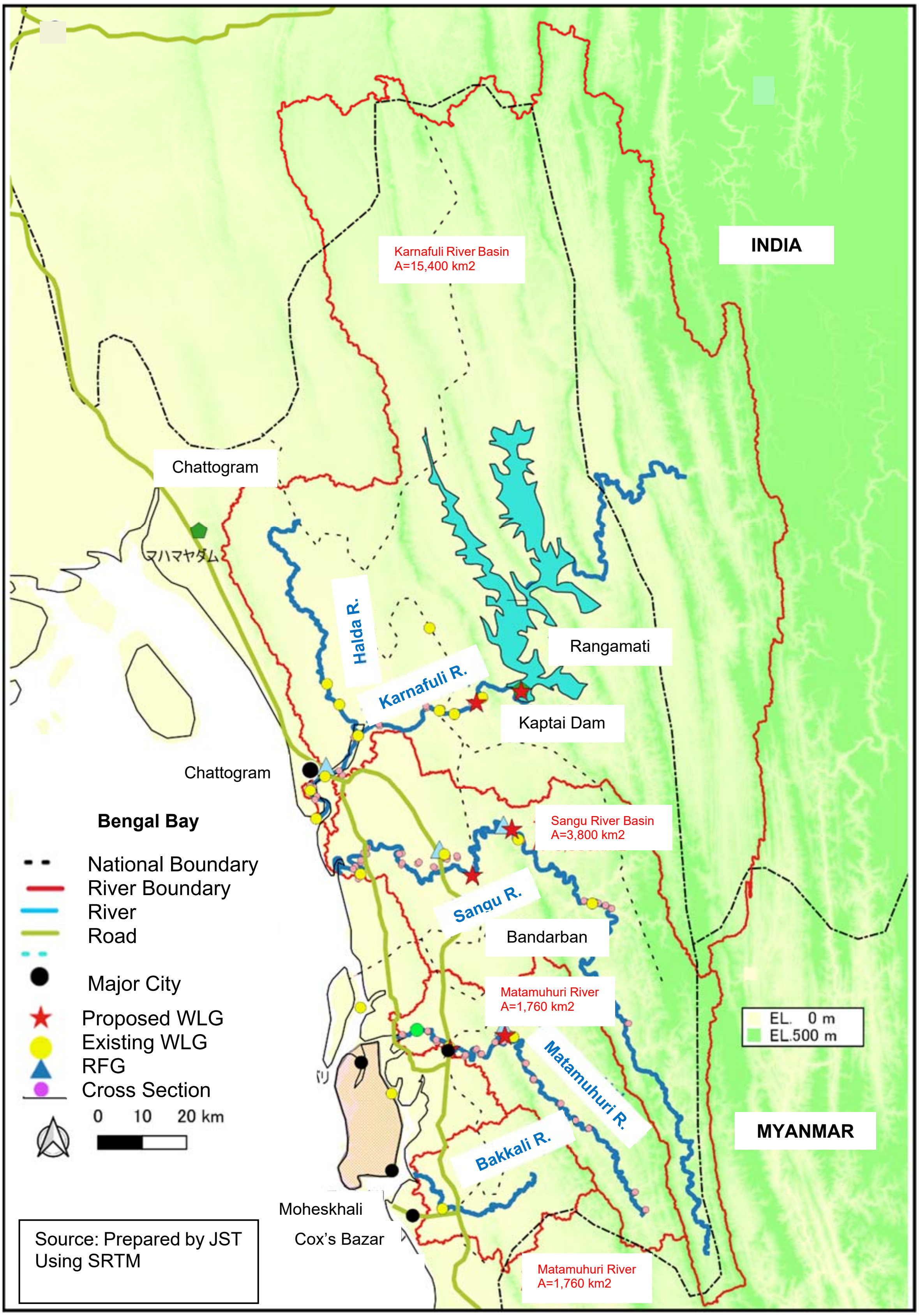
（As of April 2022）

Location Map



I INTRODUCTION

1.1 The objectives of the Survey are:

(1) Survey of present available water resources and water usage in southern Chattogram region,

(2) Forecast of future water demand, taking into consideration the comprehensive development plan in the Moheshkhali/Matarbari region, and

(3) Preliminary study on candidate sites of water sources and water-use facilities (water resources development method).

1.2 The survey area is the southern Chattogram region in the Chattogram Division of Bangladesh, of which the location map is shown in the frontispiece of this Final Report.

1.3 This Final Report is submitted as the final output of the survey work which was conducted from the commencement of the Survey in mid-December 2019 through mid-August 2022.

II COMPONENT 1 : ANALYSIS OF CURRENT SITUATION OF WATER RESOURCES IN SURVEY AREA INCLUDING AVAILABLE WATER RESOURCES THROUGH FIELD SURVEY

Creation of Technical Working Group

2.1 Both the Bangladeshi and Japanese sides discussed and created "Technical Working Group (hereinafter referred to as "the TWG")", in order to establish a high-level cooperation system consisting of the related Bangladeshi organizations for the Survey. The TWG is chaired by the Senior Secretary of MoWR. Furthermore, a Sub TWG was also created under the TWG, which acts as a coordinating body. The Sub TWG is divided into three (3) groups, namely (i) Surface Water/Water Demand, (ii) Ground Water, and (iii) Environment.

2.2 During the first field survey, the 1st TWG meeting was held on 19 January 2020 and the Sub TWG meeting for Surface Water/Water Demand was held on 4 February, respectively to explain and exchange opinions on the survey outline and establishment of the TWG.

Field Works

Surface Water Survey

3.1 Water level observations have been being implemented in the Karnafuli, the Halda, the Sangu and the Matamuhuri Rivers at 14 water level gauge (WLG) stations in total, out of which 7 stations have recorded the water levels continuously for more than 50 years after 1965.

3.2 Staff-gauges and water level sensors (pressure type) were installed in this survey on 30 January

2020 in each of the said 4 Rivers (4 locations in total) for the purpose of verifying the accuracy of existing water level data (observation period at the 4 locations: 1 February 2020 to January 2021). At the 4 locations, discharge measurements were also carried out periodically with an Acoustic Doppler Current Profiler (ADCP), more than once a month, excluding the period from mid-March to the end of May 2020 due to COVID-19. The accuracy of BWDB's observation data was verified by comparing them with the measurement values of the JICA Survey Team. The verification results are stated in the following "4.1" and "4.2".

3.3 Water quality monitoring of surface water was conducted in the said 4 rivers from February 2020 to May 2021. In Bangladesh, the "Environmental Conservation Rule" stipulates the standards for environmental water as a source for drinking water as shown in the table below, whereas no specific environmental standard for agricultural, industrial and fishery water is stipulated.

Items (Unit)	pH	BOD（mg/l)	DO（mg/l)	Total Coliform Number/100
Environmental Standard as source of drinking water	6.5-8.5	2 or less	6 or above	50 or less

Source: Environmental Conservation Rule 1997, Bangladesh

(1) Lake Kaptai

The COD value is high and the pollution is extremely advanced. One possibility is that pollutants, such as domestic wastewater, are regularly flowing in from the areas around the dam lake. Besides, human waste in the upstream area flowed in during the inflow of surface water in the rainy season. Since the COD value is very high and mercury and cadmium are detected in the dry season, it is necessary to consider the utilization only in the rainy season as a water source for clean water. For industrial water use, pH and alkalinity should be controlled within appropriate ranges, and the turbidity should be controlled by precipitation and filtration. Manganese and iron need to be removed by contact filtration or the like. In addition, since zinc levels exceed the standard values for many months, it is necessary to consider the effects on aquatic organisms over the medium term to long term and reduce them with appropriate policies and measures. It is recommended to conduct further precise monitoring so as to make an appropriate judgment regarding water utilization in consideration of the timing of use, policies for pollution load reduction, necessary treatments, and their economic efficiency.

(2) Halda River

E. coli and turbidity values are high overall, and the BOD value also exceeds the standard for many months. One possibility is that pollutants, such as domestic wastewater from the upstream area, may be normally flowing in, and pollutants may have flowed in due to human waste, sewage, etc. during the period when the turbidity increased. It is considered that there is almost no influence by saltwater. Since the BOD, as well as E.coli, are very high, lead is detected in the rainy season and cadmium is detected in the dry season. It is recommended to conduct further precise monitoring to clarify the pollution source, consider whether it is derived from water-soluble/suspended solids, and evaluate the accuracy of analysis, aiming at making an appropriate judgment regarding water utilization in consideration of the timing of use, policies for pollution load reduction, necessary treatments, and their economic efficiency.

For industrial water use, alkalinity should be controlled within appropriate ranges, turbidity should be controlled by precipitation and filtration, and iron needs to be removed by contact filtration or the like. In addition, since zinc levels exceed the standard values for many months, it is necessary to consider the effects on aquatic organisms over the medium term to long term and reduce them with appropriate policies and measures.

(3) Sangu River

E. coli and turbidity values are very high, and the BOD value also exceeds the standard for many months. One possibility is that pollutants, such as domestic wastewater from the upstream area, may be normally flowing in, and pollutants may have flowed in due to human waste, sewage, etc. during the period when the turbidity increased. It is considered that there is almost no influence by saltwater. Since the BOD values, as well as E.coli values, are very high, and the Fluoride value also exceeds the standard, it is appropriate to make a judgment in consideration of the effectiveness and economic efficiency of the processing technology in the existing processing facilities.

For industrial water use, pH and alkalinity should be controlled within appropriate ranges, the turbidity should be controlled by precipitation and filtration. Iron needs to be removed by contact filtration or the like. In addition, since zinc levels exceed the standard values for many months, it is necessary to consider the effects on aquatic organisms over the medium term to long term and reduce them with appropriate policies and measures.

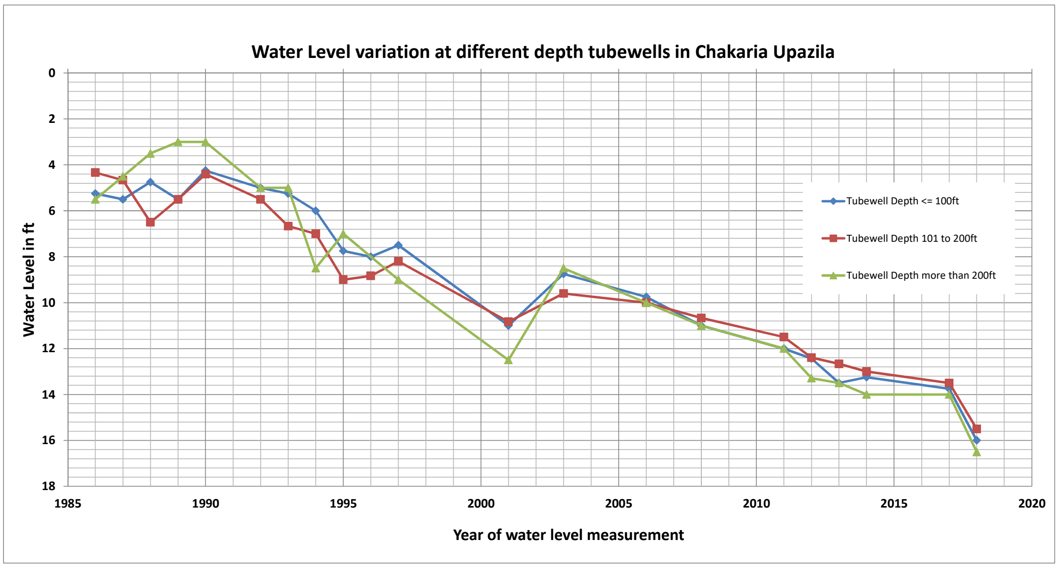
(4) Matamuhuri River

E. coli and turbidity values are very high, and the BOD value also exceeds the standard for many months. One possibility is that pollutants, such as domestic wastewater from the upstream area, may be flowing in during the period when the turbidity is high, and pollutants may have flowed in due to human waste, sewage, etc. during the period when the turbidity increased. It is considered that there is almost no influence by saltwater.

Since the BOD values, as well as E.coli values, are very high, the Fluoride value also exceeds the standard. Besides, cadmium is detected in the dry season, and therefore it is necessary to consider the utilization only in the rainy season as a water source for clean water. In addition, it is recommended to conduct further precise monitoring to clarify the pollution source, consider whether it is derived from water-soluble/suspended solids, and evaluate the accuracy of analysis, aiming at making an appropriate judgment regarding water utilization in consideration of the timing of use, policies for pollution load reduction, necessary treatment, and their economic efficiency. For industrial water use, pH and alkalinity should be controlled within appropriate ranges, the turbidity should be controlled by precipitation and filtration, and iron needs to be removed by contact filtration or the like. In addition, it is necessary to consider the effects on aquatic organisms over the medium term to long term and reduce them with appropriate policies and measures since zinc levels exceed the standard values for many months.

Groundwater Survey

3.4 Ground water level monitoring has been carried out by DPHE, BWDB and BADC. Ground water level fluctuation from 1986 to 2018 in Chakaria is shown in the figure below as a typical example by using the data of DPHE. In addition, the table below shows the amount of the declination of ground water level in the same period. Three (3) lines in the figure show average ground water levels of three (3) groups of boreholes: boreholes with depths up to 100 feet, 101 to 200 feet and more than 200 feet.



Source: JICA Survey Team. Data of DPHE was used.

Depth of well	Ground Water Level (m)		Declination of Ground Water Level (m)	Average Declination of Ground Water Level (m/year)
	1986	2018		
Up to 100 feet (less than about 30m)	1.6	4.9	3.3	0.10
101 to 200 feet (about 30 to 60m)	1.3	4.7	3.4	0.10
200 feet or more (about 60m or more)	1.7	5.0	3.3	0.10

Source: JICA Survey Team

3.5 Ground water levels have been declining since 1986 in all of three (3) borehole groups. The amounts of ground water level declination are in the range between 3.3 and 3.4 m in 32 years, showing similar behaviors, and the average amount of water level declination is 0.10 m/year. As three (3) groups of boreholes are extracting ground water from aquifers with different depths, it is highly possible that there may be some connections among the aquifers.

3.6 In the survey, thirteen (13) parameters of ground water quality were measured in 104 wells (38 for Chakaria, 19 for Moheshkhali, 27 for Cox's Bazar and 20 for Ramu). These parameters are pH, Electric conductivity (EC), Turbidity, Color, Ammonia Nitrogen, Nitrate Nitrogen, Iron, Manganese, Arsenic, Temperature, Nitrite Nitrogen, Total Coliform and Faecal Coliform.

3.7 As a result of the geophysical exploration in the survey area, it was revealed that it cannot be expected that a new aquifer other than the previously developed aquifer will exist at a depth of 300 m or more.

Kaptai Dam Survey

3.8 The reservoir water level at the Kaptai Dam is operated in the range from 76 feet up to 109 feet (water level at the start of spillout operation). The reservoir operation has not changed significantly since the start of operation after construction in 1962. From 1 February in each year, the Nos. 1 to 5 turbines are used in sequence to discharge as required in order to prevent downstream salt water intrusion and to supply water for Chattogram in the dry season. However, this is only a matter of verbal understanding with the parties concerned. The basic purpose of the lake water discharge is for hydro-power generation, and not for water supply to the downstream. According to the Kaptai Dam staff, the sedimentation of the reservoir has been currently hindering the navigation of vessels in the lake, and a dredging plan is formulated through BIWTA's survey as of May 2022.

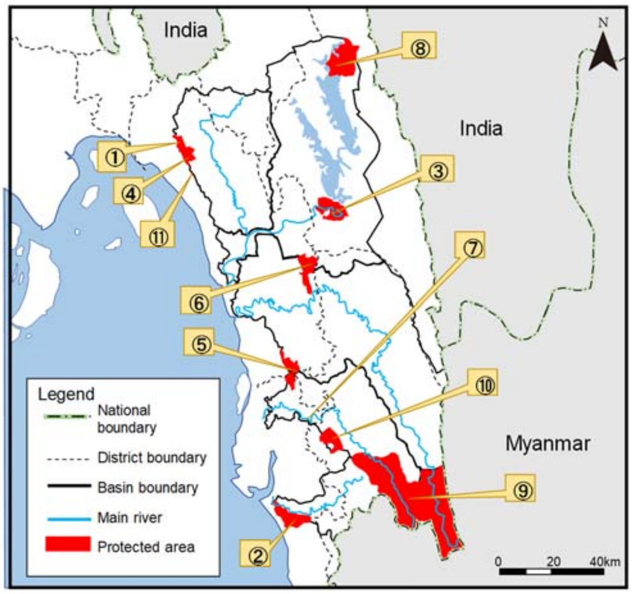
3.9 Based on the records of the power generation and lake water release from the spillways from 1988 to 1997 and 2012 to 2018, the average annual spillout volumes of lake water are 1,542 million m^3 and 939 million m^3, respectively. It is considered that it might be possible to develop new water resources by improving the dam operation and reducing the said lake water spillout. For example, if 70% of this spillout water is distributed constantly during the dry season of 6 months, it is calculated that a flow of about 41 to 68 m^3/s, equivalent to about 8 to 14 % of the annual mean discharge at the Kaptai Dam, would be generated for the downstream.

Basic Environmental Survey

3.10 There are three national parks, six wildlife reserves, one large reserved forest and one eco-park designated in the survey area, as presented in the following table and figure.

No.	Name	Category
1	Baroiyadhala	National Park
2	Himchari	National Park
3	Kaptai	National Park
4	Hajarikhil	Wildlife Sanctuary
5	Chunati	Wildlife Sanctuary
6	Dudpukuria-Dhopachari	Wildlife Sanctuary
7	Fasiakhali	Wildlife Sanctuary
8	Pablakhali	Wildlife Sanctuary
9	Matamuhuri	Reserved Forest
10	Sangu	Wildlife Sanctuary
11	Sitakundu	Eco-park

Source: Department of Forest



Source: Department of Forest

3.11 Many of valuable species recorded in the survey area are mammals, according to the literature survey, such as Asian elephant, Asiatic black bear, Western hoolock, gibbon, Phayre's leaf monkey, Eurasian otter, Smooth Indian otter, Sambar deer defined as Critically Endangered (CR) species, and Rufous-tailed hare/Fishing cat defined as endangered (EN) species.

3.12 According to the GOB's census in 2010, the population of indigenous and ethnic people in Bangladesh was approximately 1.6 million, equivalent to 1.8% of the total population of the country at that time. Around 80% of these indigenous people live in the northern and south-eastern flat land of the country, and the others live in the Chattogram Hill Tracts (CHT).

3.13 According to interview with Cox's District Land Management Office, the proposed site for regulation pond is owned by Cox's Bazar District. Therefore, private land acquisition will not be expected for construction of the regulation pond. In the northern area of the proposed site, several local communities are existing with around 200 of households according to field reconnaissance, but no residence is confirmed within the proposed area. Therefore, resettlement will not be expected by construction of the regulation pond. Land use of the proposed site is salt farms and shrimp ponds leased from Cox's Bazar District of which the contract period is 10 years. Although the number of the lessees in the proposed site is uncertain and to be confirmed in the next survey phase, but it is supposed that there are around 100 of lessees contract with Cox's Bazar District according to interview with Cox's Bazar land management office and 30 of lessees during the survey. It is required to survey lessee's income level particularly. According to preliminary interview in this Survey, annual income of the lessees is around 300,000 BDT. Since these lessees' livelihoods will be affected due to construction of the regulation pond, it will be necessary to prepare livelihood restoration program.

III COMPONENT 2 : THROUGH ANALYSIS OF SURVEY RESULTS, WATER RESOURCES ANALYSIS AND WATER DEMAND FORECAST

Data Analysis and Model Construction

Verification and Analysis of Hydrological Observation Data

4.1 Through verification of the reliability of past discharge data observed from 1966 to 2019 at three stations (Panchpukuria, Bandarban and Lama) by BWDB, the following issues were found.

(1) Lama Station (Matamuhuri River)

Significant trend changes in discharge conditions were confirmed from 1995 to 2015. Since such changes are not confirmed from the amount of rainfall, it is assumed that some kinds of errors occurred in the water level observation and/or the process of converting the water level to the discharge. In addition, since the annual runoff ratio shows very large values during the period from 1966 to 2011, it is inferred that some errors occurred in the process of generating time-series discharge data during this period as well.

(2) Bandarban Station (Sangu River):

In both the time-series data and annual runoff ratios, quite low values were confirmed in 1995 only. It is presumed that some errors occurred in the process of generating time-series discharge data during the year.

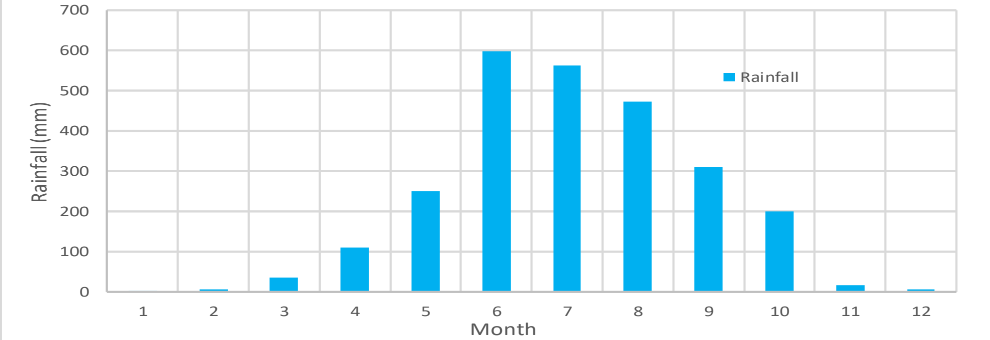
(3) Panchpukuria Station (Halda River):

The values of annual runoff ratios are extremely high during the period from 1974 to 1999. The time-series discharge data is missing during the other three periods of 1971-72, 2002-03 and 2005-06. In addition, the river water level has continuously decreased due to the sand mining of the riverbed since 2007, and water intake from the rubber weir constructed upstream of the Panchpukuria Station has been being carried out since 2012. Due to these artificial influences, the reliability of time-series discharge data after 2007 is assumed to be low.

4.2 In order to solve these issues, the time-series discharge data at the Bandarban Station, which ensures the reliability of time-series data for most of the period, was updated only in 1995. Then, those of the Lama (1966-2015) and the Panchpukuria (1971-2019) Stations, which are unreliable for many periods, were updated through converting from the highly reliable Bandarban discharge data by using correlating equations.

Precipitation Analysis

4.3 Bangladesh belongs to the area of tropical monsoon climate with high temperature and humidity, and is located in the course of the cyclone which occurs in the Indian Ocean, suffering an intensive rainfall in a short period of time, and the Chattogram Hill Tracts (CHT), situated in this survey area, lies in the cyclone-prone area, which has an annual rainfall of 2,500 mm and is the second highest rainfall area in Bangladesh. The climate in Bangladesh is classified roughly into the rainy season from April to October and the dry season from November to March. In the rainy season, rainfall is much higher especially from May to October due to the influence of the monsoon, accounting for about 90% of the annual rainfall. At the Bandarban Station, as presented below, the rainfall from May to October is 2,392 mm, equivalent to 93% (= 2,392 / 2,568).



Rainfall Sta.: Bandarban WLG Sta.: Bandarban C.A.: 2199 km^2

Item	Unit	1	2	3	4	5	6	7	8	9	10	11	12	Ave.	Tot.
Rainfall	mm/month	1	6	35	110	250	597	563	473	309	200	18	6	214	2,568

Source: Prepared by JICA Survey Team based on data (2010 to 2019) at Bandarban rainfall station, BWDB

4.4 Regarding the average rainfalls over the watersheds in the respective river basins of the Karnafuli, the Sangu and the Matamuhuri Rivers, some trends on watershed rainfall have been found that those in a whole year and the rainy season have an increasing trend, while that in the dry season has a decreasing trend in each basin, based on the 54 year time-series rainfall data.

Provisional Settings of River Maintenance Flow

4.5 In Bangladesh, the term "environmental flow" is more commonly used than "river maintenance flow". As a result of literature review, the concept of "environmental flow" is a relatively new one in the country, and there is no legal requirement for assessing the environmental flow of rivers. However, an environmental impact assessment (EIA) is essential as a requirement for a water resources development project, and the EIA itself includes analysis of river flow and evaluation of impact on flow reduction. The river maintenance flows of the 3 object rivers are provisionally set for the Survey, as compiled below.

Discharge Data (Observation)

River		Karnafuli (Halda)	Sangu	Matamuhuri
Station		Panchpukuria	Bandarban	Lama
Period		1966/1/1-2019/12/31	1966/1/1-2019/12/31	1966/1/1-2019/12/31
Catchment Area (km^2)	Total	1,758	3,663	2,511
	at WL gauge	856	2,199	1,201
Discahrge (m^3/s) @ WL Station	Mean Annual Flow (MAF)	27.36	92.26	49.05
	95% discharge:	1.23	4.13	2.14
	85% discharge:	1.89	6.45	3.51
	50% discharge:	7.16	23.43	13.25

Maintenance Flow (preliminary estimation)

River		Karnafuli (Halda)	Sangu	Matamuhuri
Station		Panchpukuria	Bandarban	Lama
(1) Method in Japan	$0.73m^3/s/100km^2$	12.8	26.7	18.3
(2) Methods in Bangadesh	Tenanto method (10% of MAF)	2.7	9.2	4.9
	FDC method (90% discharge in dry season)	0.9-3.8	3.0-13.1	1.6-7.0
	FDC method (90% discharge in wet season)	18.8-49.5	62.0-167.4	32.3-90.0
(3)-1 Method in Indonesia	95% discharge	1.2	4.1	2.1
(3)-2 Method in Philippines	90% of the 85% discharge	1.7	5.8	3.2

Source: JICA Survey Team

4.6 In the Karnafuli River, the concentration of salt increased significantly in 2007 at the potable water intake point. Therefore, BWDB carried out an investigation to grasp the actual situation, resulting in the estimation that the river stretches over 40 km from the estuary were affected by salinization. Based on this result, a memorandum between BWDB and the dam managers was exchanged in relation to the operation of the Kaptai Dam, in which it was stipulated that at least two power generation units must be operated so as to release discharges to the downstream, and then maintenance discharges have already been secured.

Ground Water Development Potential

4.7 The ground water potential of the survey area is examined in terms of ground water level fluctuation and macro water balance.

(1) Fluctuation of ground water level

The monitoring results of ground water levels (1986 to 2018) in shallow and deep wells owned by DPHE in the four (4) Upazilas of Chakaria, Moheshkhali, Cox's Bazar and Ramu, present a common tendency of groundwater level, which declined faster after around 2000, while there are some differences in behavior of ground water level, which suggest that there was some event around 2000 that increased the amount of ground water extraction. However, no clear data or information is available at this moment.

In the survey area, the fluctuations of ground water level behaved more or less in the same way in the shallow and deep wells except for Ramu, so even if they are separated by aquicludes, they may be hydro-geologically connected to each other in some places.

(2) Ground water balance

The amount of ground water extraction in the whole survey area is estimated at about 156.7 x 10^6 m^3/year in total, as tabulated below.

	Shallow Well (m^3)	Deep Well (m^3)	Total (m^3)
Domestic water in the rural area	30,650,085	37,471,588	68,121,673
Urban water supply (Cox's Bazar)	-	876,000	876,000
Project site in Matarbari	-	226,665	226,665
Irrigation water	87,498,872		87,498,872
Total	-	-	156,723,210

Sources: 1) Numbers of well: DPHE& Data of Ministry of Agriculture
2) Data from Matarbari Project Office

On the other hand, it is estimated that 1,323.4 x 10^6 m^3/year of surface water percolates into the underground, resulting in ground water recharge.

As mentioned above, the amount of ground water extraction is 156.7 x 10^6 m^3, while the amount of ground water recharge from surface water is 1,323.4 x 10^6 m^3. Therefore, the amount of recharge exceeds the extracted water by 1,166.7 x 10^6 m^3/year. This indicates that ground water extraction in the survey area is about 12% of ground water recharge from surface water, and at least 1,166.7 x 10^6 m^3/year has outflowed from the survey area.

(3) Consideration

From the distribution of ground water levels, the ground water in the survey area is considered to flow from north to south and east to west. The total amount of the ground water extraction and the outflow to the outside of the survey area exceeds that of inflow to the survey area and the ground water recharge from the surface water. Therefore, this situation means "over pumping". Since well construction for ground water extraction has continued and the population is also increasing, it is anticipated that the amount of ground water extraction will increase further. It is apparent that the ground water levels of the aquifers up to the depth of 300m is decreasing and hence it is considered that the ground water is excessively extracted from these aquifers.

Water Demand Forecast

Industrial and Domestic Water Demands

5.1 Future industrial and domestic water demands will be affected by the development situation explained below, and hence the water demands were studied in careful consideration of development plans and projects in the south Chattogram region.

Development projects of the economic zone, the power hub and the port are implemented in Matarbari Island, Moheshkhali Island, Sonadia Island and Chakaria City in the south Chattogram region. In the Moheshkhali/Matarbari region, several infrastructure developments are implemented together with the development of "Matarbari Ultra Super-critical Coal-fired Power Project" supported by JICA in the short term. In the middle and long terms, the Moheshkhali economic zone is planned and the development area will be expanded to the south area of the Moheshkhali/Matarbari region. On the other hand, the east and south of the Moheshkhali/Matarbari region are designated as conservation areas, and the development area is restricted.

5.2 Industrial water demands in the short and long terms for the Moheshkhali/Matarbari region are as tabulated below.

Location	Area (ha)	Water demand (m^3/day)	
		Short term (2026)	Long term (2041)
Matarbari Port	-	600	600
General EZ	450	7,400	38,300
Seaborne EZ	700	49,400	140,200
Moheshkhali EZ	1,604	0	180,504
Total	-	57,400	359,600

Source: JICA Study Team

Industrial water demand for the Moheshkhali/Matarbari region is shown in the below.

Upazila	Water demand (m^3/day)	
	Short term (2026)	Long term (2041)
Moheshkhali	50,000	321,304
Chakaria	7,400	38,300
Total	57,400	359,600

Source: JICA Study Team

Source: JICA Study Team

5.3 The domestic water demands in the Moheshkhali/Matarbari region and surrounding areas, consisting of Cox's Bazar City, Moheshkhali Upazila, Pekua Upazila, Chakaria Upazila, and Kutubdia Upazila, are shown below.

Upazila	2011	2026	2036	2041
Cox's Bazar	40,392	60,891	81,097	91,619
Moheshkhali	28,248	42,584	56,715	64,073
Pekua	15,136	22,817	30,389	34,332
Chakaria	41,712	62,881	83,747	94,613
Kutubdia	11,000	16,582	22,085	24,951

Upazila	2011	2026	2036	2041
Total	136,488	205,755	274,032	309,589

Note: unit_m^3/day

Source: JICA Study Team

Agricultural Water Demand

5.4 The ratio of agricultural water source is “groundwater : surface water = 3 : 1” throughout Bangladesh, whereas the ratio is “1 : 1.3” in the survey area: the degree of dependence on groundwater is lower than that on surface water in the survey area, compared with the degree of the whole country, for which the reason is that most of the survey area is located in a mountainous area with relatively many underground rock layers, and is unsuitable for well digging. In addition, the Bangladeshi agricultural policy indicates that the supply of irrigation water from groundwater is to be reduced in the future since land subsidence has occurred due to excessive groundwater extraction.

5.5 In order to forecast agricultural water demand from the rivers in the 4 target river basins (Bakkhali, Karnafuli, Matamuhuri and Sangu Rivers), the current amounts of water requirements from the rivers were calculated. The current irrigation water requirements from the surface water of each target river basin and each upazila are calculated by the Penman method, using the available irrigated area, in consideration of the cropping patterns used there. This calculation was based on the meteorological data and estimated irrigation area for each of the 54 years from 1966 to 2019. The forecasted irrigation areas for 2026 and 2041 were calculated, using the growth rate of irrigated area of 0.96%/year, which was estimated based on past data. The decrease of groundwater irrigation amount was also considered for the forecast.

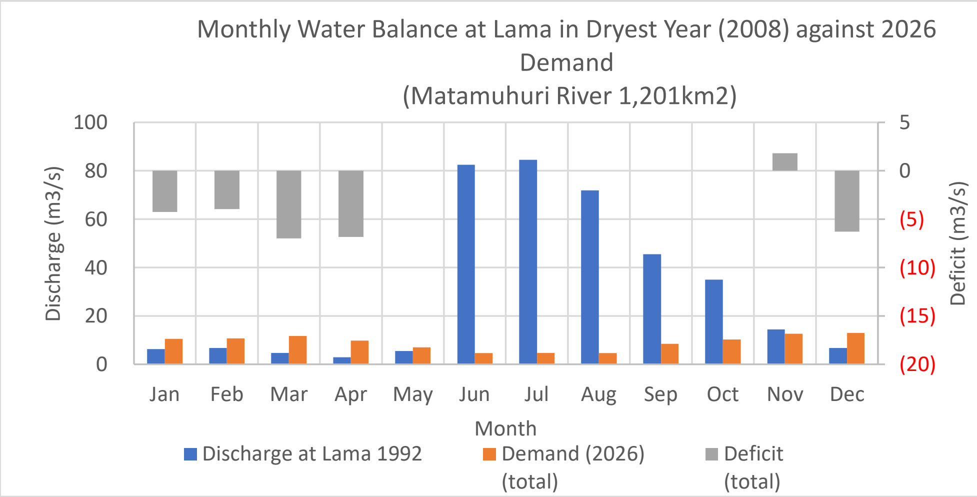
IV COMPONENT 3 : EVALUATION OF WATER RESOURCES DEVELOPMENT POTENTIAL BASED ON RESULTS OBTAINED IN COMPONENTS 1 AND 2, AND SUGGESTIONS REGARDING INSTITUTIONAL ARRANGEMENTS OF PROJECT IMPLEMENTATION

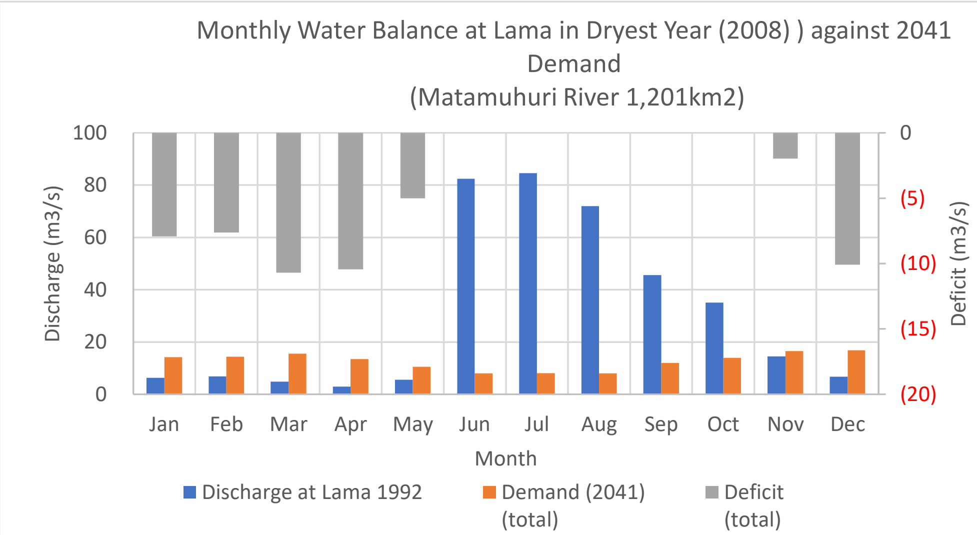
Potential Assessment of Water Resources Development

6.1 Based on the assessment results of current water resources reserves of surface water and groundwater obtained from the studies in Components 1 and 2, the basic approach for formulating a water resources development plan is established. Based on this basic approach, conceivable basic development alternatives are drafted, and short-term and long-term water resources development potentials are assessed through map surveys, field reconnaissance, and preliminary studies on the alternatives.

Assessment of Surface Water Potential (Present Conditions)

6.2 The monthly water balance between the surface water (discharge) and the water demand in the target years of 2026 (short term) and 2041 (long term) is presented in the following figures, which show that the shortage of surface water occurs in the dry season. The shortage amounts in March 2026 and March 2041 are approximately $7m^3/s$ and $10.7m^3/s$, respectively





Source : JICA Survey Team

6.3 The survey area has a considerable difference in natural river flow between the rainy and dry seasons, which makes it difficult to secure new municipal water (domestic and industrial water), river maintenance flow, and irrigation water in the dry season by using the natural river flow. Therefore, it is essential to temporarily store the abundant rainy season river water into storage facilities for stable year-round water supply to demand areas.

Assessment of Ground Water Development Potential

6.4 The ground water levels in both the shallow and deep aquifers have been gently declining in the survey area, as compiled in the table below.

Upazila	Average Ground Water Level Declination (m/year)	
	Shallow Well	Deep Well
Chakaria	0.10	0.10
Moheshkhali	0.02	0.03
Cox's Bazar	0.12	0.15
Ramu	0.13	0.10

Source: DPHE

In due consideration of the above ground water level declination and other study outcomes on groundwater obtained in the Survey, the following are considered.

(1) Whereas the recharge to ground water is much higher than the ground water extraction, the ground water level is on a downward trend. This suggests that the total amount of ground water extraction and the outflow from the aquifer to the outside of the study area is larger than the total amount of ground water recharge and inflow from the upstream side of the aquifer.

(2) If the current situation of ground water utilization continues in the future, the ground water in the survey area is feared to continue its moderate declination. If the ground water level drops below the sea level, there is a possibility of saltwater intrusion into the ground water in the areas facing the sea. In addition, it is assumed that the pumps installed in the wells will be unable to pump water up.

(3) Since the ground water level is lowering and the recharge exceeds the ground water extraction, it is considered that the current amount of ground water extraction exceeds the potential of ground water development in the survey area. Therefore, it seems impossible to newly promote large-scale development of ground water.

(4) In order to develop the groundwater in the survey area, it is necessary to take measures so as to store or delay in aquifers the groundwater flowing to the outside of the survey area. A typical example of measures is an underground dam, but there is no topographical or geological condition suitable for construction of underground dam in the survey area.

(5) In the survey area, DPHE has been constructing wells for installing hand pumps, which is supposed to continue in the future. It is unlikely that the said wells construction will greatly hasten the declination of ground water level in the short term, since the number of wells to be constructed in a year is rather limited.

(6) In the survey area, the ground water exceeding the urban and domestic water demands has been being used for irrigation as well. From a long-term perspective, if it is possible to convert the water source for irrigation from ground water to surface water, the ground water taken for irrigation can be utilized for future urban and domestic water demands.

Basic Approach for Formulation of Water Resources Development Plan

6.5 The basic approach for plan formulation of water resources development in line with the future water demand forecast is set up, as enumerated below.

(1) The development policy is to aim at water resources management which takes one river basin as a basic unit for the integrated water resources management, and the first priority for the development is given to the Matamuhuri River basin where the Moheshkhali/Matarbari region (major water demand center) is situated.

(2) After that, inter-basin water transfer from the Karnafuli River and the Sangu River basins to the Matamuhuri River basin is to be considered as phased development of water sources.

(3) Since the groundwater has many unknown matters compared to surface water, surface water development shall be prioritized. And

(4) The surface water has a great seasonal fluctuation, while the water demand to the Moheshkhali/Matarbari region is mainly for domestic and industrial use, and is of less seasonal variation. The regulation within a year is essential for water supply in this region.

Alternative Study by Potential Assessment on Water Resources Development in Matamuhuri River Basin

6.6 Since the Matamuhuri River also has a considerable difference in river water between the rainy and dry seasons, it is necessary to temporarily store the abundant rainy season river water into storage facilities so as to provide a stable year-round water supply for the demand areas. The capacities of storage facilities required in the Matamuhuri River basin are estimated below.

Development Target Year	Required Reservoir Capacity (Million m^3)	River Maintenance Flow (m^3/s)	Domestic Water (m^3/s)	Industrial Water (m^3/s)	Irrigation Water (m^3/s)	Total Demand (m^3/s)
Short-term 2026	70	3.30	0.39	0.97	4.40	9.06
Long-term 2041 Addition on short-term	71	---	0.63	2.67	0.26	3.56
2041 (total)	141	3.30	1.02	3.64	4.66	12.62

Source: JICA Survey Team

6.7 The following alternatives are expected to meet the water demands in the short and long terms from the viewpoint of the required reservoir capacity and possibility of related facilities construction in the Matamuhuri River basin. The long term alternatives include the water transfer from other river basins as well.

(1) Short-term alternatives

- S1; intake + pond
- S2; intake + pond + groundwater
- S3; intake + pond+ seawater desalination (small scale)

(2) Long-term alternatives

- M1; short-term alternative (S1) + pond expansion
- M2-1; short-term alternative (S1) + dam/reservoir in the Matamuhuri River
- M2-2; short-term alternative (S1) + dam/reservoir in the Sangu River with inter-basin water transfer
- M3; inter-basin water transfer alternative (Lake Kaptai water supply pipeline)

6.8 A map study was conducted, using topographic maps, geological maps, land use maps, and aerial photographs, based on the above-mentioned water resources development alternatives in the Matamuhuri River basin.

(1) Conditions for map study

The layouts of intake weirs and ponds in the Matamuhuri River basin were examined on the maps in consideration of the following.

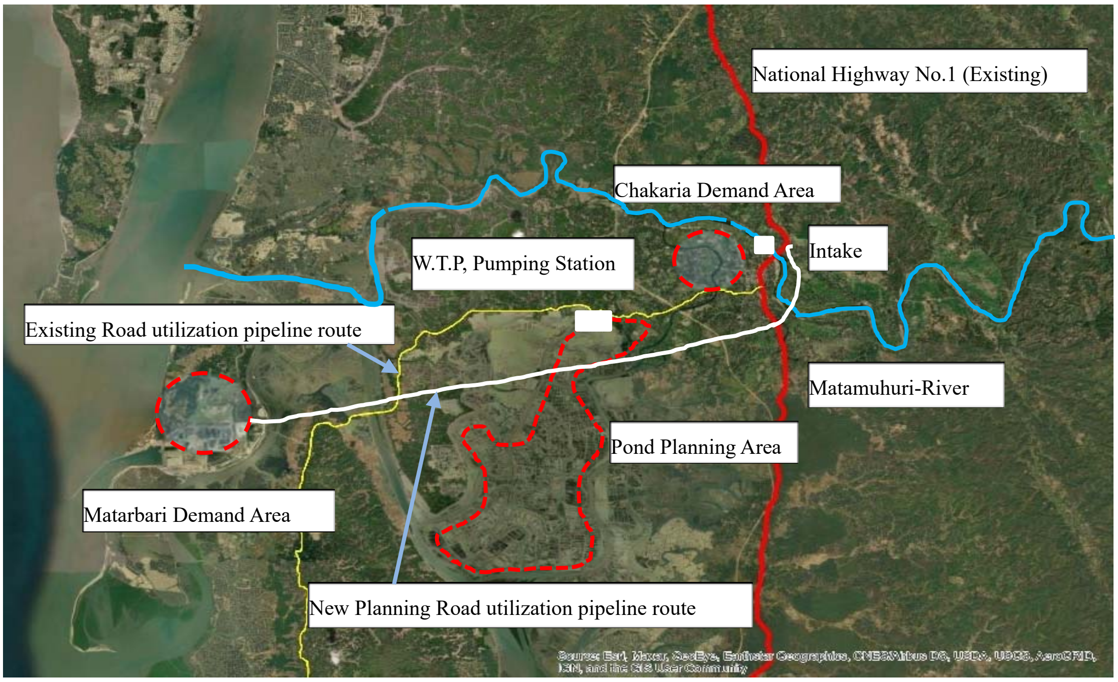
- The river basin has small ponds which have been used for domestic water for local residents.
- In terms of locations of water demand areas (Chakaria and Matarbari), the intake weir is assumed to be near the Matamuhuri River Bridge on National Highway No. 1 (N-1), and the pond near the midpoint between the intake weir and the Matarbari demand area. And
- The pond construction site is to be located in the brackish water area along the lower Matamuhuri River, where fish ponds and salt pans are operated. There are also roads (R-172 etc.), new roads (Matarbari Port Access Road), and new railroads between Chakaria and Matarbari.

(2) Plan of regulation pond

The pond construction site was identified in the floodplain situated immediately upstream of the estuary of the Matamuhuri River since it is near the demand areas. The raw water in the pond is mainly river water during the rainy season.

(3) Arrangement of water conveyance facilities

The facilities are composed of Matamuhuri River pump type intake → Headrace → Pond → Water treatment plant (W.T.P) → Water supply pumping station → Tailrace → Water distribution pond. There are 2 ideas identified about the water conveyance route: one is along the existing roads and the other along the new roads (under planning/design), as presented in the next figure).



Source: JICA Survey Team

Note: The map study on the long term alternatives is described in “8.2”.

Formulation of Alternative Plans for Short-term Water Resources Development

6.9 Based on the results of the map study and field reconnaissance, the short-term alternatives are proposed to intercept the rainy season water in the Matamuhuri River, transfer and temporarily store the water into the regulation pond near Palakata, Cox’s Bazar, and supply the water to the demand areas through a water treatment plant.

(1) Regulation pond

According to the field reconnaissance, the candidate sites of regulation pond are found in the floodplains in the Palakata area, where a wide flat land spreads out near the demand areas. The table below compiles the hydraulic quantities for the alternative plans of the regulation pond by combination of object water demands based on a water balance study.

Object Water Supply Demand	**Domestic Water + Industrial Water**	**Domestic Water + Industrial Water +River Maintenance Flow**	**Domestic Water + Industrial Water +River Maintenance Flow +Irrigation Water**
Water Supply Amount (m^3/s)	Domestic water: 1.04, Industrial water: 0.66, irrigation water: 3.09, River maintenance flow:7.07 (at pond site)		
Required Pond Effective Volume (MCM)	16	36	95
River Water Intake Amount (m^3/s)	4.7		10.0

Object Water Supply Demand	**Domestic Water + Industrial Water**	**Domestic Water + Industrial Water +River Maintenance Flow**	**Domestic Water + Industrial Water +River Maintenance Flow +Irrigation Water**
Water Treatment Plant Capacity	1.7m³ / s = 150,000m³ / day		
Matarbari Demand Area Water Supply Amount	1.32m³ / s		
Chakaria Demand Area Water Supply Amount	0.38m³ / s		
River Maintenance Flow	0	7.89m³ / s	11.97m³ / s

Source: JICA Survey Team

(2) Water conveyance facilities

The facilities for water conveyance from the intake site up to the water supply areas consist of a pump-type intake in the Matamuhuri River, a headrace, a regulation pond, a water treatment plant, a water supply pumping station, a transmission pipeline and a water distribution pond in demand areas.

a) Intake site

The intake site is identified, which would avoid substantial negative impacts of salt water intrusion in the lower reaches of the Matamuhuri River. It is recommended that the intake site be provided with a fixed river channel and revetment without weir facilities, and two intake sites are identified, taking into account the pipeline routes to the pond, as stated below;

- Case 1-Intake site at Matamuhuri River Bridge: the pipeline route shall use the existing N-1 road, which would affect the traffic on the N-1 road and surrounding areas, particularly during its construction.
- Case 2- Intake site 3.6km upstream of Matamuhuri River Bridge, where Chattogram – Cox's Bazar Highway is under planning: the pipeline route shall use this new road and the intake site is near the new road.

b) Pipeline route

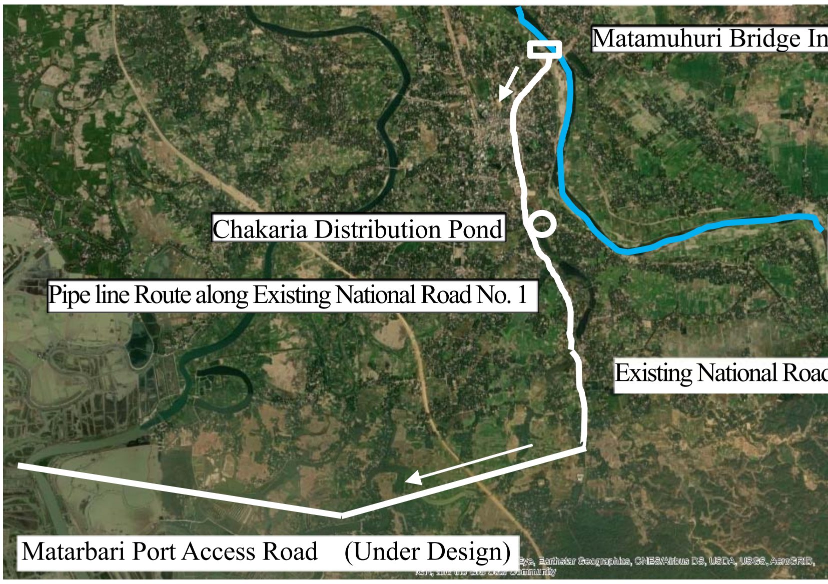
A pressure type pipeline is generally laid under the road for domestic and industrial water supply from viewpoints of easy maintenance, land acquisition, pipe fixing method, etc. Therefore, there are two options for the pipeline route; namely, those along (i) the existing National Highway No-1, and (ii) the new Chattogram-Cox's Bazar Highway (under planning) and Matarbari Port Access Road (under design). In the case of the (ii), the pipeline length can be shortened.

The approximate locations of the intake sites and the lengths of the pipelines are as explained in the table and photo below.

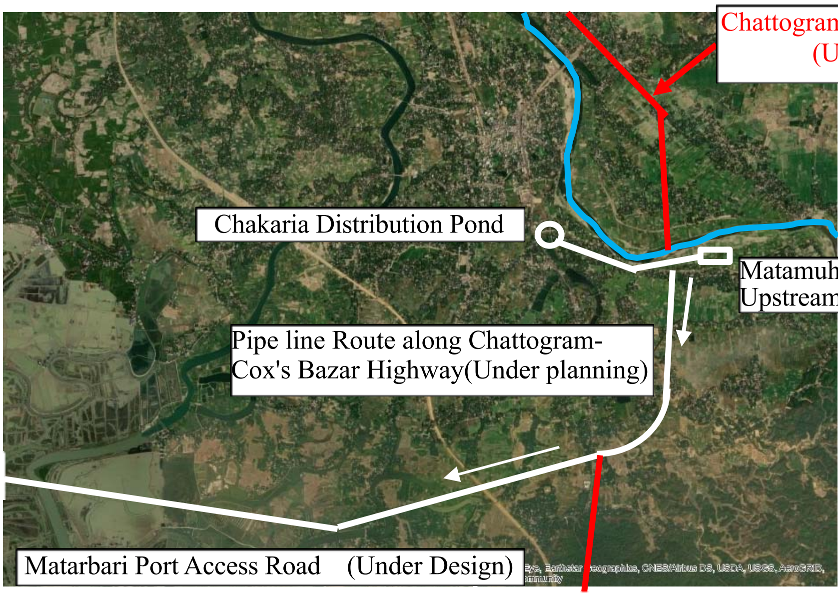
Items		Alternative Pipeline Route using Existing Road (Matamuhuri Bridge Intake)	Alternative Pipeline Route using New Planning Road (Matamuhuri Bridge Upstream Intake)
Pipeline Routes	Intake - Pond	13.0km	10.9km
	Pond - Matarbari Port	23.8km	19.7km
	Pond - Chakaria	10.9km	10.5km
	Total length	47.8km	41.3km

Source: JICA Survey Team

Alternative Pipeline Route using Existing Road



Alternative Pipeline Route using New Planning Road



Source: JICA Survey Team

6.10 The short-term alternatives mentioned above are considered as discussed below, based on the following comparison table.

(1) The most economical short-term alternative is to set "domestic water + industrial water demands" as water supply objects for the highest priority plan in the light of the current development state in the Moheshkhali/Matarbari region.

(2) As to the construction cost of headrace and transmission pipelines, the (ii) route along the new roads is more economical than that of the existing roads. And

(3) The pipeline construction sites along the new roads, which are far particularly from Chakaria Upazila proper, could reduce the negative impact on the current road traffic and their surrounding areas compared to those along the existing roads.

<Principal futures of short term alternatives (pond plan) >

Supply Target	**Domestic+Industrial Water**	**Domestic+Industrial +River Maintenance Flow**	**Domestic+Industrial+ Irrigation+River Maintenance Flow**
Pond	Inclined impermeable zone type, Height 8.2m, Crest EL.10.2, Embankment width 42.5m		
Pond effective volume (MCM)	16	36	95
Ponding area (km^2)	3.2 (320 ha)	7.2 (720 ha)	19.0 (1,900 ha)
Pond around length (km)	8.7	12.6	26.6
Spillway (length x width)	33m x 130m	33m x 570m	33m x 790m
Outlet works Bridge section	Box culvert 2.0 H x 3.0 W x 1 gate		
Palakata water treatment plant (Rapid filtration, sludge drying method)	$1.70m^3/s = 150,000m^3/day$		
Intake amount in river (m3/s)	4.7 ($406,000m^3$ / day) Vertical mixed flow pump 1.8m D		10.0 ($864,000m^3$ /day) Vertical mixed flow pump 1.8m D x 2units
Transmission pump station (Chakaria $0.38m^3/s$)	Pump= 0.5m D		
Transmission pump station (Matarbari $1.32m^3/s$)	Pump=1.0m D		
Headrace (Intake~Pond) +Transmission line (Pond~Matarbari, Chakaria)	Headrace 1.8m D Matarbari transmission line 1.0m D Chakaria transmission line 0.5m D		Headrace 1.8m D x 2 Matarbari transmission line 1.0m D Chakaria transmission line 0.5m D

< Cost comparison of short term alternatives (pond plan) >

Facilities \ Supply Target		Domestic+Industrial Water	Domestic+Industrial+ River Maintenance Flow	Domestic+Industrial+ Irrigation+River Maintenance Flow
Pond		JPY 16 billion	JPY 23 billion	JPY 50 billion
Palakata water treatment plant		JPY 14 billion		
Intake pump equipment		JPY 4.6 billion		JPY 4.6 billion x 2 units = JPY 9.2 billion
Intake and river bank protection work		JPY 0.7 billion		JPY 1.6 billion
Transmission pump station (Chakaria, 0.38m^3 / s)		JPY 0.6 billion		
Transmission pump station (Matarbari, 1.32m^3 / s)		JPY 1.9 billion		
Pipeline	Intake; Matamuhuri Bridge	JPY 90.9 billion		JPY 163.2 billion
	Intake; Upstream Matamuhuri Bridge	JPY 62.0 billion		JPY 115.5 billion
Total Cost	Intake; Matamuhuri Bridge	JPY 128.7 billion	JPY 135.7 billion	JPY 250.5 billion
	Intake; Upstream Matamuhuri Bridge	JPY 99.8 billion	JPY 106.8 billion	JPY 202.8 billion

Source: JICA Survey Team

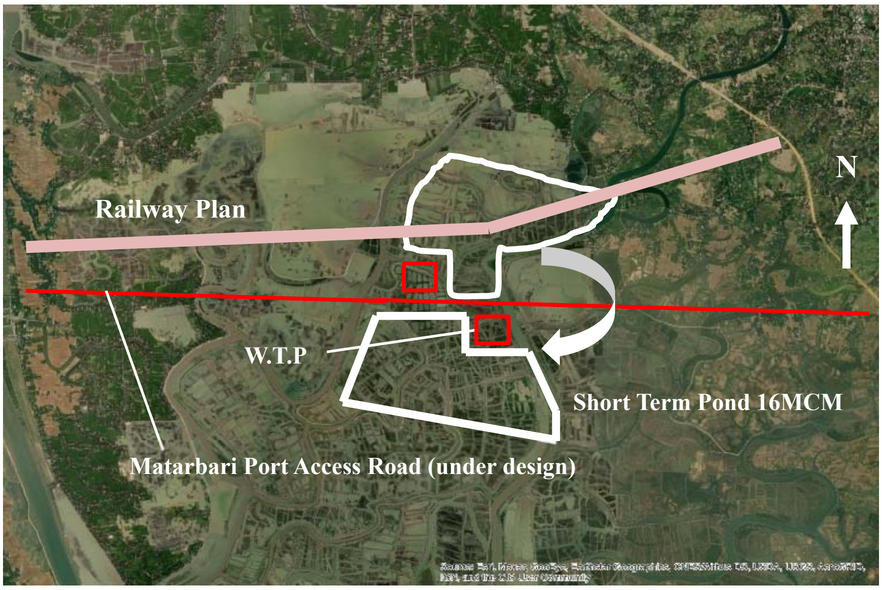
Note: The above-mentioned costs are calculated only for cost comparison of the three short term alternatives, based on the following guideline and manual, excluding land acquisition/compensation costs, and are not the construction costs.

1. "Guide line for Calculating Facility Renewal Costs Related to Restructuring of Water Services, December 2011, (Waterworks Division, Health Bureau, Ministry of Health, Labor and Welfare)"

2. "Civil Engineering Work Estimation Standard Manual 2020, (Ministry of Land, Infrastructure, Transport and Tourism, Japan)"

6.11 Through hearing on the comprehensive development project in the Moheshkhali-Matarbari region in March 2022, it is confirmed that the location of the proposed pond may overlap with the alignment of the railway plan. Therefore, it is proposed that the location of the pond is to be moved to the south of "Matarbari Port Access Road" so as to avoid confliction of the facilities layouts with each other, as shown below.

To Matarbari Port



To National Highway No.1

Source: JICA Survey Team

Water Balance Study (Short-term Plan)

6.12 A water balance analysis model was developed for the Palakata Regulation Pond which is considered to be the most promising candidate for the short-term plan and the required capacities of major structures in the plan were calculated with the primary rules of water balance analysis model, as described below.

(1) Whereas the priority of water supply for water demands is as stated below in general, conducted are multiple case studies that combine these demands.

Maintenance Flow ⇒ Domestic Water ⇒ Industrial Water ⇒ Agricultural Water

(2) The water demands located downstream of the storage structure are to be covered by water supply from the storage structure.

(3) The water level in the storage structure should be managed within the range of surplus water available in the Matamuhuri River so as not to disturb water supply for the existing demands. And

(4) The operation of the storage structure is to be made basically so as to recover its full capacity once at least in a rainy season.

6.13 The following 6 cases were prepared for combination of maintenance flow, domestic water, industrial water, and agricultural water to be covered by water supply from the Palakata Regulation Pond, and the required capacity of the pond was calculated in each case.

- Case 1 : Maintenance Flow
- Case 2-1 : Maintenance Flow + Domestic Water
- Case 2-2 : Maintenance Flow* + Domestic Water
- Case 3-1 : Maintenance Flow + Domestic Water + Industrial Water
- Case 3-2 : Maintenance Flow* +Domestic Water + Industrial Water

- Case 4 : Maintenance Flow + Domestic Water + Industrial Water + Agricultural Water

*Note : * In case of no supply for maintenance flow by Palakata Regulation Pond*

In addition, prepared were "Case A" where the domestic water, industrial water and agricultural water to be taken only from the river are set in the water balance analysis model, and "Case B" where the groundwater use for domestic water and industrial water is to be shifted to river water use. In combination with the above 6 cases, the water balance analysis was carried out for 12 cases in total.

6.14 Based on the following directions, the three cases shown in bold frames in the table (Case B) below are considered to be promising candidates for structure planning.

(1) Domestic and industrial water demands are essential objects of water supply (Case3-1, Case3-2).

(2) It is necessary to verify the feasibility of including the agricultural water demand for water supply (Case-4).

(3) A new water supply plan shall conform with the policy of shifting groundwater use to surface water use for future water source development ("Case B"). And

(4) The safety factor of water use is to be defined as 1/5 drought year (the matter to be discussed with the Bangladeshi side on the technical working group meeting).

Case A:

Item		Case1	Case2-1	Case2-2	Case3-1	Case3-2	Case4
Chakaria Intake Pump		3.0 m^3/s	3.0 m^3/s	3.0 m^3/s	3.0 m^3/s	3.0 m^3/s	10.0 m^3/s
Palakata Regulation Pond	5 yr 1)	20.642 MCM	23.486 MCM	2.793 MCM	28.843 MCM	8.934 MCM	83.907 MCM
	10 yr 1)	32.251 MCM	35.556 MCM	3.706 MCM	40.686 MCM	10.546 MCM	104.510 MCM

1) safety factor of water use

Case B:

Item		Case1	Case2-1	Case2-2	Case3-1	Case3-2	Case4
Chakaria Intake Pump		3.0 m^3/s	3.0 m^3/s	3.0 m^3/s	3.0 m^3/s	3.0 m^3/s	10.0 m^3/s
Palakata Regulation Pond	5 yr 1)	20.642 MCM	29.170 MCM	9.209 MCM	35.952 MCM	15.934 MCM	94.051 MCM
	10 yr 1)	32.251 MCM	40.945 MCM	10.923 MCM	49.502 MCM	17.763 MCM	113.082 MCM

1) safety factor of water use

Source: JICA Survey Team

Basic Environmental Examination

6.15 In accordance with the Environmental Conservation Rules and Regulations of Bangladesh (amended in 2002), the short-term water resources development option proposed by the Survey, which envisages construction and operation of a regulation pond in Kalakata, Cox's Bazar, would need the Environmental and Social Impact Assessment (ESIA), and the Income Restoration Program (IRP) for the project affected people who lose their incomes from shrimp cultivation and salt refining in the future due to the pond construction (the results of preliminary examination of environmental and social impacts are as referred to in Table 4.1.17).

The long-term water resources development options proposed by the Survey would need ESIAs in the future, and Resettlement Action Plans (RAPs) also in the case of the option which includes dam/reservoir construction, since the Matamuhuri Reserved Forest and Reserved Forest is situated upstream of a dam candidate site and there would be a possibility that some small settlements are scattered in the upstream (the results of preliminary examination of environmental and social impacts are referred to in Table 4.1.18).

Study on Institute/Legal System and Implementation Frame Work

6.16 The JICA Survey Team conducted an interview survey on projects and legal systems concerned, including water resources development projects and organizations responsible for industrial and domestic water supply and sewerage works. The target organizations for the interview survey were set as in the table below.

	Projects (including Legal Systems)/Facilities	Target Organizations to be Interviewed
The Short-term Alternatives	☐ Water Resources Development Projects: Execution of River Management Power	● Ministry of Water Resources (MoWR) ● Water Resources Planning Organization (WARPO) ● Bangladesh Water Development Board (BWDB)
	☐ Industrial Water and Domestic Water and Sewerage Works: Water Treatment Plant, Water Supply Pumping Station, Pipeline and Water Distribution Facilities, etc.	● Local Government Division (LGD) ● Department of Public Health Engineering (DPHE) ● Water Supply and Sewerage Authority (CWASA)
Long-term Alternatives	☐ Water Resources Development Projects: Execution of River Management Power, Dam at the Matamuhuri River or the Sangu River with a Headrace, Headrace from the Kaptai Dam at Karnafuli River to the Matamuhuri River	● Ministry of Water Resources (MoWR) ● Water Resources Planning Organization (WARPO) ● Bangladesh Water Development Board (BWDB)
	☐ Industrial Water and Domestic Water and Sewerage Works: Pomp-type intake, Headrace, Expanded Pond, Water Treatment Plant, Water Supply Pumping Station, Pipeline and Water Distribution Facilities, etc.	● Local Government Division (LGD) ● Department of Public Health Engineering (DPHE) ● Water Supply and Sewerage Authority (CWASA)

Source: JICA Survey Team

The eligible organizations for the execution of river management power are deemed to be WARPO and BWDB, and the organization for construction of these facilities, the water resources management, and O&M of the facilities after completion of them is deemed to be BWDB. The grounds are as follows;

- WARPO is in charge of granting water use permission.
- BWDB has its responsibilities to construct dams, barrages, reservoirs, embankments, and

facilities for water level and discharge adjustment aiming at river training, flood control, drainage, irrigation and drought prevention for all rivers, channels and groundwater aquifers in the country.

- As the result of the interview survey, WARPO and BWDB itself recommended that BWDB be more suitable as the organization in charge of water resources development etc.

However, the interviewees pointed out some issues, as enumerated below.

- BWDB is able to manage irrigation water, but not municipal water.
- It would be possible for BWDB to carry out its project if there would exist a total project owner different from BWDB and it would outsource BWDB the project including the management and O&M after completion.

The most eligible organizations for industrial water and domestic water and sewerage works are DPHE. The reasons are as follows.

- DPHE is able to implement its responsibilities throughout the country except for the project areas of WASA (Dhaka, Chattogram, Khulna, and Rashchahi), while CWASA is not able to operate in the Moheshkhali/Matarbari region, etc.
- LGD, the competent ministry of CWASA, recognizes that a new WASA would need to be established instead of CWASA if WASA were in charge.
- In Bangladesh, it is actually not practical to create not just WASA but also a new organization, because it requires a lot of effort and time to coordinate with related institutions.
- However, DPHE doesn't have actual achievement of the water supply and sewerage services for the users and thus there is a concern about its capacity. Meanwhile, legal system of PPP has already been established in Bangladesh, DPHE is able to launch the services adopting a foreign company by means of concession method.

The proposals for legal systems for the future project promotion are as stated below:

- BWDB currently is able to handle only irrigation water and does not have the authority to handle municipal water. The BWDB Act 2000 needs to be reformed immediately so as to bestow on BWDB the power to handle municipal water.
- Water resources development requires river management techniques at low water level during a certain drought term, but BWDB has no experiences of such river water management and does not have such techniques. It is necessary for Bangladesh to set up the river act that stipulates "low water control" as well as "high water control" similar to the River Act in Japan. And
- A law corresponding to the Japanese River Act is needed to be enacted for the low water level management and high water management as well, including stipulation of river water occupancy, river area and its occupancy. The rivers in the Chattogram Division are

generally similar to the characteristics of Japanese rivers, and it is effective to establish a legal system based on the Japanese River Act.

<u>Selection of Basic Plan for Water Resources Development in Short Term</u>

6.17 Regarding the short-term water resources development plan, of which the demand areas are the Moheshkhali/Matarbari region and Chakaria City, several ideas and alternatives of water source and water-use facilities were conceived as stated in the foregoing "6.5" to "6.16", and studied mainly from the following viewpoints:

- Target year (2026) of development plan in the short term,
- Reliabilities of surface water and ground water as future water sources to be developed for the demand areas,
- Preliminary estimates of cost related to water-use facilities construction, and
- Institutional arrangements.

In due consideration of the study results, the development candidate which is to use the Matamuhuri River water as a surface water source and to be composed of the following facilities from an intake site to water demand areas, is selected in the Survey as a basic plan for water resources development in the short term. The table below explains the flow of the said selection.

- Pump type intake: on left river bank 3.6km upstream of Matamuhuri River Bridge on National Highway "N-1" (Chakaria),
- Headrace: Pipeline along Chattogram - Cox's Bazar Highway (under planning) and Matarbari Port Access Road (under design),
- Regulation pond, water treatment plant and distribution pump station: Palakata area (Cox's Bazar), and
- Distribution pipelines to, and distribution facilities in, water demand areas.

Work Flow		Notable Outputs
1. Map study	1.1 To set up basic approaches towards alternative plans for water resources development	• The first priority for the short-term plan is given to the **Matamuhuri River basin** where the Moheshkhali/ Matarbari region (major water demand center) is located.
	1.2 To study availability of surface water in the Matamuhuri River basin to secure water sources for new water demands	• It is essential to temporarily store the rainy season river water into **storage facilities** to provide a stable water supply for demand areas throughout the year.
	1.3 To examine alternatives of water resources development (1) Short term : S1, S2 and S3*	• Short term : **S1** (**intake** + **regulation pond**)is more feasible than each of S2 and S3.
3. Formulation of alternative	To examine alternatives regarding **S1**, incorporating findings from "**2. Field Reconnaissance**"	

Work Flow		Notable Outputs
plans in the short term	(1) Intake sites and pipeline routes to regulation pond - 2 cases of pipeline routes along "existing and new roads" (2) Regulation pond (including "**4. Water Balance Study**") 1) First step : 3 cases with combination of water supply demands 2) Second step : 12 cases with combination of water supply demands and"with and without ground water use"	• The pipeline route along **new roads** (Chattogram-Cox's Bazar Highway and Matarbari Port Access Road) is preferable from economic and social viewpoints. • The regulation pond was roughly located in the **Palakata area**, Cox's Bazar. • Cases of "**domestic + industrial water supply without ground water use**" are considered to be promising for the highest priority plan.
5. Selection of candidate of basic plan in the short term	To select candidate of basic short-term plan, based on the above study outputs	• **Water source** : **Matamuhuri River** water as surface water • **Water-use facilities** : from intake site to water demand areas (1) Pump-type intake (Chakaria) : Left bank of **Matamuhuri River**, 3.6km upstream of Matamuhuri River Bridge on "N-1", (2) Headrace : Pipeline along the said **new roads**, (3) **Regulation pond**, Water treatment plant & Distribution pump station: **Palakata area** (Cox's Bazar), and (4) Distribution pipelines & Distribution facilities

Notes: * See "Sub-section 4.1.1 (4)".
Source: JICA Survey Team,

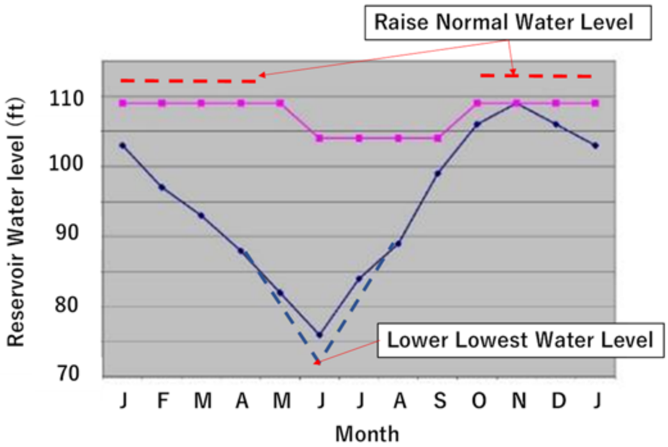
Recommendation on Improvement Plan of Kaptai Dam Operation

Study on Dam Operation Rule

7.1 The Kaptai Dam has a vast reservoir capacity of about 200 million m^3 per meter of water depth (near the lowest water level of the dam). By improving dam operation, for example by increasing the water level drawdown by 10 cm as a new water source, it would be possible to expect an increase in water resources (storage capacity) of 20 million m^3. A study on dam operation rule is carried out concerning the applicability of the following ideas:

(1) To secure a new water source development capacity in the reservoir by increasing its drawdown range by means of lowering the minimum water level or rising the normal one, and

(2) To reallocate the existing water storage capacity by expanding the discharge facilities or introducing pre-release procedure.



Source: JICA Survey Team

The right figure shows an example of examining the rule curve for dam operation. Concerning the idea (1), it is necessary to confirm the negative impact on reservoir-side residents due to water level increase and the intake structure due to lowering the minimum water level (designed minimum depth above the intake, sediment suction, etc.). As for the idea (2), any existence of inundation in the past due to dam release and the river channel flow capacity need to be confirmed so as to evaluate impacts on the downstream.

7.2 In order to meet the future increase in water demands, the following two cases are examined as revised operation rule curves to increase the dry season regulated discharge by the Kaptai Dam, of which the result of each case is compiled in the table below.

(Case 1) Minimum reservoir water level of the rule curve is lowered by 1 m.

(Case 2) Minimum reservoir water level of the rule curve is lowered by 2 m.

Item	Unit	Present	Case 1	Case 2	Case 1 (Diff.)	Case 2 (Diff.)
Annual dam inflow	m^3/s	515.2	515.2	515.2	0.0	0.0
Annual dam outflow	m^3/s	509.0	509.6	510.1	0.6	1.1
Regulated discharge in dry season	m^3/s	263.1	268.8	272.2	5.7	9.1
Annual power generation	GWh	887.4	887.2	847.3	-0.2	-40.1

Source: JICA Survey Team

(1) The increase in regulated discharge in the dry season (from December to May) is about 5.7 m^3/s in Case 1 and about 9.1 m^3/s in Case 2. By lowering the lowest water level of the rule curve, additional water resources development could be expected.

(2) On the other hand, regarding the impact on hydroelectric power generation at the Kaptai Dam, the effective head would decrease by lowering the lowest level of dam operation,

but the amount of water to be used for power generation would increase, and thereby the respective effects would offset each other and the extent of the impact would be small. As a result, Case 1 reduces the current annual power generation by 0.2 GWh, and Case 2 reduces it by 40.1 Gwh.

7.3 As an alternative case, “to raise the maximum reservoir water level of the rule curve" is conceivable. However, in the process of data collection in the Survey, it was confirmed that (i) a hydraulic impact by backwater on the drainage and (ii) a negative social impact on land use in the surrounding areas of the reservoir would occur in connection with the rise of the reservoir water level. Taking into account such impacts, this case is not considered in this comparative study.

7.4 Regarding the plan to reallocate the existing storage capacity by improving the spillway structures and lowering the controlled water level by pre-releasing, the existing water storage area of the Kaptai Dam is huge and the water level reduction effect is small. Although the flood control effect of the Kaptai Dam has not been quantitatively evaluated in the original development plan, its natural flood control effect is considerably high owing to its vast water storage capacity. The Kaptai Dam plays a very important role of flood discharge mitigation in the lower reaches of the Karnafuli River.

Confirmation of Present Sedimentation Situation and Study on Necessity of Countermeasure against Sedimentation

7.5 In this survey, the latest reservoir sedimentation was confirmed based on the simple survey by the sub-contracted local consultant, to confirm present sedimentation situation and study about necessity of countermeasures against sedimentation as discussed hereunder.

(1) Review of the 1980 F/S

It was found that the reservoir surface area was slightly larger than the value calculated from the map created in 1968, and also that the effective storage capacity had hardly changed since 1968. Hence, it was considered that the amount of sedimentation in the reservoir above the minimum operation level was very small and did not affect the effective capacity of the reservoir.

In addition, it was said that the effective capacity could be secured much safely in the future for the following reasons.

- The riverbed slope of the Karnafuli River is as gentle as 1/10,000. Since its flow velocity is generally very slow, no erosion on the riverbed and banks of the river rarely occurs.
- Most of the upstream basin of the Karnafuli River is gently sloping and covered with jungle, and there is no high mountain near the river. In such conditions, it can be said that the entire basin forms a stable terrain.
- This area is located over a typical monsoon zone, and after a long geological transition, it has formed a local terrain that can withstand harsh weather conditions. Therefore, there

will be less sedimentation in the reservoir that affects the generation of electricity in the future.

(2) The following reservoir bathymetric survey data of the Kaptai Reservoir were collected through the subcontracting work

- Results of bathymetric survey (12 survey lines) in 2012
- Results of bathymetric survey (12 survey lines) in 2019 (for same cross sections as in 2012 survey)

These surveys were carried out in the central part of the Kaptai Reservoir, and no progress of sedimentation was observed in the cross sections other than the upstream section. Therefore, although sedimentation is partially progressing in the fringe area of the reservoir, the progress rate of sedimentation is considered to be slow in the central part of the reservoir, and the reservoir effective storage for power generation and water resource utilization would not be affected by sedimentation for the time being.

Preliminary Study on Recommended Water Resources Development Options

Formulation of Alternative Plans for Long-term Water Resources Development

8.1 As stated in “6.5”, the basic approach for plan formulation of water resources development in line with the future water demand forecast is set up, as stated below.

(1) The development policy is to aim at water resources management which takes one river basin as a basic unit for the integrated water resources management, and the first priority for the development is given to the Matamuhuri River basin where the Moheshkhali/Matarbari region is located.

(2) After that, inter-basin water transfer from the Karnafuli River and the Sangu River basins to the Matamuhuri River basin is also to be considered as phased development of water sources. And

(3) Since the groundwater has many unknown matters compared to surface water, surface water development shall be prioritized

Based on the above approach, the following four (4) alternatives are worked out for the long term plan.

<Plan to supply water demands with self-water potential in the Matamuhuri River basin>

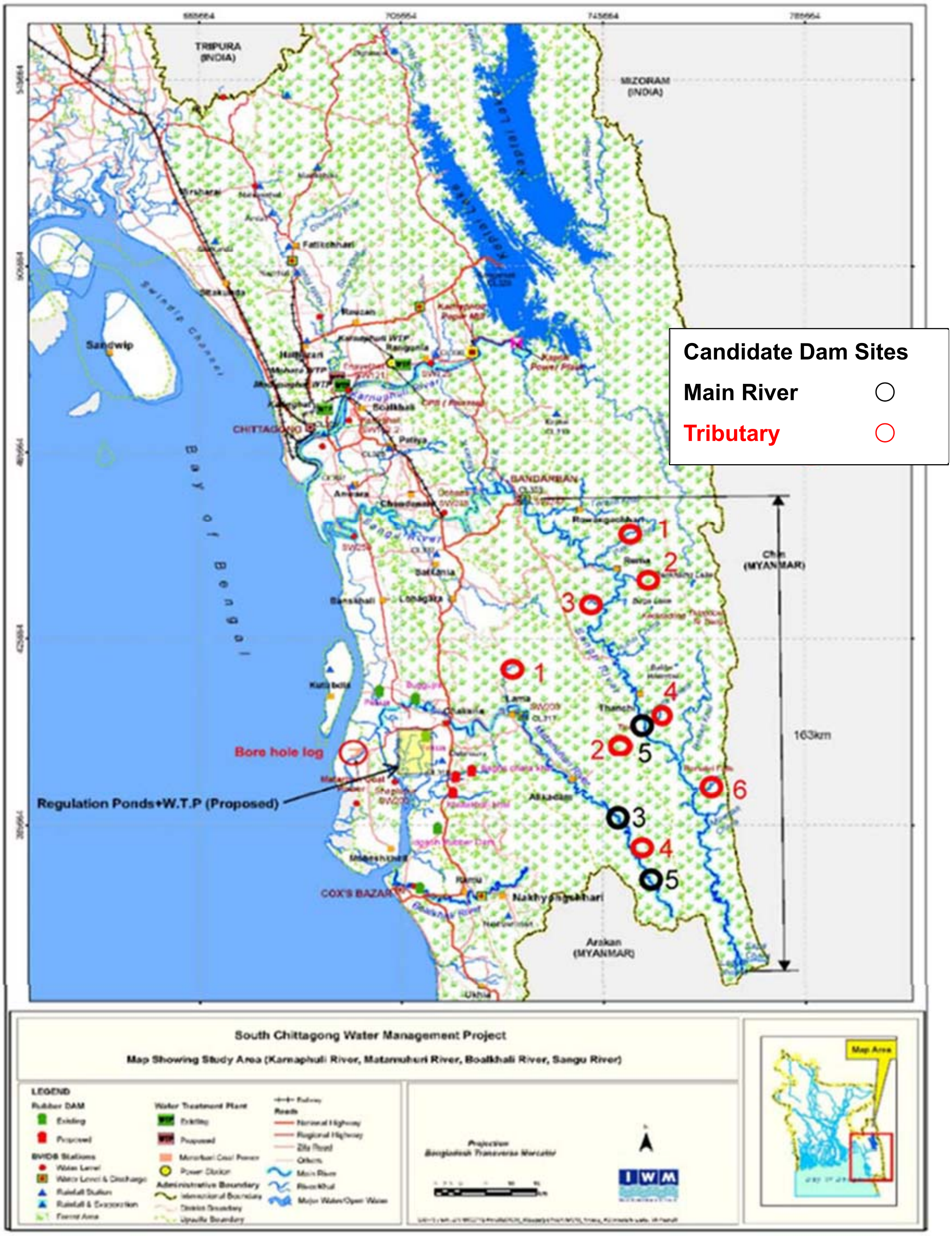
- M1; short-term alternative (S1) + pond expansion
- M2-1; short-term alternative (S1) + dam/reservoir in the Matamuhuri River basin

<Plan of inter-basin water transfer>

- M2-2; short-term alternative (S1) + dam/reservoir in the Sangu River basin
- M3; inter-basin water transfer alternative (Lake Kaptai water supply pipeline)

8.2 The long-term alternatives aim to satisfy the water demand by “Expanding the short-term pond (M1)”, “Short-term pond+ Dam/reservoir (M2-1, M2-2), and/or “Kaptai Dam Pipeline (M3; existing lake water conveyance to demand areas by pipeline)”. The map study was conducted by obtaining information of land use, aerial photographs, and topographic conditions from Google Earth. Regarding dam candidate sites, careful attention was paid to residential houses, land use, and rare species. The alternative dam sites in the Matamuhuri River and the Sangu River basins are shown in the following figure, which were compared in terms of catchment area, distribution of settlements, reserve efficiency, and capacity to reserve water. As the result, the following 4 dam sites are proposed.

- Matamuhuri River basin: - Main River Dam-1 Bit Phar (3), - Main Dam-2 (5)
- Sangu River basin: - Ghalangya Khal (3), - Chema Khal (4)



Source: JICA Survey Team Note: The numbers at the circles correspond to those in Figures 4.3.3 & 4.3.4.

8.3 The alternative of M3 is an option which uses the water impounded below the L.W.L (23.60 m) of the existing Kaptai Reservoir by changing the current reservoir operation rule. Non-pressure water is to be conveyed approximately 96 km from the Kaptai Dam to the W.T.P. near Chakaria through an open channel.

8.4 In order to select the long-term alternatives to be subjected to the water balance analysis mentioned in the following ”8.5”, primary evaluation of the four (4) alternatives discussed in “8.2” was made as the first screening, based on a preliminary study in terms of cost, social, environmental, and technical aspects. As a result, M1, M2-1, and M2-2 are selected, excluding M3 which is evaluated to be unpractical due to the large-scale land acquisition necessary for construction of the 96km long headrace waterway and a higher cost than the other alternatives.

Water Balance Study (Long-term Plan)

8.5 Through the water balance study which was aimed at examining the required storage volumes and practicality of the pond and the dams/reservoirs adopted as water storage structures for the facility plans in the three (3) long-term development alternatives of **M1**, **M2-1** and **M2-2**, the results in the following table are obtained from a hydrological viewpoint.

Alternative Plan		Results of Water Balance Study
Long-term Plan 1: **M1**	Palakata regulation pond (Short-term plan) + Expansion of Palakata regulation pond	In addition to the storage capacity:16 MCM of regulation pond in the short-term plan, a capacity expansion of 173.7 MCM for the regulation pond is required.
Long-term Plan 2: **M2-1**	Palakata regulation pond (Short-term plan) + Matamuhuri Main River Dam	In addition to the storage capacity:16 MCM of regulation pond in the short-term plan, required is an effective storage capacity of 175.5 MCM at the Matamuhuri Main River Dam.
Long-term Plan 3: **M2-2**	Palakata regulation pond (Short-term plan) + Sangu River Dam and water transfer to Matamuhuri Main River	Since water supply to the water demands even in the Sangu River basin is not satisfied through construction of the new Sangu River Dam, water transfer by diversion channel from the Sangu to the Matamuhuri River basins is considered to be impossible.

Source: JICA Survey Team

Evaluation of Alternative Plans for Long-term Water Resources Development

8.6 Since it was found from a hydrological viewpoint that the water transfer from the Sangu River to the Matamuhuri River basins is impossible in the case of the alternative plan of “M2-2”, as explained in “8.5”, the alternative plans of “M1” and “M2-1” were evaluated by using the Multi-Objective Analysis（MOA）Method.

Through careful consideration of natural conditions and socio-economy in the survey area in addition to the contents of alternative plans, the MOA adopted 5 assessment objectives and 21 assessment items in total, as tabulated below.

Assessment Objectives	Items*
Social issues	6
Environmental issues	3
Institutional issues	3
Financial issues	2
Technical considerations	7

Assessment Objectives	Items*
Total	21

Note: * The details are as referred to in Annex4.3-4 (Table 1).
Source: JICA Survey Team

8.7 The following table presents the assessment result in terms of the above five (5) objectives.

Alternative Plans		Total Score (GMI)	Degree of Unbalance
M1	Palakata Regulation Pond (Short-term) + Expansion of Palakata Regulation Pond	33	38.1
M2-1	Palakata Regulation Pond (Short-term) + Matamuhuri Main River Dam	54	7.4

Note: The details are as referred to in Annex4.3-4 (Table 2).
Source: JICA Survey Team

According to the above result, the alternative plan of "**M2-1**" is proposed to be positioned as the recommended water resources development option in the south Chattogram region, since "M2-1" has obtained a higher score and a lower degree of unbalance and is evaluated to have the higher soundness and priority recognized in terms of GMI and degree of unbalance of impacts.

Preparation of Roadmap for Water Resources Development

8.8 The plan of **"M2-1 : Palakata Regulation Pond (Short-term) + Matamuhuri Main River Dam**", which is positioned in this survey as the recommended water resources development option in the south Chattogram region, is outlined in the table below,.

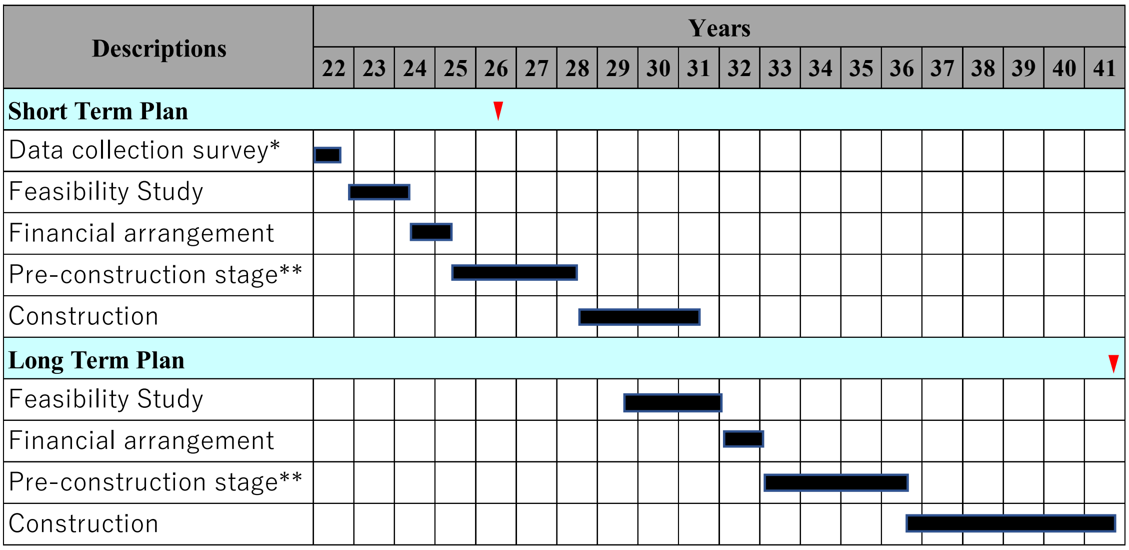
Item	Descriptions
Short-term Plan	
Project goal	Domestic and industrial water supply in Moheshkhali/Matarbari industrial areas and domestic water supply in Chakaria City
Target year	Year 2026*
Water source	Surface water: rainy season river water in Matamuhuri River
Major water-use facilities	• Pump type intake: on left riverbank, 3.6km upstream of Matamuhuri River Bridge on National Highway "N-1" (Chakaria), • Headrace: Pipeline along Chattogram - Cox's Bazar Highway (under planning) and Matarbari Port Access Road (under design), • Regulation pond, water treatment plant and distribution pump station: Palakata area, Cox's Bazar • Distribution pipelines to and distribution facilities in water demand areas.
Social impact	It is supposed that there would be impacts caused on the people who have been running shrimp cultivation and salt refining due to the pond (storage area: about 3.2km^2) construction.
Construction cost**	99,800 x 10^6 (JPY) • Pump type intake: 4,600 x 10^6 (JPY) • Headrace: 700 x 10^6 (JPY)

Item	Descriptions
	• Regulation pond, water treatment plant and distribution pump station: 32,500 x 10^6 (JPY) • Distribution pipelines to and distribution facilities in water demand areas: 62,000 x 106 (JPY)
Long term Plan	
Project goal	• Project goal in short term plan • Agricultural, industrial and domestic water in South Chattogram region
Target year	Year 2041
Water source	Surface water: rainy season river water in the Matamuhuri River
Major water-use facilities	• Facilities in short term plan • Matamuhuri Main River Dam (23km upstream of Alikadam)
Social impact	The Matamuhuri Reserved Forest, stipulated by Bangladesh Forest Act in 1927 for reserving forest environment, is situated upstream of the dam candidate site and it is supposed that there is a possibility that some small settlements (approx. 20 settlements) scattering in the upstream would be resettled due to implementation of the dam plan (reservoir area: about 25km^2).
Construction cost**	110,000 x 10^6 (JPY) • Facilities in short term plan: 99,800 x 10^6 (JPY) • Matamuhuri Main River Dam: 10,200 x 106 (JPY)

Notes:
1) * The year 2031 is assumed for completion of construction works in the roadmap presented below, because of delay of the Survey's progress due to COVID-19.
2) ** Calculated only for cost comparison to the other alternative plan, based on the following guideline and manual, excluding land acquisition/compensation costs, not the construction costs
   1. "Guide line for Calculating Facility Renewal Costs Related to Restructuring of Water Services, December 2011, (Waterworks Division, Health Bureau, Ministry of Health, Labor and Welfare)"
   2. "Civil Engineering Work Estimation Standard Manual 2020, (Ministry of Land, Infrastructure, Transport and Tourism, Japan)"

Source: JICA Survey Team

Furthermore, the roadmap for the above recommended option is proposed as presented in the figure below, including several processes before implementation of project construction.



Notes :

1) ▼ Target years, * The completion of the Study was delayed due to COVID19.

2) ** including procurement of consultant, D/D, P/Q & Tender

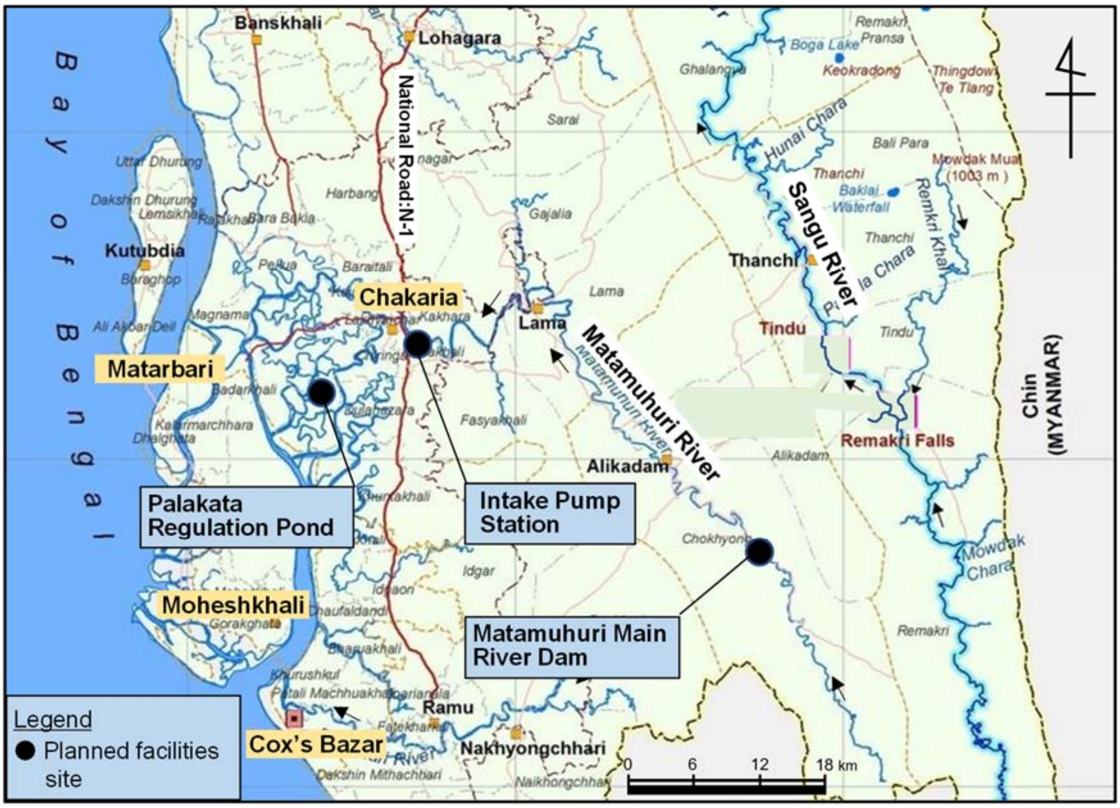
3) The long term road map is to be reviewed in future state of developments in the Moheshkhali/ Matarbari region and its suburbs.

Source: JICA Survey Team

V CONCLUSIONS AND RECOMMENDATIONS

9.1 This Data Collection Survey has proposed the water resources development method of "**M2-1: Palakata Regulation Pond (Short-term) + Matamuhuri Main River Dam**[1] (see the figure below)", through a preliminary study on water resources development in the south Chattogram region, as a recommended water resources development option in the region. This Survey has drawn out the road map for "M2-1" as well.

[1] While the recommended development option has a higher priority from a technical viewpoint, the dam site planned in the recommended option is located on the fringe of the reserved forest according to the basic environmental survey. Therefore, the practicability of the recommended option needs to be fully examined based on impacts of environmental and social consideration.



Source: JICA Survey Team

9.2 This Survey was repeatedly compelled to delay its progress and revise its work schedule due to the COVID-19 constraint. It was conducted, pushing the progress forward by partly incorporating remote work in Japan and also online-discussions between the Japanese and Bangladeshi sides. For the next survey stage of the water resources development plan in the south Chattogram region, it is recommended that future actions be successively taken in due consideration of the following issues and concerns：

(1) Hydrological study in the Matamuhuri River basin: accuracy improvement of river maintenance flow and update of water balance analysis model,

(2) Water quality for use of the Matamuhuri River water: detailed water quality inspection of heavy metals and pesticides by bringing samples back to Japan,

(3) Municipal water demand forecast: while the development of the Moheshkhali/Matarbari region is the national strategy and is expected to be developed stepwise in the short, medium, and long terms, it is necessary to take into account the economic situation in the "after-COVID19" and other trends due to global policies (such as low carbon and energy savings),

(4) Environmental and social assessment, particularly on construction and operation of Parakata regulation pond: to support the Environmental and Social Impact Assessment based on Bangladesh regulations, and conduct Environmental and Social Consideration Study based on the JICA Environmental and Social Consideration Guidelines,

(5) To conduct topographic, geological and geotechnical surveys for planning water-use facilities in the short-term and long term water resources development plan, and to coordinate the plan of the said water-use facilities with new roads and railways under planning/design in other MIDI-related projects,

(6) To continue study on institutional arrangements for implementation of short-term and long-term water resources development plan,

(7) To assess and confirm viability of the short-term and long-term water resources development plans through economic and financial analyses, and

(8) To make a study on additional projects which are expected to promote a synergy effect by using the vast water-surface and riparian areas in and around the Palakata regulation pond so that the short-term and long-term plan would add value to a whole of MIDI as one of the MIDI projects.

DATA COLLECTION SURVEY
ON
WATER RESOURCES DEVELOPMENT IN SOUTHERN CHATTOGRAM

ABBREVIATIONS

英　語		日本語
ADCP	Acoustic Doppler Current Profiler	音波式ドップラー流速計
Al	Aluminum	アルミニウム
As	Arsenic	砒素
BADC	Bangladesh Agricultural Development Corporation	バングラデシュ農業開発公社
BBS	Bangladesh Bureau of Statistics	バングラデシュ統計局
BD	Bangladesh	バングラデシュ
BDP2100	Bangladesh Delta Plan 2100	バングラデシュデルタプラン 2100
BETS	Bangladesh Engineering and Technological Services	BETS 社(再委託業務コンサルタント地下水調査)
BEZA	Bangladesh Economic Zones Authority	バングラデシュ経済特区庁
BIG-B	Bengal Bay Growth Zone Plan	ベンガル湾成長地帯構想
BIWTA	Bangladesh Water Transport Authority	バングラデシュ内陸水運公社
BMD	Bangladesh Meteorological Department	バングラデシュ気象局
BOD	Biochemical Oxygen Demand	生物化学的酸素要求量
BPDB	Bangladesh Power Development Board	バングラデシュ電力開発庁
BREB	Bangladesh Rural Electrification Board	バングラデシュ地方電化庁
BRRI	Bangladesh Rice Research Institute	バングラデシュ稲研究協会
BUET	Bangladesh University of Engineering and Technology	バングラデシュ工科大学
BWDB	Bangladesh Water Development Board	バングラデシュ水開発庁
CC-MIDI	Moheshkhali and Matarbari Integrated Infrastructure Development Initiative Coordination Committee	モヘシュカリ・マタバリ統合的インフラ開発イニシアティブ調整委員会
Cd	Cadmium	カドミウム
CEGIS	The Center for Environmental and Geographic Information Services	CGIS 社(再委託業務コンサルタント：概略環境調査)
CEPZ	Chittagong Export Processing Zone	チョットグラム輸出加工区
CHT	Chattogram Hill Tract	チョットグラム丘陵地
Cl-	Chloride	塩化
CN-	Cyanides	シアン化物
COD	Chemical Oxygen Demand	化学的酸素要求量
CPA	Chattogram Port Authority	チョットグラム港湾機構
CPGCBL	Coal Power Generation Company. Bangladesh Limit	バングラデシュ石炭火力発電会社
Cr	Chrome	クロム
Cu	Cupper	銅
CWASA	Chattogram Water Supply and Sewerage Authority	チョットグラム上下水道公社
DAE	Department of Agriculture Extension	農業普及局
DBHWD	Department of Bangladesh Haor and Wetlands Development	バングラデシュハオール・湿地開発局
DC	Deputy Commissioner	県副行政官
DEM	Digital Elevation Model	数値標高モデル
DFR	Draft Final Report	ドラフトファイナルレポート
DLRS	Department of Land Record and Surveys	土地記録調査局
DO	Dissolved Oxygen	溶存酸素量
DOE	Department of Environment	環境局
DPHE	Department of Public Health Engineering	公衆衛生工学局
EA	Environmental Assessment	環境評価
EC	Electro Conductivity	伝導率
EIA	Environmental Impact Assessment	環境影響評価
ECNWRC	Executive Committee of the National Water Resources Council	国家水資源評議会執行委員会
EIP	Eco Industrial Park	環境に配慮した工業団地
EL	Elevation	標高
EPWAPDA	East Pakistan Water and Power Development Authority	東パキスタン水資源・電力開発局

EZ	Economic Zone	経済特区
F-	Fluoride	フッ化物
FAO	Food and Agriculture Organization	国連食糧農業機関
FAP	Flood Action Plan	洪水行動計画
Fe	Iron	鉄分
FPCO	Flood Plan Coordination Organization	洪水計画調整機構
FR	Final Report	ファイナルレポート
GOB	Government of Bangladesh	バングラデシュ国政府
GPS	Global Positioning System	全地球測位システム
GSMaP	Global Satellite Mapping of Precipitation	降水量グローバル衛星マッピング
Hg	Mercury	水銀
IBRD	International Bank for Reconstruction and Development	国際復興開発銀行
ICR	Inception Report	インセプションレポート
ISO	International Organization for Standardization	国際標準化機構
ITR	Interim Report	インテリムレポート
IUCN	International Union for Conservation of Nature and Natural Resources	国際自然保護連合
IWM	Institute of Water Modelling	水モデル研究所
JAXA	Japan Aerospace Exploration Agency	宇宙航空研究開発機構
JETRO	Japan External Trade Organization	独立行政法人日本貿易振興機構
JICA	Japan International Cooperation Agency	国際協力機構
JP	Japan	日本
JRC	Joint Rivers Commission	バングラデシュ合同河川委員会
JSS	Japan Security Service	日本セキュリティサービス
JWA	Japan Water Agency	水資源機構
KKCD	Khuta Khali Chara Dam	Khuta Khali Chara ダム
LG	Local Government	地方政府
LGD	Local Government Division	地方行政総局
LGED	Local Government Engineering Department	地方政府技術局
MCM	Million Cubic Meters	百万立方メートル
MIDI	Moheskhali and Matabari Integrated Infrastructure Development Initiative	モヘシュカリ・マタバリ統合的インフラ開発イニシアティブ
MLD	Million Liter per Day	百万立法リットル/日
MoA	Ministry of Agriculture	農業省
Mn	Manganese	マンガン
MoDMR	Ministry of Disaster Management and Relief	防災支援省
MOE	Ministry of Energy	エネルギー省
MoEF	Ministry of Environment and Forests	環境森林省
MoEF	Ministry of Environment and Forests	環境森林省
MoLGRD ＆C	Ministry of Local Government, Rural Development and Cooperatives	地方自治・農村開発協同組合省 地方自治総局
MoS	Ministry of Shipping	海運省
MoU	Memorandum of Understanding	了解覚書
MoWR	Ministry of Water Resources	水資源省
MPEMR	Ministry of Power, Energy and Mineral Resources	電力、エネルギー、鉱物資源省
M/P	Master Plan	マスタープラン
MPO	Master Plan Organization	マスタープラン機関
MSL	Mean Sea Level	平均潮面
mS	Milli Siemens	ミリジーメンス
MW	Mega Watt	メガワット
NGO	Non-governmental Organization	非政府組織
N-NH4	Ammonium-nitrogen	アンモニウム窒素
N-NO3	Nitrous-nitrogen	亜硝酸窒素
NTU	Nephelometric Turbidity Unit	比濁法濁度単位
NWMP	National Water Management Plan	国家水管理計画
NWPo	National Water Policy	国家水政策
NWRC	National Water Resources Council	国家水資源評議会
O&M	Operation and Maintenance	運用管理
ODA	Official Development Assistance	政府開発援助
PD	Project Director	プロジェクト統括責任者
PCU	Platinum Cobalt Units	色度
PDB	Power Development Board	電力開発庁

PFI	Private Finance Initiative	民間資金主導
PMO	The Prime Minister's Office	大統領官邸
PPP	Public Private Partnership	官民パートナーシップ
PPPA	Public Private Partnership Authority	官民パートナーシップ庁
QCBS	Quality and Cost Based Selection	技術・価格評価
Qtu	Qtu	現世堆積物（砂丘砂、海岸砂）
RRI	River Research Institute	河川研究所
RDCD	Rural Development and Co-operatives Division	農村開発協同組合総局
SDGs	Sustainable Development Goals	持続可能な開発目標
SEZ	Special Economic Zone	経済特区
SIA	Social Impact Assessment	社会影響評価
SRTM	Shuttle Radar Topography Mission	スペースシャトル立体地形データ
SoB	Survey of Bangladesh	バングラデシュ測量局
SPM	Single-Point Mooring	一点係留
STWG	Sub-Technical Working Group	サブテクニカルワーキンググループ
Tmbb	Bokabil Formation	ボカビル層
Tmts	Tipam Formation	ティパム層
Tmub	Upper Part of Bhuban Formation	ブバン上層
ToR	Terms of Reference	付託条項
Tpmd	Dupitila Formation	ドゥピティラ層
TWG	Technical Working Group	テクニカルワーキンググループ
UNICEF	United Nations Children's Fund	国際連合児童基金
USAID	United States Agency for International Development	アメリカ合衆国国際開発庁
WASA	Water Supply and Sewerage Authority	上下水道公社
WHO	World Health Organization	世界保健機関
WL	Water Level	水位
WLG	Water Level Gauge	水位計
WR	Water Resource	水資源
WRDOs	Water Resources Development Options	水資源開発オプション
WARPO	Water Resources Planning Organisation	水資源計画機構
Zn	Zinc	亜鉛

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CHAPTER 1 INTRODUCTION

1.1 Background of the Survey

The Moheshkhali/Matarbari region in Cox's Bazar Province of the People's Republic of Bangladesh (hereinafter referred to as “Bangladesh”) is progressing as an important infrastructure base; for instance, through the construction of the Matarbari Port, the first deep-sea port in Bangladesh and an ultra-supercritical power plant under the Japanese technical assistance based on “The Bay of Bengal Industrial Growth Belt (BIG-B)” agreed at the Japan-Bangladesh Summit in September 2014.

Furthermore, concept formulation, institutional arrangements, a legal framework, etc. for the comprehensive development of the Moheshkhali/Matarbari region have been currently being studied and/or proposed. In such a situation, the development of water resources essential for relocation of residents and attraction of industry to the region is needed. In “Land Use and Development Planning Survey of Moheshkhali and Matarbari Area in Bangladesh (JICA, August 2019)”, the water demands necessary for the development in the General Economic Zone and the Seaborne Economic Zone and also housing-related development were estimated at 61,800 m^3/day and 194,500 m^3/day in the short term to 2026 and the medium/long terms to 2041, respectively.

Hence, it is required to develop the water resources immediately as the measures to be taken for promotion of industrial location and growth of population in the regions.

1.2 Survey Objectives

The objectives of the Survey are:

1) Survey of present available water resources and water usage in southern Chattogram region,
2) Forecast of future water demand, taking comprehensive development plan in the Moheshkhali/Matarbari region into consideration, and
3) Preliminary study on candidate sites of water source and water-use facilities (water resources development method).

1.3 Survey Area

The survey area is the southern Chattogram region in the Chattogram Division of Bangladesh, of which the location map is shown in the frontispiece of this report.

1.4 Related Agencies (Counterpart Body)

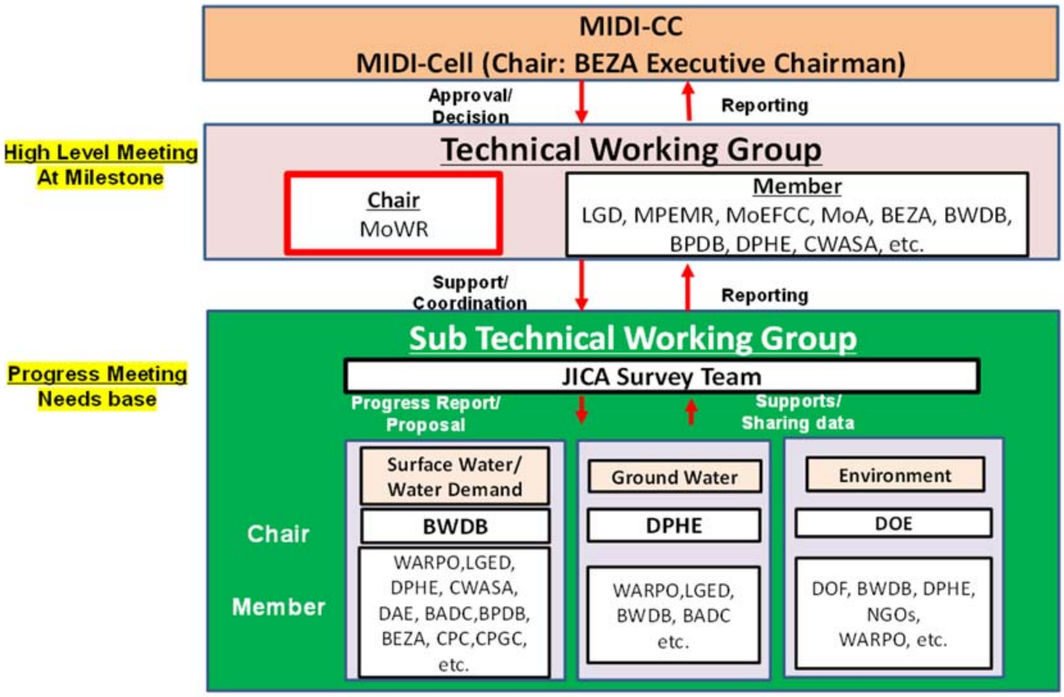
It is essential that the Survey cooperate closely with several organizations/institutions which cover extensively beyond each administrative division.

The Moheshkhali/Matarbari Integrated Infrastructure Development Initiative Coordination Committee (hereinafter referred to as “the MIDI Coordination Committee”), composed of the secretary level officers of relevant ministries and other agencies concerned, is the organization responsible for the cross-sectoral comprehensive development in the Moheshkhali/Matarbari region. Table 1.4.1 shows the cooperation organizations of this survey, including the MIDI Coordination Committee.

Table 1.4.1 Cooperating Organizations for This Survey

• Moheshkhali Matabari Integrated Infrastructure Development Initiative Coordination Committee (CC-MIDI)
• Bangladesh Economic Zone Authority (BEZA)
• Ministry of Water Resources (MoWR) - Bangladesh Water Development Board (BWDB) - Water Resources Planning Organizations (WRPO)
• Ministry of Industries (MoI)
• Ministry of Disaster Management and Relief (MoDMR)
• Chittagong Water and Sewerage Authority (CWASA)
• Bangladesh Power Development Board (BPDB)
• Department of Agriculture Extent (DAE)
• Department of Public Health Engineering (DPHE)
• Local Government Division (LGD) - Local Government Engineering Division (LGED)

Moreover, a Technical Working Group (TWG), of which the leading agency is the Ministry of Water Resources (hereinafter referred to as "the MoWR"), has been established under the MIDI Coordination Committee, as referred to in Figure 1.4.1, and the TWG is the counterpart body for this survey.

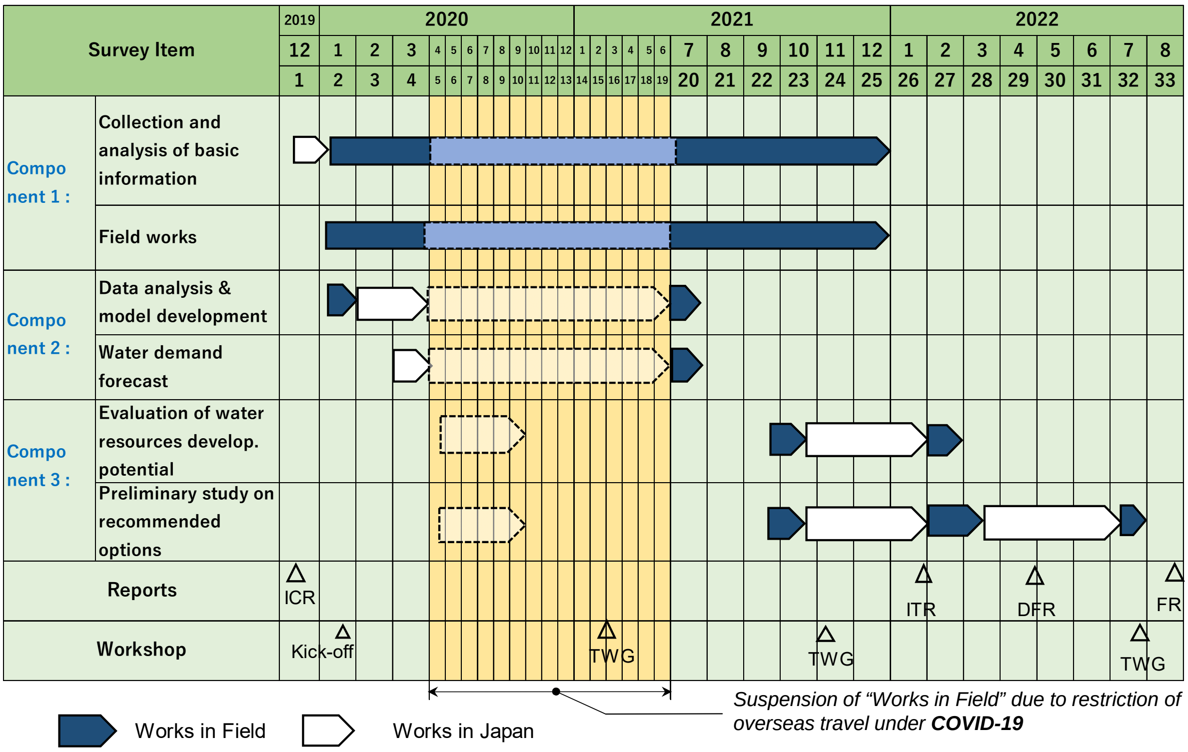


Source: JICA Survey Team

Figure 1.4.1 TWG and Sub TWG

1.5 Survey Schedule

The works in the field by the Japanese members of the JICA Survey Team were suspended due to restrictions of overseas travel under the COVID-19 pandemic, and resumed in July 2021 after 15 months of suspension. Figure 1.5.1 shows the revised overall survey schedule.



Source: JICA Survey Team

Figure 1.5.1 Revised Survey Schedule

1.6 Final Report

This Final Report is submitted as the final output of the survey work which was conducted from the commencement of the Survey in mid-December 2019 through mid-August 2022. This report is composed of five chapters, as explained below.

Chapter	Major Survey Work and Outputs
Chapter 1 Introduction	
Chapter 2 Component 1	• Current situation analysis of water resources, including available water resources, through field survey
Chapter 3 Component 2	• Analysis of water resources and forecast of water demands based on current situation analysis,
Chapter 4 Component 3	• Evaluation of water resources development potential based on results from Chapters 1 and 2 • Proposition of (i) recommended option of water resources development plan, holding the possibility of JICA's assistance for which a preparatory survey and project formulation are to be considered, and (ii) road map of the development plan

Chapter	Major Survey Work and Outputs
Chapter 5 Conclusions and Recommendations	• Recommendation of future actions to be taken successively for next survey stage of the recommended option of water resources development plan

Source: JICA Survey Team

CHAPTER 2 COMPONENT 1 : ANALYSIS OF CURRENT SITUATION OF WATER RESOURCES IN SURVEY AREA INCLUDING AVAILABLE WATER RESOURCES THROUGH FIELD SURVEY

This chapter describes the current situation of water resources, including available water resources, in the survey area, analyzed based on the outcomes from the following field surveys which were conducted under subcontracts with a local institute and consultants in Bangladesh:

- Surface water survey,
- Topography, geology and ground water survey,
- Kaptai Dam survey, and
- Basic environmental survey.

2.1 Surface Water Survey

2.1.1 Collection and Summarization of Basic Information

(1) Subcontracted Field Survey Works

The subcontracted field survey works regarding watershed basic information, surface water investigation and present situation survey of Kaptai Dam were undertaken under a contract with a local consultancy company. The outline of the local subcontracted field works for surface water survey is summarized in Table 2.1.1.

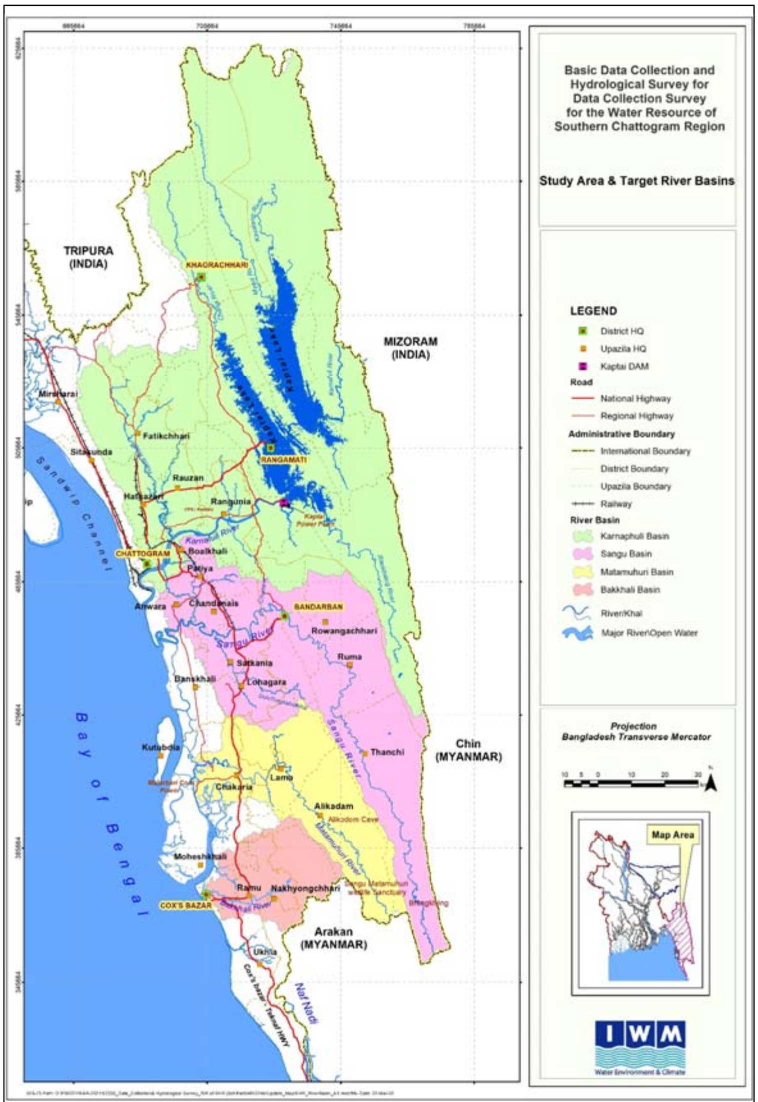
Table 2.1.1 Outline of Subcontracted Surface Water Survey

Subcontract	Scope of Works
Collection of basic information and analysis	<u>Collection of existing basic information and analysis</u> Object matters: Watershed features, weather characteristics, flood damage, hydrological data, water use (domestic/industrial water), agricultural water, socio-economy, present development plan, etc.
Surface water observation	<u>Object rivers</u> Four rivers: Karnafuli River, including Halda River (tributary), Sangu River and Matamuhuri River <u>Major works</u> • Installation of water level (WL) observation stations: 4 rivers x 1 station = 4 stations in total, • River cross-section survey: New WL 4 stations x 2 times (1 time each in dry and rainy seasons) = 8 times in total, • River discharge measurement: New WL 4 stations x 9 times (6 and 3 times in low and high water seasons, respectively) = 36 times in total, and • Water quality sampling: 3-rivers x 1 location each x 3-cases of water depth x 12 times (1 time a month) = 108 samples in total

Source: JICA Survey Team

(2) Watershed Feature

The basin map (Karnafuli, Sangu, Matamuhuri, Bakkhali Rivers) of the target area in this project and watershed specifications are shown in Figure 2.1.1 and Table 2.1.2. The South Chattogram Region has a series of hills with an altitude of about 300 to 500 m, which is an extension of the Himalaya mountains, and each river flows from the hills to the Bay of Bengal via the plain area. The Karnafuli River basin has the largest area, Kaptai Dam had been installed in the middle basin and the regional city of Chattogram is located in the low basin area. The second-largest Sangu River basin has the regional city of Bandarban in the middle basin area. The Matamuhuri and Bakkhali River basin have the regional cities of Lama and Cox's Bazar in each basin area, respectively and are facing the border with Myanmar. The hilly area of each river basin occupies 57% to 79%, and the Sangu River has the largest number (79%) of hilly area.



Source: JICA Survey Team

Figure 2.1.1 Basin Map

Table 2.1.2 Basic Information of Watersheds

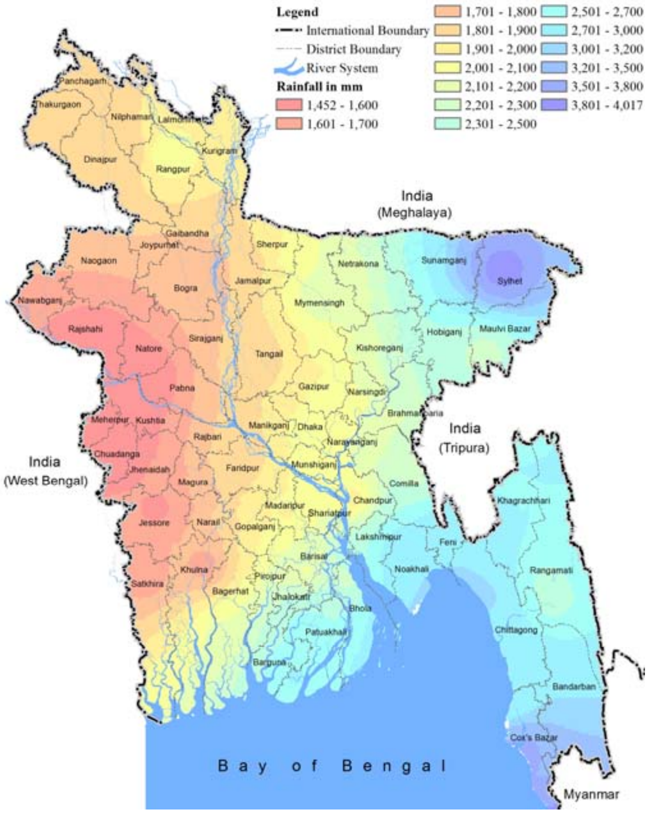
No.	Items	River Dimension			
		Karnafuli	Sangu	Matamuhuri	Bakkhali
01	Total Basin	14,362 km^2	3,667 km^2	2,511 km^2	845 km^2
02	Hilly Area	8,186 km^2 (57%)	2,897 km^2 (79%)	1,484 km^2 (59%)	600 km^2 (71%)
03	Plain area	6,176 km^2 (43%)	770 km^2 (21%)	1,027 km^2 (41%)	245 km^2 (29%)
04	Length	175 km	294 km	176 km	69km
05	Width	161m to 960m	76m to 180m	86 m to 238m	17m to 400m
06	Avg. Slope	1/2,940 (34 cm/km)	1/6,250 (16 cm/km)	1/3,570 (28 cm/km)	1/3,570 (28 cm/km)

Source: JICA Survey Team

(3) Weather characteristics

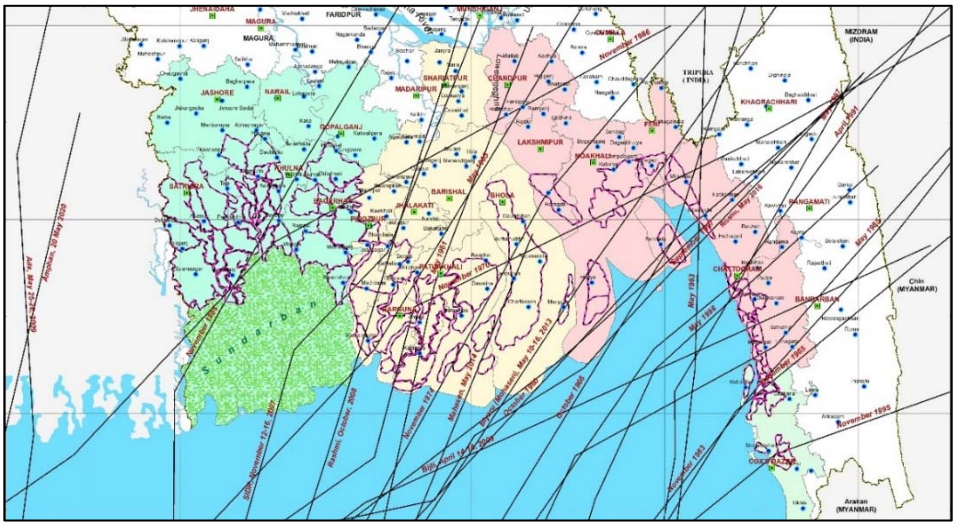
Bangladesh belongs to the area of tropical monsoon climate with high temperature and humidity, and is located in the course of the cyclone which occurs in the Indian Ocean, suffering intensive rainfalls in a short period of time. As shown in Figure 2.1.3, the Chattogram hills area targeted in this survey lies in the cyclone-prone area.

As shown in Figure 2.1.2, the annual rainfall is 1,500 mm in the western part of Bangladesh, 2,500 mm in the eastern part, and 3,500 mm in the northern hills, and the amount of rainfall tends to be higher in the eastern and northern hills. The Chattogram hills area has an annual rainfall of 2,500 mm, which is the same as that in the eastern region, and is the second highest rainfall area in Bangladesh, next to the northern hill area.



Source: Bangladesh Delta Plan 2100, BWDB

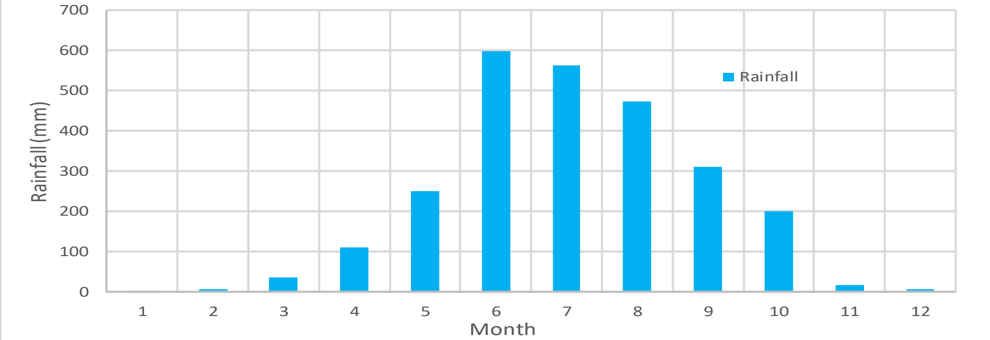
Figure 2.1.2 Contour Map of Average Annual Rainfall (1980-2014)



Source: Cyclone data sourced from Bangladesh Meteorological Department (BMD)

Figure 2.1.3 Record Map of Cyclone Courses

Figure 2.1.4 shows the average monthly rainfalls at the Bandarban Station, located in the center of the Chattogram hills area. The climate in Bangladesh is classified roughly into the rainy season from April to October and the dry season from November to March. In the rainy season, the rainfall is higher due to the influence of the monsoon, especially from May to October, accounting for about 90% of the annual rainfall. At the Bandarban Station, as presented below, the rainfall from May to October is 2,392 mm, equivalent to 93% (= 2,392 / 2,568) .



Rainfall Sta.: Bandarban WLG Sta.: Bandarban C.A.: 2199 km^2

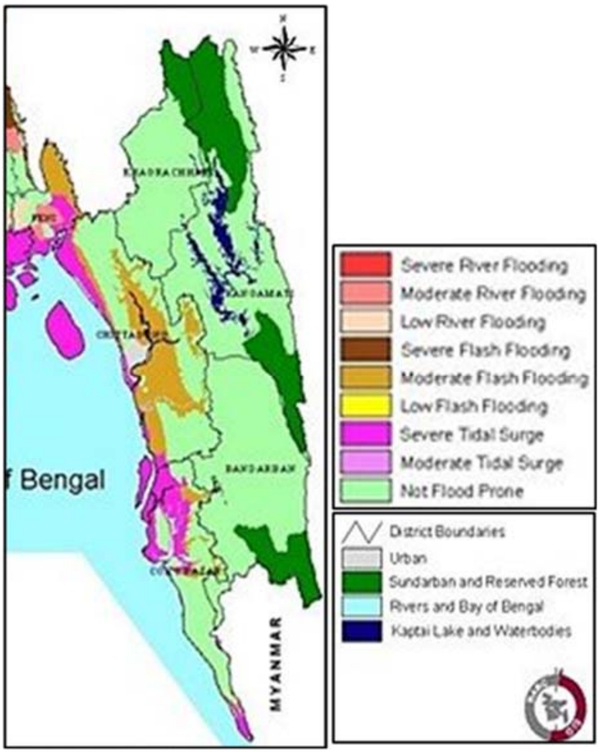
Item	Unit	1	2	3	4	5	6	7	8	9	10	11	12	Ave.	Tot.
Rainfall	mm/month	1	6	35	110	250	597	563	473	309	200	18	6	214	2,568

Source: Prepared by JICA Survey Team based on data at Bandarban rainfall station, BWDB

Figure 2.1.4 Average Monthly Rainfall (Bandarban, from 2010 to 2019)

(4) Flood damage

The flood prone area prepared by the Bangladesh Agricultural Research Council (BARC) is shown in Figure 2.1.5. The orange area is the flood inundation area caused by the flash flow from the hills, and the area around the Chattogram area is the main flood prone area. The purple area indicates a storm surge inundation area, and the Moheshkhali Matarbari area is the main storm surge inundation prone area. The dangerous water levels (river water levels that start flood inundation) have been set in the target rivers (Karnafuli River, Halda River (branch river), Sangu River, Matamuhuri River). The number of days that exceeded the dangerous water levels in recent major floods (2017, 2018) and past maximum floods (1998) are shown in Table 2.1.3. It is confirmed that the number of days of flooding in the lower Karnafuli River (Chattogram) and its



Source: Bangladesh Agricultural Research Council (BARC)/GIS Project, BGD/95/006)

Figure 2.1.5 Flood Prone Area Map

tributary Halda River is relatively long.

Table 2.1.3 Number of Days above Dangerous Water Levels in Major Floods

Sl. No	River	Station	Water Level (m PWD)					Days above Danger Level		
			Recorded Maximum	Danger Level 1)	Peak of the Year					
					2018	2017	1998	2018	2017	1998
1	Karnafuli	Chattogram	4.98	4.60	4.65	4.98	-	1	7	-
2	Halda	Narayanhat	19.30	15.25	16.92	16.85	16.57	5	11	21
3	Halda	Panchpukuria	12.54	9.50	10.90	9.70	10.44	2	2	4
4	Sangu	Bandarban	20.70	15.25	15.85	16.60	15.25	2	3	1
5	Sangu	Dohazari	9.05	7.00	7.50	7.79	7.42	3	3	2
6	Matamuhuri	Lama	15.46	12.25	13.29	13.79	13.05	4	5	2

1) Danger Level: River water levels that start flood inundation

Source: JICA Survey Team

2.1.2 Surface Water Observation

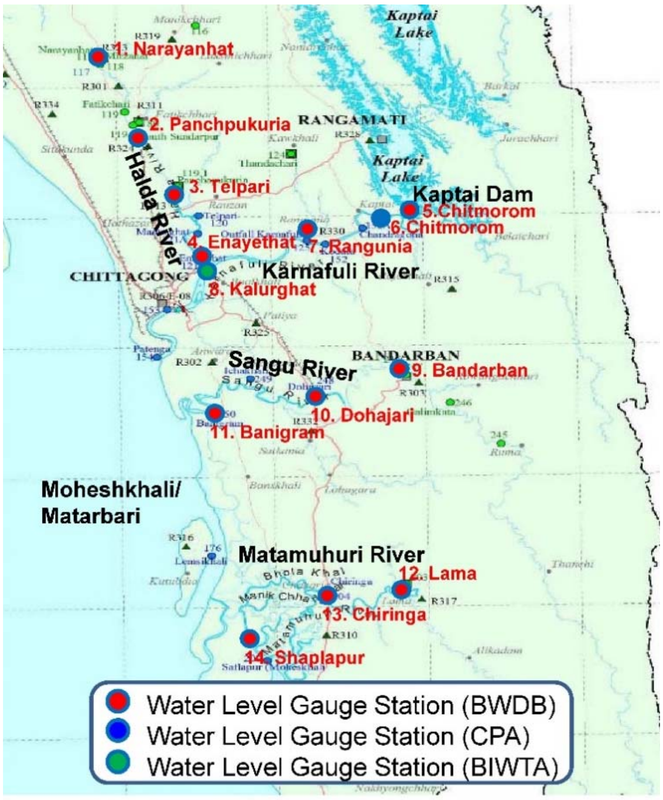
For the purpose of verifying the existing observation data of water level and discharge, water level gauge stations were installed, and the observation of water level and discharge had been conducted in this survey. In addition, a water quality survey was conducted for the purpose of finding the current state of river water quality. The outline of the observation survey is described below.

(1) Current conditions of river water level observation

The current conditions of water level observation in the Karnafuli, the Halda, the Sangu and the Matamuhuri Rivers are as stated hereunder.

The observations in the above-mentioned rivers have been implemented at 14 water level gauge (WLG) stations in total, whose locations and survey conditions are shown in Figure 2.1.6 and Table 2.1.4, respectively.

The water levels have been continuously recorded for more than 50 years since 1965 at 7 stations. The observations are carried out five times a day by a manual method (visual observation and recording of water level) by local gauge readers commissioned by government agencies such as BWDB. Hourly water levels observed by pressure sensors installed by the Chattogram Port Authority (CPA) have been automatically recorded into data loggers at the Kaptai (No. 5) and the Chitmorom (No. 6) stations in the Karnafuli River.



Source：JICA Survey Team

Figure 2.1.6 Location Map of Existing WLG Stations

Table 2.1.4 Summary of Current Survey Conditions of Existing WLG Stations

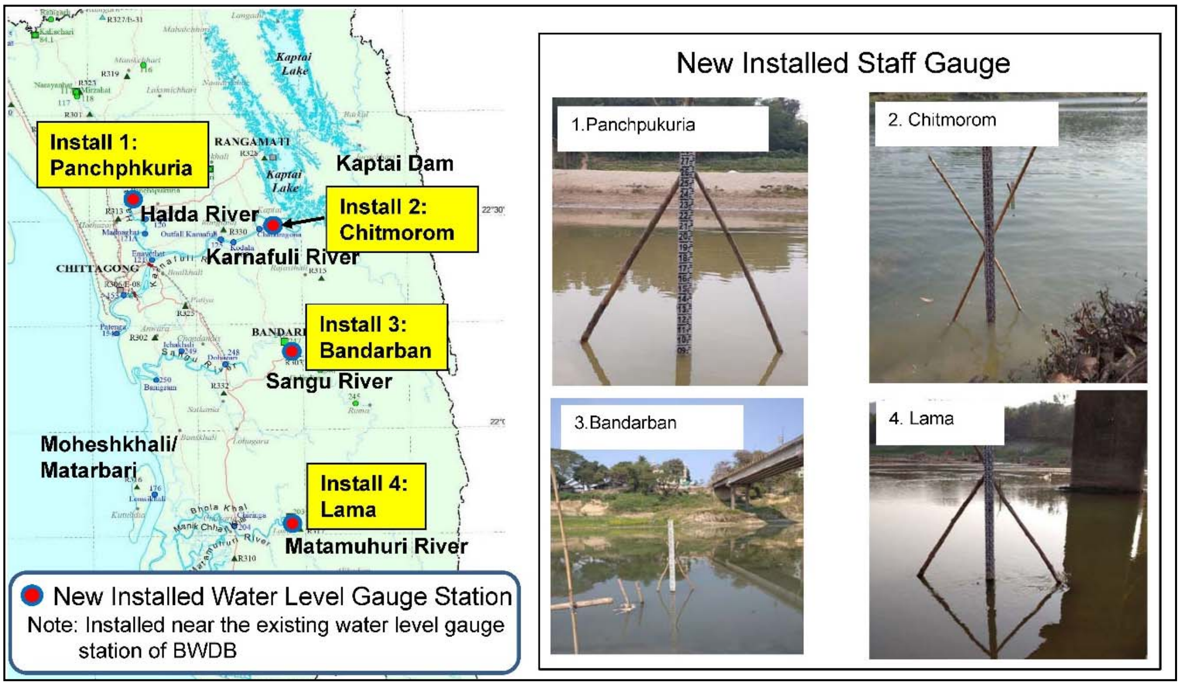
No.	Station	River	Organization	Start Year	Record Type	Frequency
1	Narayanhat	Halda	BWDB	1965	Manual	5 times/day
2	Panchpukuria	Halda	BWDB	1965	Manual	5 times/day
3	Telpari	Halda	BWDB	1965	Manual	5 times/day
4	Enayethat	Halda	BWDB	1965	Manual	5 times/day
5	Kaptai	Karnafuli	BPDB	1990	Automatic	24 times/day
6	Chitmorom	Karnafuli	CPA	2011	Automatic	24 times/day
7	Rangunia	Karnafuli	BWDB	1965	Manual	5 times/day
8	Kalurghat	Karnafuli	BIWTA	2012	Manual	5 times/day
9	Bandarban	Sangu	BWDB	1965	Manual	5 times/day
10	Dohajari	Sangu	BWDB	1969	Manual	5 times/day
11	Banigram	Sangu	BWDB	1968	Manual	5 times/day
12	Lama	Matamuhuri	BWDB	1965	Manual	5 times/day
13	Chiringa	Matamuhuri	BWDB	1968	Manual	5 times/day
14	Shaplapur	Matamuhuri	BWDB	1968	Manual	5 times/day

Source: JICA Survey Team

(2) Installation of WLG stations and monitoring of water level/discharge

1) Installation of WLG stations

Staff-gauges and water level sensors (pressure type) were installed in the Survey on 30 January 2020 in each of the Karnafuli, the Halda, the Sangu and the Matamuhuri Rivers (4 locations in total; refer to Figure 2.1.7) for the purpose of verifying the accuracy of existing water level observations (commencement of observation at the 4 locations: 1 February 2020). The best locations were determined in the selection of the installation sites by comprehensively evaluating from the viewpoints of observation periods at, influence of tide level on and road access from the existing WLG stations (refer to Annex 2.1-1 Site Selection for Installation of Water level Gauge Stations).



Source: JICA Survey Team

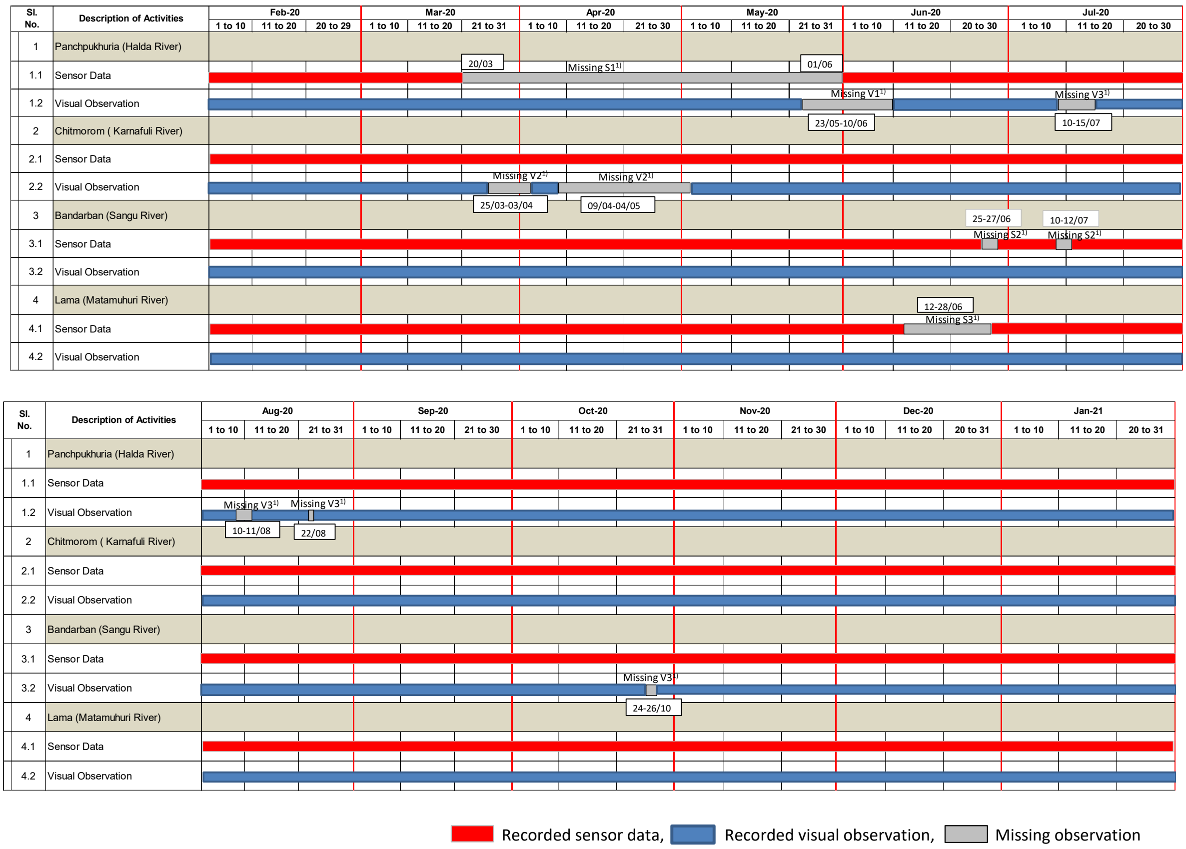
Figure 2.1.7 Location Map of Newly Installed WLG Stations

2) Monitoring of water level

Throughout one year (February 2020 - January 2021) from the commencement of the survey, visual observation of the staff gauges and recording with the water level sensors were carried out. Visual observations were recorded every hour, and the water level sensors recorded at 10 minute intervals. The record periods are shown in Table 2.1.5 below. The cyclone "Amphan" struck Bangladesh on 24 May 2020 and washed away the staff-gauge and the water level sensor that had been installed in this survey at Panchpukuria in the Halda River. The sensor equipment was re-installed on 1 June 2020 when the activity restriction until the end of May 2020 due to COVID-19 was unlocked. The staff gauge was re-installed on 10 June 2020 after the river water level lowered. Although the stored sensor data for more than two months (from 21 March to 31 May 2020) had been lost, the missing period was finally counted just for 8 days (from 24 May to 31 May 2020) before the re-installation of the water level sensor on 1

June 2020 since the visual observation had been implemented continuously until 23 May 2020, and the other periods succeeded in observing the data throughout the year. In addition, the reason and countermeasures for other data missing periods, such as missing visual observation at the Chitmorom Station, due to movement restriction under COVID-19, were also summarized in Table 2.1.5. Although some missing observation by sensor or visual observation had occurred partially, the water level data could be recorded successfully at three WLG stations, excluding the Panchpukuria Station, by sensor and/or visual observation throughout all periods.

Table 2.1.5 Record Periods of Water Level at WLG Stations Installed by JICA Survey Team



Note: The reason and countermeasure for missing observation can be referred to in Table 2.1.6.
Source: JICA Survey Team

Table 2.1.6 Reason for Missing Observation and Countermeasure

<Visual Observation of Staff Gauge>

Missing No.	Missing Period (Gauge Station)	Reason	Countermeasure for Recurrence Prevention
Missing V1	23 May-10 Jun. 2020 (Panchpukuria)	The staff gauge was washed away due to the flash flood caused by cyclone Amphan at the end of May 2020	Strengthened its stability by piling pillar deeper into riverbed to prevent recurrence and fastening staff gauge to a tree on the riverbank with a rope
Missing V2	25 Mar.-03 Apr. 09 Apr.-04 May 2020 (Chitmorom)	Visual observation was suspended due to restriction on moving under lock down of COVID-19.	N/A
Missing V3	10-15 July, 10-11 Aug., 22 Aug. 2020 (Panchpukuria) 27-29 May 2020, 24-26 Oct. 2020 (Bandarban)	The staff gauge was submerged during flash floods	The manual staff gauge had been installed as a complement for calibration and comparison of sensor data. Since the sensor was in operation there, did not install extra staff gauge for recording short period during very high stages.

<Sensor Observation>

Missing No.	Missing Period (Gauge Station)	Missing reason	Countermeasure for recurrence prevention
Missing S1	20 Mar.- 01 Jun. 2020 (Panchpukhuria)	The sensor was washed away due to the flash flood caused by cyclone Amphan at the end of May 2020.	The casing of the sensor was tied with a rope to a tree log driven into the riverbed.
Missing S2	25-27 Jun. 2020, 10-12 Jul. 2020 (Bandarban)	The sensor failed recording due to mechanical trouble, resulting in no stored data.	Replaced the sensor with new one.
Missing S3	12-28 Jun. 2020 (Lama)	Sensor was buried under sediment loads after flash flood.	Location of sensor installation was changed.

Source: JICA Survey Team

3) Monitoring of discharge

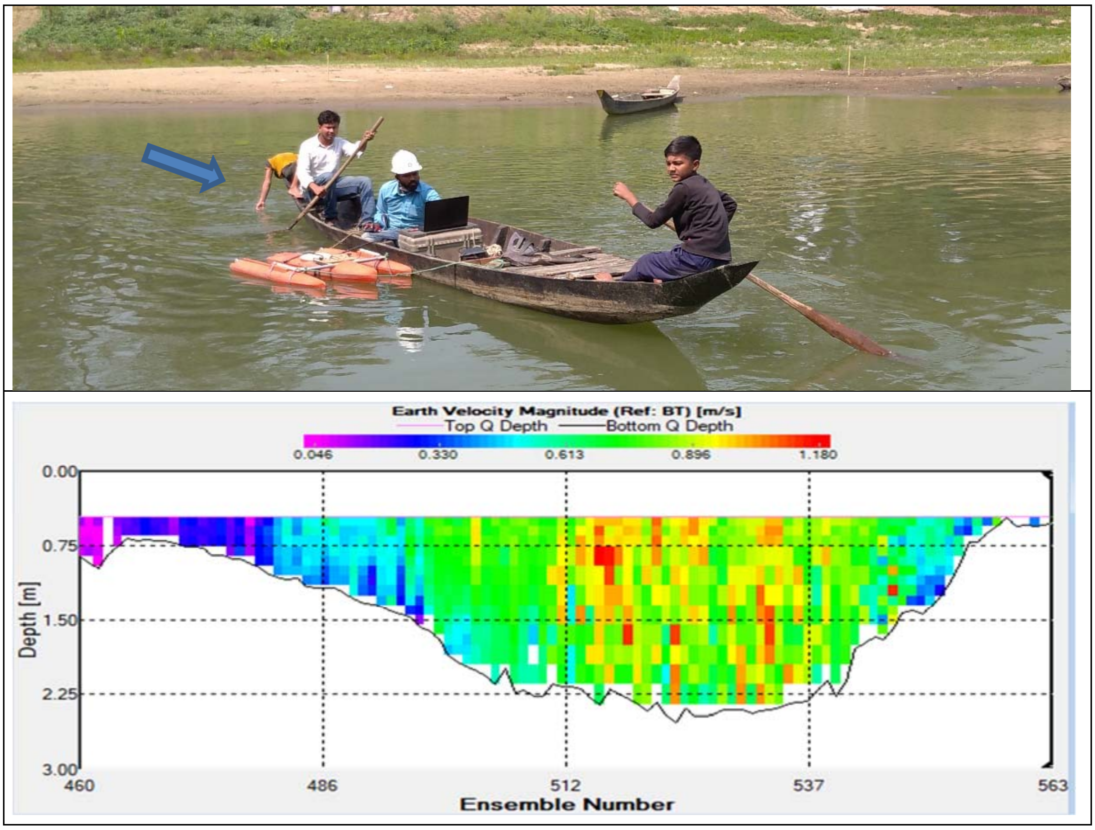
Discharge observations were carried out periodically at each of the newly installed WLG stations, as shown in Table 2.1.7. During the two and a half months from mid-March to the end of May 2020, no observation was possible due to restrictions under COVID-19, but observations in other periods were carried out more than once a month. Cross-section surveys were also conducted 6 times in total throughout the year. The cross-section surveys and flow velocity measurements were conducted by using an Acoustic Doppler Current Profiler (ADCP) (refer to Figure 2.1.8). The passing discharge was estimated by calculating the average flow velocity based on the flow velocity distribution obtained in the cross section by the ADCP and multiplying the average by the cross-section area.

The accuracy of the water level and discharge observations carried out by the JICA Survey Team was verified, and then the accuracy of BWDB's observation data was also verified by comparing them with the observation values of the JICA Survey Team. The details of the verification are described in the following Sub-section "3.1.2 Verification and Analysis of Hydrological Observation Data".

Table 2.1.7 Observations of Actual Discharge by JICA Survey Team

SL	Station Name	Description of Activities	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20	Sep-20	Oct-20	Nov-20	Dec-20	Jan-21	Total No
1	Panchpukhuria	Discharge Measurement	● 22 Feb	● 8 Mar			● 2 Jun	● 13 Jul ● 18 Jul	● 8 Aug ● 18 Aug	● 12 Sep ● 25 Sep	● 13 Oct ● 27 Oct	● 19 Nov	● 20 Dec	● 19 Jan	14
		Cross section survey	● 22 Feb						● 8 Aug	● 12 Sep	● 13 Oct	● 19 Nov		● 19 Jan	6
2	Bandarban	Discharge Measurement	● 23 Feb	● 7 Mar			● 1 Jun	● 12 Jul	● 7 Aug ● 19 Aug	● 13 Sep ● 24 Sep	● 12 Oct ● 24 Oct	● 18 Nov	● 19 Dec	● 17 Jan	13
		Cross section survey	● 23 Feb				● 1 Jun		● 7 Aug	● 13 Sep	13 Oct	● 18 Nov		● 17 Jan	6
3	Lama	Discharge Measurement	● 23 Feb	● 7 Mar			● 1 Jun	● 12 Jul	● 7 Aug ● 19 Aug	● 14 Sep ● 25 Sep	● 14 Oct ● 25 Oct	● 18 Nov	● 18 Dec	● 16 Jan	13
		Cross section survey	● 23 Feb						● 19 Aug	● 14 Sep	● 14 Oct	● 18 Nov		● 16 Jan	6
4	Chitmorrom	Cross section survey	● 22 Feb				● 2 Jun		● 20 Aug		● 15 Oct	● 20 Nov		● 18 Jan	6

Source: JICA Survey Team



Source: JICA Survey Team

Figure 2.1.8 Discharge Observation by Acoustic Doppler Current Profiler (ADCP) (Bandarban in Sangu River)

(3) Water quality survey of surface water

The water quality survey of surface water was carried out according to the following procedures. (i) Samplings were conducted at the points in the Karnafuli, Sangu, and Matamuhuri Rivers, where there are sufficient water depths expected, close to the river discharge observation points, as well as the most downstream points where the influence of saltwater intrusion can be minimized, and there is a possibility that these points will be the candidates of intake point for water use. In the lake of Kaptai Dam, samplings were carried out near the intake of the power generation facilities and at a point which is closer to the center of the lake within a reachable area. The coordinates of the points are shown in Table 2.1.8. In addition, it has been confirmed that there is little direct influence on the points due to drainage, the confluence of tributaries, etc.

The samples were collected at 20%, 50%, and 80% of the water depths basically and when the water depth is less than 1.5 m, the samples were collected at 20% and 80% water depths. (ii) As for monitoring of this survey, continuous observation for 12 months was initially planned for the whole year, but it was carried out from February 2020 to May 2021 with interruptions due to the influence of COVID-19. Photographs of the sampling situation are shown in Annex 2.1-2 (1).

Table 2.1.8 Water Quality Sampling Information

River/Lake		Kaptai Lake		Halda	Sangu	Matamuhuri
Sampling Locations		Kaptai Intake	Kaptai Lake	Panchpukuria	Bandarban	Lama
Location	Easting (m)	420,157	420,663	374,882	419,235	416,295
	Northing (m)	2,488,001	2,488,541	2,507,041	2,454,880	2,409,212
Sampling Dates	Feb. 2020	23rd Feb. 2020	23rd Feb. 2020	23rd Feb. 2020	24th Feb. 2020	24th Feb. 2020
	Mar. 2020	7th Mar. 2020	7th Mar. 2020	7th Mar. 2020	8th Mar. 2020	8th Mar. 2020
	Jun. 2020	2nd Jun. 2020	2nd Jun. 2020	2nd Jun. 2020	1st Jun. 2020	1st Jun. 2020
	Jul. 2020	13th Jul. 2020	13th Jul. 2020	13th Jul. 2020	12th Jul. 2020	12th Jul. 2020
	Aug. 2020	8th Aug. 2020	8th Aug. 2020	8th Aug. 2020	7th Aug. 2020	7th Aug. 2020
	Sep. 2020	13th Sep. 2020	13th Sep. 2020	12th Sep. 2020	13th Sep. 2020	14th Sep. 2020
	Oct. 2020	13th Oct. 2020	13th Oct. 2020	13th Oct. 2020	12th Oct. 2020	14th Oct. 2020
	Nov. 2020	13th Nov. 2020	13th Nov. 2020	13th Nov. 2020	12th Nov. 2020	14th Nov. 2020
	Dec. 2020	19th Dec. 2020	19th Dec. 2020	19th Dec. 2020	19th Dec. 2020	18th Dec. 2020
	Jan. 2021	18th Jan. 2021	18th Jan. 2021	18th Jan. 2021	17th Jan. 2021	16-Jan. 2021
	Apr. 2021	12th Apr. 2021	12th Apr. 2021	12th Apr. 2021	13th Apr. 2021	13th Apr. 2021
	May. 2021	25th May. 2021	25th May. 2021	24th May. 2021	25th May. 2021	26-May. 2021

Note: Due to the effects of COVID-19, sampling in April and May 2020 and February and March 2021 was not conducted.
Source: JICA Survey Team

Samples were brought to Dhaka and analyzed at the facilities shown in Table 2.1.9.

Table 2.1.9 Items for Water Quality Analysis

Description	Parameter	Location of Testing	Remarks
Examination-1	pH, Temperature, Turbidity, Color, EC, DO, BOD, Ammonium Nitrogen, Nitrate Nitrogen, Nitrite Nitrogen, Sulfate Ion, Zinc, Iron, Manganese, Chloride Ion, Alkalinity, Hardness	In-situ/IWM Laboratory	Once per month
	E-coli, Odor, Fluoride	ICDDR, B & BUET	Once per month
Examination-2	Copper, Cyanide, Chromium, Lead, Mercury, Aluminum, Cadmium	BUET	Once during monsoon (Aug.2020), Once during dry season (Jan. 2021)

The results of the quality analysis and their graphs are described in Annex 2.1-2. In this report, the value at 50% of the water depth is used as a representative, and when the water depth is shallow, an average of the values at 80% and 20% is used as a representative. For heavy metals, the detected value is used when the above conditions are not satisfied.

Consideration

In Bangladesh, the "Environmental Conservation Rule" stipulates the standards for environmental water as a source of drinking water, as shown in Table 2.1.10. In the evaluation of pH, BOD and DO, the standard below is used, while the standard for E. coli is used for reference because the measured value is for fecal E. coli, not for Total coliform.

Regarding Total coliform, the Environmental Standards Expert Committee, Ministry of the Environment, Japan, has long said that coliform bacteria corresponding to Total Coliform Number in Table 2.1.10 are also measured for bacteria that are not derived from feces. There has been a movement to revise the standard in Japan. Therefore, in this survey, Escherichia Coli (E-coli) which will be the new standard for coliforms in Japan is measured. Consequently, the evaluation is made, referring to the following criteria. COD was evaluated using Japanese environmental standards for lakes (Class A: 3 mg/L).

Table 2.1.10 Environmental Standard as Source of Drinking Water

Items (unit)	pH	BOD（mg/L)	DO（mg/L)	Total Coliform Number/100
Environmental Standard as source of drinking water	6.5-8.5	2 or less	6 or above	50 or less

Source: Environmental Conservation Rule 1997, Bangladesh

Since the above Bangladesh standards cannot be used for human health, the "Environmental Standards for the Protection of Human Health", Ministry of the Environment, Japan, was used for the following items.

Table 2.1.11 Environmental Standards for Protection of Human Health

Item	Standard Value
Cadmium (Cd)	up to 0.003 ㎎/L
Total cyanide	Not detectable
Lead (Pb)	up to 0.01 ㎎/L
Mercury (Hg)	up to 0.005 ㎎/L
Nitrate Nitrogen and Nitrite Nitrogen	up to 10 ㎎/L
Fluoride (F)	up to 0.8 ㎎/L

Source: Environmental Standards, Ministry of the Environment, Japan

In addition, there are no specific environmental standards for agricultural water, industrial water, and fisheries.

Regarding agricultural utilization, the JICA Survey Team discussed the applicability of the water quality standard for agriculture (paddy rice) by the Agriculture, Forestry and Fisheries Technology Council of Japan as shown in Table 2.1.12 with the expert of the local subcontractor. According to the expert, currently, in Bangladesh, salinity is the only influential factor. In addition, information such as academic papers on the effects of water quality items on the growth of local rice species could not be found during the survey period. Therefore, the evaluation of agriculture (rice farming) was limited to detecting seawater intrusion by looking at the values of chloride ions.

Table 2.1.12 Water Quality Standard for Paddy Rice

Item	Standard Value
pH	6.0～7.5
COD	up to 6 mg/L
DO	5 mg/L or more
EC	up to 0.3 mS/cm
Zinc (Zn)	up to 0.5 mg/L
Copper (Cu)	up to 0.02 mg/L

Source: Agriculture, Forestry and Fisheries Technology Council, Japan

To evaluate industrial water, the following standards set by the Industrial Water Quality Standards Establishment Committee, Japan Industrial Water Association, were used.

Table 2.1.13 Industrial Water Quality Standards

Item	Standard Value
Turbidity	up to 20
pH	6.5～8.0
Total Hardness	up to 120 mg/L
Chloride Ion (mgCI-/L)	up to 80 mg/L
Iron (Fe)	up to 0.3 mg/L
Manganese (Mn)	up to 0.2 mg/L

Source: Industrial Water Quality Standards Establishment Committee, Japan Industrial Water Association

For fisheries, the standard value of "zinc 0.003 mg /L or less" under "Adaptation of aquatic organism habitat" by the Ministry of the Environment, Japan, was used for the evaluation.

The following are the descriptions of the water quality in each water body. Correlation analyses were conducted to evaluate the results of the water quality analysis. The results of the correlation analysis are shown in Annex 2.1-2 (4). The analysis results were evaluated by t-test (significance level 0.05)

1) Kaptai Lake

The results of water quality analysis in Lake Kaptai are shown in Table 2.1.14.

Table 2.1.14 Results of Water Quality Analysis: Kaptai Intake

Item	Conditions	Achievement of Standard	
pH	In March, it shows a value near 8.0, but in other months, it shows values in the range of 7.5-6.5 except in October. It shows a value below 6.5 in October.	Environmental Standard as Source of Drinking Water: 6.5-8.5 Industrial Water Quality Standards: 6.5-8.0	Rainy Season: ☐ Dry Season: ☐
Temperature	It shows the minimum value of 22℃ in February and the maximum value of 31℃ in May and September.		
DO	It shows about 3 mg/L in both August and September, and 5.93 mg/L, 4.41 mg/L, and 1.9 mg/L in November, April, and May respectively which do not meet the standard value of 6 mg/L. The values meet the standard value in all other months.	Environmental Standard as Source of Drinking Water: >= 6.0	Rainy Season: ☐ Dry Season: ☐
EC	After showing the minimum value of 60 us/cm in June, the value		

Item	Conditions	Achievement of Standard	
	increases and shows values of 100 us/cm or more except in August. It shows the maximum value of 135 us/cm in May.		
E-coli	It shows the maximum value of 30 CFU/100 mL in March while all values are below the standard value in all months.	Environmental Standard as Source of Drinking Water: =< 50	Rainy Season: ☑ Dry Season: ☑
Odor	The data is below 0.05 or less in all months. It shows the maximum value of 0.047 mg/L in August.		
COD	It shows the values exceed the standard value of 3 mg/L in all months except for December. It shows the maximum value of 31 mg/L in July.	Environmental standards for lake (Class 2&3): =< 3	Rainy Season: ☐ Dry Season: ☐
Color	It shows the maximum value of 135 PtCo in August. It tends to show lower values in the dry season.		
Turbidity	It shows the maximum value of 63 NTU in August. It tends to show lower values in the dry season.	Industrial Water Quality Standards: =< 20	Rainy Season: ☐ Dry Season: ☑
Alkalinity	It shows the maximum value of 151 mg/L exceeding the standard value in September. In other months, it shows values within a range of 40 to 70 mg/L.	Industrial Water Quality Standards: =<7 5	Rainy Season: ☐ Dry Season: ☑
Hardness	It shows values within a range of 45 to 65 mg/L and no clear difference has been confirmed between the values in the rainy season and the dry season. All the values are below the standard value in all months.	Industrial Water Quality Standards: =< 120	Rainy Season: ☑ Dry Season: ☑
Chloride Ion	It shows relatively large values of 20 mg/L, and 26 mg/L in July and October, respectively. The values tend to be low in the dry season. All the values are below the standard value in all months.	Industrial Water Quality Standards: =< 80	Rainy Season: ☑ Dry Season: ☑
Fluoride	It shows the maximum value of 0.55 mg/L in May. All the values are below the standard value in all months.	Environmental Standard for human health: =< 0.8	Rainy Season: ☑ Dry Season: ☑
Ammonium Nitrogen	It shows the maximum value of 0.5 mg/L in May. It shows a relatively large value of 0.37 mg/L in August, and then gradually decreases until January.		
Nitrate Nitrogen	In all months, the sum of nitrate nitrogen and nitrite nitrogen values are below the standard value of 10 mg/L. It shows the maximum value of 0.07 mg/L in February.	Environmental Standard for human health: Nitrate Nitrogen + Nitrite Nitrogen=< 10	Rainy Season: ☑ Dry Season: ☑
Nitrite Nitrogen	It shows the maximum value of 0.032 mg/L in October while it shows the values of 0.02 mg/L or less in other months.		
Sulfate Ion	It shows the maximum value of 14 mg/L in July, and then gradually decreases until January with some fluctuations. The values tend to be slightly lower in the dry season than in the rainy season.		
Zinc	It shows a relatively large value of 0.4 mg/L in August, and then gradually decreases until January. Except for October and January, it shows the values exceed the standard value of 0.03 mg/L in all months.	Environmental Standard for the conservation of aquatic life: =< 0.03 mg/L	Rainy Season: ☐ Dry Season: ☐
Manganese	It shows the minimum value of 0.005 mg/L in February and the maximum value of 0.074 mg/L in October. All the values are below the standard value in all months. The values tend to be lower in the dry season than in the rainy season.	Industrial Water Quality Standards: =< 0.2	Rainy Season: ☑ Dry Season: ☑
Iron	It shows the maximum value of 0.58 mg/L in August while it shows the values of 0.3 mg/L or less in other months.	Industrial Water Quality Standards: =< 0.3	Rainy Season: ☐ Dry Season: ☑
Copper	It has not been detected in both the rainy season and the dry season.		
Chromium	It has been detected in both the rainy season and the dry season.		
Lead	It has not been detected in both the rainy season and the dry season.	Environmental Standard for human health: =< 0.01	Rainy Season: ☑ Dry Season: ☑

Item	Conditions	Achievement of Standard	
Mercury	It has not been detected in both the rainy season and the dry season.	Environmental Standard for human health: =< 0.0005	Rainy Season: ☑ Dry Season: ☑
Aluminum	It has not been detected in both the rainy season and the dry season.		
Cadmium	The analysis values exceed the standard value in the dry season.	Environmental Standard for human health: =< 0.003	Rainy Season: ☑ Dry Season: ☐
Cyanide	It has not been detected in both the rainy season and the dry season.	Environmental Standard for human health: Not detected	Rainy Season: ☑ Dry Season: ☑

Note: Items that exceed the standard value are hatched.
Source: JICA Survey Team

Table 2.1.15 Results of Water Quality Analysis: Kaptai Lake

Item	Conditions	Achievement of Standard	
pH	In March, it shows a value near 8.0, but in other months, it shows values in the range of 7.5-6.5 except in October and January. It shows values below 6.5 in October and January.	Environmental Standard as Source of Drinking Water: 6.5-8.5 Industrial Water Quality Standards: 6.5-8.0	Rainy Season: ☐ Dry Season: ☐
Temperature	It shows the minimum value of 22℃ in February and the maximum value of 31℃ in May and September.		
DO	It shows 2.2 mg/L in June, about 3 mg in both August and September, and 1 mg/L in January which do not meet the standard value of 6 mg/L. The values meet the standard value in all other months.	Environmental Standard as Source of Drinking Water: >= 6.0	Rainy Season: ☐ Dry Season: ☐
EC	After showing the minimum value of 60 us/cm in June, the values increased and it shows values of 100 us/cm or more except in August. It shows the maximum value of 135 us/cm in May.		
E-coli	It shows the maximum value of 24 CFU/100 mL in May while all values are below the standard value in all months.	Environmental Standard as Source of Drinking Water: =< 50	Rainy Season: ☑ Dry Season: ☑
Odor	The data is below 0.06 or less in all months. It shows the maximum value of 0.054 mg/L in August.		
COD	Except for September, it shows the values exceed the standard value of 3 mg/L in all months. It shows the maximum value of 23 mg/L in May and July.	Environmental standards for lake (Class 2&3): =< 3	Rainy Season: ☐ Dry Season: ☐
Color	It shows the maximum value of 247 PtCo in August. It tends to show lower values in the dry season.		
Turbidity	It shows the maximum value of 97.6 NTU in August. It tends to show lower values in the dry season.	Industrial Water Quality Standards: =< 20	Rainy Season: ☐ Dry Season: ☑
Alkalinity	It shows the maximum value of 149 mg/L exceeding the standard value in September. In other months, it shows values within a range of 40 to 70 mg/L.	Industrial Water Quality Standards: =< 75	Rainy Season: ☐ Dry Season: ☑
Hardness	It shows values within a range of 35 to 65 mg/L and no clear difference has been confirmed between the values in the rainy season and the dry season. All the values are below the standard value in all months.	Industrial Water Quality Standards: =< 120	Rainy Season: ☑ Dry Season: ☑
Chloride Ion	It shows relatively large values of 19 mg/L and 18 mg/L in July and October respectively. The values tend to be low in the dry season. All the values are below the standard value in all months.	Industrial Water Quality Standards: =< 80	Rainy Season: ☑ Dry Season: ☑
Fluoride	It shows the maximum value of 0.23 mg/L in May. The range of the values is smaller than that of Kati1. All the values are below	Environmental Standard for human health: =<0.8	Rainy Season: ☑ Dry Season: ☑

Item	Conditions	Achievement of Standard	
	the standard value in all months.		
Ammonium Nitrogen	It shows the maximum value of 9 mg/L in August, and then gradually decreases until January. It also shows relatively large values in April and May.		
Nitrate Nitrogen	In all months, the sum of nitrate nitrogen and nitrite nitrogen values are below the standard value of 10 mg/L. It shows the maximum value of 0.08 mg/L in February.	Environmental Standard for human health: Nitrate Nitrogen + Nitrite Nitrogen=< 10	Rainy Season: ☑ Dry Season: ☑
Nitrite Nitrogen	It shows the maximum value of 0.043 mg/L in October while it shows the values of 0.02 mg/L or less in other months.		
Sulfate Ion	It shows the maximum value of 9 mg/L in August, and then gradually decreases until January. The values tend to be slightly lower in the dry season than in the rainy season.		
Zinc	It shows the maximum value of 0.25 mg/L in February while it shows a relatively large value of 0.22 mg/L in July and the value gradually decreases until January with some fluctuations. Except for March, January, and May, it shows the values exceed the standard value of 0.03 mg/L in all months.	Environmental Standard for the conservation of aquatic life: =< 0.03mg/L	Rainy Season: ☐ Dry Season: ☐
Manganese	It shows a value exceeding the standard value of 0.2 mg/L in June and the values generally decrease until December with some fluctuations. It shows the values less than the standard value in all months except in June. The values tend to be lower in the dry season than in the rainy season.	Industrial Water Quality Standards: =< 0.2	Rainy Season: ☐ Dry Season: ☑
Iron	It shows the maximum value of 0.8 mg/L in August while it shows the values of 0.3 mg/L or less in other months. The values tend to be slightly lower in the dry season than in the rainy season.	Industrial Water Quality Standards: =< 0.3	Rainy Season: ☐ Dry Season: ☑
Copper	It has not been detected in both the rainy season and the dry season.		
Chromium	It has been detected in the dry season.		
Lead	It has not been detected in both the rainy season and the dry season.	Environmental Standard for human health: =< 0.01	Rainy Season: ☑ Dry Season: ☑
Mercury	The analysis value exceeds the standard value in the dry season.	Environmental Standard for human health: =< 0.0005	Rainy Season: ☑ Dry Season: ☐
Aluminum	It has not been detected in both the rainy season and the dry season.		
Cadmium	It has not been detected in both the rainy season and the dry season.	Environmental Standard for human health: =< 0.003	Rainy Season: ☑ Dry Season: ☑
Cyanide	It has not been detected in both the rainy season and the dry season.	Environmental Standard for human health: Not detected	Rainy Season: ☑ Dry Season: ☑

Note: Items that exceed the standard value are hatched.
Source: JICA Survey Team

The COD value is high, showing a value of 10 mg/L or more in both the rainy season and the dry season, and the pollution is extremely advanced. Considering the increase in turbidity, color value, and fluctuation of water level, one possibility is that pollutants such as domestic wastewater are normally flowing in from areas around the dam lake which contributes to the constant high value of COD, and the increased surface water flow in the rainy season may contribute to dilution and decrease of COD value. At Kaptai Lake, color values show a very strong positive correlation with turbidity and iron, and a strong positive correlation with ammonia nitrogen and sulfate ions. The turbidity also shows a positive correlation with ammonia nitrogen, a strong positive correlation with sulfate ions, and a very strong positive correlation with iron. From this, it is possible that human waste in the upstream area flowed in during the inflow of surface water in the rainy season. In addition, since the value of nitrate nitrogen is large, contamination by human waste in the past may generate the nitrate nitrogen within a certain period.

Since there is a strong positive correlation between nitrate nitrogen and sulfate ion, it is possible that chemical fertilizers such as ammonium sulfate may have been utilized upstream and flowed into the waterbody. For DO, the value closer to the surface layer is higher in most months, and at Kaptai Intake, it shows a strong negative correlation with ammonia nitrogen. It may be due to the reducing action in redox conditions in the deep end.

Since the COD value is very high and mercury and cadmium are detected in the dry season, it is necessary to consider the utilization as a water source for clean water only in the rainy season.

In addition, it is recommended to conduct further precise monitoring to estimate the pollution source as well as to consider whether it is derived from water-soluble/suspended solids, and to evaluate the accuracy of analysis for making an appropriate judgment regarding water utilization in consideration of the timing of use, policies for pollution load reduction, necessary treatment, and their economic efficiency. For industrial water use, pH, turbidity, alkalinity, manganese, and iron exceed the standard values, so pH and alkalinity should be controlled within appropriate ranges, the turbidity should be controlled by precipitation and filtration, and manganese and iron need to be removed by contact filtration or the like. In addition, since zinc levels exceed the standard values for many months, it is necessary to consider the effects on aquatic organisms over the medium to long term and reduce them with appropriate policies and measures.

2) Halda River

The results of water quality analysis in the Halda River are shown below.

Table 2.1.16 Results of Water Quality Analysis: Panchpukuria

Item	Conditions	Achievement of Standard	
pH	Analysis values range from 8.0-6.5 for all months.	Environmental Standard as Source of Drinking Water: 6.5-8.5 Industrial Water Quality Standards: 6.5-8.0	Rainy Season: ☑ Dry Season: ☑
Temperature	It shows the maximum value of 35℃ in May. It decreases from October and reaches the minimum value of 22°C in December.		
DO	After showing a minimum value of 5.7 mg/L below the standard value in July, it gradually increased to the maximum value of 9.4 mg/L in January, although there were some fluctuations. Except for July, it shows values exceeding 6.0 or more in all months.	Environmental Standard as Source of Drinking Water: >= 6.0	Rainy Season: ☐ Dry Season: ☑
EC	It shows the maximum value of 285 us/cm in March. It shows a minimum value in July and gradually increases toward January.		
E-coli	It shows a very large value of 22,000 MPN/100 mL in March. Except for January and May, it shows the values exceed the standard value of 50 MPN/100 mL in all months.	Environmental Standard as Source of Drinking Water: < 50	Rainy Season: ☐ Dry Season: ☐
Odor	The data is below 0.04 or less in all months. It shows the maximum value of 0.039 mg/L in July.		
BOD	In the first half of the dry season, it shows the values of 2 mg/L or	Environmental Standard as	Rainy Season: ☐

	less while it shows the values exceeding the standard value in other months except for March and June. It shows the maximum value of 5.25 mg/L in September.	Source of Drinking Water: =< 2	Dry Season: ☐
Color	It shows large values of 164 PtCo, and 188 PtCo in June and October, respectively. It tends to show lower values in the dry season.		
Turbidity	Except for February and March, it shows the values exceed the standard value of 20 NTU in all months. It shows large values of 254 NTU, and 157 NTU in June and October, respectively.	Industrial Water Quality Standards: =< 20	Rainy Season: ☐ Dry Season: ☐
Alkalinity	It shows the maximum value of 157.5 mg/L in September while also showing relatively large values exceeding 100 mg/L in March and May.	Industrial Water Quality Standards: =< 75	Rainy Season: ☐ Dry Season: ☐
Hardness	The values in the dry season tend to be larger than those in the rainy season. All the values are below the standard value in all months.	Industrial Water Quality Standards: =< 120	Rainy Season: ☑ Dry Season: ☑
Chloride Ion	It shows the maximum value of 27 mg/L in April while it also shows a relatively large value of 19 mg/L in October. All the values are below the standard value in all months.	Industrial Water Quality Standards: =< 80	Rainy Season: ☑ Dry Season: ☑
Fluoride	It shows the maximum value of 0.27 mg/L in June. It fluctuates in the range of 0 to 0.24 mg/L in other months. All the values are below the standard value in all months.	Environmental Standard for human health: =< 0.8	Rainy Season: ☑ Dry Season: ☑
Ammonium Nitrogen	After reaching the maximum value of 0.48 mg/L in July, it fluctuates and decreases toward January. It also shows relatively large values in April and May.		
Nitrate Nitrogen	In all months, the sum of nitrate nitrogen and nitrite nitrogen values are below the standard value of 10 mg/L. It shows the maximum value of 0.36 mg/L in October. It shows values less than 0.1 mg/L in other months except in March and August.	Environmental Standard for human health: Nitrate Nitrogen + Nitrite Nitrogen=< 10	Rainy Season: ☑ Dry Season: ☑
Nitrite Nitrogen	It shows the maximum value of 0.13 mg/L in October while it also shows a relatively large value of 0.094 mg/L in January.		
Sulfate Ion	After reaching the maximum value of 9 mg/L in July and August, it decreases in September and October, but increases again in November and then decreases the values exceed until January.		
Zinc	After reaching the maximum value of 0.31 mg/L in August, it gradually decreases until January. Except for March, October, and January, it shows the values exceed the standard value of 0.03 mg/L in all months.	Environmental Standard for the conservation of aquatic life: =< 0.03 mg/L	Rainy Season: ☐ Dry Season: ☐
Manganese	It shows the maximum value of 0.098 mg/L in November. All the values are below the standard value in all months.	Industrial Water Quality Standards: =< 0.2	Rainy Season: ☑ Dry Season: ☑
Iron	It shows the values exceed the standard value of 0.3 mg/L in all months except in May in which it shows the minimum value of 0.12 mg/L. It shows the maximum value of 0.95 mg/L in November.	Industrial Water Quality Standards: =< 0.3	Rainy Season: ☐ Dry Season: ☐
Copper	It has not been detected in both the rainy season and the dry season.		
Chromium	It has been detected in both the rainy season and the dry season.		
Lead	The value at the 0.5 depth level, which is a representative value, is below the standard value in both the rainy season and the dry season, but in the rainy season, a value exceeding the standard value is detected at the 0.8 depth level.	Environmental Standard for human health: =< 0.01	Rainy Season: ☑ Dry Season: ☑
Mercury	It has not been detected in both the rainy season and the dry season.	Environmental Standard for human health: =< 0.0005	Rainy Season: ☑ Dry Season: ☑
Aluminum	It has not been detected in both the rainy season and the dry season.		
Cadmium	The analysis value exceeds the standard value in the dry season.	Environmental Standard for human health: =< 0.003	Rainy Season: ☑ Dry Season: ☐

Cyanide	It has not been detected in both the rainy season and the dry season.	Environmental Standard for human health: Not detected	Rainy Season: ☑ Dry Season: ☑

Note: Items that exceed the standard value are hatched.
Source: JICA Survey Team

E. coli value is very high, turbidity value is also high overall, and the BOD value also exceeds the standard for many months. Pollutants such as domestic wastewater from the upstream area may be normally flowing in since the BOD values do not correlate with turbidity and color values which are considered to be strongly affected by rainwater inflow. Odor shows a very strong positive correlation with turbidity and a strong positive correlation with ammonia nitrogen. Turbidity shows a positive correlation with ammonia nitrogen. DO also shows a strong negative correlation between turbidity and ammonia nitrogen. From this, pollutants may have flowed in due to human waste, sewage, etc. during the period when the turbidity increased, and it may have been shortly after being contaminated. From the value of chloride ion, it is considered that there is almost no influence by saltwater.

Since the BOD, as well as E-coli, values, are very high, lead is detected in the rainy season and cadmium is detected in the dry season, it is recommended to conduct further precise monitoring to estimate the pollution source as well as to consider whether it is derived from water-soluble/suspended solids, and to evaluate the accuracy of analysis for making an appropriate judgment regarding water utilization in consideration of the timing of use, policies for pollution load reduction, necessary treatment, and their economic efficiency. For industrial water use, turbidity, alkalinity, and iron exceed the standard values, so alkalinity should be controlled within appropriate ranges, the turbidity should be controlled by precipitation and filtration, and iron needs to be removed by contact filtration or the like. In addition, since zinc levels exceed the standard values for many months, it is necessary to consider the effects on aquatic organisms over the medium to long term and reduce them with appropriate policies and measures.

3) Sangu River

The results of the water quality analysis in the Sangu River are shown below.

Table 2.1.17 Results of Water Quality Analysis: Bandarban

Item	Conditions	Achievement of Standard	
pH	In February and March, it shows a value exceeding 8.0, but in other months, it shows values in the range of 8.0-6.5.	Industrial Water Quality Standards: 6.5-8.0	Rainy Season: ☑ Dry Season: ☐
Temperature	It shows the maximum value of 33℃ in May and October. It decreases from October and reaches the minimum value of 21°C in December.		
DO	After showing a minimum value of 5.5 mg/L which is below the standard value in June, it gradually increases until January, although there were some fluctuations. The values exceed 6 mg/L in all months.	Environmental Standard as Source of Drinking Water: >= 6.0	Rainy Season: ☐ Dry Season: ☑
EC	After showing the minimum value of 111 us/cm in June, the values increased, and it shows the maximum value of 297 us/cm in April. The values exceed100 us/cm in all months.		
E-coli	It shows a very large value of 21,000 MPN/100 mL in March. Except for January, it shows the values exceed the standard value of 50 MPN/100 mL in all months.	Environmental Standard as Source of Drinking Water: < 50	Rainy Season: ☐ Dry Season: ☐

Item	Conditions	Achievement of Standard	
Odor	The data is below 0.03 or less in all months. It shows the maximum value of 0.021 mg/L in July.		
BOD	While it shows values less than the standard value of 2 mg/L in October, December, January, and March, the values exceed the standard value in all other months. It shows the maximum value of 12 mg/L in September.	Environmental Standard as Source of Drinking Water: =< 2	Rainy Season: ☐ Dry Season: ☐
Color	It shows the maximum value of 796 PtCo in June. It tends to show lower values in the dry season.		
Turbidity	It shows the values exceed the standard value of 20 NTU in the rainy season and shows the maximum value of 1304 NTU in August. It tends to show lower values in the dry season.	Industrial Water Quality Standards: =< 20	Rainy Season: ☐ Dry Season: ☐
Alkalinity	It shows the maximum value of 250 mg/L in September. In most months, the values exceed the standard value.	Industrial Water Quality Standards: =< 75	Rainy Season: ☐ Dry Season: ☐
Hardness	After showing the minimum value of 40.9 mg/L in June, the values tend to increase gradually. The values in the dry season tend to be larger than those in the rainy season. All the values are below the standard value in all months.	Industrial Water Quality Standards: =< 120	Rainy Season: ☑ Dry Season: ☑
Chloride Ion	It shows the maximum value of 30 mg/L in October. All the values are below the standard value in all months.	Industrial Water Quality Standards: =< 80	Rainy Season: ☑ Dry Season: ☑
Fluoride	The values for August and September were 1.97 mg/L and 1.7 mg/L, respectively, exceeding the standard value. In other months, the values are below the standard value.	Environmental Standard for human health: =< 0.8	Rainy Season: ☐ Dry Season: ☐
Ammonium Nitrogen	After reaching the maximum value of 1.27 mg/L in June, it gradually decreases until December. The values are increasing from April to May.		
Nitrate Nitrogen	In all months, the sum of nitrate nitrogen and nitrite nitrogen values are below the standard value of 10 mg/L. It shows the maximum value of 0.65 mg/L in June. In other months, it shows values below 0.1 mg/L or less except in February, May, and March.	Environmental Standard for human health: Nitrate Nitrogen + Nitrite Nitrogen=< 10	Rainy Season: ☑ Dry Season: ☑
Nitrite Nitrogen	It shows the maximum value of 0.074 mg/L in May while it also shows relatively large values in June, October, and January.		
Sulfate Ion	It shows a maximum value of 13 mg/L in June, then decreases, then rises again in November, and then decreases until January.		
Zinc	After reaching the maximum value of 0.36 mg/L in June, it gradually decreases until January. The values tend to be slightly lower in the dry season than in the rainy season. Except for October, it shows values that exceed the standard value of 0.03 mg/L in all months.	Environmental Standard for the conservation of aquatic life: =< 0.03 mg/L	Rainy Season: ☐ Dry Season: ☐
Manganese	After showing a relatively large value of 0.047 mg/L in June, it gradually decreases until October, but increases and shows a maximum value of 0.05 mg/L in November. All the values are below the standard value in all months.	Industrial Water Quality Standards: =< 0.2	Rainy Season: ☑ Dry Season: ☑
Iron	After reaching the maximum value of 2.19 mg/L in June, it gradually decreases until December. It shows values that exceed the standard value in May, June, and July. The values tend to be slightly lower in the dry season than in the rainy season.	Industrial Water Quality Standards: =< 0.3	Rainy Season: ☐ Dry Season: ☑
Copper	It has not been detected in both the rainy season and the dry season.		
Chromium	It has been detected in the dry season.		
Lead	It has not been detected in both the rainy season and the dry season.	Environmental Standard for human health: =< 0.01	Rainy Season: ☑ Dry Season: ☑
Mercury	It has not been detected in both the rainy season and the dry season.	Environmental Standard for human health: =< 0.0005	Rainy Season: ☑ Dry Season: ☑
Aluminum	It has not been detected in both the rainy season and the dry		

Item	Conditions	Achievement of Standard	
	season.		
Cadmium	It has not been detected in both the rainy season and the dry season.	Environmental Standard for human health: =< 0.003	Rainy Season: ☑ Dry Season: ☑
Cyanide	It has not been detected in both the rainy season and the dry season.	Environmental Standard for human health: Not detected	Rainy Season: ☑ Dry Season: ☑

Note: Items that exceed the standard value are hatched.
Source: JICA Survey Team

E. coli and turbidity values are very high, and the BOD value also exceeds the standard for many months. Pollutants such as domestic wastewater from the upstream area may be normally flowing in since the BOD values do not correlate with turbidity and color values which are considered to be strongly affected by rainwater inflow. Odor shows a strong positive correlation with chromaticity, turbidity, and iron, and shows a positive correlation with ammonia nitrogen and zinc. Turbidity shows a very strong positive correlation with ammonia nitrogen and iron and a strong positive correlation with sulfate ion. DO also shows a strong negative correlation with odor and a negative correlation with chromaticity, turbidity, and ammonia nitrogen. From this, pollutants may have flowed in due to human waste, sewage, etc. during the period when the turbidity increased, and it may have been shortly after being contaminated. From the value of chloride ion, it is considered that there is almost no influence by saltwater.

Since the BOD, as well as E-coli, values, are very high, and the fluoride value also exceeds the standard, it is appropriate to make a judgment in consideration of the effectiveness and economic efficiency of the processing technology in the existing processing facility. For industrial water use, pH, turbidity, alkalinity, and iron exceed the standard values, so pH and alkalinity should be controlled within appropriate ranges, the turbidity should be controlled by precipitation and filtration, and iron needs to be removed by contact filtration or the like. In addition, since zinc levels exceed the standard values for many months, it is necessary to consider the effects on aquatic organisms over the medium to long term and reduce them with appropriate policies and measures.

4) Matamuhuri River

The results of water quality analysis in the Matamuhuri River are shown below.

Table 2.1.18 Results of Water Quality Analysis: Lama

Item	Conditions	Achievement of Standard	
pH	In February and March, it shows a value exceeding 8.0, but in other months, it shows values in the range of 8.0-6.5.	Industrial Water Quality Standards: 6.5-8.0	Rainy Season: ☑ Dry Season: ☐
Temperature	It shows the maximum value of 37℃ in October. It decreases from October and **reaches** the minimum value of 22°C in January. It shows the minimum value of 22℃ in February.		
DO	After showing a minimum value of 1.3 mg/L which is below the standard value in June, it gradually increased until January when it shows the maximum value of 9.8 mg/L, although there were some fluctuations. The values exceed 6 mg/L in all months.	Environmental Standard as Source of Drinking Water: >= 6.0	Rainy Season: ☐ Dry Season: ☑
EC	After showing the minimum value of 105 us/cm in June, it increases gradually and shows the maximum value of 256 us/cm in April. The values exceeds100 us/cm in all months.		

Item	Conditions	Achievement of Standard	
E-coli	Except for January, it shows the values exceed the standard value of 50 MPN/100 mL in all months.	Environmental Standard as Source of Drinking Water: < 50	Rainy Season: ☐ Dry Season: ☐
Odor	The data is below 0.03 or less in all months. It shows the maximum value of 0.022 mg/L in July.		
BOD	While it shows values less than the standard value in March, December, and January, the values exceed the standard value in all other months. It shows the maximum value of 9.7 mg/L in June and September.	Environmental Standard as Source of Drinking Water: =< 2	Rainy Season: ☐ Dry Season: ☐
Color	It shows the maximum value of 2389 PtCo in June. It tends to show lower values in the dry season.		
Turbidity	It shows the values exceed the standard value of 20 NTU in the rainy season and shows the maximum value of 3440NTU in August. It tends to show lower values in the dry season.	Industrial Water Quality Standards: =< 20	Rainy Season: ☐ Dry Season: ☐
Alkalinity	It shows the maximum value of 241 mg/L in September. In most months, the values exceed the standard value.	Industrial Water Quality Standards: =< 75	Rainy Season: ☐ Dry Season: ☐
Hardness	After showing the minimum value of 41 mg/L in June, it increases gradually. The values in the dry season tend to be larger than those in the rainy season. All the values are below the standard value in all months.	Industrial Water Quality Standards: =< 120	Rainy Season: ☑ Dry Season: ☑
Chloride Ion	It shows the maximum value of 34 mg/L in July while it also shows a relatively large value of 27.59 mg/L in October. All the values are below the standard value in all months.	Industrial Water Quality Standards: =< 80	Rainy Season: ☑ Dry Season: ☑
Fluoride	It shows a value exceeding the standard value in June while the values are below the standard value in other months.	Environmental Standard for human health: =< 0.8	Rainy Season: ☐ Dry Season: ☑
Ammonium Nitrogen	After reaching the maximum value of 3.03 mg/L in June, it gradually decreases until December with some fluctuations. It increases from April to May.		
Nitrate Nitrogen	In all months, the sum of nitrate nitrogen and nitrite nitrogen values are below the standard value of 10 mg/L. It shows the maximum value of 0.52 mg/L in May. It shows values less than 0.1 mg/L in all months except for February and April.	Environmental Standard for human health: Nitrate Nitrogen + Nitrite Nitrogen=< 10	Rainy Season: ☑ Dry Season: ☑
Nitrite Nitrogen	It shows the maximum value of 0.186 mg/L in October while generally showing the values of 0.05 mg/L or less in other months.		
Sulfate Ion	It shows a maximum value of 12 mg/L in June, then it fluctuates in the range of 2-6 mg/L until January.		
Zinc	After reaching the maximum value of 0.29 mg/L in August, it gradually decreases until January. Except for October and January, it shows the values exceed the standard value of 0.03 mg/L in all months.	Environmental Standard for the conservation of aquatic life: =< 0.03 mg/L	Rainy Season: ☐ Dry Season: ☐
Manganese	After showing a maximum value of 0.348 mg/L exceeding the standard value of 0.2 mg/L in June, it gradually decreases until December. It shows the values less than the standard value in all months except in June. The values tend to be lower in the dry season than in the rainy season.	Industrial Water Quality Standards: =< 0.2	Rainy Season: ☐ Dry Season: ☑
Iron	After reaching the maximum value of 3.37 mg/L in June, it gradually decreases until January. It shows values that exceed the standard value in June, July, October, November, and December. The values tend to be lower in the dry season than in the rainy season.	Industrial Water Quality Standards: =< 0.3	Rainy Season: ☐ Dry Season: ☐
Copper	It has not been detected in both the rainy season and the dry season.		
Chromium	It has been detected in both the rainy season and the dry season.		
Lead	It has not been detected in both the rainy season and the dry season.	Environmental Standard for human health: =< 0.01	Rainy Season: ☑ Dry Season: ☑

Item	Conditions	Achievement of Standard	
Mercury	It has not been detected in both the rainy season and the dry season.	Environmental Standard for human health: =< 0.0005	Rainy Season: ☑ Dry Season: ☑
Aluminum	It has not been detected in both the rainy season and the dry season.		
Cadmium	The analysis value exceeds the standard value in the dry season.	Environmental Standard for human health: =< 0.003	Rainy Season: ☑ Dry Season: ☐
Cyanide	It has not been detected in both the rainy season and the dry season.	Environmental Standard for human health: Not detected	Rainy Season: ☑ Dry Season: ☑

Note: Items that exceed the standard value are hatched.
Source: JICA Survey Team

E. coli and turbidity values are very high, and the BOD value also exceeds the standard for many months. Since BOD shows a positive correlation with turbidity, pollutants such as domestic wastewater from the upstream area may be flowing in during the period when the turbidity is high. Odor shows a very strong positive correlation with turbidity and chromaticity, and a positive correlation with ammonia nitrogen and iron. Turbidity shows a very strong positive correlation with ammonia nitrogen, manganese, and iron, and a strong positive correlation with sulfate ions. DO shows a very strong negative correlation with turbidity and ammonia nitrogen, and a strong negative correlation with odor and chromaticity. From this, pollutants may have flowed in due to human waste, sewage, etc. during the period when the turbidity increased, and it may have been shortly after being contaminated, or dissolved oxygen may have been deficient due to the large degree of organic contamination. From the value of chloride ion, it is considered that there is almost no influence by saltwater.

Since the BOD, as well as E-coli values, are very high, the fluoride value also exceeds the standard. Besides, cadmium is detected in the dry season, and therefore, it is necessary to consider the utilization as a water source for clean water only in the rainy season. In addition, it is recommended to conduct further precise monitoring to estimate the pollution source as well as to consider whether it is derived from water-soluble/suspended solids, and to evaluate the accuracy of analysis for making an appropriate judgment regarding water utilization in consideration of the timing of use, policies for pollution load reduction, necessary treatment, and their economic efficiency. For industrial water use, pH, turbidity, alkalinity, and iron exceed the standard values, so pH and alkalinity should be controlled within appropriate ranges, the turbidity should be controlled by precipitation and filtration, and iron needs to be removed by contact filtration or the like. In addition, since zinc levels exceed the standard values for many months, it is necessary to consider the effects on aquatic organisms over the medium to long term and reduce them with appropriate policies and measures.

5) Overall trend

At all of the water sampling points, the pH value tends to be high in the dry season and low in the rainy season. The decrease in pH value may be affected by rainfall. Turbidity peaks during the flood season, and at the same time, the values of ammonia nitrogen, nitrate nitrogen, zinc, and iron also reach their peak values.

Although geological structures, such as mines, ore deposits, and hot water that possibly affect water quality, have not been confirmed and there are no large-scale factories upstream of the sampling point so far, heavy metals have been detected. It is possible that fertilizer was sprayed over a long period and soil spilled during the flood season, contributing to the increase in the values of these items.

The levels of Escherichia coli were high in March at all points, and high in July and October in the Matamuhuri River. Regarding these, manure may be sprayed at the time of rice planting.

More than half of the alkalinity values in the Sangu and Matamuhuri Rivers exceed the standard value. The geographical conditions of the upstream might contribute to this result.

Regarding the above, it is not a definitive conclusion because there is little statistical data on factories and fertilizer spraying, and the factors that affect water quality have been diversified, including temporal factors. However, it shows the possibility, resulting from the water quality analysis.

2.2 Topography, Geology and Ground water survey

2.2.1 General

The survey area is distributed in an area from the Chattogram Hill Tracts (CHT) to the coastal plain, including Moheshkhali and Matarbari Islands. The northern end of the study area is around the Kaptai Dam and the southern end is the south of Cox's Bazar. Other than the urban areas such as Cox's Bazar and Chakaria, the study area is a village area. Since there are no rivers available throughout the year in the survey area, both urban and rural areas rely on ground water for domestic use. Irrigation water is also highly dependent on ground water. In this survey, existing topographic maps, geological maps, borehole logs, and existing data and information related to ground water were collected, and field reconnaissance and geophysical surveys were conducted in order to understand the topography and geology that provide basic information on the natural conditions of the survey area.

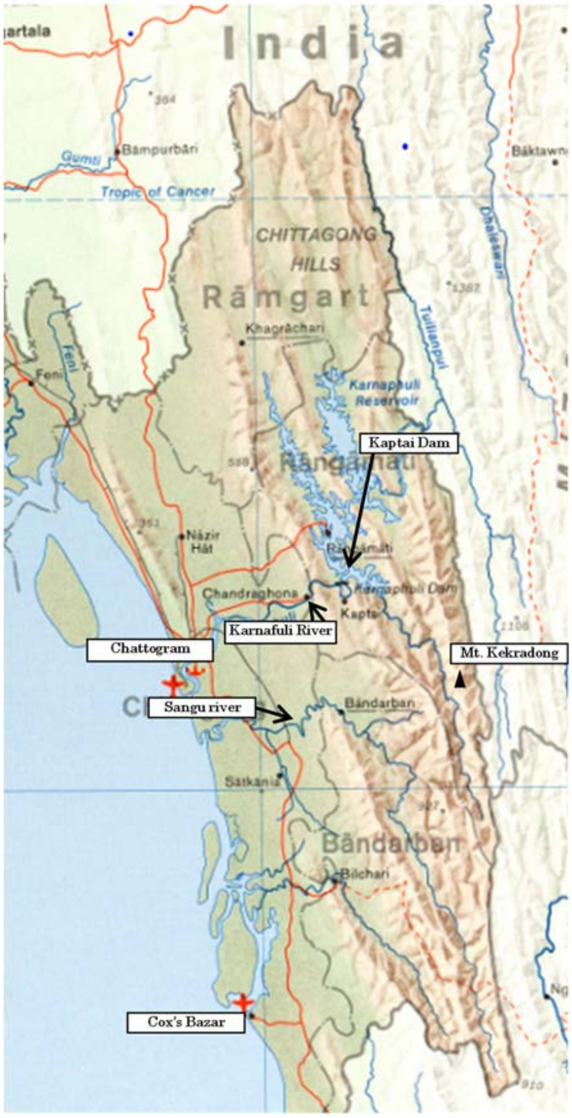
In addition, the borehole log of wells constructed by DPHE, ground water level monitoring data by DPHE / BWDB, and existing data were collected for the purpose of grasping the ground water utilization situation in the survey area and obtaining basic data for evaluating the ground water potential. Furthermore, a ground water survey (well inventory survey, simultaneous / long-term observation of ground water level, water quality measurement) was carried out by subcontracting a local consultant. These results are described below.

2.2.2 Topography

A topographic map of the CHT is shown as Figure 2.2.1. The CHT is located in the southeastern area of Bangladesh, where hills with an altitude of 300 to 500 m are distributed, which is an extension of the Himalayas. The area occupies about 13,180 km^2 and is facing the borders with India and Myanmar. The eastern part of the hilly area is connected to the Arakan Mountains of Myanmar, and the west side of the hilly area extends to the coastal plain from Chattogram to Cox's Bazar, facing the Bay of Bengal. The CHT becomes higher toward the east and the highest point is Mt. Kekradong at an altitude of 1,230 m.

The boundary between the Indian Plate and the Burma Plate is located in an area from Bengal Bay to Andaman Bay, where it is said that the former is sinking below the latter at a rate of about 10 mm/year (Shishikura *et al* 2007[2]). Therefore, the hilly areas are extending in the north-northwest-southeast-south direction reflecting the geological structure (folding structure, fault structure, etc.) in the north-northwest to south-southeast direction that is developing in the entire study area. That is, the axis of the anticline structure (anticlinal axis) of the stratum is a hilly area, and the axis of the synclinal structure (syncline axis) is a valley.

In the CHT, the rivers flowing from the north-northwest direction to the south-southeast direction and the rivers flowing from the south-southeast direction to the north-northwest direction merge and flows through the eroded valley crossing the hills to the west and flows into the Bay of Bengal. These rivers flow across the hills, therefore, it is considered to be the so-called "antecedent river" which is formed because the amount of erosion of the rivers that flowed through the area was higher than the amount of uplift when the hills were formed.



Source: Added by the JICA Survey Team to a map prepared by Texas University[1]

Figure 2.2.1 Topography of Chattogram Hill Tract

A coastal plain is formed on the west side of the CHT and is used as a paddy field and dry field. On the further west side of the coastal plain, soft tidal flat lowlands are formed along the coastline, most of which are used as salt fields and part of which is used for shrimp aquaculture ponds.

1: Map No. 503753 1979 Bangladesh, Map Collection Perry-Castañeda Library, University of Texas Library, http://legacy.lib.utexas.edu/maps/middle_east_and_asia/txu-pclmaps-oclc-6423840 -bangladesh_1979.jpgを使用。

2: Masanobu Shishikura, Yukinobu Okamura and Shigehiro Fujino 2007: Paleoearthquake Survey Report in Myanmar West Coast, No.76, pp.1-3, Active Fault Research Center News

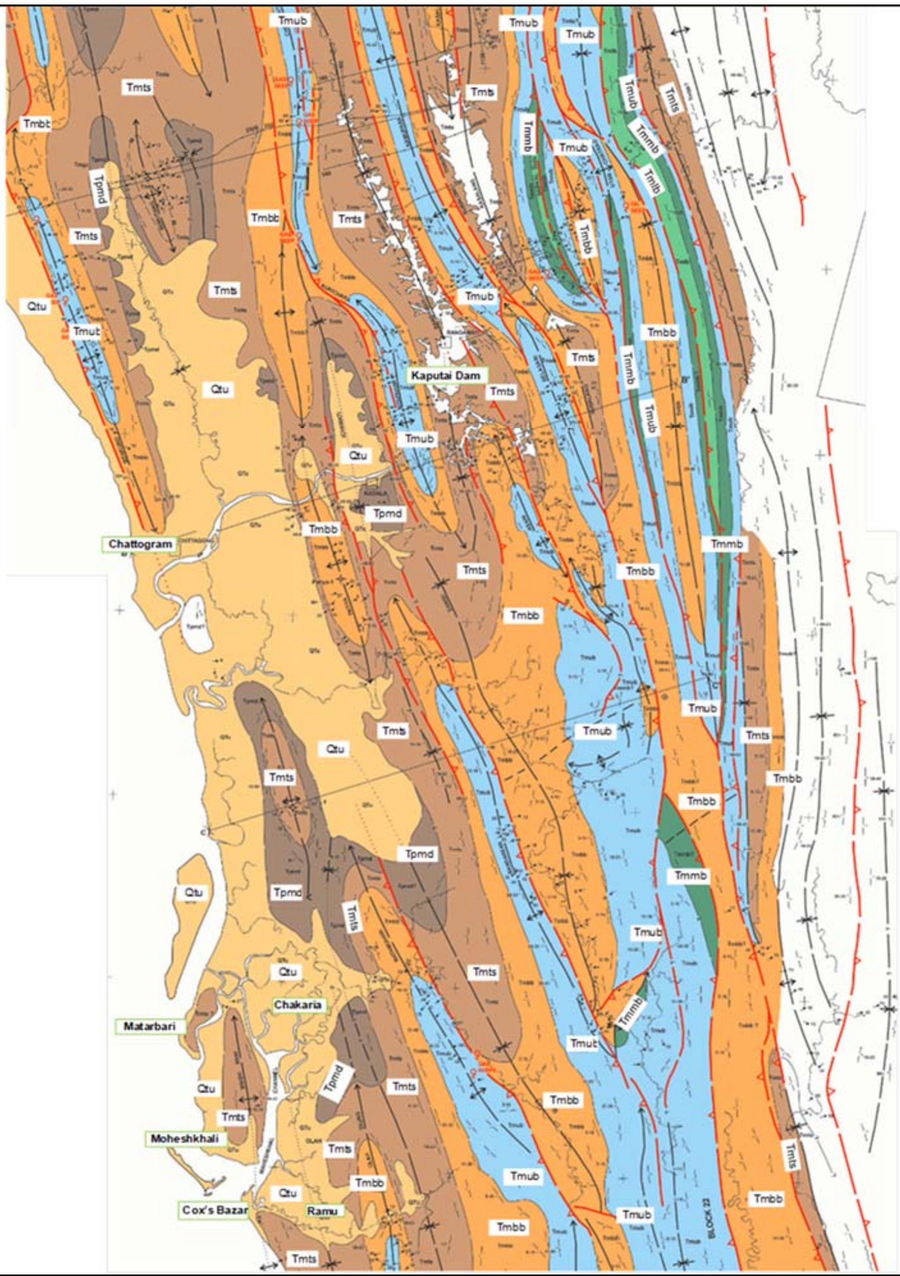
There is a hill range extending from north-northwest to south-southeast in the central part of Moheshkhali Island, and coastal plains and tidal flat-like lowlands extend from the foot of the hill to the coast. The tidal flat-like lowlands are mainly used as salt fields and shrimp aquaculture ponds as well as on the mainland (Figure 2.2.2).

To the south of Moheshkhali Island is Sonadia Island, which has been designated as an Ecologically Critical Area (ECA) by the Government of Bangladesh.

Figure 2.2.2 Salt Fields in Northern Side of Moheshkhali Island (Source: the Survey Team)

2.2.3 Geology

In the survey area, Miocene Bhuban and Bokabil Formations, Miocene to Pliocene Tipam Formation, and the Quaternary formations such as Dupitila Formation are distributed. The stratigraphy and distribution of these formations are shown in Figure 2.2.3 as a geological map. The survey area is up to the eastern side of the Kaptai Dam. In the eastern area of the dam, the Middle and Lower Members of the Bhuban Formation, and Undifferentiated Sedimentary Formation are distributed. Those are shown in the Geological Map.



Legend of the Geological Map

Period	Colour/Symbol		Name of Dormation
Quaternary		Qtu	Recent Deposits
		Tpmd	Dupitila Formation
Upper Miocene - Pliocene		Tmts	Tipam Formation
Middle MIocene		Tmbb	Bokabil Formation
Lower Miocene		Tmub	Upper Member, Bhuban Formation
		Tmmb	Middle Member, Bhuban Formation (Out of the survey area)
		Tmlb	Middle Member, Bhuban Formation & Undifferentiated Sedimentary Formation (Out of the survey area)

Source：Thomas L. Davis (2016) Geologic Map, Chittagong Hill Tracts, Bangladesh

Figure 2.2.3 Geological Map of Survey Area

Formations distributed in the survey area are summarized as Table 2.2.1 by Afros (2012), Hossain &

Hassan (2012) and Md. Zakaria et al (2015), etc.

Table 2.2.1 Stratigraphy in Survey Area

Period	Formation		Phases	Thickness
Recent	Coast sand, dune sand		Well sorted fine sand	Max. 120 m
Plio-Pleistocene	Dupitila Formation		Reddish brown to yellowish brown medium to coarse sand	Max. 300 m
Pliocene	Girjan Clay		Red and brown dotted clay	70～300 m
Miocene-Pliocene	Tipam Formation		Grayish brown to pale gray coarse sand Well-developed cross bedding	610m
Miocene	Bokabil Formation		Shale, silt stone, sandstone. Bluish gray shale with well-developed laminae and bedding plane. Occasionally lenticular silt and sand appear. Characterized by very hard and compact calcareous band	1800 m
Pligocene-Miocene	Bhuban Formation	Upper	Mainly sandstone	3,500 m
		Middle	Mainly shale	
		Lower	Mainly sandstone: Undifferentiated Sedimentary formation under Bhuban Formation is included in **Figure 2.2.3.**	

Source: "Geological Group-Formation, Banglapedia[3]" (The description of the Bhuban Formation was modified by the JICA Survey Team).

The survey area is located in the Chittagong-Tripula Folded Belt formed by the lateral pressure caused by the subduction of the Indian plate into the Burma plate. Anticline and syncline structures extending in the northwest-southeast direction form a row, and there are a number of reverse and thrust faults running parallel to these structures. Around the center of the hilly area formed by the anticline structure, old geological formations such as the Bhuban and Bokabil formations are distributed, and the Tipam Formation and younger formations are distributed in the lowlands formed by the syncline structure.

The lowest formation in the survey area is the Miocene Bhuban Formation. The Lower and Middle Members of the Bhuban Formation are zonally distributed along the several reverse faults/thrusts that run in a northwest-southeast to south-southeast direction on the east side of the Kaptai Dam. The Upper Member of the Bhuban Formation is distributed along the Lower and Middle Members of the Formation in the eastern side of the Kaptai Dam, while it is distributed along the axes of the anticlinal structures in the western side of the dam.

The Miocene Bokabil Formation is underlain by the Upper Member of the Bhuban Formation. It is distributed along the anticlinal and synclinal structures in the survey area. The facies of the formation is silt stone, sandy shale, and shale. Cross bedding is sometimes observed in the sandstone.

The Tipam Formation covers the Bokabil Formation and is widely distributed mainly along the syncline structure. The facies is mainly composed of sandstone and contains mudstone and alternation of sandstone and mudstone.

Since the facies of the Bokabil Formation and Tipam Formation are similar and weathered in the outcrops, it may be difficult to distinguish between the two only by observation in the outcrop.

3 Geological Group-Formation, Banglapedia, http://en.banglapedia.org/index.php?title=Geological_Group-Formation

The Girjan Clay is thought to be the lake, flood plain, and riverbank deposits. The distribution area of this formation was not confirmed in the survey due to restrictions.

The Dupitila Formation is distributed in the hilly area in the eastern part of Chakaria overlying the Tipam Formation. The facies are unconsolidated sand, mud, and clay. The distribution area of this formation was not confirmed in the field survey.

The Recent Deposits are the youngest deposits in the survey area and is distributed in the upper part of the coastal plain, along the rivers and in the lowland along the coast.

As for the formations distributed in the survey area, an older formation is distributed from west to east.

In the western part of the survey area, relatively young geological formations such as Tipam Formation, Girjan Clay, and Dupitila Formation are distributed, and old geological formations such as Bokabil Formation and Bhuban Formation are mainly distributed in the eastern part.

In order to grasp the geological situation in the survey area, the reconnaissance survey was carried out in some areas of Moheshkhali, Chakaria, Cox’s Bazar and Ramu Upazilas. For security reasons, the survey was carried out only within Cox’s Bazar District, and the neighboring Bandarban District was excluded from the survey. Figure 2.2.4 shows the outcrops of Tipam and Bokabil Formations observed in the survey area.

Observations from Cox’s Bazar to Ramu Upazilas show that the following horizons are distributed there:

- Alternations of thin layers of brown and bluish gray fine to medium sand,
- Massive gray medium sand, and
- Alternation of thin gray layers of fine to medium sand and bluish gray thin fine sand layers (intercalated with extremely thin white layers).

From these characteristics, the formation seems to be the Tipam Formation. It inclines about 20 degrees near the anticline axis with a direction of NNW-SSE which runs in the east of Ramu Upazila, and inclines about 5 degrees near the syncline axis which runs between Cox’s Bazar and Ramu Upazilas. It never shows a high degree of inclination like 70 degrees which the Bokabil Formation shows in Teknaf Peninsula. These characteristics seem to give no large effect to ground water flow in the survey area.

There are small hills where the Tipam Formation is distributed in the area from Chakaria to Moheshkhali. The Tipam Formation in this area consists mainly of pale brown and/or pale gray well sorted fine to medium sand intercalated with thin silt to clay layers like the Tipam Formation as shown in Photo-1 in Figure 2.2.4. The Bokabil Formation sometimes crops out at the foot of hills. In fresh outcrops, it consists mainly of pale gray bedded fine to medium sand intercalated with thin silt to clay layers like the Tipam Formation. If these formations are weathered, their color becomes pale brownish as a whole. Therefore, it is difficult to classify these formations.

The Tipam Formation is also distributed in the hill which runs in the central part of Moheshkhali Island.

A fault was observed in the Tipam Formation. It runs in the NW-SE direction. The Tipam formation in the eastern side of the fault shows very gentle inclination although it is almost vertical in the western side of the fault. Going ten meters further west from the fault, the inclination of the formation becomes gentle again. The continuity of this fault cannot be traced because it is covered with vegetation on the northeast side and covered with modern sediments on the south side. The effect of this fault on groundwater flow is also unknown.

	
Photo-1 : Outcrop of the formation which seems to be the Tipam Formation observed near the border between Chakaria and Bandarban. The formation is mainly well bedded pale brown to pale gray fine to medium sand intercalated with silt to clay layers. It is weakly consolidated (taken by the JICA Survey Team in January 2020).	Photo-2 : Outcrop of the formation which seems to be the Bokabil Formation observed near the border between Chakaria and Bandarban. The formation is mainly well bedded and consolidated pale gray fine to medium sand stone intercalated with siltstone or clay stone. It is consolidated harder than the Tipam Formation (taken by the JICA Survey Team in January 2020).

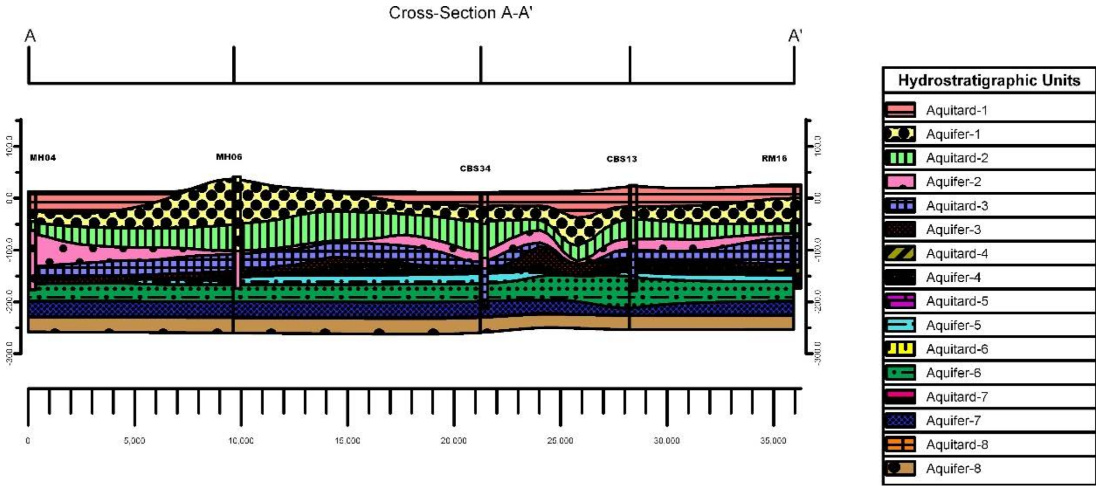
Source: JICA Survey Team

Figure 2.2.4 Outcrops of Tipam and Bokabil Formations

Hereunder, the hydrogeological structure is described.

DPHE has prepared borehole logs for wells constructed within the survey area. Data such as geology and water quality are summarized in the borehole logs. Borehole logs for 53 wells with a depth of 200 m or more were collected. Based on these data, geological columns were prepared by the JICA Survey Team. A geological cross section was also prepared as shown in Figure 2.2.5. Since borehole logs lack information for comparing strata, it is difficult to determine which stratum shown in the cross section corresponds to which geological formation. However, those are likely the Tipam Formation or higher, considering the field survey result that the Tipam Formation and its overlying formation are widely distributed below the ground surface.

Beside these boreholes, there are 16 deep production wells in the Matarbari Project site. However, these boreholes have no geological description.



Source: Prepared by the JICA Survey Team by using the data of DPHE

Figure 2.2.5 Geological Cross Section in Survey Area (North-South Direction)

Up to a depth of 300 m in the survey area, approximately eight aquicludes (clay, silt, etc.) and eight aquitards (mainly sand layers) are distributed alternately. However, these strata are not always continuously distributed throughout the survey area. For example, discontinuity of the 3rd aquiclude from the top (Aquitard-3) is observed between CBS34 and CBS13. In this case, there is a possibility that the ground water in the survey area is continuous as a whole, although it is partly separated by aquicludes.

2.2.4 Ground Water

A ground water survey was carried out including following contents in order to understand the hydrogeological situation in the survey area:

1) To confirm the number of boreholes constructed by DPHE and current ground water extraction, and collect borehole logs and other data,
2) Inventory survey of boreholes described in 1) above and boreholes for irrigation (952 boreholes),
3) Measurement of ground water level and of water quality in boreholes selected from the boreholes for the inventory survey (104 boreholes; ground water level: once in each of rainy and dry seasons and water quality measurement: once in rainy season),
4) Ground water level monitoring in boreholes selected from the boreholes of the inventory survey (9 boreholes: once a month), and
5) Geophysical exploration (29 exploration sites: mainly to confirm if a new aquifer exists at a depth deeper than 300m).

The results of these surveys are described below.

1) Survey on existing wells constructed by DPHE

The wells for domestic use have been constructed by DPHE in the survey area. Construction of boreholes in the survey area is managed by the DPHE Cox's Bazar office and its Upazila office in each Upazila. Therefore, the JICA Survey Team visited these offices in order to confirm the number of boreholes constructed and to collect borehole logs. As a result, it was revealed that the total number of boreholes constructed by January 2020 was 8,825 shallow wells and 6,765 deep wells, totaling 15,590 wells as shown in Table 2.2.2. In this survey, a borehole of which the drilling depth is less than 200 feet (about 60 m) is classified as shallow well, and a well deeper than that is classified as deep well.

Table 2.2.2 Numbers of Functioning Boreholes Constructed by DPHE (as of Mar. 2020)

Upazila	Shallow Well	Deep Well	Total
Chakaria	2,809	2,436	5,245
Moheshkhali	1,975	1,305	3,280
Cox's Bazar Sadr	1,925	1,836	3,761
Ramu	2,116	1,188	3,304
Total	8,825	6,765	15,590

Source: JICA Survey team, data of DPHE was used.

Besides the boreholes constructed by DPHE, there are boreholes constructed for irrigation. According to the "Minor Irrigation Survey Report (2017-2018)" published by Ministry of Agriculture in 2019, there are 3,573 irrigation wells (583 shallow wells and 2,990 deep wells, Table 2.2.3). However, in the case of irrigation wells, the classification of shallow and deep wells is based on the depth between the ground water level and the pump (7 m), not the drilling depth of borehole. For this reason, it is impossible to distinguish shallow and deep wells by the drilling depth of borehole. Therefore, as for irrigation wells, shallow wells and deep wells are treated together in this survey. The number of wells in Table 2.2.3 is the total of shallow and deep wells classified by the Ministry of Agriculture.

Table 2.2.3 Number of Irrigation Wells

Upazila	Total (Shallow and Deep Wells)
Chakaria	1,215
Moheshkhali	470
Cox's Bazar Sadr	1,173
Ramu	715
Total	3,573

Source: Minor Irrigation Survey Report (2017-2018), Ministry of Agriculture

2) Inventory survey of existing wells

The inventory survey was carried out to understand the current conditions of the boreholes for domestic and irrigation use. The details of this survey are explained in Annex 2.2-1. Although the number of initially planned boreholes was about 900, it increased to 938. Then, it was found that 14 boreholes were not suitable for the survey and other 14 boreholes were further surveyed. Therefore, 952 wells were surveyed in the end: 688 domestic and 264 irrigation wells, as shown in Table 2.2.4. The locations of the wells surveyed are shown in Figure 2.2.6.

There are more than 280 villages in the survey area. In order to avoid bias of distribution of the target wells for the Inventory Survey, plural target wells, with at least one (1) well, were basically selected in each village.

Since the central areas widely situated from the southwestern part of Chakaria to the northern part of Cox’s Bazar and in the eastern and western sides of the Moheshkhali Island are used for salt cultivation, no borehole exists in these areas. Since there are about 280 villages distributed in the survey area, the wells targeted for the inventory survey were selected so that multiple wells could be surveyed in each village in order to avoid bias.

Table 2.2.4 Number of Wells Surveyed in the Inventory Survey

Upazila	**Shallow Well**		**Deep Well**		**Total**
	Domestic	**Irrigation**	**Domestic**	**Irrigation**	
Chakaria	33	19	243	44	339
Moheshkhali	19	9	100	36	164
Cox's Bazar Sadr	18	20	151	69	258
Ramu	13	12	111	55	191
Total	83	60	605	204	952
	143		809		952
	952				

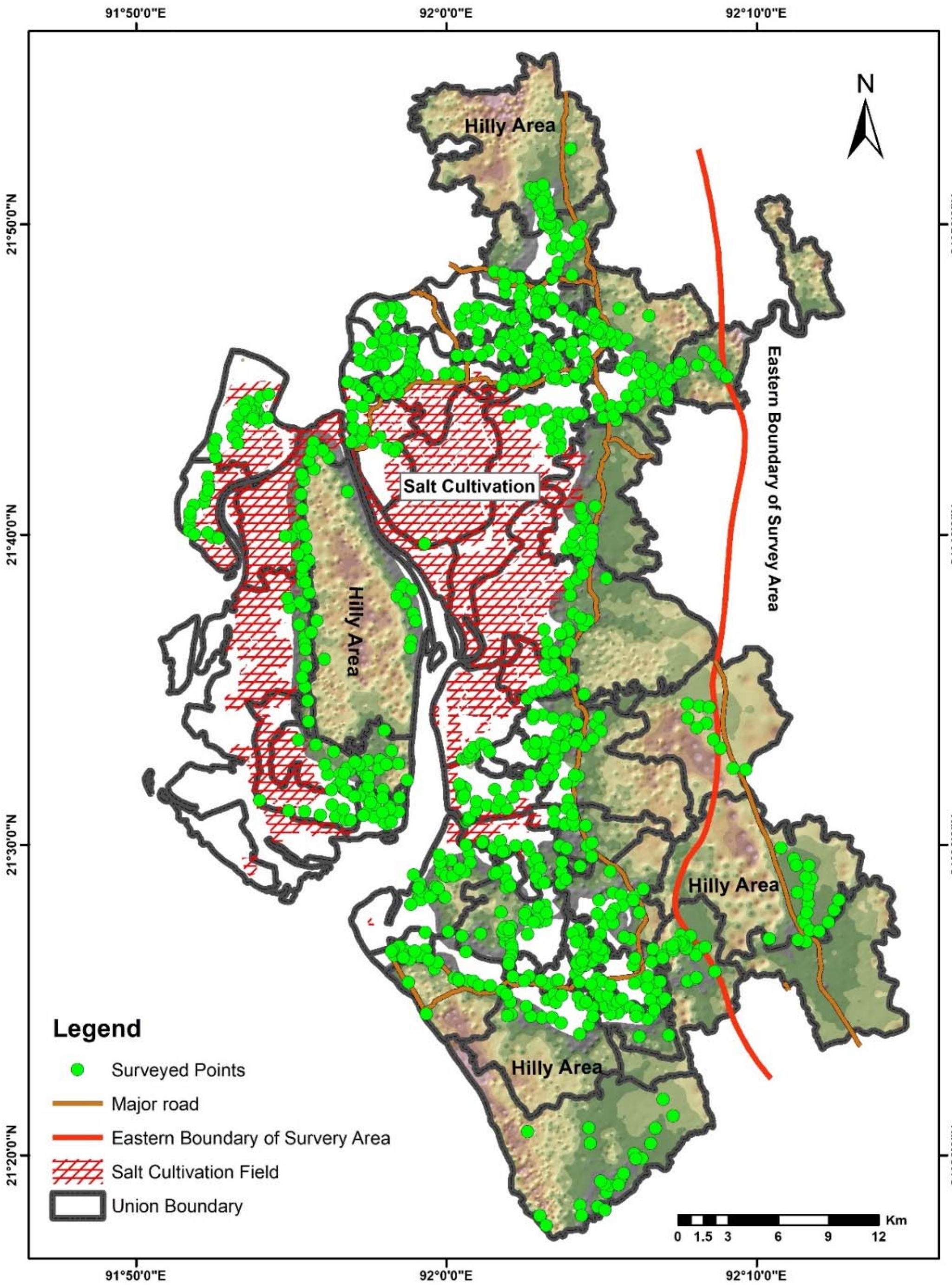
Source: JICA Survey Team

The percentage of surveyed boreholes by use to all existing boreholes for use is as follows:

- Shallow wells for domestic use: 83 wells (0.94%),
- Deep wells for domestic use: 605 wells (8.94%), and
- Shallow/deep wells for irrigation use: 264 wells (7.39%).

In the inventory survey, the following items were surveyed through interview with the owners and handlers.

- Location (name of village, coordinates), year of construction, handler, number of users, well structure, well depth, depth of screen, diameter of casing pipe, type of well, pumping rate, usage of water.



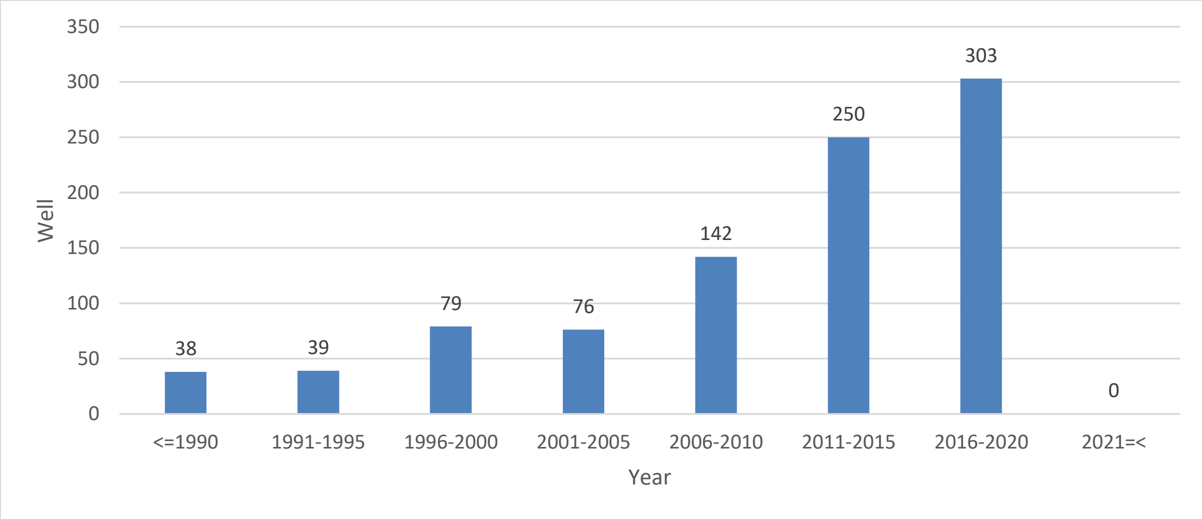
Source: JICA Survey Team (DEM data was used as the base map)

Figure 2.2.6 Locations of Boreholes Surveyed in Inventory Survey

The survey results of the main survey items of the inventory survey are described below.

(i) Year of construction

Figure 2.2.7 shows a graph summarizing the number of wells constructed by 2020 for the wells distributed in the study area.



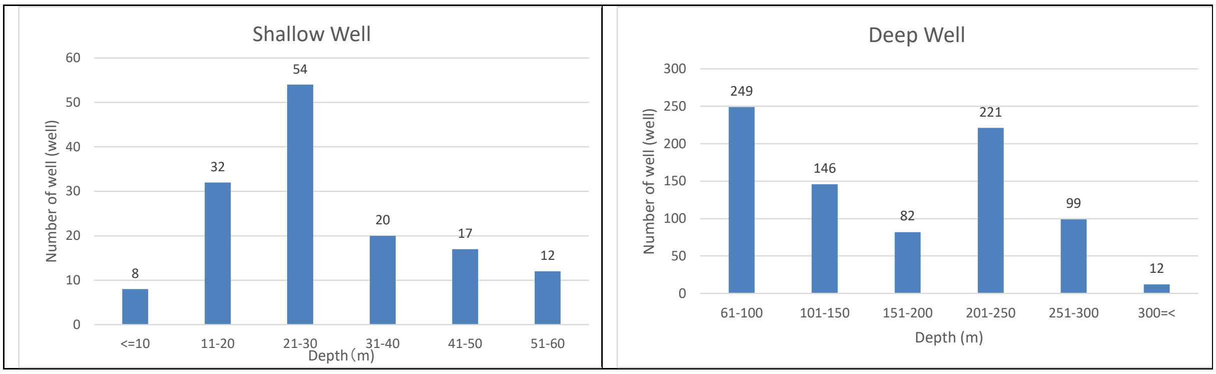
Source: JICA Survey Team

Figure 2.2.7 Year and Number of Construction of Wells

Construction of wells started before 1990s. Up to 1995, 38 to 39 wells were constructed on average in 5 years, averaging 7 to 8 wells per year. The number of wells constructed had almost doubled in the 10 years since 1996, and by 2005, about 13 to 16 wells were constructed in a year. Since then, the number of wells constructed continued to increase, resulting in 142 wells (28 wells/year) in the 5 years from 2006, 250 wells (50 wells/year) in the 5 years from 2011 and 303 wells (60 wells/year) in the 5 years after 2016.

(ii) Well depth

Figure 2.2.8 shows the distribution of the depth-wise number of shallow and deep wells in the survey area.



Source: JICA Survey Team

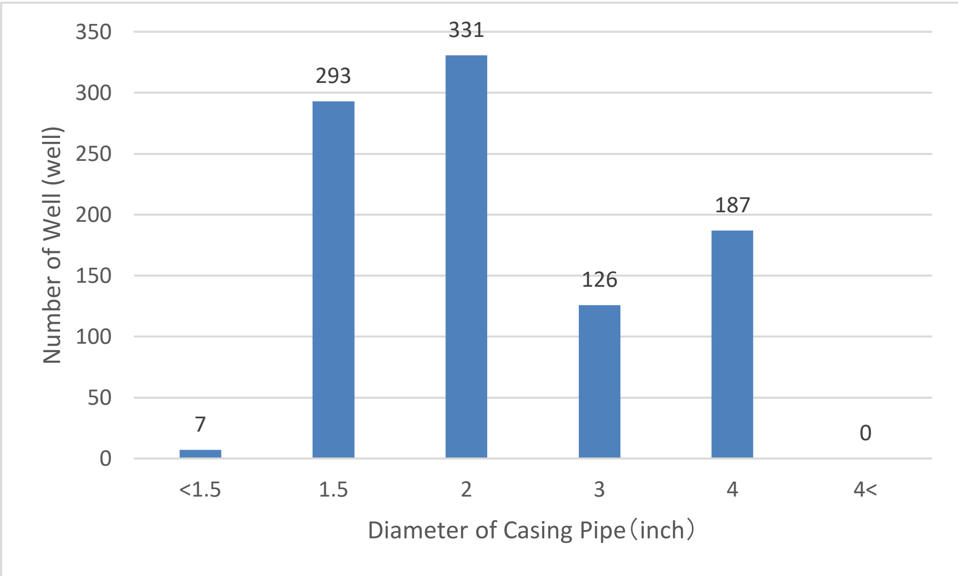
Figure 2.2.8 Distribution of Depth-wise Number of Wells

The shallow wells of which the depths are in the range of 21 to 30 m have the largest number of 54 and account for 38%. This is followed by 32 wells (22%) of 11 to 20m depth, 20 wells (14%) of 31 to 40m depth, 17 wells (12%) of 41 to 50m depth, and 12 wells (8%) of 51 to 60m depth. The wells of 10m depth or less are only 8 wells (6%).

The number of deep wells is 249 wells (30%) with 61 to 100m depth and 221 wells (27%) with 201 to 250m depth, the total of both accounts for 470 wells (58%) of deep wells. Then, the number of wells is as follows: 146 wells (18.0%) with 101 to 150m depth, 99 wells (12%) with 251 to 300m depth, and 82 wells (10%) with 151 to 200m depth. There are only 12 wells (1.5%) for over 300m depth.

(iii) Diameter of casing pipe

The maximum diameter of the casing pipe is 4 inches. The minimum diameter is 1 inch. The diameter-wise number of wells is shown in Figure 2.2.9.



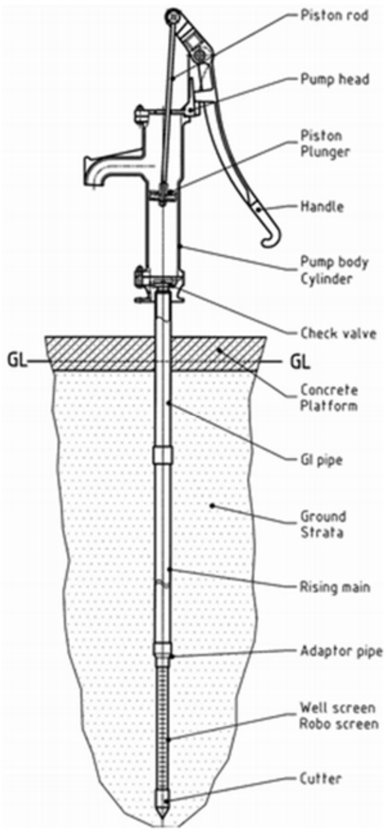
Source: JICA Survey Team

Figure 2.2.9 Casing Diameter-wise Number of Wells

The most common diameter of casing pipe is 2 inches, which accounts for 331 wells (35.4%), followed by 1.5 inches which accounts for 293 wells (31.0%). Hand pumps are mainly installed in these wells. The numbers of casings with a diameter of 3 inches or more have decreased at 126 wells (13.3%) with 3 inches and 187 wells (19.8%) with 4 inches, and no casing larger than 4 inches can be seen. Submersible pumps and other power pumps are generally installed in wells with casing diameter of 3 inches or more.

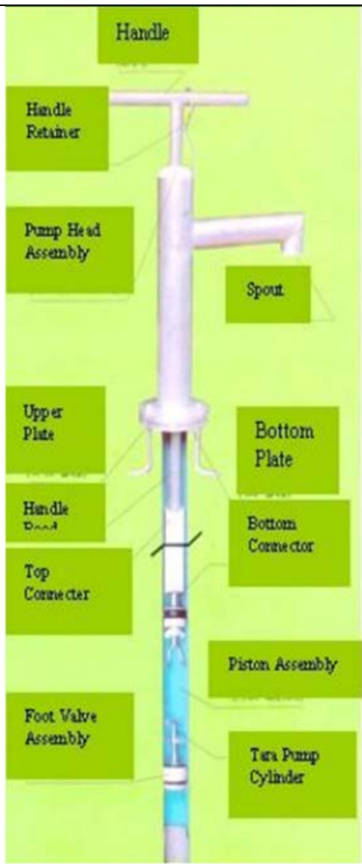
(iv) Types of pumps installed in the wells

Hand pumps or lift pumps (submersibles or engine pumps) are installed in the boreholes for domestic and irrigation uses. The number of each pump type for domestic use (shallow and deep wells) was surveyed in the Inventory Survey. The result is shown in Table 2.2.5. DPHE generally installs the No. 6 type of pump in the wells, of which the ground water level is shallower than 7.5m, the Tara Dev. type of pumps for ground water levels from 7.5 to 25m, and the motor pumps for ground water levels more than 25m. Figure 2.2.10 shows the structural drawings of the No. 6 and Tara hand pumps.



Source: Web site of Rural Water Supply Network (https://www.rural-water-supply.net/en/implementation/public-domain-handpumps/no-6-pump)

No. 6 Hand Pump



Source: DPHE Portal Site (https://dphe.portal.gov.bd/sites/default/files/files/dphe.portal.gov.bd/page/64999904_bd61_4df2_9b2f_4031aaf4b1b7/R%20%26%20D.pdf)

Tara Hand Pump

Figure 2.2.10 Structural Drawings of No. 6 and Tara Hand Pumps

Table 2.2.5 Number of Lifting Pumps Installed in Areas for Inventory Survey

Upazila	Type of Borehole	Type of Pump[4]				Total
		No. 6	Tara	Motor	Other	
Chakaria	Shallow Well	26	0	20	6	52
	Deep Well	165	0	84	38	287
	Total	191	0	104	44	339
Moheshkhali	Shallow Well	13	1	14	0	28
	Deep Well	55	1	60	20	136

[4] No. 6 Pump: It is the most popular hand pump in Bangladesh. It is a type of hand pump manufactured according to the specifications of the Rural Water Supply Network (RWSN) formed in 1996 by the World Water Council. This type of pump is easy to install and easy to maintain at a village level. The ground water level that can be lifted is about 7 m. It is suitable for use by about 100 people.

Tara Dev Pump: It is a type of hand pump manufactured according to RWSN specifications and Indian standards. It is corrosion resistant, easy to install and easy to maintain at a village level. It is designed to make the handle work lighter when pumping, not for heavy-duty use. It is suitable for about 100 users. The maximum pumping capacity is about 50 L/min at a ground water level of about 15 m.

Motor pump: It is a type of submersible pumps, of which the power source is electricity.

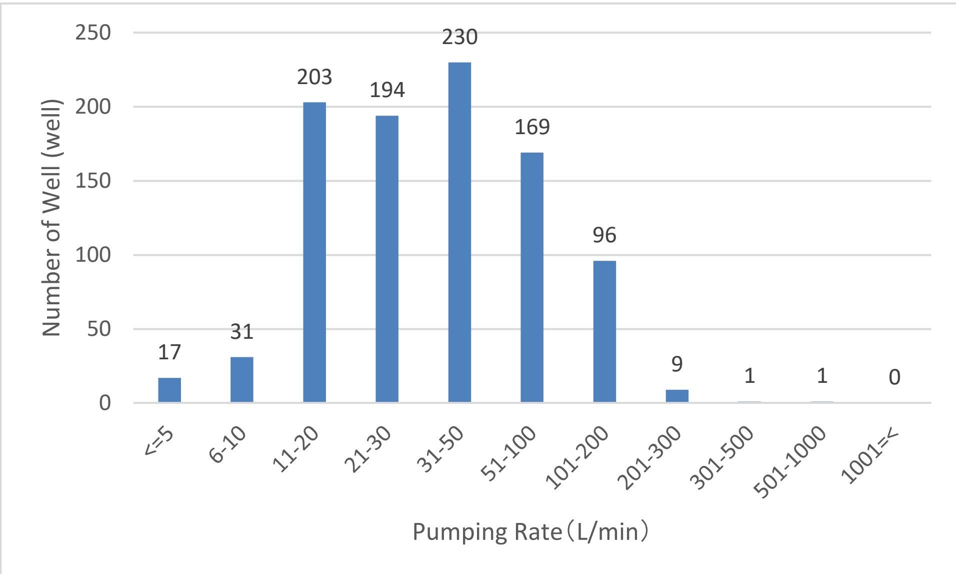
Upazila	Type of Borehole	Type of Pump[4]				Total
		No. 6	Tara	Motor	Other	
	Total	68	2	74	20	164
Cox's Bazar Sadr	Shallow Well	10	0	28	0	38
	Deep Well	71	3	137	9	220
	Total	81	3	165	9	258
Ramu	Shallow Well	12	2	9	2	25
	Deep Well	39	0	112	15	166
	Total	51	2	121	17	191
Total	Type of Pump	391	7	464	90	952
	(%)	41.1	0.7	48.7	9.5	100.0

Source: JICA Survey Team

Most of the pumps installed are No. 6 type hand pumps, which are installed in 464 wells out of 952 wells, accounting for 48.7%. Then, the motor pumps follow, installed in 391 wells and amount to 41.1%. The Tara type hand pumps were found only in 7 wells. The remaining 90 wells are of other types (artesian well or dug well). In Chakaria, there are more hand pumps installed than motor pumps, but in other Upazilas there are slightly more motor pumps installed than others. The diameter of screen pipe for domestic water uses is generally 1.5 and 2 inches and the No. 6 type of hand pump has been installed. However, it is supposed that the number of cases where motor pumps for private homes are installed is increasing from the viewpoint of convenience.

(v) Pumping rate of ground water

Figure 2.2.11 shows the distribution of wells by pumping rate of ground water.



Source: JICA Survey Team

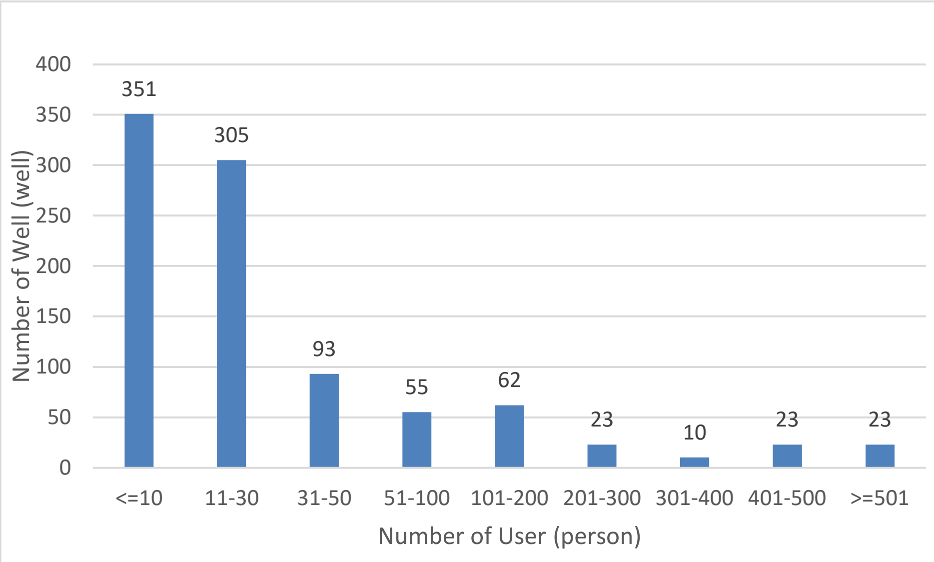
Figure 2.2.11 Distribution of Wells by Pumping Rate

In terms of the pumping rate per minute, majority or 892 wells (93.8%) have pumping rates from 11 to

200 L/min. In descending order of the number of wells, 230 wells (24.1%) have pumping rates from 31 to 50 L/min, 203 wells (21.3%) have 11 to 20 L/min, 194 wells (20.4%) have 21 to 30 L/min, 169 wells (17.8%%) have 51 to 100 L/min, and 96 wells (10.1%) have 100-200 L/min. The numbers of wells with pumping rates below 10 L/min and above 201 L/min are extremely small.

(vi) Number of user

The distribution of wells by number of users is shown in **Figure 2.2.12.**



Source: JICA Survey Team

Figure 2.2.12 Distribution of Wells by Number of User of Wells

In terms of the number of well users, there are 351 wells (37.1%) with 10 or less users and 305 wells (32.3%) with 11 to 30 users, i.e., 656 wells with 30 or less users. It accounts for 69.4% (about 70%) of the total. This is considered to reflect the fact that a large number of hand pumps are installed in the study area. There are 93 wells (9.8%) with 31 to 50 users, 55 wells (5.8%) with 51 to 100 users, 62 wells (6.6%) with 101 to 200, and 10 to 23 wells with 200 to 500 users.

(vii) Correlation between each survey item

< Relationship among borehole depth, diameter, and construction time>

No relationship was observed among borehole depth, diameter, and construction time.

<Relationship between borehole diameter and type of pump>

Boreholes for domestic water in the survey area are finished with a diameter of 1.5 or 2 inches regardless of the planned drilling depth. The installed pump is the No. 6 pump or a motor pump. Both of them account for 90%. If the ground water level is deeper than 7 m, Tara pumps are installed, but only 7 Tara pumps are installed, accounting for 0.7% of the total survey quantity.

If the ground water level is low, if the borehole is for irrigation, or if a large amount of ground water needs to be pumped such as a water source for piped water supply, the diameter of the borehole is 4 inches and the motor pump has been installed to 88% of the boreholes surveyed.

<Relationship between borehole depth and yield>

Figure 2.2.13 shows the relationship between the depth of the borehole and yield. Most of the shallow wells with a depth of 30 m or less have a yield of 1 to 3 m^3/hour, accounting for 54% of the boreholes with a depth of 30 m or less. Next to this is the yield of 1 m^3/hour or less, which accounts for 23%.

As with the former, most shallow wells with a depth of 31 to 60 m or less have the yield of 1 to 3 m^3/hour, accounting for 49% of the wells with a depth of 31 to 60 m or less. The boreholes with 3 to 5 m^3/hour of yield accounts for 27% next to this.

Wells with a depth of 61 m or more (deep wells) are most concentrated at a pumping volume of 1 to 3 m^3 / hour, accounting for 56% of the total deep wells. Wells with a pumping volume of 1 m3 / hour or less, 3-5 m^3 / hour and 5-10 m^3 / hour occupy 12, 13 and 15% at almost the same ratio, respectively.

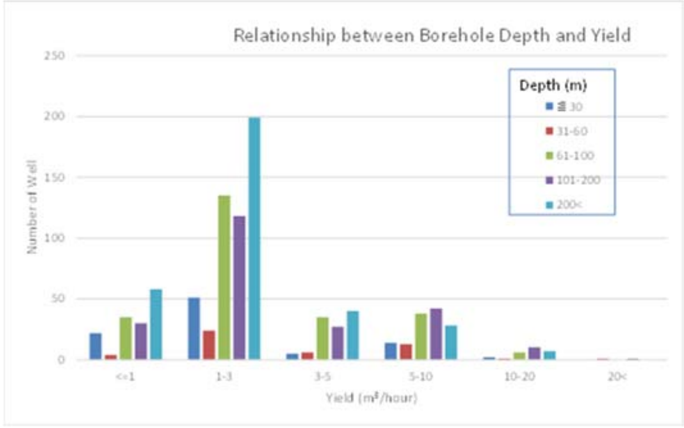
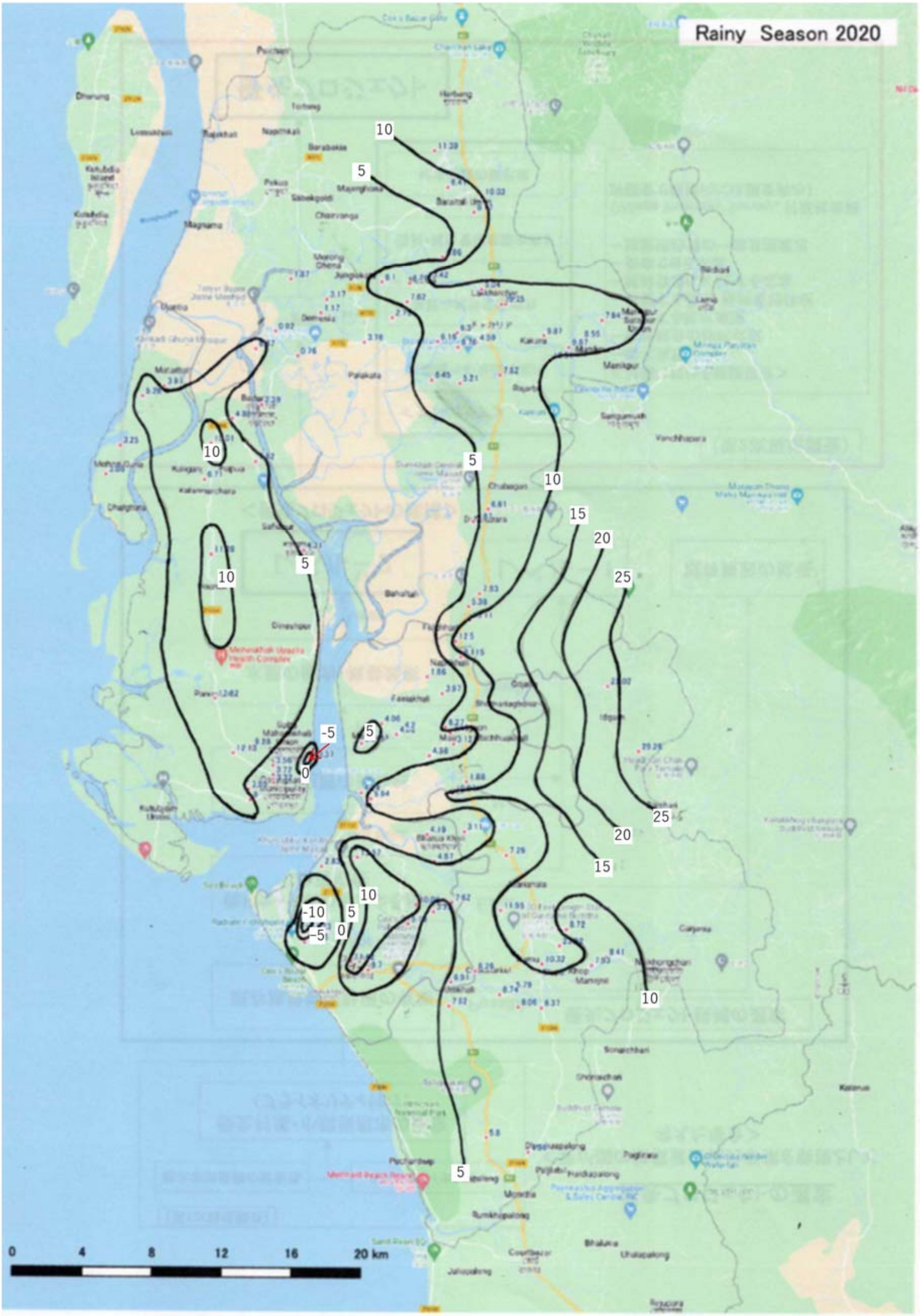


Figure 2.2.13 Relationship between Borehole Depth and Yield (Source: JICA Survey Team)

3) Ground water level (simultaneous measurement)

One hundred and four (104) boreholes were selected so as to avoid bias from the boreholes for the inventory survey, and the ground water levels of these 104 boreholes were measured simultaneously in the rainy season (August to September 2020) and the dry season (February to March 2021). The top elevation of each well was measured by a portable GPS, but the accuracy was inferior, so it was calculated using the DEM data (30m x 30m) of SRTM-1[5], which is said to be relatively accurate. The measured elevation data were converted to the data above mean sea level (MSL). Ground water level contour maps for both seasons are shown in Figures 2.2.14 and 2.2.15, respectively.

[5] DEM data of SRTM-1: SRTM is an abbreviation for Shuttle Radar Topography Mission. SRTM is mounted on the shuttle and uses remote sensing technology using a synthetic aperture radar to acquire radar images of the ground surface and process them into elevation data called DEM (Digital Elevation Model). The DEM data of SRTM-1 is the data that divides the ground surface into meshes of 30m x 30m and shows the elevation of the center of each mesh. This data is published on the US Geological Survey website.

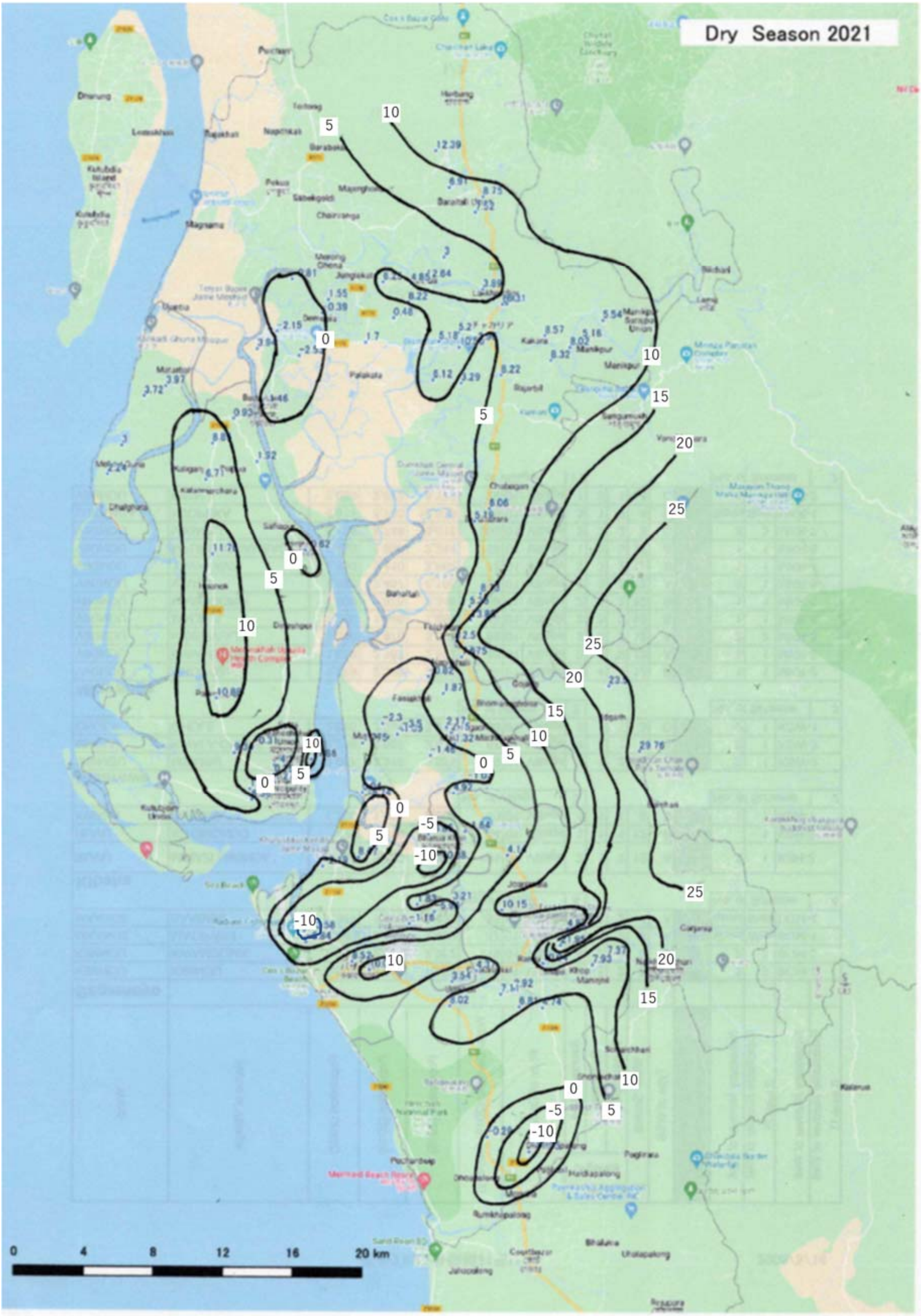


Source: JICA Survey Team (DEM data was used for the base map)

Figure 2.2.14 Ground Water Level Contour Map (Rainy Season: Aug. to Sep. 2020)

In the rainy season, the ground water level contour lines (hereinafter called "contour line") of 5 m and 10 m run in the north-south direction so that the contour line runs along the edge of CHT near the center of the survey area. The east side of the contour line of 10 m is a hilly area and the ground water levels become higher. Ground water levels of 29.26 m and 22.02 m were observed in CHT[6]. On the west side of the 8 m contour line, the groundwater level gradually drops. Among these, the ground water level is -11.43 m, which is below the sea level, near the downtown of Cox's Bazar. The ground water level is -2.53 m in the dry season, which is below the sea level, near the mouth of the Matamuhuri River in western Chakaria. The ground water level is more than 2 m in Moheshkhali and Matarbari Islands in the rainy season, and no ground water level below the sea level is observed.

6 CHT (Chittagong Hill Tracts): the hilly area situated in the southeastern Bangladesh, which occupies an area of 13,180 km^2. CHT is an extension of the Himalayas and borders India and Myanmar.



Source: JICA Survey Team (DEM data was used for the base map)

Figure 2.2.15 Ground Water Level Contour Map (Dry Season: Feb. to Mar. 2021)

Contour lines of 5m and 10m in the rainy season slightly shifted eastward. It shows that the ground water level has dropped in the dry season. The ground water level is high on the east side of the 10m contour line because the east side areas are CHT and its foothills. In the vicinity of Cox's Bazar downtown and the northern part of Cox's Bazar, the ground water levels in the dry season are below sea level, which are -13.58m and -10.88m, respectively. From the northern part of Cox's Bazar to the boundary with Chakaria, there are scattered areas where the ground water level is below the sea level. The ground water level of the Moheshkhali Island was above the sea level in the rainy season, but there are some areas where the ground water levels are below the sea level: e.g., -4.1 m in the downtown of Moheshkhali and -0.62 m on the east side of the central part of the island, in the dry season.

4) Ground water level (long term monitoring: existing data)

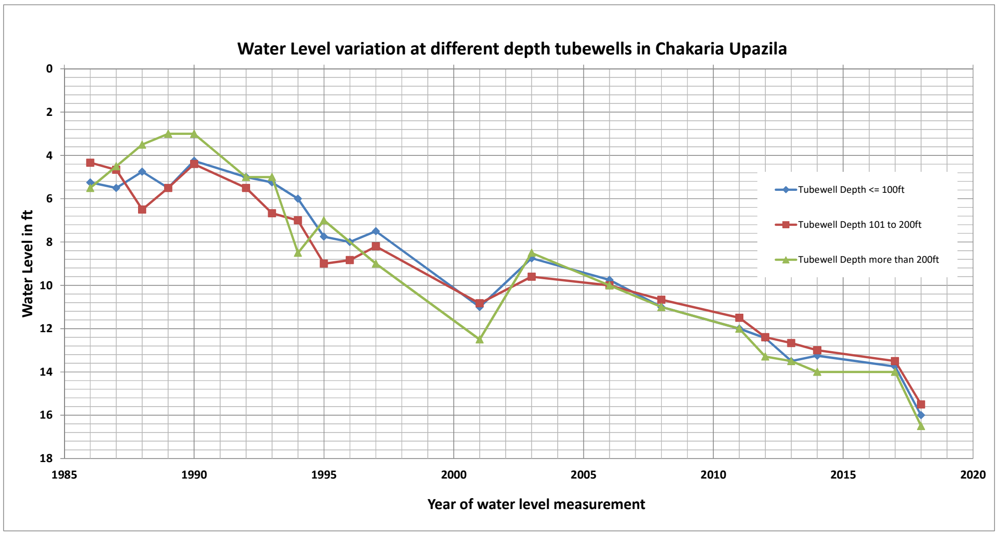
Ground water level monitoring has been carried out by DPHE, BWDB and BADC. Table 2.2.6 shows the list of monitoring data collected by the JICA Survey Team.

Table 2.2.6 List of Monitoring Data Collected

Organization	Number of Observation Well		Most Longest Monitoring Period of Data Collected	Monitoring Interval
	Shallow Well	Deep Well		
DPHE	40	10	1986-2018	Once a year in dry season
BWDB	16	-	1967-2019	Once a week
BADC	5	-	2016-2018	Every half month

Source: JICA Survey Team

The ground water level fluctuation from 1986 to 2018 in Chakaria is shown in Figure 2.2.16 as a typical example by using the data of DPHE. Table 2.2.7 shows the amount of declination of ground water level in the same period. The ground water level is shown as the depth from the ground level. Three (3) lines in the Figure show the average ground water levels of three (3) groups of boreholes: Boreholes with depths up to 100 feet, 101 to 200 feet and more than 200 feet.



Source: JICA Survey Team. Data of DPHE was used.

Figure 2.2.16 Ground Water Level Fluctuations in Chakaria Upazila (1986-2018)

Ground water levels have been declining since 1986 in all of the three (3) borehole groups. The amounts of ground water level declination are in the range between 3.3 and 3.4 m in 32 years, showing similar behaviors, and the average amount of water level declination is 0.10 m/year. As the three (3) groups of boreholes are extracting ground water from aquifers with different depths, it is highly possible that there may be some connections among the aquifers.

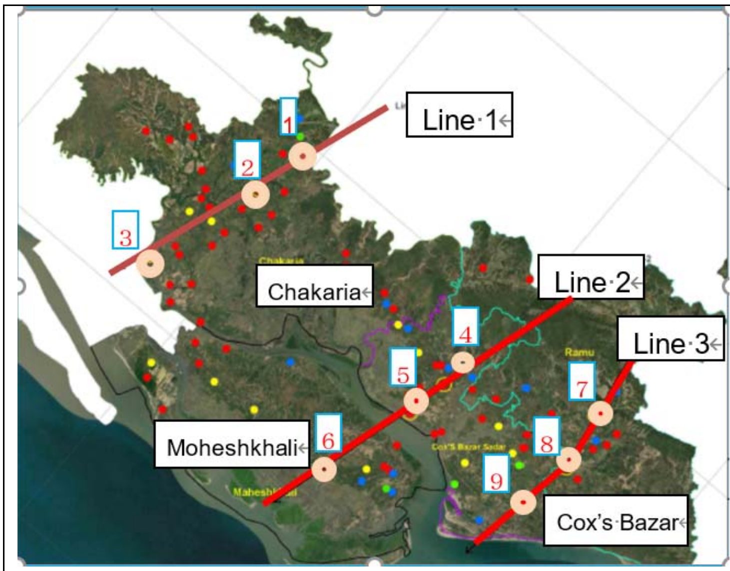
Table 2.2.7 Ground Water Fluctuations of Chakaria Upazila from 1986 to 2018

Depth of Well	Ground Water Level (m)		Declination of Ground Water Level (m)	Average Declination of Ground Water Level (m/year)
	1986	2018		
Up to 100 feet (less than about 30m)	1.6	4.9	3.3	0.10
101 to 200 feet (about 30 to 60m)	1.3	4.7	3.4	0.10
200 feet or more (about 60m or more)	1.7	5.0	3.3	0.10

Source: JICA Survey Team

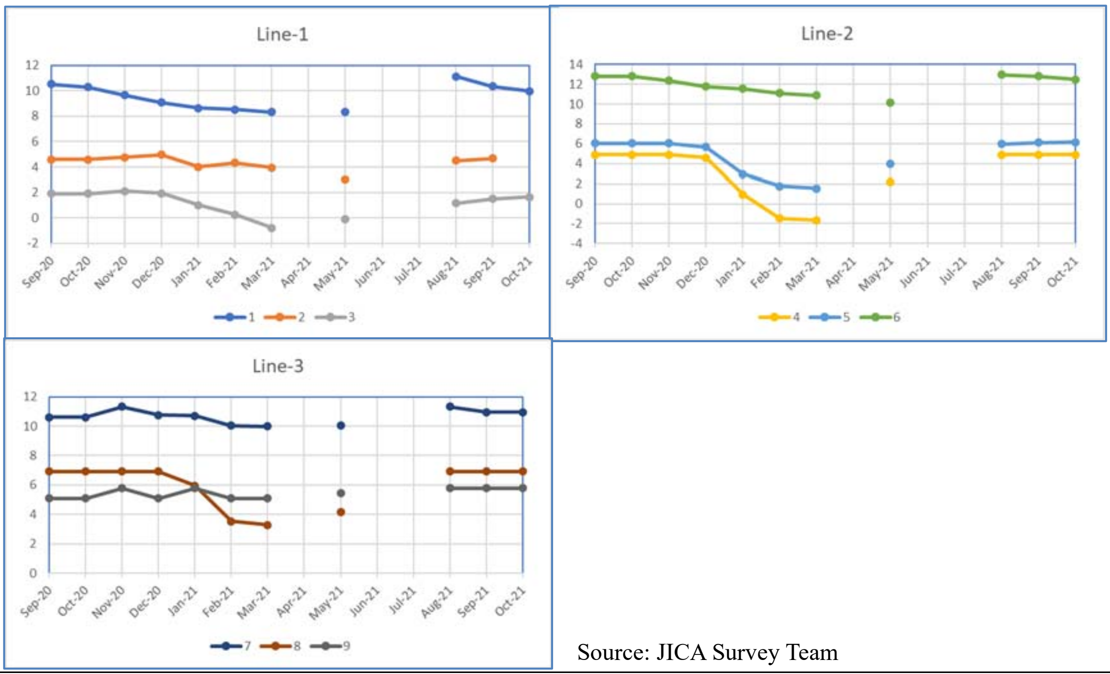
5) Ground water level monitoring (Carried out in this survey)

Ground water level monitoring (about 1 year) was carried out at nine (9) boreholes in this survey. Observation wells were selected from wells located in the western, central, and eastern parts of the survey lines, crossing three locations in the northern, central, and southern parts of the survey area. The monitoring period is from September 2020 to October 2021 (excluding April, June, and July 2021 due to lockdown by GOB caused by COVID-19). The arrangement of monitoring boreholes is shown in Figure 2.2.17. There are 9 monitoring boreholes in total, three (3) monitoring boreholes on each of the three (3) lines from Line 1 to Line 3, which run in the east-west direction. Figure 2.2.18 shows the fluctuation of the ground water level height above mean sea level in each well.



Source: JICA Survey Team (the image of Google Earth was used as the base map, which belongs to Google)

Figure 2.2.17 Arrangement of Monitoring Wells



Source: JICA Survey Team

Figure 2.2.18 Fluctuation of Ground Water Level in Lines 1 to 3

Line-1 is located in the northern part of Chakaria, Line-2 in the area from southern Chakaria to Moheshkhali, and Line-3 in the Cox's Bazar area in the east-west direction.

As seen in the observation data, the water level of each line declined from January 2021, which corresponds to the dry season, and continued to decline until around March. Although the data for June and July 2021 are missing, the water level has recovered to the initial water level at the start of observation in August 2021, which corresponds to the rainy season (however, no declination of water level in the dry season was observed only in Well-9 of Line-3). From these facts, it can be seen that the aquifer in the survey area generally has a low or no recharge in the dry season, so the ground water level declines, and in the rainy season, the water level recovers due to recharge. Table 2.2.8 shows a comparison of the water level of September 2020 when the observation started, and the water level of the month when the water level was the lowest in each line.

Table 2.2.8 Comparison of Ground Water Level at Start of Monitoring and Lowest Data

Line	No. of Observation Well	Ground Water Level (Sep. 2020) (m)	Lowest Ground Water Level Observed (m)		Declination (m)
1	1	10.54	Mar. – May 2021	8.32	2.22
	2	4.59	May 2021	3.03	1.56
	3	1.90	Mar. 2021	-0.78	2.68
2	4	4.88	Mar. 2021	1.65	3.23
	5	6.03	Mar. 2021	1.54	4.49
	6	12.82	Mar. 2021	10.18	2.64
3	7	10.62	May. 2021	10.00	0.62
	8	6.91	Mar. 2021	3.29	3.62
	9	5.09	Feb. Mar. 2021	5.09	0.00

Source: JICA Survey Team

Among the observation wells, the ones with the lowest water level in the dry season are the observation wells -4 and 5 of Line-2 located in the hills extending to the west from CHT and at the foot of the hills in the northern part of Cox's Bazar. The amounts of water level declinations are 3.23m and 4.49m, respectively. In contrast, observation wells -7 and 9 on Line-3 passing through Ramu and Cox's Bazar have lower water level declination, with water level declinations of 0.62 m and 0.00 m, respectively.

Next, the ground water level fluctuation in each line is described. In Line-1 in northern Chakaria, the water level declines moderately in the dry season in observation wells-1 and 2 located in the eastern and central parts, while in observation well-3. The water level declines slightly after December 2020. It becomes a little bigger.

In Line-2 in the central part of the survey area, the water level declination in the dry season is gradual at the observation well-6 in the western part of the Moheshkhali Island. On the other hand, the water levels of observation wells-4 and 5 located at the edge and foot of CHT declined relatively rapidly from January to March 2021. In Line-3, which passes through Ramu and Cox's Bazar in the southern part of the survey area, almost no water level declination in the dry season is seen in observation wells-7 and 9 on the eastern and western sides. On the other hand, the water level of the central observation well-8 declines sharply from January 2021.

In the observation wells of Lines 1 to 3, where the water level declined in the dry season, the water level almost recovered in August 2021, which is the rainy season.

6) Ground water quality

In the survey, 13 parameters of ground water quality were measured in the 104 wells selected. The 13 parameters are:

- 8 parameters instructed in the technical specifications: pH, Electric Conductivity (EC), Turbidity, Color, Ammonia Nitrogen, Nitrate Nitrogen, Iron and Manganese,
- Arsenic, of which contamination is widely recognized in Bangladesh,
- Temperature, to be measured together with pH and EC,
- Nitrite Nitrogen, as an indicator of pollution by manure, and
- Total Coliform and Faecal Coliform, to be used as evaluation criteria for drinking water.

Among them, Total coliform and Faecal coliforms were analyzed in the laboratory. The numbers of wells for which water quality was measured were 38 for Chakaria, 19 for Moheshkhali, 27 for Cox's Bazar, and 20 for Ramu.

Both the total coliforms and faecal coliforms are specified in the Water Quality Parameters Bangladesh Standards; therefore, both of them were analyzed in the survey. Many coliforms derived from the natural world such as soil and plants are included in the total coliforms, but it is said that the faecal coliforms can be regarded as the number of fecal-derived bacteria (Escherichia coli) (River Glossary, Edogawa

River Office, Kanto Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism, Japan).

As for the ground water quality in the survey area, UNICEF conducted a nationwide survey, and there are also water quality data measured by DPHE when wells were drilled. Some of the data of salinity and iron (Fe) exceed the water quality standards for drinking water in Bangladesh (hereinafter referred to as "standard values"). However, no data of arsenic (As) and other parameters related to health significance exceed the standard values. Hereinafter, each parameter is described based on the data obtained in this survey. For items for which guidelines have been set as “Guidelines for drinking-water quality” by WHO (hereinafter referred to as “guideline”), evaluations based on the guidelines were also added.

(i) pH

The standard value of pH ranges from 6.5 to 8.5. No guideline is set by WHO. Of the 104 wells measured in this survey, 19 wells (18.3%) did not meet the standard value. All of them are below the lower limit of 6.5, and the lowest is 5.4 for wells in Cox's Bazar. The number of wells that do not meet the standard value is 3 for Chakaria, 5 for Moheshkhali, 8 for Cox's Bazar, and 2 for Ramu.

(ii) Electric Conductivity (EC)

No standard value and guideline are provided for Electric Conductivity. The measurements in this survey range from 0.02 mS/cm (Ramu) to 3.63 mS/cm (Moheshkhali). There are 10 wells (9.6%) that exceed 1 mS/cm in all measured values, and it can be said that the salinity tends to be low as a whole. There are four (4) wells (1.1-3.63 mS / cm) in Moheshkhali and four (4) wells (1,59-3.08 mS/cm) in the area facing the Bay of Bengal in Cox's Bazar. In these areas, the impact of saltwater infiltration from the Bay of Bengal is considered. In addition, two (2) wells (2.39, 3.38 mS/cm) in Ramu have 1 mS/cm or more. Ramu is located inland, not facing the sea, and the reason for its slightly higher electrical conductivity is unknown. No wells with above 1 mS/cm were found in Chakaria.

(iii) Turbidity

The standard value for turbidity is 10 NTU or less and the guideline is 5 NTU or less. The measured values in the survey range from 0 to 309 NTU. The highest turbidity is measured in Cox’s Bazar. Only one (1) well in Ramu shows 8.36 NTU which exceeds the guideline and is below the standard value. Five (5) wells (4.8%) exceed the standard value, two (2) wells in Moheshkhali (28.4～37.6 NTU) and three (3) wells in Cox's Bazar (18.46～309 NTU. Turbidity is 0 NTU in 95 wells (96.9%) out of the remaining 98 wells.

(iv) Chromaticity (Color)

Both the standard value and guideline of chromaticity is 15 PCU/Hazen or less. The measured value in this survey is in the range between 0 and 500 or more PCU/Hazen. Only one (1) well in Cox's Bazar (1.0%) exceeds the standard value and guideline. All other wells meet the standard and guideline.

(v) Ammoniacal nitrogen (NH_4-N)

The standard value of ammoniacal nitrogen is 0.50 mg/L or less. The guideline is 0.20 mg/L or less. In this survey, there are five measurement ranges: 0 to 0.25 mg/L, 0.25 to 0.50 mg/L, 0.50 to 1 mg/L, 1 to 2 mg/L, and 2 to 4 mg/L for simple on-site measurement. Therefore, in the case of a measured value of 0 to 0.25 mg/L, it cannot be determined whether the guideline value is satisfied or not. The following measured values from 0.25 to 0.50 mg/L indicate that they exceed the guideline values but are below the standard values. Measured values in the range above 0.50 exceed the standard value.

There are 22 wells (21.2%) in the range of 0 to 0.25 mg/L in the survey area: 13 wells (12.5%) in Chakaria, 5 wells (4.8%) in Moheshkhali, 2 wells (1.9%) in Cox's Bazar, and 2 wells (1.9%) in Ramu.

The total number of wells exceeding the guideline and below the standard value is 56 wells (53.8%): 18 wells (17.3%) in Chakaria, 10 wells (9.6%) in Moheshkhali, 16 wells (15.4%) in Cox's Bazar, and 12 wells (11.5%) in Ramu.

Twenty-six (26) wells (24.0%) exceeded the standard values in this survey: Seven (7) wells in Chakaria, four (4) in Moheshkhali, nine (9) in Cox's Bazar, and six (6) in Ramu.

(vi) Nitrate nitrogen (NO_3-N)

The standard value of nitrate nitrogen is 10 mg/L or less. The guideline is 50 mg/L as Nitrate. Nitrate nitrogen in the survey shows a value of 10 mg/L or more and 20 mg/L or less in one (1) well of Cox's Bazar, but it is not detected in the remaining 103 wells. When this is converted as nitrate, it becomes 44 mg/L or more and 88 mg/L or less, and there is a possibility that it exceeds the guideline.

(vii) Nitrite nitrogen (NO_2-N)

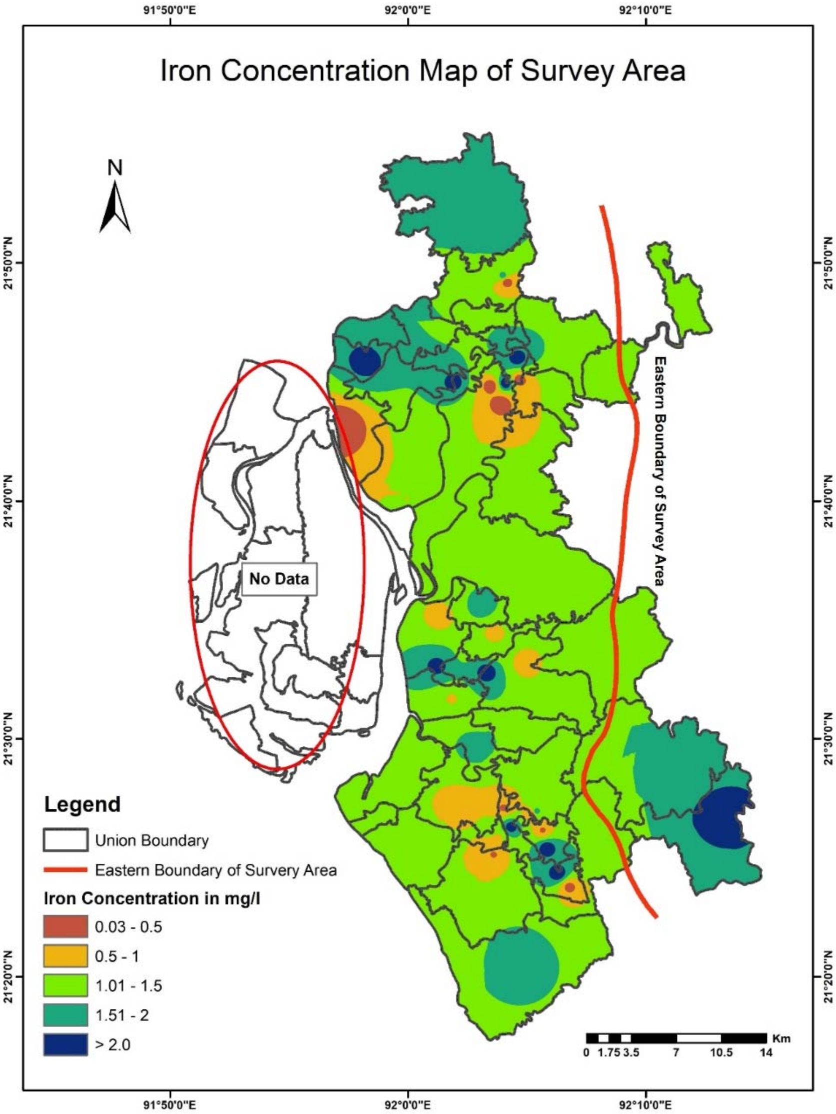
The standard value of nitrite nitrogen is 1 mg/L or less. The guideline is 0.06 mg/L as nitrite for chronic toxicity. As for the measurement in this survey, all 104 wells are below the standard. In the wells where the above-mentioned nitrate nitrogen in Cox's Bazar exceeds the standard value, the measured value is 0 to less than 0.2 mg/L. When converted to a nitrite gardener, it is 0 to 0.66 mg / L, which may exceed the guideline.

(viii) Iron (Fe)

The standard value of iron is in the range between 0.3 and 1.0 mg/L. No guideline is provided. In the measurement of this survey, 70 wells (67.3%) out of 104 wells did not meet the standard. All of these wells have concentrations above the upper limit of 1.0 mg/L, indicating that iron levels are generally high in the study area.

The maximum iron concentration values are 3.4, 3.17, 2.4 and 2.63 mg / L for Chakaria, Moheshkhali, Cox's Bazar, and Ramu, respectively. On the other hand, the minimum values are 0.3, 0.05, 0.73 and 0.01 mg/L, respectively. In Chakaria and Moheshkhali, about 50% of the concentration values are within the standard values (0.3-1.0 mg/L). On the other hand, about 75% of Cox's Bazar and about 75% or more of Ramu's concentration values exceed the standard values.

Figure 2.2.19 shows the distribution of iron concentration prepared by using the data of UNICEF. As for the distribution of iron concentration values, the range of 1.01-1.5 mg/L widely covers the survey area. Areas of 1.5 mg/L or more are distributed in the northern part of Chakaria, a part of the northern part of Cox's Bazar, and the eastern part of Ramu. Areas of 0.5-1.0 mg/L are partially distributed around areas of 1.5 mg/L and above.



Source: JICA Survey Team. Data of UNICEF was used.

Figure 2.2.19 Distribution of Iron (Fe) Concentration

(ix) Manganese (Mn)

The standard value of manganese is 0.1 mg/L or less. No guideline is provided. In the measurement in this survey, 12 wells (11.5%) exceeded the standard value. In Chakaria, all wells meet the standard. Four (4) wells in Moheshkhali, five (5) in Cox's Bazar and three (3) in Ramu exceed the standard. Wells with manganese concentrations above the standard value also tend to have higher iron concentrations.

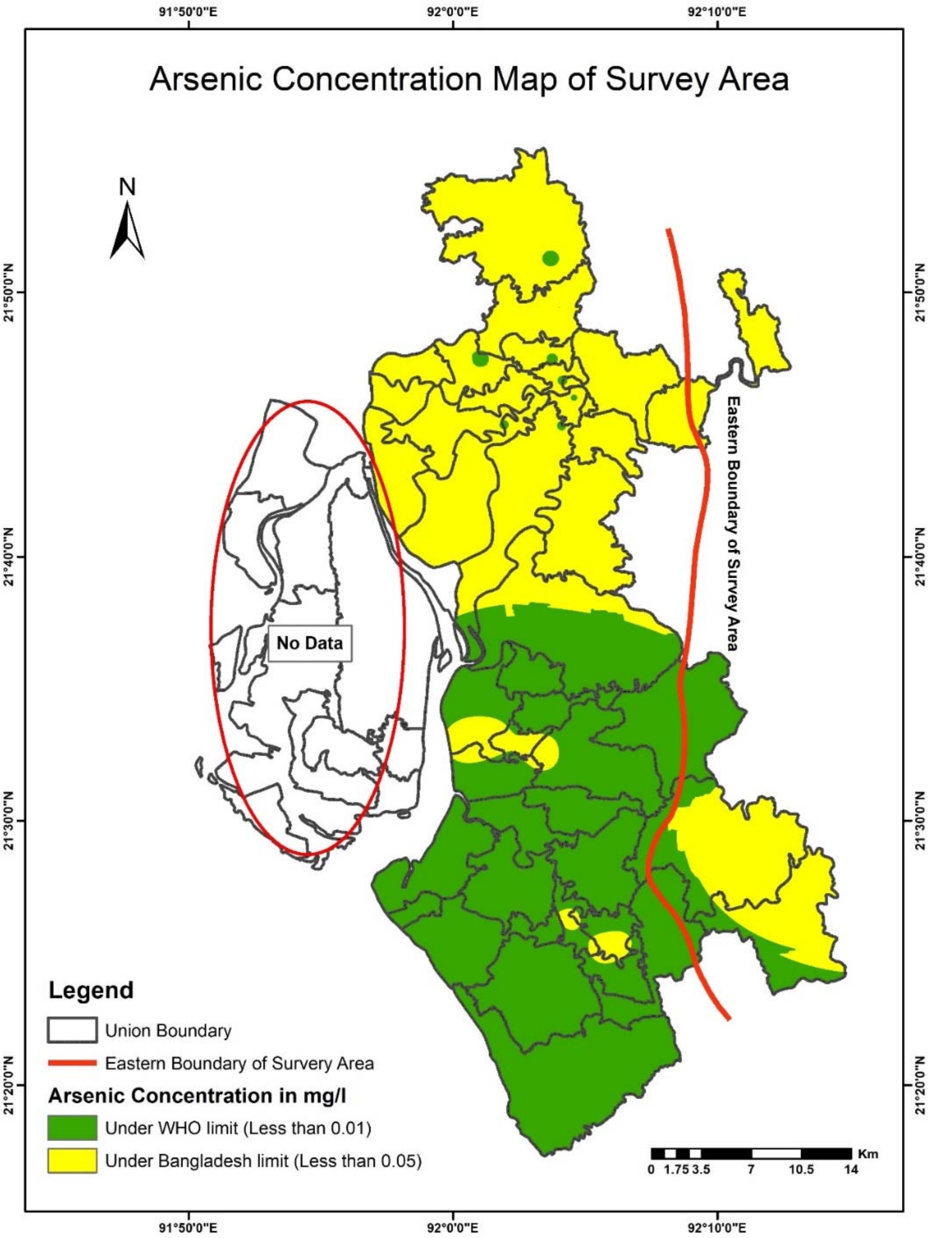
According to the data of UNICEF, the concentration values of manganese are less than the standard value (0.1 mg/L). On the other hand, about half of the values exceed the standard value. The maximum value is 0.36 mg/L which is the highest value in the survey area.

(x) Arsenic (As)

The standard value for arsenic is 0.05 mg/L. The guideline is 0.01 mg/L. In the measurements in this survey, arsenic is below the detection limit of the simple measurement at the sites of all 104 wells.

According to the UNICEF data, the concentration of arsenic is below the standard value (0.05 mg/L) in all data. However, some wells exceed the guideline (0.05 mg / L). The maximum value for each Upazila is about 0.02 mg/L for Cox's Bazar and Ramu, and much smaller than the WHO guideline value (hereinafter referred to as “guideline value”) (0.01 mg/L) for Moheshkhali.

The distribution of arsenic concentration is shown in Figure 2.2.20. In the southern half of the study area (South of Cox's Bazar, Ramu, and Chakaria), the arsenic concentration is low, and the area below the guideline value is widespread, and the area partially exceeding the guideline value and below the standard value is distributed. In the northern half of the survey area, the concentration of arsenic exceeds the guideline value but below the standard value. No DPHE data is available for Moheshkhali and Matarbari. However, arsenic was not detected in the water quality analysis of 17 wells constructed on the site of the Matarbari Ultra Super Critical Coal-Fired Power Plant Project in Matarbari.



Source: JICA Survey Team. Data of UNICEF was used.

Figure 2.2.20 Distribution of Arsenic Concentration

(xi) Water Temperature

The standard value of water temperature ranges from 20 to 30 °C. No guideline is provided. Only three (3) wells (2.9%) exceed the standard in the measured values in this survey. These water temperatures are only slightly above the standard value of 30.2 to 31.1 °C. There is one (1) well in Chakaria and two (2) in Moheshkhali that exceed the standard.

(xii) Total Coliform

The standard value and guideline for total coliform are "not detected". In the analysis of this survey, total coliform was detected in 88 wells (84.6%) out of 104 wells. The number of wells in which total coliform were detected was 35 out of 38 (92.1%) in Chakaria, 18 out of 19 (94.7%) in Moheshkhali, 16 out of 27 (59.3%) in Cox’s Bazar, and 19 out of 20 in Ramu (95.0%). In the study area, wells in Cox’s Bazar are about 60% contaminated, while the other three (3) Upazilas all exceed 90%. From this situation, it can be said that contamination by total coliform is progressing in the survey area except for Cox’s Bazar.

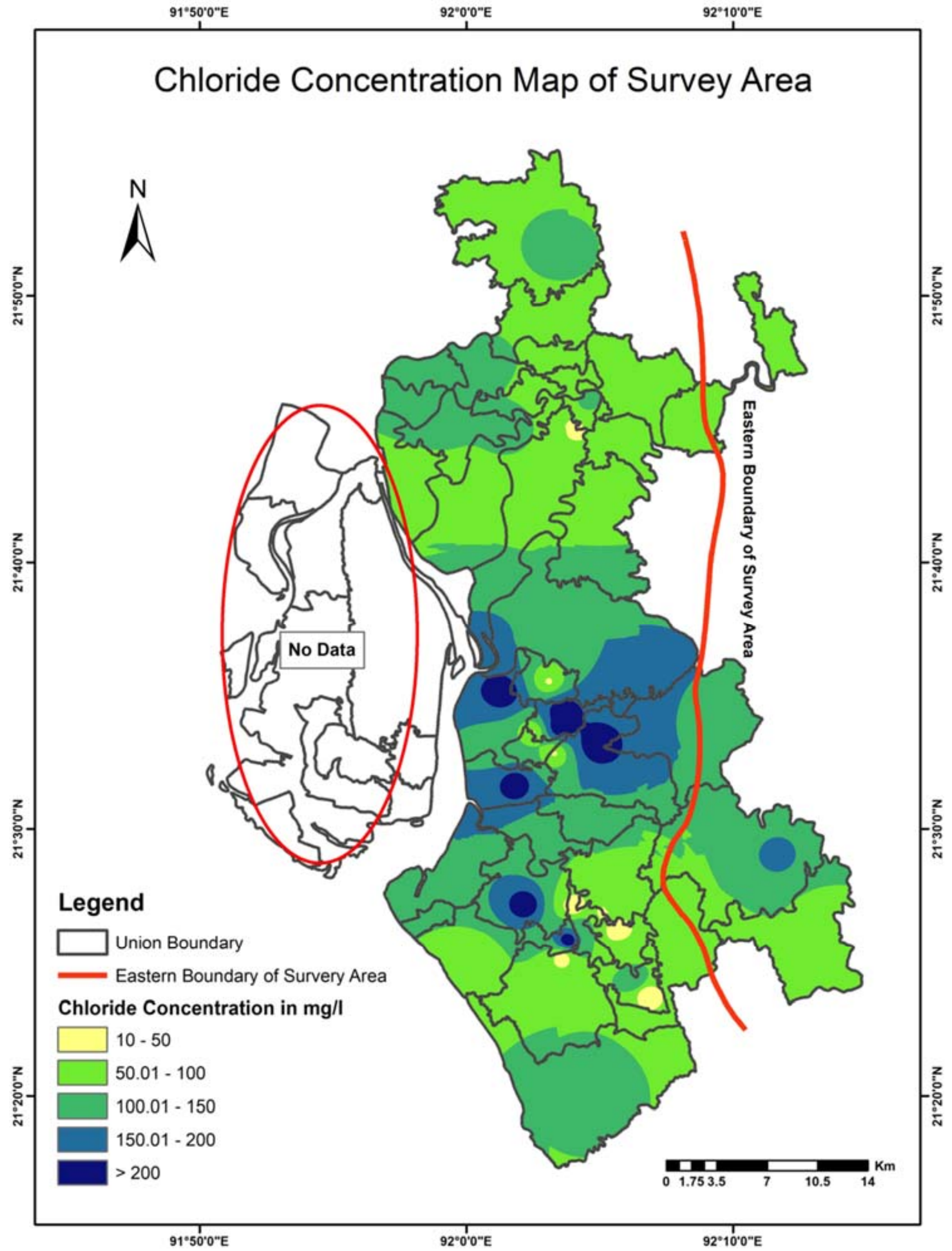
(xiii) Faecal Coliform

The standard value and guideline for faecal coliform are "not detected". In the analysis in this study, fecal coli was detected in 39wells (37.5%) out of 104 wells. In Chakaria, it is detected in 19 wells (50%), which is 1/2 of the 38 wells. In Moheshkhali, 11 of the 19 wells (57.9%) are contaminated: about 60% of the wells are contaminated. In contrast, of the 27 wells in Cox's Bazar, only four (4) wells (14.8%) are contaminated. Even in Ramu, the proportion of contaminated wells is low at five (5) out of 20 (25%). Looking at the status of contamination by faecal coliform, the contamination is progressing in Chakaria and Moheshkhali, which have a large proportion of agricultural land, and the contamination ratio tends to be low in Cox's Bazar, which has a large urban area.

(xiv) Chloride

Although chloride was not measured in the survey, data of the UNICEF is available. The standard value is 150-600 mg/L. No guideline value is provided for chloride concentration. All concentration values of chloride in the survey area are below the standard value. The maximum chloride concentration is 350 mg/L for Chakaria. The minimum values for Chakaria, Moheshkhali, Cox's Bazar, and Ramu are 1.2, 8.0, 45, and 10 mg/L, respectively.

Figure 2.2.21 shows the concentration values of chloride. From central to northern Chakaria, the range of concentrations of 50-100 mg/L extends. Higher concentrations in the range of 100-150 mg/L are observed in the north-western and northern parts of Chakaria.



Source: JICA Survey Team. Data of UNICEF was used.

Figure 2.2.21 Distribution of Chloride Concentration

According to the field survey of the JICA Survey Team and the interview at each Upazila office of DPHE, saline water intrusion into the ground water is confirmed in the following areas.

- Moheshkhali: The area from the western part to the southern part of Moheshkhali Island. Some wells in the site of the "Ultra-supercritical Coal-fired Power Plants" on Matarbari Island have high salinity.
- Cox's Bazar: Three unions of Pokkhali, Khurushkul and Chautoldondi facing the Bay of Bengal.

According to the DPHE Moheshkhali Upazila Office, three (3) wells with a depth of about 300 m were drilled by DPHE in the southern part of Moheshkhali Island, but all of them detected salt concentrations far exceeding the salt concentration of seawater.

7) Geophysical Exploration

A geophysical exploration survey was carried out in order to grasp the geological situation in the survey area. The main purposes of this exploration survey are as follows:

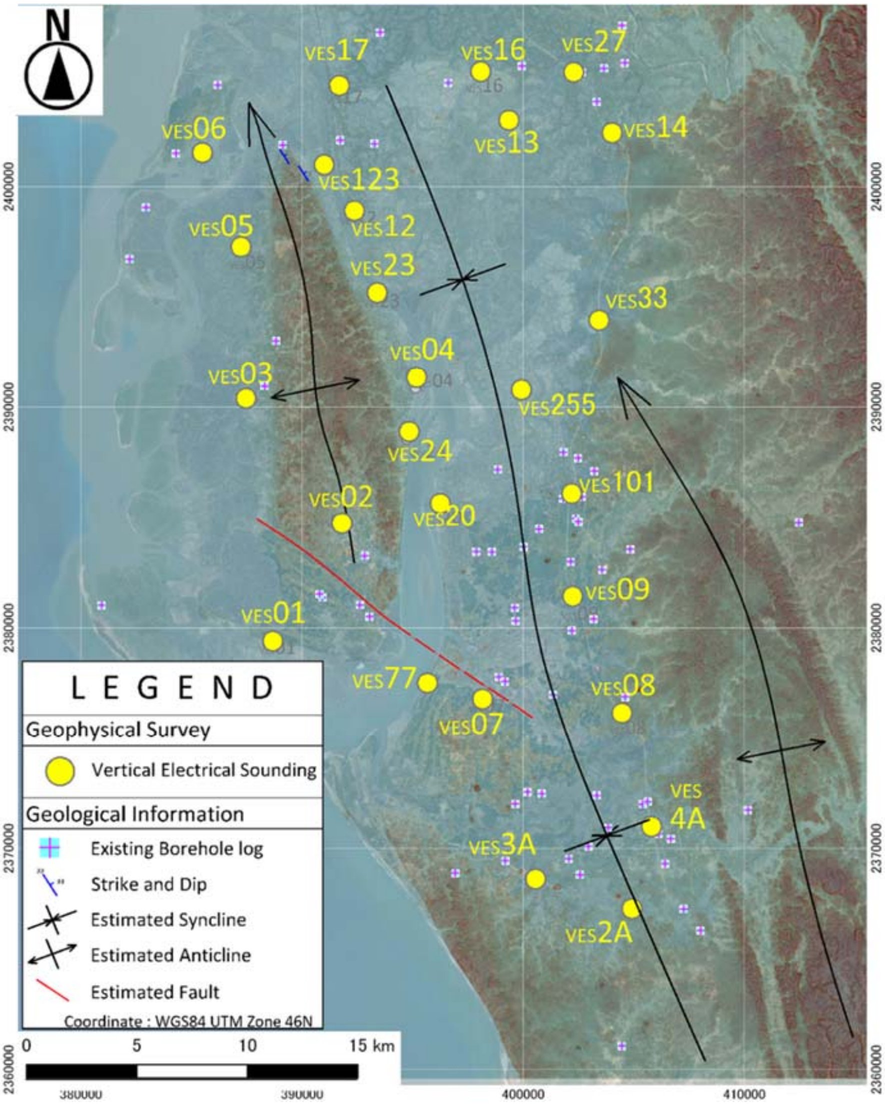
- To understand the geological structure in the survey area, and
- To confirm if new aquifers exist at a depth deeper than 300m, although the aquifer of which the depth is more than 300m from the ground surface have not been the object for ground water development.

The summary of exploration method is:

- Exploration method: Vertical electric survey by Schlumberger method,

- Average exploration depth: About 660m, and

- Number of exploration site: 26 sites (the locations of sites are shown in Figure 2.2.22).



Source: JICA Survey Team (The DEM data was used for the base map.)

Figure 2.2.22 Location Map of Geophysical Exploration Sites

The equipment and materials used for the exploration are shown in Table 2.2.9. The geophysical equipment used for the survey and exploration are shown in Figure 2.2.23.

Table 2.2.9 List of Equipment and Materials for Geophysical Exploration

Name	Q'ty	Unit	Remarks
McOHM Profiler-4	1	set	Resistivity meter
Power booster	1	set	Booster for resistivity meter
Observation cable	1800	m	ϕ 2mm electric wire
Electrode	4	piece	Reinforcing bar, ϕ 30mm L=1000mm
Others	1	set	Hammer, 12V battery, measuring tape, etc.
IX1Dv3	1	set	Analysis software for vertical electrical sounding

Equipment and Materials for Exploration

Measurement Work at Exploration Site

Source: JICA Survey Team

Figure 2.2.23 Equipment for Geophysical Exploration and Measurement Works

a) Results of exploration

Based on the apparent resistivity curves obtained from the measurements, the resistivity values and layer thicknesses were analyzed. The analysis was carried out, using the linear filter method. The analysis results are reported in Annex 2.2-6.

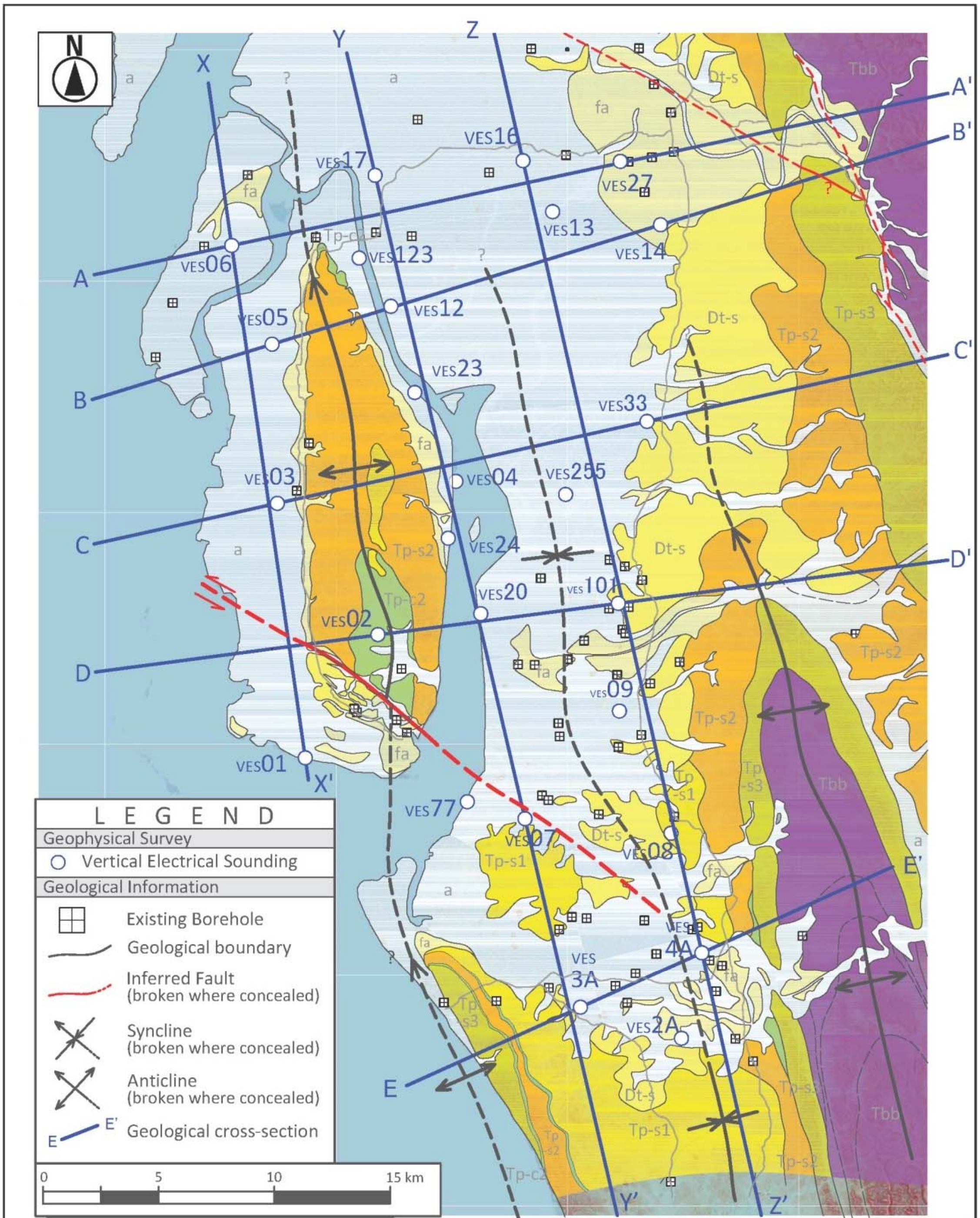
b) Preparation of geological map and cross-sections

A geological map and geological cross-sections are prepared to grasp the hydrogeological structure in the survey area. The geological map is shown in Figure 2.2.24 and the geological cross-sections are shown in Figures 2.2.25 and 2.2.26. The existing data and information used as references in the preparation of these maps are shown in Table 2.2.10.

Table 2.2.10 Existing Data and Information Used as References for Preparation of Geological Maps

Type	Title of Document	Source
Characteristics of resistivity	Resistivity diagram	This exploration
Existing borehole information	Borehole log	DPHE
Existing topographical map	Digital Elevation Model SRTM-1	NASA
Existing geological map	Geologic Map Chittagong Hill Tracts Bangladesh	Thomas Davis , 2016
Existing report on hydrogeological survey	Ground water resources investigation in Ukhia, Cox's Bazar	DPHE/JICA , 2017

Source: JICA survey team

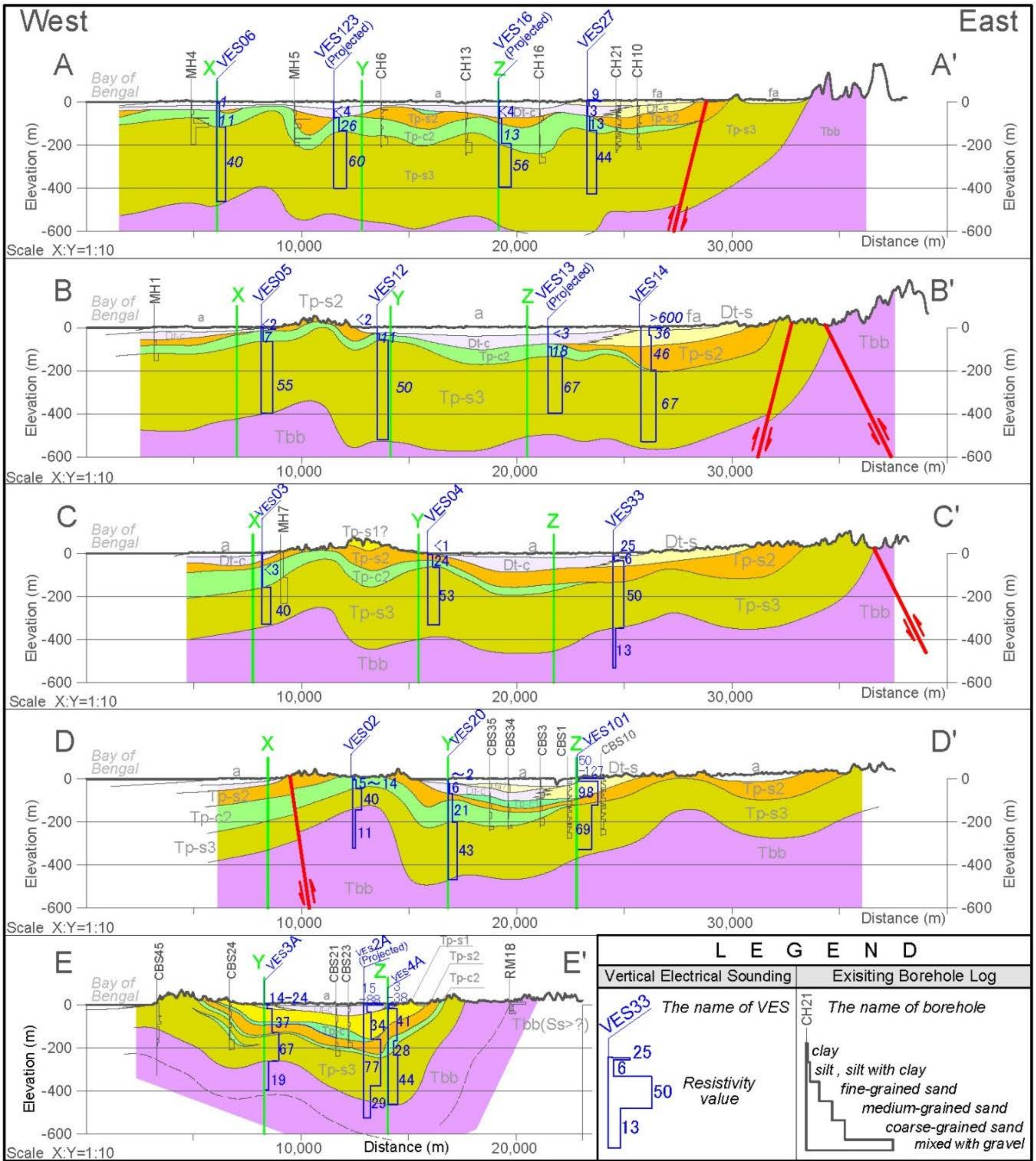


Stratigraphy

System	Series	Group	Symbol	Litology	
Quaternary	Holocene	Alluvium	a	sand,silt,clay, clay dominates?	
	Pleistocene	fan /terrace deposits	fa	sand,silt	
		Dupi Tila Group	Dt-c / Dt-s	Dt-c : clay predominant Dt-s : sand predminant	
Neogene	Pliocene	Tipam Group	Tp-s1	sandstone predominant	alternation of sandstone and mudstone
			Tp-c1	mudstone predominant	
			Tp-s2	sandstone predominant	
			Tp-c2	mudstone predominant	
			Tp-s3	sandstone predominant	
	Miocene	Suma Group	Tbb	Boka bil formation: shale with sandstone	

Source: JICA Survey Team

Figure 2.2.24 Geological Map of Survey Area

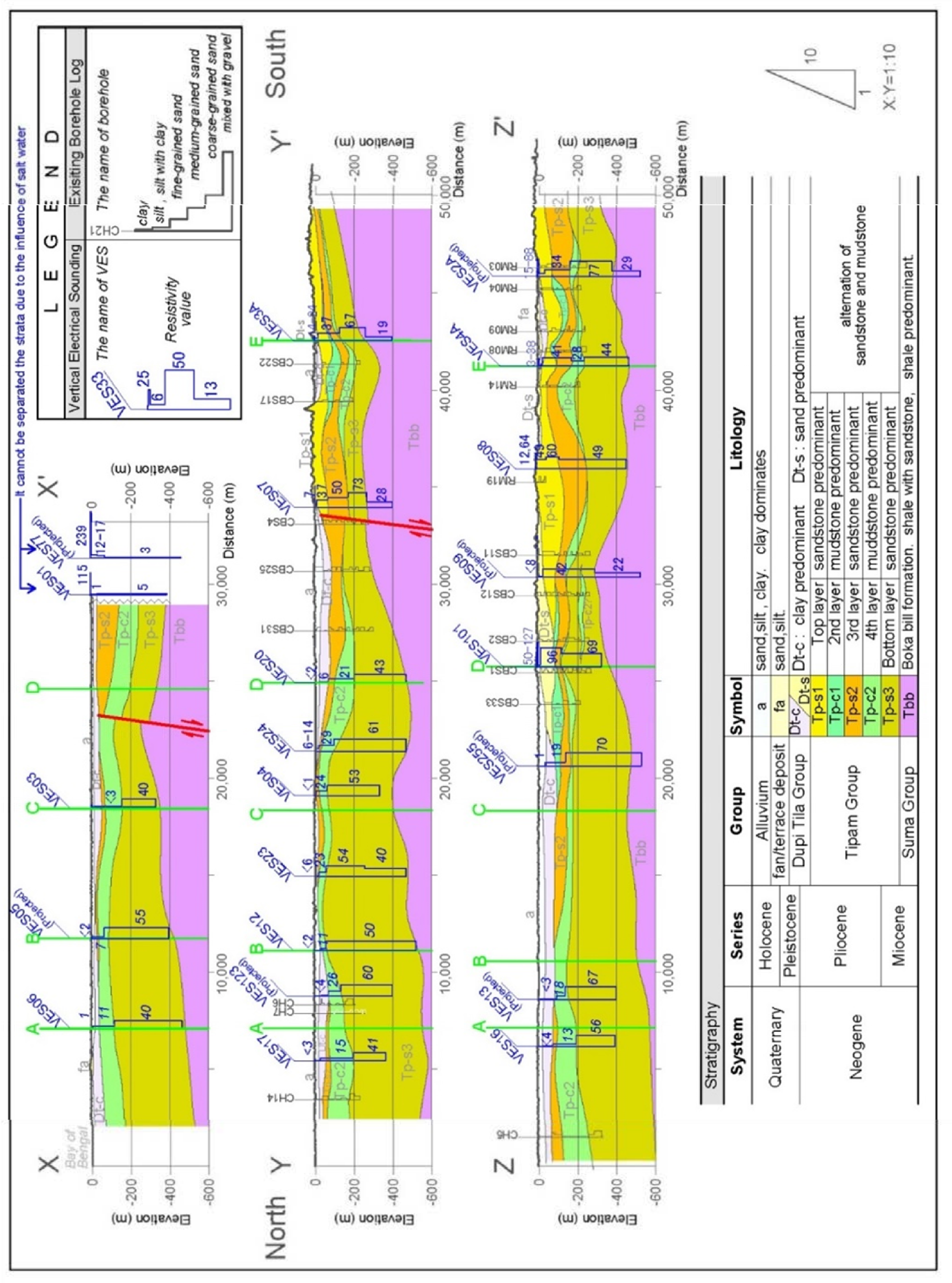


Stratigraphy

System	Series	Group	Symbol	Layer	Litology	
Quaternary	Holocene	Alluvium	a		sand,silt , clay. clay dominates	
		fan/terrace deposit	fa		sand,silt.	
	Pleistocene	Dupi Tila Group	Dt-c / Dt-s		Dt-c : clay predominant Dt-s : sand predominant	
Neogene	Pliocene	Tipam Group	Tp-s1	Top layer	sandstone predominant	alternation of sandstone and mudstone
			Tp-c1	2nd layer	mudstone predominant	
			Tp-s2	3rd layer	sandstone predominant	
			Tp-c2	4th layer	muddstone predominant	
	Miocene		Tp-s3	Bottom layer	sandstone predominant	
		Suma Group	Tbb		Boka bill formation. shale with sandstone, shale predominant.	

Source: JICA Survey Team

Figure 2.2.25 Geological Cross-section (East-West Direction)



Source: JICA Survey Team

Figure 2.2.26 Geological Cross-section (North-South Direction)

c) Assumption of hydrogeological structure in survey area

The hydrogeological structure around the survey area was assumed based on the resistivity value and distribution trend of strata.

First, the layers were classified into aquifers and aquicludes (low permeable layer), with reference to the resistivity values. In this survey, the criteria for classification were set based on the existing study results. The existing study result used as a reference is shown in Table 2.2.11.

Table 2.2.11 Relation between Resistivity Values and Strata in Previous Study

Lithology				Resistivity (Ω-m) This survey	Resistivity (Ω-m) Previous study *1)
Alluvium deposit (Mainly Clay)			al		○ 2-11Ω-m Medium sand with low resistivity, Water quality: Saline ○ 7-10 Ω-m Clay ○ 11-13 Ω-m Silty Clay
Tipam Sandstone	Clay		Tt-1	20	
	Silt		Tt-1		○ 15Ω-m Very Fine sand, Water quality: Slightly Saline
	Sand	Very Fine	Tt-1	Aquiclude ↑ 40	○ 18-27Ω-m Fine sand, Water quality: Brackish
		Fine	Tt-2	Aquifer ↓	○ 25-32Ω-m Fine to Medium sand, Water quality: Brackish
		Medium	Tt-2	60～70	
		Coarse	Tt-3	100	○ 34-1,000Ω-m Medium sand, Water quality: Brackish to Fresh
Unsaturated Soil (Mainly Sand)				5,000	

*1) Delineation of Fresh-Saline Water Interface In and Around Cox's Bazar Town, Bangladesh : Rafiq 2013 (Unpublished MS Thesis)

Source: Ground water Resources Investigation in Ukhia, Cox's Bazar, DPHE/JICA, December 2017.

In the case where the layer of which the apparent resistivity shows more than 40 Ω-m, it is assumed to be an aquifer composed of a sand predominant layer. In the case of the resistivity which is lower than 40 Ω-m, the layer is assumed to be an aquiclude composed of a clay predominant layer.

Then, the distribution of the aquifers was correlated with the information of existing wells (borehole logs) to confirm the ground water extraction situation from the aquifers. The distribution of geological formations was analysed based on the information of the cross-section Z-Z', which runs the center of the survey area.

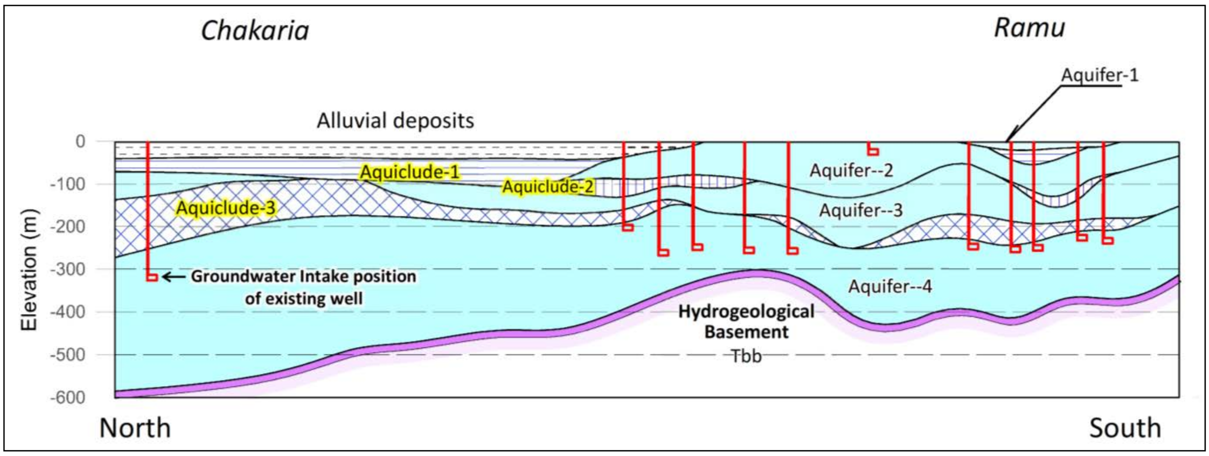
The analysis results are shown in Table 2.2.12 and the schematic hydrogeological cross sections are shown in Figure 2.2.27.

Table 2.2.12 Analyzed Hydrogeological Structure around Survey Area

Age		Group	Symbol	Lithology	Characteristics of resistivity: range Ω-m	median Ω-m	judgment of aquifer[*1)]	Distribution Depth GL -m	Hydro geological structure/ Use situation of an aquifer[*2)]	
Quaternary	Holocene	Alluvium	a	sand, silt, clay	1 - 239	6	–	0 - 40m	-	Surface water to shallow groundwater..
Quaternary	Pleistocene	fan / terrace deposits	fa	sand, silt	2 - 600	55	○	0 - 25m	**Aquifer-1**	Groundwater sources for shallow well
Quaternary	Pleistocene	Dupi Tila Group	Dt-c	clay predominant	2 - 19	6	×	20 - 100m	Aquiclude-1	
Neogene	Pliocene	Dupi Tila Group	Dt-s	sand predominant	14 - 46	36	○-×	0 - 90m	**Aquifer-2**	Groundwater sources for shallow/ deep well
Neogene	Pliocene	Tipam Group	Tp-s1	sandstone predominant	12 - 64	38	○-×	0 - 130m	**Aquifer-2**	Groundwater sources for shallow/ deep well
Neogene	Pliocene	Tipam Group	Tp-c1	mudstone predominant	-	19	×	60 - 80m	Aquiclude-2	
Neogene	Pliocene	Tipam Group	Tp-s2	sandstone predominant	19 - 98	49	○	50 - 250m	**Aquifer-3**	Groundwater sources for deep well
Neogene	Pliocene	Tipam Group	Tp-c2	mudstone predominant	2 - 29	14	×	80 - 250m	Aquiclude-3	
Neogene	Pliocene	Tipam Group	Tp-s3	sandstone predominant	40 - 77	53	○	120 - 550m	**Aquifer-4**	Main groundwater sources for deep well
Neogene	Miocene	Suma Group	Tbb	shale predominant	11 - 29	22	×	>300-550m	Hydrogeological Basement	

*1) × : Aquiclude ○:: Aquifer *2) Shallow well : <60m Deep well >60m

Source: JICA Survey Team



Source: JICA Survey Team

Figure 2.2.27 Schematic Hydrogeological Cross Section around Survey Area

The summary of each aquifer and evaluation of hydrogeological potential for ground water development are as stated below.

- Aquifer-1 : Ground water source for shallow wells

  The thickness is generally thin. The maximum thickness is about 25 m. It is distributed only in a shallow part near the ground surface. The distribution in a horizontal direction is poor. Thus, it is evaluated that ground water potential is very low.

  Evaluation as the new ground water source: Not suitable (Distribution depth: < 300m)

- Aquifer-2: Ground water source for shallow/ deep wells

The maximum thickness of the layer is about 130 m, and it is distributed from the ground surface to the depth of around GL-130 m. Although this layer is partially covered by the aquiclude consisting of the Dt-c layer, it is mostly unconfined aquifer.

It consists mainly of a sand predominant layer intercalated with clay and silt layers, and is the aquifer for shallow/deep wells.

Evaluation as the new ground water source: Not suitable (Distribution depth: < 300m)

- Aquifer-3: Ground water source for deep wells

The aquifer consists of confined to unconfined aquifer. The maximum thickness of the layer is about 115 m, and it is distributed around the depths of GL-50 to GL-250m.

Although Aquiclude-2 consisting of Tp-c1 exists between Aquifer-3 and Aquifer-2, its horizontal continuity of the distribution is poor. Therefore, Aquifer-2 and Aquifer-3 are not completely separated from the hydrogeological point of view. Aquifer-2 and Aquifer-3 are hydrogeologically connected, and these form a series of aquifers at most parts of the survey area.

Evaluation as the new ground water source: Not suitable (Distribution depth: < 300m)

- Aquifer-4: Ground water source for deep wells

The aquifer consists of confined to unconfined aquifers. The thickness of the layer is about 200～350m, and it is distributed around the depths of GL-120 to GL-550m. This aquifer is distributed in the deepest area around the survey area. The underlain stratum is the Tbb formation (Bokabil Formation) which forms the hydrogeological basement,

As in the case of Aquifer-3, it is not completely separated from the upper aquifer. In the eastern to southern side of the survey area, it forms the series of semi-confined aquifers with the upper aquifer. In the western to northern side of the survey area, this layer exists as unconfined aquifer, that is separated by a thick aquiclude. In any case, Aquifer-4 is used as the deep ground water aquifer of which the depth exceeds 200 m. The layer is distributed also in the depth of 300m or more, and it is hydrogeologically connected with other shallower aquifers. Therefore, extraction of ground water from this aquifer will cause negative impact on other shallower aquifers.

Evaluation as the new ground water source: Not suitable (Although the distribution depth is over 300m, the aquifer is already developed.)

- Conclusion

It cannot be confirmed that the existence of deep aquifers for a new source for ground water development.

2.3 Kaptai Dam Survey

(1) Field Reconnaissance (20 January 2020)

On 20 January 2020, the JICA Survey Team conducted a field reconnaissance of the Kaptai Dam and interviews with related staff. The result of discussions and site photographs are presented below.

1) Conditions of Reservoir Sedimentation

In the Survey, IWM had planned a bathymetric survey of the reservoir, and hence it was not necessary to get prior approval for the execution of this reconnaissance survey. According to the Kaptai Dam staff, the sedimentation of the reservoir has been currently hindering the navigation of vessels in the lake and BIWTA has been conducting a dredging project.

2) Data Provision

The JICA Survey Team presented a list of data to be collected for the dam and received the reply from the dam staff that they would provide the JICA Survey Team with data such as structural drawings of the dam and discharges which had been used for hydropower generation and overflowed from the spillway. After that, the above data and information were collected by the sub-contractor (see. Table 2.3.1).

3) Reservoir Operation

- The reservoir water level is operated in the range from 76 feet up to 109 feet (water level at the start of spill out operation). Reservoir operation has not changed significantly since the start of operation after construction in 1962. The reservoir water level was 94 feet at the date of the field visit on 20 January 2020.
- According to the site officer, the frequency of discharging from the spillway depends on the amount of inflow, and in this sense, it actually occurred once every two to three years in the past.
- From 1 February 2020, the No. 1 to No. 5 turbines are used in sequence to discharge as required for preventing downstream salt water intrusion and to supply water for Chattogram in the dry season. But this is a matter of oral understanding with the parties concerned. The basic purpose of the lake water discharge is for hydro-power generation, but not for water supply to the downstream.
- According to the interview with CWASA on 21 January 2020, there was an MoU between the competent ministries and agencies. After that. a memo from the Prime Minister Office to CWASA and BPDB dated December 2015 was obtained. This memo states that “to avoid the risk of salinity intrusion in Halda River, at least two turbines should run 24 hours from November to May”.
- There is almost no road in the surrounding area of the Kaptai Lake. Transportation and

logistics of the residents living around the lake are carried out by BIWTA's shipping. Investigation and maintenance dredging for the navigation was implemented, and the detailed project proposal was submitted as of May 2022.

- The dam operation office has an H-V curve of the Kaptai Reservoir, and the figure and data of the curve have been obtained by the JICA Survey Team.

4) Dam projects on upstream tributaries

There are four major tributaries flowing into the Kaptai reservoir: i.e., Kasalong River from upper north, Cholok River from upper south, Changi River from lower north and Rainkhiang River from lower south. There were some dam plans where the Chinese technology (Hydraulic Elevation Dam) was applied. The objective of the plans is to develop drinking and irrigation water. The implementing agency is BWDB. Plans for constructing dams are for three rivers in which two are flowing into the Kaptai reservoir while the other one is located in Patiya, Chattogram. It was approved to build the one in Patiya, Chattogram and the other two are rejected at this moment as of May 2022.

5) Results of interview in site reconnaissance

- There is a gallery for collecting and measuring water leakage inside the dam embankment. The water leakage was planned to be monitored by two small indoor measuring instruments in the center of the downstream surface of the dam, but they are broken and unused at present.
- Currently, there is little water leakage and there is no problem.
- A water level gauge is installed on the right bank of the dam embankment.
- The rain gauge is installed on the left bank of the dam. But the maintenance is in poor condition. Garbage adheres to rainwater collecting bins (PET bottle), residual water remains, and there is a tall leafy tree standing in the vicinity, etc.
- The spillway gate has not been replaced yet since its installation. Only electrical and mechanical equipment was replaced.
- The riverbed protection works downstream of the spillway are being repaired. A temporary cofferdam is under construction downstream of the apron.
- The power outlet is affected by the tide level from the Karnafuli River.

2020/01/20@Kaptai Dam O&M Office
Center left: Mr. Jahangin Alam, Acting Manager
Center right: Mr. Kayesup Bar

2020/01/20@Kaptai Dam Spillway
Rehabilitation of concrete blocks downstream of the apron

2020/01/20@Kaptai Dam Rainfall Gauge

2020/01/20@Kaptai Dam Water Level Gauge

2020/01/20@Kaptai Dam Reservoir (right side)

2020/01/20@Kaptai Dam Reservoir (left side)

2020/01/20 @Kaptaidam P/S Outlet

2020/01/20 @Kaptai Dam Reservoir

Source：JICA Survey Team

Figure 2.3.1 Site Photos of Kaptai Dam

(2) Collection of data on Kaptai Dam

The following relevant reports on the Kaptai Dam were collected.

1) East Pakistan Karnafuli Hydroelectric Power Generation Plan Basic Survey Report, March 1973, Overseas Technical Cooperation Agency (OTCA)
2) Feasibility Study Report for Kaptai Hydropower Station Extension Project, September 1980,
3) Feasibility Survey of Kaptai Hydro-power Station Extension (Units 6 and 7), March 2000, Japan External Trade Organization
4) 2016 Power MP

The JICA Survey Team reviewed the contents of the above reports in terms of the following items:

- Development history,
- Dam basic information (basic specifications),
- Status of water level and rainfall observation upstream of the dam,
- Review of dam operation rules, and
- Checking of the spillout discharge.

(3) Data collection by subcontracting survey works

On 24 and 25 October 2020, the subcontractor IWM visited the Kaptai Dam office and collected the information compiled in Table 2.3.1. It was found that there were errors in some of the provided data. The specifications and errored data were checked and corrected.

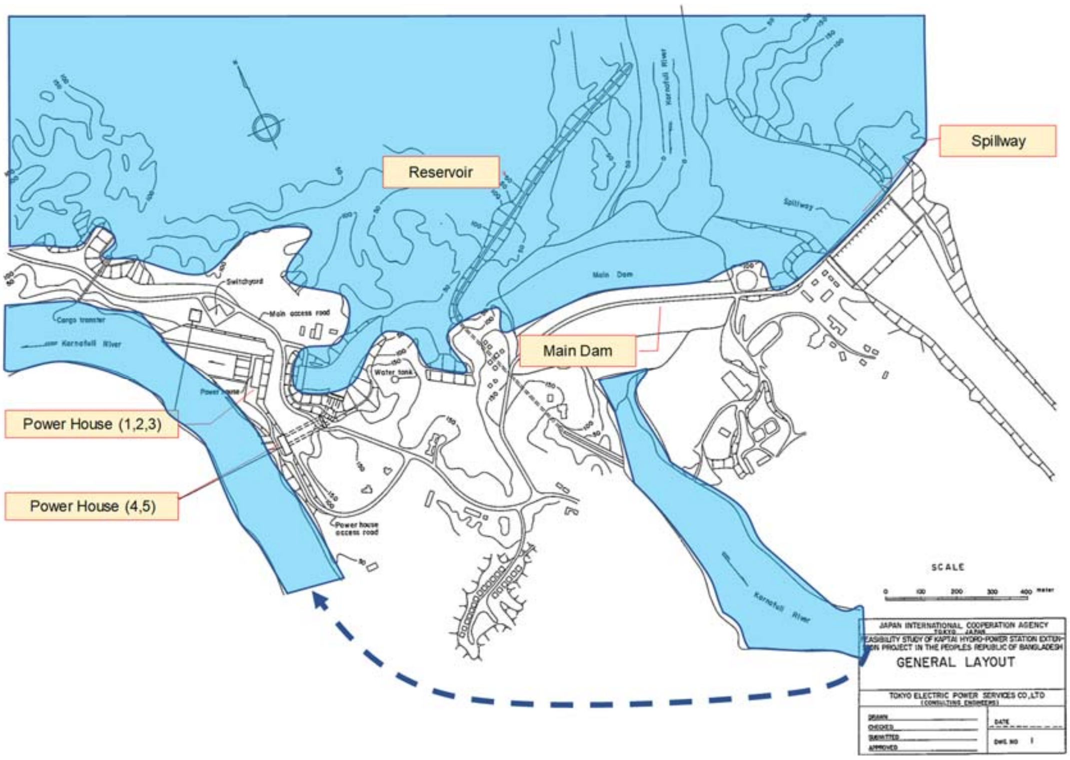
Table 2.3.1 Basic Data Collection for Kaptai Dam

Items	Status of Data Collection
Dam Structure	Basic drawings of dam
Review of Dam Operation Rule	Rule curves (original plan & present)
Hydropower generation	Daily Power Generation (2015-2020)
WL, rainfall monitoring	Collected（ref. to hydrology）
Water Quality	Sampling and analysis under Surface Water Survey by IWM
Reservoir sedimentation	1999 HV curve. 2012 and 2019 cross section (12 sections).
Past data for variation of storage volume and inflow /outflow	Monthly discharge (1968-2019), WL (1968-2019)
Study for available water resources throughout year and by month	ditto
Actual operation of gate facilities of the dam	Daily operation (2012/6/1-2018/12/31)
Status of Earthquake countermeasures	Though detailed information and data could not be collected, related information were obtained through interview with dam manager of Kaptai Dam
Inspection status of maintenance and management	ditto
Downstream warning system of dam release	ditto

Source: JICA Survey Team

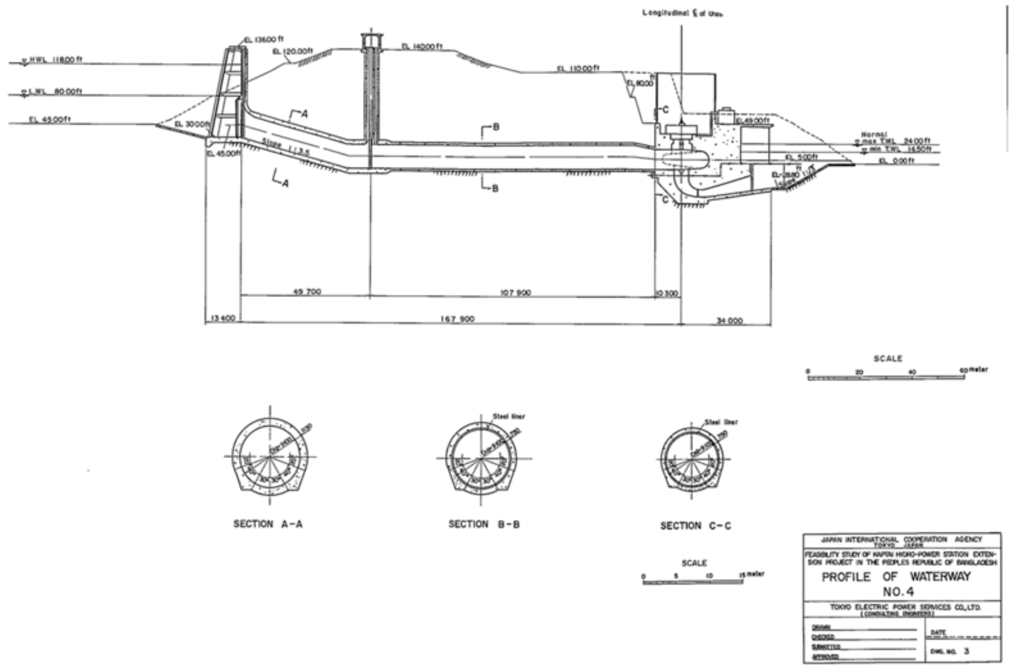
(4) Data and information of Kaptai Dam

1) Drawings of related facilities



Source: 1980JICA F/S

Figure 2.3.2 General Layout of Kaptai Dam Hydropower Station



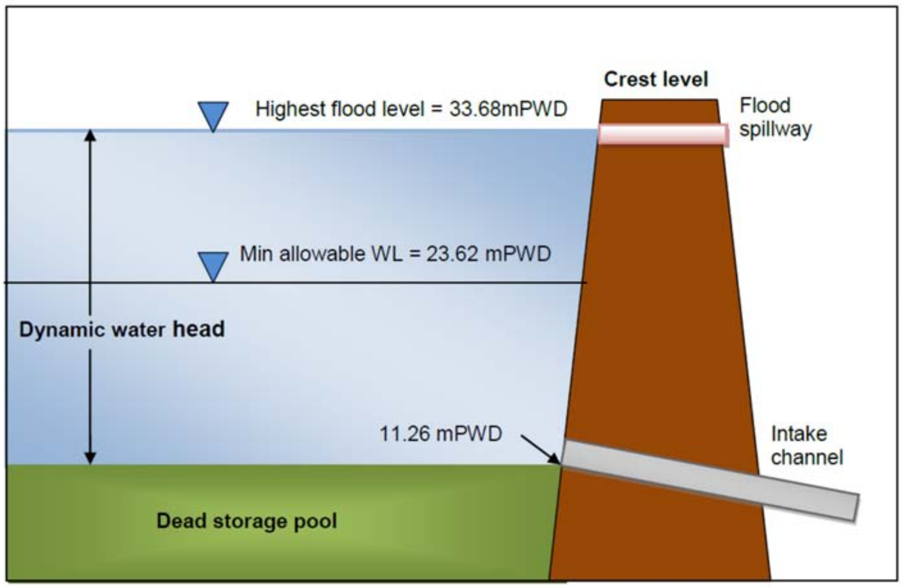
Source: 1980JICA F/S

Figure 2.3.3 General Profile of Waterway of Turbine No.4 of Kaptai Dam Hydropower Station

2) Data of reservoir sedimentation

i) Original plan of sedimentation storage capacity

As shown in Figure 2.3.4, the sedimentation storage capacity of the Kaptai Dam is up to 11.26 m PWD or less. This capacity corresponds to 1,800 x MCM.



Source : 2016 Power MP

Figure 2.3.4 Plan of Kaptai Dam

ii) Review of 1980 F/S

The relation curves between reservoir water level and reservoir area/storage capacities of the Kaptai Reservoir were established in 1968. Then, in 1980, a JICA study reevaluated the reservoir storage capacity by using LANDSAT photographs and power plant operation records.

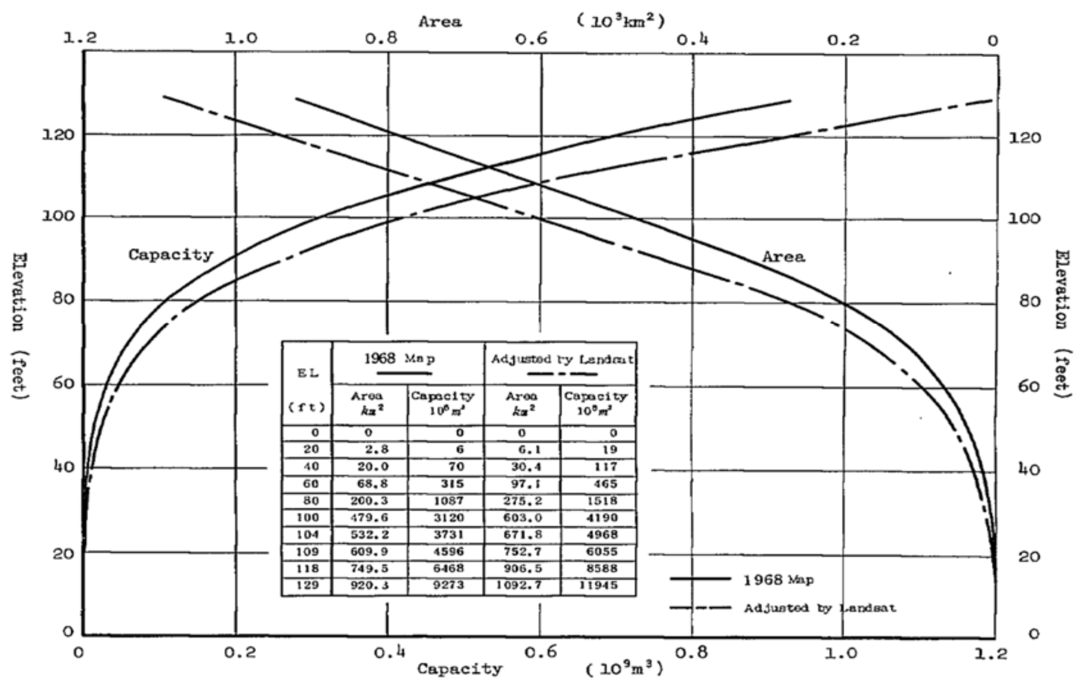
As a result, it was found that the reservoir surface area was slightly larger than the value calculated from the map in 1968. It was also found that the effective storage capacity had hardly changed since 1968. From these results, it was considered that the amount of sedimentation in the reservoir above the minimum water level was very small and did not affect the effective storage capacity of the reservoir.

However, it is needed to clarify the current state of the reservoir sedimentation by bathymetric survey and measuring the thickness of actual sedimentation.

In addition, it is said that the effective reservoir storage capacity can be secured safely in the future for the following reasons.

- The riverbed slope of the Karnafuli River is as gentle as 1/10,000. Since its flow velocity is generally very slow, erosion on the riverbed and banks of the river rarely occurs.
- Most of the upstream river basin of the Karnafuli Dam is gently sloping and covered with jungle, and there are no high mountains near the river. In such conditions, it can be said that the entire basin forms a stable terrain.
- This area is located over a typical monsoon zone, and after a long geological transition, it has formed a local terrain that can withstand harsh weather conditions. Therefore, there will be less sedimentation in the reservoir that will affect the generation of electricity negatively in the future.

Fig. 5.3 Area and Capacity Curve of Kaptai Reservoir



EL (ft)	1968 Map Area km^2	1968 Map Capacity $10^6 m^3$	Adjusted by Landsat Area km^2	Adjusted by Landsat Capacity $10^6 m^3$
0	0	0	0	0
20	2.8	6	6.1	19
40	20.0	70	30.4	117
60	68.8	315	97.1	465
80	200.3	1087	275.2	1518
100	479.6	3120	603.0	4190
104	532.2	3731	671.8	4968
109	609.9	4596	752.7	6055
118	749.5	6468	906.5	8588
129	920.3	9273	1092.7	11945

Source: 1980F/S

Figure 2.3.5 Reservoir Area and Storage Curve

3 Reservoir sedimentation data collected by subcontracting works

The following reservoir bathymetric survey data were collected in the subcontracting work.

- Results of bathymetric survey (12 survey lines) in 2012 and 2019

4) Confirmation of spillway

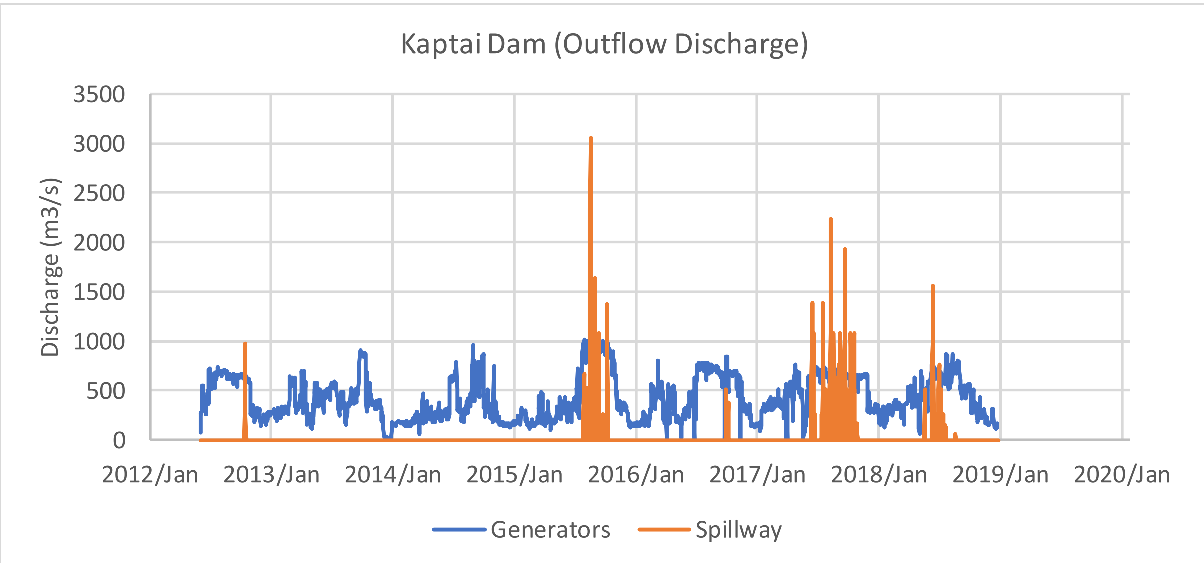
The power generation records from 1988 to 1997 and records of discharge released from spillways were collected as shown in Table 2.3.2. The average annual spillout volume is 1,542 million m^3.

Table 2.3.2 Average Annual Power Generation and Spillout Discharge

Year	Power Generation	Rainfall	Spillout Discharge	Loss of Power Generation due to Spillout
	Mil. kW	mm	MCM	Mil. kW
1988	1,002	2,746	3,743	299
1989	739	3,734	986	73
1990	823	2,265	0	0
1991	936	2,764	2,435	146
1992	583	1,522	0	0
1993	868	3,287	4,060	289
1994	492	1,746	0	0
1995	607	1,927	0	0
1996	678	2,274	0	0
1997	723	2,365	4,197	305
Average	745	2,463	1,542	111

Source: 2016Power MP

The records of hydropower generation discharge and spillway discharge from 2012 to 2018 were also collected as shown in Figure 2.3.6 and Table 2.3.3. The average annual spillout discharge during this period is 939 million m^3.



Source: BPDB KHPP data

Figure 2.3.6 Outflow of Turbine Discharge and Spillout Discharge of Kaptai Dam (2012 – 2018)

It is considered that it would be possible to develop new water resources by improving the dam operation and reducing the said spillout discharge, For example, if 70% of this spillout discharge is distributed constantly during the dry season of 6 months, it is calculated that a flow of about 41 to 68 m^3/s (about 8-14% of the annual dam outflow from the Kaptai Dam of 509 m^3/s) can be generated downstream.

Table 2.3.3 Outflow of Turbine Discharge and Spillout Discharge of Kaptai Dam (2012 – 2018)

Year	Generator (MCM)	Spillway (MCM)
2012	9,168	213
2013	12,378	0
2014	9,574	0
2015	13,981	2,129
2016	13,933	143
2017	15,877	3,259
2018	13,522	832
Average	12633	939

Source: BPDB KHPP data

5) Present measures against earthquake for dam safety

While detailed information and data on earthquake could not be collected, related information were obtained through interview with a dam manager of the Kaptai Dam, as enumerated below:

- There were two inspections carried out in the past after earthquakes. Both the inspections were carried out by BUET. Unfortunately, the reports could not be traced.
- However, it was recalled that the report had concluded stating the healthy state of the dam.
- Monitoring gauges (Piezometers) are out of order for about 30 years and the report recommended to repair the gauges and conduct routine monitoring. But repair has not been done yet as of May 2022.

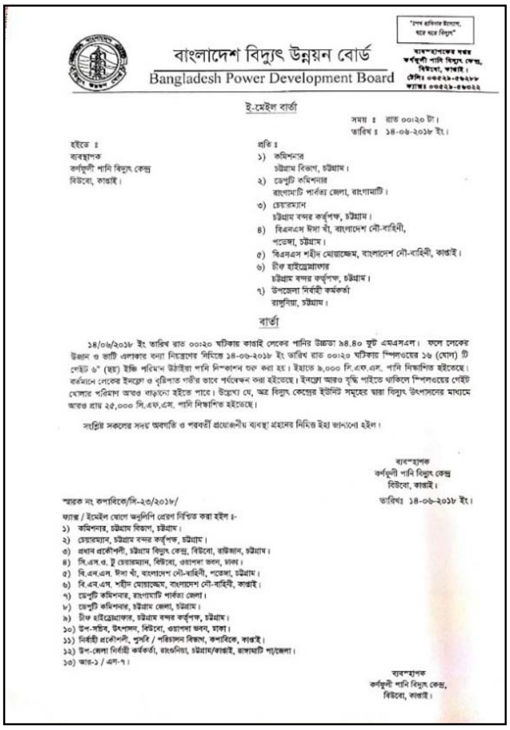
6) Present inspection activities for operation and maintenance of dam structure

As a result of the interview, present monitoring and O & M of the dam structure are limited to cleaning of the drain gutters, mowing, and removing shrubs. The maintenance activities are usually done during the monsoon months only. The maintenance activities are conducted 4 times a year with no fixed interval (twice in monsoon) by an outsourced contractor.

They have also checked for any erosion and sliding through visual inspections. Inspection activities are conducted monthly during monsoon by department people. Since no document of the O&M record in writing could be collected, it is presumed that these storage conditions are not good enough.

7) Dam discharge warning system for downstream area

As a result of the interview, before opening the spillway gates, they serve notice to three upazila administrations, namely: Kaptai, Rangamati Sadar, and Rangunia. They also make announcements like miking. A sample of the notice is presented below:



বাংলাদেশ বিদ্যুৎ উন্নয়ন বোর্ড
Bangladesh Power Development Board

英訳

Bangladesh Water Development Board
Email message

Time: 2:00 AM
Date: 14 June 2018

From

Managing Director
Karnaphuli Hydro Power Plant
BPDB, Kaptai

To

1. Commissioner, Chattogram Division
2. Deputy Commissioner, Rangamati HT District
3. Chairman, Chattogram Port Authority, Chattogram
4. BNS Isha Kha, Bangladesh Navy, Potenga, Chattogram
5. BNS, Shahid Moyzzem, Bangaldesh Navy, Kaptai
6. Chief Hydrographer, Chattogram Port Authority, Chattogram
7. Upazia Nirbahi Officer, Rangunia, Chattogram

Message

Water Level of Kaptai Lake is 94.40 feet (MSL), at 2:00 AM, 14 June 2018. Under such circumstances, to control flood around downstream and upstream area of Kaptai lake, 16 gates of the spillway has been raised 6 inches since 2:00 AM, 14 June 2018 to divert water. For this 9,000 CFS (cubic feet per sec) water is diverting. Currently the water inflow inside the lake and rainfall is under closely monitoring. In case of increasing inflow more, the gate raising may also be increased more. It is to be noted that, through different units of the power plant, for power generation, 25,0000 CFS water is also diverting.

This is for the information and necessary action for all concern.

Signed
Managing Director
Karnaphuli Hydro Power Plant
BPDB, Kaptai
Date: 14 June 2018

Refence No. C-23/2018
Copy:

1. Commissioner, Chattogram Division
2. Chairman, Chattogram Port Authority, Chattogram
3. Chief Engineer, Chattogram Power Plant, Rawzan, Chattogram
4. PSO to Chairman, BPDB, WAPDA Bhaban, Dhaka
5. BNS Isha Kha, Bangladesh Navy, Potenga, Chattogram
6. BNS, Shahid Moyzzem, Bangaldesh Navy, Kaptai
7. Deputy Commissioner, Rangamati HT District
8. Deputy Commissioner, Chattogram District, Chattogram
9. Chief Hydrographer, Chattogram Port Authority, Chattogram
10. Deputy Secretary, Generation, BPDB, WAPDA Bhaban, Dhaka
11. Executive Engineer, Operation, Kaptai Hydro Power Plant, Kaptai

Source: BPDB KHPP data

Figure 2.3.7 Sample of Dam Discharge Warning System to Dam Downstream Area

2.4 Basic Environmental Survey

(1) Natural environment

1) Protected area such as national park and wildlife sanctuary

The survey area has 3 national parks, 6 wildlife sanctuaries, 1 large reserved forest and 1 eco-park. Among these reserves, the national parks, wildlife reserves, and eco-park are designated by the "Wildlife Conservation and Security Act (2012)". In the national park and wildlife sanctuary, agriculture and livestock farming, mining, and industrial operations are prohibited. On the other hand, while the above-mentioned activities are prohibited in the eco-park, the area can be used as a place for education on wildlife such as safari park. The forest reserves are stipulated in the "Bangladesh Forest Act (1927)". In the area, deforestation, agriculture, and industrial operations are prohibited, but such development activities can be carried out in case the government permits.

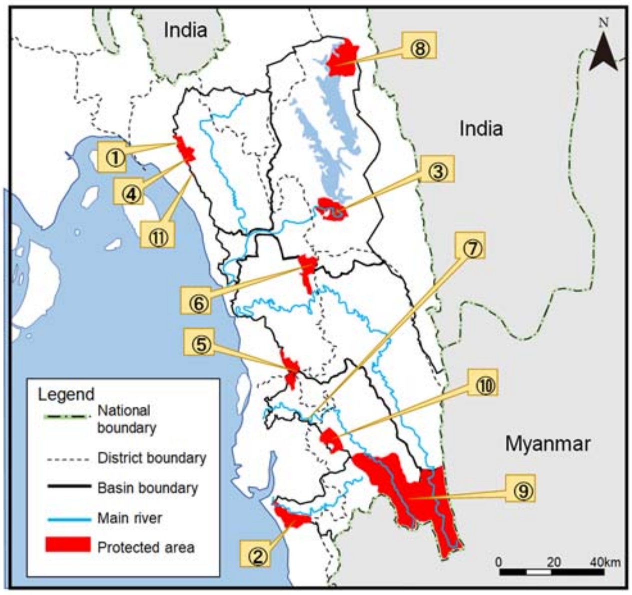
The characteristics of some of these protected areas are as follows.

- The Sangu-Matamuhuri area is the largest protected area in the survey area, that comprises a forest reserve and a wildlife sanctuary, and has been covered with an evergreen forest. Although it has been affected by mankind's impacts in recent years, the area still works as a habitat for animals to be cared, such as Asian elephant, Sambar deer, Asian black bears, leopard, and tiger.
- Chunati Wildlife Sanctuary is located in Chakaria and Banshkhali Upazilas, Cox's Bazar District, and it is the first wildlife reserve established in Bangladesh in 1986. Asian elephants have been observed in the area, since the wildlife sanctuary includes their moving route between Myanmar and Bangladesh.
- Himchari National Park is located approximately 13 km east of Cox's Bazar. The area has mixed tropical broadleaf forests maintained in a good condition and works as a valuable habitat for large animals including small groups of Asian elephants.
- Fashiakhali Wildlife Sanctuary is located in Chakaria Upazila, the northern part of Cox's Bazar District. The area has a diverse natural environment comprising mixed evergreen forests of broadleaf and coniferous trees, shrubs, wetlands, and mountain streams, and several types of animal inhabitants, such as Asian elephants, northern pig-tailed macaque, slow loris, jungle cat, fishing cat, and white-crested laughing thrush. Currently, the forest environment has been deteriorated due to the impacts of the residents who have settled into the area.

Table 2.4.1 List of Protected Areas

No.	Name	Category
1	Baroiyadhala	National Park
2	Himchari	National Park
3	Kaptai	National Park
4	Hajarikhil	Wildlife Sanctuary
5	Chunati	Wildlife Sanctuary
6	Dudpukuria-Dhopachari	Wildlife Sanctuary
7	Fasiakhali	Wildlife Sanctuary
8	Pablakhali	Wildlife Sanctuary
9	Matamuhuri	Reserved Forest
10	Sangu	Wildlife Sanctuary
11	Sitakundu	Eco-park

Source: Department of Forest



Source: Department of Forest

Figure 2.4.1 List of Protected Areas

2) Key biodiversity areas

The International Union for Conservation of Nature (IUCN) defines 25 of the key biodiversity areas, depending on the function as wildlife habitat, in Bangladesh. As shown in Table 2.4.2, 1 of lake and marsh, 3 of coastal plains, and 5 of hilly environments are designated as key biodiversity areas in the survey area.

Table 2.4.2 Key Biodiversity Areas

No.	Watershed	Category	Area (ha)
1	Karnafuli	Lake	65,768
2	Matamuhuri	Coastal plane	1,031
3	Sangu	Coastal plane	1,113
4	Karnafuli	Coastal plane	438
5	Bakkhali	Hilly environment	58,677
6	Matamuhuri	Hilly environment	157,958
7	Sangu	Hilly environment	359,240
8	Karnafuli	Hilly environment	273,754
9	Halda	Hilly environment	170,134

Source: International Union for Conservation of Nature 2002

3) Flora and fauna

The inland vegetation of the survey area is categorized as evergreen forests and deciduous forests in humid tropical region under the Koppen Climate Classification, defined as large amount of rainfall and small temperature difference. The vegetation is classified into (a) tropical humid evergreen forest, (b) tropical humid secondary evergreen forest, (c) tropical humid deciduous forest, (d) secondary forest, (e) shrub forest, and (f) grassland. Wetland environments are distributed along with rivers and coastal areas, where floating plants and natural and afforested mangrove forests are observed.

According to the literature survey, the following valuable species have been recorded in the survey area. Many of the valuable species recorded are mammals, such as Asian elephant, Asiatic black bear, western hoolock, gibbon, Phayre's leaf monkey, Eurasian otter, smooth Indian otter, Sambar deer defined as critically endangered (CR) species, and rufous-tailed hare/fishing cat defined as endangered (EN) species.

Table 2.4.3 Valuable Species Identified by Literature Survey

Classification	Critically Endangered (CR)	Endangered (EN)	Vulnerable (VU)	Near Threatened (NT)	Least Concern (LC)	Data Deficient (DD)
Mammals	7	2	2	3	13	3
Birds	-	-	-	-	16	-
Reptiles	-	-	2	4	15	1
Amphibians	-	-	-	-	7	-

Source: EIA Report for Proposed Gas Transmission Pipeline for Mirsarai Economic Zone and KGDCL Gas Distribution Network Upgradation Project 2018
EIA Report for River Port at Cox's Bazar under Development of Teknaf, Cox's Bazar (Kasturaghat), Chhatak, Faridpur and Nowapara River Ports and Some Other Ferry Ghats and Jetties at Various Locations 2018
IEE,ESIA/ESMP, RAP and Other Studies for Transmission Line from Sonagazi to Mirsarai 2018
Environmental Impact Assessment (EIA) Study on Construction of Production Boreholes to Provide Water Supply to Forcibly Displaced Myanmar Citizen and Communities Hosting them in Ukhia &Teknaf Upazila, Cox's Bazar 2019

(2) Social environment

1) Land use

The existing main land use types are forest, shrub and agricultural land. According to the analysis of satellite image taken in 2020, the forest area occupies about 35% of the survey area. Following the forest area, shrub area is about 31%, and agricultural land occupies about 17% of the survey area. In recent years, the land use in the survey area has changed significantly with industrial development. According to the survey for MIDI development plan, in the relevant areas, the ratio of agricultural land has tended to decrease. On the other hand, the ratio of urban and commercial areas has increased: i.e., urban land is increasing. In Chattogram and Cox's Bazar, rapid growth and urbanization have been observed with port and harbor development and tourism industry development.

2) Industry

The main industries in Bandarban District and Cox's Bazar District are agriculture such as cultivating rice and vegetables etc. In Chattogram District, wholesaling, retailing, manufacturing, and tourism industries are developed. In addition, the tourism industry such as hotels and restaurants is also active, since the district has the longest tourist beach in the world. The survey area is also rich in forest resources and is a source of regional income. Fisheries are also an important source of income, and in the rainy season aquaculture such as shrimp is also operated. In addition to the coastline of Chattogram District mentioned above, the tourism industry has been developed by utilizing the local natural and social tourism resources, such as mountain stream environment in Bandarban area, and the traditional cultural events of indigenous peoples in the Chattogram hill region.

Table 2.4.4 Status of Local Industry

Item	Bandarban	Chattogram	Cox's Bazar
Major industries	Agriculture	Wholesale and retail industries, manufacturing industries, hotels and restaurants	Agriculture
Main crops	Rice, cotton, tobacco, vegetables, etc.	Rice, kimmer leaves, potatoes, corn, turmeric, tea, etc.	Rice, potatoes, onions, garlic, ginger, etc.
Number of farms (2008)	45,423	367,514	148,271
Number of enterprises (2013)	16,149	380,550	95,614
Number of employees (2013)	64,754	1,968,862	260,078

Source: Preparatory Survey for Development of the Southern Chattogram Region in Bangladesh 2022

3) Income

According to the Annual Household Expenditure Survey (HIES; 2016) in Bangladesh, the national income per capita has increased due to economic growth. The average monthly income per household in current price was about BDT 16,000 at the national level in 2016.

According to the report of the household income and expenditure survey in 2010, the number of poor households was approximately 30% of the total households.

Table 2.4.5 shows the income levels and poverty rates in the surveyed area. Among the districts, the income level in Chattogram District is highest, followed by Cox's Bazar District and Bandarban District. At a part of Bandarban District, high poverty rates are observed.

Table 2.4.5 Income Level and Poverty Rate

Item/Prefecture	Bandarban	Chattogram	Cox's Bazar
Revenue Level (Monthly Revenue)	BDT 14,000 or more	BDT 26,000～ BDT 39,000	BDT 12,000～ BDT 28,000
Poverty Rate (%), Percentage of Poor Households	37.3 - 70.8	23.4 - 30.5	23.4 - 30.5

Source: Bandarban Paurashava Master Plan (2017-2037), June 2019, (LGED)
Chittagong Strategic Urban Transport Master Plan, November 2018 (WB)
Cox's Bazar Urban Vulnerability Assessment, July 2020 (WFP)
Bangladesh Poverty Assessment,2019 (World Bank)

4) Indigenous people

According to the census by the Government of Bangladesh in 2010, the population of indigenous and ethnic people in the country was approximately 1,586,000, that was equivalent to 1.8% of the total population of the country at that time. Approximately 80% of these indigenous people live in the northern and south-eastern flat land of the country, and others live in the Chattogram Hill Tracts (CHT). In the survey area, the following indigenous people were identified. These indigenous peoples are collectively called as Jumma, those who engage in sifting cultivation, and are mainly distributed in Bandarban District.

Table 2.4.6 Distribution of Indigenous People

District	Year	Indigenous People					
		Marma	Muro	Tripler	Chakum	Racaine	Tonchon Ga
Bandarban	201	77,47	38,02	20,68	-	-	-
	202	87,57	42,97	23,38	-	-	-
Khagrachhari	201	44,88	-	16,02	39,14	-	-
	202	50,72	-	50,89	44,24	-	-
Rangamati	201	51,23	-	-	260,44	-	27,052
	202	57,91	-	-	294,37	-	30,576
Chattogram	201	5,27	-	11,22	6,853	-	-
	202	5,96	-	12,68	7,746	-	-
Cox's Bazar	201	-	-	-	439	5,660	2,257
	202	-	-	-	496	6,397	2,551

Source: Bangladesh Population and Housing Census 2011

5) Cultural heritage

In the survey area, 13 of the archaeological and cultural heritage sites are distributed. The main archaeological and cultural heritages are shown in Table 2.4.7

Table 2.4.7 Archaeological and Cultural Heritages

Name	Position	Features
Anderkilla Shahi Jame	Chattogram City in Chattogram District, along J M Sen Street	A fort with a mosque built during the earliest Mughal Empire.
Chattogram Circuit House	Chattogram City in Chattogram District, along 20 Chatteshwari Street	A building built by the British Empire in 1913
The War Cemetery	Chattogram City in Chattogram District, along19 Badshah Miah Chowdhury Street	Tombs of 731 soldiers

Source: JICA Survey Team

(3) Laws and Regulations on EIA

1) National Environment Policy 1992

With a major theme of ensuring the protection and improvement of the environment, the National Environment Policy has introduced a number of environment principles like precautionary approach and environmental impact assessment (EIA). The policy necessitated firmly to review the EIA on the industries of the public and private sectors. The objectives of the policy include: maintain ecological balance and overall development through protection and improvement of the environment; protect the country against natural disasters; identify and regulate activities which pollute and degrade the environment; ensure environmentally sound development in all sectors; ensure sustainable, long term and environmentally sound use of all national resources; and actively remain associated with all international environmental initiatives to the maximum possible extent.

2) The National Environment Management Action Plan (NEMAP) of 1995

NEMAP was formulated to provide action plans to respond to environmental issues and promote sustainable development as recommended by the National Conservation Strategy (NCS).

3) The Environment Conservation Act (ECA) of 1995

This act has gone through several amendments in 2000, 2002 and 2010. It defines a variety of enforcement objectives governing industry and other projects in Bangladesh. It has established the Department of the Environment (DoE) headed by a Director General (DG), that is responsible for environmental conservation activities in the country. Article 12 of this act stipulates, “No industrial unit or project shall be established or undertaken without obtaining, in the manner prescribed by rules, an Environmental Clearance Certificate from the Director General.”

4) Environmental Conservation Rules (ECR) of 1997

The ECR (amended in 2002) supports the ECA by laying down a set of rules for preparation of an EIA for development projects in Bangladesh. The ECR provides a basic framework for environmental evaluation of proposed projects in all sectors and establishes procedures. According to the ECR, the developer should first obtain a Location Clearance and conduct the appropriate study to obtain the

Environmental Clearance of the project. Any project constructed in Bangladesh must obtain an Environmental Clearance before it begins its construction.

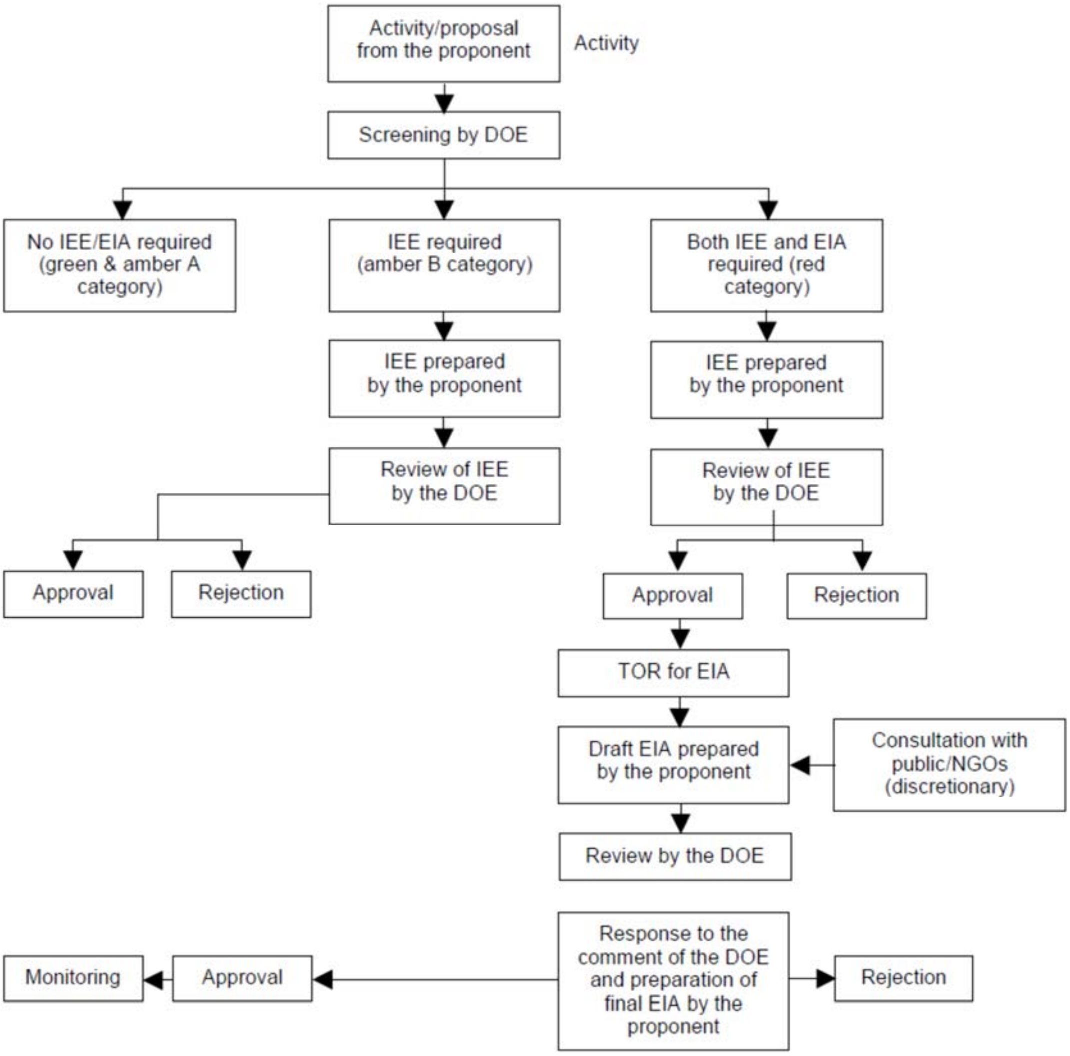
Rule 7 of the ECR classifies the projects into four categories based on their site conditions and the impacts on the environment: i.e., (a) Green, (b) Orange A, (c) Orange B, and (d) Red. Various industries and projects falling under each category have been listed in Schedule 1 of the ECR. According to the ECR, Environmental Clearance Certificate (ECC) is issued to all existing and proposed industrial units and projects falling in the Green category without undergoing EIA. However, for categories Orange A, Orange B and Red projects, location clearance certificate is required, followed by the issuance of the Environmental Clearance upon the satisfactory submission of the required documents.

5) Other Laws and Policies

Other laws and policies that address issues of environment and development in Bangladesh include: Water Pollution Control Ordinance (1973), Environment Pollution Control Ordinance (1977), Forest Policy (1994), Fisheries Policy (1998), Water Policy (1998), and New Agriculture Extension Policy (1995), among others.

6) EIA Implementation Procedures

The EIA implementation procedure based on the "Guide to Environmental Clearance Procedure" enforced by the GOB in 2010 is shown below.

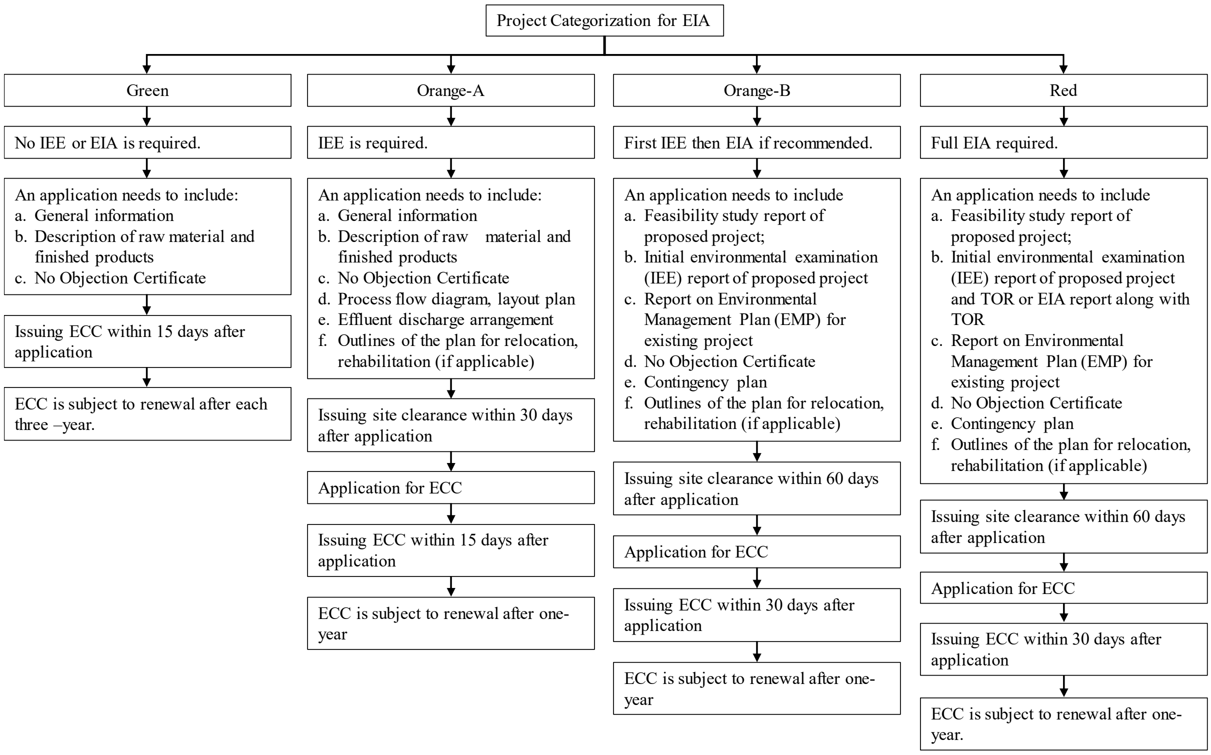


Source: ECR (1997)

Figure 2.4.2 Implementation Procedures of EIA

7) ECC Obtaining Procedure

Figure 2.4.4 summarizes the process and/or steps required in obtaining the ECC for each category as described in the Guide to Environmental Clearance Procedure, issued by the Department of Environment in 2010.



Source: ECR (1997)

Figure 2.4.3 ECC Obtaining Procedures

8) Legislation on Land Acquisition and Involuntary Resettlement in Bangladesh

a) Background

The past land-related laws and regulations of Bangladesh including the Acquisition and Requisition of Immovable Property Ordinance II (1982) were not adequate to address the needs of those affected and displaced persons, especially for resettlement and income restoration. Additionally, there were gaps between the national legislation and the international standards for involuntary resettlement, which caused double "standards" regarding the compensation for the displaced and project-affected persons for nationally-funded projects and donor-funded projects.

Between 2006 and 2008, to address these issues, the National Policy on Involuntary Resettlement and Rehabilitation (NPIRR) was drafted with ADB's technical assistance, to aim (1) to safeguard the rights of the affected and/or displaced households/persons; (2) to ensure that appropriate mitigation measures and resettlement plans are implemented; (3) to ensure that appropriate assistance is provided to affected households and communities to restore and improve their socio-economic conditions; and (4) to establish community social systems and networks during post-resettlement in addition to cash compensation to the land owners. However, the NPIRR was not approved by the Government, and the Acquisition and Requisition of Immovable Property Act, 2017 was passed instead.

b) Acquisition and Requisition of Immovable Property Act, 2017

Table 2.4.8 describes the procedure on land acquisition in the "Acquisition and Requisition of Immovable Property Act (ARIPA)" enacted in July 2017.

The act discusses both (1) permanent acquisition of immovable properties under Chapter 2 and (2) requisition of immovable property (temporary acquisition or the possession of immovable property for a specific time period) under Part 3. The act has improvements including increased land compensation rate such as adding the premium of 200% of the market rate for a public purpose and the premium of 300% of the market rate for a non-government purpose.

Table 2.4.8 Major Steps for Land Acquisition as per ARIPA 2017

Section No. in the Act	Procedure	Section No. in the Act	Appeal/Objection Procedure
Section 4 (3)(a)	**Recording & report preparation:** Record the real nature, condition and infrastructures built, crops and trees of the proposed immovable properties in video, still picture or any other technology and prepare a report accordingly	-	-
Section 4	**Preliminary notice** of property acquisition by the Deputy Commissioner (DC)	-	-
Section 4 (3)(b)	**Joint verification survey** by DC with concerned parties	-	-
Section 4 (7)	DC shall not record the change of the nature of land in the joint list, if the nature of the land is changed by building houses or infrastructures in bad motive after the initiation of proceeding under Section 4 (3) (a).	-	-
Section 4 (3) (b), (6)	**Preparation and disclosure of results of the joint verification**	Section 4 (8), (9), (10)	Within **7 working days**, **appeal to the Commissioner** for the decision by the DC under Section 4 (7). The Commissioner shall **hear the appeal and provide the final decision within 15 days or 10 days** for a nationally important project.
Section 5 (3)	If no objection within 15 working days, the DC shall make **a decision within 10 days, 30 days** with the Divisional Commissioner permits, or **15 days** for a nationally important project.	Section 5 (1), (2), (3) (a) (b)	File an objection against the acquisition proceeding to the DC within **15 working days**. DC shall hear the objection, prepare a report within **30 working days or 15 working days** for a nationally important project, and submit the records of the proceedings for the decision of the Ministry of Land if it exceeds **50 standard bighas (or 16.5 acre)** of land or submit it for the decision of the Commissioner if it does not exceed 50 standard bighas.
Section 6	Final decision of land acquisition within **60 days** after the submission of	-	-

Section No. in the Act	Procedure	Section No. in the Act	Appeal/Objection Procedure
	DC's report and within **15 days** of the Commissioner's report submission or **30 days** in case of recording the report of delay.		
Section 7 (1)	**Notice of land acquisition and its disclosure** at convenient places or near such property by the DC.	-	-
Section 7 (2)	**Interested persons appear personally or by agent** before the DC **15 days** after the notice or **7 days** for a nationally important project.	-	-
Section 8 (1), (3)	**Award of compensation by the DC** DC's notice of his award to be given to the person interested within **7 days** from the date of making the award of compensation.	Section 30	**If the award is not accepted, make an application** to the Arbitrator for revision of the award **45 days** from the date of service of the notice of the award.
-	-	Section 31	Have a **hearing of the application** within 90 days and give the order.
-	-	Section 34	**Award determined by the Arbitrator (not exceeding the DC's award by more than 10%)**. If it is more than 10% increase, it is subject to the decision of an Appellate Arbitration Tribunal.
-	-	Section 36	**Appeal against the award of Arbitrator and decision by the Arbitration Appellate Tribunal:** An appeal shall lie to the Arbitration Appellate Tribunal. If the amount determined by an Arbitration Appellate Tribunal is higher than the amount specified in the award of the Arbitrator, the additional compensation shall not exceed the amount specified in the award of the Arbitrator by more than 10%.
Section 8 (5)	**The estimated amount of the award** of compensation shall be prepared within **30 days** after the publication of notice under Section 7.	-	-
Section 8 (4)	**Payment shall be paid (deposited)** to the DC by the requiring persons or organization within **120 working days** after receiving the estimation sent by the DC.	-	-
Section 11	**Payment of compensation** by DC to those eligible for compensation within **60 days** from the date of deposit by the requiring persons after the submission of the estimated amount to the requiring persons but before taking possession of the property.	-	-
Section 13(1), (2)	**Land and property acquisition** by DC after the compensation is paid. A declaration by the DC shall be published in the official gazette.	-	-

Source: ARIPA 2017

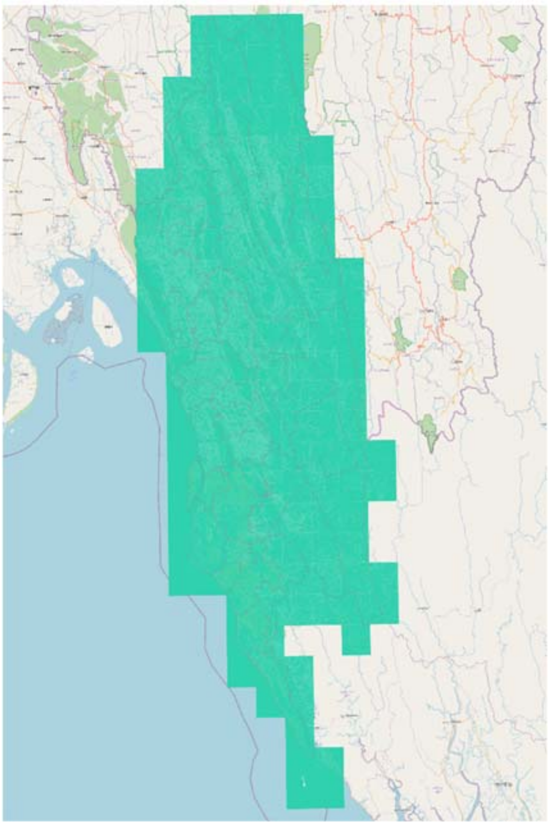
CHAPTER 3 COMPONENT 2 : THROUGH ANALYSIS OF SURVEY RESULTS, WATER RESOURCES ANALYSIS AND WATER DEMAND FORECAST

3.1 Data Analysis and Model Construction

3.1.1 Analysis through Topographic Maps, Aero Photographs and Satellite Images

The Survey on Bangladesh (SOB) has prepared a land use map produced from SPOT satellite images (resolution 2.5m) in 2011, which is newer than the aerial photgraphs taken 15 years ago, and the land cover and vegetation are well classsified, as referred to in Figure 3.1.1.

The land use map of the Moheshkhali/Matarbari region is shown in Figure 3.1.2. Mangrove areas are formed on the east side of the region, bamboo forests and sparsely planted areas are formed on the west side, and saltwater areas, settlements, and agricultural areas are formed in the central part. An aerial photograph around the Moheshkhali/Matarbari region is shown in Figure 3.1.3.

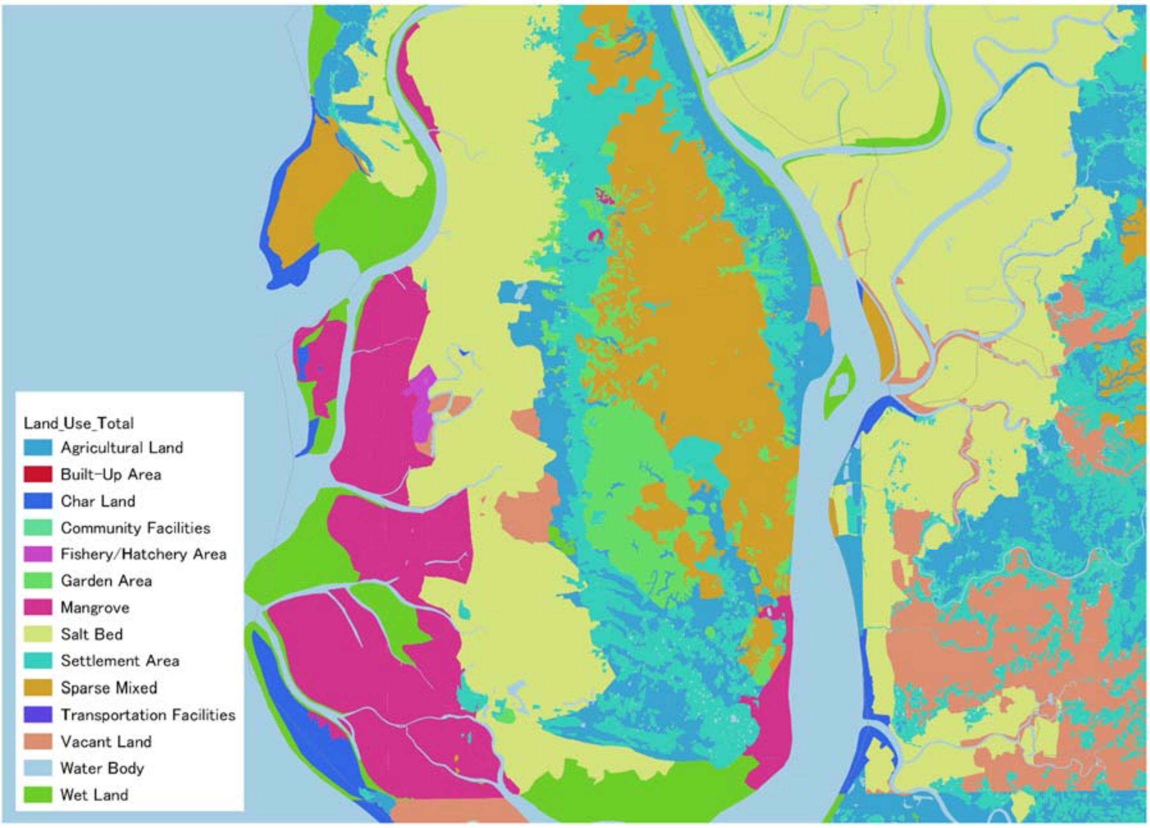


Agricultural Land	Settlement Area
Cultivation Land	Building / House
Built-Up Area	Building/House
Built-Up Area	Cultivation Land
Char Land	Mainly Bamboo
Char	Sparse Mixed
Island	Uncultivation Land
Sand	Vegetation
Community Facilities	Vegetation Land
Playground	Sparse Mixed
Power Transmission Plant	Mainly Bamboo
Stadium	Sparse Mixed
Fishery/Hatchery Area	Transportation Facilities
Fishery	Railway Station
Hatchery	River Port
Garden Area	Runway
Betel Garden	Uncultivation Land
Lichi Orchard	Vacant Land
Mango Orchard	Uncultivation Land
Orchard	Vegetation Land
Rubber Garden	Water Body
Tea Garden	Bay of Bengal
Mangrove	Beel
Mangrove	Haor
Sparse Mixed	Lake
Salt Bed	Non Tidal River
Salt Bed	Pond
Wet Land	River Nontidal
Marsh	River Tidal
Mud Cultivated	
Mud Uncultivated	
Swamp	

Note: Collected information highlighted by green color

Source: JICA Survey Team

Figure 3.1.1 Land Use Classification



Source：JICA Survey Team

Figure 3.1.2 Land Use of Moheshkhali/Matarbari Region

Source: JICA Survey Team

Figure 3.1.3 Aerial Photograph Map of Moheshkhali/Matarbari Region

3.1.2 Verification and Analysis of Hydrologic Observation Data

The observation data of water level and discharge are the most important resource data for analyzing the amount of available water resources and calculating the capacity of water development structures. Whereat, the accuracy of the water level and discharge observed by the JICA Survey Team and the BWDB was verified as explained below.

(1) Verification of accuracy of observation data (observed by JICA Survey Team in 2020)

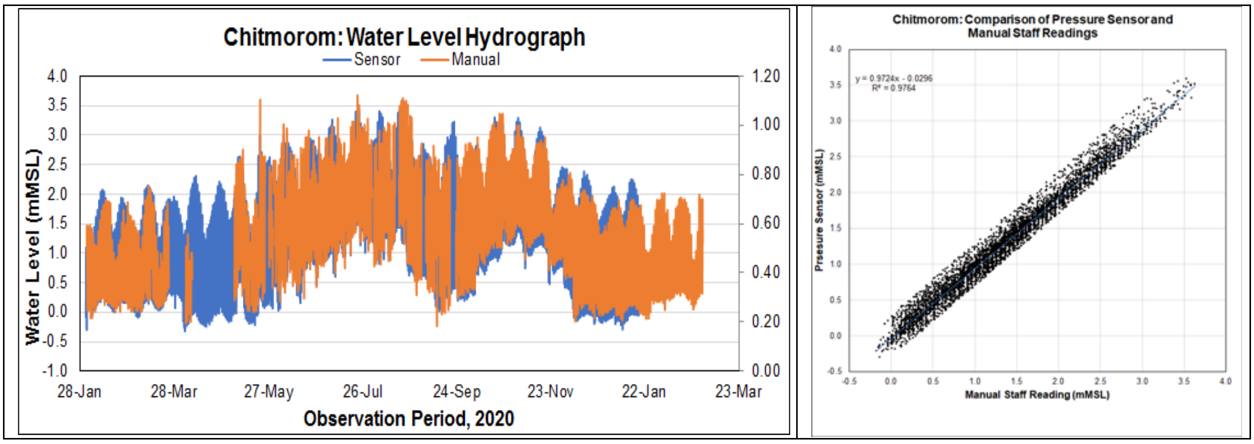
1) Verification of water level data (observed by JICA Survey Team in 2020)

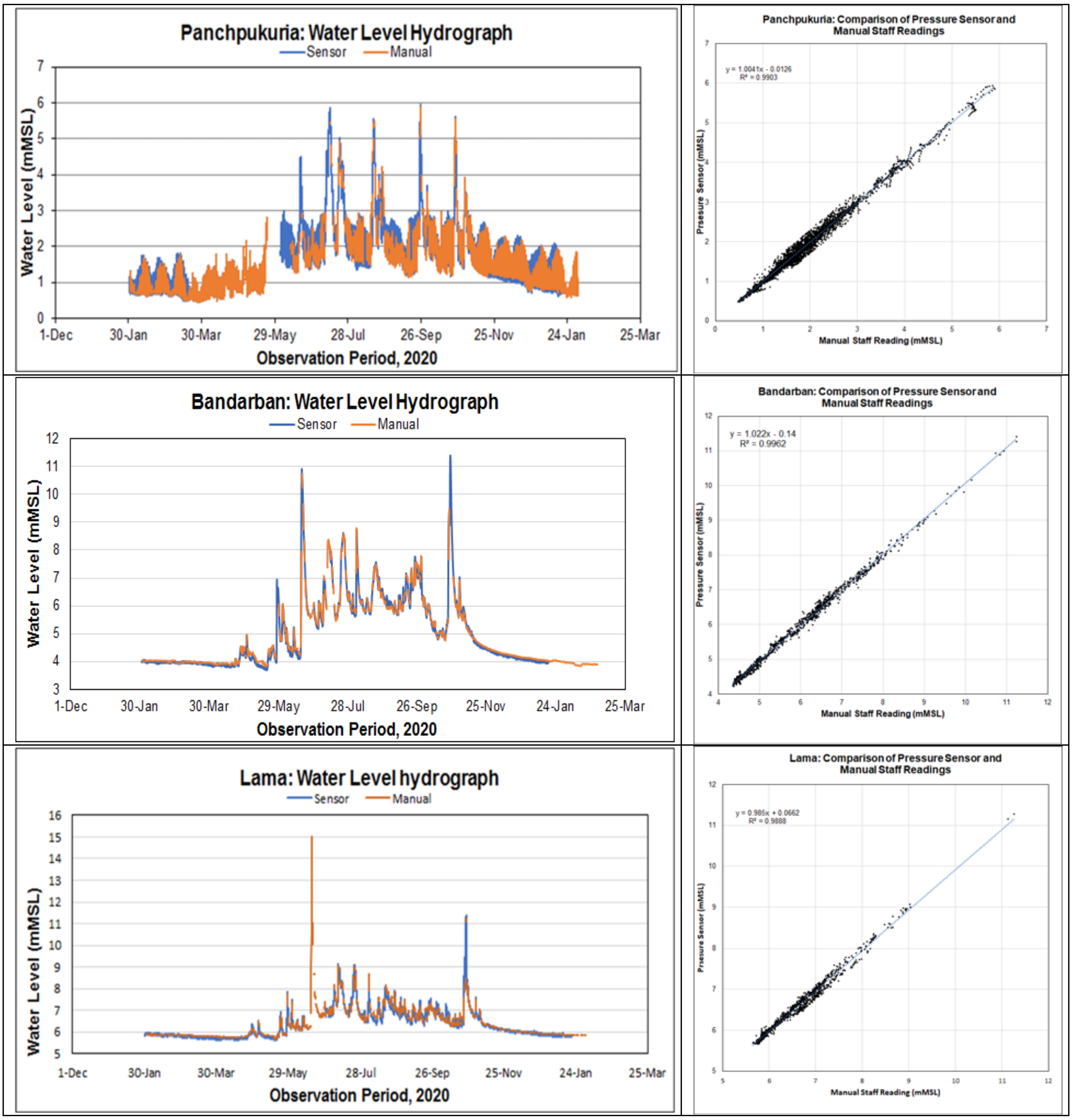
The accuracy of the water level data observed in 2020 by the JICA Survey Team was verified by comparing the visual observation values and the water level sensor recorded values at the WLG stations installed by the JICA Survey Team, and confirming the matching of both values through visual observation and sensor recording. Graphs comparing both values in time series, correlation diagrams, and “coefficients of determination: R^2 ” in the correlation diagrams are shown in Table 3.1.1and Figure 3.1.4. Since the coefficients of determination are very high, it is judged that both the data through visual observation and sensor recording are highly reliable.

Table 3.1.1 “Coefficient of Determination” between Visual Observation and Sensor Recording (Observed by JICA Survey Team)

WLG Station	River	Coefficient of Determination, R^2
Chitmorom	Karnafuli	0.976
Panchpukuria	Halda	0.990
Bandarban	Sangu	0.996
Lama	Matamuhuri	0.989

Source: JICA Survey Team





Source: JICA Survey Team

Figure 3.1.4 Verification of Observed Water Levels (Observed by JICA Survey Team)

2) Verification of discharge data (observed by JICA Survey Team in 2020)

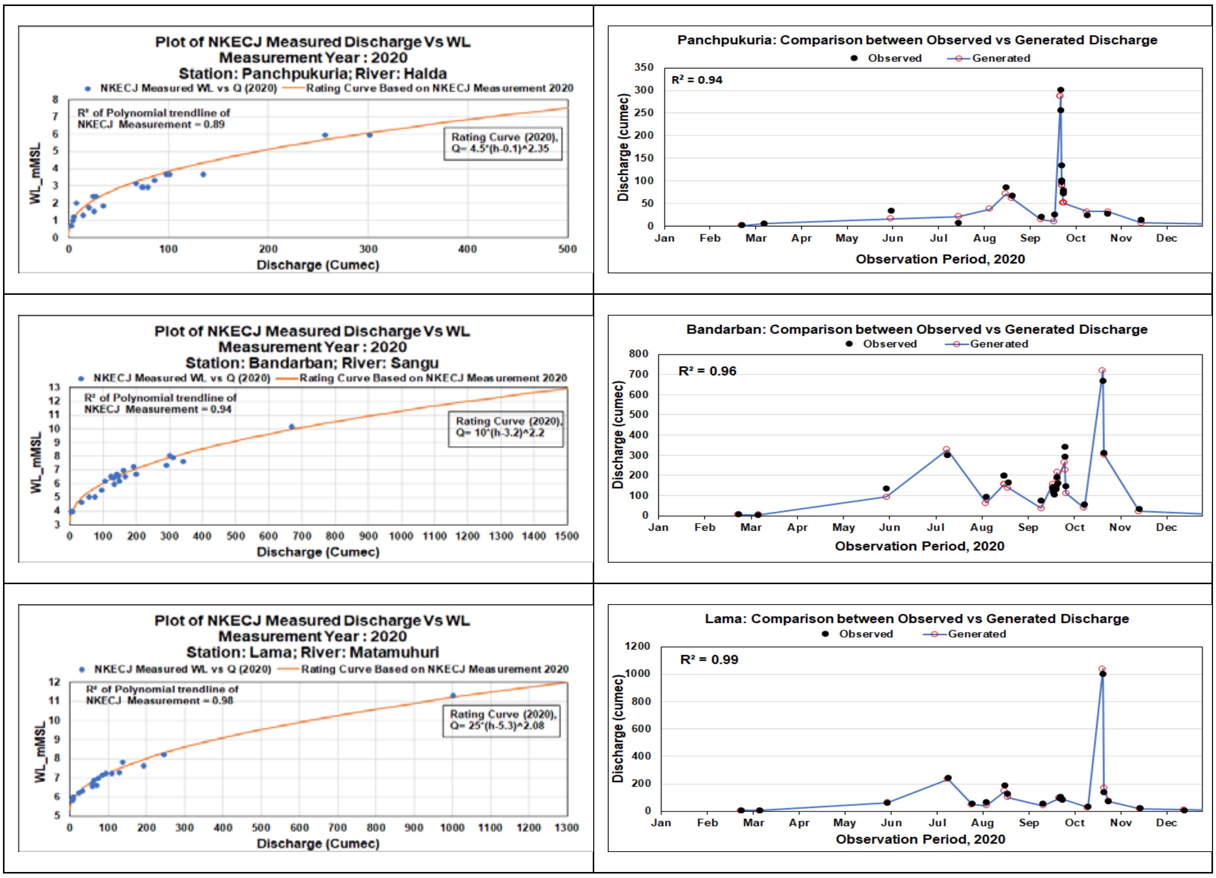
The discharge rating curves ("H-Q curve") were generated by using the water level and discharge data observed in 2020 by the JICA Survey Team in this survey, as shown in Figure 3.1.5. Since the Chitmorom Station is located in the tidal section of the Karnafuli River and is affected by the tidal movement, it was excluded in this verification and the data at the other three stations were verified.

Each graph on the right side in Figure 3.1.5 shows a comparison of the observed discharge and the converted one from the water level based on the H-Q curve, and it can be confirmed that each H-Q curve is highly reproducible. The coefficients of determination (R^2) between the generated and observed values are shown in Table 3.1.2, which are as high as 0.89 or higher. Generally, if the R^2 value is 0.5 or more, it is judged that there is a high correlation. Therefore, it is judged that the accuracy of the water level and discharge observation in this survey could be sufficiently secured. It is considered that the observed discharges by BWDB and the JICA Survey Team highly fit in with each other, since BWDB has religiously carried out the discharge observation work based on the standard process through river cross section survey by levelling, river flow velocity measurement by using a current meter, and discharge calculation by multiplying the river flow area by the flow velocity.

Table 3.1.2 R^2 Values between Observed and Generated Discharge (Observed by JICA Survey Team)

WLG Station	River	Coefficient of Determination (R^2)
Panchpukuria	Halda	0.890
Bandarban	Sangu	0.940
Lama	Matamuhuri	0.980

Source: JICA Survey Team



Source: JICA Survey Team

Figure 3.1.5 Verification of Observed Discharge (Observed by JICA Survey Team)

(2) Verification of accuracy of observation data (observed by BWDB in 2020)

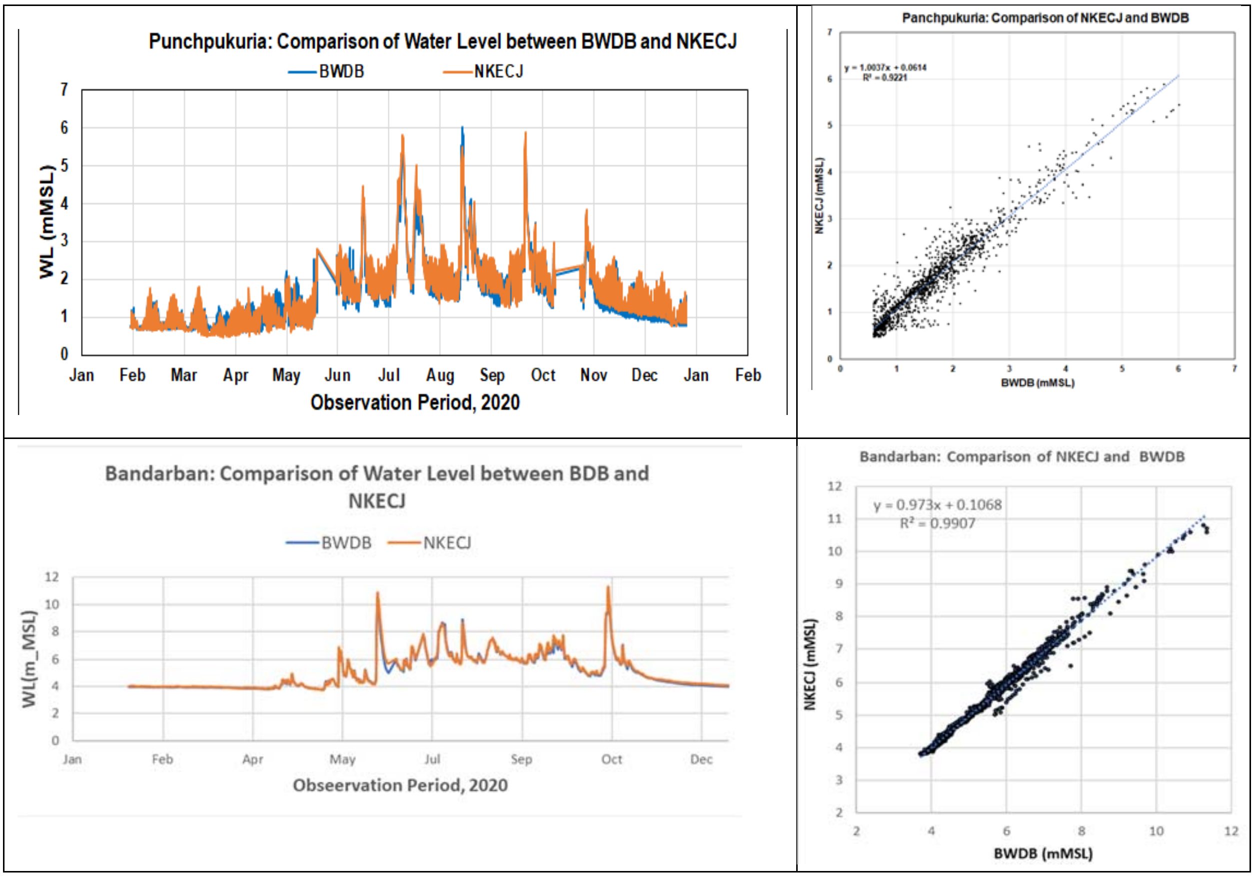
1) Verification of water level data (observed by BWDB in 2020)

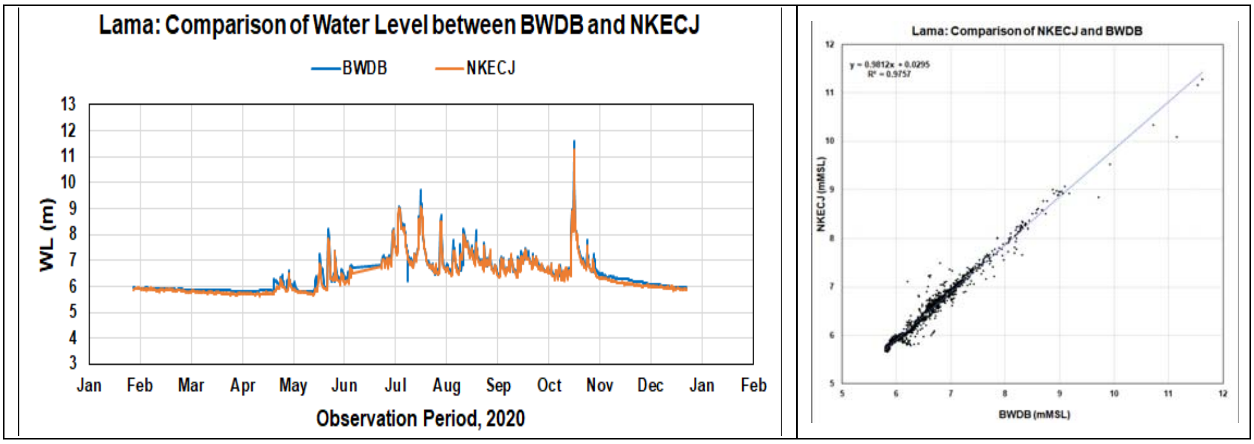
The accuracy of the observed water levels in 2020 by the BWDB was verified by comparing the observed water levels by the BWDB and the JICA Survey Team and confirming the matching between both observed water levels. A graph comparing both the levels in time series, correlation diagrams, and coefficients of determination (R^2) in the correlation diagrams are shown in Table 3.1.3 and Figure 3.1.6. Since the R^2 are very high, it was judged that the observed water levels by the BWDB are highly reliable.

Table 3.1.3 R^2 Values between Observed Water Levels by BWDB and JICA Survey Team

WLG Station	River	Coefficient of Determination (R^2)
Panchpukuria	Halda	0.922
Bandarban	Sangu	0.991
Lama	Matamuhuri	0.976

Source: JICA Survey Team





Source: JICA Survey Team

Figure 3.1.6 Verification of Observed Water Level (Observed by BWDB)

2) Verification of discharge data (observed by BWDB in 2020)

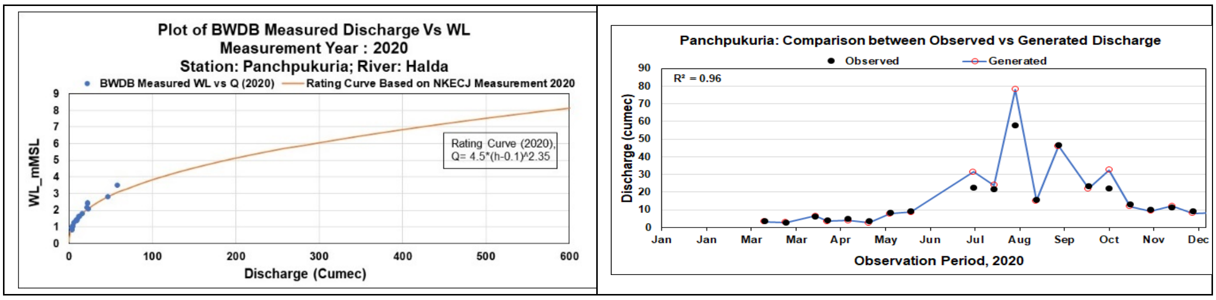
The accuracy of the observed discharge values in 2020 by the BWDB was verified by comparing the observed discharge data by the BWDB and those generated with the H-Q curves of the JICA Survey Team. Since the discharge observation at the Chitmorom Station had not been conducted, the verification at this station was excluded and the discharge data at the other three stations were verified.

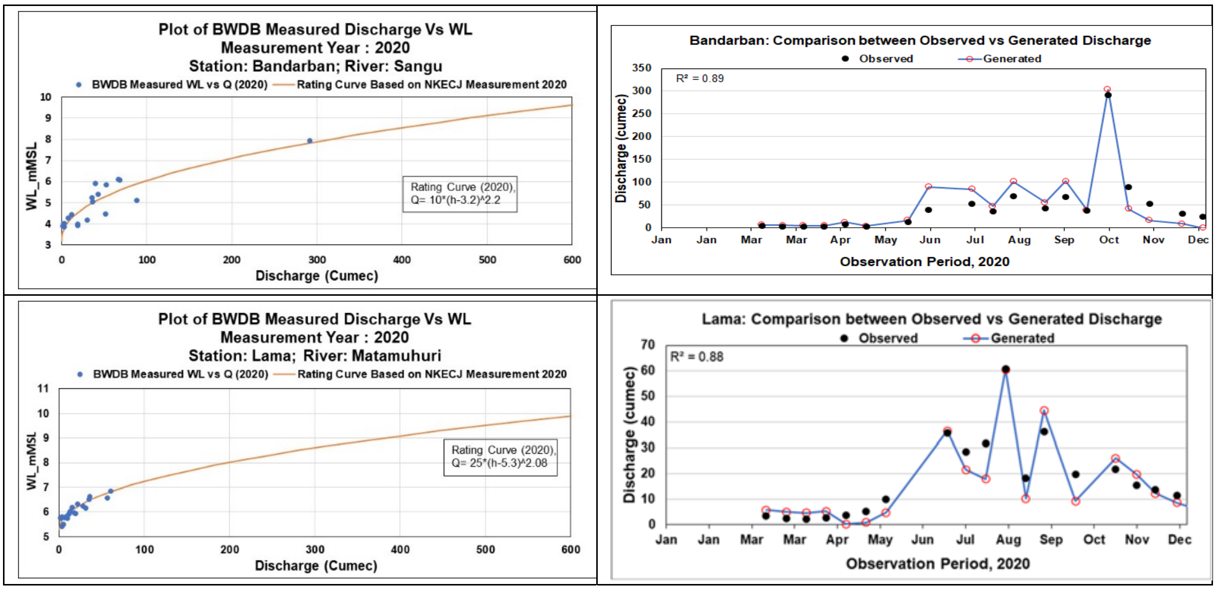
The following graphs on the right side in Figure 3.1.7 show a comparison of the observed discharges by the BWDB and the converted ones from the water levels based on the H-Q curves, and it can be confirmed that the discharge values from the H-Q curves are highly matching with the BWDB observed ones. The R^2 between the generated and observed values are shown in Table 3.1.4, which are as high as 0.88 or higher. Generally, if the R^2 value is 0.5 or more, it is judged that there is a high correlation. Therefore, it was judged that the accuracy of the water level and discharge observation in 2020 by the BWDB could be sufficiently secured.

Table 3.1.4 R^2 Values between Generated and Observed Discharge (Observed by BWDB)

WLG Station	River	Coefficient of Determination (R^2)
Panchpukuria	Halda	0.960
Bandarban	Sangu	0.890
Lama	Matamuhuri	0.880

Source: JICA Survey Team



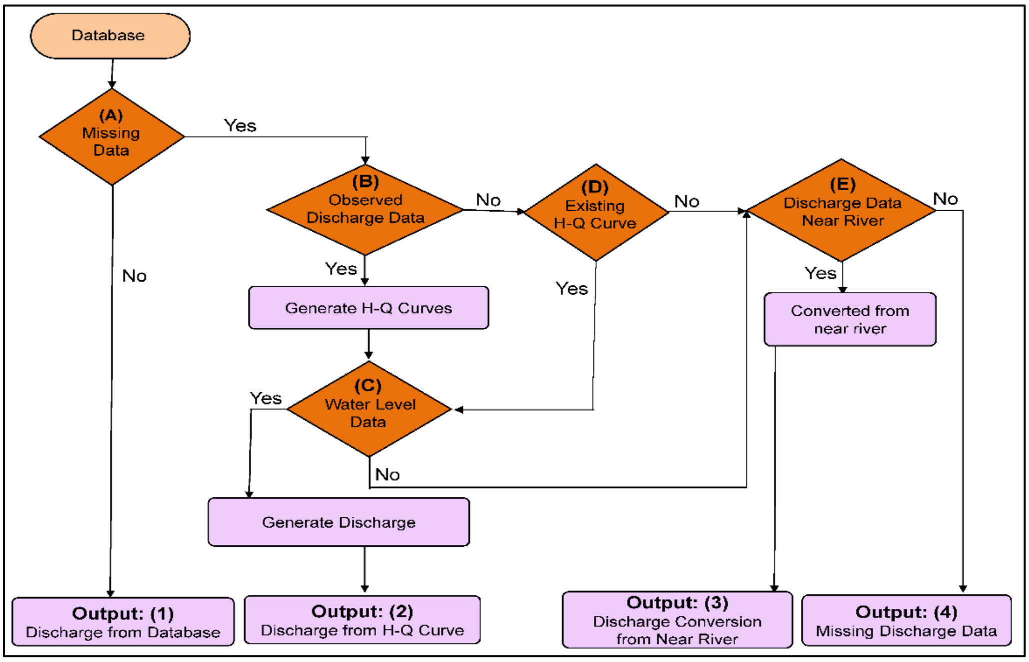


Source: JICA Survey Team

Figure 3.1.7 Verification of Observed Discharge (Observed by BWDB)

(3) Verification of past observed discharge data (observed by BWDB from 1966 to 2019)

The reliability of the observed discharge data was verified by collecting the past discharge data observed by the BWDB. At the three stations (Panchpukuria, Bandarban and Lama), the observation of water level and discharge has been conducted since 1965, but there are many data that are missing in the first year. The available period after 1966 was set as the target period for the verification. Time-series data of water level and generated discharge, observed discharge data, and H-Q curves were collected, and all time-series discharge data of the target period was generated according to the flow chart shown in Figure 3.1.8.



Source: JICA Survey Team

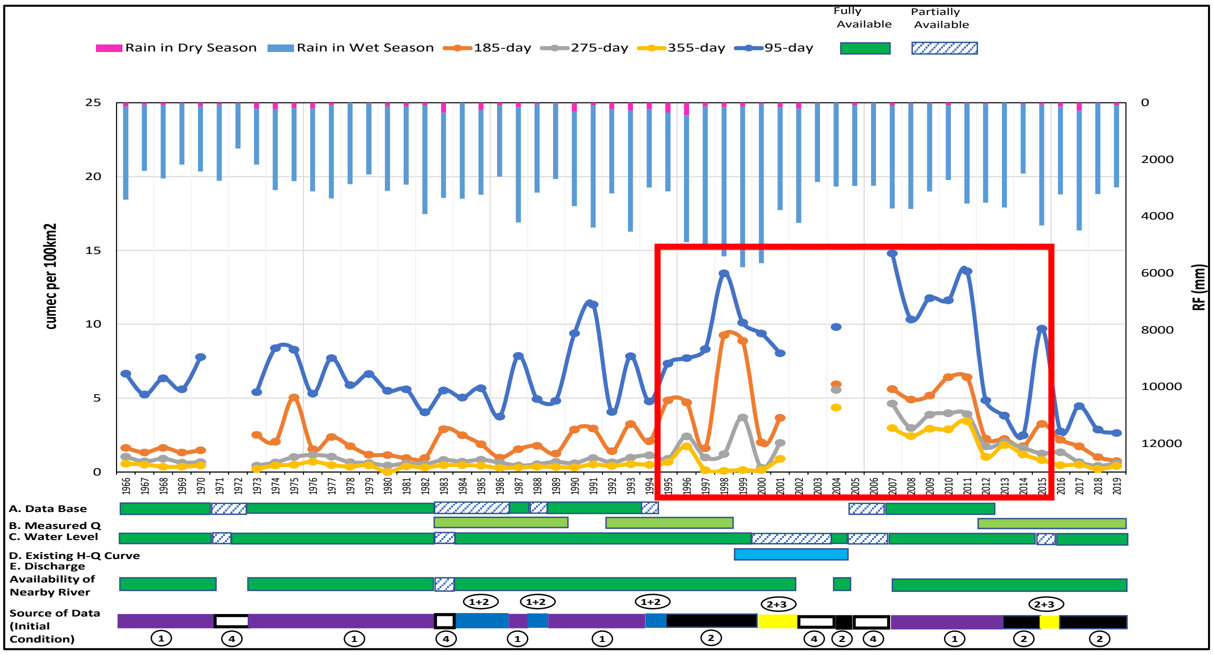
Figure 3.1.8 Flow Chart for Generating Time-series Discharge Data

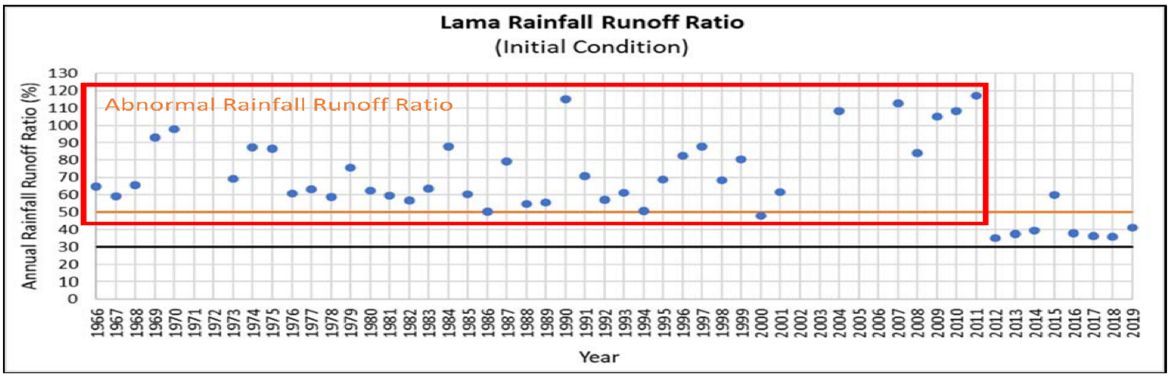
As shown in Figures 3.1.9 to 3.1.11, the generated time-series discharge data was graphed as a time-series line graph for each of the discharge values of 95-day, 185-day, 275-day, and 355-day (not all through a year), and the annual runoff ratio with respect to the rainfall was also graphed. Since the values of runoff ratio at the three stations observed by the JICA Survey Team in 2020 were in the 30% to 50% range, the range was indicated as a guide in the annual runoff ratio graphs. From these graphs, the following issues were confirmed in the time-series discharge data of each station.

Lama Station (Matamuhuri River): Significant trend changes in discharge conditions were confirmed from 1995 to 2015. Since such changes are not confirmed from the amount of rainfall, it is assumed that some kinds of errors have occurred in the water level observation and in the process of converting the water level to the discharge. In addition, since the annual runoff ratio graph shows very large runoff ratios during the period from 1966 to 2011, it is inferred that some errors occurred in the process of generating the time-series discharge data during this period as well.

Bandarban Station (Sangu River): In both graphs of the time-series line and annual runoff ratio, very low values were confirmed only in 1995. It is presumed that some errors have occurred in the process of generating the time-series discharge data in the target year.

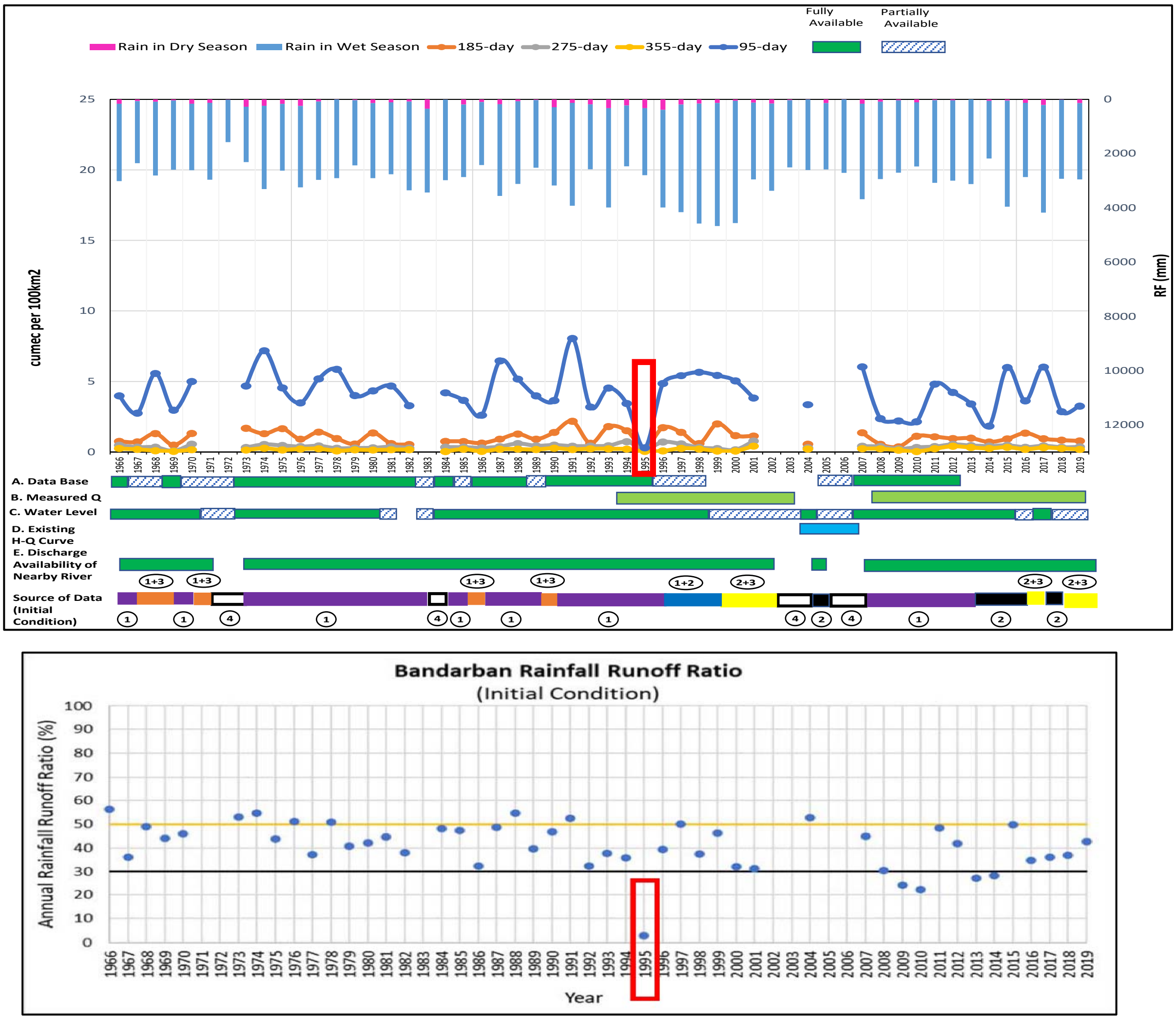
Panchpukuria Station (Halda River): It was confirmed that the values of annual runoff ratio are extremely high during the period from 1974 to 1999. The time-series discharge data is missing during the other three periods (1971-72, 2002-03 and 2005-06). In addition, it is confirmed that the river water level has continuously decreased due to the sand mining of riverbed since 2007, and water intake from the rubber weir installed upstream of the Panchpukuria Station has been being carried out since 2012. Due to these artificial influences, the reliability of the time-series discharge data after 2007 is assumed to be low.





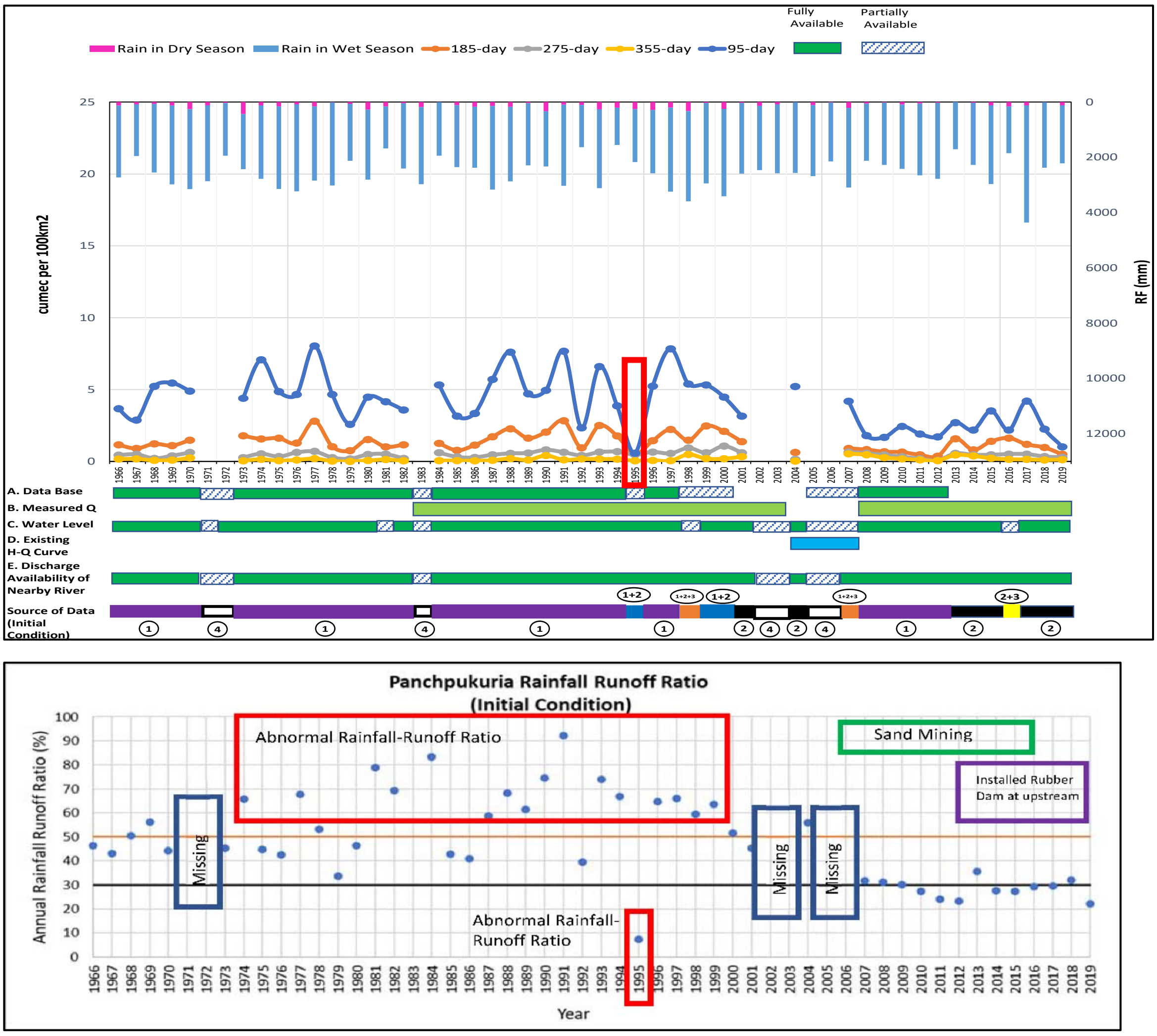
Source: JICA Survey Team

Figure 3.1.9 Verification Result of Time-Series Discharge Data (Initial Analysis Stage: Lama Station)



Source: JICA Survey Team

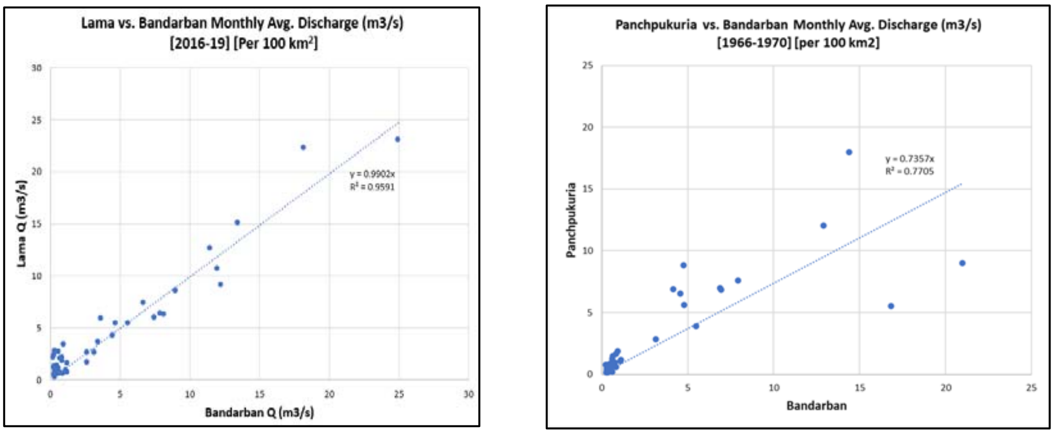
Figure 3.1.10 Verification Result of Time-Series Discharge Data (Initial Analysis Stage: Bandarban Station)



Source: JICA Survey Team

Figure 3.1.11 Verification Result of Time-Series Discharge Data (Initial Analysis Stage: Panchpukuria Station)

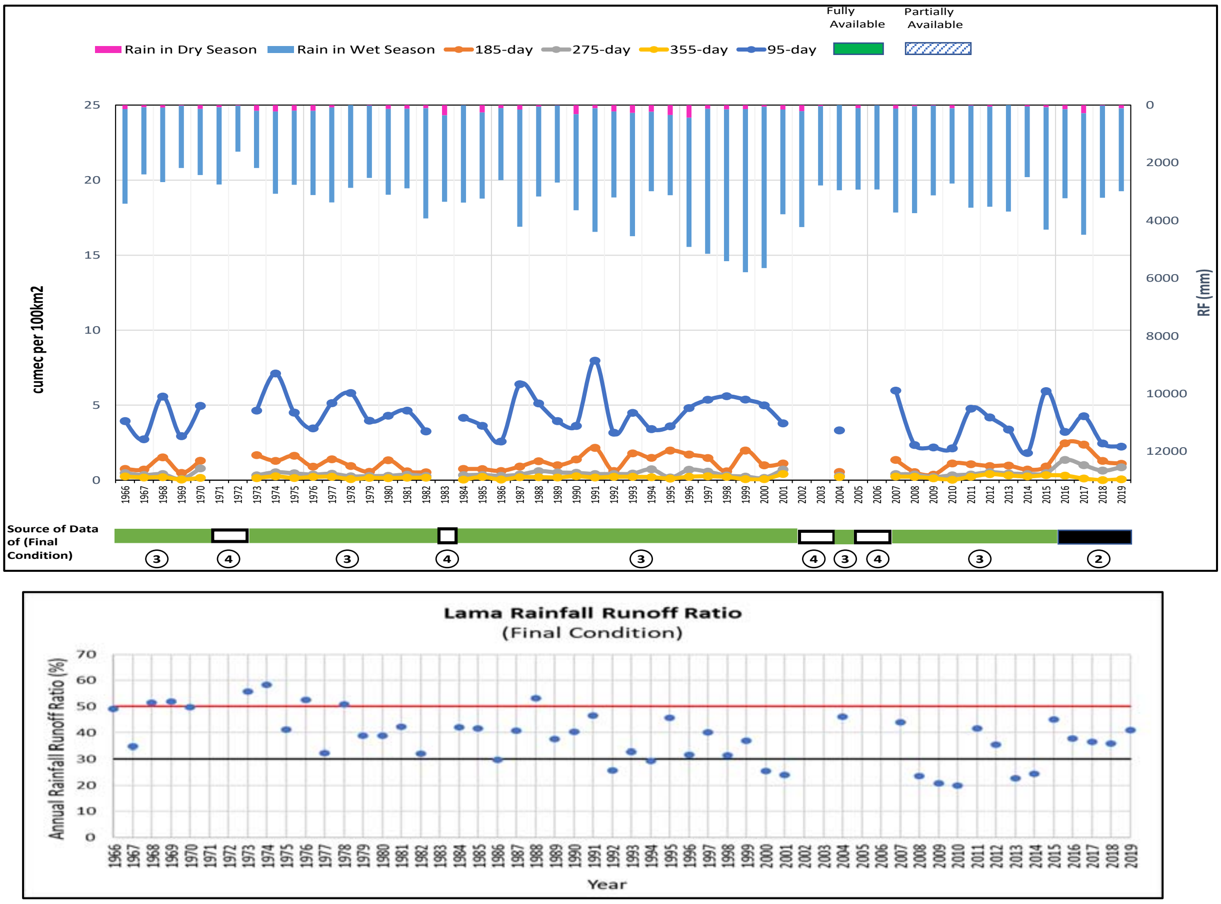
The following solutions have been taken for the above issues. The time-series discharge data at the Bandarban Station, which ensures the reliability for most of the period, was updated only in 1995. On the other hand, the time-series discharge data of the Lama (1966-2015) and the Panchpukuria (1971-2019) Stations, which are unreliable for many periods, were updated through converting from the highly reliable Bandarban discharge data by using correlation equation (refer to Figure 3.1.12).



Source: JICA Survey Team

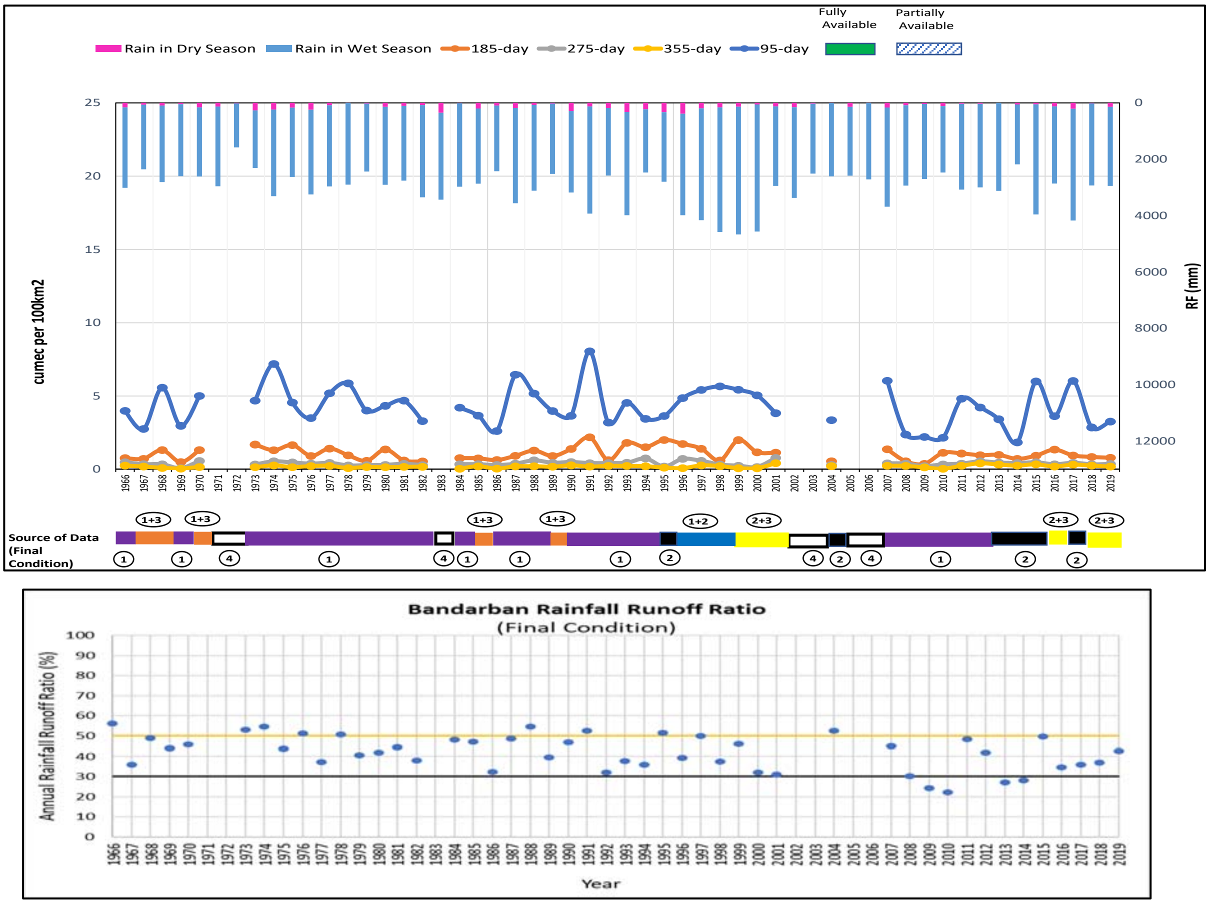
Figure 3.1.12 Correlation Diagram of Discharge Data

Figures 3.1.13 to 3.1.15 show the results of the updated time-series discharge data at each station. All issues with abnormal trends in both graphs of the time-series line and annual runoff ratio have been resolved. It was decided to analyze the available water resources and water balance by using the updated final time-series discharge data.



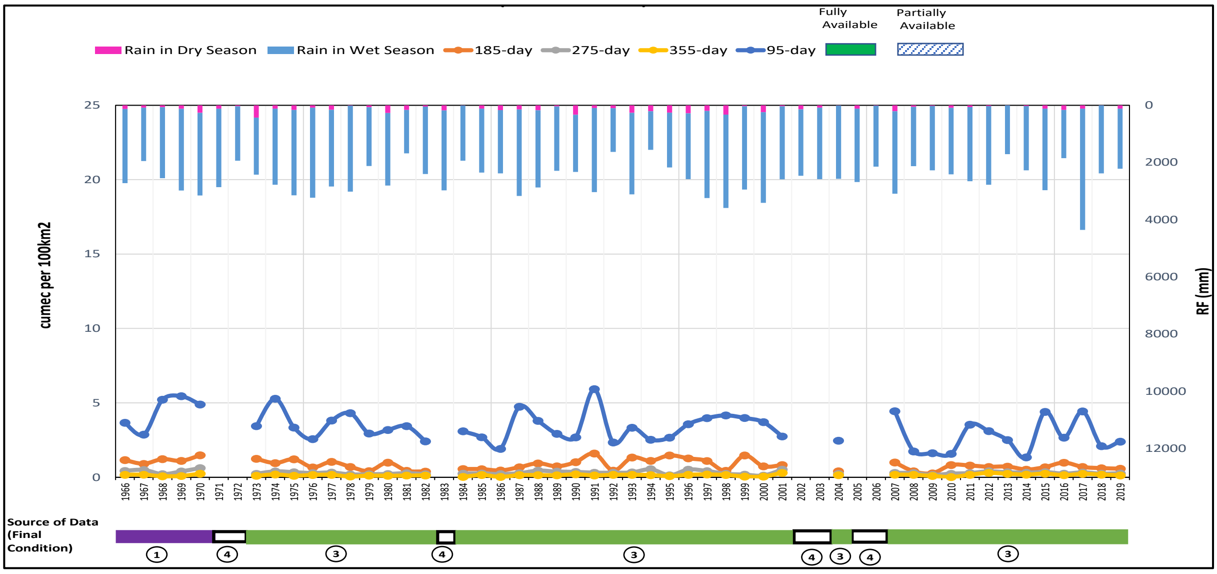
Source: JICA Survey Team

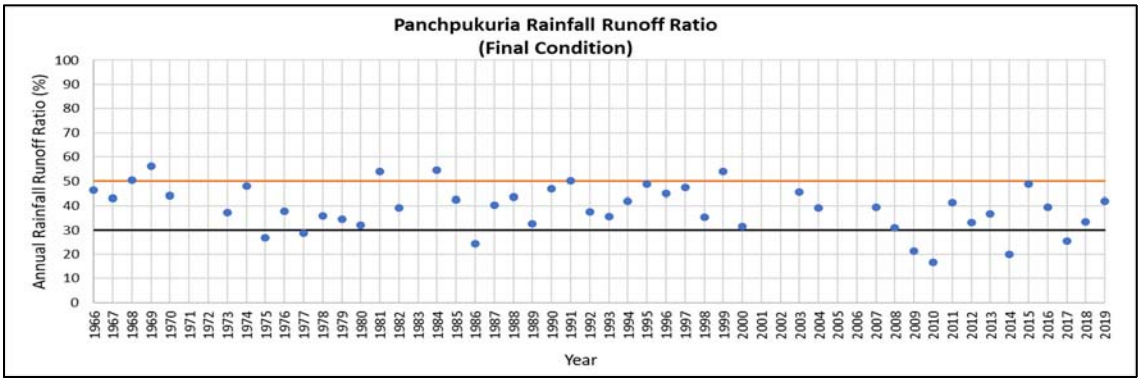
Figure 3.1.13 Verification Result of Time-Series Discharge Data (Updated Final Stage: Lama Station)



Source: JICA Survey Team

Figure 3.1.14 Verification Result of Time-Series Discharge Data (Updated Final Stage: Bandarban Station)





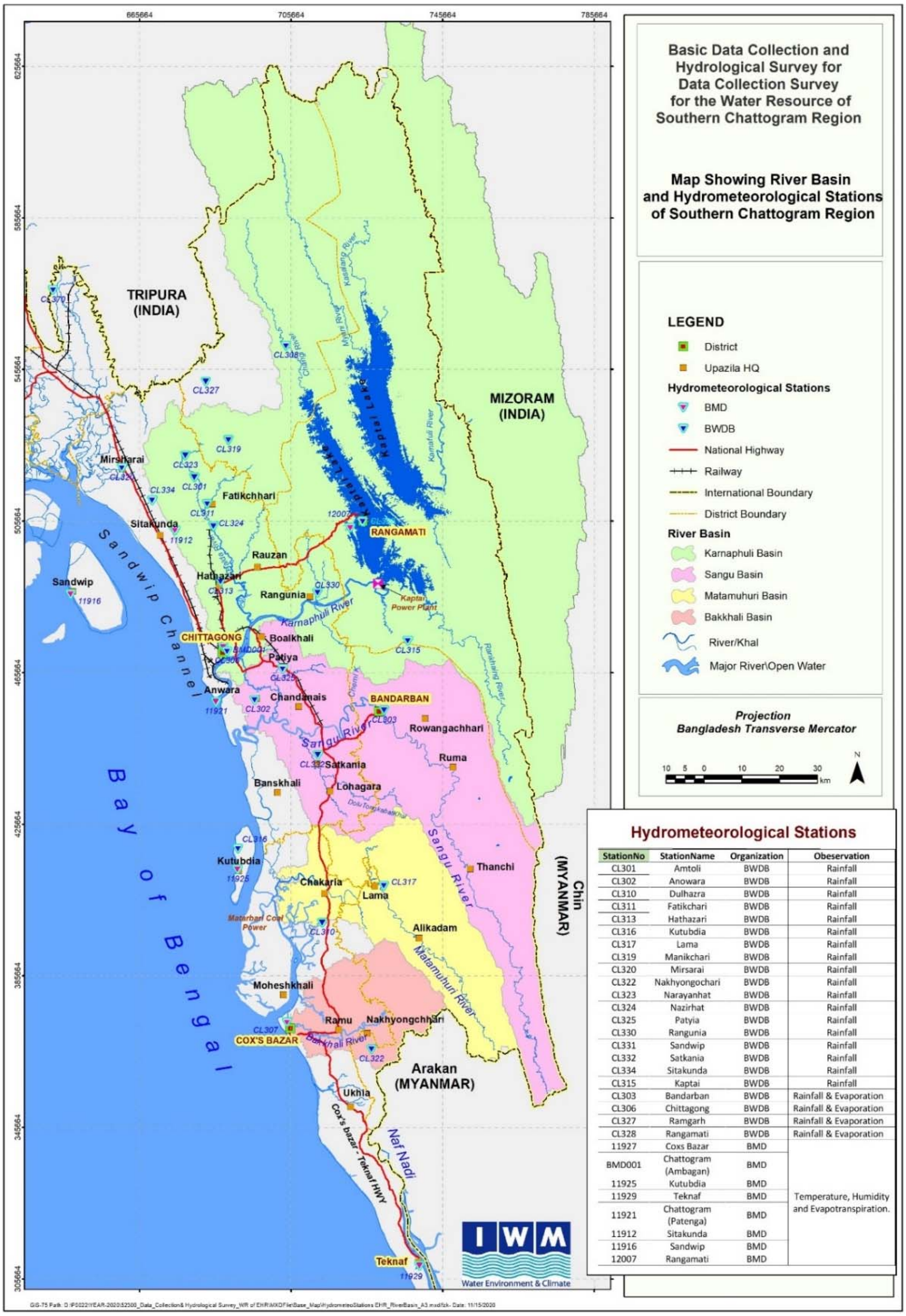
Source: JICA Survey Team

Figure 3.1.15 Verification Result of Time-Series Discharge Data (Updated Final Stage: Panchpukuria Station)

3.1.3 Precipitation Analysis

(1) Calculation of average rainfall over watershed

The rainfall data of the rainfall gauging stations in the three river basins (Karnafuli, Sangu and Matamuhuri River basins) were collected, and the observation periods with data missing periods are summarized as shown in Table 3.1.5. Basically, the observation data are released with one year delay after detailed checking by the BWDB or the BMD, so all available data up to 2019 were collected in this survey. As shown in Table 3.1.5, most rainfall stations in the target basin area started observation after 1962. Since there are many data missing until 1965, for the target period of 54 years from 1966 until 2019, the missing data were filled out by the coefficient correlation method and the average rainfall over each watershed was calculated by the Thiessen Method.



StationNo	StationName	Organization	Obeservation
CL301	Amtoli	BWDB	Rainfall
CL302	Anowara	BWDB	Rainfall
CL310	Dulhazra	BWDB	Rainfall
CL311	Fatikchari	BWDB	Rainfall
CL313	Hathazari	BWDB	Rainfall
CL316	Kutubdia	BWDB	Rainfall
CL317	Lama	BWDB	Rainfall
CL319	Manikchari	BWDB	Rainfall
CL320	Mirsarai	BWDB	Rainfall
CL322	Nakhyongochari	BWDB	Rainfall
CL323	Narayanhat	BWDB	Rainfall
CL324	Nazirhat	BWDB	Rainfall
CL325	Patyia	BWDB	Rainfall
CL330	Rangunia	BWDB	Rainfall
CL331	Sandwip	BWDB	Rainfall
CL332	Satkania	BWDB	Rainfall
CL334	Sitakunda	BWDB	Rainfall
CL315	Kaptai	BWDB	Rainfall
CL303	Bandarban	BWDB	Rainfall & Evaporation
CL306	Chittagong	BWDB	Rainfall & Evaporation
CL327	Ramgarh	BWDB	Rainfall & Evaporation
CL328	Rangamati	BWDB	Rainfall & Evaporation
11927	Coxs Bazar	BMD	Temperature, Humidity and Evapotranspiration.
BMD001	Chattogram (Ambagan)	BMD	
11925	Kutubdia	BMD	
11929	Teknaf	BMD	
11921	Chattogram (Patenga)	BMD	
11912	Sitakunda	BMD	
11916	Sandwip	BMD	
12007	Rangamati	BMD	

Source: JICA Survey Team

Figure 3.1.16 Location Map of Rainfall Gauging Stations

Table 3.1.5 Observation Periods with Missing Data Periods of Rainfall Gauging Stations

Karnafuli Basin:

No	Name	Source	Elevation (m)	Remarks
CL301	Amtoli	BWDB	16	57 years
CL306	Chittagong	BWDB	16	63 years
CL311	Fatikchari	BWDB	12	59 years
CL315	Kaptai	BWDB	52	36 years
CL319	Manikchari	BWDB	51	56 years
CL320	Mirsarai	BWDB	11	57 years
CL323	Narayanhat	BWDB	20	58 years
CL324	Nazirhat	BWDB	11	55 years
CL327	Ramgarh	BWDB	24	59 years
CL328	Rangamati	BWDB	48	59 years
CL330	Rangunia	BWDB	13	55 years
CL331	Sandwip	BWDB	5	59 years
CL334	Sitakunda	BWDB	11	54 years
CL313	Hathazari	BWDB	15	58 years
12007	Rangamati	BMD	50	59 years
11921	Patenga	BMD	5	62 years
11912	Sitakunda	BMD	95	42 years
11916	Sandwip	BMD	5	51 years
	Ambagan	BMD	36	20 years

Sangu Basin:

No	Name	Source	Elevation (m)	Remarks
CL302	Anwara	BWDB	7	58 years
CL303	Bandarban	BWDB	24	59 years
CL325	Patyia	BWDB	13	58 years
CL332	Satkania	BWDB	7	59 years

Matamuhuri Basin:

No	Name	Source	Elevation (m)	Remarks
CL310	Dulhazra	BWDB	10	58 years
CL316	Kutubdia	BWDB	8	58 years
CL317	Lama	BWDB	18	56 years
11925	Kutubdia	BMD	8	37 years

Notes : Full data, Missing (Partially unavailable), Missing (Fully unavailable)

Source: JICA Survey Team

The missing data were filled out by the following formula (1), using weighting ratios of the correlation coefficients (refer to Table 3.1.6) of nearby rainfall gauging stations.

$$P = \frac{\sum_{i=1}^{n} x_i r_i}{\sum_{i=1}^{n} r_i} \qquad (1)$$

Where, P: Estimated rainfall value (mm), x_i: Rainfall value of nearby rainfall gauging station No.i (mm), r_i : Correlation coefficient of nearby rainfall gauging station No.i

Table 3.1.6 Correlation Coefficients of Nearby Rainfall Gauging Stations

Station	Near Station	Correlation Coefficient	Station	Near Station	Correlation Coefficient
Amtoli	CL323_Narayanhat	0.993	Nakhyongo-chari	CL316_Kutubdia	0.998
	CL311_Fatikchari	0.995		CL317_Lama	0.997
	CL334_Sitakunda	0.988		CL310_Dulhazra	0.997
Anwara	CL325_Patyia	0.999		CL332_Satkania	0.986
	CL332_Satkania	0.982	Narayanhat	CL319_Manikchari	0.980
	CL306_Chittagong	0.998		CL301_Amtoli	0.993
Bandarban	CL325_Patyia	0.999		CL320_Mirsarai	0.995
	CL302_Anwara	0.997		CL327_Ramgarh	0.997
	CL332_Satkania	0.985		CL334_Sitakunda	0.997
	CL317_Lama	0.994	Nazirhat	CL319_Manikchari	0.982
Chittagong	CL302_Anwara	0.998		CL301_Amtoli	0.995
	CL325_Patiya	0.998		CL311_Fatikchari	0.999
	CL313_Hathazari	0.998		CL323_Narayanhat	0.999
Dulhazra	CL317_Lama	0.997	Patyia	CL306_Chittagong	0.998

	CL322_Nakhyongochari	0.997		CL330_Rangunia	0.997
	CL316_Kutubdia	0.992		CL302_Anwara	0.999
Fatikchari	CL301_Amtoli	0.995		CL332_Satkania	0.985
	CL334_Sitakunda	0.995	Ramgarh	CL319_Manikchari	0.990
	CL313_Hathazari	0.998		CL320_Mirsarai	0.990
Hathazari	CL330_Rangunia	0.996		CL328_Rangamati	0.995
	CL311_Fatikchari	0.998		CL323_Narayanhat	0.997
	CL306_Chittagong	0.998	Rangamati	CL319_Manikchari	0.988
Kaptai	CL328_Rangamati	0.996		CL330_Rangunia	0.995
	CL330_Rangunia	0.997		CL327_Ramgarh	0.995
	CL325_Patiya	0.997	Rangunia	CL328_Rangamati	0.995
Kutubdia	CL302_Anwara	0.991		CL325_Patiya	0.997
	CL317_Lama	0.995		CL313_Hathazari	0.996
	CL310_Dulahazra	0.992	Sandwip	CL320_Mirsarai	0.987
Lama	CL316_kutubdia	0.995		CL334_Sitakunda	0.989
	CL310_Dulahazra	0.997		CL313_Hathazari	0.983
	CL322_Nakhyongochari	0.997	Satkania	CL302_Anwara	0.982
Manikchari	CL323_Narayanhat	0.980		CL325_Patiya	0.985
	CL27_Ramgarh	0.990		CL316_Kutubdia	0.977
	CL311_Fatikchari	0.985		CL317_Lama	0.989
Mirsarai	CL331_Sandwip	0.987		CL310_Dulhazra	0.984
	CL301_Amtoli	0.982	Sitakunda	CL320_Mirsarai	0.999
	CL323_Narayanhat	0.995		CL323_Narayanhat	0.997
	CL327_Ramgarh	0.990		CL301_Amtoli	0.988
	CL334_Sitakunda	0.999		CL311_Fatikchari	0.995

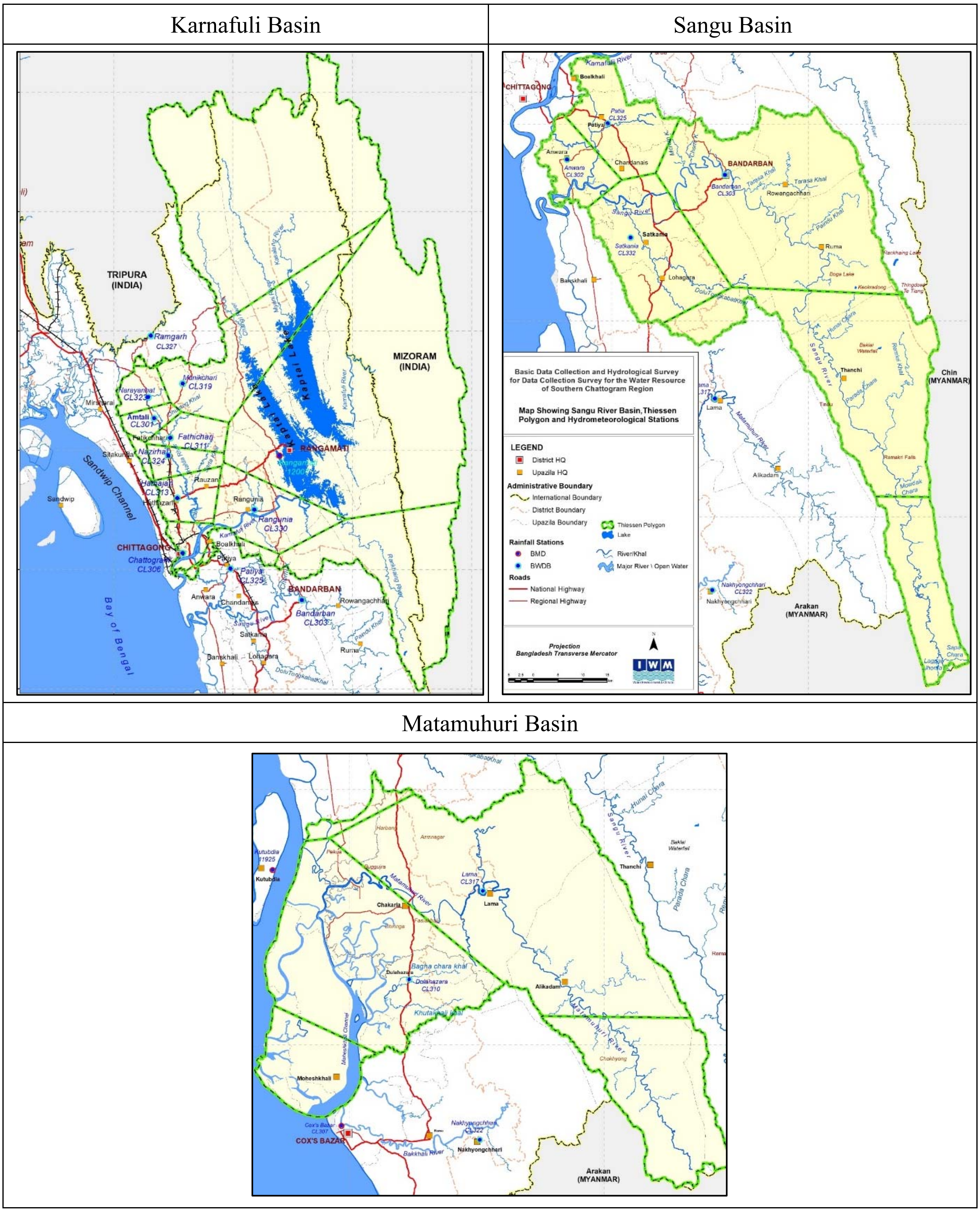
Source: JICA Survey Team

The average rainfall over the watershed of each basin was calculated based on the Thiessen polygon and coefficient value of the Thiessen Method shown in Figure 3.1.17 and Table 3.1.8, and the statistical values were summarized in Table 3.1.7 (refer to "Annex 3.1-2 ").

Table 3.1.7 Statistical Values of Annual Watershed Rainfalls (54 years:1966-2019)

Statistical Value		Karnafuli Basin	Sangu Basin	Matamuhuri Basin
Whole Year	Average	2,496 mm	2,843 mm	3,392 mm
	Maximum	3,737 mm	4,183 mm	5,666 mm
	Minimum	1,174 mm	1,598 mm	1,864 mm
	1/5 drought year	2,060 mm	2,362 mm	2,687 mm
	1/10 drought year	1,871 mm	2,282 mm	2,568 mm
Rainy Season	Average	2,362 mm	2,716 mm	3,270 mm
	Maximum	3,541 mm	4,002 mm	5,491 mm
	Minimum	999 mm	1,488 mm	1,761 mm
	1/5 drought year	2,002 mm	2,243 mm	2,660 mm
	1/10 drought year	1,818 mm	2,274 mm	2,567 mm
Dry Season	Average	134 mm	128 mm	122 mm
	Maximum	196 mm	181 mm	176 mm
	Minimum	176 mm	110 mm	102 mm
	1/5 drought year	58 mm	118 mm	28 mm
	1/10 drought year	53 mm	8 mm	1 mm

Source: JICA Survey Team



Source: JICA Survey Team

Figure 3.1.17 Thiessen Polygon Map

Table 3.1.8 Thiessen Coefficients

Sl. No.	Rainfall Station	Weightage Factor		
		Karnafuli Basin	Sangu Basin	Matamuhuri Basin
1	Manikchari	0.09	-	-
2	Bandarban	0.11	0.35	-
3	Patyia	0.02	0.09	-
4	Chittagong	0.02	-	-

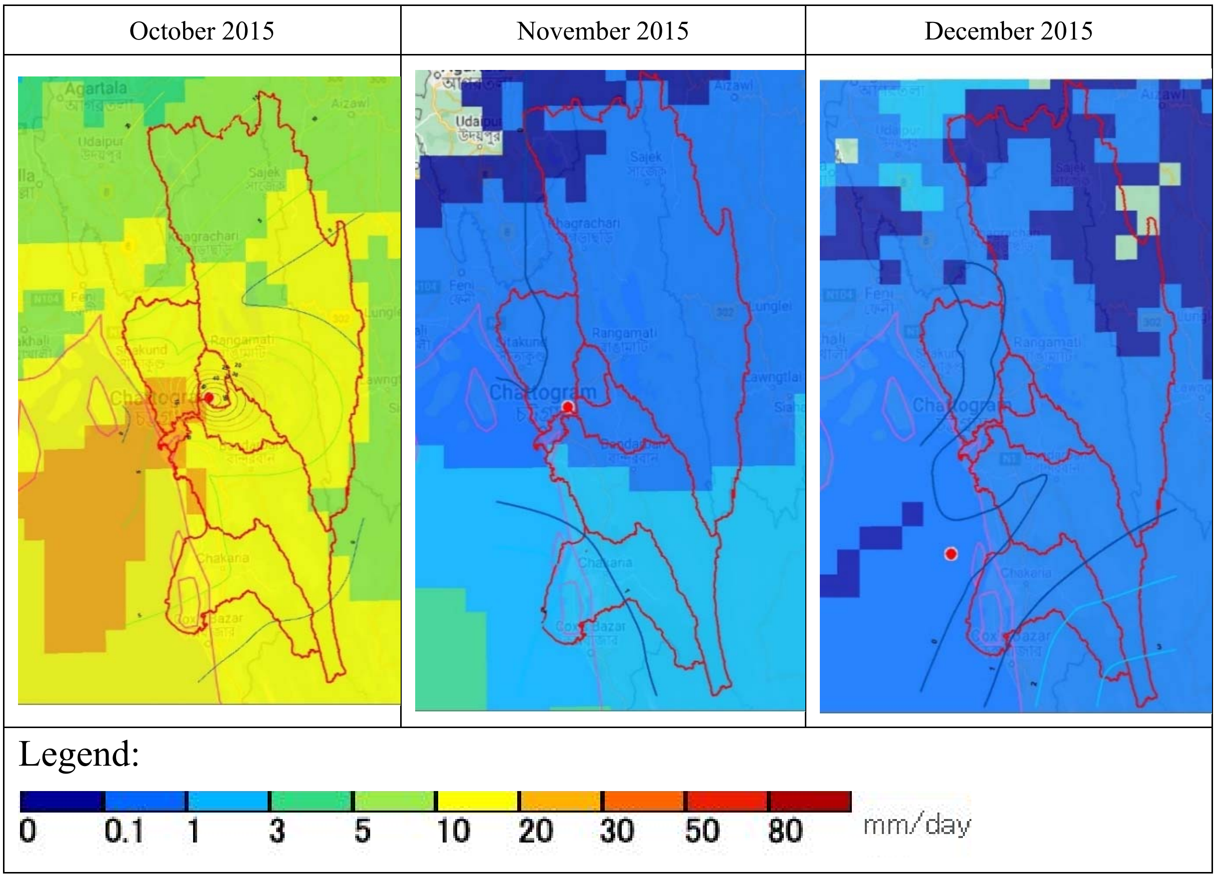
Sl. No.	Rainfall Station	Weightage Factor		
		Karnafuli Basin	Sangu Basin	Matamuhuri Basin
5	Fatikchari	0.02	-	-
6	Narayanhat	0.01	-	-
7	Rangunia	0.05	-	-
8	Rangamati (BMD)	0.36	-	-
9	Ramgarh	0.28	-	-
10	Nazirhat	0.01	-	-
11	Hathazari	0.02	-	-
12	Amtoli	0.01	-	-
13	Satkania	-	0.14	-
14	Lama	-	0.27	0.44
15	Nakhyongochari	-	0.10	0.16
16	Anwara	-	0.05	-
17	Dulhazra	-	-	0.21
18	Cox's Bazar (BMD)	-	-	0.09
19	Kutubdia	-	-	0.10
Total		**1.00**	**1.00**	**1.00**

Source: JICA Survey Team

(3) Verification of average rainfall over watershed

The validity of the average rainfalls over watersheds estimated based on the data of rainfall gauge stations was verified by comparing the average rainfalls with the Global Satellite Mapping of Precipitation (GSMaP) data, which has been published on the website of the Japan Aerospace Exploration Agency (JAXA).

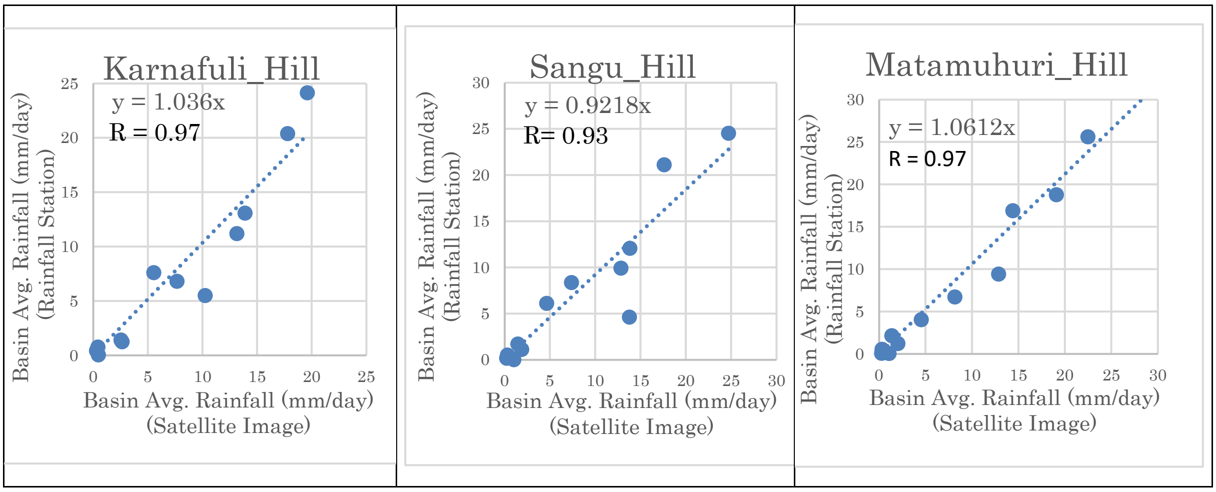
GSMaP is a global rainfall map (refer to Figure 3.1.18) composed of 11 square-km rainfall data observed by microwave radiometer installed in the climate satellite. The verification was conducted by using monthly rainfall data from 2015 to 2019 (5 years) in mountain and plain basin areas.

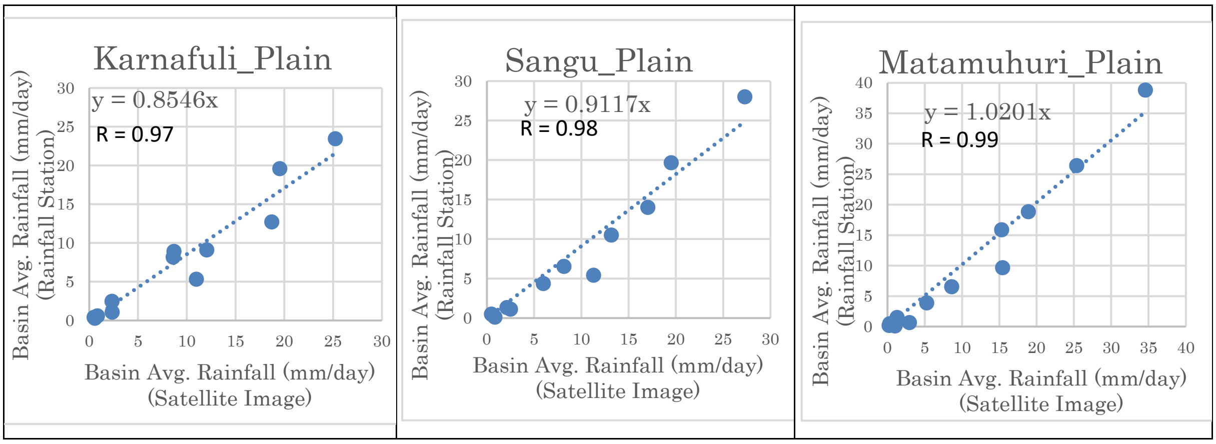


Source: Rainfall data of GSMaP (JAXA homepage)

Figure 3.1.18 Daily Average Rainfall in Each Month (GSMaP Data)

Correlation analyses between average daily watershed rainfalls in each month based on the data of rainfall gauge stations and those of GSMaP were made for the mountain and plain basin areas in the Karnafuli, Sangu and Matamuhuri River basins, as shown in Figure 3.1.19 and Table 3.1.9. The values of correlation coefficients indicate high correlation in both the mountain and plain basin areas as the values more than 0.9. Since the slope of the fitted straight line also indicates the same trend with the values around the line in each case, the estimated average rainfalls over watersheds based on the rainfall gauge station data in this survey are deemed appropriate.





Source: JICA Survey Team

Figure 3.1.19 Correlation Diagram of Monthly Average Daily Rainfall between Rainfall Gauge Station and GSMaP Data

Table 3.1.9 Results of Correlation Analysis of Monthly Average Daily Rainfall between Rainfall Gauge Station and GSMaP Data

Basin Name	Hill Basin		Plain Basin	
	Slope of Fitted Straight Line (Slope)	Correlation Coefficient (R)	Slope of Fitted Straight Line (Slope)	Correlation Coefficient (R)
Karnafuli	1.036	0.97	0.855	0.97
Sangu	0.922	0.93	0.912	0.98
Matamuhuri	1.061	0.97	1.020	0.99

Source: JICA Survey Team

(4) Influence study of rainfall by climate change

Previous literatures on climate change in Bangladesh have been collected and summarized in Table 3.1.10. By 2060, temperatures are predicted to rise by 1.8 °C and average annual rainfall by 7%. It is predicted that the impact of floods caused by cyclones will also increase, and it is assumed that rainfall will increase, especially during the rainy season.

Table 3.1.10 Summary of Recent Climate Change Trends and Future Climate Change Forecasts

	Recent Climate Change Trend	Future Climate Change Forecast
Temperature	Average temperature from 1960 to 2003 is on the rise. [1)]	Average temperature will be increased by 1.8 °C in 2060 and 2.7 °C in 2090 (compared to 2010). [1)]
Rainfall	Rainfall is increasing in the whole country. Strong increasing trend in the west and northwest. [1)]	Average annual rainfall will increase by 7% in 2060 (compare to 1970-2000 average). [1)]
Flood	Two-thirds of the country is within 5 meters above sea level, making it a dangerous area by floods and cyclones. [2)]	By 2030, 14.3% of the land will be new high-risk areas by floods. [3)]

Cyclone	Cyclones have made landfall almost every year. Large-scale flood of 26-34% inundation area of the country has arrived about once every three years. [4)]	By 2050, cyclone-affected areas will increase by 55%. Prediction that the frequency of cyclones will increase. [5)]

Source: 1) Climate Change Profile Bangladesh (2018)
2) Bangladesh Climate Change Strategy and Action Plan (2009)
3) Policy Agenda for Addressing Climate Change in Bangladesh (2010)
4) Modeling Recent Climate Change Induced Extreme Events in Bangladesh, A Review (2015)
5) Changes in the Tropical Cyclone Genesis Potential Index over the Western North Pacific in the SRES A2 Scenario (2010)

For the average rainfall over watershed of the three river basins (Karnafuli, Sangu and Matamuhuri river basins), the time series graphs of annual rainfall for 54 years were prepared for each period, whole year, rainy season and dry season as shown in Figure 3.1.20. The increase/decrease values of rainfall per year are summarized as shown in Table 3.1.11 based on the slope of the fitting line shown in Figure 3.1.20. It was confirmed that the rainfall of the whole year and the rainy season are increasing and that of the dry season is decreasing in each river basin. Using these increase/decrease values per year, the rates of increase/decrease in the average rainfall over watershed as of the long-term target in 2041 were calculated as shown in Table 3.1.12. The rates of decrease in the dry season of the three river basins were calculated from 16% to 24%. It was estimated that the average rainfall over watershed in the three river basins will decrease by nearly 20%. Changes of rainfall, which is the source of surface water in water resource development, are assumed to affect the scale of development facilities.

As a future agenda, it is important to improve the prediction accuracy of rainfall in the long-term by analysing climate change in the south Chattogram region by referring the scenario of the IPCC Fifth Assessment Report (scheduled to be published in September 2022).

Table 3.1.11 Increase / Decrease Values per Year of Average Rainfall over Watershed Based on Past Rainfall Data

Basin	Increase and decrease values of basin average rainfall per year		
	Whole year	Rainy Season	Dry Season
Karnafuli	0.9 mm/year	2.8 mm/year	-1.0 mm/year
Sangu	8.5 mm/year	10.3 mm/year	-1.4 mm/year
Matamuhuri	17.0 mm/year	18.2 mm/year	-1.2 mm/year

Note: ☐ Increase trend, ☐ Decrease trend

Source: JICA Survey Team

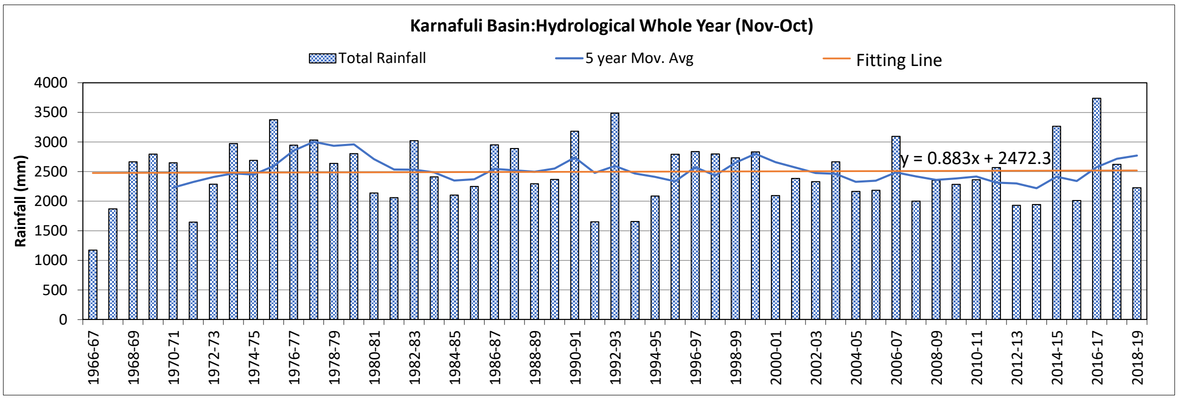
Table 3.1.12 Increase / Decrease Rate of Average Rainfall over Watershed in Long-term (2041)

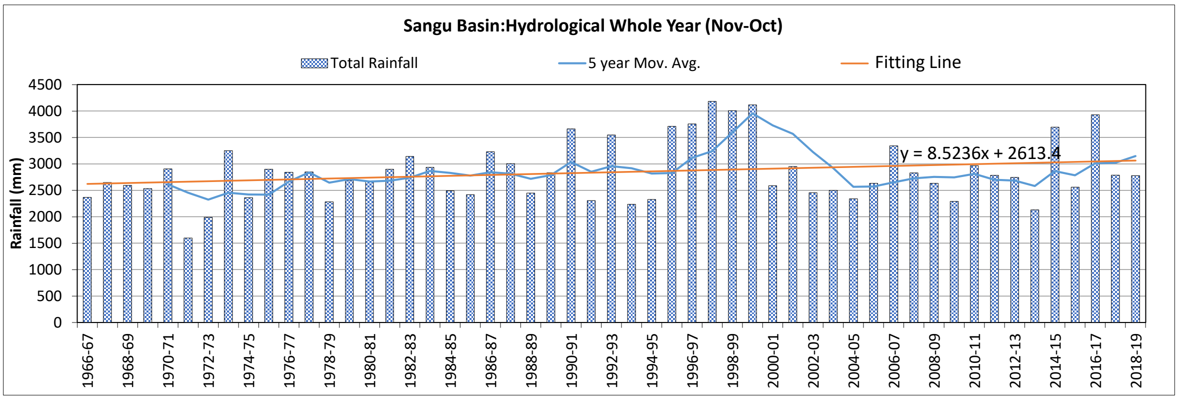
Basin	Period	(1)Change value per year	Basin average rainfall		(4)Change rate =((3)/(2)-1)*100
			(2)Present 2019 1)	(3)Long-term 2041	
Karnafuli	Whole year	0.9 mm/year	2,496 mm	2,516 mm	1%
	Rainy season	2.8 mm/year	2,362 mm	2,424 mm	3%
	Dry season	-1.0 mm/year	134 mm	112 mm	-16%
Sangu	Whole year	8.5 mm/year	2,843 mm	3,030 mm	7%
	Rainy season	10.3 mm/year	2,716 mm	2,943 mm	8%
	Dry season	-1.4 mm/year	128 mm	97 mm	-24%
Matamuhuri	Whole year	17.0 mm/year	3,392 mm	3,766 mm	11%
	Rainy season	18.2 mm/year	3,270 mm	3,670 mm	12%
	Dry season	-1.2 mm/year	122 mm	96 mm	-22%

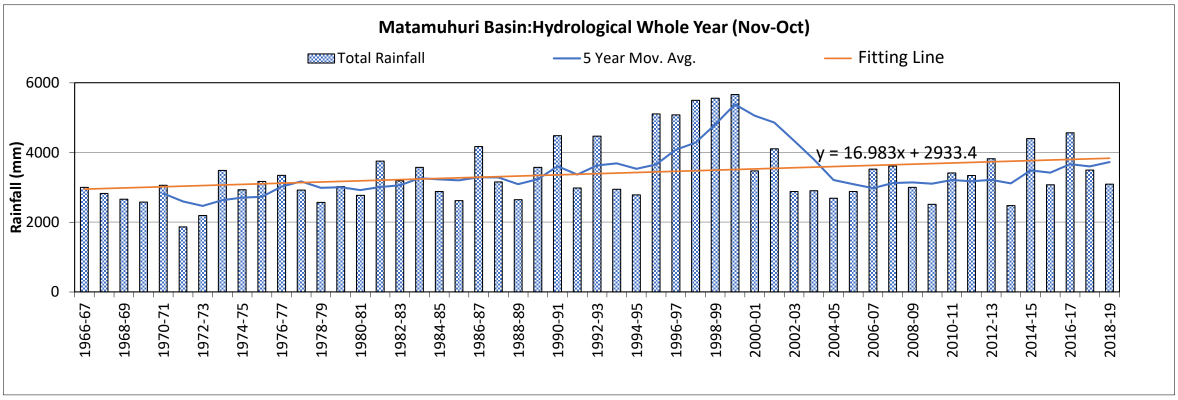
1) Average rainfall for 54 years from 1966 to 2019

Source: JICA Survey Team

< Whole Year Rainfall >







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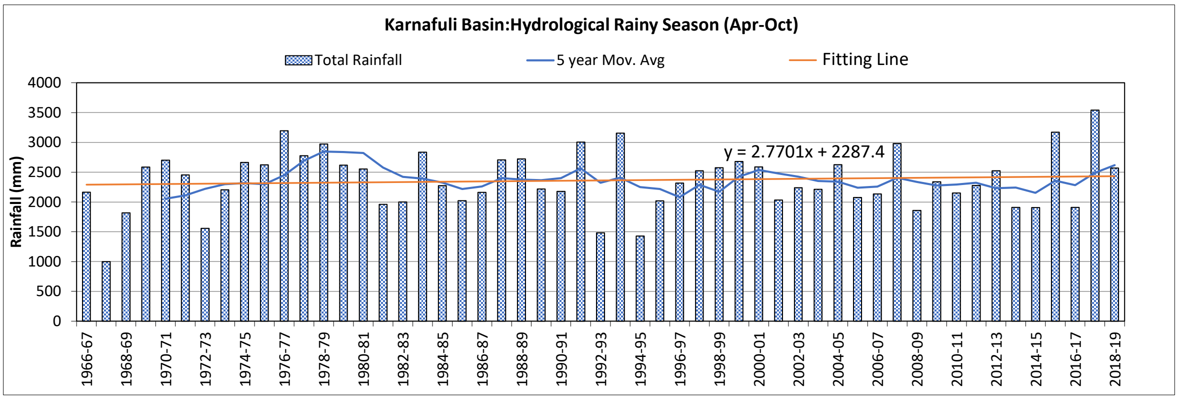

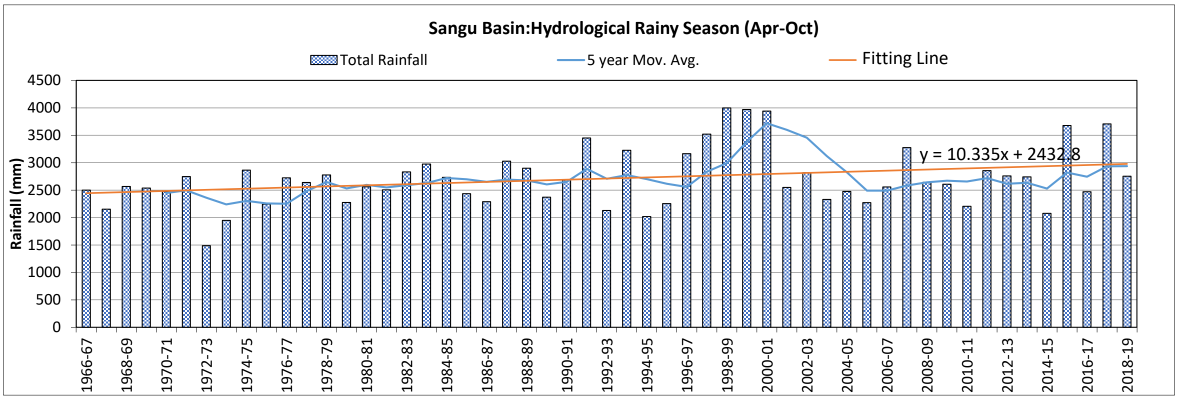

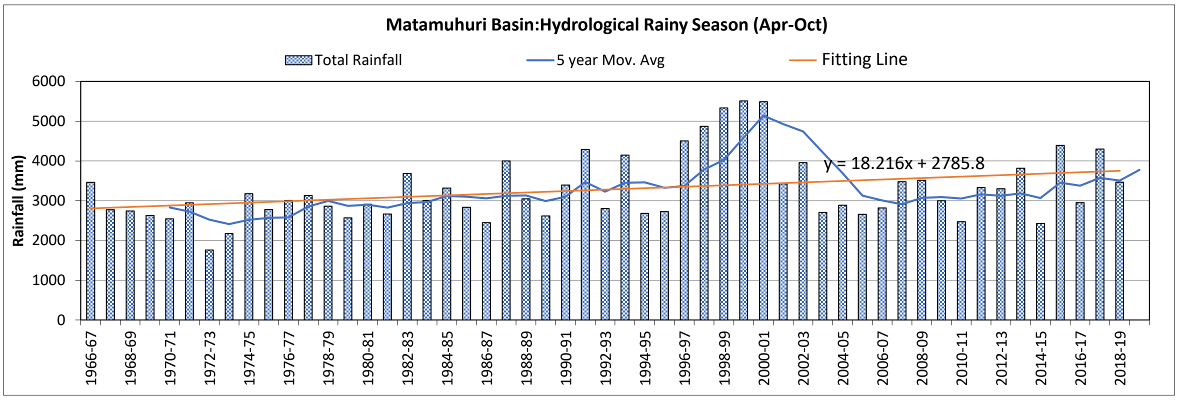

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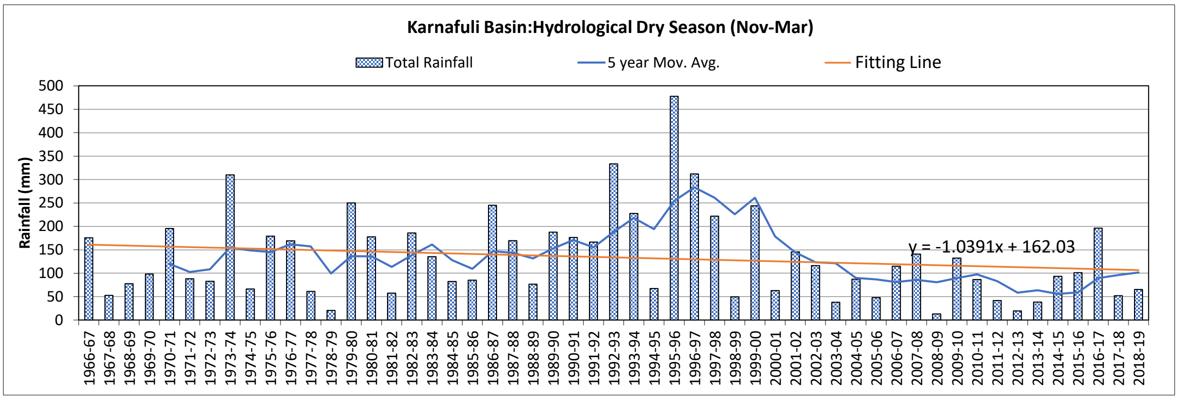
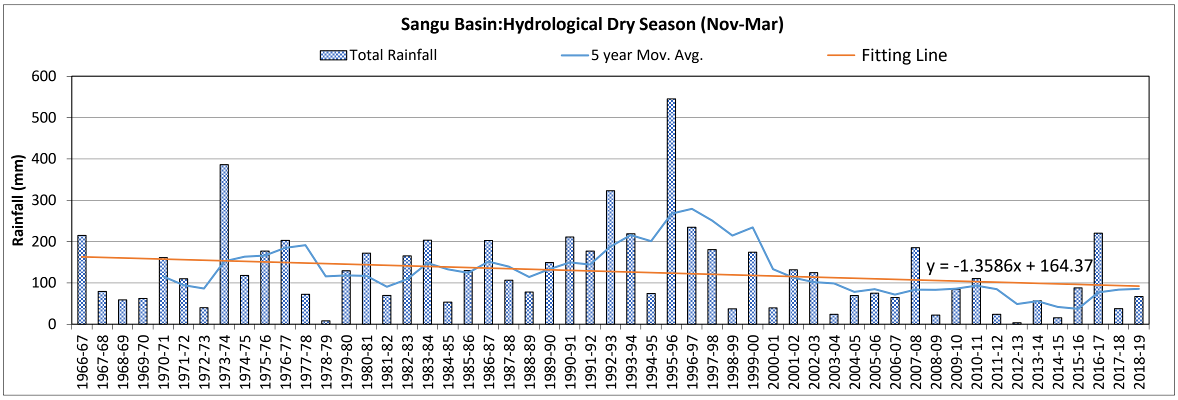
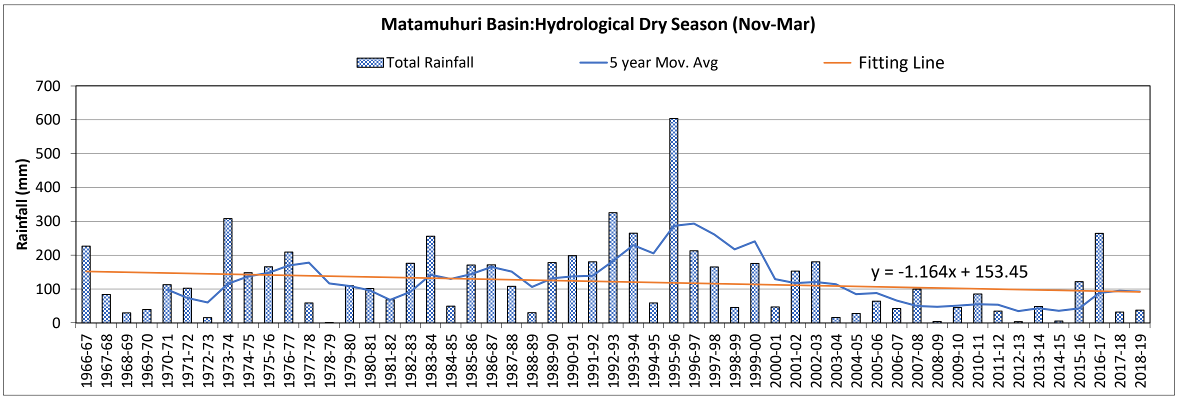






Source: JICA Survey Team

Figure 3.1.20 Time-Series Graphs of Average Rainfall over Watershed

3.1.4 Hydrologic Analysis

Based on the discharge data of the Karnafuli, Sangu and Matamuhuri Rivers verified and finalized in “Sub-section 3.1.2”, the statistical values (95-day, 185-day, 275-day, 355-day, maximum and minimum discharges) and the annual total amounts of discharge were summarized as shown in Tables 3.1.13 to 3.1.15 (refer to "Annex 3.1-3"). In addition, monthly rainfall graphs (average, maximum and minimum for 54 years: 1966-2019) were created in Figure 3.1.21. As shown in Table 3.1.14, it was confirmed that the discharge amounts in the rainy season account for more than 90% of the whole year and 7% to 8% in the dry season.

Table 3.1.13 Statistical Discharge Values of Each River (54 years: 1966-2019)

Unit：$m^3/s/100km^2$

Item	Statistical Event	Lama WLG Station in Matamuhuri River	Bandarban WLG Station in Sangu River	Panchpukuria WLG Station in Halda River
Average (1966-2019)	95-day	4.18	4.55	3.34
	185-day	1.09	1.10	0.83
	275-day	0.44	0.41	0.30
	355-day	0.18	0.20	0.15
	Average	4.05	4.20	3.16
1/5 Drought Year	355-day	0.08	0.14	0.09
1/10 Drought Year	355-day	0.04	0.07	0.05
Maximum		175.31	179.84	132.29
Minimum		0.00	0.00	0.00

Source: JICA Survey Team

Table 3.1.14 Annual Total Amounts of Discharge of Each River (54 years: 1966-2019)

Unit：MCM

Statistical Event	Season	Lama WLG Station in Matamuhuri River CA: 1,201 km^2	Bandarban WLG Station in Sangu River CA: 2,199 km^2	Panchpukuria WLG Station in Halda River CA: 856 km^2
Average (1966-2019)	Whole Year	1,536（100%）	2,913（100%）	854（100%）
	Dry Season	122（8%）	220（8%）	64（7%）
	Rain Season	1,417（92%）	2,693（92%）	790（93%）
Maximum (1966-2019)	Whole Year	2,454	4,610	1,426
	Dry Season	328	526	151
	Rain Season	2,380	4,471	1,354
Minimum (1966-2019)	Whole Year	580	1,090	312
	Dry Season	24	45	13
	Rain Season	556	1,045	299
1/5 Drought Year	Whole Year	1,078	2,025	602
	Dry Season	73	137	39
	Rain Season	946	1,777	519
1/10 Drought Year	Whole Year	905	1,700	487
	Dry Season	59	111	32
	Rain Season	832	1,563	448

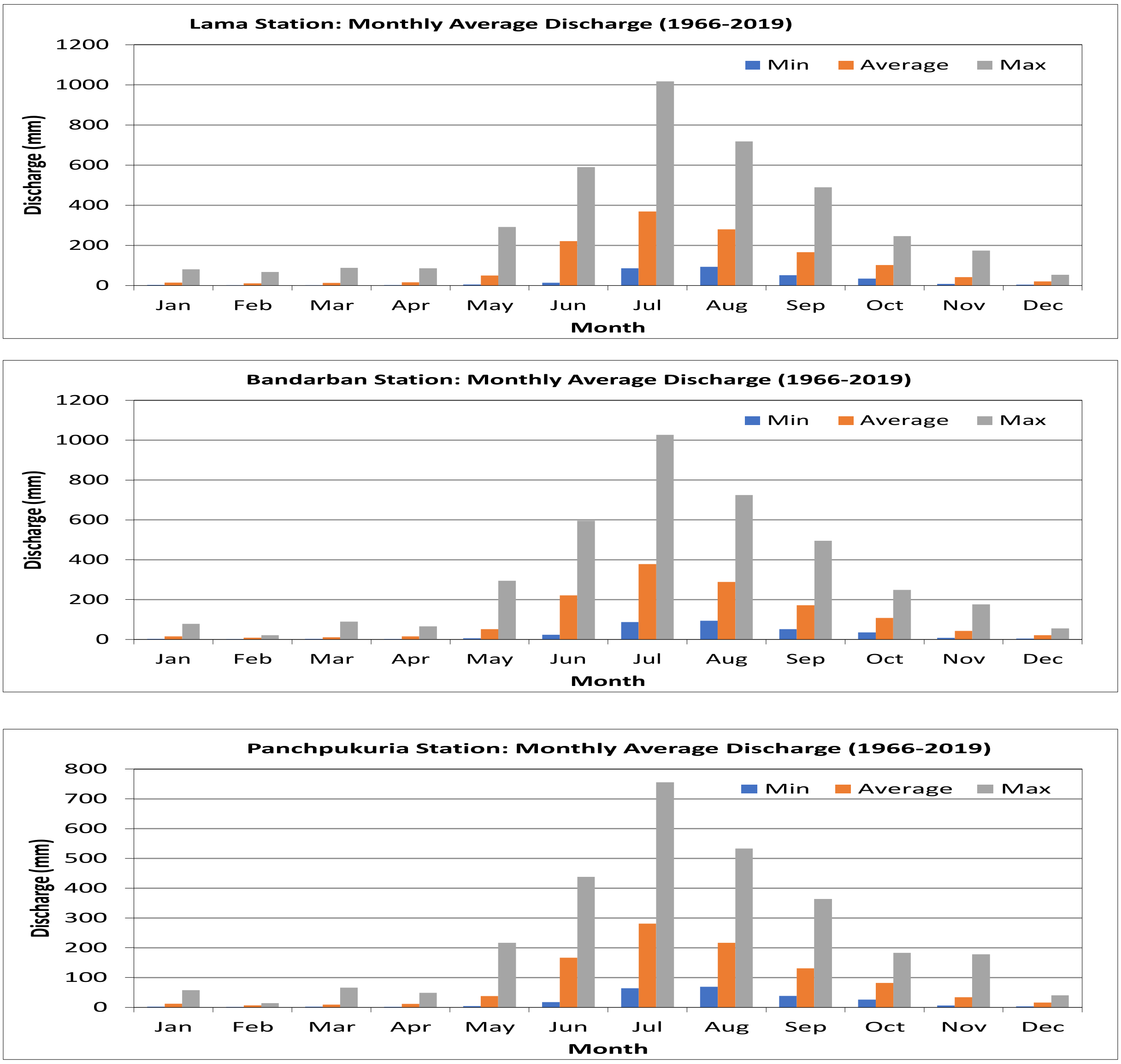
Source: JICA Survey Team

Table 3.1.15 Annual Runoff Depths of Each River (54 years: 1966-2019)

Unit：mm

Statistical Event	Season	Lama WLG Station in Matamuhuri River	Bandarban WLG Station in Sangu River	Panchpukuria WLG Station in Halda River
Average (1966-2019)	Whole Year	1,279	1,325	997
	Dry Season	102	100	75
	Rain Season	1,177	1,225	922
Maximum (1966-2019)	Whole Year	2,043	2,096	1,666
	Dry Season	273	239	176
	Rain Season	1,982	2,033	1,582
Minimum (1966-2019)	Whole Year	483	496	365
	Dry Season	20	20	15
	Rain Season	463	475	350
1/5 Drought Year	Whole Year	897	921	703
	Dry Season	61	62	46
	Rain Season	788	808	606
1/10 Drought Year	Whole Year	754	773	569
	Dry Season	49	50	37
	Rain Season	693	711	523

Source: JICA Survey Team



Source: JICA Survey Team

Figure 3.1.21 Monthly Runoff Depths at Each WLG Station

Since the whole river stretches from the river mouth to the Kaptai Dam in the Karnafuli River is a tidal river, it is difficult to calculate the runoff discharge accurately. Hence, the runoff discharge in the Karnafuli River was estimated by using the inflow discharge into the Kaptai Dam. The inflow discharge was calculated based on the following equation by using other data on the Dam, such as reservoir water level and outflow discharge data, for 23 years from 1997 to 2019, since the outflow discharge data is available in and after 1997. Besides, a feasibility study of hydro power plant expansion of the Kaptai Dam was implemented by the Japan External Trade Organization (JETRO) in 2000, and monthly inflow discharges were calculated in the study by the same method for 30 years from 1968 to 1997. By incorporating the monthly inflow discharges, the statistical values of inflow discharge at the Kaptai Dam for 52 years from 1968 to 2019 are summarized in Table 3.1.16.

$$Q_i = Q_T + Q_S + \Delta S + \Delta ET$$

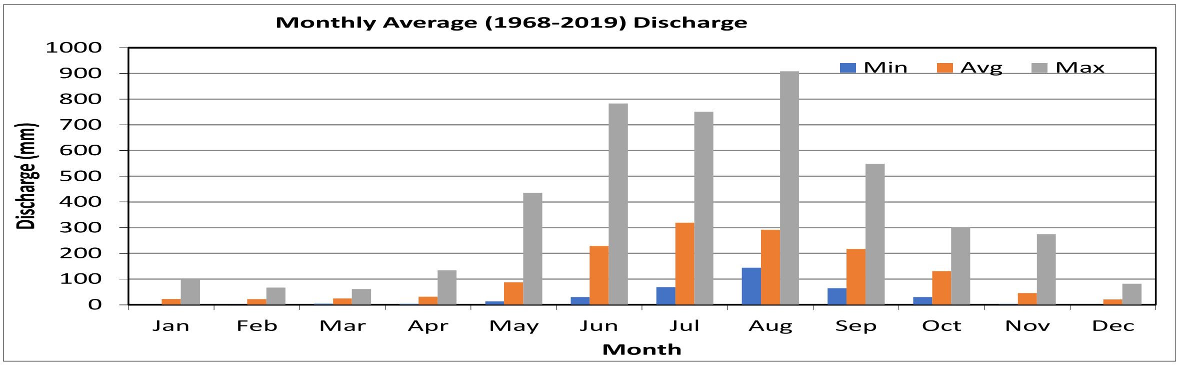
Where,

Q_i = Natural inflow (m^3)
Q_T = Turbine discharge (m^3)
ΔS = Change in storage (m^3) = S2-S1
S1 = Reservoir storage corresponding to WL of day 1 at 8:00 AM
S2 = Reservoir storage corresponding to WL of day 2 at 8:00 AM (next day)
ΔET= ETo * Surface Area

Table 3.1.16 Annual Runoff Volume and Depth into Kaptai Dam (52 years: 1968-2019)

Statistics	Season	At Kaptai Dam, CA: 11,366 km^2	
		Runoff Volume (MCM)	Runoff Depth (mm)
Average (1968-2019)	Whole Year	16,275 (100%)	1,432 (100%)
	Dry Season	1,536 (9%)	135 (9%)
	Rain Season	14,739 (91%)	1,297 (91%)
Maximum (1968-2019)	Whole Year	28,394	2,498
	Dry Season	4,826	425
	Rain Season	26,039	2,291
Minimum (1968-2019)	Whole Year	7,911	696
	Dry Season	209	18
	Rain Season	6,994	615
1/5 Drought Year	Whole Year	12,875	1,133
	Dry Season	819	72
	Rain Season	10,903	959
1/10 Drought Year	Whole Year	10,483	922
	Dry Season	617	54
	Rain Season	9,380	825

Source: JICA Survey Team



Source: JICA Survey Team

Figure 3.1.22 Monthly Runoff Depth into Kaptai Dam

3.1.5 Provisional Settings of River Maintenance Flow

(1) Definition and concept of river maintenance flow

The river maintenance flow is defined as the discharge that should be maintained comprehensively in the river considering the protection of flora and fauna, fisheries, landscape, maintenance of cleanliness of running water (water quality), prevention of salt damage, prevention of clogging of river mouth, etc.

This is established mainly considering the items in Table 3.1.17.

Table 3.1.17 Study Items and Concept of River Maintenance Flow

Items	Concept	Method (Example of Japan*)
i) Protection of Flora, Fauna and Fisheries	The flow required for flora and fauna to inhabit and grow.	Setting target type of fish and specifying required water depth and flow velocity as hydraulic

Items	Concept	Method (Example of Japan*)
		conditions, the required discharge is set for each season. It shall be secured at least 10 cm as the minimum water depth.
ii) Landscape	The flow required to satisfy hydraulic conditions that the river should secure in order to maintain and form a main landscape of the river.	It is said that when the ratio of water surface width to river width (= W / B) is 0.2 or more, dissatisfaction of water volume tends to disappear.
iii) Water Quality	The flow required to improve water quality by securing discharge in rivers where water quality deteriorates during dry season.	Securing discharge to be about twice the environmental standard.
iv) Navigation	The flow required to maintain water surface and draft depth for navigation.	Setting required water surface width and draft depth according to the target ship type.
v) Protection from saltwater damage	The flow required to protect from saltwater intrusion so that salt concentration would not increase in river water and groundwater and not hinder water use when river discharge decreases.	Required discharge that does not cause saltwater damage is estimated based on the relationship between discharge and saltwater intrusion that is obtained by actual survey or a simulation model.
vi) Protection from river mouth clogging	The flow required to protect from constant sedimentation at river mouth to avoid clogging when river discharge decreases.	Required discharge is set by examining actual conditions and tractive force at the river mouth based on a study of current situation, investigation of the relationship between river discharge and river mouth clogging and/or forecasting by simulation.
vii) Protection of river structures	The flow required to secure certain hydraulic conditions for the protection of river management facilities, such as keeping a certain water level to prevent corrosion of wooden facilities (revetment foundations and pile shelves) due to a lowering in water level.	Referring to the required discharges determined by other items, it is examined whether this condition is satisfied. Countermeasures including alternative options are considered, if necessary.
viii) Maintain ground water level	The flow required not to cause groundwater level drop in connection with lowering of river water levels due to decrease of river discharge	In the areas where a considerable amount of rainfall can be expected throughout the year, river discharge would not be a problem on ground water. However, if necessary, countermeasures including alternative options are considered.

Note: Prepared referring to "Guideline of Study of Maintenance Flow (draft)" (MLIT Japan)

Source: JICA Survey Team

(2) Items to be considered for study on maintenance flows in object rivers.

Table 3.1.18 shows the items to be considered for the study on maintenance flows in the object rivers.

Table 3.1.18 Items to be Considered for Study on Maintenance Flows in 3 Object Rivers

Items		Karnafuli	Sangu	Matamuhuri
i)	Protection of flora, fauna and fisheries	H	H	H
ii)	Landscape	L	L	L
iii)	Water quality	M	M	M
iv)	Navigation	H	H	H
v)	Protection from saltwater damage	H	M	M
vi)	Protection from river mouth clogging	L	L	L
vii)	Protection of river structures	L	L	L
viii)	Maintain ground water level	L	L	L

Note: Importance of investigation: H: high, M: medium, L: low

Source: JICA Survey Team

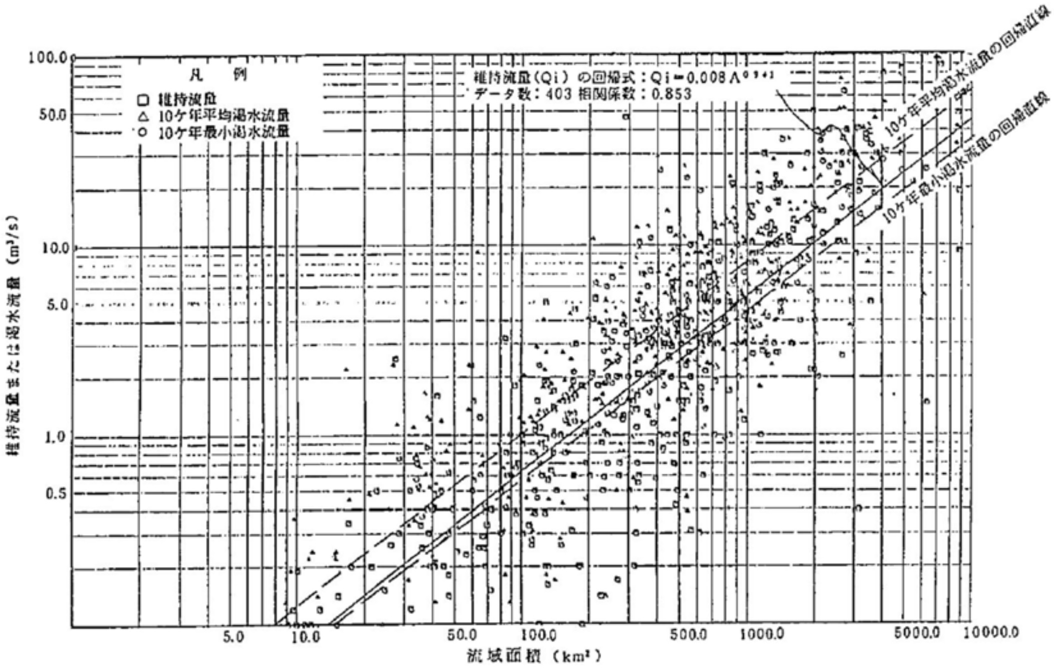
(3) Preliminary Study on maintenance flow

It is necessary to calculate the maintenance flow from detailed examination based on the above (1) and (2). However, the purpose of the Survey is to study the overall water balance associated with the development of water resources in the object basins, thereby the maintenance flow is preliminarily set by adopting the following approaches.

- Example of maintenance discharge in major rivers in Japan
- Example of Bangladesh
- Example of neighboring countries

1) Example of study for maintenance discharge in major rivers in Japan

The results of the study on maintenance flow and river characteristics in major rivers in Japan are shown in Figure 3.1.23. According to this study, the maintenance flows are almost plotted between the 10-year average drought discharge and the 10-year minimum drought discharge. It is estimated that the overall average is 0.69 $m^3/s/100\ km^2$, almost all of which are concentrated in the range of about 0.3 to 2.0 $m^3/s/100\ km^2$. The average maintenance flow of the main rivers is 0.73 $m^3/s/100km^2$ (depending on the maximum value in the case it is set for each season).



Source: Guideline of Study of Maintenance Flow (Draft)" (MLIT Japan)

Figure 3.1.23 Relation between Catchment Area and Maintenance Flow (Example of Japan)

Referring to the above value of 0.73 $m^3/s/100km^2$, the maintenance flow of each object river is estimated as shown below.

Table 3.1.19 Maintenance Flow of Object Rivers According to the Cases of Japan

Item	Karnafuli (Halda)	Sangu	Matamuhuri
Catchment Area (km^2)	1,758	3,663	2,501
Maintenance Flow according to the case of Japan(m^3/s)	12.8	26.7	18.3

Source: JICA Survey Team

2) Examples of maintenance flow in Bangladesh

In Bangladesh, the term "environmental flow" is more commonly used than "maintenance flow". As a result of literature review, the concept of "environmental flow" is a relatively new one in the country, and there is no legal requirement for assessing the environmental flow of rivers. However, an environmental impact assessment (EIA) is essential as a requirement for water resources development projects, and the EIA itself includes analysis of river flow and evaluation of impact of flow reduction.

There are several examples of setting the environmental flow in Bangladesh.

Table 3.1.20 shows an example of a study on environmental flow in the Gorai River.

When subdivided, "environmental flow" covers the entire river ecosystem and does not include river use (boat transportation, estuary blockage prevention, river facility protection), while "maintenance flow" includes river use but does not include the environmental views from "material cycle" and “sediment balance" in the river. However, there is no clear definition of the environmental flow in Bangladesh, and it is practically ambiguous. Looking at the case of the environmental flow setting of the Gorai River in Bangladesh, river use (navigation) is considered as well as the "maintenance flow" setting in Japan. In this survey, there is no difference in the definition between the two terms, and both just consider the items in Table 3.1.17.

Table 3.1.20 Example of Setting Environmental Flow in Bangladesh

Item	Contents
Example of Study	Basic Features on the ‘Environmental Flow Assessment of Gorai River under Gorai River Restoration Project (Phase II)’ Report, (2017, BUET)
Background and Purpose	The Gorai River is one of the major tributaries of the Ganges (Padma) River. After the large barrage (Farakka) built in 1975 by the Indians on the river Ganges which is very near to the western border of Bangladesh, the flow of Ganges reduced significantly. Thus, the impact on the Gorai River was huge. It resulted in an increase in salinity intrusion in the southwest region including Sundarbans, which caused adverse impact on irrigation, fisheries, navigation, and biodiversity of the Gorai dependent areas. Under the Gorai River restoration project, capital dredging has been done in the Phase II Maintenance Dredging and further dredging was also done for the restoration of the river. The purpose of the study is to understand the environmental flow of the Gorai River for the sustainability of the Gorai River restoration and resuscitation.
Method	The following methods are applied for assessment of environmental flow in Gorai River: (1) Hydrological Methods (2) Hydraulic Rating Method (3) Habitat Method (4) E-Flow Assessment based on Salinity Condition (5) E-Flow Assessment for Navigation (6) Holistic Approach
Result	The following results are obtained by applying the above methods (1) Hydrological Methods: minimum flow of 160 m^3/s for fair habitat quality during dry period. (2) Hydraulic Rating Method：The analyzed result shows that average breakpoint discharge of Gorai River is 38 m^3/s and average incipient asymptote discharge is 3686 m^3/s. These are critically important for keeping the condition favorable for habitat. (3) Habitat Method: Considering the dominant fish species, physical habitat model simulates minimum requirement of low flow as 300 m^3/s d(Jan. – Mar.), 400m^3/s (Apr.-Jun.), 7,000 m^3/s (Jul. – Sep.), and 400 m^3/s (Oct. – Dec.) (4) E-Flow Assessment based on Salinity Condition: the minimum flow needed to be conveyed by the Gorai River at the Gorai Railway Bridge is 400 m^3/s. (5) E-Flow Assessment for Navigation: Considering Class-IV navigational route, Gorai demands a minimum of 140 m^3/s flow during dry period. (6) Holistic Approach: , this study recommends the Gorai flow of 160 – 400 m^3/s at the Gorai Railway Bridge during dry period (January to May). Based on the above, the study reveals the environmental flow requirement of the Gorai River as 160 m^3/s to 400 m^3/s (minimum) during the dry period (January to May) considering the salinity intrusion, sustainable ecosystem, good habitat for aquatic species, hydrological aspects and navigational requirement.

Source: Basic Features on the 'Environmental Flow Assessment of Gorai River under Gorai River Restoration Project (Phase II)' Report, (2017, BUET)

Among the above methods, the Tennant Method, which is one of the hydrological methods, is adopted as the simplest method.

i) Tennant Method

As shown in Table 3.1.21, the Tennant Method defines the habitat condition in a river by ratio of river discharge to a Mean Annual Flow (MAF).

Table 3.1.21 Example of Estimating Maintenance Flow in Bangladesh (Tennant Method)

Habitat quality	% of MAF	
	Low flow season	High flow season
Flushing or Maximum	200	200
Optimum	60-100	60-100
Outstanding	40	60
Excellent	30	50
Good	20	40
Fair	10	30
Poor	10	10
Severe degradation	<10	<10

Source: BWDB

Referring to (a) the 10% of MAF which gives poor condition in a river and (b) the MAF obtained from the discharge observation data (1966 to 2019) in each object river, the maintenance flows are calculated as follows.

Table 3.1.22 Maintenance Flows in Three Object Rivers according to the Case of Bangladesh (Tennant Method)

Item	Karnafuli (Halda)	Sangu	Matamuhuri
Mean Annual Flow (MAF) (m^3/s)	34.8	92.3	78.2
Maintenance Flow according to Tennant Method (m^3/s)	3.4	9.2	7.8

Source: JICA Survey Team

ii) Flow Duration Curve Method (FDC Method)

The FDC Method utilizes historical records to construct a flow duration curve for each month to provide various dependable flows. The recommended maintenance flow in each month is set at 90 % and 50 % dependable flows in the dry season months and the wet season months, respectively.

The results of the FCD Method using the discharge observation data (1966 to 2019) in each object river are as follows.

Table 3.1.23 Maintenance Flow in Three Object Rivers according to Example of Bangladesh (FDC Method)

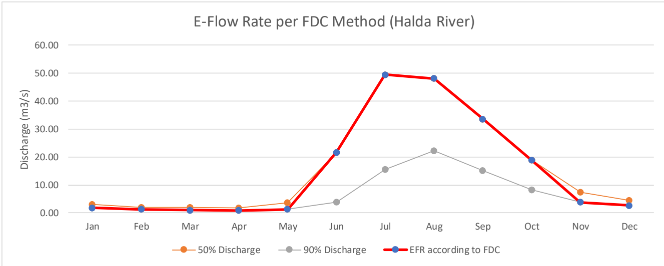
Item	Karnafuli (Halda)	Sangu	Matamuhuri
90% dependable flow in dry season month（m^3/s）	0.9-3.8	3.0-13.1	1.6-7.0
50% dependable flow in wet season month（m^3/s）	18.8-49.5	62.0-167.4	32.3-90.0

Source: JICA Survey Team

[Halda River]

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10% Discharge	6.32	3.92	3.35	7.42	23.00	136.90	206.78	128.88	78.66	51.80	18.50	9.06
50% Discharge	2.98	2.06	1.89	1.82	3.74	21.68	49.50	48.10	33.61	18.80	7.48	4.47
90% Discharge	1.80	1.30	1.03	0.86	1.31	3.78	15.58	22.28	15.18	8.16	3.84	2.62
Flow Season	Low	Low	Low	Low	Low	High	High	High	High	High	Low	Low
EFR according to FDC	1.80	1.30	1.03	0.86	1.31	21.68	49.50	48.10	33.61	18.80	3.84	2.62

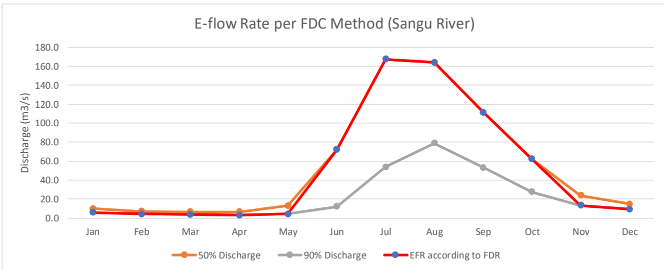
Dry Season	0.9	-	3.8
Wet Season	18.8	-	49.5



[Sangu River]

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10% Discharge	20.4	12.9	11.7	23.5	77.6	454.6	663.3	426.7	254.0	160.0	62.9	26.5
50% Discharge	9.9	7.2	6.3	6.4	12.8	72.0	167.4	163.8	111.3	62.0	23.9	14.6
90% Discharge	5.8	4.3	3.6	3.0	4.3	11.9	53.6	78.9	53.2	27.3	13.1	9.1
Flow Season	Low	Low	Low	Low	Low	High	High	High	High	High	Low	Low
EFR according to FDR	5.8	4.3	3.6	3.0	4.3	72.0	167.4	163.8	111.3	62.0	13.1	9.1

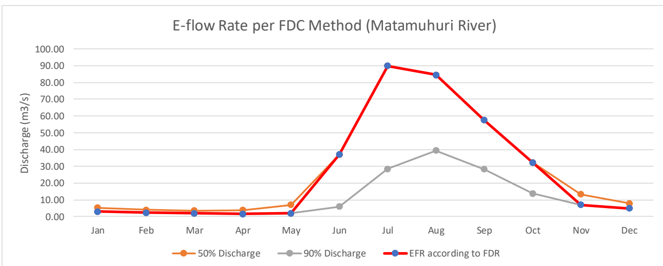
Dry Season	3.0	-	13.1
Wet Season	62.0	-	167.4



[Matamuhuri River]

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10% Discharge	11.23	9.25	8.59	18.21	36.89	247.07	372.59	228.52	135.83	84.10	34.97	14.82
50% Discharge	5.32	3.99	3.47	3.80	6.93	36.89	89.96	84.56	57.49	32.26	13.25	7.92
90% Discharge	2.99	2.24	1.93	1.64	1.99	5.96	28.41	39.33	28.32	13.73	7.03	4.94
Flow Season	Low	Low	Low	Low	Low	High	High	High	High	High	Low	Low
EFR according to FDR	2.99	2.24	1.93	1.64	1.99	36.89	89.96	84.56	57.49	32.26	7.03	4.94

Dry Season	1.6	-	7.0
Wet Season	32.3	-	90.0



Source: JICA Survey Team

Figure 3.1.24 Flow Duration Curve Method in Karnafuli (Halda), Sangu and Matamuhuri Rivers

3) Examples of maintenance flow estimation in other neighboring countries

In Indonesia and the Philippines, the maintenance flow is estimated based on the following criteria:

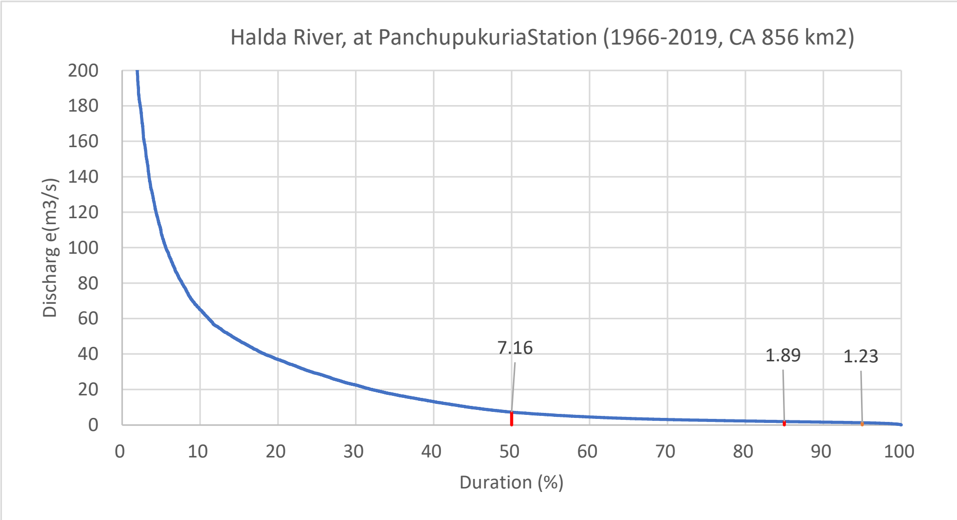
- Indonesia: 95% daily dependable flow (PU: for maintenance of river ecosystem), and
- Philippines: 90% of 85% daily dependable flow (NWRB).

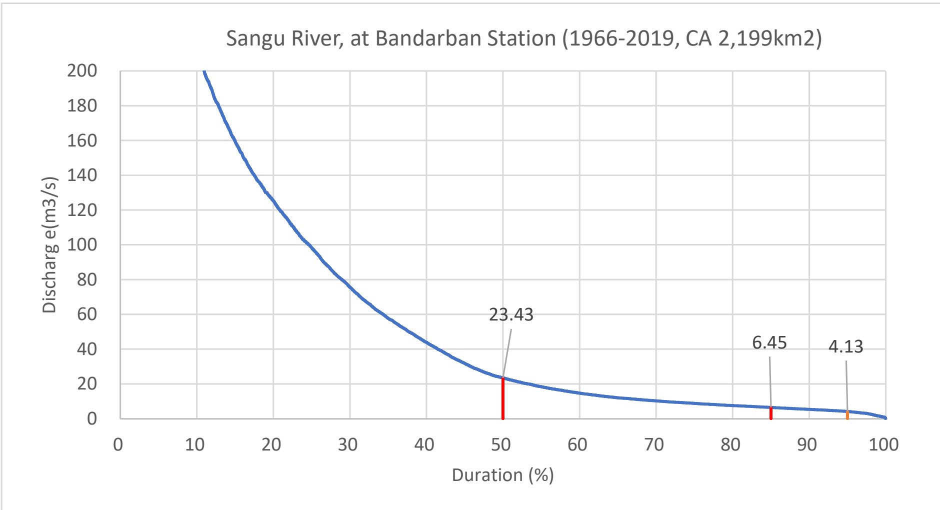
The maintenance flows in the 3 object rivers are calculated as tabulated below, by using the above mentioned criteria.

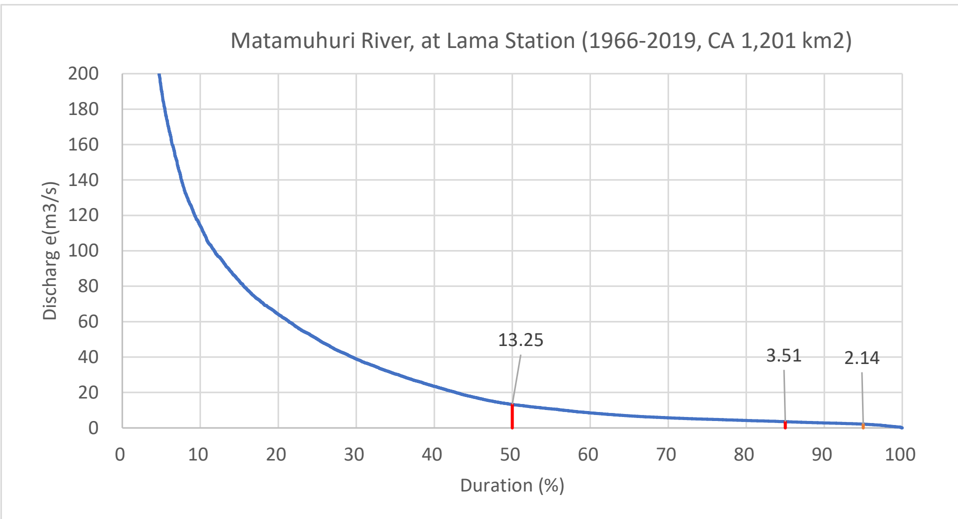
Table 3.1.24 River Maintenance Flows in Three Object Rivers

Item	Karnafuli (Halda) River	Sangu River	Matamuhuri River
Indonesia (95% dependable flow)	1.2	4.1	2.1
Philippines (90% of 85% dependable flow)	1.7	5.8	3.2

Source: JICA Survey Team







Source: JICA Survey Team

Figure 3.1.25 Flow Duration Curve in Karnafuli (Halda), Sangu and Matamuhuri Rivers

4) Provisional Settings of Maintenance Flow

The data and calculation results in 1) - 3) above are compiled in **Table 3.1.25**.

Table 3.1.25 Provisional Settings of Maintenance Flows in Three Object Rivers

Discharge Data (Observation)

River		Karnafuli (Halda)	Sangu	Matamuhuri
Station		Panchpukuria	Bandarban	Lama
Period		1966/1/1-2019/12/31	1966/1/1-2019/12/31	1966/1/1-2019/12/31
Catchment Area (km^2)	Total	1,758	3,663	2,511
	at WL gauge	856	2,199	1,201
Discahrge (m^3/s) @ WL Station	Mean Annual Flow (MAF)	27.36	92.26	49.05
	95% discharge:	1.23	4.13	2.14
	85% discharge:	1.89	6.45	3.51
	50% discharge:	7.16	23.43	13.25

Maintenance Flow (preliminary estimation)

River		Karnafuli (Halda)	Sangu	Matamuhuri
Station		Panchpukuria	Bandarban	Lama
(1) Method in Japan	$0.73m^3/s/100km^2$	12.8	26.7	18.3
(2) Methods in Bangadesh	Tenanto method (10% of MAF)	2.7	9.2	4.9
	FDC method (90% discharge in dry season)	0.9-3.8	3.0-13.1	1.6-7.0
	FDC method (90% discharge in wet season)	18.8-49.5	62.0-167.4	32.3-90.0
(3)-1 Method in Indonesia	95% discharge	1.2	4.1	2.1
(3)-2 Method in Philippines	90% of the 85% discharge	1.7	5.8	3.2

Source: JICA Survey Team

(4) Maintenance Flow in Karnafuli River

In the Karnafuli River, the concentration of salt increased significantly in 2007 at the potable water intake point. Therefore, the BWDB carried out an investigation to grasp the actual situation, resulting in the estimation that the river stretches over 40 km from the estuary was affected by salinization.

Based on this result, a memorandum between the BWDB and the dam managers was exchanged in relation to the operation of the Kaptai Dam, in which it was stipulated that at least two power generation units must be operated so as to release discharges to the downstream, and then maintenance discharges have already been secured.

3.1.6 Ground Water Development Potential

The ground water potential of the survey area is examined in terms of ground water level fluctuation and macro water balance.

(1) Fluctuation of ground water level

In order to see the fluctuation of the ground water level in the survey area, the ground water level fluctuation curve diagrams of shallow and deep wells were prepared for each of four Upazilas (Chakaria, Moheshkhali, Cox's Bazar and Ramu) in the survey area. The data used are the ground water level monitoring data by DPHE from 1986 to 2018. However, the observation period may be shorter than the above period in some upazilas.

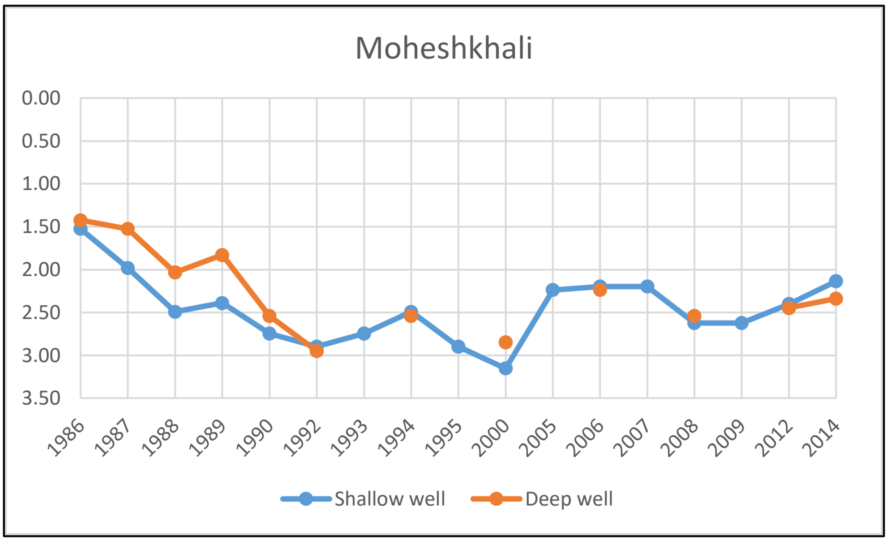
1) Ground water fluctuation in Chakaria

The fluctuation of the average ground water level in Chakaria from 1986 to 2018 is shown in Figure 2.2.16 and Table 2.2.7 in Chapter 2. The following are clarified by these data.

- The fluctuation curves of the ground water levels in the shallow and deep wells show almost the same behaviour.
- The ground water level fluctuation of each aquifer is between 3.3 m and 3.4m for 32 years, and the average ground water level declination of each aquifer is 0.10 m/year.
- Although the shallow and deep wells extract ground water from different aquifers, it is suggested that the aquifers have hydrogeological connections with each other.

2) Ground water fluctuation in Moheshkhali

Figures 3.1.26 and Table 3.1.26 show the fluctuations and decrements of ground water level, respectively in the shallow and deep wells for 28 years (1986 to 2014) in Moheshkhali.



Source: JICA Survey Team. Data of DPHE was used.

Figure 3.1.26 Fluctuation of Average Ground Water Level in Moheshkhali (1986-2014)

Table 3.1.26 Decrements of Average Ground Water Level in Moheshkhali (1986-2014)

Depth of Well	Water Level(m)		Declination (m)		Aver. Decrement (m/year)
	1986	2014			
Shallow well: less than 200 feet (less than about 61m)	1.53	2.14	0.61		0.02
Deep well: 200 feet or more (about 61m or more)	1.42	2.34	0.92		0.03

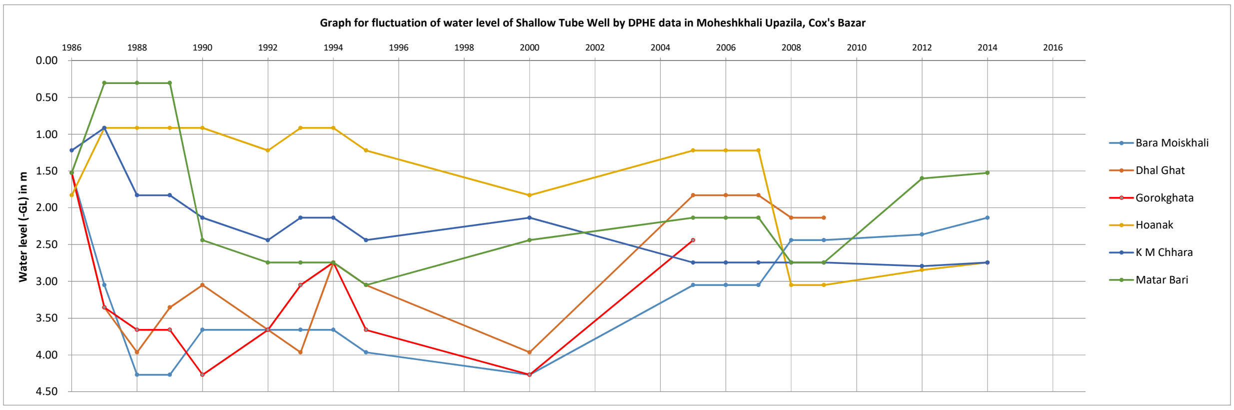
Source: JICA Survey Team. Data of DPHE was used.

Table 3.1.27 shows the water levels of 5 shallow and 3 deep wells in 1986 and 2014 (the final year of the observation data). The fluctuation of the ground water level in this period is shown in Figure 3.1.27.

Table 3.1.27 Fluctuation of Ground Water Level in Moheshkhali

Well	Water Level (m)		Declination		
	1986	2014	Declination (m)	Average of Well (m/year)	Average of Wells (m/year)
<Shallow Well>					0.22
Bara Moiskhali	1.53	2.14	0.61	0.022	
Dhai Ghat	1.53	1.53	0.00	0.000	
Hoanak	1.83	2.75	0.92	0.033	
K. M. Chhara	1.22	2.75	1.53	0.055	
Matarbari	1.53	1.53	0.00	0.000	
＜Deep Well＞					0.03
Dhal Ghat	1.53	1.83	0.30	0.01	
K M Chhara	1.22	2.75	1.53	0.05	
Matarbari	1.53	2.44	0.91	0.03	

Source: JICA Survey Team. Data of DPHE was used.



Source: JICA Survey Team. Data of DPHE was used.

Figure 3.1.27 Ground Water Fluctuation of Shallow Wells in Moheshkhali (1986-2014)

The ground water levels of shallow wells in 1986 concentrated in a range between 1.22m and 1.83m. Considering topographical factors, it can be said that it is highly possible that the 5 shallow wells extracted ground water from almost the same aquifer. After the commencement of observation in 1986, the ground water levels of the 4 wells, except for the Hoanak well, showed a downtrend, but they began to show a slight upward trend around 2000. The ground water level of the Hoanak well has not changed significantly until 1994, but declined after 1994. Especially from 2007 to 2008, it decreased sharply by

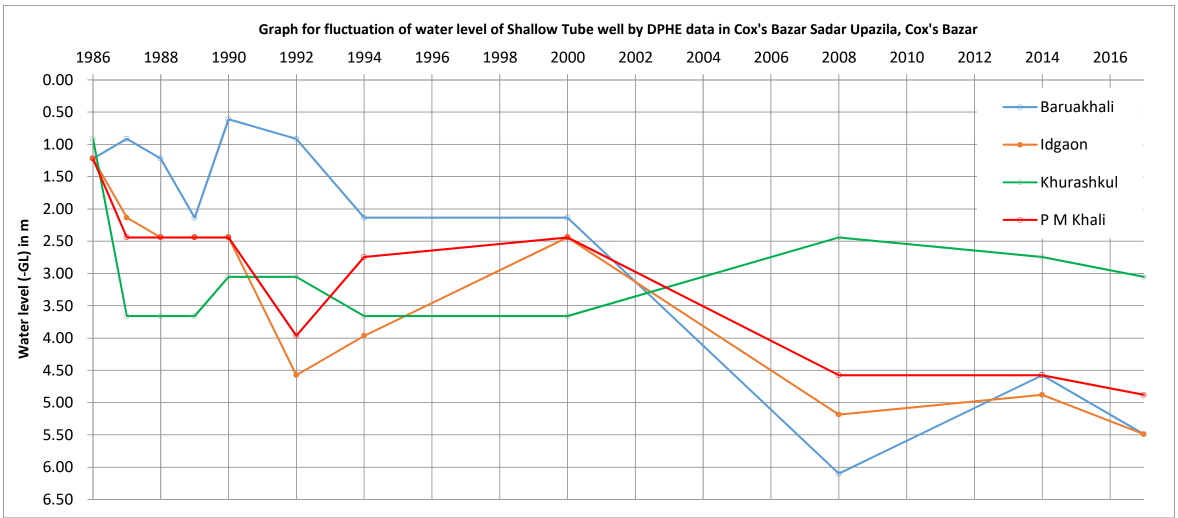
1.83m and then showed a very gradual upward trend. As a whole, the ground water levels of shallow wells in Moheshkhali dropped once and then kept the dropped ground water level or showed a gradual upward trend. Comparing the water levels in 1986 when monitoring started and in 2014, which is the final year of the data, there are two (2) wells showing the same water level. The ground water level declination of the other three (3) wells ranges from 0.61 m to 1.53 m. The average declination in the 28 year observation period is in a range from 2.2 to 5.5 cm/year, which indicates an extremely small declination of ground water level. However, from 1986 to 1990, the four (4) wells showed large decreases of ground water level which were 2 m or more per year. No major development has been seen in Moheshkhali. There are few factors considered that significantly increased the amounts of pumped water. This may indicate that it is susceptible to slight increase in pumping volume. Then, it can be said that the potential of the shallow aquifer distributed in Moheshkhali is small.

As to deep wells, the ground water level in 1986 was in a range from 1.22 m to 1.53 m, which is almost the same as those in the shallow wells. The ground water levels began to fall in two (2) of the three (3) wells after 1986, and dropped rapidly until around 1990, dropping by about 0.9 m to 1.5m. After that, small changes of ground water level were repeated. Only the Matarbari well showed a sharp ground water level rise of 1.8 m in 1987, then in 1989 the water level also fell, and then behaved the same way as the other wells. In Matarbari, the ground water potential is unlikely to be high as in Moheshkhali.

In Moheshkhali, there are areas where ground water is artesian, mainly near the foot of the hill from the southern part to the southwestern part of the island.

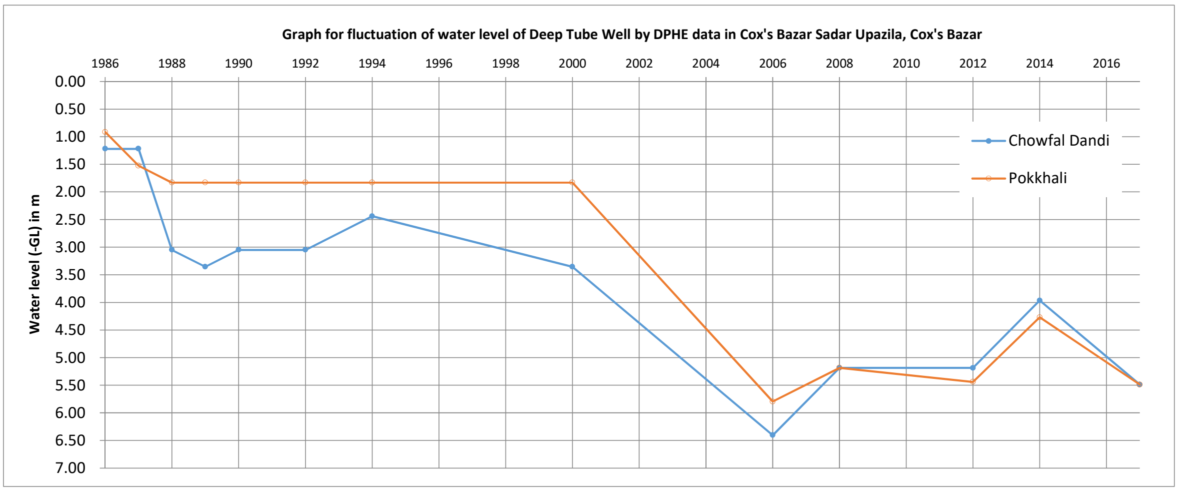
3) Ground water fluctuation in Cox’s Bazar

The ground water level fluctuations of the shallow and deep wells in Cox's Bazar are shown in Figure 3.1.28 and Figure 3.1.29, respectively.



Source: JICA Survey Team. Data of DPHE was used.

Figure 3.1.28 Ground Water Fluctuation of Shallow Wells in Cox’s Bazar (1986 -2017)



Source: JICA Survey Team. Data of DPHE was used.

Figure 3.1.29 Ground Water Fluctuation of Deep Wells in Cox's Bazar (1986 -2017)

Data for four (4) shallow and two (2) deep wells are available in Cox's Bazar. The observation period is 31 years from 1986 to 2017. Table 3.1.28 shows the changes of the ground water level in 1986 and 2017.

Table 3.1.28 Changes of Ground Water Level in Cox's Bazar in 1986 and 2017

Well	Water Level (m)		Declination		
	1986	2017	Declination (m)	Average of Well (m/year)	Average of Wells (m/year)
<Shallow Well>					0.12
Baruakhali	1.22	5.49	4.27	0.14	
Idgaon	1.22	5.49	4.27	0.14	
Khurashkul	0.92	3.05	2.13	0.07	
P M Khali	1.22	4.88	3.66	0.12	
<Deep Well>					0.15
Chowfal Dandi	1.22	5.49	4.27	0.14	
Pokkhali	0.92	5.49	4.57	0.15	

Source: JICA Survey Team. Data of DPHE was used.

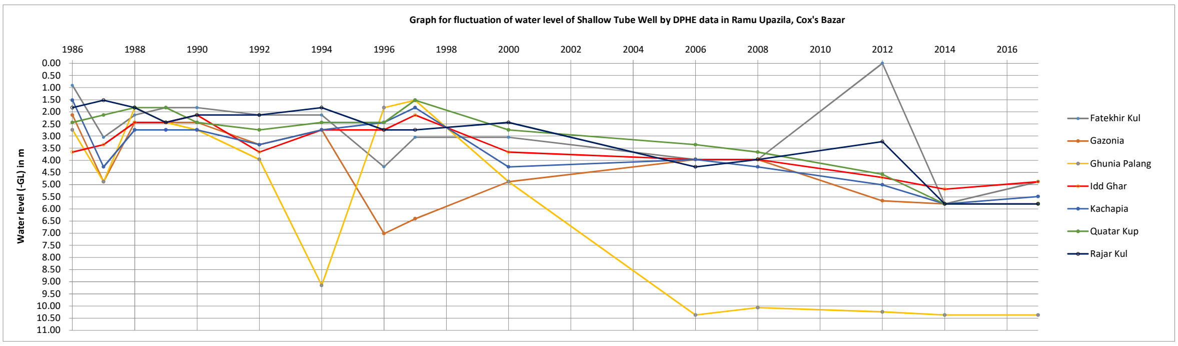
As for the ground water level of shallow wells, the water level began to fall after 1986, and the water level dropped by about 2.7 to 5.2 m up to 1994. After that, except for the well in Khurashkul, the ground water level dropped again from 2000 and reached the water level of 2017. The ground water level in 2017 is in a range from 3.1to 5.5m. After descending from 0.9m to 3.7m, the Khurashkul well maintained almost the same ground water level, albeit with some ups and downs. The ground water level started to rise gradually from 2000. The behaviour of the ground water level at the Khurashkul well is clearly different from those of the other three (3) wells. This indicates that even if the ground water is pumped from the same shallow aquifer, it may be affected by different recharge mechanism depending on the distribution of the aquifer.

Two (2) wells data are available for the deep wells. The ground water levels in the deep wells dropped by 0.9 to 1.8m from 1986 to 1988, and then there was no significant change in the ground water level. The declination began again from 2000 to 2008, and both wells fell to 5.5 m in 2017.

Except for the Khurashkul well, both the ground water levels of the shallow and deep wells show similar behaviours, with the ground water level dropping once around 1988 and then dropping again from 2000. From this, it is presumed that there is some connection between the shallow aquifer and the deep aquifer.

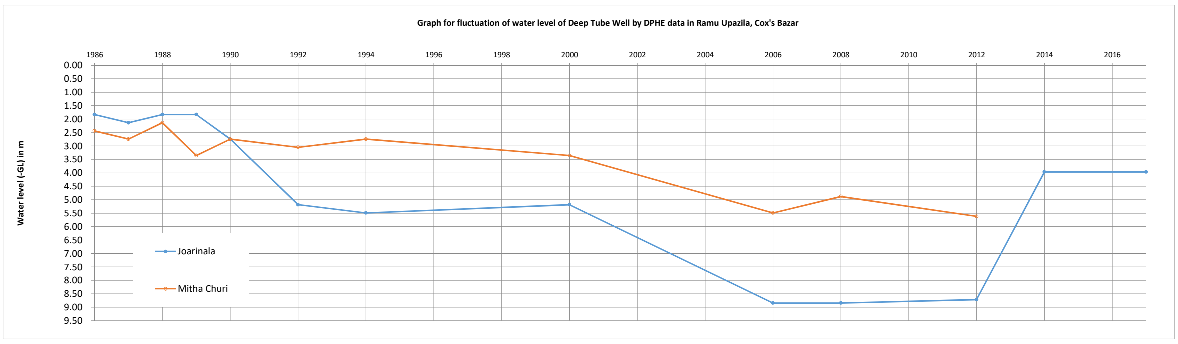
4) Ground water fluctuation in Ramu

According to the DPHE Ramu Upazila office, artesian wells are distributed throughout the upazila. Therefore, the data of the observation wells excluding the artesian well are used. The period of the data is from 1986 to 2017. Using the data, the ground water level fluctuation curves for the shallow and deep wells were prepared, as shown in Figures 3.1.30 and 3.1.31.



Source: JICA Survey Team. Data of DPHE was used.

Figure 3.1.30 Ground Water Level Fluctuation of Shallow Wells in Ramu (1986-2017)



Source: JICA Survey Team. Data of DPHE was used.

Figure 3.1.31 Ground Water Level Fluctuation of Deep Wells in Ramu (1986-2017)

Table 3.1.29 shows the ground water level declination in Ramu for 31 years from 1986 to 2017.

Table 3.1.29 Ground Water Level Declination in Ramu (1986 – 2017)

Well	Water Level (m)		Declination		
	1986	2017	Declination (m)	Average (m/year)	Average of Wells (m/year)
<Shallow Well>					0.13
Fatekhir Kul	0.91	4.88	3.97	0.13	
Gazonia	2.13	5.79	3.66	0.12	
Ghunia Palang	2.74	10.36	7.62	0.25	
Idd Ghar	3.66	4.88	1.22	0.04	

Well	Water Level (m)		Declination		
	1986	2017	Declination (m)	Average (m/year)	Average of Wells (m/year)
Kachapia	1.52	5.49	3.96	0.13	
Quatar Kup	2.44	5.79	3.35	0.11	
Rajar Kul	1.83	5.79	3.96	0.13	
<Deep Well>					
Mitha Churi	2.44	6.40	3.96	0.13	0.10
Joarinala	1.83	3.96	2.13	0.07	

Source: JICA Survey Team. Data of DPHE was used.

As a whole, the ground water levels of the shallow wells have not changed significantly until around 1998. The ground water levels began to decline around 1998, and the ground water levels continued to decline gradually, reaching the water level in 2017. However, only the ground water level of the well in Ghunia Palang behaves quite differently. Although no significant change of the ground water level was observed until around 1997, the ground water level dropped sharply from 4.9 m to 10.4 m from around 1997. After that, the ground water level remained almost unchanged until 2017. On the contrary, at the Fatekhir Kul well (artesian well) the ground water level rose in 2012 and dropped again in 2014. In this way, although there are exceptions in the shallow aquifer of Ramu, the ground water level is gradually decreasing as a whole, indicating that there are many areas subject to excessive pumping.

Only two (2) wells data are available for the deep wells, and therefore it is difficult to discuss the overall trend in the area. However, ground water levels generally declined until 2012. The ground water level in the Joarinala well did not change significantly until 1989, and showed a sharp drop from 1.8m to 5.2m from 1989 to 1992. After that, although the ground water level was different from that of the Mitha Churi well until 2012, the water level change behaved similarly. The Joarinala wells maintained almost the same ground water level until 2000, but dropped to 8.9 m from 2000 to 2006. After that, there was no change of water level until 2012, and it showed a large ground water level rise of 4.8m by 2014. The ground water level after that was almost constant. Since the ground water level of the Ramu deep well behaved in the same way and/or differently depending on the year, it has some hydrogeological relation with the aquifer, and the recharge and other conditions differ by area.

As the fluctuation curves of ground water levels in the shallow and deep wells show different behaviours, it may be possible that the shallow and deep aquifers separate from each other in Ramu.

The monitoring results of ground water level in the four (4) Upazilas in the survey area show a common tendency of the groundwater level which declined faster after around 2000, although there are differences in the behaviour of the change in the ground water levels. This suggests that there was some event around 2000 that increased the amount of ground water extraction. However, no clear data or information is available on this at this time.

In the survey area, the fluctuations of ground water level behaved more or less in the same way in the shallow and deep wells except for Ramu, so even if they are separated by aquicludes, they may be connected to each other in some places. This is consistent with the discontinuity of some aquicludes shown in "Figure 2.2.5 Geological Cross Section of Survey Area" in Chapter 2.

(2) Ground water balance

1) Ground water extraction

In the survey area, ground water is extracted for (a) domestic use in the rural areas, (b) urban water supply to Cox's Bazar and Matarbari Project and (c) irrigation. Among these, the annual amount of water extraction for the domestic and irrigation uses was calculated based on the inventory survey results and the data on the number of existing wells by DPHE and the Ministry of Agriculture. Table 3.1.30 shows the average amounts of ground water extraction per well obtained from the inventory survey results, and Table 3.1.31 shows the purpose-wise annual amounts of ground water extraction from wells. The amount of irrigation water extraction is shown in Table 3.1.32.

Table 3.1.30 Average Ground Water Extraction per Well

Item		Number of Well	Extraction Rate	Extraction Hours	Extraction Days	Annual Extraction	Average Extraction
		(well)	(m³/hour)	(hour/day)	(day/year)	(m³/year)	(m³/well/year)
Domestic use	<Shallow Well>						
	Chakaria	32	60.2	6.1	365	134,674	4,209
	Moheshkhali	18	29.4	5.5	365	59,021	3,279
	Cox's Bazar	18	29.9	6.4	365	69,347	3,853
	Ramu	11	11.0	5.7	365	22,764	2,069
	Total	77	130.5			285,805	
	<Deep Well>						
	Chakaria	243	493.5	8.5	365	1,531,825	6,304
	Moheshkhali	98	196.8	8.9	365	641,460	6,546
	Cox's Bazar	143	298.5	6.1	365	664,610	4,648
	Ramu	107	204.7	5.8	365	431,771	4,035
	Total	591	1,193.5			3,269,666	
Irrigation use	<Shallow Well and Deep Well>						
	Chakaria	63	427.0	12.0	115	621,809	9,870
	Moheshkhali	45	158.8	12.3	134	286,306	6,362
	Cox's Bazar	88	472.4	11.3	117	615,103	6,990
	Ramu	66	467.7	8.8	108	428,155	6,487
	Total	262	1,525.8			1,951,373	

Source: JICA Survey Team; As to the "Number of well" for irrigation use, the data of the Ministry of Agriculture was used.

Table 3.1.31 Ground Water Extraction for Domestic Use

Upazila	Shallow Well			Deep Well			Total
	Extraction	Number of Well	Annual Extraction	Extraction	Number of Well	Annual Extraction	
	(m³/well/year)	(well)	(m³)	(m³/well/year)	(well)	(m³)	(m³)
Chakaria	4,407	2,809	12,379,025	6,405	2,436	15,602,791	27,981,816
Moheshkhali	3,279	1,975	6,475,860	6,546	1,305	8,541,888	15,017,748
Cox's Bazar	3,853	1,925	7,416,285	4,648	1,836	8,533,038	15,949,323

Upazila	Shallow Well			Deep Well			Total
	Extraction	Number of Well	Annual Extraction	Extraction	Number of Well	Annual Extraction	
	(m^3/well/year)	(well)	(m^3)	(m^3/well/year)	(well)	(m^3)	(m^3)
Ramu	2,069	2,116	4,378,915	4,035	1,188	4,793,871	9,172,786
Total		8,825	30,650,085		6,765	37,471,588	68,121,673

Source: JICA Survey Team

Table 3.1.32 Ground Water Extraction for Irrigation Use

Upazila	Shallow and Deep Wells		
	Extraction	Number of Well	Annual Extraction
	(m^3/well/year)	(well)	(m^3)
Chakaria	29,189	1,215	35,464,485
Moheshkhali	16,347	470	7,683,002
Cox's Bazar	22,475	1,173	26,363,742
Ramu	25,158	715	17,987,643
Total		3,573	87,498,872

Source: JICA Survey Team; The "Number of Well" is derived from BADC/DAE data.

From Tables 3.1.31 and 3.1.32, the amounts of ground water extraction for one year are 68,121,673 m^3 for domestic use and 87,498,872 m^3 for irrigation use. The extraction amount of ground water for urban water supply in Cox's Bazar is estimated as stated below. There are 10 deep wells as the water sources in Cox's Bazar. In order to estimate the amount of ground water extraction, the following assumptions are made.

- ➢ The pumping amount from each of the 10 wells shall be 30 m^3/hour, which is the pumping amount of the wells at the Primary School Pump Station, and the operation hour shall be 10 hours.
- ➢ Among the 10 wells, two (2) are to be used as standby wells. That is, eight (8) wells are constantly used.

From the above conditions, the amount of ground water extraction is calculated as follows.

30 (m^3/hour/well) x 10 (hour/day) x 8 (well) x 365 (day) = 876,000 (m^3)

It is planned in Bangladesh to shift the water source for urban water to surface water because of the risk of declination of ground water level and infiltration of salt water into the ground water in Cox's Bazar.

As of October 2021, DPHE was constructing the following new water supply facilities, which are scheduled to be completed around mid-2022.

- Intake from the Bakkhali River: 1 unit
- Water treatment plant: 1 unit
- Ground tank: 1 unit
- Overhead tank: 4 unit
- Expansion of pipeline

Besides, in Chakaria City, urban water supply facilities were under construction. The water source is ground water, and five (5) deep wells for the water source were constructed. Repair works were carried out because some parts of the pipeline were damaged. The repair works were completed and urban water supply to Chakaria City is expected to be commenced by the end of December 2022 (as of August 2022).

Sixteen (16) deep wells were constructed in the site of the Matarbari Ultra-supercritical Coal-fired Power Generation Project, which is being promoted with the cooperation of Japan, and 14 wells are used for domestic water and also construction water (as of January 2020). The daily extraction volume is about 621 m^3. Therefore, the amount of extraction of water for one year is 621 (m^3/day) x 365 (day) = 226,665 m^3.

From the above examination results, the amount of ground water extraction in the whole survey area is summarized as shown in Table 3.1.33.

Table 3.1.33 Annual Ground Water Extraction in Survey Area

	Shallow Well (m^3)	Deep Well (m^3)	Total (m^3)
Domestic water in the rural area (Other than urban water supply in Cox's Bazar)	30,650,085	37,471,588	68,121,673
Urban water supply (Cox's Bazar)	-	876,000	876,000
Project site in Matarbari	-	226,665	226,665
Irrigation water	87,498,872		87,498,872
Total	-	-	156,723,210

Source: JICA Survey Team

From Table 3.1.33, in the whole survey area, about 69.2 x 10^6 m^3 of ground water for domestic use and urban water supply, including the project site in Matarbari, and about 87.5 x 10^6 m^3 for irrigation water are extracted in a year, totalling about 156.7 x 10^6 m^3.

3.1.7 Water Cycle Analysis

(1) Surface water analysis

Rainfall is divided into evapotranspiration, surface water and percolation water into the underground, and the rough water balance of surface water in each basin (Karnafuli, Sangu and Matamuhuri River basins) was grasped. The amounts of water resources were calculated by using the calculation method and data shown in Table 3.1.34 for the target period of 54 years (1966-2019).

Table 3.1.34 Method and Resource Data for Calculation of Surface Water Resources

Item	Calculation Method	Resource Data
Rainfall	Calculation of average rainfall over watershed by Thiessen Method	Observed daily rainfall data
Evapotranspiration	Penman-Monteith Method	Observed daily temperature, humidity, sunshine hour and wind speed
Surface Water	Discharge conversion by using catchment area rate from water level gauge station	Observed daily discharge data

Item	Calculation Method	Resource Data
Percolation Water into underground	Percolation rate considering rain date Percolation rate: Mountain area 5 mm/day, Plain area 2.5 mm/day	Percolation rate and daily rainfall data

Source: JICA Survey Team

The percolation rate per day into the underground at a plain area for calculating the percolation amount is based on the results of the survey conducted by the Barind Multipurpose Development Authority (BMDA) in the south Chattogram region in the past, and was set at 2.5 mm/day (refer to Table 3.1.35 and Figure 3.1.32). Since there were no survey results in the mountainous areas, the survey results of 5.0mm/day for the northwest hills area (Panchagarh and Thakurgaon areas), where the geotechnical structure (sand, silt, clay) and physiographic feature (hills) are similar, is applied for the percolation rate in the mountain area of the south Chattogram region.

Table 3.1.35 Survey Results of Percolation Rate into Underground

< Target Plain Area-2 >

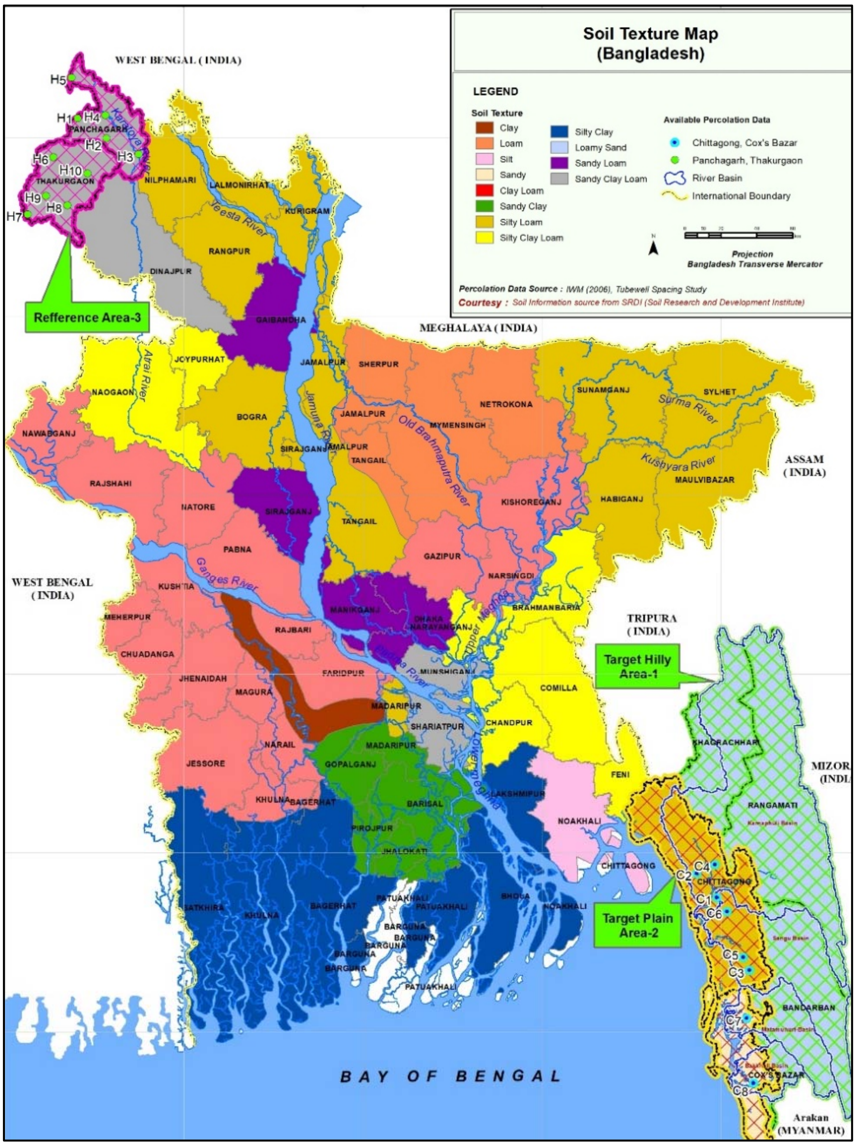
District		Thana	Percolation Rate (mm/day)
Chittagong	C_1	Boalkhali	2.5
	C_2	Hathazari	2.5
	C_3	Lohagara	2.5
	C_4	Raozan	2.5
	C_5	Satkania	2.5
	C_6	Patiya	2.5
Cox's bazar	C_7	Chakaria	2.5
	C_8	Ramu	2.5
Average			2.5

Source: Tubewell Spacing Study, BMDA, June 2006

< Reference Area-3 >

District		Thana	Percolation (mm/day)
Panchagarh	H_1	Atwari	5.0
	H_2	Boda	5.0
	H_3	Debiganj	5.0
	H_4	PanchgarhSadar	5.0
	H_5	Tentulia	5.0
Thakurgaon	H_6	Baliadangi	5.0
	H_7	Haripur	5.0
	H_8	Pirganj	5.0
	H_9	Ranisankail	5.0
	H_{10}	ThakurgaonSadar	5.0
Average			**5.0**

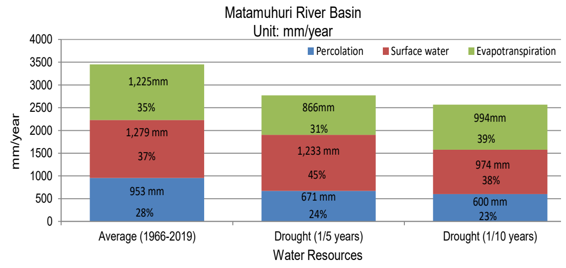
Source: Tubewell Spacing Study, BMDA, June 2006

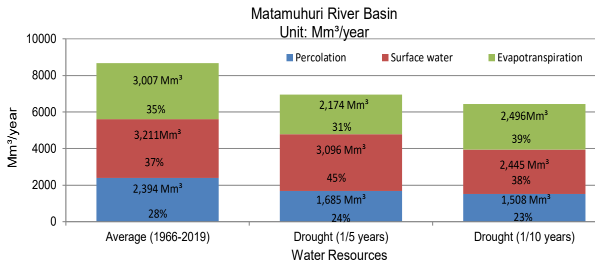


Source: Tubewell Spacing Study, BMDA, June 2006

Figure 3.1.32 Location Map of Percolation Rate Survey

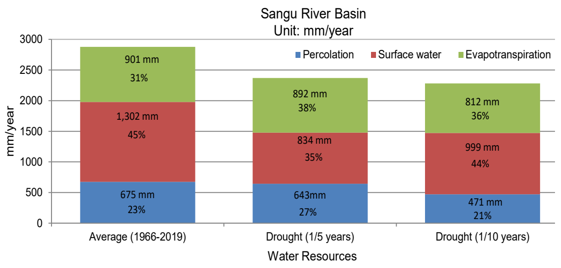
The amounts of surface water resources in the Matamuhuri and Sangu River basins were calculated from the calculation for the 54 years (1966-2019) (refer to the "Annex 3.1-4 "), and the amounts of the 54 year average, 1/5 drought year and 1/10 drought year were summarized as shown in Figures 3.1.33 to 3.1.35 and Tables 3.1.36 to 3.1.38. The amount of surface water resources in the Karnafuli River basin was calculated by dividing it into the upstream and downstream basins of the Kaptai Dam. The calculations in both basins were based on the discharges of Kaptai Dam inflow and Panchpukuria water level gauge station, respectively, and the values in both basins were combined to estimate the statistics of surface water resources for the average for 52 years (1968 to 2019) and drought years (1/5 and 1/10) in the whole Karnafuli River basin.

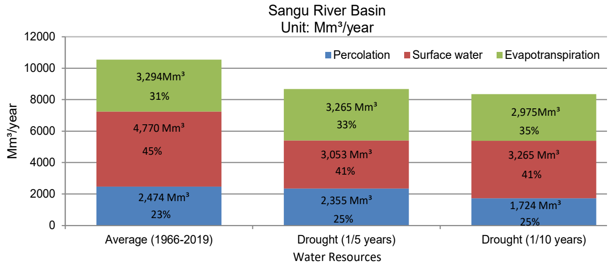




Source: JICA Survey Team

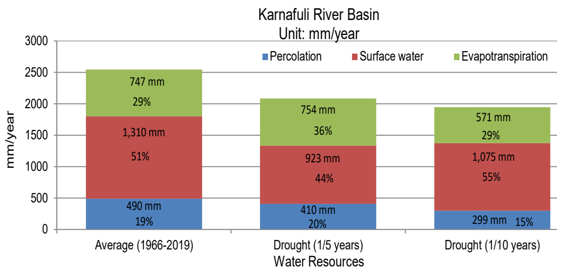
Figure 3.1.33 Graphs of Surface Water Resource in Matamuhuri River Basin

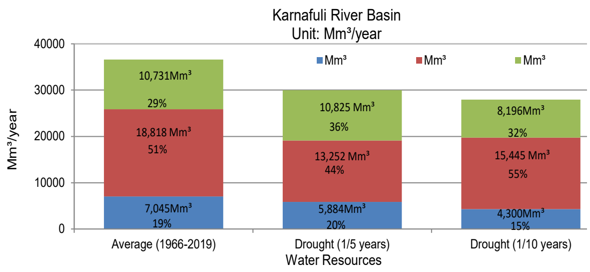




Source: JICA Survey Team

Figure 3.1.34 Graphs of Surface Water Resource in Sangu River Basin





Source: JICA Survey Team

Figure 3.1.35 Graphs of Surface Water Resource in Karnafuli River Basin

Table 3.1.36 Calculation Result Table of Surface Water Resource in Matamuhuri River Basin

Water Resources	Drought Year	Rainfall	Percolation		Surface water		Evapotranspiration	
		mm	mm	%	mm	%	mm	%
Average (1966-2019)	-	3,457	953	28	1,279	37	1,225	35
Drought (1/5 years)	(1980-81)	2,769	671	24	1,233	45	866	31
Drought (1/10 years)	(1978-79)	2,568	600	23	974	38	994	39

Note: Droght year selected based on rainfall

Water Resources	Drought Year	Rainfall	Percolation		Surface water		Evapotranspiration	
		Mm³	Mm³	%	Mm³	%	Mm³	%
Average (1966-2019)	-	8,681	2,394	28	3,211	37	3,077	35
Drought (1/5 years)	(1980-81)	6,954	1,685	24	3,096	45	2,174	31
Drought (1/10 years)	(1978-79)	6,449	1,508	23	2,445	38	2,496	39

Note: Droght year selected based on rainfall

Source: JICA Survey Team

Table 3.1.37 Calculation Result Table of Surface Water Resource in Sangu River Basin

Water Resources	Drought Year	Rainfall	Percolation		Surface water		Evapotranspiration	
		mm	mm	%	mm	%	mm	%
Average (1966-2019)	-	2,877	675	23	1,302	45	901	31
Drought (1/5 years)	(1966-67)	2,368	643	27	834	35	892	38
Drought (1/10 years)	(1978-79)	2,282	471	21	999	44	812	36

Note: Droght year selected based on rainfall

Water Resources	Drought Year	Rainfall	Percolation		Surface water		Evapotranspiration	
		Mm³	Mm³	%	Mm³	%	Mm³	%
Average (1966-2019)	-	10,538	2,474	23	4,770	45	3,294	31
Drought (1/5 years)	(1966-67)	8,673	2,355	27	3,053	35	3,265	38
Drought (1/10 years)	(1978-79)	8,359	1,724	21	3,659	44	2,975	36

Note: Droght year selected based on rainfall

Source: JICA Survey Team

Table 3.1.38 Calculation Result Table of Surface Water Resource in Karnafuli River Basin

Water Resources	Drought Year	Rainfall	Percolation		Surface water		Evapotranspiration	
		mm	mm	%	mm	%	mm	%
Average (1966-2019)	-	2,548	490	19	1,310	51	747	29
Drought (1/5 years)	(1994-95)	2,086	410	20	923	44	754	36
Drought (1/10 years)	(2013-14)	1,945	299	15	1,075	55	571	29

Note: Droght year selected based on rainfall

Water Resources	Drought Year	Rainfall	Percolation		Surface water		Evapotranspiration	
		Mm³	Mm³	%	Mm³	%	Mm³	%
Average (1966-2019)	-	36,595	7,045	19	18,818	51	10,731	29
Drought (1/5 years)	(1994-95)	29,962	5,884	20	13,252	44	10,825	36
Drought (1/10 years)	(2013-14)	27,942	4,300	15	15,445	55	8,196	29

Note: Droght year selected based on rainfall

Source: JICA Survey Team

(2) Ground water analysis

It was thought that the ground water in the survey area had been stored in the unconfined shallow and confined deep aquifers. However, according to the survey result, it is now thought that both aquifers are partially connected with each other in the survey area as described in "Sub-section 2.2.2".

The shallow aquifer is mainly distributed in the basin-shaped coastal plain that opens to the Bay of Bengal to the west, surrounded by the foothills of the CHT in the east, the hills in the northern part of Chakaria in the north, and the hills in the southern part of Cox's Bazar in the south. Therefore, it is considered that the ground water of the shallow aquifer is directly recharged by the precipitation and surface water that have fallen on these coastal plain and the CHT.

The ground water level of the aquifers distributed in the survey area is affected by the rainy season and the dry season as described in Chapter 2. This means that the aquifer is recharged from surface water.

Since it is not possible to directly measure the amount of recharge from surface water to ground water, the amount of ground water recharge is estimated by using the amount of percolation into the underground obtained in the examination in Section 3.1.7 (1) Surface water analysis". Hydrological analysis is performed on the Matamuhuri River basin. The Matamuhuri River basin is adjacent to the groundwater survey area. The river basin and the groundwater survey area are located on the western edge of the CHT area, and the geological conditions are similar. Topographically, there is a valley-like topography between the Moheshkhali Island and the western edge of the CHT area, and there are topographical similarities. A large area of the coastal plain extending between the western edge of CHT and the Moheshkhali Island is used as a salt pan, covered by sheets for flooding with salt water, and no underground infiltration of surface water can be expected. The area of the salt pans is 149 km^2 in total in the three Upazilas of Chakaria, Moheshkhali and Cox's Bazar.

Since there is no data that covers the entire survey area, the said data is used for estimation.

The results of the hydrological analysis in the Matamuhuri River basin are as follows:

- River basin area: 2,511.10 km^2, and
- Percolation volume into underground: 2,394 x 10^6 m^3 (28%).

The total area of the four Upazilas in the survey area is 1,387 km^2. If the area of the salt pans is subtracted, it is 1,238 km^2. The percolation amount into underground is calculated by using the area ratio of the Matamuhuri River basin and the ground water survey area, as follows.

$$(2,394 \times 10^6\ m^3) \times (1,238\ km^2) / (2,511\ km^2) = 1,180 \times 10^6\ m^3$$

From the above, it is estimated that 1,180 x 10^6 m^3 of surface water percolates into underground from the surface water, resulting in ground water recharge.

Furthermore, from the examination results of 1) and 2), the amount of ground water extraction is 156.7 x 10^6 m^3, while the amount of ground water recharge from surface water is 1,180 x 10^6 m^3. Therefore, the amount of recharge exceeds the amount of extracted water by 1,166.7 x 10^6 m^3. This indicates that ground water extraction in the survey area is about 12% of ground water recharge from surface water and at least 1,023 x 10^6 m^3 has been outflowed from the survey area.

From the distribution of ground water levels, the ground water in the survey area is considered to flow from north to south and from east to west. The amount of ground water extraction and the amount of outflow to the outside of the survey area exceed the total amount of inflow to the survey area and ground water recharge from the surface water. Therefore, this situation is over pumping. Since well construction for ground water extraction has continued and the population is also increasing, it is expected that the amount of ground water extraction will increase further. It is apparent that the ground water level in the aquifers up to the depth 300m is decreasing. Therefore, it is considered that the ground water is excessively extracted from the aquifers up to the depth of 300m.

Contour maps of the ground water level in the rainy and dry seasons are shown in Figures 2.2.14 and 2.2.15 in Chapter 2. Looking at these maps, the ground water level is generally higher in the rainy season than in the dry season. It suggests that the ground water is recharged by the surface water in the survey area even on the CHT area.

The ground water is higher in the CHT than in the coastal plain. This fact shows that the ground water is flowing from the CHT to the coastal plain (in the westerly/south-westerly direction).

Distribution of ground water level is discussed based on the contour map in the rainy season (Figure 2.2.14, Chapter 2). The ground water level is generally high in the hilly areas and low in the coastal plain. In and around the downtown of Cox's Bazar and Moheshkhali, there are areas where ground water levels are lower than the sea level: that is presumed to be caused by ground water extraction. The groundwater level is high in the area from Chakaria to Ramu on the east side of National Highway No. 1 and the area in the south of Cox's Bazar. The ground water level is 11.39m in the north of Chakaria, 10.51m-22.02m in the north of Ramu, 23.92m in the downtown of Ramu and 11.42m in the south of Cox's Bazar. The hills overhang towards the coast near the border between Chakaria and Ramu, where the groundwater level is also high. When entering the coastal plain from the hills, the ground water level generally drops significantly. In the coastal plain, there are spots with high ground water levels. They are 9.76m near Chakaria, 6.61m near the river on the south side of the Matamuhuri River, 10.07m and 10.08m near the boundary between Cox's Bazar and Ramu, and 11.42m southeast of Cox's Bazar Pourashava. In addition, in Moheshkhali, ground water levels of about 10m to less than 13m are distributed on the hills in the central part of the island.

From the distribution of these ground water levels, it is supposed that the following flows exist in the survey area:

- The flow that flows down from the hills in the east of the survey area to the coastal plain in the west of the survey area (shown by blue arrows in the figures),
- The flow from the vicinity of Chakaria to the south, passing between the above-mentioned hilly overhang and the Moheshkhali Island, and heading for Cox's Bazar (shown by orange arrows in the figures),
- The flow from the hills of the Moheshkhali Island towards the eastern coastal plain (shown in orange arrows in the figures),
- The flow from Chakaria to the west to the coastal plain that is distributed to the north of Moheshkhali and Matarbari (shown in red arrows in the figures), and
- The flow from the hills around Cox's Bazar to the coastal plain which is distributed around Cox's Bazar Pourashava (shown in red arrows in the figures).

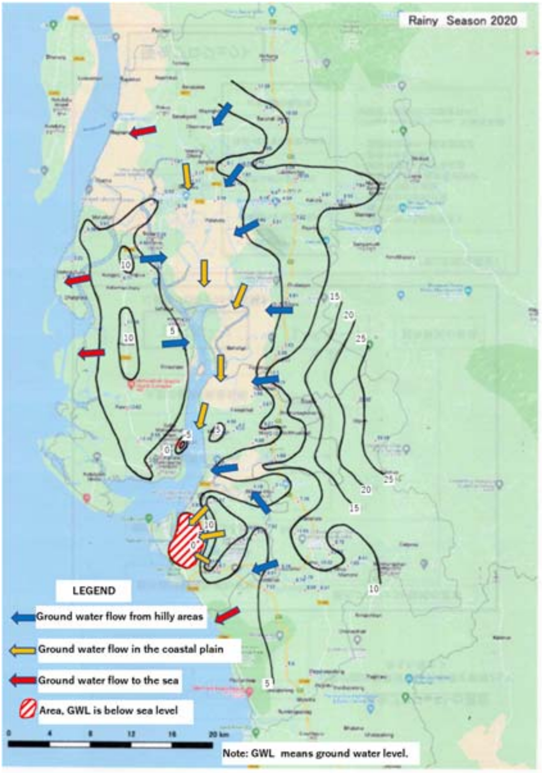
The above is the main flow direction of ground water in the survey area, and there is a flow affected by ground water extraction. The largest one is the flow towards the area of the downtown of Cox's Bazar, where the ground water level is -11.23m. In this area, ground water is pumped up from 8 to 10 wells as water source for urban water supply to the downtown of Cox's Bazar. As a result of this ground water extraction, the ground water level in this area has declined significantly below the sea level. This situation will easily cause sea water intrusion to ground water aquifers in the Cox’s Bazar area.

Figure 3.1.36 shows the ground water flows mentioned above and the areas where the ground water levels are below the sea level based on the contour map in the rainy season in 2020 (Figure 2.2.14, Chapter 2).

Next, the groundwater flow in the dry season is examined from the contour map of the ground water level in the dry season (Figure 2.2.15, Chapter 2). Compared with the ground water level contour map in the rainy season, there is no big change in the flow direction of ground water. However, some changes are observed as follows.

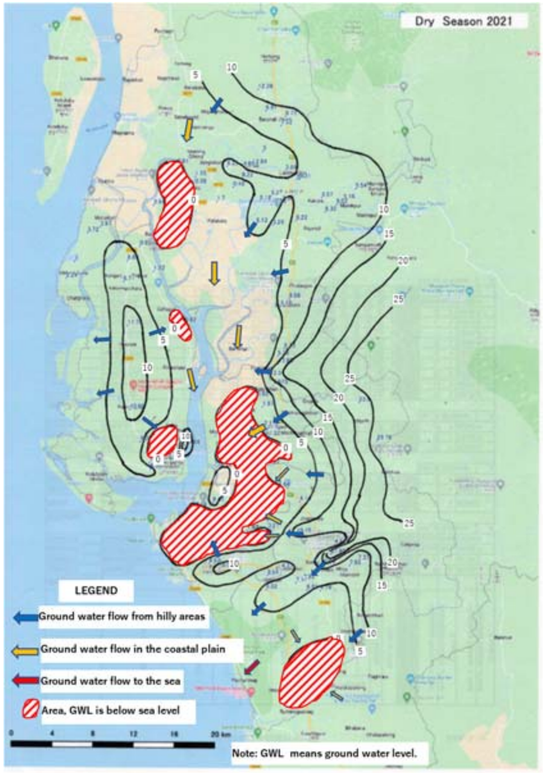
- The high ground water level in the hills at the end of the CHT in the eastern part of the survey area is similar to that in the rainy season, but the ground water level is higher than in the rainy season. The ground water levels rose from 11.39m to 12.39m in northern Chakaria, from 29.26m to 29.76m in northern Ramu, and from 21.95m to 23.92m in Ramu. The reason is not clear, but the following possibilities are presumed. The Tipam Formation, which is presumed to be the main component of the deep aquifer, is exposed to the ground surface in the part of the CHT, so it is possible that it is receiving recharge from precipitation and surface water. It takes a certain amount of time to flow from the recharged area to the survey area, and it is supposed that the rise of groundwater level is delayed.
- In the coastal plain, there is little or no recharge from surface water in the dry season, so the area where the ground water level is below the sea level is expanding like a spot than in the rainy season. In the downtown area of Cox's Bazar, where the ground water level was the deepest in the rainy season, the water level of 11.23m in the rainy season has dropped to 13.58m, it is a decrease of more than 2m. The area where the groundwater level is below the sea level extends significantly northward from the Cox's Bazar city area, compared to that of the dry season. In addition, the areas where the groundwater levels are lower than the sea level have newly emerged to the west of Chakaria and to the northeast of the Moheshkhali Island. All of these areas are likely to be infiltrated with salt water.

Figures 3.1.36 and 3.1.37 show the ground water flow mentioned above and the areas where the ground water level is below the sea level on the contour map (Figures 2.2.14 and 2.2.15, Chapter 2).



Source: JICA Survey Team. The image of Google Map was used as the base map. Copyright of the image of Google Map belongs to Google.

Figure 3.1.36 Ground Water Flows (Rainy Season)



Source: JICA Survey Team. The image of Google Map was used as the base map. Copyright of the image of Google Map belongs to Google.

Figure 3.1.37 Ground Water Flows (Dry Season)

3.2 Water Demand Forecast

3.2.1 Industrial and Domestic Water Demands

(1) Development plans and projects of south Chattogram region

Development projects of the economic zone, the power hub and the port are implemented in Matarbari Island, Moheshkhali Island, Sonadia Island and Chakaria City in the south Chattogram region. In the Moheshkhali/Matarbari region, several infrastructure developments are implemented together with the development of "Matarbari Ultra Super-critical Coal-fired Power Project" supported by JICA in the short term. In the middle and long term, the Moheshkhali Economic Zone is planned, and the development area will be expanded to the south area of the Moheshkhali/Matarbari region. On the other hand, the east and south of the Moheshkhali/Matarbari region is designated as a conservation area, and therefore a development area is restricted.

Since future industrial and domestic water demands will be affected by the above development situation, the urban development projects to be considered in the estimate of future industrial and domestic water demands are shown in Table 3.2.1.

The "Sector Development Plan of Local Government Division (LGD) for Moheshkhali-Matarbari Integrated Infrastructure Development Initiative (MIDI) Area of Cox's Bazar District (2021)", which was made by LGD is summarized the urban development plan and infrastructure plan in the Moheshkhali/Matarbari region. Based on this sector development plan, the location of urban development plan (SEZ development, urban development, etc.) and infrastructure plan (railway, road, port, etc.) is summarized in Table 3.2.1. On the other hand, due to lack of information about industrial development and MIDI development in above sector development plan, the detailed progress and schedule of the development are collceted based on the "Land Use and Development Planning Survey of Moheshkhali and Matarbari Area in the People's Republic of Bangladesh", which was implemented by JICA in 2019, and updated based on the "Industrial and Economic Zones Sector Development Plan (IEZ-SDP) (2021)" and other information.

Table 3.2.1 Development Plans and Projects of South Chattogram Region

Sector	Project name	Location	Schedule
Port	Karnafuli Container Terminal	Chattogram Port	N/A
	Laldia Multipurpose Terminal	Chattogram Port	Procurement stage (by CPA) [1]
	Patenga Containar Terminal	Chattogram Port	Operation starts from 2022. (Prepare a tender. Before operator decides, CPA will operate.) [2]
	Bay Container Terminal	Chattogram Port	Operation starts from 2024. (Land acquisition and land creation work is completed.) [3]
	Sitakunda Terminal	Chattogram Port	N/A
	Matarbari Port (Phase-1)	Matarbari Port/ Moheshkhali/Matarbari	Completion in 2026 Completed land acquisition[4]
	Matarbari Port (Phase-2)	Matarbari Port/ Moheshkhali/Matarbari	Completion in 2028
	Matarbari Port (Phase-3)	Matarbari Port/ Moheshkhali/Matarbari	Completion in 2035
Road	National Highway Expansion Project (Chattogram – Cox's Bazar)	Chattogram – Cox's Bazar	2024 (Detailed design (ADB)) 2021(Preparatory survey (JICA))
	Matarbari Port Access Road	Moheshkhali/Matarbari	Completion in 2025[5] (Preparation of the tender of construction stage.)
	Moheshkhali - Cox's Bazar Road	Cox's Bazar	~2031 (Middle – Long term)

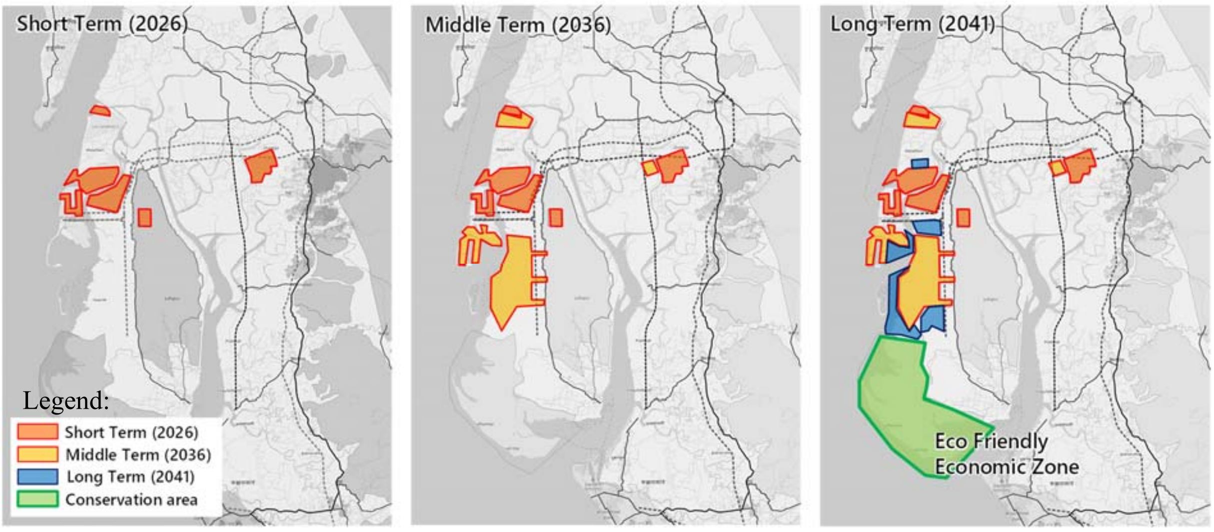
[1] Prime Minister's Office「Project Profile」URL: http://www.pppo.gov.bd/projects-laldia-bulk-terminal.php
[2] Container News（Jan 17, 2022）「Chittagong Port Authority to start operating new box terminal in April」
URL: https://container-news.com/chittagong-port-authority-to-start-operating-new-box-terminal-in-april/
Daily sun (Jan 25, 2022)「Patenga Container Terminal to start operation in May」
URL: https://www.daily-sun.com/printversion/details/601486/Patenga-Container-Terminal-to-start-operation-in-May
[3] Container News (Aug 20, 2021)「Bangladesh sets target to build Bay Terminal by 2024」
URL: https://container-news.com/bangladesh-sets-target-to-build-bay-terminal-by-2024/
[4] Dhaka Tribuni (Aug 6, 2020)「State Minister: First phase of Matarbari deep sea port by 2026」
URL: https://archive.dhakatribune.com/bangladesh/development/2020/08/06/state-minister-first-phase-of-matarbari-deep-sea-port-by-2026
[5] BEZA「Industrial and Economic Zones Sector Development Plan (IEZ-SDP)(2021)」

Sector	Project name	Location	Schedule
	and Bridges		
	Regional Highway (R170) – Patiya-Anowara-Banshkhali-Toitong-Pekua-Badarkhali-Chakaria (Eidmoni) Road	South of Chattogram	N/A
	Construction of Cox's Bazar – Chowfaldi – Eidmony Road	South of Chattogram	~2031 (Middle – Long term)
	Improvement of Janatabajar-Gorakghata Road (Z-1004)	Sonadia	N/A
	Marine Drive from Mirshorai to Cox' s Bazar through Maheshkhali-Matarbari	South of Chattogram	N/A
Railway	Chakaria Station to Matarbari Deep Sea Port and Moheshkhali	MIDI	Completed DD/FS
	Dohazari-Cox's Bazar Railway Development Project	South of Chattogram	On-going
Power/ Energy[6]	Matarbari 2x600MW USC CFPP (Phase-1)	Moheshkhali/Matarbari	Completion in 2026
	Matarbari 2x600 MW USC CFPP (Phase-2)	Moheshkhali/Matarbari	Completion in 2031
	Bangladesh – Singapore 700 MW USC CFPP (Phase-1)	Moheshkhali/Matarbari	Completion in 2025
	Bangladesh – Singapore 700 MW USC CFPP (Phase-2)	Moheshkhali/Matarbari	Completion in 2030
	CPGCBL-Mitsui 500-630 MW LNG Based CCPP	Moheshkhali/Matarbari	Completion in 2028
	CPGCBL-Sumitomo 2x600-660 MW USC CFPP	Moheshkhali/Matarbari	Completion in 2026
	Matarbari Coal Transshipment Terminal	Moheshkhali/Matarbari	N/A
	Solar Power Project	Moheshkhali/Matarbari	N/A
	BPDB 10,000MW Power Hub	Moheshkhali/Matarbari	Completion in 20265
	Transmission Line by PGCB	Moheshkhali/Matarbari	Completion in 20264
EZ	General Economic Zone	Chakaria	Total area: 450ha ~2026: 100ha ~2041: 150ha, 200ha
	Seaborne Economic Zone	Moheshkhali/Matarbari	Total Area: 708.1ha ~2026: 50% completed ~2041: 50% completed
	Moheshkhali EZ-1	Moheshkhali/Matarbari	2041
	Moheshkhali EZ-2	Moheshkhali/Matarbari	2041
	Moheshkhali EZ-3	Moheshkhali/Matarbari	2036
	Sabrang Tourism SEZ	Cox's Bazar (south part)	2026

[6] CPGCBL Homepage （Retrieved March 2021 and June 2022 from URL: http://www.cpgcbl.gov.bd/site/page/4b81edcd-a942-45eb-a092-bb0d8020c0fd/-

Sector	Project name	Location	Schedule
	Naf Tourism Park	Cox's Bazar (south part)	Short term: 2024 Middle term: 2031 (Preparation of the master plan) [7]
	Gohira Anowara Economic Zone	Chattogram/Anwara	On-going
	Mirshorai Industrial Zone	Mirshorai	Short term: 2026 Long term: 2040

Source JICA Survey Team



Source: Adapted by JICA Survey Team based on the township development plan

Figure 3.2.1 Development phase of Moheshkhali/Matarbari Region

(2) Industrial water demand in Moheshkhali/Matarbari region

1) Water demand for port development

The water demand for port development in the Moheshkhali/Matarbari region is calculated to be 600 m^3 / day, assuming the domestic water demand calculated based on the estimated number of employees at the terminal, container wash water, repair shop water, ship water supply, etc. As for the current water supply system, two deep wells are considered, and a pressure tank system has been proposed for adjusting the water supply pressure. The capacity of the underground water tank is expected to secure at least 600 m^3 of water supply for one day.

2) Water demand for general EZ

Along the road connecting the Moheshkhali/Matarbari region and Chakaria,, there is a general EZ development plan aimed at the integrated development of special economic zones and new urban areas. The development scale of the general EZ is expected to be a site area of about 450ha, composed of short-term development areas of 100ha and medium- to long-term development areas of 150ha and 200ha. In

[7] BEZA Homepage 「Government Approved EZ Sites」(Retrieved Jul, 2022 from URL: https://www.beza.gov.bd/economic-zones-site/government-owned-sites/

the JICA study (2019), the water demand for gradual development of the general EZ is calculated as follows.

Table 3.2.2 Water Demand for General EZ

Priority Industry	Area (ha)	Unit water Demand (m^3/day/ha)	Water Demand (m^3/day)	
			Short Term (2026)	Long Term (2041)
Agro-processing/food processing (including halal food)	20	241	1,203	4,812
Logistics/ distribution industry	20	35	351	702
Garment and textile (including Jute)	30	148	2,216	4,432
High value-added garment and textile (incl. Jute)	30	148	2,216	4,432
Leather & related products	25	40	602	1,003
Plastic	20	137	683	2,732
Furniture	5	17	85	85
Transport machine (Automobile/parts, motor cycle/parts, railroad wagon)	75	37		2,742
Electrical and electric goods/parts	45	36		1,608
Pharmaceuticals (medicine, medical goods, nutrition, health food, cosmetics)	45	348		15,645
Total	450		7,400	38,300

Source: JICA Study（2019）

3) Water demand for seaborne economic zone

The JICA study (2019) plans a site area of about 708.1 ha as a seaborne EZ in the Moheshkhali/Matarbari region. The seaborne EZ is planned to be a Logistics Centre (about 203.8ha) formed mainly in the logistics restricted zone and export processing of the logistics and processing industry, and an Energy Industry Zone (about 504.3ha) formed mainly in the petrochemical industry. From this, the water demand for phased development of the seaborne EZ is calculated as follows.

Table 3.2.3 Water Demand for Seaborne EZ

Priority Industry	Area (ha)	Unit Water Demand (m^3/day/ha)	Water Demand (m^3/day)	
			Short Term (2026)	Long Term (2041)
Import grain	10	241	2,406	2,406
Logistics / processing industry	200	35	3,514	7,028

Petrochemical	250	348	43,459	86,919
Oil refinery	200	180	-	36,000
Iron and steel (electrical furnace, steel rolling mill, steel process mill)	20	203	-	4,059
Fertilizer industry	10	300	-	2,997
Cement manufacturing industry	10	78	-	782
Total	700	-	49,400	140,200

Source: JICA Study（2019）

4) Water demand for Moheshkhali EZ

In the Moheshkhali/Matarbari region, short-term and middle/long-term developments of the Moheshkhali Economic Zone (Moheshkhali EZ) are planned. The estimated development areas of the Moheshkhali EZ are 320ha (northern part of Moheshkhali/Matarbari area) for middle-term development, 630ha (middle area) and 654ha (southern part of Moheshkhali/Matarbari area) for long-term development (1,604ha in total). Therefore, in order to calculate the amount of water demand in the development of the Moheshkhali EZ, the basic unit of water demand for an industrial zone in Bangladesh is set. According to BEZA, the unit water demand is considered based on the water consumption per sales area of the existing four special economic zones, CEPZ, AEPZ, CoEPZ, and KEPZ, and the demand is 162m^3 /day per sales area. The area for sales is 60% of the whole land area, and if the purpose of industrial land use is unknown, the percent is multiplied by 1.15 to calculate the water demand of the Moheshkhali EZ. The result is shown below.

Table 3.2.4 Water Demand for Moheshkhali EZ

EZ	Area (ha)	Unit Eater Demand (m^3/day/ha)	Water Demand (m^3/day)	
			Short Term (2026)	Long Term (2041)
Moheshkhali EZ-1	630	162	0	70,896
Moheshkhali EZ-2	654	162	0	73,597
Moheshkhali EZ-3	320	162	0	36,011
Total	1,604	-		180,504

Source: JICA Study Team

5) Industrial water demand for Moheshkhali/Matarbari region

Based on the above-mentioned estimates, compiled are the short-term and long-term industrial water demands in the Moheshkhali/Matarbari region, as presented in Table 3.2.5.

Table 3.2.5 Industrial Water Demand for Moheshkhali/Matarbari Region

Location	Area (ha)	Water Demand (m^3/day)	
		Short Term (2026)	Long Term (2041)
Matarbari Port	-	600	600
General EZ	450	7,400	38,300
Seaborne EZ	700	49,400	140,200
Moheshkhali EZ	1,604	0	180,504
Total	-	57,400	359,600

Source: JICA Study Team

Besides, the industrial water demand of every upazila in the Moheshkhali/Matarbari region is shown in Table 3.2.6.

Table 3.2.6 Industrial Water Demands for Moheshkhali/Matarbari Region

Upazila	Water Demand (m^3/day)	
	Short Term (2026)	Long Term (2041)
Moheshkhali	50,000	321,304
Chakaria	7,400	38,300
Total	57,400	359,600

Source: JICA Study Team

(3) Domestic water demand

1) Population forecast

The future population in the south Chattogram region is estimated based on the actual populations of 1981, 1991, 2001 and 2011 based on the “District Statistics 2011” published by the Bangladesh Bureau of Statistics (BBS). For the population growth rate, the average growth rate from 1981 to 2011 was set for each prefecture, and the future population was estimated as stated hereunder.

The south Chattogram region is a city with a population of 10 million at present, and it can be estimated that the population will double by 2041. In addition, the "Population Projection of Bangladesh Dynamics and Trends", published in 2015, has estimated the future population based on multiple scenarios. According to the above statistics, it is pointed out that the high fertility rate will still be maintained in the south Chattogram region, and it is estimated that the number will reach 14.77 million by 2026.

Since the Moheshkhali/Matarbari region and its surrounding area will be developed through 2041, the south Chattogram region, where housing and urban developments are expected to accompany the development, is considered to continue to see population growth.

For reference, the average annual population growth rate of Dhaka District, whose economic development and residential development are progressing ahead of other districts, was 3.74% (the Dhaka metropolitan area is 4.03%) from 1981 to 2011. It can be inferred that a similar transition will take place in the south Chattogram region.

Table 3.2.7 Population Forecast of Each District

District	Population Growth Rate	1981	1991	2001	2011	2026	2036	2041
Bandarban	2.44	180	230	298	388	557	709	800
Chattogram	1.88	3,985	4,450	5,950	6,938	9,174	11,052	12,131
Cox's Bazar	2.47	1,061	1,420	1,774	2,289	3,301	4,213	4,759
Khagrachhari	2.91	270	342	528	614	944	1,258	1,452
Rangamati	2.49	299	400	507	598	865	1,106	1,251
Total (average)	(2.38%)	5,795	6,842	9,057	10,827	14,841	18,338	20,393

Unit: thousand (000) population;

Reference: From 1981 to 2011, the population of Dhaka District has increased at an average rate of 3.74% per year, and in the metropolitan area, it has increased at an average rate of 4.03% per year.

2) Unit domestic water demand

The unit domestic water demand is 0.11 m^3 / day based on interviews with related organizations, referring to the water demand intensity used in the "Chattogram Water Supply Improvement Project Preparation Survey" conducted by JICA (2013). It is assumed in this survey that it will be 0.12m^3 / day in the future since Cox's Bazar City will reach the standard of Chattogram City through developing the Moheshkhali/Matarbari region. Furthermore, it is assumed that the penetration rate of clean water is 80%.[8]

Table 3.2.8 Unit Domestic Water Demand

Items	Unit	2011	2026	2036	2041
Unit water demand	litter/day/person	110	115	120	120
Coverage of the water supply system	%	80	80	80	80

Source: JICA Study Team

3) Domestic water demand in the south Chattogram region

Table 3.2.9 Domestic Water Demands for South Chattogram Region (m^3/day)

District	2011	2026	2036	2041
Bandarban	34,144	51,246	68,052	76,770
Chattogram	610,544	844,027	1061,033	1164,592
Cox's Bazar	201,432	303,658	404,423	456,898
Khagrachhari	54,032	86,860	120,748	139,369
Rangamati	52,624	79,563	106,172	120,065
Total	952,776	1,365,354	1,760,428	1,957,694

Source: JICA Study Team

[8] CWASA has set the penetration rate to be achieved by 2015 as 80% (JICA "Bangladesh Chittagong Water Supply Improvement Project Preparation Survey Final Report (2013)")

4) Domestic water demand for Moheshkhali/Matarbari region

The domestic water demands of the Moheshkhali/Matarbari region and surrounding areas consisting of Cox's Bazar City, Moheshkhali Upazila, Pekua Upazila, Chakaria Upazila, and Kutubdia Upazila are shown below.

Table 3.2.10 Domestic Water Demands for Moheshkhali/Matarbari Region and Surrounding Areas (m^3/day)

Upazila	2011	2026	2036	2041
Cox's Baza	40,392	60,891	81,097	91,619
Moheshkhali	28,248	42,584	56,715	64,073
Pekua	15,136	22,817	30,389	34,332
Chakaria	41,712	62,881	83,747	94,613
Kutubdia	11,000	16,582	22,085	24,951
Total	136,488	205,755	274,032	309,589

Source: JICA Study Team

(4) Estimation of amount for domestic water supply development

The amount for domestic water supply development is estimated by dividing into the demand of surface water and ground water to consider the future water supply development.

According to the "Population & Housing Census (2011)" published by the Bangladesh Bureau of Statistics (BBS), the intake percentages of drinking water sources are defined as the "Tap", "Tube-well" and "Others".

Thus, the following policy is made in order to divide the three categories shown in the "Population & Housing Census (2011)" into "Surface water demand", "Ground water demand" and "Others" shown in this survey.

- "Tap": To calculate by divided into "Surface water demand" and "Ground water demand". Since Chattogram city is supplied from surface water but other upazilas are supplied from ground water,
    - Chattogram city: "Tap" is source mainly from "Surface water".
    - Other upazilas: "Tap" is source from "Ground water".
- "Tube-well": "Tube-well" is source from "Ground water".
- "Others": Others includes rainwater, ponds, river intake, etc. Thus others is divided into "Others (rainwater, ponds, etc.)" and "Surface water (river intake)" based on the location of Upazilla.

Based on the above policy, Table 3.2.11 shows the percentage of surface water demand, groundwater demand, and other (stormwater, ponds, etc.) for each upazila. And the surface water demand, groundwater demand, and other (rainwater, ponds, etc.) demand for each upazila are organized in Appendix 3.2-1.

Table 3.2.11 Intake Percentages of Water Sources by Upazila

No	District	Upazila	River Basin	Surface Water (River Water)	Ground Water	Others
1	Bandarban	Rowangchhari	Sangu River	7	62	31
2		Ruma	Sangu River	8	74	18
3		Thanchi	Sangu River	41	41	18
4		Alikadam	Matamuhuri River	28	28	45
5		Lama	Matamuhuri River	18	18	64
6		Naikhongchhari	Bakkhali River	22	22	55
7		Bandarban Sadar	Sangu River	18	18	64
8	Chattogram	Mirsharai	Outside of study area	2	2	96
9		Sandwip	Outside of study area	0	6	94
10		Anwara	Sangu River	4	4	93
11		Boalkhali	Sangu River	2	2	97
12		Chandanais	Sangu River	2	2	96
13		Lohagora	Sangu River	4	4	93
14		Patia	Sangu River	2	2	96
15		Satkania	Sangu River	3	3	94
16		Bashkhali	Outside of target basin	2	2	95
17		Sitakunda	Outside of target basin	2	2	96
18		Chattogram Metr	Karnafuli River	50	2	48
19		Fatikchhari	Karnafuli River	6	6	88
20		Hathazari	Karnafuli River	0	6	94
21		Rangunia	Karnafuli River	4	4	92
22		Rauzan	Karnafuli River	2	2	97
23	Cox's Bazar	Kutubdia	Outside of target basin	0	4	96
24		Moheshkhali	Outside of target basin	1	9	90
25		Pekua	Outside of target basin	1	1	98
26		Teknaf	Outside of target basin	10	10	80
27		Ukhia	Outside of target basin	2	15	84
28		Chakaria	Matamuhuri River	1	7	92
29		Cox's Bazar Sadar	Bakkhali River	0	3	96
30		Ramu	Bakkhali River	1	10	88
31	Khagrachari	Matiranga	Outside of target basin	3	28	69
32		Ramgarh	Outside of target basin	0	35	65
33		Dighinala	Karnafuli River	17	17	66
34		Khagrachari Sadar	Karnafuli River	10	10	80
35		Laksmichhari	Karnafuli River	39	39	22
36		Mohalchhari	Karnafuli River	3	31	66
37		Manikchhari	Karnafuli River	3	29	68
38		Panchhari	Karnafuli River	3	27	71
39		Baghaichhari	Karnafuli River	31	31	38

No	District	Upazila	River Basin	Surface Water (River Water)	Ground Water	Others
40	Rangamati	Barkal	Karnafuli River	45	45	11
41		Belaichhari	Karnafuli River	35	35	30
42		Juraichhari	Karnafuli River	68	0	32
43		Kaptai	Karnafuli River	39	0	62
44		Betbunia	Karnafuli River	22	22	56
45		Langadu	Karnafuli River	73	0	27
46		Nannerchar	Karnafuli River	34	34	32
47		Rangamati Sadar	Karnafuli River	25	0	75
48		Rajasthali	Karnafuli River	0	32	68

Note: The source of tap water is assumed to be groundwater except for Chattogram City. In other areas, water sources are composed of surface water (river water), ground water, rainwater, ponds, etc. based on the regional characteristics of each area.

Based on the above, the intake percentages of water sources in each basin are shown below.

Table 3.2.12 Intake Percentages of Water Sources by River Basin

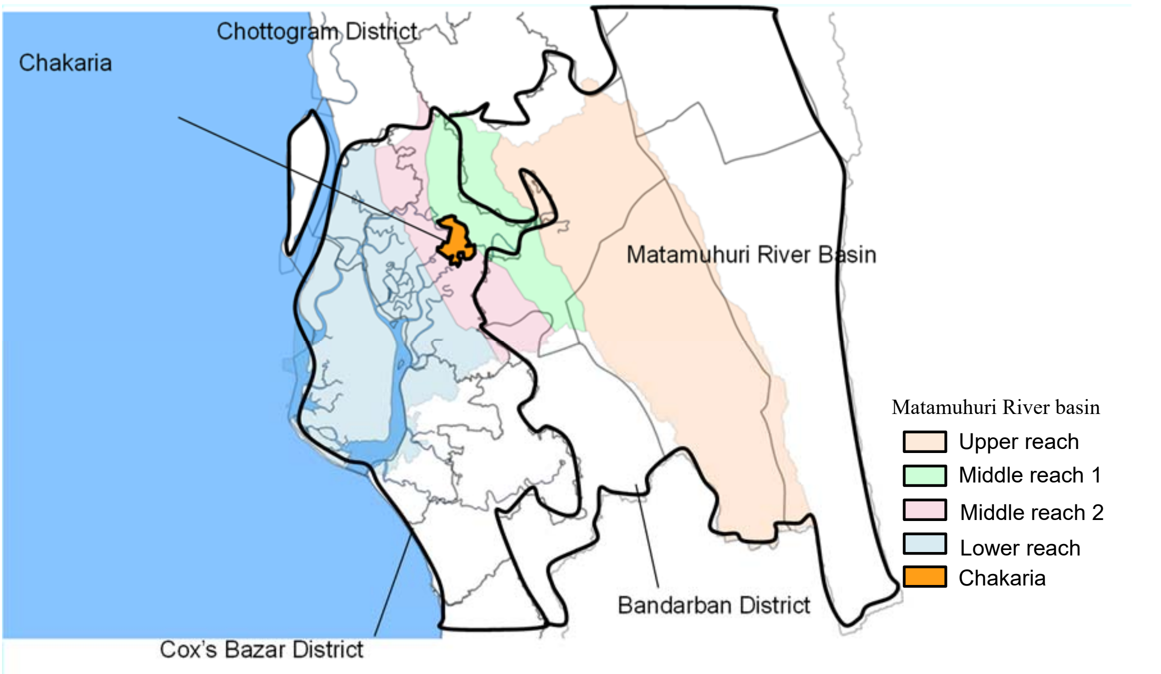
Basin	River Water	Ground water	Others
Bakkhali River	7.9	80.0	12.0
Karnafuli River	24.2	58.1	17.7
Matamuhuri River	15.5	66.9	17.6
Sangu River	9.0	69.9	21.1
Outside of target basin	2.4	85.8	11.8
Outside of study area	1.1	94.9	4.0
Average	14.4	69.2	16.4

Source: JICA Study Team

(5) Industrial water demand and domestic water demand in Matamuhuri river basin

1) Area of Matamuhuri river basin

Moheshkhali/Matarbari Region and Chakaria, which are expected to be developed in the future, are located in the Matamuhuri River basin, and the industrial water demand and domestic water demand are calculated for the upazilas included in the Matamuhuri River basin. The Matamuhuri River watershed shall be divided into four sub-basins of upstream/downstream areas based on the points where water can be taken from the river, and the respective demands shall be determined.



Source: JICA Study Team

Figure 3.2.2 Area of Matamuhuri River Basin

Table 3.2.13 Upazila in Matamuhuri River Basin

Sub-basin	District (Upazila)
Upper Reach	Bandarban District: Alikadam, Thanchi, Lama, Ruma, Bandarban Sadar
Middle Reach 1	Bandarban District: Naikhongchhari, Alikadamy, Lama, Lohagora
Middle Reach 2	Bandarban District: Naikhongchhari, Lama Chattogram District: Lohagora, Bashkhali Cox's Bazar District：Pekua
Lower Reach	Bandarban District: Naikhongchhari Chattogram District：Bashkhali Cox's Bazar District：Cox's Bazar Sadar, Moheshkhali, Pekua

Source: JICA Study Team

2) Industrial water demand and domestic water demand in Matamuhuri River basin

The upazilas included in the Matamuhuri River basin are described in Table 3.2.13, and after aggregating the domestic and industrial water demands of each upazila, the future domestic water demands of the Matamuhuri River basin are shown in Table 3.2.14.

Table 3.2.14 Water Demand by Sub-basin in Matamuhuri River Basin

Matamuhuri River Sub-basin	Water Demand (m^3/day)					
	2020		2026		2041	
	Domestic	Industrial	Domestic	Industrial	Domestic	Industrial
Upper Reach	10,816	0	12,543	0	21,432	0
Middle Reach 1	12,903	0	15,829	0	24,307	0
Middle Reach 2	16,472	0	20,077	3,714	30,502	19,223
Lower Reach	49,633	0	60,504	53,286	92,076	340,981

Chakaria	7,507	0	9,182	0	14,046	0
合計	97,331	0	118,135	57,000	182,363	360,200

Source: JICA Study Team

(6) Water saving solutions (demand adjustment)

The water-saving solution by demand adjustment was studied, as referred to in the following explanation,, since a large amount of water demand forecast results in a larger facility size, which might make it difficult to realize the scheme due to cost increase. These are selected based on the land use and situation in the Moheshkhali/Matarbari region, and furthermore these are positioned in the projects of the Ministry of Environment in Japan etc.

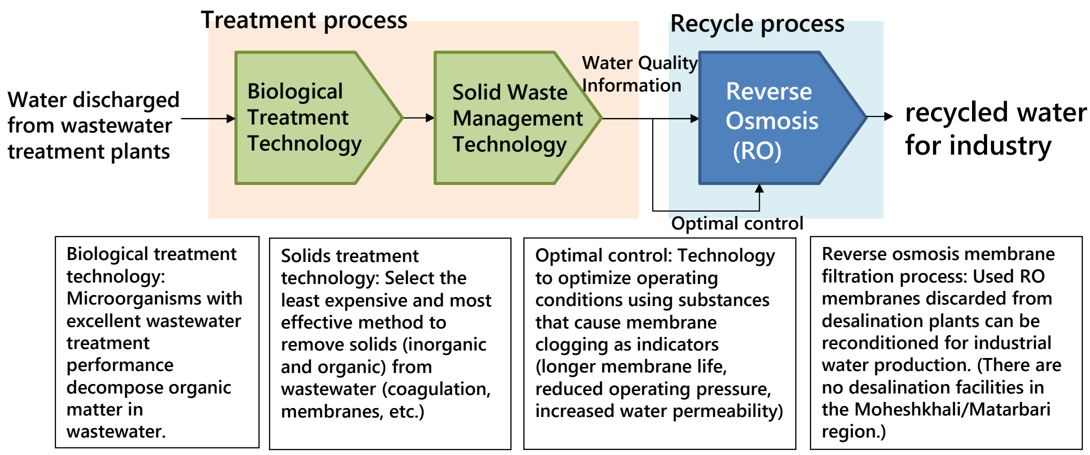
Table 3.2.15 Precedent Studies and Solution for Water Saving

Country	Target Area	Purpose	Solutions	Expected Outputs
India	Maharashtra/ Patalganga Industrial Zone	Effective use of water resources through the construction of a reclaimed water system at a communal wastewater treatment plant in an industrial zone	· Biological Treatment Technology · Solids Removal Treatment · Reverse Osmosis (RO) Filtration Treatment · Reverse osmosis (RO) membrane cleaning and operation technology	· Securing water sources (Control of surface water and groundwater use by recycling water)
India	Haryana	Diagnosis of the western part of the Indian government-owned oil refinery plant content wastewater treatment. Improvement plan and FS to promote wastewater reuse.	· MBR (Membrane bioreactor)	· Promotion of wastewater reclamation · Reduction of water withdrawal to conserve water resources
Singapore	Singapore	The purpose of the project is to promote efficiency in water supply services and water-saving behavior in Singapore, where water resources are scarce.	· Smart meter	· Analyze water consumption patterns, detect leaks quickly, and promote water conservation

Source: JICA Survey Team

Patalganga industrial zone, Maharashtra, India

- Major industries in Maharashtra include chemical, electric and electrical equipment, and textile industries, and the water demand for industrial parks is increasing. There are concerns about the shortage of water for industrial and domestic use in the future. In addition, there are concerns about the deterioration of water environment in the basin due to the situation where unachieved are the standards for the quality of water discharged into the basin.
- Therefore, Japanese-affiliated technologies are being introduced to improve the water environment and build water reclamation and utilization technologies. According to the results of a field test, it was estimated that the water reclamation process would reduce the amount of wastewater discharged into the environment by 50% (from 10,000 t/day to 5,000 t/day). Water recycled by the reclamation process is used as industrial water at each plant.



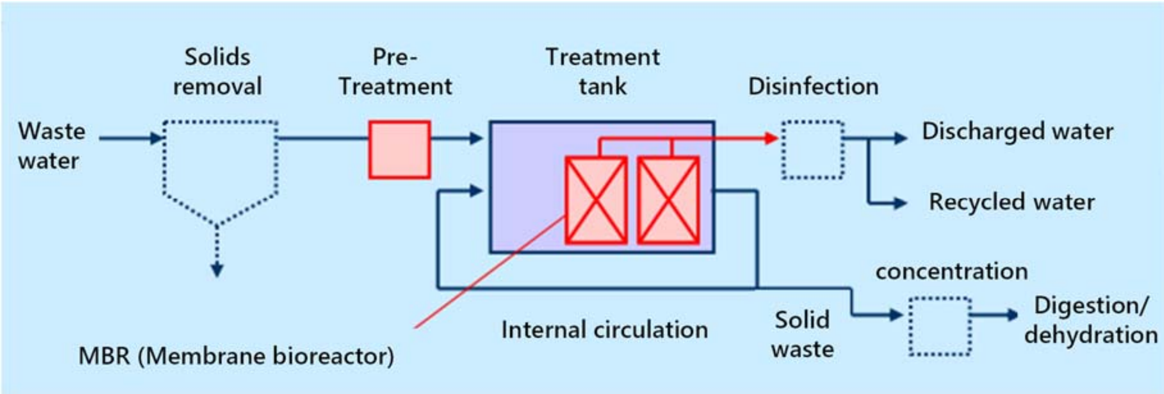
Source: Prepared by the JICA Survey Team based on Fuji Electric Co., Ltd.

Figure 3.2.3 Image of Recycling Process

Panipat Oil Refinery, Haryana, India

- An Indian government-affiliated oil company is conducting a diagnosis of the wastewater treatment facilities in its Panipat oil refinery plant and studying ways to achieve proper treatment and promote wastewater reclamation for environmental conservation. Therefore, a study was conducted in 2011 on the application of Membrane Bioreactor (MBR), a method in which Japanese companies have an advantage.
- In the subject area, the performance of the in-plant wastewater treatment facilities is not fully demonstrated, and a large amount of raw water (45,000 m^3/day) is continuously taken from the irrigation canal. In addition, there are concerns about the occurrence of water

environmental pollution. The introduction of Japanese technology is expected to reduce water consumption through wastewater reclamation.

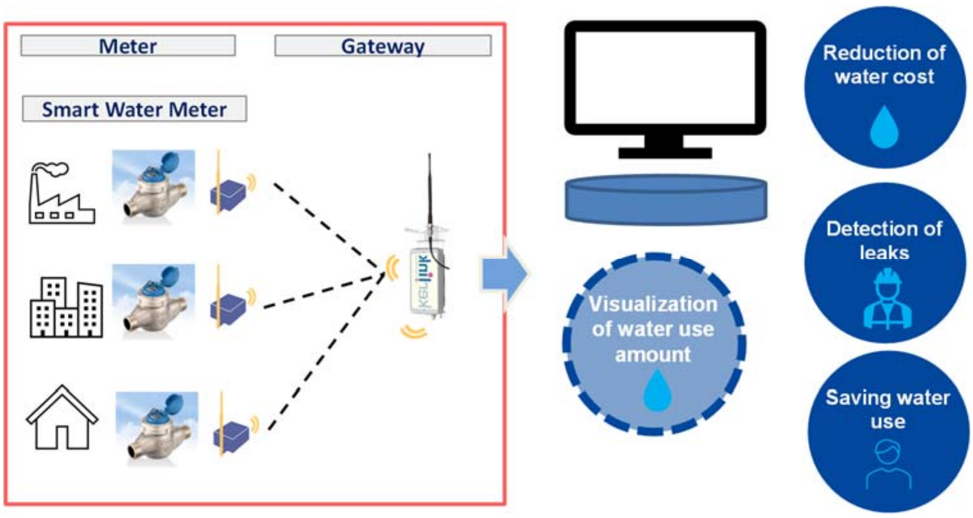


Source: Japan Sewage Works Agency

Figure 3.2.4 Image of Membrane Bioreactor (MBR)

Installation of smart meter, Singapore

- The Public Utilities Board of Singapore provides water supply services to a population of approximately 5.4 million people (total population in Singapore). The Public Utilities Board started the pilot project in 2015.
- The introduction of smart meters has also included analysis of water consumption patterns and the distribution of a mobile application to the consumers to track their water consumption, which has resulted in about 5% water saving by detecting leaks quickly and promoting water-saving habits.



Source: JICA Study Team

Figure 3.2.5 Image of Smart Meter

3.2.2 Agricultural Water Demand

(1) Current status of agricultural water use

The agricultural sector of Bangladesh generates 47% of employment, but agriculture's contribution to GDP is only 16%. The cultivable area is 8,856,000 ha, which occupies 58.17% of the total land area (14,760,000 ha). In accordance with the "Minor Irrigation Survey Report 2017-2018 (BADC)", in the 2017-2018 irrigation season, the total irrigated area is 5,556,614 ha, which occupies 65% of net cultivable area (8,585,207 ha). Out of the said total irrigated area, 4,081.41 ha (73.4%) is irrigated through utilization of groundwater and 1,475,573 ha (26.56%) is through utilization of surface water. Increased groundwater accessibility resulting from the expansion of deep and shallow tube wells helped Bangladesh to attain near self-sufficiency in rice in 2011-2012. Available evidence suggests that the policy focus so far has been largely on "resource development", and not on "resource management". This resulted in serious problems: most notably excessive drawdown (declined static water level) in intensively irrigated areas and the deterioration of groundwater quality. The ratio of agricultural water source is "groundwater : surface water = 3 : 1" throughout Bangladesh, whereas the ratio is "1 : 1.3" in the 4 target districts. That is, the degree of dependence on groundwater is lower than that on surface water in these districts, compared with the degree of the whole country (source: above-mentioned BADC's report). This is because most of the target area is located in a mountainous area with relatively many underground rock layers, and is not suitable for well digging. Bangladeshi agricultural policy indicates that the supply of irrigation water from groundwater will be reduced in the future since land subsidence due to excessive pumping of groundwater has occurred.

The administrative organizations involved in irrigation projects in Bangladesh are BWDB, WARPO, LGED, BADC and DAE. The roles of each organization are shown below.

BWDB (MWR): A monitoring agency for irrigation projects and the executing agency of the project with irrigated area of 1,000 ha or more. The scale of the individual project handled is large, but the total scale is only 6% of the irrigated area in Bangladesh.

WARPO (MWR): An organization that has jurisdiction over laws and systems, and comprehensively controls the irrigation projects.

LGED (MLGRDC): An executing agency of relatively small projects with irrigated areas of not more than 1,000 ha. The scale of the individual project handled is small, and the total scale is only about 5% of the irrigated area in Bangladesh

BADC (MoA): An executing agency of relatively small projects with irrigated areas of not more than 1,000 ha. Although the scale of the individual irrigation project handled is small, it has jurisdiction over 47% of the irrigation area of Bangladesh as a whole, and has the greatest influence on the irrigation projects in Bangladesh.

DAE (MoA): An extension organization of agricultural cultivation technology.

(2) Current irrigation water requirements from rivers in each river basin

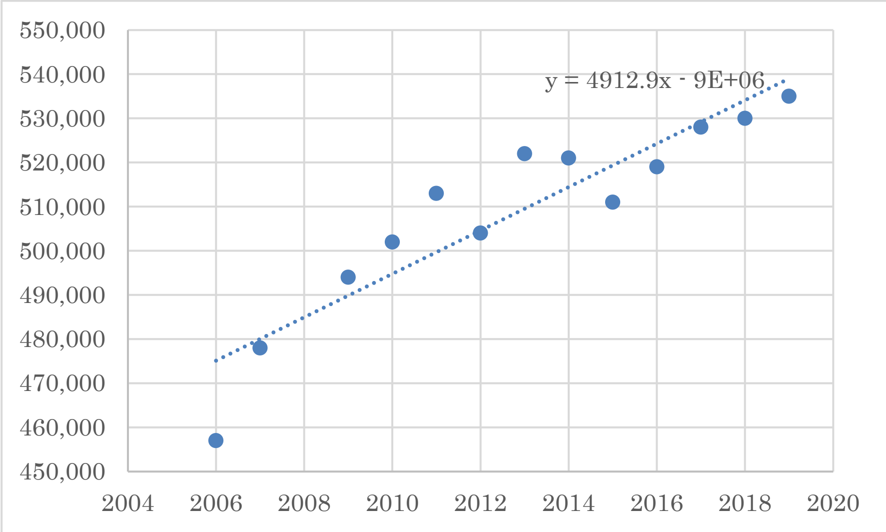
In order to forecast agricultural water demand from the rivers in the 4 target basins (Karunafuli, Sangu, Matamuhuri and Bakkhali), the current amount of water requirements from the rivers was calculated.

It is found that there is no statistical data that summarize the amount of irrigation water in Bangladesh for estimating the water amount withdrawn from the rivers. The current irrigation water requirements from the surface water of each target river basin and each upazila are calculated by the Penman Method using the available irrigated area, taking into consideration the cropping patterns used there. In the calculation, the current irrigation water requirements were calculated based on the meteorological data and estimated irrigated area for each of the 54 years from 1966 to 2019.

1) Irrigated area

Concerning the irrigated area, the data collected from each related organization are unreliable since the data collected could be obtained only in a fragmental manner and they are inconsistent among the organizations. Moreover, the obtained data cannot make it clear which river basin the irrigated area belongs to. Therefore, the irrigated areas for each river basin and each upazila are determined based on the reliable topographic maps obtained from the Survey Bureau (SOB). However, the area determined from the topographic maps is the cultivated land area. According to the Bangladesh Bureau of Statistics (BBS) data on cultivated areas and irrigated areas, the average ratio of irrigated area to cultivated area from 2006 to 2019 is 59.23%. The irrigated areas were calculated, using this value. In addition, the irrigated areas determined from the topographic map data include both areas irrigated by groundwater and by surface water. In order to determine the area irrigated by surface water, as the "Minor Irrigation Survey Report 2017-2018 (BADC)" describes the groundwater and surface water irrigated areas separately by upazila, the ratio of “groundwater: surface water” is used to calculate the area irrigated by surface water from the area determined by the topographic map data (Annex 3.2-2: Attachment 1 shows the surface water proportion for each upazila.).

The topographic map data are those in 2011 and there is a difference from the current state. In order to correct the difference, the BBS data of the irrigated land area in the whole country of Bangladesh are used. However, as the BBS data is from 2006, the growth rate was calculated by an approximate linear formula based on the data from 2006 to 2019. The growth rate was calculated to be 0.96%/year, based on which calculated were the surface water irrigated areas from 1966 to 2019 by upazila.



Source: JICA Study Team

Figure 3.2.6 Growth Rate of Irrigated Area from BBS Data (2006 – 2019)

2) Cropping Patterns

It was unable to obtain the data specifying the cropping patterns for each upazila, but it was able to obtain the document "Diversity of Cropping Systems in Chittagon Region (BRRI: 2017)" that describes the typical cropping patterns in the Chattogram region. In accordance with this document, there are 93 types of cropping patterns implemented in the region, and the top 14 patterns out of them account for more than 82% in the region. Since these top 14 patterns represent the cropping pattern in the region, the unit water requirements of these 14 patterns were calculated by the Penman Method. The calculated values were multiplied by the occupancy rate of each pattern in the river basin, and the total of each unit water requirement became the unit water requirement representing the river basin. (Annex 3.2-2: Attachment 2 shows the typical cropping patterns with the occupancy rate in the Chattogram region. Attachment 2' shows Sample of Cropping Pattern and Demand Supply Gap According to Each Crop Season (Sangu River Basin 2011))

3) Calculation of unit water requirement

In calculating the unit water requirement, ETo (reference evapotranspiration) is calculated by the Penman Method, using the meteorological data of 1966 – 2019 in each basin. For the effective rainfall, (i) the daily rainfalls of 80 mm to 5 mm multiplied by 0.8 and (ii) those of 5 mm or more multiplied by 0.8 are used for the paddy field and the upland field, respectively. As the irrigation efficiency, 0.38 recommended by BADC is applied. It is judged that this value is reasonable in due consideration of the fact that the value of irrigation efficiency adopted in each Asian country has varied from 18% to 40% (IWMI 1998).

4) Current water requirements of each basin

The current water requirements of each basin were calculated by the above-mentioned method. The calculation results are shown in Annex 3.2-2, where Attachments 3 - 6 show the surface water irrigated land areas of each upazila and Attachments 7 – 10 show the current gross water requirements of each upazila and for each month from 4 river basins for 54 years (1966 – 2019).

Table 3.2.16 shows the calculated monthly average of the current irrigation water requirements by each basin for 54 years.

Table 3.2.16 Monthly Average of Current Irrigation Water Requirements (m^3/sec) (1966 - 2019)

Water Basin	Irrigated Area (ha)	1	2	3	4	5	6	7	8	9	10	11	12
Bakkhali	13,073	9.26	10.05	11.65	8.98	1.35	0.24	0.04	2.28	3.08	6.58	10.99	14.79
Karnafuli	65,790	51.41	57.19	68.79	48.10	6.91	1.83	1.06	40.25	17.37	45.15	65.32	92.45
Matamhuli	18,362	14.72	16.27	18.36	11.75	2.18	0.47	0.14	9.78	6.12	12.88	18.89	24.73
Sangu	32,901	20.22	22.35	25.22	16.14	3.00	0.64	0.20	13.43	8.41	17.69	25.94	33.96

Source: JICA Study Team

5) Current reduced water amount of each basin

The current reduced water amount required for the water balance calculation of each basin was calculated by adding the total amount of rainfall to the amount of gross water requirement for each upazila calculated above and multiplying it by the reduction rate of 60% of the basin rainfall. (Annex 3.2-2, Attachments 11 – 14 show current reduced water amount of each upazila and for each month of 4 river basins for 54 years (1966 – 2019).)

(3) Agricultural water demand forecast

In the Master Plan for Agricultural Development in the Southern Region of Bangladesh (June 2012), the future plans focus on improved agricultural productivity, weather-resistant development and improved surface water irrigation systems. According to this master plan, the planting rate in the southern region is 159%, which is 17% behind the national average of 176%, and 15% of the total cultivable area is fallow or unused. The reasons for this include salty soil, salt water, land subsidence, land inundation, lack of surface water irrigation facilities (irrigation equipment), and lack of farmers' knowledge. There is also an opportunity to increase surface water irrigation, with 700,000 hectares of land capable of introducing surface water irrigation.

In forecasting the water demand for agricultural water, the study on the master plans of irrigation development in the target area revealed that there is only an abstract description of the future plan, but no specific numerical description. Therefore, the forecasted irrigation areas for 2026 and 2041 were calculated, using the above-mentioned growth rate of irrigated area of 0.96%/year, which was calculated using past data (2006 - 2019). As mentioned above, according to the "Master Plan for Agricultural Development in the Southern Region of Bangladesh, June 2012", it is possible in the southern Chattogram region to develop irrigated areas with 700,000 hectares of surface water. Additionally, according to the 8th Five-Year Plan (2021-25), the agricultural sector's share of GDP has dropped to

13.3% and 36% of children under the age of 5 are suffering from chronic malnutrition, and 14% are acutely malnourished. Furthermore, graduating from LDC is taken up as a challenge in the Five-Year Plan, and as described, it is far from the situation where economic growth ends in Bangladesh. It can be judged that the current trend of agricultural development will continue as it is. Therefore, it can be said that the 0.96% growth rate calculated from past trends will not be excessive. As a result, the growth rates from 2011 to 2026 (short-term target) and 2021 to 2041 (long-term target) became 14.4% and 28.8%, respectively. However, instead of using these values as they are, the following was considered.

As mentioned above, the problem of groundwater level declination due to increase in groundwater use for agriculture has arisen in Bangladesh, and the National Water Policy 1999 shows the movement of regulation on the use of groundwater. Looking at the trends of groundwater irrigation and surface water irrigation estimated from the trend of irrigation facilities from 1961 to 2019 in accordance with the Minor Irrigation Survey Report 2019-20 (BADC), the amount of groundwater irrigation seems to suddenly decrease from 2010. This rate of decrease was calculated to be 0.36%/year. However, this figure has no significant impact on the seven years up to the short-term target year (2019-2026), so it can be ignored and the 14.4% is adopted for the short-term target year. In the long-term target plan, since the period is as long as 22 years from 2019, the rate becomes 7.92% in 22 years and it is to be taken into consideration. Regarding groundwater development, its future development is impossible if the current groundwater level is declining, and it is presumed that the groundwater use irrigation shall shift to surface water use irrigation, taking into consideration that the Government of Bangladesh has been also making efforts to reduce the groundwater irrigation amount. Therefore, 28.8% shall be applied to the growth rate of the irrigated area from 2011 to 2041, and the ratio of surface water for each upazila used to calculate the irrigated area shall be revised by considering the reduction rate of the groundwater irrigation amount, and the revised value shall be used together. (Annex 3.2-2: Attachment 15 shows details of consideration of increase in surface water irrigation due to restrictions on groundwater use. Attachment 16 shows the revised surface water proportion for each upazila. Attachments 17 – 20 and Attachments 21 – 24 show the forecasted gross water requirements of each upazila and for each month from 4 river basins for 54 years (1966 – 2019) in 2026 and 2041, respectively.)

The future forecast of the amount of reduced water was also calculated in the same way. (Annex 3.2-2, Attachments 25 - 28 and Attachments 29 - 32 show the orecasted reduced water amount of each upazila and for each month from 4 river basins for 54 years (1966 – 2019) in 2026 and 2041, respectively.)

The data used for the forest of irrigation water demand are collected from the reports issued by the authorized organizations in Bangladesh, such as the BADC, BBS and BRRI, which are sufficiently reliable sources. Having said that, it was important to verify the accuracy of the data and the JICA Survey Team conducted verification meetings with the officials concerned in the LGED, BWDB and BADC who have the strong influence on the irrigation projects in Bangladesh to get their consensus on the results of the forecast calculation, and the result of the forecast was mostly acknowledged concerning the method of data acquisition and calculation.

(4) Agricultural Water Saving Solutions (Demand Adjustment)

Since agricultural water accounts for a large proportion of the water demand forecast, it was considered to introduce water-saving irrigation to reduce the orecast. In considering water-saving irrigation, the amount of water required for rice cultivation and the amount of water required for upland cultivation had been calculated and compared in the cropping patterns used to calculate the irrigation water requirements this time. As a result, the amount of water required for rice cultivation accounted for 93.7% of the total amount of water requirements, and the amount of water required for upland cultivation was small. Therefore, as the effect of introducing water-saving irrigation into upland cultivation would be insignificant, only the water-saving irrigation technology for rice cultivation was considered.

1. Water-saving Irrigation for Rice Cultivation
Water-saving rice cultivation techniques include Saturated Soil Culture (SSC), Alternate Wetting and Drying (AWD), System of Rice Intensification (SRI), Aerobic Rice, and so forth. AWD technology shall be considered, since its extension is advancing in Bangladesh and its feasibility is relatively high.

AWD (Alternate Wetting and Drying)
AWD is a technology with intermittent irrigation developed and popularized by the International Rice Research Institute (IRRI). By performing intermittent irrigation (water depth 5 cm at the time of irrigating) except for the root taking period and flowering period after sowing of rice, it saves 15 - 30% water (Lampayan et al., 2005, Tabbal et al., 2002). On the other hand, there is no reduction in yield by introducing this technology. In addition, since the generation of methane gas can be suppressed compared to the constant flooding, it is often talked about in the context of climate change countermeasures.
In accordance with the dissertation (Asia and African Area Studies, 15 (2), 2016) by T. Yamaguchi and others, in Vietnam, the extension of AWD was started in 2005, and its extension rate became only 18% in the dry season of 2009 and it expanded to 47% in the dry season of 2013. Therefore, in Bangladesh, if its extension starts from now on, it is considered and expected to spread by 50% by 2041.

2. Examination of the Amount of Reduction in the Predicted Amount by Introducing AWD
Ratio of rice cultivation to the forecasted water demand: 93.7%
Estimated amount of spread of AWD after introduction: 50% (2041), 15% (2026)
Water saving amount: 20%
Percentage of water savings in the 2041 forecast of water demand: 0.937x0.5x0.2=0.0937=9.4%
Percentage of water savings in the 2026 forecast of water demand: 0.937x0.15x0.2=0.0281=2.8%
Therefore, the water demand forecast for agricultural irrigation in 2041 can be reduced by 9.4%.
The water demand forecast for agricultural irrigation in 2026 can be reduced by 2.8%.

3. Consideration in Introducing AWD

As mentioned above, in introducing AWD, it is estimated to be possible to reduce the agricultural water demand forecast by 9.4% in 2041. However, in Bangladesh, it is reported that the extension of AWD was not so successful due to insufficient extension officers to transfer the technology and disparity between the AWD logic and local farmers' perception regarding paddy rice farming. Therefore, in order to increase the extension rate of AWD to 50% in 2041 in the survey area, it is indispensable to provide the farmers with awareness creation and capacity building training, and secure sufficient extension officers.

When it is recognized that it is necessary to reduce the agricultural water demand forecast in order to realize this plan, and when deciding to introduce AWD, it is essential to discuss the feasibility of AWD extension with the Bangladeshi side, carefully estimate the extension rate of AWD, and assume the reduction rate cautiously.

CHAPTER 4 COMPONENT 3 : EVALUATION OF WATER RESOURCES DEVELOPMENT POTENTIAL BASED ON RESULTS OBTAINED IN COMPONENTS 1 AND 2, AND SUGGESTIONS REGARDING INSTITUTIONAL ARRANGEMENTS OF PROJECT IMPLEMENTATION

4.1 Potential Assessment of Water Resources Development

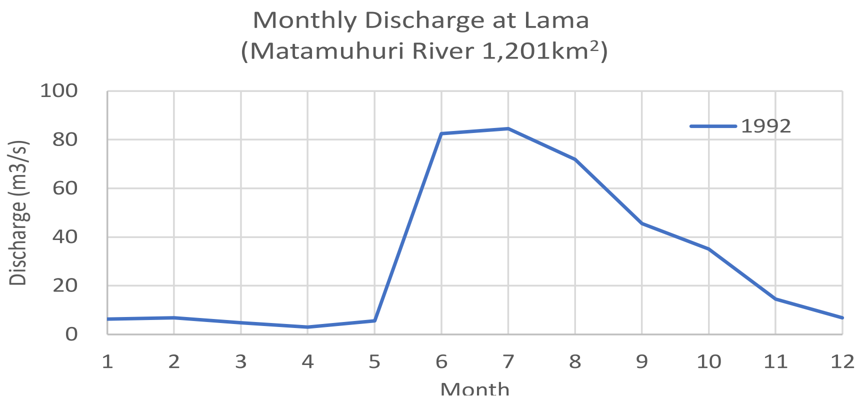
Based on the evaluation results of the current water resources reserves of surface water and groundwater obtained from the study on Components 1 and 2, the basic approach for formulating a water resources development plan is established. Based on this basic approach, conceivable basic alternatives are drafted, and short-term and long-term water resources development potential evaluations are conducted using each countermeasure option through map surveys, field reconnaissance, and outline studies.

4.1.1 Assessment of Surface Water Potential (Present Conditions)

Referring to the study results of Components 1 and 2, basic conditions of “water resources (surface water)”, “water demands” and “water balance study” are preliminarily evaluated for map study on water resources development options in short and long terms.

(1) Water resources (surface water)

The year 1992 is equivalent to a 1/5 drought year in the Matamuhuri River basin based on its river runoff discharge. Figure 4.1.1 shows the river regime at the Lama control point (C.A=1,201km^2) in 1992. These flow data are converted to the whole basin area of the Matamuhuri River (2,511km^2) as surface water.



Source : JICA Survey Team

Figure 4.1.1 Monthly Average Flow at Lama Control Point in 1992

(2) Water demands

The water demands for river maintenance flow, irrigation water, domestic water, and industrial water are investigated as follows.

a) Water demand area

- River maintenance flow：Control point（Lama）

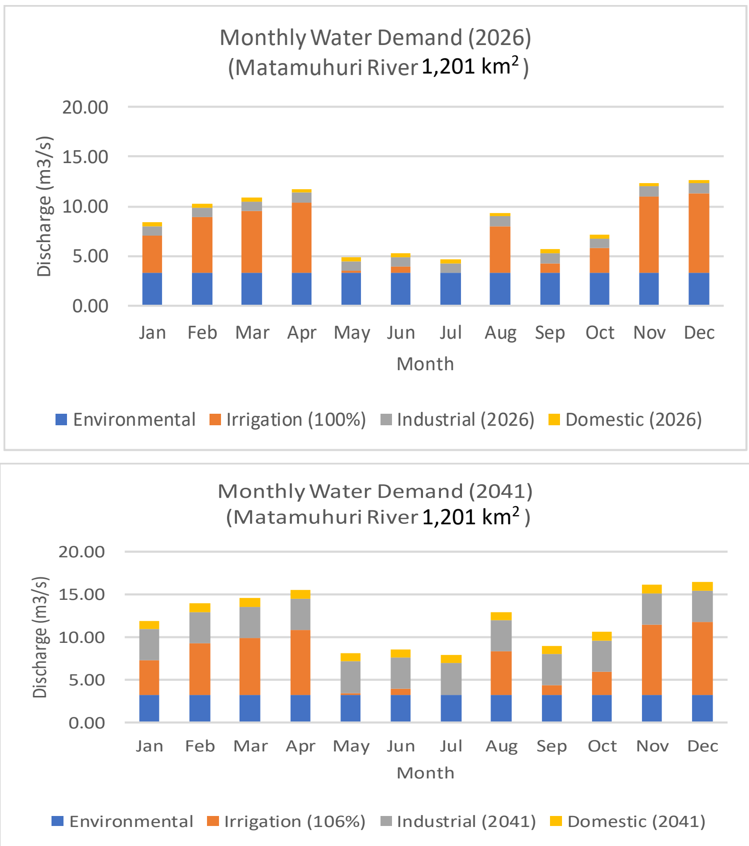
  The control point of water utilization was set at the Lama water level gauge (WLG) station, located at the upstream end of the main water demand area, where it is possible to manage water flow without any tidal influence from the sea.
- Irrigation demand：Irrigation areas of the Matamuhuri River basin
- Industrial water：Moheshkhali /Matarbari region (Matabari Port, General EZ, Seaborn EZ, Moheshkhali EZ)
- Domestic water： Cox's Bazar District (Moheshkhali, Pekua, Chakaria and Kutubdia) in the Matamuhuri River basin where is expected to increase the demand by the development of Moheshkhali /Matarbari region.

b) Water demand

The water demand was calculated for the four upazilas in Cox's Bazar District in the Matamuhuri River basin.

The maximum demand is forecasted to occur in December in both cases of the short term target year (2026) and the long term target year (2041). The annual average demands are as follows.

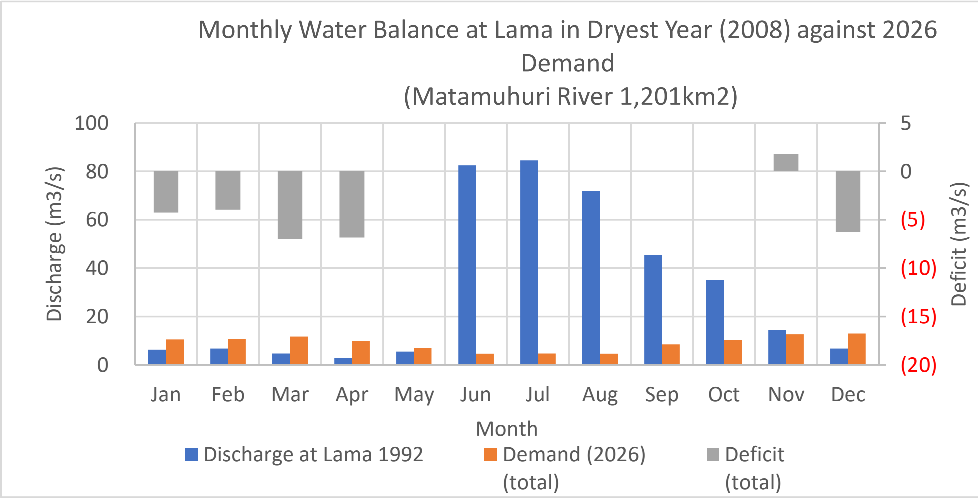
- Short term demand 9.06 m^3/s
- Middle to long-term demand 12.62 m^3/s

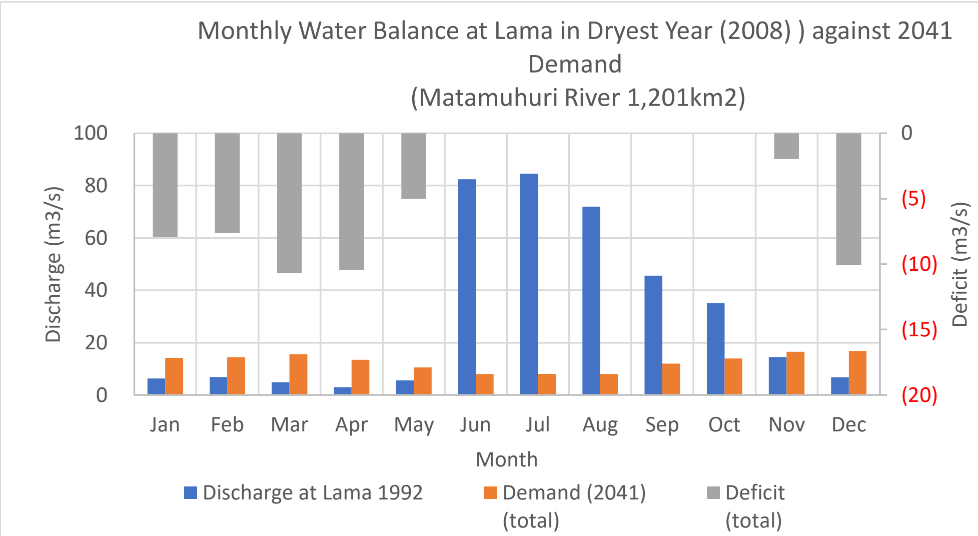


Source：JICA Survey Team

Figure 4.1.2 Water Demand Forecast in 2026 and 2041 (Preliminary Estimation in Desk Study)

The monthly water balance between the surface water (discharge) and the water demands in the target years of 2026 and 2041 is presented in Figure 4.1.3, which shows that the shortage of surface water occurs in the dry season. The shortage amounts in March 2026 (short-term target year) and March 2041 (long-term target year) are approximately 7 m^3/s and 10.7 m^3/s, respectively





Souce : JICA Survey Team

Figure 4.1.3 Forecast of Water Demand and Water Shortage in 2026 and 2041 (Preliminary Estimation in Desk Study)

4.1.2 Assessment of Ground Water Development Potential

This survey has revealed the ground water situation in the survey area as stated hereunder.

The ground water levels in both the shallow and deep aquifers have been gently decreasing in the survey area. The ground water declination is compiled in Table 4.1.1.

Table 4.1.1 Average Ground Water Declination in Survey Area

Upazila	Average Ground Water Declination (m/year)	
	Shallow Well	Deep Well
Chakaria	0.10	0.10
Moheshkhali	0.02	0.03
Cox's Bazar	0.12	0.15
Ramu	0.13	0.10

Source : JICA Survey Team

The ground water declination in the shallow wells is in a range between 0.10 and 0.13 m/year, excluding Moheshkhali, where it is as small as 0.02 m/year. The same tendency applies to the deep wells, where it ranges from 0.10 to 0.15 m/year, excluding Moheshkhali, where it is 0.03 m/year and is small as in the shallow wells.

Judging from the borehole logs of the existing wells and the change of the ground water levels, the shallow and deep aquifers up to a depth of 300 m are not necessarily separated by aquiclude in some places; both the aquifers may have connected hydrogeologically with each other.

From the survey results, the ground water extraction is estimated at 156.7 x 10^6 m^3, while the recharge from surface water to ground water is at 1,323.38 x 10^6 m^3. Therefore, the amount of groundwater pumped up is equivalent to about 12% of the recharge.

Although the recharge to ground water is much higher than the ground water extraction, the ground water level is on a downward trend. This suggests that the total amount of ground water extraction and the outflow from the aquifer to the outside of the study area is larger than the total amount of ground water recharge and inflow from the upstream side of the aquifer.

If the current situation of ground water utilization continues in the future, the ground water in the sturvey area is feared to continue the moderate declination. If the ground water level drops below the sea level, there is a possibility of saltwater intrusion into ground water in the areas facing the sea. In addition, it is assumed that the pumps installed in the wells will be unable to pump water. Of the pumps, the one most affected by the drop of ground water level is the No. 6 type hand pump, which is mostly used in the survey area. The screen position of the No. 6 type hand pump is about 7.5 m below the ground surface. The possible future operating period of the No. 6 hand pump is calculated by using the following formula, in due consideration of the ground water level declination.

(Operating years) = (7.5m- [Current ground water level]) / (Annual average ground water level declination rate in the area)

Since the ground water level is decreasing and the recharge exceeds the ground water extraction, it is considered that the current amount of ground water extraction exceeds the potential of ground water development in the survey area. Therefore, it seems impossible to newly promote large-scale development of ground water.

In order to develop the groundwater in the survey area, it is necessary to take measures so as to store or delay in aquifers the groundwater flowing outside the survey area. A typical example of the measures is an underground dam, but there are no topographical or geological conditions suitable for the construction of an underground dam in the survey area. The reasons are described below. The underground dam is a system that stores ground water by constructing an impermeable wall in the flow path of the ground water, and is the same as a normal dam in principle. However, since the target of water storage is ground water, the matters that need to be considered when planning an underground dam and the consideration based on the results of this survey are as follows.

- ✧ Item 1: Targeting deep ground water as a target for underground dams will result in an excessive scale of construction work and cost, so it is common to target shallow ground water.

  Shallow and deep aquifers are distributed in the survey area. However, since both are considered to be linked to hydrogeologically as described in Chapter 2, even if the ground water in the shallow aquifer is stored by the impermeable wall, it may flow out through the deep aquifer. If the impermeable wall that reaches the base of the deep aquifer is to be constructed, the impermeable wall that must reach a depth of 200 to 300 m is required. It is considered unrealistic.

- ✧ Item 2: The sides and bottom of the reservoir area must be impervious.

  If the aquifer of the ground water to be stored is the Tipam Formation or the stratum above it, the strata distributed on the sides and bottom of the reservoir are the Bokabil Formation which consists of sand and shale. Ground water is stored in the sandstone although water quality is not suitable for development, therefore the sandstone is not impervious. Accordingly, the Bokabil Formation is not suitable as the basement of the underground dam.

- ✧ Item 3: Similar to the normal dam, there must be an area where the impervious ground forms a constriction and has a wide aquifer on the upstream side. Assuming that the Bocabil Formation is an impermeable layer, the first condition, "the impervious ground forms a constriction," is met by the flow path in the CHT of rivers such as the Sang and Matamuhuri rivers. In addition to the second point, "it has a wide aquifer on the upstream side", "the amount of water stored in the underground dam is decided by the effective porosity of the aquifer in the reservoir area, so it should be considered that the water storage in the underground reservoir is only 10 % to 30% of the volume of the reservoir area. Ground dams are already planned in these areas. Even if an underground dam is planned, the storage capacity of such underground dams will not meet the water demand estimated in this survey. On the other hand, the shallow aquifer is widely distributed in the coastal plain, and the ground water flows toward the Bay of Bengal. However, there is no constriction of the impervious layer between the coastal plain and the Bay of Bengal.

  From the above, no topographical or geological conditions suitable for underground dams can be found in the survey area.

In the survey area, DPHE has been constructing wells for installing hand pumps, which is supposed to continue in future. It is unlikely that the said well construction will greatly hasten the declination of ground water level in a short term, since the number of wells to be constructed in a year is rather limited.

In the survey area, the ground water exceeding the industrial and domestic water demands has been being used for irrigation as well. From a long-term perspective, if it is possible to convert the water source for irrigation from ground water to surface water, the ground water taken for irrigation can be utilized for future industrial and domestic water demands.

4.1.3 Basic Approach for Formulation of Water Resources Development Plan

(1) Basic approach for formulation of water resources development plan

In order to solve the shortage of water resources associated with the development of the Moheshkhali/Matarbari region and surrounding areas, it is necessary to consider water resources development extending over river basins. In addition to diversified viewpoints (in terms of comparison of alternatives, water rights, costs, consideration for the social environment, necessary permits and licenses, and development period), examination of feasibility and site selection that meets the requirements of water demand side as well as water resources development is required.

In this survey, the following approaches are adopted so that a highly feasible water resources development plan will be proposed in accordance with the philosophy of integrated water resources management that aims at rational and equitable use of limited water resources, through sufficient discussions with the Government of Bangladesh.

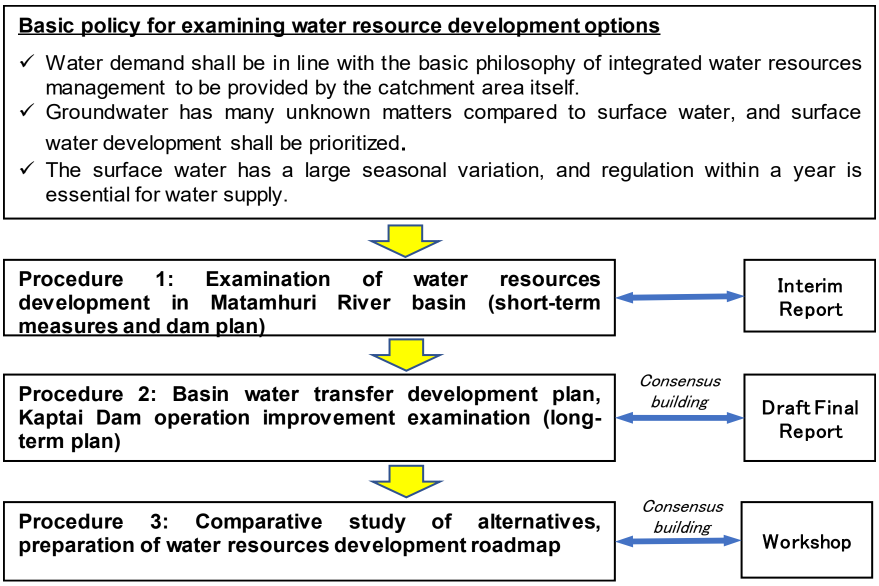
- ✓ It is planned that water resources are to be rationally available based on the consents of the relevant central government agencies, local governments and residents. As a result, the friction with the water supply plan is decreased, the feasibility is guaranteed, and it enables early implementation. In this Survey, at first the consensus among the relevant government agencies is to be built. In the feasibility study to be implemented in the next stage, consensus building with stakeholders (local residents) will be formulated.
- ✓ Some present water uses have plans to expand their services in the near future. The new water use plan that accompanies the current MIDI development shall be in harmony with those future plans.
- ✓ The development policy is to aim at water resources management which takes one river basin as a basic unit for the integrated water resources management, and the first priority for the development is given to the Matamuhuri River basin where the Moheshkhali/Matarbari region is located.
- ✓ The demand survey takes into account the current and future demands for environmental preservation, as well as the central and local governments and residents.
- ✓ The evaluation of alternative plans in the Survey is to be made in terms of social, environmental, institutional, financial and technical issues, sustainability, etc.)

✓ To gather opinions from survey partners at survey milestones, whose opinions will be incorporated into the plan, and seek a consensus on water resources development plan from multiple organizations and institutions across multiple watersheds.

(2) Procedures for plan formulation of water resources development

Figure 4.1.4 shows the procedures step-by-step for water resources development in line with the future water demand forecasts. The basic development policy is as stated below.

- The development policy is to aim at water resources management which takes one river basin as a basic unit for the integrated water resources management, and the first priority for the development is given to the Matamuhuri River basin where the Moheshkhali/Matarbari region is located.
- The short-term plan will secure water resources in the Matamuhuri River basin and propose water supply and utilization facilities.
- After that, inter-basin water transfer from the Karnafuli and the Sangu River basins to the Matamuhuri River basin is also to be considered as phased development of water sources. Based on this, a road map for the water resources development is formulated.
- Since the groudwater has many unknown matters compared with surfac ewater, and hence surface water development shall be prioritized.
- The surface water has a large seasonal variation, while the water demand to the Moheshkhali/Matarbari region is mainly for domestic and industrial use, and is of less seasonal variation. The regulation within a year is essential for water supply in this region.



Source; JICA Survey Team

Figure 4.1.4 Policy on Water Resources Development Options and Study Flow

4.1.4 Preparation of Alternatives for Water Resources Development Plan

(1) Setting of basic alternative

As mentioned above, the short-term alternative secures a water source in the Matamuhuri River basin where the Moheshkhali/Matarbari region is situated, and proposes water supply and water utilization facilities in the basin. The following table explains the possible facility measures. In response to these measures, a map study was conducted as a primary screening. Then, a comparative study was conducted on the feasibility of adopting each measure alternative based on the results of field reconnaissance, and then realistic alternatives were selected.

Table 4.1.2 Individual Measures on Water Sources and Water Utilization Facilities in the Survey <Candidates for Alternatives for Each Basin>

Measures		Surface Water Development				Groundwater Development	Desalination of Seawater	Water Demand Management
		Dam*	Movable Weir	Pond	Tidal Weir			
Remarks		Typical method for adjusting the dry season flow. Careful social environmental consideration is required.	Currently being implemented. .	Currently being implemented.	Not available due to shipping.	Currently being implemented locally.	Complementing measures in case the amount of water is small	Water-saving in irrigation, Water leakage measures, Reclaimed water utilization, etc.
Practi-cability	Short term	×	◎	◎	×	◎	△	◎
	Long term	○	◎	◎	×	◎	△	◎

Notes: ◎ Highly practical ○ Practical △ Partially practical × Less practical

- In this survey, the division between the dam and the pond is defined as a structure that stores water with a dam height of 15 m or more as a dam, and those lower than that are defined as pond.

Source: JICA Survey Team

These short-term and long-term measures and water resources development options in the Matamuhuri River basin were studied according to the procedures shown in Figure 4.1.5.

(2) Primary screening

The results of primary screening among the basic alternatives are enumerated below:

- Movable weirs and ponds are the structures that have been actually constructed in the survey area. Since these structures are considered feasible in the target area, these are to be studied as one of the candidates of the main measures.
- As for the dam plan, after comparing three alternative sites for flow regulating facilities in a dry season on the Matamuhuri River, construction of Khuta Khali Chara Dam (capacity: 61 MCM) and intake weir (rubber weir, height: 5 m and width: 40 m) were proposed as dry season flow regulating facilities in the "JICA Comprehensive Development Study (2016)". However, the dam plan was evaluated as a poor feasible option due to the need of large-scale resettlement and low study accuracy. In this survey, the water source candidates that can be realized in a short term are to be extracted. The dam plan is regarded as a long-term plan because it requires environmental and social assessments of resettlement and land acquisition, and requires long time.
- Among the dam plans, an inter-basin water transfer plan by dam construction in the Sangu River basin and improvement of Kaptai Dam in the Karnafuli River basin are also regarded as a long-term plan because of same reason of the dam plans.
- For the tidal weir, the rivers in the survey areas are used for navigation. It is difficult to construct a large scale of the tidal weir, and unapplicable for the proposed measure.
- In addition, the "seawater desalination plan" is considered to need large scale facilities to meet the short term demand, and it is assumed that it would be difficult to implement the water supply project by "seawater desalination plan" only. This is treated as supplemental measures in the case of local and small scale water demands.
- On the other hand, as for the "groundwater utilization plan", currently there is a policy where groundwater use is to be limited in Bangladesh. There are many uncertainties about its potential for the time being compared with the surface water because ground water cannot be visually confirmed and observed like rivers and lakes, and its flow, distribution, and potential should be estimated by well surveys and geophysical investigations. The ground water is treated as supplemental measures in the case of local and small scale water demands.
- The idea on water demand management can be adopted together with the main structural measures. This is treated as supplemental measures.

(3) Procedures for study on water resources development options

Based on the above, the short-term plans of "movable weir and pond" and the long-term plans of "dam and inter-basin water transfer" are considered as main measures, and "seawater desalination", "groundwater development", and "water demand management" plans are positioned as supplemental measures.

In addition, as the order of the short-term plan, if the amount of surface water and ground water is sufficient, those developments will be prioritized, and if it is insufficient, the demand management will be considered.

Assuming these short- and long-terms basic measures, water resources development options are examined, using the procedures explained in **Figure 4.1.5**.

Basic policy for examining water resource development options

- ✓ Water demand shall be in line with the basic philosophy of integrated water resources management to be provided by the catchment area itself.
- ✓ Groundwater has many unknown matters compared to surface water, and surface water development shall be prioritized.
- ✓ The surface water has a large seasonal variation, and regulation within a year is essential for water supply.

Procedure 1: Examination of water resources development in Matamhuri River basin (short-term measures and dam plan)

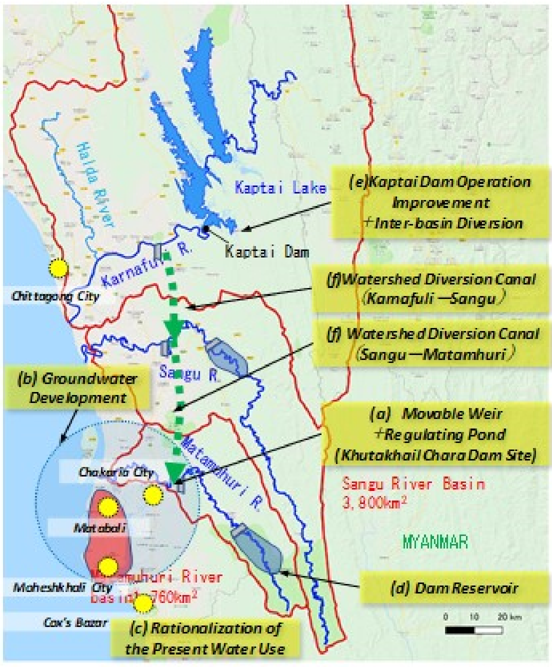
i) Examine the possibility of (a) movable weirs, headrace + regulating ponds in the Matamfuri River basin.
ii) If the supply capacity is insufficient with the plan (a) alone, (b) Consider the development of groundwater.
iii) If it is still insufficient, (c) to streamline existing water use (demand).
iv) If there is a further shortage, (d) consider the possibility of dam construction. (Long-term plan)

Procedure 2: Basin water transfer development plan, Kaptai Dam operation improvement examination (long-term plan)

i) If water supply development in the Matamhuri River basin alone is insufficient, (e) consider countermeasures outside the basin. First, the diversion of the Kamafuri River from the Kaptai Dam is examined , which has the most potential for water resources development.
ii) If diversion from the Kaptai Dam is impossible or insufficient, consider (f) the surplus of the nearby basin and attempt diversion from the area with surplus water.
iii) (f) If there is no surplus in the neighboring basin, the same study as the proposals (a) to (d) for the Matamhuri River basin will be studied for the neighboring basin, and find the water resources surplus.

Procedure 3: Comparative study of alternatives, preparation of water resources development roadmap

i) The above measures have different effects, cost, construction period, impacts society and environment depending on the scale and study depth. Formulate multiple plan candidates that combine plans satisfying water demand, assuming the scale and depth of various measures, and then carry out multi-objective evaluations to select the best one for recommendation.



Source; JICA Survey Team

Figure 4.1.5 Alternative Study Procedures on Water Resources Development Options and Conceivable Alternatives

4.1.5 Alternative Study by Potential Assessment on Water Resources Development in Matamuhuri River Basin

(1) Study for storage facilities

The Matamuhuri River has a considerable difference in river water between the rainy and dry seasons. In the dry season, the amount of river water is small, and hence it is difficult to secure new municipal water (domestic water and industrial water), river maintenance flow, and irrigation water by using the natural river flow. Therefore, it is necessary to temporarily store the abundant river water during the rainy season into storage facilities, and to provide a stable water supply from the storage facilities for the demand area throughout the year. The scale of the storage facilities required in the Matamuhuri River basin is as follows:

Table 4.1.3 Development Requirements for New Water Demands

Development Target Year	Required Reservoir Volume (Million m^3)	River Maintenance Flow (m^3/s)	Domestic Water (m^3/s)	Industrial Water (m^3/s)	Irrigation Water (m^3/s)	Total Demand (m^3/s)
Short-term 2026	70	3.30	0.39	0.97	4.40	9.06
Long-term 2041 Addition on short term	71	---	0.63	2.67	0.26	3.56
2041 (total)	141	3.30	1.02	3.64	4.66	12.62

Source: JICA Survey Team

The required reservoir volume in the above table is based on the natural river regime in 1992 (1/5 drought year), which has the lowest dry season flow out of several drought years. The reservoir volume that can satisfy all the demands for domestic water, industrial water, irrigation water, and river maintenance flow is estimated by a water balance study.

(2) Candidate sites for water storage facilities

The candidate sites for water storage and conveyance facilities are roughly selected, using information from Google Earth in consideration of the following:

- The intake site in a river should consider the risk of salt water intrusion.
- In due consideration of water storage area and volume, a wide flat land is required.
- The candidate site is required to avoid the areas which are crowded with houses and infrastructures for minimization of land acquisition.
- The water supply pipeline to demand areas and headrace pipeline from an intake site to a water treatment plant for water conveyance are assumed to be laid under a road.

(3) Alternatives for water resources development in Matamuhuri River basin

The following alternatives are expected to meet the water demands in short and long terms from the viewpoint of the required reservoir volume and the construction possibility in the Matamuhuri River basin. Regarding the long-term alternatives, the water transfer from other river basins is also included in the study.

(a) Short-term alternatives

- S1; intake + pond
- S2; intake + pond + groundwater
- S3; intake + pond+ seawater desalination (small scale)

(b) Long-term alternatives

- M1; short-term alternative (S1) + pond expansion

- M2-1; short-term alternative (S1) + dam/reservoir in the Matamuhuri River
- M2-1; short-term alternative (S1) + dam/reservoir in the Sangu River with inter-basin transfer
- M3; inter-basin water transfer alternative (Lake Kaptai water supply pipeline)

The advantages and disadvantages of each short-term alternative are compared in Table 4.1.4.

Table 4.1.4 Comparison of Short-term Alternatives

Project Code	ZERO Option	S1	S2	S3
Alternatives	**None**	**Intake + Pond**	**S1+Groundwater**	**S1 + Seawater Desalination**
Features	No alternative	The intake and pond will be constructed near the Matamuhuri River. The water will be supplied from the pond to the demand area via the adjacent water purification plant.	In addition [S1], by using groundwater to reduce the volume of the pond.	In addition [S1], by using desalination of seawater, to reduce the volume of the Pond. The desalination facilities will be constructed near the demand area.
Environment	× ▪ Environmental impact due to water resource development project will be not be arisen. ▪ The impacts due to increase of water demand would be arisen, such as impact on hydrology.	△ • Some environmental impact would be arisen, but environmental condition of the proposed site is different from habitat of endangered species designated by Bangladesh regulations and international treaties.	△ ▪ Same kinds of environmental impacts as alternative S1will be expected. ▪ The impact on hydrology would be arisen due to use of groundwater.	△ ▪ Same kinds of environmental impacts as alternative S1will be expected. ▪ The impact on water quality would be arisen due to discharge of salt water.
Social	× ▪ Social impact due to water resource development project will not be arisen. ▪ The impacts due to increase of water demand would be arisen, such as impact on	△ ▪ The proposed site for the Pond is owned by Cox's Bazar district. ▪ Private land acquisition will not be expected for construction of the Pond. ▪ Resettlement will not be also expected. On	△ ▪ Comparing with alternative S1, impact on lessees would be smaller, since size of the Pond will decrease. ▪ The impact on uneven distribution of damage and	△ ▪ Comparing with alternative S1, impact on lessees would be smaller, since size of the Pond will decrease. ▪ The impact on fishery would be arisen due to discharge of salt water.

Project Code	ZERO Option	S1	S2	S3
	water use and uneven distribution of damage and benefit.	the other hand, the proposed site is used as salt farm and shrimp cultivation pond. ▪ According to the interview survey result, around 100 of lessees would be affected on their livelihood.	benefit would be arisen due to use of groundwater.	
Economical	× ▪ The developments of Matabari-Moheshkhari aera will be affected by negative impact of water shortage. ▪ The economical development in this area would be obstructed.	○ ▪ Basic option of economical evaluation to compare with S2 and S3. ▪ Initial investment cost of intake and pond, and operation and maintenance cost for facilitates will be necessary.	◎ ▪ If there is groundwater potential in this area, the size of proposed pond can be reduced, and the economical effect would be better than S1.	× ▪ As an example of desalination, the estimated construction cost of a small scale desalination of 40,000 m3 / day is JPY 9 billion, and the annual cost (electric power, chemicals, RO membrane replacement, labour cost) is estimated to be JPY 1 billion. ▪ Moreover, the running cost is high so that economy is poor in total.
Technical	× ▪ At present, seasonal variation of water potential is big, water shortage in dry season is expected.	◎ ▪ A Pond will be constructed on the flat land of the floodplain downstream of the Matamuhuri River. ▪ Although there may be issues such as compensation for floodplains, minimization of the impact on surrounding structures, and soft ground treatment. ▪ It is more	△ ▪ The availability of deep groundwater is uncertain for the time being. ▪ Therefore, the alternative is poor certainty.	× ▪ RO membrane method is lower energy consumption and less environmental impact, but in case sea water is polluted adjacent to the propose desalination plant site, the initial treatment cost would be more expensive due to occurrence of clogged of membrane, etc.)

Project Code	ZERO Option	S1	S2	S3
		feasible than other alternatives.		

Source: JICA Survey Team

From the above table, the short term alternative: “Intake + Pond” is recommended.

The policy of water resources development alternative is to focus on the "surface water utilization", while the "groundwater utilization" and "seawater desalination" could be given to the positions for supplement of water shortage and be examined in the future.

In addition to the short-term and long-term alternatives mentioned above, appropriate implementation of the following measures is important to improve the efficiency and effect of water resources development:

- Construction of rainwater storage facilities,
- Non-revenue water measures, and
- Water saving measures.

<u>Long-term alternatives</u>

The details of study for the long-term alternatives are described in the following “Sub-section 4.3.1”.

(4) Map study of short-term alternatives

A map study was conducted based on the water resources development options (see Figure 4.1.6) envisioned at the time of the Inception Report (December 2019) in the Matamuhuri River basin with reference to topographic maps, geological maps, land use maps, and aerial photographs.

1) Conditions of the map study

The layouts of intake weirs and ponds in the Matamuhuri River basin were examined on the map in consideration of the following:

- The basin has existing small ponds, which have been used for domestic water for local residents.
- In terms of locations of water demand areas (Chakaria, Matarbari, Moheshkhali and others), the intake weir is assumed to be near the Matamuhuri Bridge on National Highway No. 1 (N-1), and the pond near the midpoint between the intake weir and the Matarbari demand area.
- The pond construction site is located in the brackish water area along the lower Matamuhuri River, where fish ponds and salt pans are operated. There are also existing roads (R-172 etc.), new roads (Matarbari Port Access Road), and new railroads between Chakaria and Matarbari.

2) Study for pond facilities

The short-term alternative is to construct a "pond" in the floodplain that extends immediately upstream of the estuary of the Matamuhuri River, and to convey the water to the demand areas (see Figure 4.1.6).

(a) Scale of Regulation Pond

The pond construction site was selected in the floodplain situated immediately upstream of the estuary of the Matamuhuri River since it is near the demand areas. The raw water in the pond is mainly river water during the rainy season.

- Effective volume[*1]: short-term 70 MCM, long-term 141 MCM (71 MCM expansion)
- Effective water depth: a pond crest ≥ EL.10 m is required to reduce storm surge damage, and a free board height of 3 m is required above a normal pond water level (W.L.7 m) and hence an effective water depth of 5 m is provided.
- Ponding area: short-term 14.0 km^2, long-term 28.2 km^2 (extension 14.2 km^2)

Note: Since the pond height of 8 m is rather low, it could be adapted to the soft ground.

(b) Arrangement of water conveyance facilities

The facilities are composed of the Matamuhuri River pump type intake → Headrace → Pond → Water treatment plant (W.T.P.)/River outlet works→ Water supply pumping station → Tailrace→ Water distribution pond.

- Whereas the Matamuhuri River near the pond area is located in the salt water intrusion area, existing movable weirs have been installed downstream of the Matamuhuri Bridge to prevent the saltwater run-up. Therefore, the intake site is to be upstream of the existing weirs.
- A pumping station is to be set up at the intake site to pump up the river water in the rainy season to the pond.
- The storage water for domestic and industrial uses is pumped to the W.T.P., and then pumped up to a water distribution pond (in demand area) by transmission pipeline.
- The storage water for river maintenance and irrigation purpose is also to be discharged to the river near the pond by outlet works.

(c) Pond basic layout[*2]

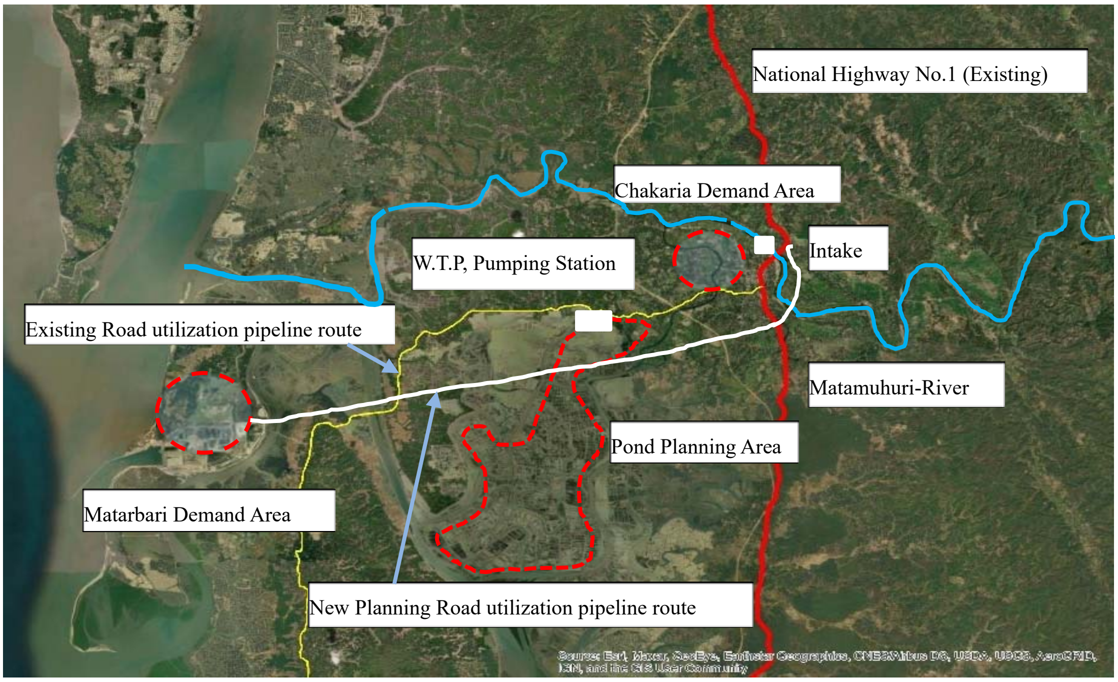
- The ground surface of the pond is in a flat land of EL.+1.0 to 3.0 m, and therefore, a pond is surrounded by a low height dyke structure.
- The dyke is assumed to be a zone-type soil embankment with low risk of damage, and the slope on the pond side is covered with a revetment.
- The upstream side of the soil embankment is covered with blanket to prevent seepage flow.

- A spillway shall be installed to control the water level in the pond owing to the rainwater falling into the pond. The rainwater is discharged to adjacent rivers by a non-gated natural flood control method.
- Outlet works shall be provided to discharge into the adjacent river not only irrigation water and river maintenance flow but also the pond water to lower its level in the case of dredging mud or maintenance of the dyke, as required.
- It is necessary that the pond secure water quality and take measures against mud deposit.
- As for the pond structure, it is recommended that the height of outer ring dyke (embankment) should be low because the dyke foundation in the floodplain is assumed to be very soft.
- “Excavated Pond” and “Non Excavated Pond” are compared. In the case of the former, it is expected that the dyke height is low through securing the effective pond volume by excavating the floodplain.
- As the result of the comparison as stated below, “Non Excavated Pond” has the following advantages compared with the former. Therefore, “Non Excavated Pond” is adopted.
    - ➢ The construction cost is about 50 % smaller than that of the "Excavated Pond".
    - ➢ In the case of “Non Excavated Pond” (crest EL.10.2), it is assumed that the risk of storm surge damage is smaller than that in the case of “Excavated Pond” (crest EL.6.7).
    - ➢ “Non Excavated Pond” does not need pump facilities as outlet works, while “Excavated Pond” needs pump facilities. Therefore, additional pump operation and maintenance costs can be saved.

Notes;

- *1 The pond alternatives above cover all the water demand for domestic, industrial, river maintenance flow, and irrigation water. For finalization of the pond alternative, the following study is conducted, as the top priority water resource development plan, in
[4.1.7 Formulation of alternative plans for short term water resources development]:
    - Case- 1; Domestic + Industrial water,
    - Case-2 ; Domestic + Industrial + River maintenance flow, and
    - Case-3 ; Domestic + Industrial + Irrigation + River maintenance flow.

- *2 "Reservoir Maintenance Guideline" in Land Improvement Project Design Guideline, Ministry of Agriculture, Forestry and Fisheries, Japan, 26 February 2015, as referred to in Annex 4.1-1



Source: JICA Survey Team

Figure 4.1.6 Map Study of Pond

4.1.6 Field Reconnaissance of Candidate Sites for New Water-use Facilities in Water Resources Development Options

The JICA Survey Team conducted field reconnaissance at and around the seven (7) sites presented in Fig. 4.1.18 during the six (6) day period from 14 to 19 October 2021 with the aim of confirming the present land use and other site conditions concerning the candidate sites of new water-use facilities (weirs, dams, water conveyance canals, regulation ponds, reservoirs, etc.) which are included in the options of water resources development plans in short and long terms worked out through the map study in "Sub-section 4.1.1". The field reconnaissance proceeded in safety and as scheduled, getting a great deal of support and advice from Bangladeshi organizations concerned, such as Deputy Commissioner offices and Superintendent of Police offices in Cox's Bazar, Chattogram and Bandarban Districts, BWDB Cox's Bazar, Chattogram and Bandarban Division Offices and local police offices, as well as JICA Bangladesh Office.

Table 4.1.5 compiles major findings in the field reconnaissance, which are useful particularly for the succeeding study and plan formulation in the Survey.

Table 4.1.5 Major Findings in Field Reconnaissance (14 to 19 October 2021)

Sites Visited*	Major Findings
Site 1: Dohazari **(Sangu** Intake Pump Station; *see **Photo-4.1.1***)	• The idea of weir construction to intercept river water with pumps from the **Sangu River** is practicable. • The color of river water is brown due to excess sedimentation. Hence, proper countermeasures are important to avoid malfunction of the weir in an operation stage.

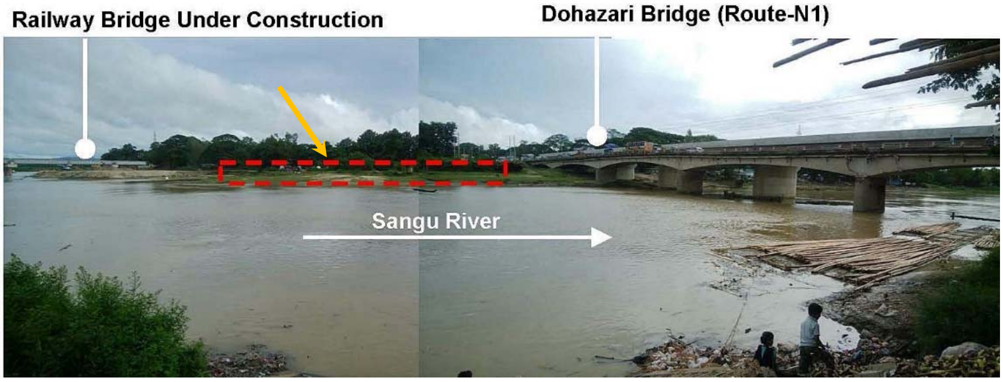


Photo-4.1.1 Dohazari : Candidate Site of **Sangu I**ntake Pump Station

Sites Visited*	Major Findings
Site 2: Ruma (near **Sangu** Branch Dam site)	• From the technical viewpoint, the Sangu Branch Dam site seems to be practicable through visual inspection. • As to access to the dam site, use of Cimbuk Road on the left side of the **Sangu River** is preferable during the dry season at this moment and access by small boat is also possible from Ruma (*see **Photo-4.1.2***).

Photo-4.1.2 Jetty in the **Sangu** River near Ruma

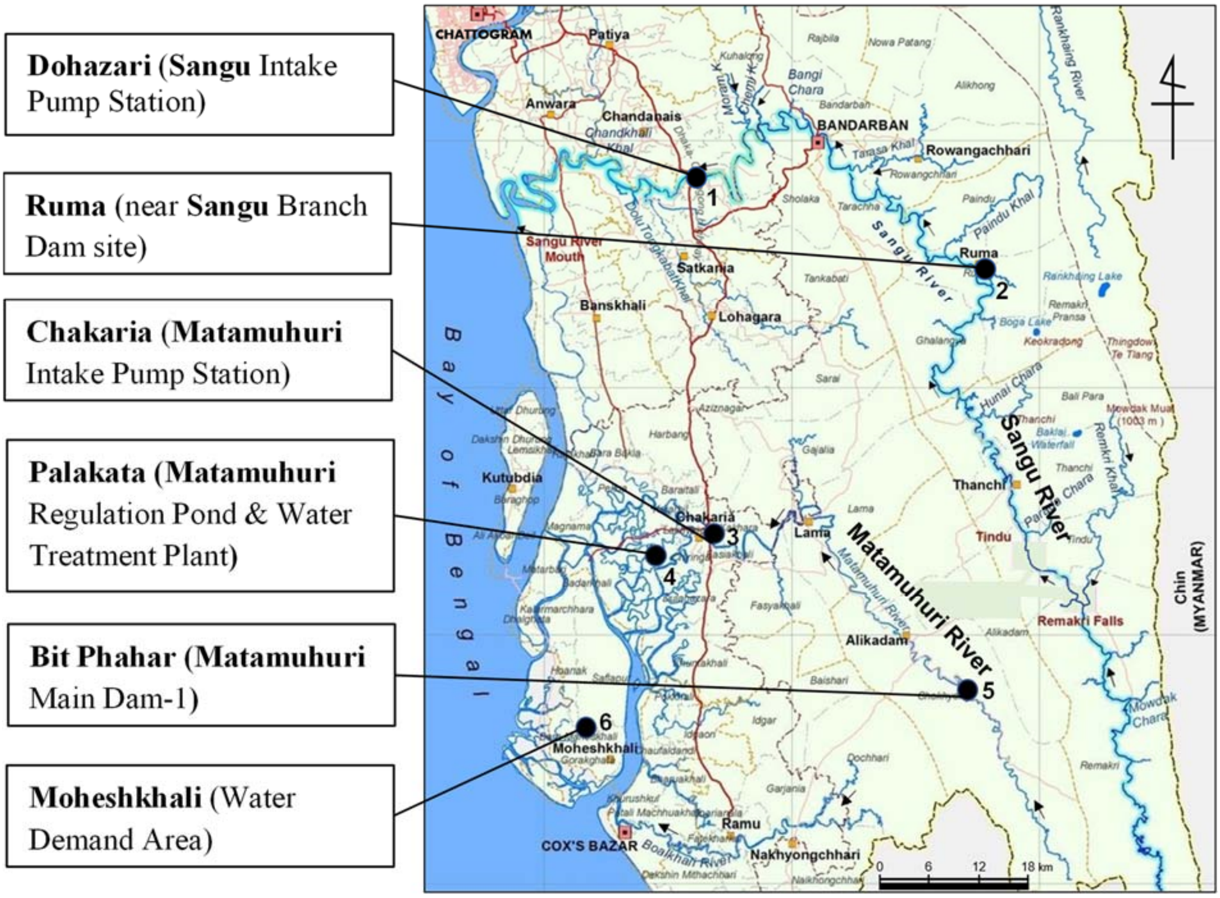
Sites Visited*	Major Findings
Site 3: Chakaria (**Matamuhuri** Intake Pump Station; *see* ***Photo-4.1.4***	• The idea of weir construction to intercept river water with pumps from the **Matamuhuri River** is practicable. • The operation of weir could be conducted without serious negative impacts on current small boat navigation, since the frequency of boat passing is 2 to 3 times per day in all seasons (*see **Photo-4.1.3***).

<table>
<tr><th>Sites Visited*</th><th>Major Findings</th></tr>
<tr><td colspan="2">
Photo-4.1.3 Small Boat Navigation in the **Matamuhuri** River

Photo-4.1.4 Chakaria : Candidate Site of **Matamuhuri** Intake Pump Station</td></tr>
<tr><td>**Site 4**: Palakata (**Matamuhuri** Regulation Pond**)**</td><td>• A large part of the regulation pond area is located in the areas already used for fish ponds (*see **Photo-4.1.5***).
• It is better that the pipeline routes from the **Matamuhuri** intake pump station to the regulation pond and Moheshkhali water demand areas are to be aligned along the new Matarbari Deepsea Port Road, which is under construction, as one of practical options.</td></tr>
<tr><td colspan="2">
Photo-4.1.5 Fish Ponds in Palakata Area</td></tr>
<tr><td>**Site 4**: Palakata (**Matamuhuri** Water Treatment Plant: WTP)</td><td>• The pipeline route from the WTP to Moheshkali water demand areas needs to apply new shortcut routes in some sections, because the existing roads zigzag and substantial people are living in places along the existing roads.</td></tr>
</table>

Sites Visited*	Major Findings
Site 5: Bit Phahar (**Matamuhuri** Main Dam-1**)**	• At and around the **Matamuhuri** Main Dam site (near Bit Phahar), there are rocks cropping out in some mountain slopes along the local roads (*see **Photo-4.1.6***.) • Access to the dam site by jeep is possible, and access by small boat is also possible during the monsoon, pre- and post-monsoon seasons.
 **Photo-4.1.6** Rock Cropping out in Mountain Slope in Bit Phahar	
Site 6: Moheshkhali (Water Demand Area)	• There are some brick factories operated in the Moheshkhali Island and the factories have been obtaining the brick manufacturing material within the island. Hence, the earth material necessary for construction of the blanket to be laid on the bottom surface of the regulation pond seems to be procured within the island.

Notes: 1) * See Figure 4.1.7
2) Candidate site of facilities, Pointing location, White arrow: Flow direction
Source: JICA Survey Team



Note: The site numbers of 1 to 6 correspond to those in Table 4.1.5.

Source: JICA Survey Team

Figure 4.1.7 Sites Visited in Field Reconnaissance (14 to 19 October 2021)

4.1.7 Formulation of Alternative Plans for Short-term Water Resources Development

Based on the results of the map study and the field reconnaissance explained in the foregoing subsections, the short-term alternatives are proposed to intercept the rainy season water in the Matamuhuri River, transfer and temporarily store the water into the regulation pond near Plakata, Cox Bazar, and supply the water to the demand areas through a water treatment plant. It is noted that a large area of land, where fish ponds and salt pans have been currently operated, is needed for pond construction and hence it should be carefully taken into account that various measures such as compensation for land acquisition and securing resettlement areas, among others, will be required in the future.

(1) Regulation pond

According to the field reconnaissance, the candidate sites of the regulation pond are found in the floodplain in the Palakata area, where a wide flat land spreads out near the demand areas.

Regarding the object demands for water supply, "domestic water", "industrial water", "irrigation water", and "river maintenance flow" are examined in the water balance study for the water resources development. The study considers the case where the current groundwater use is to be converted to the surface water use, as well.

Table 4.1.6 shows the hydraulic quantities for alternative plans of the regulation pond by combination of the object water demands based on the water balance study.

Table 4.1.6 Hydraulic Quantities for Object Water Supply Demands in the Short Term

Object Water Supply Demand	**Domestic Water + Industrial Water**	**Domestic Water + Industrial Water +River Maintenance Flow**	**Domestic Water + Industrial Water +River Maintenance Flow +Irrigation Water**
Water Supply Amount (m^3/s)	Domestic water: 1.04, Industrial water: 0.66, irrigation water: 3.09, River maintenance flow: 7.07 (at pond site)		
Required Pond Effective Volume (MCM)	16	36	95
River Water Intake Amount (m^3/s)	4.7		10.0
Water Treatment Plant Capacity	1.7 m^3 / s = 150,000 m^3 / day		
Matarbari Demand Area Water Supply Amount	1.32 m^3 / s		
Chakaria Demand Area Water Supply Amount	0.38 m^3 / s		
River Maintenance Flow	0	7.89 m^3 / s	11.97 m^3 / s

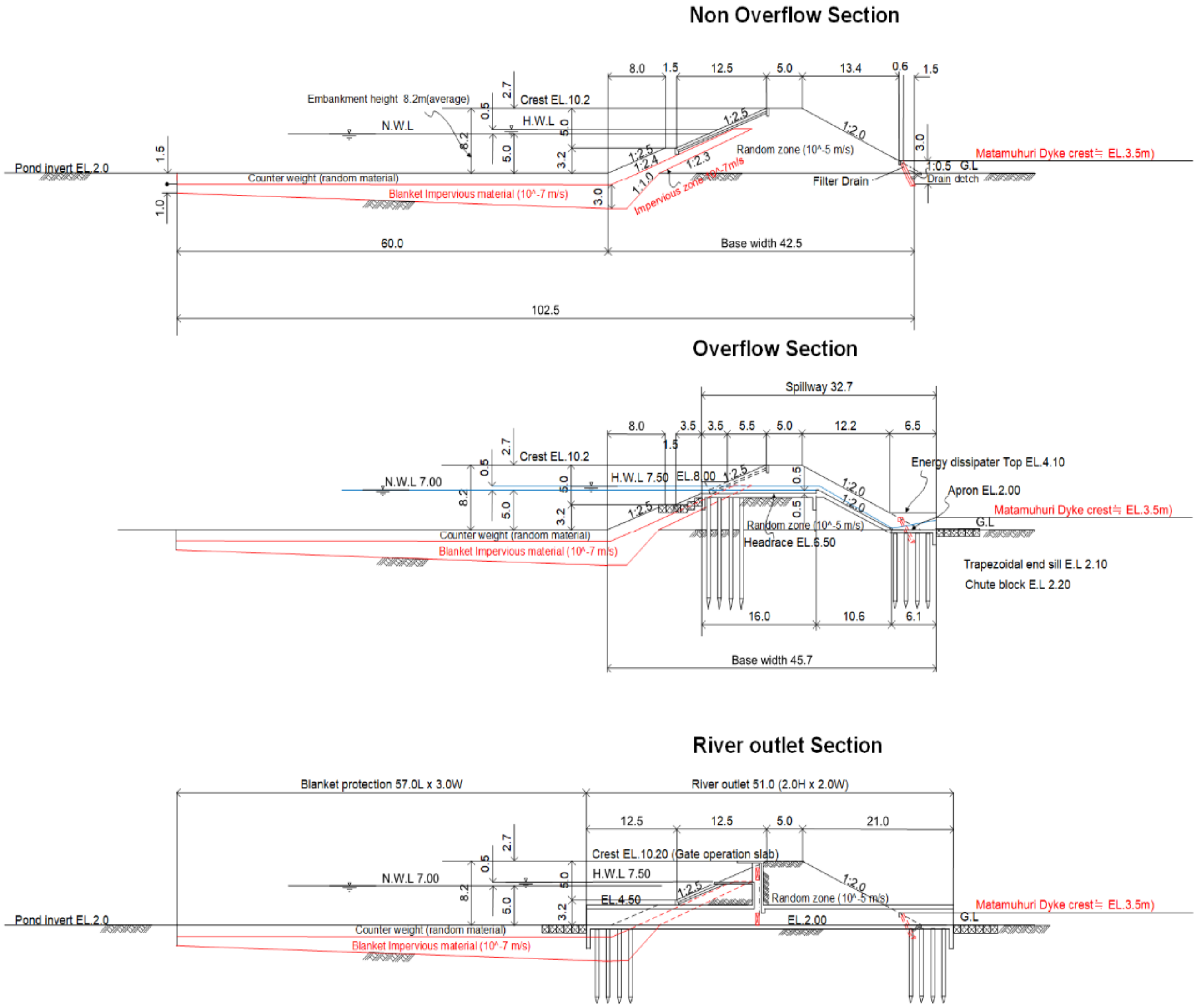
Source: JICA Survey Team

Currently, as referred to in "3.2.1 (1)", the port facilities, industrial complexes and housing development, which are required for the development of the Moheshkhali-Matarbari region, have been being planned and developed at a rapid pace. The case of "Domestic water + Industrial water" demands has the smallest scale of facilities which supply water to the region. This case is recommended in consideration of start of their services in 2026 (short-term target year). Although the recommended case does not supply the maintenance flow from the pond, the pond operation is planned so that the current river flow conditions will not be worsened by pumping up only the river water that exceeds the river maintenance flow for the downstream river stretches of the pump station..

The basic outline of the pond facilities to satisfy the object demands in Table 4.1.6 is presented below.

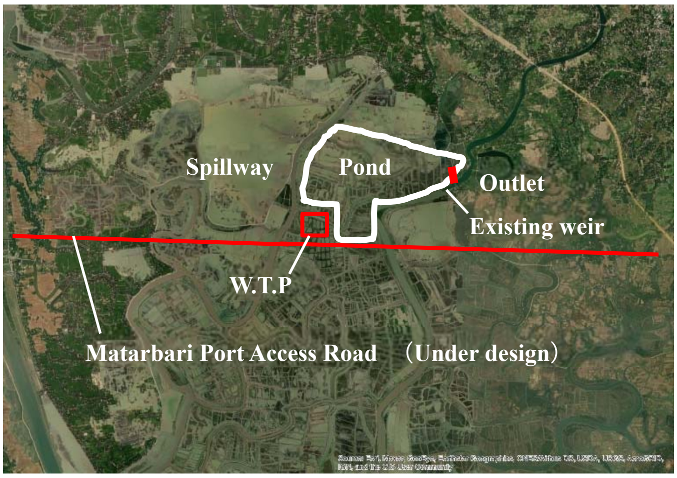
- The pond having a required effective reservoir volume is planned by using the typical pond sections in Figure 4.1.8. And
- Spillway and river outlet facilities are also provided for the pond.

It is noted that in this survey, the geology of the pond site was assumed based on the geological survey data of the Matarbari ultra-supercritical thermal power plant site. However, the future survey is required for the geological and soil properties of the pond construction site to determine the specifications of the pond and related facilities. The general soft ground countermeasures are shown in Annex 4.1-1.

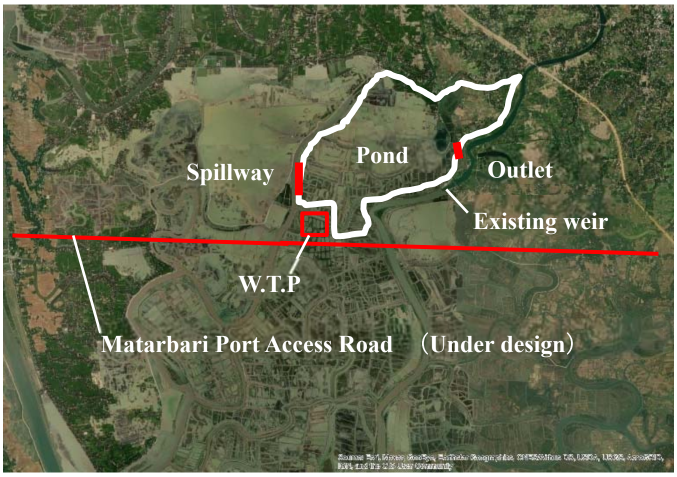


Source; JICA Survey Team

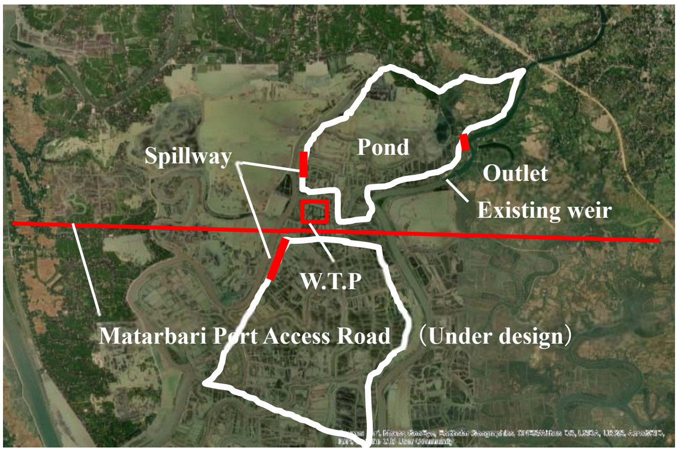
Figure 4.1.8 Pond Typical Section for Short-term Alternative Plan



Domestic and industrial water supply / Ponding Area 320 ha



Domestic, industrial, and river maintenance flow / Ponding Area 720ha



Domestic, industrial, irrigation, and river maintenance flow / Ponding Area 1,900ha

Source: JICA Survey Team

Figure 4.1.9 Alternatives of Regulation Pond Area in Short-term Plan by Object Water Supply Demand

(2) Water conveyance facilities

The facilities for water conveyance from an intake site up to the water supply areas consist of a pump-type intake in the Matamuhuri River, a headrace, a regulation pond, a water treatment plant, a water supply pumping station, a transmission pipeline and a water distribution pond in demand areas.

a) Intake site

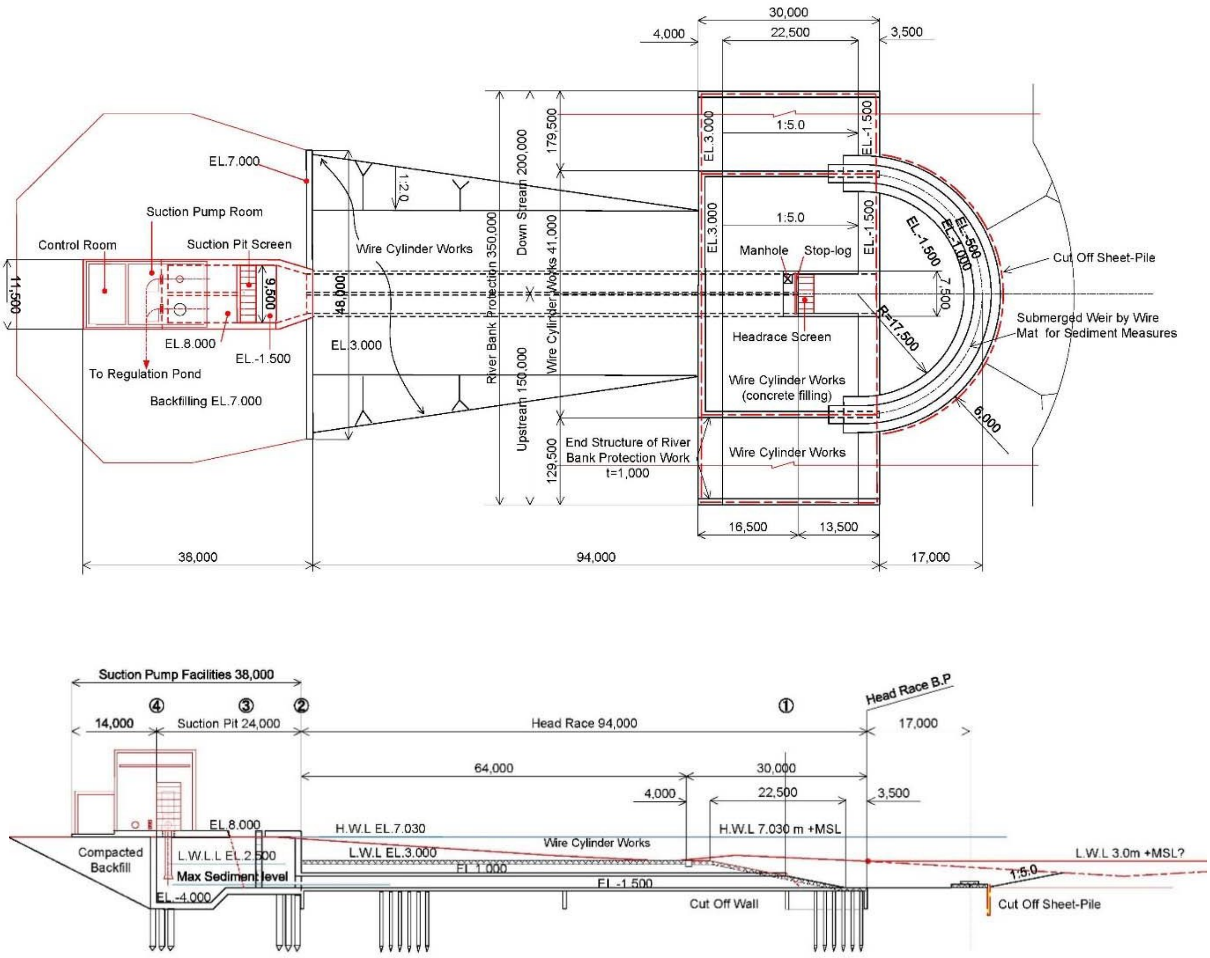
The intake site is identified, which would avoid substantial negative impact of salt water intrusion in the lower reach of the Matamuhuri River.

In the field reconnaissance, it was confirmed that the frequency of current river transportation is rather small near the Matamuhuri Bridge, and the impact on the river transportation due to river closure after weir construction downstream of the intake site seems to be low. Therefore, the idea of weir construction is considered to be practicable for water interception near the Matamuhuri Bridge.

On the other hand, the movable weir for irrigation purpose has been currently operated downstream of the Matamuhuri Bridge, and hence the risk of the salt water intrusion is expected to be low even if the intake site would not be provided with weir facilities.

In due consideration of the above, it is recommended that the intake site be provided with a fixed river channel with revetment without weir facilities, and two intake sites are identified, taking into account the pipeline routes to the pond, as stated below;

- Case 1-Intake site at the Matamuhuri River Bridge: the pipeline route shall use the existing N-1 Road , which would affect the traffic on the N-1 Road and surrounding areas, particularly during its construction.
- Case 2- Intake site 3.6km upstream of the Matamuhuri River Bridge, where Chattogram – Cox's Bazar Highway is under planning: the pipeline route shall use this new road and the intake site is near the new road.



Source: JICA Survey Team

Figure 4.1.10 Matamuhuri Intake Pump Station for Short-term Alternative 3.0m^3/s (for reference only)

b) Pipeline route

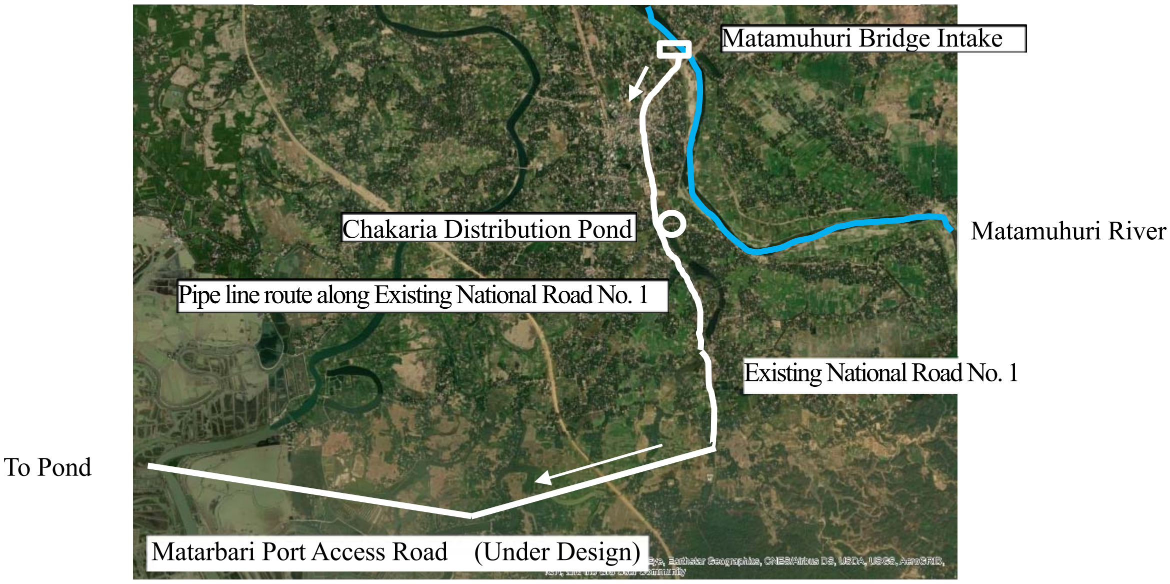
A pressure type pipeline is generally laid under the road for the domestic and industrial water supply from the viewpoint of easy maintenance, land acquisition, pipe fixing method, etc. Therefore, there are two options of pipeline route; namely, those along the existing National Highway No. 1, and the new Chattogram-Cox's Bazar Highway (under planning) and Matarbari Port Access Road (under design). In the case of the new road route, the pipeline length can be shortened.

The approximate locations of the intake sites and the lengths of the pipelines are shown as follows;

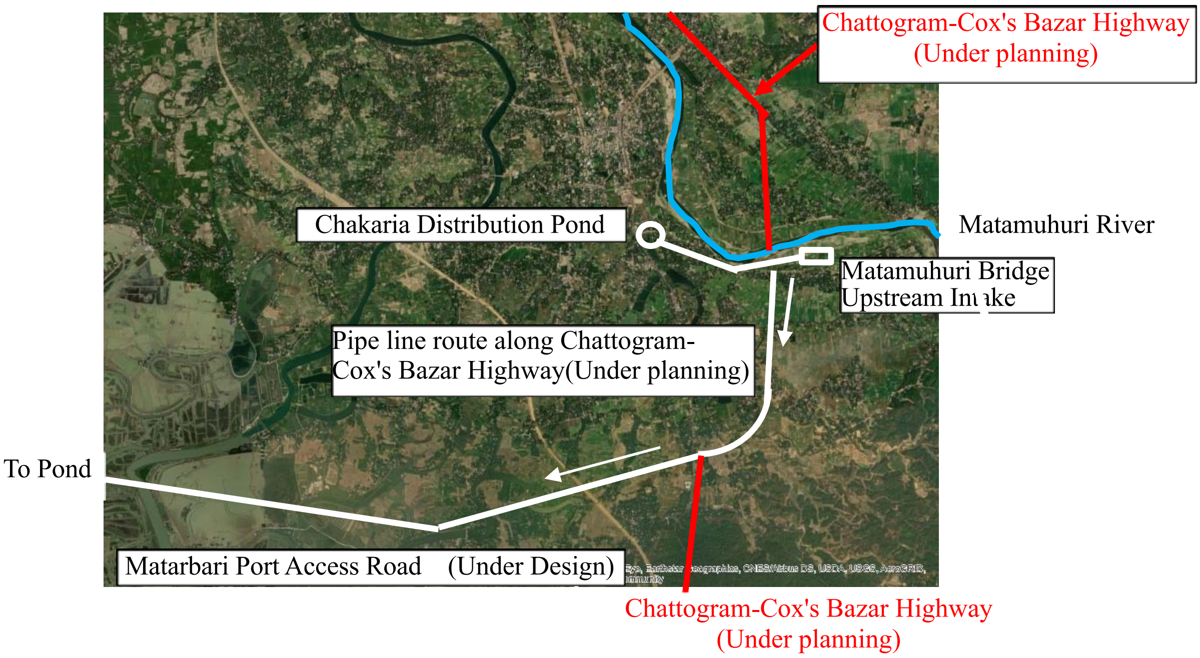
Table 4.1.7 Alternative Pipeline Routes

Items		Alternative Pipeline Route Using Existing Road (Matamuhuri Bridge Intake)	Alternative Pipeline Route using New Planning Road （Matamuhuri Bridge Upstream Intake）
Pipeline Routes	Intake ‐ Pond	13.0km	10.9km
	Pond ‐ Matarbari Port	23.8km	19.7km
	Pond - Chakaria	10.9km	10.5km
	Total length	47.8km	41.3km
Features		Intake location; Matamuhuri bridge down stream Pipeline routes to Pond; Via the existing National Highway No.1 and Matarbari Port Access Road (under design)	Intake location; Matamuhuri bridge upstream Pipeline routes to Pond; Via the Chattogram-Cox's Bazar Highway (under planning) and Matarbari Port Access Road (under design)
Cost aspect（refer Table 4.1.9）		△ Higher than using New Planning Road with short extension	○ Lower than using Existing Road with long extension
Technical aspect		△ Since pipeline construction will occur on the existing road, there are restrictions on the construction time and pipe burial method. The construction difficulty is higher than the New Planning Road utilization plan.	○ Due to the construction inside a new wide road width, the pipeline installation assumed easy than Existing Road utilization plan.
Environmental aspect		△ The impact of the project is expected, no particular environment requiring protection has been confirmed along the Existing Road.	△ The impact of the project is expected, no particular environment requiring protection has been confirmed along the New Planning Road.
Social aspect		△ When performing night time construction on the existing road, it is expected that there will be impacts on local residents, activities along existing road, and traffic congestion due to traffic regulations.	△ When performing night time construction on the road, it is expected that there will be impacts on local residents, and traffic congestion due to traffic regulations.

Alternative Pipeline Route using Existing Road



Alternative Pipeline Route using New Planning Road



Source; JICA survey team

Figure 4.1.11 Alternative Pipeline Routes along Existing Roads and New Planning/Designing Roads

(3) Comparison of supply target in short-term alternatives (pond)

Table 4.1.8 Specifications for Supply Target in Short-term Alternatives (Pond)

Supply Target	**Domestic+Industrial Water**	**Domestic+Industrial +River Maintenance FLow**	**Domestic+Industrial+ Irrigation+River Maintenance Flow**
Pond	Inclined impermeable zone type, Height 8.2 m, Crest EL.10.2, Embankment width 42.5 m		
Pond effective volume (MCM)	16	36	95
Ponding area (km^2)	3.2 (320 ha)	7.2 (720 ha)	19.0 (1,900 ha)
Pond around length (km)	8.7	12.6	26.6
Spillway (length x width)	33 m x 130 m	33 m x 570 m	33 m x 790 m
Outlet works	Box culvert 2.0 H x 3.0 W x 1 gate		
Palakata Water Treatment Plant (Rapid iltration, sludge drying method)	1.70 m^3/ s = 150,000 m^3 / day		
Intake amount in river (m3/s)	4.7 (406,000 m^3 / day) Vertical mixed flow pump 1.8m D		10.0 (864,000 m^3 /day) Vertical mixed flow pump 1.8 m D x 2 units
Transmission pump station (Chakaria 0.38 m^3/s)	Pump= 0.5 m D		
Transmission pump station (Matarbari 1.32 m^3/s)	Pump=1.0 m D		
Headrace (Intake~Pond) +Transmission line (Pond~Matarbari, Chakaria)	Headrace 1.8 m D Matarbari transmission line 1.0 m D Chakaria transmission line 0.5 m D		Headrace 1.8 m D x 2 Matarbari transmission line 1.0 m D Chakaria transmission line 0.5 m D

Table 4.1.9 Estimated Cost for Supply Target in Short-term Alternatives (Pond)

Facilities / Supply Target	**Domestic+Industrial Water**	**Domestic+Industrial+ River Maintenance Flow**	**Domestic+Industrial+ Irrigation+River Maintenance Flow**
Pond	JPY 16 billion	JPY 23 billion	JPY 50 billion
Palakata Water Treatment Plant	JPY 14 billion		
Intake pump equipment	JPY 4.6 billion		JPY 4.6 billion x 2 units = JPY 9.2 billion
Intake and river bank protection work	JPY 0.7 billion		JPY 1.6 billion

Transmission pump station (Chakaria, 0.38m^3 / s)		JPY 0.6 billion		
Transmission pump station (Matarbari, 1.32m^3 / s)		JPY 1.9 billion		
Pipeline	Intake; Matamuhuri Bridge	JPY 90.9 billion		JPY 163.2 billion
	Intake; Upstream Matamuhuri Bridge	JPY 62.0 billion		JPY 115.5 billion
Total Cost	Intake; Matamuhuri Bridge	JPY 128.7 billion	JPY 135.7 billion	JPY 250.5 billion
	Intake; Upstream Matamuhuri Bridge	JPY 99.8 billion	JPY 106.8 billion	JPY 202.8 billion

Source: JICA Survey Team

It is noted that the estimated cost of the above used for comparison as a basis for judging the superiority or inferiority of economic efficiency is an estimated value at the initial stage of the project in Japan. The estimated cost was calculated based on the following materials.

1. Pumping stations, pipelines, water purification plants and distribution pond

Guide line for Calculating Facility Renewal Costs Related to Restructuring of Water Services, December 2011 (Waterworks Division, Health Bureau, Ministry of Health, Labor and Welfare)

- ✓ Obtained 116 in 2020 from the deflator (water and sewage) with 2011 as 100, and used 1.16 times the cost of the above.
- ✓ The cost includes temporary expenses and overhead costs. Compensation cost is not included.

2. River bank protection works, pond facilities, and other civil works

Civil Engineering Work Estimation Standard Manual 2020, (Ministry of Land, Infrastructure, Transport and Tourism, Japan)

- ✓ Obtained direct construction costs and temporary equipment costs.
- ✓ The cost is multiplied to the above total cost by the overhead rate of 15% (estimated).
- ✓ The calculated costs include no land and compensation cost.

The estimated cost for the selected plan needs to be estimated with higher accuracy by the future feasibility studies.

The short-term alternatives mentioned above are considered as discussed below, in consideration of Table 4.1.9.

- The most economical short-term alternative is to set "domestic water + industrial water demands" as water supply objects for the highest priority plan.
- As to the construction cost of headrace and transmission pipelines, the route along the new roads is more economical than that of the existing roads. And

- The pipeline construction sites along the new roads, which are far particularly from Chakaria Upazila proper, could reduce the impact on the current road traffic and their surrounding areas compared with those along the existing roads.

Regarding environmental and social considerations, the results are described in "**Sub-section 4.1.9**".

(4) Supplementary examination of short-term alternatives

1) Intake examination for hydraulic type

As for the intake facilities of the Matamuhuri River, a pressure type (a plan to fix the river flow course with river bank protection works and pump up river water) has been proposed as explained above. On the other hand, considering the maintenance and management of the pump facilities and its cost, a non pressure type (gravity flow type) can be also considered. Therefore, a comparative study for the intake hydraulic type is conducted, as in Tables 4.1.10 to 4.1.12.

<Basic conditions of comparative study >

Table 4.1.10 Non-pressure Pipeline

Intake site	Matamuhuri Bridge Upstream 6.6km	Riverbed E.L 7.00		
Weir	Rubber tube weir	3.00 H x 50.00 L x 2 units	Maximum weir height E.L 9.5 Maximum overflow depth 0.6 m H.W.L 10.10 m	Allowable V-notch E.L 9.38 (9.50-0.6x20%)
Intake	Invert E.L 8.5 (7.0+1.5)	Minimum depth of intake water level E.L9.38-E.L8.5= 0.88 m L.W.L 9.38	Head between intake point and pond 9.38-7.00=2.38 m	Pipeline gradient 2.38m/11,000m =1/4621≒ 1/5000
	Section 2.00 H x 4.00 B x 2units	Rectangular concrete pipeline on the embankment (embankment:2.00 H x 5.00 B)		
River bank, river bed protection works	Required in downstream and upstream of weir	Low-flow channel revetment work L ＝350 m	Gabion, impermeable sheet pile required	
Dike(river embankment)	Required in upstream of weir	Right bank 8.55 km Left bank 7.40 km	Crest of dike (embankment top EL.12 estimated)	

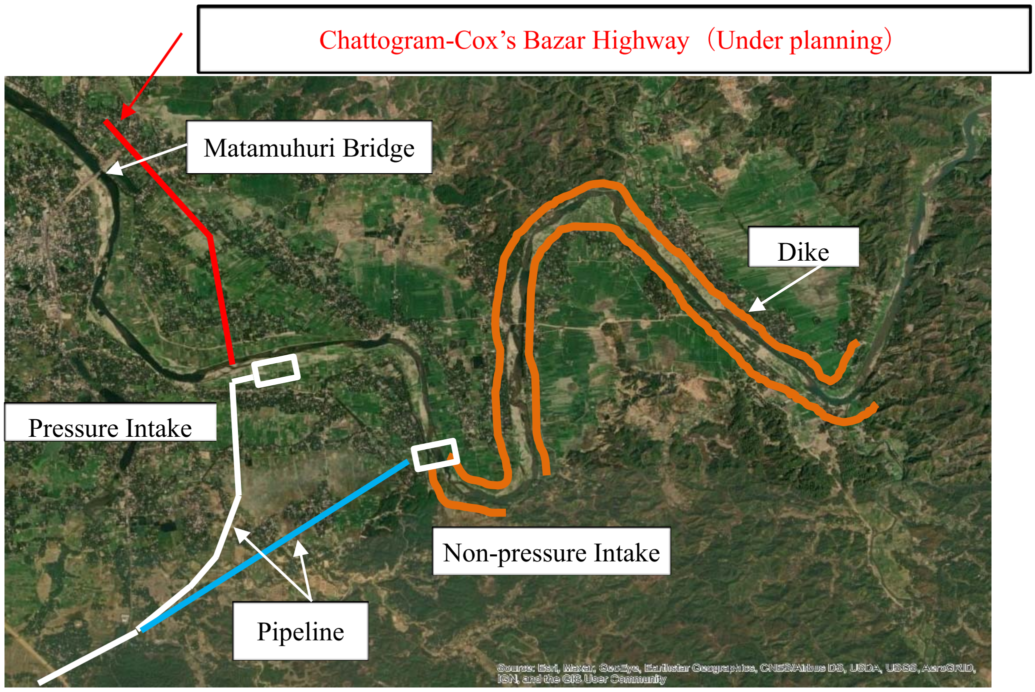
Source JICA Survey Team

Table4.1.11 Pressure Pipeline

Intake site	Matamuhuri Bridge upstream 3.6km	Riverbed E.L 3.00		
Intake, pipeline, and pump station	Intake invert E.L -1.50 2.00 H x 3.00 B x 2 units (culvert)	Intake～Pump station 7.5 Bx94.0 L (culvert)	Pump station floor EL.7.00 Vertical-shaft mixed flow pump 1.8 D 4800 kW	Pipeline Ductile steel pipe 1.2 D x 2 units x 10.9 km
River bank protection works	Required in downstream and	Low flow channel	Gabion, impermeable sheet pile required.	

	upstream of intake	revetment work L=350 m(left bank only)	

Source JICA Survey Team



Source: JICA Survey Team

Figure 4.1.12 Location Map of Non-pressure and Pressure Pipelines

<Considerations>

Table 4.1.12 Comparison of Non-pressure and Pressure Pipelines

Items	Non-pressure Pipeline	Pressure Pipeline
Necessity of weir facility	Weir facility is needed to maintain intake water level approx. E.L 10 to guide water F.S.L 7.0m at the pond. △	The revetment work will fix the river flow course at low water levels then stabilizes the flow at intake. Thus, weir facilities are not necessary.〇
Necessity of dike (river embankment)	River embankment is required in the upstream of the intake point due to the raising river water level approx. 3m. The revetment works are required around the intake weir. △	No need to construct a dike. The revetment works around the intake point are required for stabilized water lever at the intake point. 〇
Economic perspective (initial investment)	Approx. JPY 30.1 billion (Land requires approx. 3km of pipeline to Chittagong-Cox's Bazar Highway and 16km length dike.) △	Approx. JPY 27.8 billion (Pump operating costs JPY 2.7 billion/year required) 〇

Items	Non-pressure Pipeline	Pressure Pipeline
Impact on landscape alternation and social environment	There are modifications on the ground at intakes, dike and pipeline. Impacts on the nature and social environment are unavoidable. △	There is modification on the ground at intake. However, underground pipe line and no dike has a little landscape alteration and a low impact on the social environment. ○
Result of comparison	"Pressure pipeline" is recommended on the view points of low initial investment, less impact on landscape alternation and on the social environment.	

Source JICA Survey Team

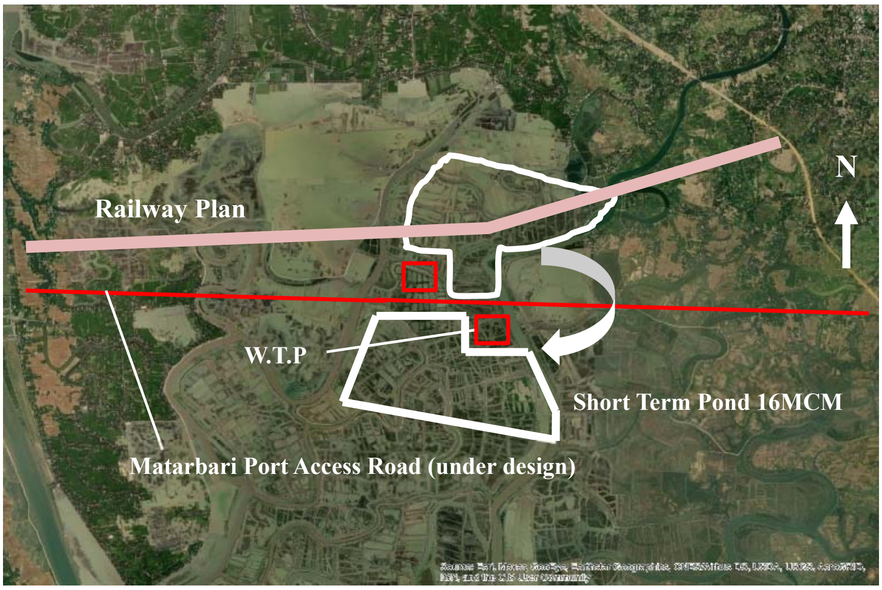
Based on the above comparative study, the non-pressure type has the following problems so that the pressure type intake plan is adopted.

- It will be an open channel flow to the pond, and will be necessary to raise the intake water level by wire (including: new construction raising of both banks).
- This will increase the risk of flooding in the upstream of the weir, and will increase the initial cost due to the construction of embankments, increase in the length of waterways, and river structures (siphons, water pipe bridges) at the crossing of the road.
- The construction an open channel will increase social costs associated with large-scale land acquisition and relocation.

It is noted that there is insufficient information for the feasibility of construction of no-pressure channels. It is proposed to conduct a survey and other investigations along non-pressure channel and the dike section in the feasibility study if required.

2) Consistency with other projects

Through the hearing on the comprehensive development project in the Moheshkhali-Matarbari region in March 2022, it is confirmed that the location of the proposed pond may overlap with the alignment of the railway plan. Therefore, it is proposed that the location of pond is to be moved to the south of "Matarbari Port Access Road" to avoid confliction on the facilities layouts with each other, as shown below.



Source JICA Survey Team

Figure 4.1.13 Location of Short-term Pond to Avoid Confliction with Railway Plan (Draft)

For the pipeline, it is recommended to use the planned Matarbari Port Access Road and Chittagong-Cox's Bazar Highway as the transmission line. However, to use the other project facilities (road) the sufficient consultation with both parties and enough time are required in the near future.

4.1.8 Water Balance Study (Short-term plan)

(1) Development of water balance analysis model (Short-term Plan)

A water balance analysis model was developed for the Palakata Regulation Pond which is considered to be the most promising candidate for the short-term plan and the required capacities of major structures in the plan were calculated. The primary rules of the water balance analysis model are described below, and the specifications and map of the model are shown in Table 4.1.13 and Figure 4.1.14 (refer to the Water Balance Calculation Procedures in "Annex 4.1-2"). The control point of water-use plan was set at the Lama WLG Station which is located at the upstream end of the main water demand area, where it is possible to manage the water flow without any tidal influence from the sea.

<u>Primary rules of water balance analysis model</u>

1) Whereas the priority of water supply for water demands is as mentioned below in general, conducted are multiple case studies that combine these demands.

Maintenance Flow ⇒ Domestic Water ⇒ Industrial Water ⇒ Agricultural Water

2) The water demands located downstream of the storage structure are to be covered by water supply from the storage structure.

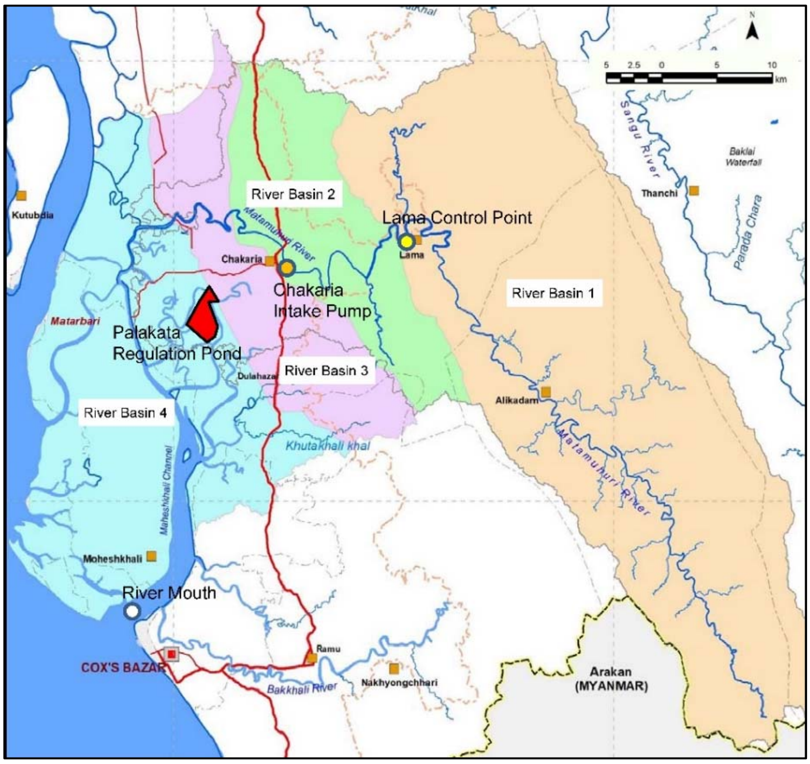
Target District (Upazila): Bandarban (Chakaria, Naikhongchhari, Lama), Chattogram (Lohagora, Bashkhali), Cox's Bazar (Cox's Bazar Sadar, Moheshkhali, Pekua)

3) The water level in the storage structure should be managed within the range of surplus water available in the Matamuhuri River so as not to disturb water supply for the existing demands.
4) The operation of the storage structure is to be conducted basically so as to recover its full capacity once at least in a rainy season.

Table 4.1.13 Specifications of Water Balance Analysis Model: Short Term: Palakata Regulation Pond Plan

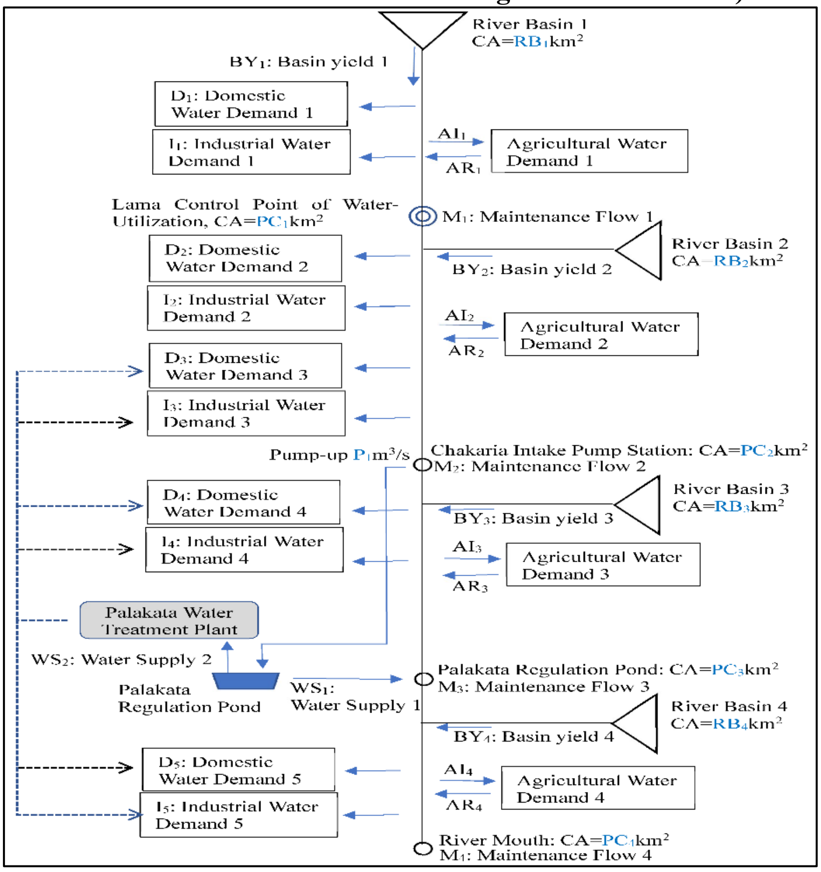
Item		Setting Conditions	Remarks
Basic Conditions	Data Target Period	1966.11－2019.10（53 years）	
	Target Year	Short Term: 2026, Long Term: 2041	
	Target River Basin	Matamuhuri River Basin: CA= 2,511 km^2	
	Control Point of Water Use Plan	Lama control point	Water level gauge station
	New Water-use Structure	Palakata Regulation Pond	
	Water Demand and Water Source	Case A: River water use for domestic, industrial and agricultural demands Case B: Case A plus river water use for domestic and industrial demands, which are using groundwater	"Case B" intends to shift groundwater use for domestic and industrial demands to surface water use.
Model Parameter	Catchment Area of River Basin	River Basin 1: 1,201 km^2 River Basin 2: 289 km^2 River Basin 3: 278 km^2 River Basin 4: 744 km^2	
	Catchment Area at Check Point	Lama Control Point : 1,201 km^2 Chakaria Intake Pump Station : 1,490 km^2 Palakata Regulation Pond : 1,767 km^2 River Mouth Point : 2,511 km^2	
	Maintenance Flow	0.8 $m^3/s/100\ km^2$	
	Capacity of Chakaria Intake Pump Station	Trial calculation of minimum capacity of Chakaria Intake Pump for fulfilling full recovery of Palakata Regulation Pond each year	

Source: JICA Survey Team



Source: JICA Survey Team

Figure 4.1.14 Basin Map of Matamuhuri River (Short Term: Palakata Regulation Pond Plan)



Source: JICA Survey Team

Figure 4.1.15 Diagram of Water Balance Analysis Model (Short Term: Palakata Regulation Pond Plan)

(2) Concept of water supply for maintenance flow (Short-Term: Palakata Regulation Pond Plan)

As shown in Figure 4.1.16, the Matamuhuri River branches off downstream of Chakaria City and the river water on both the river routes flows out to the Bengal Bay. Since the Palakata Regulation Pond is located along the south river route, a half value of the maintenance flow at the estuary of the Matamuhuri River was set as the discharge for the maintenance flow to be supplied from the Palakata Regulation Pond.

Source: JICA Survey Team

Figure 4.1.16 Map Around the River Mouth of Matamuhuri River

(3) Calculation cases and results of water balance analysis (Short-Term: Palakata Regulation Pond plan)

The following 6 cases were prepared for combination of maintenance flow, domestic water, industrial water, and agricultural water to be covered by water supply from the Palakata Regulation Pond, and the required capacity of the pond was calculated in each case.

Combinations of water demands to be covered by water supply from Palakata Regulation Pond (6 cases)

Case 1 : Maintenance Flow
Case 2-1 : Maintenance Flow + Domestic Water
Case 2-2 : Maintenance Flow* + Domestic Water
Case 3-1 : Maintenance Flow + Domestic Water + Industrial Water
Case 3-2 : Maintenance Flow* +Domestic Water + Industrial Water
Case 4 : Maintenance Flow + Domestic Water + Industrial Water + Agricultural Water
*: In case of no supply for maintenance flow by Palakata Regulation Pond

Table 4.1.14 shows the water demands for water supply (maintenance flow, domestic water, industrial water, agricultural water) in each case.

Table 4.1.14 Water Demands for Water Supply in Each Case (Short Term: Palakata Regulation Pond Plan)

Case No.	Water Supply*	Maintenance	Domestic	Industrial	Agricultural	Remarks
Case 1	WS_1	M_3, M_4	―	―	―	
	WS_2	―	―	―	―	
Case 2-1	WS_1	M_3, M_4	―	―	―	
	WS_2	―	D_3, D_4, D_5	―	―	
Case 2-2	WS_1	―	―	―	―	
	WS_2	―	D_3, D_4, D_5	―	―	
Case 3-1	WS_1	M_3, M_4	―	―	―	
	WS_2	―	D_3, D_4, D_5	I_3, I_4, I_5	―	
Case 3-2	WS_1	―	―	―	―	
	WS_2	―	D_3, D_4, D_5	I_3, I_4, I_5	―	
Case 4	WS_1	M_3, M_4	―	―	―	
	WS_2	―	D_3, D_4, D_5	I_3, I_4, I_5	AI_4	

Note (1): * Objects of water supply from Palakata Regulation Pond
WS_1 : Water supply from Palakata Regulation Pond to the Matamuhuri River
WS_2 : Water supply from Palakata Regulation Pond to Palakata Water Treatment Plant
Note (2): Each mark of M (Maintenance flow), D (Domestic water), I (Industrial water) and AI (Agricultural intake water) shows object water demand. The location of each mark with the number beside the one can be found by referring to the figure of "Water Balance Model" above.
Source: JICA Survey Team

In addition, prepared were "Case A" where the domestic water, industrial water and agricultural water to be taken only from the river are set in the water balance analysis model, and "Case B" where the groundwater use for domestic water and industrial water is to be shifted to river water use. In combination with the above 6 cases, the water balance analysis was carried out for 12 cases in total.

<u>Cases of water demand combination for river water and groundwater use (2 cases)</u>

Case A: River water use for domestic, industrial and agricultural demands
Case B: Case A plus river water use for domestic and industrial demands which are using groundwater

The results of water balance calculation for all the 12 cases are summarized in Table 4.1.15 (refer to "Annex 4.1-3 "). Based on the following directions, the three cases shown in bold frames in the table below are considered to be promising candidates for structure planning.

- Domestic and industrial water demands are essential objects of water supply (Case3-1, Case3-2).
- It is necessary to verify the feasibility of including the agricultural water demand for water supply (Case-4).
- A new water supply plan shall conform with the policy of shifting groundwater use to surface water use for future water source development (Case B).
- The safety factor of water use is to be defined as 1/5 drought year (the matter to be discussed with the Bangladeshi side on the technical working group meeting).

Table 4.1.15 Calculation Results of Water Balance Analysis (Short Term: Palakata Regulation Pond Plan)

Case A:

Item		Case1	Case2-1	Case2-2	Case3-1	Case3-2	Case4
Chakaria Intake Pump		3.0 m^3/s	3.0 m^3/s	3.0 m^3/s	3.0 m^3/s	3.0 m^3/s	10.0 m^3/s
Palakata Regulation Pond	5 yr 1)	20.642 MCM	23.486 MCM	2.793 MCM	28.843 MCM	8.934 MCM	83.907 MCM
	10 yr 1)	32.251 MCM	35.556 MCM	3.706 MCM	40.686 MCM	10.546 MCM	104.510 MCM

1) safety factor of water use

Case B:

Item		Case1	Case2-1	Case2-2	Case3-1	Case3-2	Case4
Chakaria Intake Pump		3.0 m^3/s	3.0 m^3/s	3.0 m^3/s	3.0 m^3/s	3.0 m^3/s	10.0 m^3/s
Palakata Regulation Pond	5 yr 1)	20.642 MCM	29.170 MCM	9.209 MCM	35.952 MCM	15.934 MCM	94.051 MCM
	10 yr 1)	32.251 MCM	40.945 MCM	10.923 MCM	49.502 MCM	17.763 MCM	113.082 MCM

1) safety factor of water use

Source: JICA Survey Team

Since the criteria for setting a safety factor of water use do not exist in Bangladesh, some setting samples of the safety factor in the surrounding Asian countries in Table 4.1.16 were referred to. Since most samples adopt safety factors from 1/5 to 1/10 drought years, 1/5 and 1/10 drought years were set as the safety factors of water use in the short term (2026) and the long term (2041), respectively.

Table 4.1.16 Safety Factor of Water Use in Surrounding Asian Countries

Country	Project	Safety Factor of Water Use		
		Domestic Use	Industrial Use	Agricultural Use
Philippines	Master Plan Study on Water Resources Management in the Republic of the Philippines, 1998	1/20[1)]	1/20[1)]	1/5[1)]
Indonesia	Project for Assessing and Integrating Climate Change Impacts into the Water Resources Management Plans for Brantas and Musi River Basins, 2019	1/10[2)]	1/10[2)]	1/5[2)]
Japan	Master Plans of Rivers under the Government Direct and Prefectural control	1/5 - 1/10[3)]	1/5 - 1/10[3)]	1/5 - 1/10[3)]

Sources: 1) Final Report of Master Plan Study on Water Resources Management in the Republic of the Philippines, 1998, JICA, 2) Final Report of Project for Assessing and Integrating Climate Change Impacts into the Water Resources Management Plans for Brantas and Musi River Basins, 2019, JICA,
3) Web-site of the Ministry of Land, Infrastructure and Transport.

4.1.9 Basic Environmental Examination

(1) Preliminary examination of environmental and social consideration on short-term water resource development options

In accordance with the Environmental Conservation Rules and Regulations of Bangladesh (amended in 2002), the short-term water resources development option proposed by the Survey would need the Environmental and Social Impact Assessment (ESIA), and the Income Restoration Program (IRP) for the project affected people who will lose their livelihoods in the future. At this moment, the preliminary environmental and social impact examination is necessary to avoid serious impacts. Table 4.1.17 shows the preliminary scoping results for the water resources development option, where the items with positive/negative impacts are examined with reasons, based on the information collected up to now.

Table 4.1.17 Preliminary Examination of Environmental and Social Impacts on Short-term Water Resources Development Options

Category		Environmental and Social Item	Preliminary Examination Results		Reason for Preliminary Evaluation
			During Construction	In Operation	
Pollution	1	Air pollution	−	NA	During construction: Air quality may be affected by the use of construction equipment and vehicles during construction.
	2	Water pollution	−	+ / −	In operation: By conducting the possible water resource development option, existing water flow of the target water system would be changed. Depending on the water flow condition, both positive and negative impacts would be generated.
	3	Waste	−	NA*	During construction: Construction waste and general waste from labor camps are expected to be generated. In operation: Basically, no particular negative impact is expected, as the possible infrastructure operators will be responsible for the proper collection and disposal of waste from the facilities. Besides, if dredging work is conducted.
	4	Soil pollution	NA	NA	During construction: It is expected not to arise particular negative impact, as there is no plan to excavate the areas identified soil pollution by construction
	5	Noise and vibration	−	NA	During construction: A temporary increase in noise and vibration due to the use of construction equipment and vehicles during construction is expected. When pump station is operated, noise impact may need to be examined considering surrounding land use.
	6	Land subsidence	NA	NA	During construction: No negative impact is expected, as the project will not involve pumping up of large amount of groundwater In operation: When groundwater use is planned and conducted, possibility of land subsidence needs to be examined.
	7	Odor	N	Uncertainty	During construction: No particular negative impact is expected, as no construction work is planned that may cause odor. In operation: When regulation pond is operated, possibility of odor due to eutrophication may need to be examined.
	8	Bottom sediment	NA	NA	During construction: No particular negative impact is expected, as no construction work is planned that may cause pollution of bottom sediment

Category		Environmental and Social Item	Preliminary Examination Results		Reason for Preliminary Evaluation
			During Construction	In Operation	
Natural Environment	9	Protected area	NA	NA	No protected area is existed at the planned site of the regulation pond. The proposed site is used as salt farm, and environment of the area does not work as main habitats of endangered species confirmed by the past survey in Chattogram area. Although several mangrove groves are distributed around the proposed site of regulation pond, those are not designated as protected areas.
	10	Ecosystem	−	Uncertainty	In operation: In case that river maintenance flow will be secured by operation of the regulation pond, river ecosystem would be changed.
	11	Hydrology	−	Uncertainty	During construction: In case that water intake dam is constructed, the project may affect water flow of the relevant rivers. In operation: With operation of the regulation pond, river water flow in the downstream area would be changed.
	12	Topography and geology	NA	NA	During construction: The planned site of the regulation pond is flat area, and no impact is predicted against topography at and around the project site.
Social Environment	13	Land acquisition and resettlement	NA	NA	During construction: The site of the regulation pond is owned by Cox's Bazar District, and no private land acquisition is expected. Regarding the resettlement impact, no settlement is confirmed at the project site, and resettlement impact is not predicted.
		Livelihood	−	+	During construction: The site of the planned regulation pond is used as salt farm in dry season and shrimp cultivation pond in rainy season. The project will affect the livelihood of the local people engaging salt production and shrimp cultivation. In operation: With increasing the amount of available water resource, positive impact would be expected by employment creation.
	14	Poor and indigenous people	Uncertainty	+	During construction: The site of the planned regulation pond is used as salt farm in dry season and shrimp cultivation pond in rainy season. The project will affect the livelihood of the local people engaging salt production and shrimp cultivation, and it would affect living condition of the poor group. In operation: With increasing the amount of available water resource, positive impact would be expected by employment creation.
	15	Ethnic minority and indigenous people	NA	NA	Up to now, no information on distribution of ethnic minority and indigenous people at the planned site of the regulation pond.

Category		Environmental and Social Item	Preliminary Examination Results		Reason for Preliminary Evaluation
			During Construction	In Operation	
	16	Local economy such as employment and livelihood	−	+	In operation: The site of the planned regulation pond is used as salt farm in the dry season and shrimp cultivation pond in the rainy season. The project will affect the livelihood of the local people engaging salt production and shrimp cultivation. In operation: in the long term, indirect positive impacts are expected due to creation of local employment by increasing of available water resource amount.
Social Environment	17	Land use and regional resource utilization	−	+	In operation: The site of the planned regulation pond is used as salt farm in the dry season and shrimp cultivation pond in the rainy season. The project will affect the existing land use. In operation: With increasing the amount of available water resource, positive impact would be expected by employment creation.
	18	Water use	NA	+	During construction: No significant impact is predicted by construction work. In operation: With applying the possible water resource development options, the positive impact on water use will be expected.
	19	Existing social infrastructure and social service	−	+	During construction: Impact on traffic volume on local roads due to construction is expected. Specifically, congestion is expected during construction on the existing road. In operation: No negative impact on existing social infrastructure or social services is expected. With applying the possible water resource development options, the positive impact on social service is expected with increase of available water resource.
	20	Social capital and local decision-making bodies	Uncertainty	+ / −	During construction: For construction of the dam /reservoir, several settlements need to be relocated. In operation: For use of the increased amount of available water resources, coordination among the various water users needs to be arranged.
	21	Uneven distribution of damage and benefit	NA	NA	In operation: The site of the planned regulation pond is used as salt farm in dry season and shrimp cultivation pond in rainy season. The project will affect the livelihood of the local people engaged in salt production and shrimp cultivation.
	22	Interest conflict in region	NA	Uncertainty	During construction: No significant impact is expected during construction phase. In operation: For use of the increased amount of available water resources, coordination among the various water users needs to be arranged.
	23	Cultural heritage	NA	NA	No cultural heritage exists at the planned site of the regulation pond.

Category		Environmental and Social Item	Preliminary Examination Results		Reason for Preliminary Evaluation
			During Construction	In Operation	
	24	Landscape	NA	NA	No significant change of the existing landscape by construction and operation of regulation pond.
	25	Gender	Uncertainty	NA	<u>Before and during construction:</u> Negative impacts on female socially vulnerable groups such as widowed households are expected. There is a possibility that affected persons and residents of the area will be employed during construction, but information will be collected to make a decision on the practices related to the employment and treatment of female workers. <u>In operation:</u> No project activities are planned that will increase the gender gap.
	26	Children's right	Uncertainty	NA	<u>During construction:</u> There is a possibility of occurrence of child labor by the construction contractor. <u>In operation:</u> No particular negative impact is expected, as the project is considered to be free of matters related to children's rights.
	27	Infectious disease such HIV/AIDS	Uncertainty	+	<u>During construction:</u> Increased risk of infectious diseases due to influx of construction workers. <u>In operation:</u> By increasing available water resource amount, regional hygiene condition will improve, and the risk of infection disease is expected to decrease.
	28	Labor environment including labour safety	NA*	NA*	<u>During construction:</u> Impacts on the working environment of construction workers are expected. <u>In operation:</u> Proper labor environment management needs to be conducted to actualize proper condition of labor environment.
	29	Accident	−	NA*	<u>During construction:</u> The number of construction vehicles in the area is expected to increase, and risk of traffic accident may increase if proper safety management is not conducted. <u>In operation:</u> Proper safety management of the proposed infrastructures needs to be conducted to reduce the risk of accidents.
	30	Impact of border transgression and climate change	−	NA	<u>During construction:</u> Greenhouse gas emissions by construction work are assumed.
	31	Natural disaster risk	NA	NA	<u>During construction and in operation:</u> Impacts related to flood inundation due to flood blockage in the road embankment are expected.

Note: "Negative" means that the negative impact is preliminary predicted.
"Positive" means that the positive impact is preliminary predicted.
"Uncertainly" means that further study is necessary to examine the preliminary impact.
"NA" means that no impact is predicted in existing condition.
"NA*" means that no impact is predicted with planning and implementation of proper management plan.

Source: JICA Survey Team

(2) Preliminary Examination on Environmental and Social Impact by Long-term Water Resources Development Options

In accordance with the Environmental Conservation Rules and Regulations of Bangladesh (amended in 2002), the possible water resources development options proposed by the Survey would need ESIAs and Resettlement Action Plans (RAPs) for some options in future. At this moment, preliminary environmental and social impact examination is necessary to avoid serious impacts. Table 4.1.18 shows the preliminary scoping results for the water resources development options, where the items with positive/negative impacts are examined with reasons, based on the information collected so far.

Table 4.1.18 Preliminary Examination of Environmental and Social Impacts

Category		Environmental and Social Item	Preliminary Examination Results									Reason for Preliminary Evaluation
			During Construction	In Operation								
				Dam/Reservoir	Regulation Pond	Movable Weir	Tidal Barrage	Kaptai Dam Water Use	Ground Water Use	Desalination	Water Saving	
Pollution	1	Air pollution	Negative	NA								During construction: Air quality may be affected by the use of construction equipment and vehicles during construction.

Category		Environmental and Social Item	Preliminary Examination Results									Reason for Preliminary Evaluation
			During Construction	In Operation								
				Dam/Reservoir	Regulation Pond	Movable Weir	Tidal Barrage	Kaptai Dam Water Use	Ground Water Use	Desalination	Water Saving	
Pollution	2	Water pollution	Negative	Positive / Negative	Positive / Negative	Positive / Negative	Positive / Negative	Positive / Negative	Uncertainly	Uncertainly	NA	<u>During construction</u>: It is assumed that the discharge of muddy water during construction will affect the water quality. <u>In operation</u>: By conducting the possible water resource development option, existing water flow of the target water system would be changed. Depending on the water flow condition, both positive and negative impacts would be generated. Tentatively, the following impacts would be examined by each water resource development options. Regarding dam/reservoir and regulation pond, eutrophication of the reservoir needs to be examined. Depending on the dam/reservoir, regulation pond, movable weir, and tidal barrage operation, and diversion of water from Kaptai dam for existing water use, waterflow at downstream area of river system would be changed. If waterflow is decreased in dry season, negative impact would be arisen. On the other hand, waterflow in dry season will be increased, positive impact may be expected.

Category		**Environmental and Social Item**	**Preliminary Examination Results**									**Reason for Preliminary Evaluation**
			During Construction	**In Operation**								
				Dam/Reservoir	**Regulation Pond**	**Movable Weir**	**Tidal Barrage**	**Kaptai Dam Water Use**	**Ground Water Use**	**Desalination**	**Water Saving**	
	3	Waste	Negative	Uncertainly	Uncertainly	NA*	NA*	NA*	NA*	NA*	NA	During construction: Construction waste and general waste from labor camps are expected to be generated. In operation: Basically, no particular negative impact is expected, as the possible infrastructure operators will be responsible for the proper collection and disposal of waste from the facilities. Besides, if dredging work is conducted during dam/reservoir or regulation pond operation, negative impact may arise if dredged sediment is not treated by proper manner.
Pollution	4	Soil pollution	Uncertainly (by Dam / Reservoir and Regulation Pond)	NA	NA	NA	NA	NA	NA	NA	NA	During construction: It is expected not to arise particular negative impact, as there is no plan to excavate the areas identified with soil pollution by construction of dam / reservoir, and regulation pond considering existing land use. Besides, before construction, field survey on concentration of hazardous substances should be conducted. In operation: No particular negative impact is expected, as there is no excavation during operation phase.

Category		Environmental and Social Item	Preliminary Examination Results: During Construction	In Operation: Dam/Reservoir	Regulation Pond	Movable Weir	Tidal Barrage	Kaptai Dam Water Use	Ground Water Use	Desalination	Water Saving	Reason for Preliminary Evaluation
	5	Noise and vibration	Negative	Uncertainly	Uncertainly	NA	NA	Uncertainly	Uncertainly	Uncertainly	NA	<u>During construction:</u> A temporary increase in noise and vibration due to the use of construction equipment and vehicles during construction is expected. <u>In operation:</u> When dam / pump station is operated, noise impact may need to be examined considering surrounding land use.
	6	Land subsidence	NA	NA	NA	NA	NA	NA	Uncertainly	NA	NA	<u>During construction:</u> No negative impact is expected, as the project will not involve pumping up of large amount of groundwater or any other construction work that would induce ground subsidence. <u>In operation:</u> When groundwater use is planned and conducted, possibility of land subsidence needs to be examined.
	7	Odor	NA	NA	Uncertainly	NA	NA	NA	NA	NA	NA	<u>During construction:</u> No particular negative impact is expected, as no construction work is planned that may cause odor. <u>In operation:</u> When regulation pond is operated, possibility of odor due to eutrophication may needs to be examined.

Category		Environmental and Social Item	Preliminary Examination Results									Reason for Preliminary Evaluation
			During Construction	In Operation								
				Dam/Reservoir	Regulation Pond	Movable Weir	Tidal Barrage	Kaptai Dam Water Use	Ground Water Use	Desalination	Water Saving	
Pollution	8	Bottom sediment	NA	NA	NA	NA	NA	NA	NA	NA	NA	During construction: No particular negative impact is expected, as no construction work is planned that may cause pollution of bottom sediment, such as dumping of sediment into water bodies. In operation: No particular negative impact is expected, as there is no excavation during operation phase.
Natural environment	9	Protected area	Negative	Negative	NA	NA	NA	NA	NA	NA	NA	During construction and operation: Due to construction of dam / reservoir, the Matamuhuri Reserved Forest will be affected. [Matamuhuri Reserved Forest] The proposed dam site is located at artificially developed fringe area in the Matamuhuri Reserved Forest, of which area is 40,661 ha (100,476 acres), in Babu Para in Alikadam Upazila of Bandarban District. The area has been encroached upon by Bengali and ethnic settlers since the 1980s and as a result, relatively large patch of natural forest is not left in this area.

Category		Environmental and Social Item	Preliminary Examination Results									Reason for Preliminary Evaluation
			During Construction	In Operation								
				Dam/Reservoir	Regulation Pond	Movable Weir	Tidal Barrage	Kaptai Dam Water Use	Ground Water Use	Desalination	Water Saving	
Natural Environment	10	Ecosystem	Negative	Uncertainly	Uncertainly	Uncertainly	Uncertainly	Uncertainly	NA	Uncertainly	NA	<u>During construction and operation:</u> Due to construction of dam / reservoir, the Sangu-Matamuhuri Reserved Forest will be affected, as shown in **Figure 2.4.2.** In the Matamuhuri Reserved Forest, there is a wildlife sanctuary named "Sangu-Matamuhuri Wildlife Sanctuary" where several rear / important species including Asian elephant have been observed. The tentative proposed dam site and inundated area is not overlapped with the sanctuary, but when dam / reservoir is planned, the impact on ecosystem around the project site needs to be examined. For planning of regulation pond and pipelines for Kaptai Dam water use, it is also necessary to examine the impact around the project site. For planning of movable wire and tidal barrage, the impact on downstream area of the project site needs to be examined. For planning of desalination, when the desalination plant is planned, the impact on ecosystem around the water intake area need to be examined.

Category		Environmental and Social Item	Preliminary Examination Results									Reason for Preliminary Evaluation
			During Construction	In Operation								
				Dam/Reservoir	Regulation Pond	Movable Weir	Tidal Barrage	Kaptai Dam Water Use	Ground Water Use	Desalination	Water Saving	
	11	Hydrology	Negative	Positive / Negative	Positive / Negative	Positive / Negative	Positive / Negative	Positive / Negative	Uncertainly	NA	NA	During construction: During the construction work for movable weir, and tidal barrage, waterflow of the target river would be impacted. In operation: Depending on the dam/reservoir, regulation pond, movable weir, and tidal barrage operation, and diversion of water from Kaptai Dam for existing water use, waterflow at downstream area of river system would be changed. If waterflow is decreased in dry season, negative impact on ecology would be arisen. On the other hand, waterflow in dry season will be increased, positive impact may be expected.
Natural Environment	12	Topography and geology	Uncertainly	Uncertainly	Uncertainly	NA	NA	Uncertainly	NA	NA	NA	During construction and operation: For construction of the dam/reservoir, regulation pond and pipelines for diversion of water from Kaptai Dam for existing water use, construction work altering topography will be conducted, such as soil extraction. When these infrastructures are designed and construction work plan is prepared, it is necessary to examine impact on topography of surrounding areas to mitigate / avoid the impact.

Category		Environmental and Social Item	Preliminary Examination Results									Reason for Preliminary Evaluation
			During Construction	In Operation								
				Dam/Reservoir	Regulation Pond	Movable Weir	Tidal Barrage	Kaptai Dam Water Use	Ground Water Use	Desalination	Water Saving	
Social Environment	13	Land acquisition and resettlement	Negative	Negative	Negative	Negative	Negative	Negative	Uncertainly	Uncertainly	NA	<u>Before and during construction:</u> For construction of regulation pond, pipelines for water diversion from Kaptai Dam, and other facilities such as pump station, WTP and the pipelines connecting those with water sources, land acquisition will be necessary. Regarding the dam /reservoir construction, the dam site and inundated areas are in Matamuhuri Reserved Forest, but there are several settlements, so resettlement will be necessary. <u>In operation:</u> The resettled site needs to be monitored to confirm the impact by resettlement.
	14	Poor and vulnerable group	Uncertainly	Uncertainly	Uncertainly	Uncertainly	Uncertainly	Uncertainly	Uncertainly	Uncertainly	NA	<u>During construction:</u> The poor may also be affected by land acquisition and resettlement. <u>In operation:</u> No negative impact is expected, as there is no particular event that will affect the poor. Positive impacts from local employment creation are expected.
Social Environment	15	Ethnic minority, indigenous people	Negative	Negative	NA	NA	NA	NA	NA	NA	NA	<u>During construction:</u> For construction of the dam /reservoir construction, the dam site and inundated areas are in Sangu-Matamuhuri protected area, but there are several settlements, and distribution of ethnic minority, indigenous people needs to be confirmed. <u>In operation:</u> The resettled site needs to be monitored to confirm the impact by resettlement.

Category		Environmental and Social Item	Preliminary Examination Results: During Construction	In Operation: Dam/Reservoir	Regulation Pond	Movable Weir	Tidal Barrage	Kaptai Dam Water Use	Ground Water Use	Desalination	Water Saving	Reason for Preliminary Evaluation
	16	Local economy such as employment and livelihood	Positive / Negative	Positive / Negative	Positive / Negative	Positive / Negative	Positive / Negative	Positive / Negative	Positive / Negative	Positive / Negative	Positive / Negative	During construction: Land acquisition and resettlement will occur, which affect livelihoods of the resettled people. The construction work will provide positive impact on local economy due to increased employment opportunities of construction workers and increased demand for the local business such as shops and food vendors. However, the impact on salt field operation needs to be examined. In operation: in the long run, indirect positive impacts are expected due to creation of local employment by increasing of available water resource amount.
	17	Land use and local resource use	Negative (by regulation pond construction)	Positive	Positive	Positive	Positive	Positive	Positive	Positive	Positive	During construction: A decrease of salt field is expected due to land acquisition for regulation pond construction. In operation: After applying possible water resource development options, it is expected that new positive land uses will be planned with increase of available water resource.
	18	Water use	NA	Positive	Positive	Positive	Positive	Positive	Positive	Positive	Positive	During construction: No significant impact is predicted by construction work. In operation: With applying the possible water resource development options, the positive impact on water use will be expected.

Category		Environmental and Social Item	Preliminary Examination Results									Reason for Preliminary Evaluation
			During Construction	In Operation								
				Dam/Reservoir	Regulation Pond	Movable Weir	Tidal Barrage	Kaptai Dam Water Use	Ground Water Use	Desalination	Water Saving	
	19	Existing social infrastructure and social service	Negative	Positive	Positive	Positive	Positive	Positive	Positive	Positive	Positive	During construction: Impact on traffic volume on local roads due to construction is expected. Specifically, congestion is expected during construction on the existing road. In operation: No negative impact on existing social infrastructure or social services is expected. With applying the possible water resource development options, the positive impact on social service is expected with increase of available water resource.
	20	Social capital and local decision-making bodies	Negative (by construction of dam / reservoir)	Positive	Positive	Positive	Positive	Positive	Positive	Positive	Positive	During construction: For construction of the dam /reservoir, the several settlements need to be relocated. In operation: For use of the increased amount of available water resources, coordination among the various water users needs to be arranged.
	21	Uneven distribution of damage and benefit	NA	Positive / Negative	Positive / Negative	Positive / Negative	Positive / Negative	Positive / Negative	Uncertainly	Uncertainly	NA	Before and during construction, and in operation: There is a possibility of uneven distribution of damages and benefits among land acquisition and resettlement targets and beneficiaries (users) of new water resource. In addition, socially vulnerable groups may be more negatively affected among those who are targeted for land acquisition and resettlement.

Category		Environmental and Social Item	Preliminary Examination Results									Reason for Preliminary Evaluation
			During Construction	In Operation								
				Dam/Reservoir	Regulation Pond	Movable Weir	Tidal Barrage	Kaptai Dam Water Use	Ground Water Use	Desalination	Water Saving	
	22	Interest conflict in region	NA	Uncertainly	Uncertainly	Uncertainly	Uncertainly	Uncertainly	Uncertainly	Uncertainly	Uncertainly	During construction: No significant impacts are expected during construction phase. In operation: For use of the increased amount of available water resources, coordination among the various water users needs to be arranged.
	23	Cultural heritage	NA	NA	NA	NA	NA	NA	NA	NA	NA	During construction: Impacts of land acquisition on cultural heritage sites have not been identified, but religious facilities such as mosques may be affected. In operation: No particular negative impact is expected.
	24	Landscape	NA	NA	NA	NA	NA	NA	NA	NA	NA	During construction: It is expected that the construction will affect the view temporally, but the landscape of the proposed sites does not have specific worth. In operation: No particular negative impact is expected.

Category		Environmental and Social Item	Preliminary Examination Results									Reason for Preliminary Evaluation
			During Construction	In Operation								
				Dam/Reservoir	Regulation Pond	Movable Weir	Tidal Barrage	Kaptai Dam Water Use	Ground Water Use	Desalination	Water Saving	
	25	Gender	Uncertainly	NA	NA	NA	NA	NA	NA	NA	NA	Before and during construction: Negative impacts on female socially vulnerable groups such as widowed households are expected. There is a possibility that affected persons and residents of the area will be employed during construction, but information will be collected to make a decision on the practices related to the employment and treatment of female workers. In operation: No project activities are planned that will increase the gender gap.
	26	Children's right	Uncertainly	NA	NA	NA	NA	NA	NA	NA	NA	During construction: There is a possibility of occurrence of child labor by the construction contractor. In operation: No particular negative impact is expected, as the project is considered to be free of matters related to children's rights.
	27	Infectious diseases such HIV/AIDS	Uncertainly	Positive	Positive	Positive	Positive	Positive	Positive	Positive	Positive	During construction: Increased risk of infectious diseases due to influx of construction workers. In operation: By increasing of available water resource amount, regional hygiene condition will improve, and the risk of infection disease is expected to decrease.

Category		Environmental and Social Item	Preliminary Examination Results: During Construction	In Operation: Dam/Reservoir	Regulation Pond	Movable Weir	Tidal Barrage	Kaptai Dam Water Use	Ground Water Use	Desalination	Water Saving	Reason for Preliminary Evaluation
	28	Labor environment including labor safety	Uncertainly	NA*	NA*	NA*	NA*	NA*	NA*	NA*	NA*	During construction: Impacts on the working environment of construction workers are expected. In operation: Proper labor environment management needs to be conducted to actualize proper condition of labor environment.
	29	Accident	Uncertainly	NA*	NA*	NA*	NA*	NA*	NA*	NA*	NA*	During construction: The number of construction vehicles in the area is expected to increase, and risk of traffic accident may increase if proper safety management is not conducted. In operation: Proper safety management of the proposed infrastructures needs to be conducted to reduce the risk of accidents.
	30	Impact of border transgression and climate change	Negative	Uncertainly	Uncertainly	Uncertainly	Uncertainly	Uncertainly	Uncertainly	Uncertainly	Uncertainly	During construction: Greenhouse gas emissions by construction work are assumed. In operation: In case that the flow control pump system is applied, the system would contribute for reducing greenhouse gas emissions.
	31	Natural disaster risk	Uncertainly	Positive	Positive	Positive	Positive	Positive	Positive	Positive	NA	During construction and in operation: Impacts related to flood inundation due to flood blockage in the road embankment are expected.

Note: "Negative" means that the negative impact is preliminary predicted.
"Positive" means that the positive impact is preliminary predicted.
"Uncertainly" means that further study is necessary to examine the preliminary impact.
"NA" means that no impact is predicted in existing condition.
"NA*" means that no impact is predicted with planning and implementation of proper management plan.

Source: JICA Survey Team

4.1.10 Organization and Legal Systems in Bangladesh

4.1.10.1 Current status of organizations and legal systems related to water resources development and water supply

(1) Hierarchical structure of Governmental Agencies in Bangladesh

In order to facilitate the understanding of organizations and legal systems regarding the water sector in Bangladesh, an overview of the relevant central government and local governments is as follows;

1) Central Government

In Bangladesh, the President which term of office is 5 years, and up to 2 terms is positioned as the head of state by the Constitution and is elected through election of parliamentarians. The main duties of the President are the appointment of the Prime Minister and the appointed ministers, the Deputy Minister and the Chief Justice of the Supreme Court nominated by the Prime Minister, and the approval of bills that are passed by the Diet, etc. Those are executed in the name of the President based on the advice of the Prime Minister.

The Prime Minister constitutes the Cabinet together with the appointed ministers. As the head of the Cabinet, the Prime Minister is responsible for executing the administration of Bangladesh and informing the President of domestic and international policies. Bangladesh has a parliamentary cabinet system in which the cabinet is responsible for the Parliament. The Prime Minister may resign or request the President to dissolve the parliament if s/he loses the support of the majority of parliamentarians. If the President also admits that the Prime Minister does not have the support of the majority of parliamentarians, s/he has the authority to dissolve the parliament.

The number of ministries and divisions is 58, and each ministry or division has administrative agencies (Directorates) which number is very largely at 353. Among them, the central government agency for water counts 14 at the ministry level and 33 at the administrative agency level according to the National Water Management Plan (NWMP) developed in 2001.

2) Local government agencies

Bangladesh is divided into eight Divisions. They are subdivided into 64 Districts / Zilas being all further subdivided into 492 Upazilas. Each Upazila consists of several Unions. The number of all Unions reaches 4,554. There are 11 City Corporations, major urban areas across the border between Districts and Upazilas established depending on the size of population and tax revenue. There are also 315 Pourashavas, urban areas across the border between Upazilas and Unions. Each City Corporation and Pourashava has a city hall. Divisions, Districts, Upazilas, Unions, City Corporations and Pourashavas are local administrations under the jurisdiction of the Ministry of Local Government, Rural Development and Cooperatives (MoLGRD & C), Local Government Division (LGD). The structure of the local administrations is shown in Fig. 4.1.17.

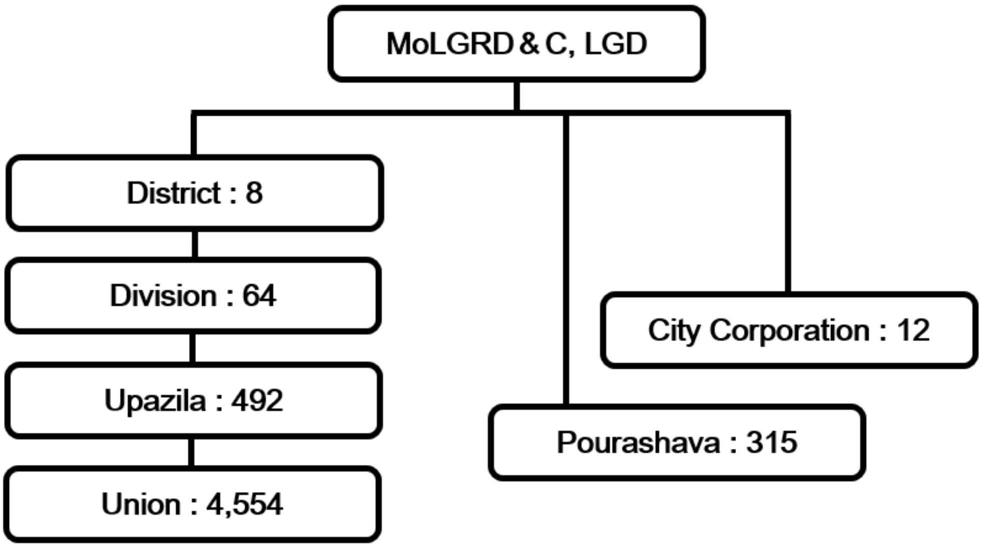


Figure 4.1.17 Government Organizations Related to Water Sector in Bangladesh

(2) Government Organization related to Water Sector in Bangladesh

Bangladesh has 50 plus years of experience in managing water resources that is reflected in numerous water policies and water programmes. A chronological list of the major initiatives is provided in Table 4.1.19.

Table 4.1.19 List of Major Water Related Policies, Acts and Their Supervisory Authorities

The Embankment and Drainage Act 1952	Ministry of Water Resources (MoWR)
The IECO Master Plan (1964)	Bangladesh Water Development Board (BWDB)
The Marine Fisheries Ordinance (1983)	Ministry of Fisheries and Livestock (MoFL)
The National Water Plan I (1986)	Master Plan Organization (MPO)
The National Water Plan II (1991)	Master Plan Organization (MPO)
Floodplain Management Pilot Project	Ministry of Water Resources (MoWR)
Flood Action Plan FAP (1990/95)	Ministry of Water Resources (MoWR)
Protections and Conservation of Fish Act (Amended 1995)	Ministry of Fisheries and Livestock (MoFL)
Environment Conservation Act (1995)	Ministry of Environment and Forests (MoEF)
National Minor Irrigation Development Project (1996)	Ministry of Agriculture (MoA)
Environmental Conservation Rules (1997)	Ministry of Environment and Forests (MoEF)
National Policy for Safe Water Supply and Sanitation 1998	Ministry of Local Government, Rural Development and Cooperatives (MoLGRDC)
Meghna Estuary Study, Master Plan (1998)	Bangladesh Water Development Board (BWDB)

National Fisheries Policy (1998)	Ministry of Fisheries and Livestock (MoFL)
National Water Policy (1999)	Ministry of Water Resources (MoWR)
Guidelines for Participatory Water Management (2000)	Ministry of Water Resources (MoWR)
The National Water Management Plan (NWMP) (2001)	Water Resources Planning Organization (WARPO)
Brick Burning (Control) (Amendment) Acts (2001)	Ministry of Environment and Forests (MoEF)
Action Plan for Solid Waste Management in 19 Towns	Department of Public Health Engineering (DPHE)
Clean Dhaka Master Plan (2005)	Ministry of Environment and Forests (MoEF)
The Coastal Zone Policy (2005)	Ministry of Water Resources (MoWR)
National Fisheries Strategy and Action Plan (2006)	Ministry of Fisheries and Livestock (MoFL)
Government Jolmohal Management Policy (2009)	Ministry of Fisheries and Livestock (MoFL)
The Master Plan for Haor Areas (2010)	Bangladesh Haor and Wetland Development Board (BHWDB)
Environment Court (Amendment) Act (2010)	Ministry of Environment and Forests (MoEF)
Hazardous Waste and Ship Breaking Waste Management Rules (2011)	Ministry of Environment and Forests (MoEF)
Dredging Plan 2012	Ministry of Shipping (MoS)
Sector Development Plan (SDP) for Water Supply and Sanitation Sector in Bangladesh (FY 2011-25)	Local Government Division, Ministry of Local Government, Rural Development and Cooperatives (MoLGRDC)
The National Water Act (2013)	Ministry of Water Resources (MoWR)
Bangladesh Water Development Board Act (2013)	Ministry of Water Resources (MoWR)
Bangladesh Haor and Water Bodies Development Board Act (2014)	Ministry of Water Resources (MoWR)
National Shrimp Policy (2014)	Ministry of Fisheries and Livestock (MoFL)
Participatory Water Management Rules (2014)	Ministry of Water Resources (MoWR)

Source: BDP 2100 Technical Team Analysis, GED, 2015, MoEF, 2012

Among these, the main government organizations involved in the water sector are the following eight councils / ministries and their implementing agencies.

i. National Water Resources Council: NWRC

ii. Executive Committee of the National Water Resources Council: ECNWRC
iii. Ministry of Water Resources：MoWR
iv. Ministry of Local Government, Rural Development and Cooperatives：MoLGRD＆C
v. Ministry of Shipping：MoS
vi. Ministry of Agriculture：MoA
vii. Ministry of Fisheries and Livestock：MoFL
viii. Ministry of Environment and Forests：MoEF

The outlines of the main ministries and implementing agencies considered to be related to water resources development and water supply to the Moheshkhali/Matarbari region are the followings;

1) National Water Resources Council (NWRC)

NWRC is the premier state body for water policy development, including inter-ministerial coordination established by the Cabinet Office in June 1992, and is responsible for making recommendations to the Cabinet on all water policy issues. It consists of 48 members, including the ministers of relevant ministries and agencies, and is headed by the Prime Minister. NWRC formulated the National Water Policy (NWPo) in January 1999, which stipulates the followings as the strategic role of the NWRC.

i. Develop various policies regarding water resource management
ii. Give instructions for optimal development and utilization of water resources
iii. Oversee the development and implementation of the National Water Management Plan (NWMP)
iv. Give instructions on the creation of efficient institutions and public organizations to manage water resources
v. Give policy directives for proper coordination between various water sector agencies
vi. Involve in other projects related to water resource management

2) Executive Committee of the National Water Resources Council (ECNWRC)

ECNWRC is an organization established in June 1997 to support NWRC, chaired by the Minister of Water Resources, and handled by the Water Resources Planning Organization (WARPO), which will be described later. NWRC is made-up by ECNWRC to carry out the following appropriate official affairs to fulfill NWRC’s responsibilities.

i. Give instructions to all water sectors on all issues related to the planning, management and coordination of widely involved water resources management that NWRC may require,
ii. Provide guidance on policies and plans for improving water resources management and investment for national, regional and local level institutions and public organizations,
iii. Regularly notify and advise NWRC on water resource management issues, and
iv. Undertake other roles that NWRC needs from time to time.

3) Ministry of Water Resources: (MoWR)

MoWR formulates project policies, plans, strategies, guidelines, rules and regulations related to the development and management of water resources in Bangladesh. Through the projects implemented by the seven agencies under the jurisdiction, including Water Resources Planning Organization (WARPO), Bangladesh Water Development Board (BWDB), which will be described later, and Department of Bangladesh Haor and Wetlands Development (DBHWD), Joint Rivers Commission (JRC), River Research Institute (RRI), etc., MoWR conducts the following measures;

i. Implement construction projects for flood control, drainage and irrigation (FCDI) such as river / coast embankments, river channel dredging, landfills, dams, sluice gates, irrigation canals, and lift / drainage pump stations,
ii. Collect and process hydrological data and providing whole Bangladesh with flood forecasting and warning message throughout the rainy season everyday,
iii. Settle water allocation based on priority in the specified area and period,
iv. Regulate the pumping of groundwater to conserve and maintain the shallow groundwater aquifer,
v. Create, implement, and monitor emergency response plans in areas where seasonal droughts occur repeatedly,
vi. Empower local governments or other agencies to allocate river water to areas where severe drought occurs, monitor the water environment and enforce regulations,
vii. Grant water right to use of groundwater / surface water to private and community organizations,
viii. Secure river environmental flow, and
ix. Discuss cross-border river management with neighboring countries.

Thus, MoWR implements policies, technical supports, researches, projects, and international cooperation in the fields of irrigation, flood control, drainage, inundation and erosion prevention, drought countermeasures, etc. In addition, MoWR regularly reviews roles of the agencies under its jurisdiction and redefine them as necessary, and makes efforts to implement efficient and effective measures and projects related to various water resources that meet changing needs and priorities.

4) Water Resources Planning Organization (WARPO)

The Government of Bangladesh established Master Plan Organization (MPO) under the MoWR in 1983 and started a project to formulate National Water Plan (1985-2005): NWP under MPO. This MPO was renamed WARPO in June 1992.

On the other hand, in Bangladesh, Flood Action Plan (FAP, officially "Bangladesh Action Plan for Flood Control") was implemented with assistance from four international organizations and 11 countries including Japan in the wake of large-scale floods occurred in 1987 and 1988. This was a floodplain initiative consisting of 26 components (FAP-1 to 26) was carried out during the period of 1990-95.

However, FAP-21 / 22: Bank Protection, River Training and Active Flood Plain Management was continued to 2005. To coordinate this project, the Flood Plan Coordination Organization (FPCO) was established under the MoWR, and FPCO was merged with WARPO in 1996 after the FAP was completed.

The WARPO is a government agency under the jurisdiction of MoWR, which specializes in the formulation of macro-level water resources plans in Bangladesh. In addition, as the secretariat of ECNWRC, it will perform the following major duties;

i. Provide operational, technical and legal support to ECNWRC,
ii. Advise ECNWRC on policies, plans and regulations on water resources management and related land and environment management,
iii. Develop and regularly update the National Water Management Plan (NWMP) and receive NWRC approval of the NWMP revision,
iv. Build and update National Water Resources Database (NWRD) and information management system,
v. Acts as an "information center" for all projects identified by various water sector agencies and reports to ECNWRC on their suitability for NWMP,
vi. Conduct special researches that ECNWRC may need to achieve objectives and programs envisioned in NWPo and water and flood management strategy, and
vii. Enforce other features that may be assigned by the Government of Bangladesh at any time.

5) Bangladesh Water Development Board (BWDB)

The predecessor of BWDB was established in 1959 as the water division of the East Pakistan Water and Power Development Authority (EPWAPDA). After the independence of Bangladesh, it was separated as BWDB in 1972 and in charge of water resource development projects under MoWR. The rest of EPWAPDA is Bangladesh Power Development Board (BPDB).

In the 1990s, the Government of Bangladesh received strong demands for BWDB reform from donors, etc., and drastically reorganized and downsized BWDB, and BWDB was reconstructed as a highly independent body that fulfills its responsibilities in line with the NWPo and BWDB Act enacted in 2000. The major reform on the BWDB Act 2000 was the establishment of Board of Directors to oversee the activities and management of BWDB. The Board of Directors consists of a total of 13 members including Minister of WR as a chairman, four secretaries of water-related ministries including MoWR, Ministry of Finance, Ministry of Local Government, Rural Development and Co-operatives and Ministry of Environment and Forests, WARPO Director General (DG), BWDB DG, four academic experts appointed by the government, one basin representative, and one NGO. BWDB itself consists of five Additional Director Generals: ADGs who are in charge of general affairs, finance, planning, eastern regional projects, and western regional projects, respectively, under the Secretary.

The BWDB Act 2000 stipulates that BWDB's projects are implemented in line with NWPo and NWMP and cover all rivers, channels and groundwater aquifers in the country. BWDB's duties cover both so-called structural (hard) and non-structural (soft) projects, specifically,

（Hard Projects）

i. Construction of dams, weirs, reservoirs, levees, water level and flow control structures, etc. for river training, flood control, drainage, surface irrigation and drought prevention
ii. Removal of estuary blockages, excavation and removal of canal deposits for the purpose of promoting water flow or diversion to support fishing, shipping, forest management, wildlife utilization and environmental improvement
iii. Projects aimed at soil conservation, land accretion, reclamation and estuary management
iv. River training and embankment conservation aiming at preserving city blocks, markets, and historically and publicly important areas from land erosion disasters
v. Construction and maintenance of coastal levees
vi. Prevention of saltwater infiltration and desertification
vii. Securing rainwater for irrigation, environmental protection and drinking water supply

（Soft Projects）

i. Hydrological observation
ii. Flood and drought forecasting and warning
iii. Forestry development and fishery development for the purpose of environmental conservation and improvement, and poverty reduction in collaboration with related government agencies through the use of land related to BWDB projects
iv. Basic and applied research on all aspects of the BWDB projects
v. Organizing water users and stakeholders for completed projects and formulating, implementing, operating and maintaining their participatory business plans, and conducting training to improve their abilities.

The Flood Forecasting and Warning Center (FFWC) is an affiliated organization of BWDB. FFWC issues warnings to more than 600 users every day during the rainy season using the flood prediction model (Mike11) from hourly rainfall data (70 points), water level every 3 hours (94 points), etc.

6) Ministry of Local Government, Rural Development and Co-operatives (MLGRDC）

In Bangladesh, the responsibility for water supply and sanitation lies primarily with the government, and therefore, LGD takes charge of it. LGD is a policy-making body for local governments, and is responsible for policy implementation and local government supervision. The main responsibilities are the formulation, implementation and monitoring of various plans related to local autonomy, the allocation of grants to local governments, the establishment of various rules and project monitoring of local governments' operations, and the executing agencies under the jurisdiction of LGD including

Department of Public Health Engineering (DPHE), Water and Sewerage Authority (WASA), Local Government Engineering Department (LGED) for local infrastructure development and water supply, capacity building of local governments, etc. In particular, the two organizations, DPHE and WASA, are considered to play an important role on water supply and sanitation for the Moheshkhali/Matarbari region.

RDCD aims to reduce the poverty of local farmers and improve socio-economic status through rural development, establishment of rural development policies and laws, formulation of rules and guidelines related to rural poverty mitigation, and implementing programs and projects. Specifically, it applies microcredit, supports co-operative-based agriculture, small-scale industries, and supports farmers through co-operative banks and insurance, and other co-operative companies.

7) Local Government Engineering Department: LGED

The LGED has responsibilities to develop infrastructures for local cities and villages, such as roads, bridges, culverts and markets, etc. and implement Small Scale Water Resources (SSWR) project which area is less than 1,000 ha. The Work Program (WP) including Rural Works Program (RWP), Thana Irrigation Program (TIP), etc. launched in the early 1960s, while Works Program Wing（WPW）in charge of WP was established under LGD in 1982, and WPW was reorganized to be Local Government Engineering Bureau (LGEB) in 1984, and LGEB was upgraded to be the current LGED. It had completed over 500 SSWR projects up to 2018.

8) Department of Public Health Engineering: DPHE

The DPHE was established by the Government of East Pakistan after the independence from India in 1947. Currently, DPHE is a subordinate organization of MLGRD＆C, as with LGED and WASA. DPHE provides drinking water supply service by pipe to other urban areas (City Corporation, Pourashavas) except Dhaka/Narayanganj, Chittagong, Khulna and Rashaji where WASA operates. In rural areas, it provides drinking water supply services through wells. DPHE also implements various projects to improve the environment for sewage and waste treatment and other waste management. For this reason, it has local agencies in all districts and Upazila throughout the country, and is also in charge of necessary infrastructure development, technical guidance, and water quality inspection. The safe water supply service to arsenic-contaminated areas, firstly identified in Bangladesh in 1993, is also an important task of DPHE.

9) Water Supply and Sanitation Authority (WASA）

Currently, 4 WASAs including Dhaka WASA: DWASA, Chattogram WASA (CWASA), Khulna WASA: KWASA) and Rajshahi WASA: RWASA were established based on the existing water supply entities of each city (City Corporation). The main roles of WASA are; 1) Construction, improvement and O&M of facilities related to the water intake, purification, storage and distribution of drinking water, 2) Construction, improvement and O&M of sanitary sewerage system facilities, 3) Abolition of unnecessary existing drainage facilities, and 4) Construction and O&M of drainage systems such as rainwater drainage ditches.

Currently, five cities, namely, Barisal, Sylhet, Rangpur, Mymensing, and Faridpur are in the process of establishing new WASA, but it will take a long time.

CWASA was initially established for the purpose of providing water and sanitary service to Chittagong and its designated suburbs in 1963 under the former East Pakistan Government's "Water Supply and Sewerage Authority Ordinance NO.XIX 1963". After that, CWASA was officially rebuilt by the enactment of the WASA Act in 1996, and was officially established CWASA in 2008. The main functions of CWASA in the Chattogram metropolitan area are as follows;

i. Construction, improvement, expansion, O&M of infrastructure required for household, industrial and commercial water supply,
ii. Construction, O&M of sewerage systems in the Chattogram metropolitan area,
iii. Construction, O&M of drainage facilities for rain, floods and surface water, and
iv. Solid waste management.

All of WASA's capital is owned by the Government, and the Board of Directors consists of 13 directors appointed by the Government under the WASA Act. CWASA is obliged to provide water supply service to 155 km^2 of 41 wards under Chattogram City Ordinance.

At present, CWASA does not provide sewage treatment and storm water drainage services, but it is provided by Chattogram City Corporation.

10) Bangladesh Power Development Board (BPDB)

The BPDB is an organization that has the Kaptai Dam built in 1962 to serve as an exclusive water power generation (230 MW) in the upper reaches of the Karnafuli River, and was spun off from the former East Pakistan Water and Power Development Authority (EPWAPDA) and established by the Presidential Decree No. 59 on May 1, 1972. BPDB is a subordinate agency of the Ministry of Power, Energy and Mineral Resources (MPEMR) and is primarily responsible for power generation and distribution in urban areas except Dhaka and the western region. Through the reforms and reorganizations so far, BPDB has the following state-owned enterprises for power generation and distribution, mainly using natural gas as fuel for thermal power generation, and as of April 2016, the power generation capacity has reached 12,339 MW.

i. Ashuganj Power Station Company Ltd. (APSCL)
ii. Electricity Generation Company of Bangladesh (EGCB)
iii. North West Power Generation Company Ltd. (NWPGCL)
iv. West Zone Power Distribution Company Ltd. (WZPDCL)

11) Bangladesh Agricultural Development Corporation (BADC)

The BADC was established as an agricultural development corporation in 1961 during the East Pakistan era, and after independence of Bangladesh. The Government sorted its functions by those of other development organizations in the agricultural sector in 1975, and continues to this day. The BACD is an autonomous entity under the Ministry of Agriculture, based in Dhaka, and has local agencies up to the Upajira level throughout the country and, in some cases, even lower levels. Its functions include production, preservation and supply of high-yielding seeds of various crops, import of fertilizer, irrigation projects based on the use of pump or pipe water supply with an area of 1,000 ha or less. It also engages in procurement, transportation and distribution of agricultural materials and equipment aiming to improve efficiently agricultural productivity through optimal use of surface water and reduction of soil water saturation.

(3) Legal system for water sector

There are already many legal systems related to water sector in Bangladesh. The main ones are shown in Table 4.1.19. The water supply organizations for the Moheshkhali/Matarbari region to be examined are in charge of development of surface water resources and purification of the raw water into domestic and industrial water, as well as the organizations in charge of sewage disposal are also considered. It is also required to consider an organization in charge of supervising and evaluating these organizations' performances, and recommending them for corrective action as necessary, and coordinating interests among these organizations and stakeholders.

For this reason, it is practical for the legal systems to appropriately guarantee the functioning of these institutions, to utilize the existing legal systems, and to revise them as necessary.

1) Outline of legal systems, etc. regarding general water resources management (including water supply and sanitation)

Currently, the comprehensive legal framework covering all aspects of water management in Bangladesh is Water Act 2013. The main purpose of the Act is to prepare for the integrated water resources management including development, intake, distribution, use, protection and conservation of water resources. The Act aligns the relevant existing organizations and legal systems, and is in good shape and provides a strong foundation for moving forward into the future. The Act is based on many of the concepts defined in the National Water Policy 1999 (NWPo) and the National Water Management Plan 2001 (NWMP, adopted in 2004), which will be described later.

In 2018, the revised version of NWMP, "Bangladesh Delta Plan 2100: BDP2100", was formulated, but the master plan (MP) for water management dated back to 1964 up to the era of East Pakistan, the predecessor of Bangladesh. This MP included a plan for large-scale flood control, and irrigation and drainage projects with the main purpose of expanding agricultural production, and formed the water sector project in Bangladesh until 1975.

In 1970, a joint mission of Bangladesh and World Bank stated the need to formulate the National Water Plan (NWP) based on a systematic assessment of total amount of available water resources and water demand. After that, the International Bank for Reconstruction and Development (IBRD) proposed a review of the MP formulated in 1964, giving consideration to fisheries, groundwater conservation, urban water, etc. Attention has been focused on the need for water utilization and conservation of the natural environment associated with the Ganges River water intake during the drought time from the Farakka Barrage constructed in 1975 by India.

In 1983, Bangladesh established the Master Plan Organization (MPO, the predecessor of WARPO) under the MoWR, and MPO developed the National Water Plan (1985-2005) (NWP) in 1987, which was already mentioned above. The NWP comprehensively evaluated the amount of available water resources, water demand, water transportation, fishing, and the amount of water resources required for the natural environment conservation, and proposed a long-term water management plan for Bangladesh and its institutional implementation.

The Flood Action Plan (FAP) was formulated with the support of four international donors and 11 countries including Japan in the wake of the large-scale floods occurred in 1987 and 1988, and put into practice from 1990 to 1995 (the component 21/22 continued until 2005). The Bangladesh Water and Flood Management Strategy (BWFMS) was formulated in 1995 based on the knowledge accumulated through the series of activities related to FAP, and further included policies for dealing with various water problems. This led to the formulation of the National Water Policy (NWPo, January 1999) and the National Water Management Plan (NWMP, approved in March 2004).

2) National Water Policy (NWPo)

The NWPo presents the following policies to all relevant ministries, local governments and private organizations in charge of the investigation, development, utilization and management of water resources in Bangladesh;

i. Addressing issues related to the use and development of all types of surface and groundwater in an efficient and equitable manner,
ii. Fair water use for all citizens, especially for women and children ,
iii. Supporting the sustainable development of public and private water supply systems through appropriate legal and financial measures and ensuring incentives including granting water rights and setting water prices,
iv. Decentralization of water resources management and strengthening the role of women in water management,
v. Improving the investment and regulatory climate of private sector in water development and management, and
vi. Promoting the achievement of water management goals and ensuring economic efficiency, gender equality, and capacity development for formulation of the future water resource management plans based on social justice.

In addition, specific goals and countermeasures for the following items are described;

i. Planning and management of water resources,

ii. Water right and its allocation,
iii. Public and private involvement in water management,
iv. Investing in public water sector,
v. Water supply and sanitation,
vi. Water and agriculture, industry, fisheries, navigation, hydropower, recreation, natural environment,
vii. Conservation of scenic water areas,
viii. Economic and financial management of water,
ix. Research and information management,
x. Stakeholder participation, and
xi. Institutional and legal reforms.

3) National Water Management Plan (NWMP)

The NWMP is a perspective plan for 25 years from 2001 to 2025, and consists of a total of 84 programs. These programs are grouped into eight sub-sectors and are also spatially located in eight regions according to the domestic hydrological and meteorological environment**.** It is also organized into three categories: cross-disciplinary programs, national programs, and regional programs. NWMP identified 35 organizations that will lead and implement these programs, each of which plans and implements the projects within the NWMP framework in accordance with the normal government administrative procedures, relevant rules and guidelines.

The target area of this Survey is a part of the East Hill (EH) area (Chattogram Hill Area), but the approach to this area in NWMP is to evaluate its characteristics that water use of major rivers for entire area is not realistic due to relatively large water shortages in the dry season, and in addition, the coastal zone is characterized by being exposed to the threat of cyclones, and these main problems are specific to this area and the programs set up to solve them are as follows;

i. Expensive crop cultivation program by utilizing well water for small-scale irrigation during dry season in CHT,
ii. Program of mini-hydropower development to solve the power shortage problem in CHT and multipurpose use of Kaptai Dam reservoir,
iii. Storm water drainage, flood protection, etc. programs for the issue of vulnerability to cyclones in Chattogram City, and
iv. Coastal levee reinforcement and afforestation program to solve coastal levee vulnerability issues.

WARPO currently works on reforming NWMP to be National Water Resources Plan.

4) Bangladesh Water Act2013 (BWA2013)

The Water Act2013 is a comprehensive legal framework that covers all aspects of water management in Bangladesh. Based on NWPo, it comprehensively stipulates development, intake, distribution, utilization, protection and conservation of water resources in Bangladesh. According to this Act, all forms of water (surface water, groundwater, seawater, rainwater, water vapour in the atmosphere, etc.) within the territory of Bangladesh belong to the Government on behalf of the people, and the use by individuals and corporations is permitted. The acquisition of water and the protection and conservation of water resources in the land are stipulated for land owners. In areas where water demand is tight, the priority of water use is set in order: drinking water supply > irrigation water supply > cultivation > securing biodiversity > wildlife conservation > securing running water > securing industrial water > salt water control > securing water for hydropower generation > recreation > others. The Act also stipulates permission for the installation of river structures, etc., and also stipulates penalties and fines for water users who violate the above various permits and regulations.

The authority to enforce these permits, regulations, etc. is clarified by the Act, which is granted to the National Water Resources Council: NRRC and the Executive Committee of the National Water Resources Council (ECNWRC).

Regarding water quality conservation measures, it is pointed out separately that the Act lacks provisions and that other laws need to be taken.

5) Bangladesh Water Rule 2018：BWR2018

The BWR2018 was enacted in August 2018 after WARPO drafted and coordinated with relevant agencies with the aim of more specific implementation of BWA2013. There is no official English version at this time.

6) Industrial Water Use Policy, 2020 (Draft)

The WARPO works on the formulation of Industrial Water Use Policy 2020. Currently, it is in the draft stage, and the contents are being confirmed and adjusted by the relevant ministries and agencies, and when this adjustment is completed, it will be sent to the Prime Minister's Office and will be enacted after further deliberation.

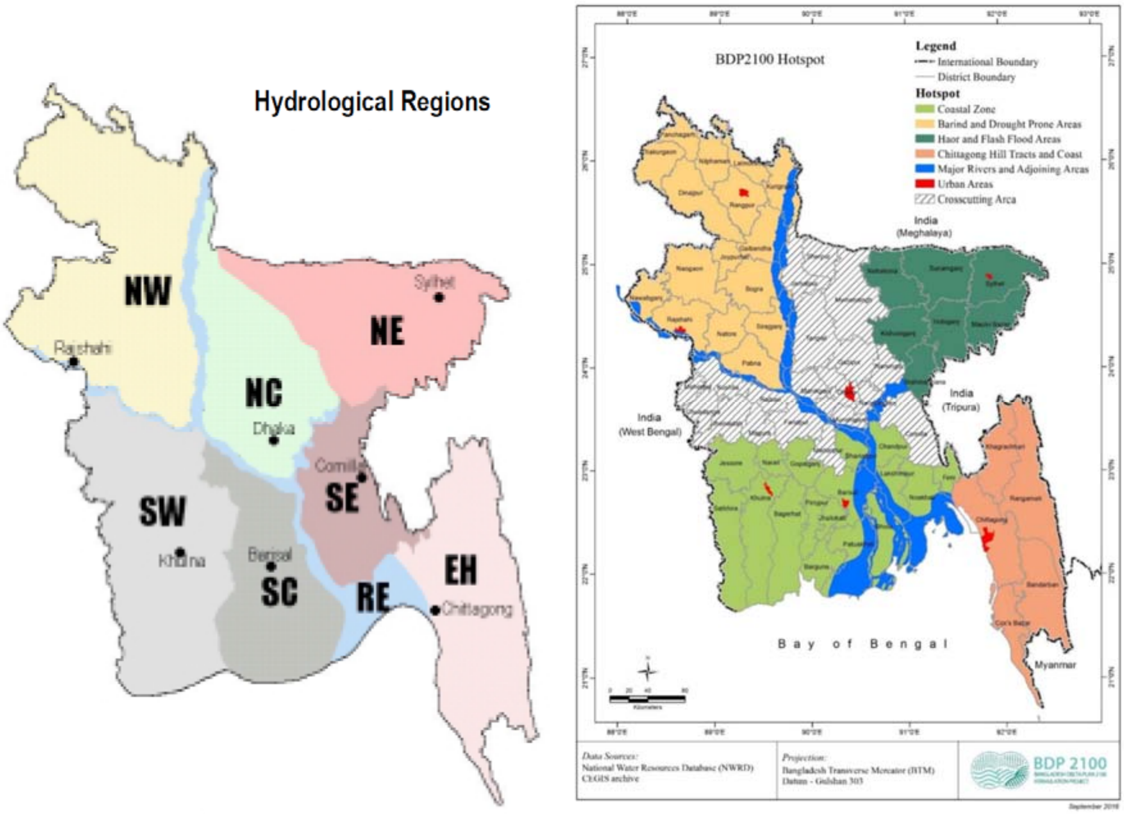
7) Bangladesh Delta Plan 2100 (BDP2100)

The Government of Bangladesh partnered with the Dutch government to formulate the Bangladesh Delta Plan 2100 (BDP2100) for the entire Bangladesh with preparatory work from 2011 to 2012 and the conclusion of the MOU in May 2012. In September 2018, the Government of Bangladesh decided to proceed with national operations in line with BDP2100 (Starting time of BDP2100 was officially 2015, but various adjustments took time and the operation started in 2018).

BDP2100 is going to provide robust water resources management including safety from the increase of natural disasters due to climate change, water security and efficient use, sustainable and comprehensive river basin, mouth area management for the next 21st century. Conservation of wetland, river ecosystem, fair governance of domestic and international rivers, and optimal use of land and water resources embody the prosperity of the country. Thus, the country has been divided into six distinctive areas due to the vulnerability to fluctuations of hydro-meteorological environment across the country such as hotspots: Coastal Zone, Barind and Drought Prone Areas, Haor and Flash Flood Areas, CHT and Coast, Major Rivers and Adjoining Area and Urban Areas. The region where there are problems common to all six hotspots and cannot be classified into any of hotspots is designated as Crosscutting Area. The areas of NWMP and BDP2100 are shown in Figure 4.1.18.

In addition, BDP2100 has three planning terms consisting of the period up to 2030 (short term), of 2030-50 (medium term) and 2050-2100 (long term), respectively, in which there are 80 target projects including ongoing ones already admitted and covered development issues in the hotspots, etc. There are also the investment plans which funding allowance should be taken into account the future growth of GDP of Bangladesh and donor supports, etc. Until the medium term (to 2050), each five-year plan is going to be a means of project review and implementation. Regarding the long term (to 2100), it appears to depend on a deployment scenario based on the uncertainty of the environment and development situations at that time.

By the way, NWMP forecasts the term from 2001 to 2025, but the Government of Bangladesh formulated BDP2100 as early as 2018. There were two points behind this background. One point was that the Government recognized that the sustainable growth of Bangladesh in the future would be very difficult if it fails to deal with the growing global concerns about climate change. The second was that the projects nominated and promoted within the framework of NWMP had not produced satisfactory results because project owners did not obtain sufficient cooperation and collaborations with related organizations. For this reason, BDP2100 was formulated under the jurisdiction of the Ministry of Planning, while NWMP was under the jurisdiction of MoWR. So to speak, an initiative for BDP2100 is under a national unity system.



Surce：https://cdkn.org/story/feature-bangladeshs-delta-plan-offers-major-opportunity-for-climate-compatible-development

Figure 4.1.18 Area Classifications in NWMP and BDP2100

Source: https://cdkn.org/story/feature-bangladeshs-delta-plan-offers-major-opportunity-for-climate-compatible-development

The southern Chattogram area, which is the target area of the Survey, is one of hotspots, "CHT and Coast". It is characterized by the fact that various disasters including landslides in CHT, inundations occurred due to sedimentation in the coastal area, etc. are pronounced. In addition, although most of the catchment areas of the huge rivers in Bangladesh are outside the country, but in this area, most of the catchment areas of important rivers are in the country, therefore, it is possible to deal with various problems from the viewpoint of integrated basin management. The overall strategy is defined as follows.

i. Protect economic activities and residential areas from floods and storm surges,
ii. Ensure water security and sustainable hygiene,
iii. Implement integrated river management,
iv. Maintain ecological balance and preserve its value as asset, and
v. Develop a multipurpose resource management system for sustainable growth.

Therefore, the following specific projects are nominated in this area.

i. Water Supply and Environmental Sanitation in Pourashavas Under CHT,

ii. Prospects for Promoting Soil Conservation and Watershed Protection in CHT,
iii. Kaptai Lake Rehabilitation Study and Pilot Project,
iv. Development Catchment and Sub-catchment Management Plans,
v. Program for Implementation of Rationalized Water related Interventions in CHT Basin,
vi. Rationalization of Polders in Chittagong Coastal Plain,
vii. Enhancement of Livelihood in the Chittagong Hill Tracts through Good Agricultural Practices,
viii. Sustainable Tourism CHT Feasibility Study,
ix. Promoting Sustainable Cultivation Practices, including Agro-forestry, and
x. Flow Control and Water Storage Structures for Water Availability in the Dry Season.

(4) National Policy and Plan regarding Water Supply and Sanitation

1) National Policy for Safe Water Supply and Sanitation (NPoSWS&S l998)

The Policy sets the government's goal to ensure that the safe water supply and sanitation (WSS) services are available to all citizens at a reasonable cost, and to achieve this, planning and management related to the above will be implemented through the participation of users to ensure sustainability. For this reason, WASA, Pourashavas, etc. will be responsible for operational and financial management and encourage private sector and NGO participation in the provision of WSS services. DPHE must have appropriate institutional coordination with them to improve their capabilities for planning, design, implementation, management and human resource development.

2) National Policy for Arsenic Mitigation and Implementation Plan 2004

The Plan aims to provide guidelines for mitigating the effects of arsenic on humans and the environment in a comprehensive and sustainable manner. From the perspective of achieving national goals of poverty alleviation, public health and food security, the Plan will promote NWPo1998 and NPoSWS & S1998. Safe water for drinking and cooking in all aspects affected by arsenic is ensured by implementing alternative water supplies, and arsenic addicts are properly diagnosed under an effective health care system.

3) Sector Development Plan for Water Supply and Sanitation Sector in Bangladesh (FY 2011-25)

The purpose of the Plan is to provide a framework for planning, implementing, coordinating and monitoring all activities of the Water Supply and Sanitation Sector (WSSS), a roadmap for WSSS development. It provides a map and a sectoral investment plan.

It has a planning period of 15 years, allocating 5 years to each of the short-term, medium-term and long-term plans, in line with the government's 5-year development cycle. In addition, the contents of the Plan will be reviewed and updated every five years. The short-term plan consists of ongoing projects and prioritized programs that have been approved and are being prepared. It is supposed to shift to the short-term plan. The long-term plan summarizes what the WSSS ultimately develops on the basis of possible sectoral funding and the expected capabilities in planning, implementation and O&M as the government vision.

(5) Outline of the legal systems for individual implementing agencies

1) Water Development Board Act, 2000 (Act No. XXVI)

BWDB is an organization separated and established by the Bangladesh Water and Power Development Boards Order (P.O. No. 59) in 1972 from the East Pakistan Water and Power Development Authority (EPWAPDA). BWDB ACT 2000 consists of 27 articles in total and abolishes P.O. No. 59, and newly regulates the projects under the jurisdiction of BWDB, the role of the board of directors, organizational management, etc., Regarding the projects, the hardware and software ones described in 4.1.6 (2) 5) are stipulated by the Act.

2) Water Supply and Sewerage Act 1996 (No. 19 of 1996) (WASA ACT 1996)

Dhaka WASA and Chittagong WASA were established in Dhaka and Chittagong, respectively in 1963 as organizations to provide water and sewage services to their citizens. The Act stipulates WASA's responsibilities, organization, budget, water fee setting, division of roles with the Government of Bangladesh, and coordination procedures. The Act allows WASA to raise water tariffs by up to 5% each year subject to the approval of the Government in order to improve the financial health of WASA.

4.1.10.2 Study on organizations/legal systems and institutional arrangements concerning water supply agencies

In due consideration of Sub-sections 4.1.4 to 4.1.7, which discuss the alternative plans for water resources development in the survey area, the JICA Survey Team conducted interview survey with the relevant organizations in charge of water resources management etc., concerning the idea on organizations and legal systems in the Moheshkhali/Matarbari region.

(1) Classification of alternatives for water resources development plan

The JICA Survey Team firstly classified the alternatives for water resources development plan into the water resources development projects and the industrial water works and domestic water and sewerage works from the following points of view for conducting interview surveys.

- ☐ Water resources development generally means to make it possible to take a certain amount of water from a specific point of river during time of drought by releasing water from dam reservoirs to increase water flow rate at the point. From this aspect, it is rather difficult in a precise sense, but it might be possible in a broad sense to term "annual use of water stored in a pond by taking flooding water from a river in only rainy season through pomp-type intake and headrace" "water resources development".
- ☐ When compared to the water resources development, it is recommended that facilities such as the pond, etc. be dealt as a unit with the industrial water works and domestic water and sewerage works in terms of project efficiency and cost allocation for users, etc.
- ☐ However, regarding the facility development, while regal system set-ups or reforms including river area designation and occupation, etc. are required in advance, enforcement of river administration powers such as a technical review of the facilities, grant of water use permission to water works

project, etc. are also required. As a reference, there is water use permission limited to rainy season in Japan. The JICA Survey Team positions the enforcement of river administration powers as a part of the water resources development project.

- In the case that environment water is discharged to the Matamuhuri River from the pond, which is one of the river administration functions, the facilities such as the pond, the gate, etc. should be operated by river administrator, i.e. MoWR and BWDB. However, it might be also possible for the project owner of the industrial water works and domestic water and sewerage works to release the environment water as the acting river administrator.

Here, regarding the industrial water works and the domestic water and sewerage works, the JICA Survey team conducts qualitative study on them located in a newly developed area (circled area connected by a pipeline shown in Figure 4.1.6) where large-scale infrastructure development is being implemented in the Moheshkhali/Matarbari region. In particular, the water supply works could be developed as a wide-area water supply project targeting City Corporations and Porshabas in entire beneficiary area (water demand areas) including the Moheshkhali/Matarbari region, but such a study on that is not so principal that the JICA survey team does not consider it.

(2) Object organizations for interview survey

Facilities related to the water resources development project, the industrial water works and the domestic water and sewerage works of the short term alternatives are composed of pomp-type intake, headrace, pond, water treatment plant, water supply pumping station, pipeline and water distribution facilities, etc. The facilities of the long-term alternatives, in addition to those of the short-term alternatives, are composed of dam located upstream of the Matamuhuri River or the Sangu River (the dam upstream of the Sangu River requires a headrace to the Matamuhuri River) and headrace from the Kaptai Dam located upstream of the Karnafuli River to the Matamuhuri River.

The implementing agency in charge of the water resources development projects is the Bangladesh Water Development Board (BWDB) under the Ministry of Water Resources (MoWR). The BWDB has implemented water management covering all rivers which number is about 700 and total length is about 24,140 km long, and all groundwater aquifers, and carried out about 800 irrigation projects over the last 60 years including constructions of water channels and embankments with the total length of 4,425 km and 11,393km, respectively[1].

The major implementing agencies in charge of water supply, sewage and waste treatment, etc. are the Department of Public Health Engineering (DPHE) which number of staff in 2020 was 5,613 and had constructed water supply facilities for about 115,761 thousands people across the country until 2015[2], and Chattogram Water Supply and Sewerage Authority (CWASA), which number of staff in 2016 was 1,048 and total water supplied population was about 60 thousands in 2015[3], under the Local Government

1 Source : Bangladesh Delta Plan 2100, Baseline Studies: Volume 1

2 Source : July, 2021, Project for Improvement of Comprehensive Management Capacity of Department of Public Health Engineering on Water Supply

3 Source : http://ctg-wasa.org.bd/site/page/6b3bf1f6-509f-4ae7-9544-ec25204d9bb4/

Division (LGD), the Ministry of Local Government, Rural Development and Co-operatives (MLGRDC)..

There are other agencies such as the Local Government Engineering Department (LGED) under the LGD and the Bangladesh Agricultural Development Corporation (BADC) under the Ministry of Agriculture (MoA). However, the JICA Survey Team excluded them from the interview survey targets because their irrigation sectors form only a small part of their entire duties and their command areas are small (less than 1,000 ha), and in addition, they have not constructed or managed any dams or any large-scale water supply facilities.

In the beneficiary area, there are City Corporations and many Porshabas that individually carried out water supply services, but they are inappropriate for the project owners over a wide area and conduct water and sewage projects for large-scale industrial areas and urban areas. Since it does not apply to the business entity that develops, it is excluded from the interview target organizations.

The JICA Survey Team conducted the interview survey on the projects and relevant legal systems including the water resources development projects and organizations responsible for industrial and domestic water supply and sewerage works. In addition, the JICA Survey Team included the Water Resources Planning Organization (WARPO) under the MoWR for the survey because WARPO is a dedicated organization to establish macro-level water resources plans and is responsible for management of granting water use permission in Bangladesh.

Based on the above points, the JICA Survey Team set the target organizations for the hearing survey given in Table 4.1.20.

Table 4.1.20 Object Organizations for Interview Survey

	Projects (including legal systems)/Facilities	Target Organizations to be Interviewed
The Short-term Alternatives	☐ Water Resources Development Projects: Execution of River Management Powe.	● Ministry of Water Resources (MoWR) ● Water Resources Planning Organization (WARPO) ● Bangladesh Water Development Board (BWDB)
	☐ Industrial Water and Domestic Water and Sewerage Works: Pomp-type intake, Headrace, Pond, Water Treatment Plant, Water Supply Pumping Station, Pipeline and Water Distribution Facilities, etc.	● Local Government Division (LGD) ● Department of Public Health Engineering (DPHE) ● Water Supply and Sewerage Authority (CWASA)
Long-	☐ Water Resources Development Projects:	● Ministry of Water Resources (MoWR) ● Water Resources Planning Organization (WARPO)

	Projects (including legal systems)/Facilities	Target Organizations to be Interviewed
	Execution of River Management Power, Dam at the Matamuhuri River or the Sangu River with a Headrace, Headrace from the Kaptai Dam at the Karnafuli River to the Matamuhuri River	● Bangladesh Water Development Board (BWDB)
	□ Industrial Water and Domestic Water and Sewerage Works: Pomp-type Intake, Headrace, Expanded Pond, Water Treatment Plant, Water Supply Pumping Station, Pipeline and Water Distribution Facilities, etc.	● Local Government Division (LGD) ● Department of Public Health Engineering (DPHE) ● Water Supply and Sewerage Authority (CWASA)

Note: * The pond is one of water resources development facilities, in the case that it impounds environmental water and other facilities such as a pump-type intake and a headrace are water resources development facilities as well.

Source: JICA Survey Team

The object organizations and dates of the interview survey are compiled in Table 4.1.21

Table 4.1.21 Object Organizations and Dates of Interview Survey

Object Organizations	Date
Ministry of Water Resources (MoWR)	Tue. 30th Nov 2021, Wed. 23rd Mar 2022
Water Resources Planning Organization (WARPO)	Sun. 28th Nov 2021, Tue. 15th Mar 2022
Bangladesh Water Development Board Head Quarters (BWDB-HQ)	Mon. 29th Nov 2021, Tue. 15th Mar 2022
Chattogram O&M Office, Bangladesh Water Development Board (BWDB-CHT)	Mon. 6th Dec 2021, Sun. 20th Mar 2022
Cox'Bazar O&M Office, Bangladesh Water Development Board (BWDB- Cox'Bazar)	Mon. 21st Mar 2022
Local Government Division (LGD)	Wed. 6th Apr 2022, Wed 27th July 2022[4]
Department of Public Health Engineering (DPHE)	Thu. 9th Dec 2021, Sun. 13th Mar 2022, Wed 27th July 2022
Chattogram Water and Sewerage Authority (CWASA)	Sun. 5th Dec 2021, Sun. 20th Mar 2022
Bangladesh Economic Zones Authority (BEZA)[5]	Thu. 2nd Dec 2021

Source: JICA Survey Team

[4] The interview survey was conducted with an officer of the Public Private Partnership Authority: PPPA. He was the same interviewee as one on 6th Apr 2022 who was transferred to PPPA from LGD.

[5] BEZA has ongoing development projects of Economic Zone and Eco Tourism Park in which it is undertaking water supply and sewerage system set-up in Chattogram Division. Thus the interview survey on BEZA's challenges was conducted.

(3) Main subjects for interview survey

Main subjects for the interview survey are as follows;

(i) Alternatives of water sources and development of water use facilities proposed by the JICA Survey Team, and

(ii) Prospective implementing agencies in charge of water resources development and water industrial/domestic supply and sewerage works, and institutions for coordinating stakeholders and monitoring project performance.

(4) Findings in interview survey

The findings of the Survey on the items (i) and (ii) are as stated below.

(i) Answers and comments on alternatives of water sources and development of water use facilities proposed by the JICA Survey Team

【Groundwater utilization】

- The ground water in the area should be the water source for existing water users in the area, but not for a new water demand. A large amount of ground water intake causes drawdown and salinization of groundwater aquifer.

【Use of Kaptai Lake water and construction of new dams】

- As the long-term water demand needs a new dam construction project upstream, the JICA Survey Team should find out a good site for the dam construction. However, it is essential to get all organizations concerned involved in coordinating the project with them to achieve it.
- It is very important to improve the operation of the Kaptai Dam to convert its water used for power generation to municipal water.
- In the interviewee's personal view, the future water demand in the region will not be fulfilled without water supply from the Kaptai Dam. As the amount of hydro-electric power generated by the Kaptai Dam has not been so large, it would be better to convert some portion of the water to the municipal water for the importance of regional development.
- The total water volume of the reservoir has gradually decreased due to sedimentation, and is by no means abundant for local residents. There are many residents around the reservoir and along the Karnafuli River who use the water for themselves, and thus many problems including water scarcity, groundwater salinity, environment damage, etc. would occur by reservoir water intake for the Moheshkhali/Matarbari region.
- Another serious problem pointed out is that communication with ethnic minorities in CHT is very difficult. In the case of drawing water from the reservoir or other rivers, it is necessary to secure the same amount of water as they use at present.
- It is very difficult for water-related ministries and agencies to achieve the conversion of power generation use of the Kaptai Dam into municipal water use by coordinating with BPDB.

- It is essential to get all organizations concerned etc. involved in coordinating the projects proposed by the Survey Team to achieve them. Therefore, the JICA Survey Team should hold meetings with them for explanation and discussion of the survey results.

(ii) Prospective implementing agencies in charge of water resources development and water supply & sewerage works, and institutions for coordinating stakeholders and monitoring project performance

【Prospective Implementing Agencies for Water Resources Development】

- BWDB is eligible for water resources development. However, BWDB is not allowed currently to convey municipal water and cannot operate the Kaptai Dam on behalf of BPDB.
- However, if the construction and operation of a new dam in the Sangu or the Matamuhuri Rivers and water conveyance facilities from the Karnafuli River are positioned as component projects, that is, an overall project is set up composing the components, BWDB can implement by being entrusted with the construction and operation of the facilities from the overall project entity. BWDB was actually entrusted with embankment construction of the relocation site for residents moved from the site of the expansion project of Cox's Bazar Airport.
- On the other hand, it is doubtful whether BWDB is eligible or not for constructing a portion of tunnel headrace, since BWDB has no track record of it.
- It is also doubtful whether BWDB will suit for the construction of a 100-km-long aqueduct or not, because it does not have any experience of too long aqueduct construction.

【Prospective Implementing Agencies for Industrial and Domestic Water Supply and Sewerage Works】

- In general, City Corporation, WASA and Pourashava can be nominated as the organization in charge of water supply and wastewater treatment in their designated urban areas. However, DPHE is eligible to implement that kind of project not only in an urban area but in a rural area except for the WASA jurisdiction area. The Moheshkhali/Matarbari region currently is not under CWASA jurisdiction, and therefore, the project executing agency here should be DPHE.
- If WASA is applied for the Moheshkhali/Matarbari region, a new WASA should be established instead of CWASA.
- It is very difficult to launch a new public organization such as new WASA, since it would take a very long time to get the approval of new organization set up from many related ministries etc. because of complicated procedures.
- CWASA can also develop its projects in the Moheshkhali/Matarbari region based on WASA Act-1996 Article-18 of Chapter-4.

Since there is no official English translation of the WASA Act, the translation made by a local staff of the JICA Survey Team is as follows.

"Chapter 4: Powers and Duties of the Authority

14. *Execution of schemes framed by the Government or agency:* Authority, after approval from the board, and with mutual agreement of both parties, can implement or maintain water supply or sanitation management related scheme which was made before establishment of authority by the government or any corporation or municipality or any other agency."

- Water sources for the development projects of EZ and the eco-tourism park carried out by BEZA across Bangladesh have a matter of concern due to the difficulty in using groundwater, but the actual problem has not yet risen up to the surface since these projects have not been completed and reached the full-scale operation stage yet.
- In October 2015, DPHE and BEZA signed the Memorandum of Understanding on water supply for Bangabandhu Sheikh Mujib Shilpa Nagar (BSMSN) EZ located in the northern part of Chattogram District and the southern part of Feni District and Sherpur EZ in Sylhet District.

The JICA Survey Team asked LGD, DPHE and CWASA if it is possible to employ a concession method under the current legal systems of the water supply and sewerage services. If not, what are the reasons and how to overcome the issue. Here, the concession method means that DPHE or CWASA in this case transfers its managerial prerogative to some private companies etc. including foreign ones during a certain period of time by contact, while it holds a property right of the water supply and sewerage facilities. The responses to the question are as stated below.

- Bangladesh has already adopted the PFI and PPP systems and it is possible to employ the concession method for the project of water supply and sewerage services.
- DPHE and CWASA have applied for participation in the water supply and sewage project in BSMSN EZ being promoted by BEZA, respectively, and in particular, a main frame of CWASA's proposal is to adopt the Korean company by means of the concession method.
- Then, the DPHE proposal was employed as of the moment, however, the Prime Minister's Office is considering to adopt the CWASA's proposal instead of DPHE's because DPHE doesn't have much experience in the water supply services. In the case that CWASA wins the chance to be in charge of, the BSMSN EZ area would be newly designated as CWASA's command area.

【Prospective Institutions for Coordinating Stakeholders and Monitoring Project Performance】

- Eligible institutions are MoWR and LGD.
- There are already many organizations executing projects in the Moheshkhali/Matarbari region and thus, it would be very important to have one comprehensive authority to coordinate their projects. The Prime Minister recently ordered the establishment of "MIDI Authority (supposed to be established)" to properly coordinate the ongoing projects in the Moheshkhali/Matarbari region and the Prime Minister Office is working on its establishment.

- The organizations that are nominated as relevant institutes and stakeholders under the coordination by "MIDI Authority（supposed to be established）" are as enumerated below:
  - National Water Resources Council (NWRC),
  - Deputy Commissioners of Chattogram, Cox'Bazar, Bandarban, Khagrachari and Rangamati Districts,
  - Ministers of Water Resources, Local Government, Rural Development and Cooperatives, Environment and Forests and Shipping,
  - Director Generals of Department of Environment, Water Resources Planning Organization, Bangladesh Water Development Board, Bangladesh Power Development Board, Department of Public Health Engineering and Bangladesh Water Transport Authority,
  - Mayors of Chattogram City Corporation and Cox' Bazar City Corporation, and
  - Heads of Local Governments in Moheshkhali/Matarbari region.

In connection with the coordination with the related organizations and projects mentioned above, the JICA Survey Team showed the interviewees "Japan's experience of IWRM" since the current situation of Bangladesh economy appears to be comparable to the Japan's high economic growth period between 1955 and 1973. Specifically, it is required for Bangladesh to develop the project implementation framework based on the similar law system of the Water Resources Development Promotion Law and the Water Resources Development Corporation Law enacted in 1961 (converted to Japan Water Agency Law in 2002) in Japan.

(5) Proposal for Project Implementation Framework

The proposal for the project implementation framework based on findings of the Survey with the relevant GoB organizations are as follows.

(i) Proposal for candidate implementing agency of water resources development project

- The JICA Survey Team proposes that the water resources be developed for its use on the basis of the Matamuhuri River basin where the water demand area is located and also cover water demand deficit in the long-term prediction by water conveyance from outside river basins. Outlines of the short- and long-term alternatives of the water resources development facilities for domestic, industrial, agricultural and environmental water are the following ;
  - The Short-term Alternatives: Execution of river administration power
  - The Long-term Alternatives: Execution of river administration power, Dam at the Matamuhuri River or the Sangu River with a headrace, Headrace from the Kaptai Dam on the Karnafuli River to the Matamuhuri River

  The eligible organizations for the execution of river administration power are deemed to be WARPO and BWDB and, the organization for construction of these facilities and O&M of the facilities after completion of them is deemed to be BWDB. The grounds are as follows;
  - ☐ WARPO is in charge of granting water use permission.
  - ☐ BWDB has its responsibilities to construct dams, barrages, reservoirs, embankments,

and facilities for water level and discharge adjustment aiming at river training, flood control, drainage, irrigation and drought prevention for all rivers, channels and groundwater aquifers in the country in line with the National Water Policy (NWPo) and National Water Management Plan (NWMP).

- ☐ As already mentioned above, although LGED and BADC are in charge of small scale irrigation projects, their duties and achievements are not enough compared to those of BWDB in view of the large scale water resources development in the Moheshkhali/Matarbari region.
- ☐ As the result of the interview survey, MoWR, WARPO and BWDB itself recommended that BWDB be more suitable for the organization in charge of the water resources development, etc.

- However, the interviewees pointed out some issues.
  - ☐ According to BWDB Act 2000 that stipulates BWDB's responsibilities, BWDB is able to manage irrigation water, but not the municipal water.
    BWDB is not able to perform a roll of the project owner of the water resources development for municipal water use. But it would be possible for BWDB to carry out its project if there would exist a total project owner different from BWDB and it would outsource BWDB the project including the management and O&M after completion. BWDB has an actual achievement to construct embankment to protect relocation area for residents resettled by an enlargement project of Cox' Bazar Airport.
  - ☐ However, it is doubtful if BWDB would be able or not able to construct a headrace tunnel and a headrace over 100 km in length from the viewpoint of BWDB's achievement.
- As for the water intake and conveyance from the Kaptai Dam as one of the long-term alternatives, this could be possible on the premise of water resources development through change of the dam operation, and thus needs understanding and cooperation of BPDB. As result of the interview survey, almost all interviewees have common recognition that the Kaptai Dam reservoir is very important as water origin for the water demand that is expected to rise sharply in the future not only in the Moheshkhali/Matarbari region but also in the total area of Chattogram and Cox' Bazar District.
  - They also have the same view that it is impossible for the water sector to urge the power sector to utilize the Kaptai Dam, and hold high expectations for MIDI Authority's power of arbitration.

(ii) Proposal for candidate implementing agencies of industrial and domestic water and sewage works

- Outlines of the short and long term alternatives of industrial and domestic water and sewage works, although the scale of the water supply varies, are as follows;
  - ☐ Short- and long-term alternatives: Pomp-type intake, Headrace, (Expanded) Pond, Water Treatment Plant, Water Supply Pumping Station, Pipeline and Water Distribution Facilities, etc.

- The DPHE and CWASA are the candidate implementing agencies. The DPHE installs water supply and sewage facilities and implements capacity building to local city and village authorities excluding WASA project areas, but does not provide water supply service itself to water users.
- On the other hand, although CWASA has no experiences in sewerage project at this time, at first, the JICA Survey Team considered CWASA to be a strong candidate because it has constructed purification plants, etc. and it provides water supply services to 155 km^2 of urban areas.
- However, LGD, DPHE and other organizations except for CWASA have the same view that DPHE is the appropriate agency. The reasons are as follows.
  - ☐ DPHE is able to implement its responsibilities throughout the country except for the project areas of WASA (Dhaka, Chattogram, Khulna, and Rashchahi), while CWASA is not able to operate in the Moheshkhali/Matarbari region.
  - ☐ LGD, the competent ministry of CWASA, recognizes that a new WASA would need to be established instead of CWASA if WASA was in charge.
  - ☐ In Bangladesh, it is actually not practical to create not just WASA but also a new organization, because it requires a lot of effort and time to coordinate with related institutions.
- CWASA tells it is possible for CWASA to implement industrial and domestic water supply and sewerage works in the Moheshkhali/Matarbari region. The specific reason is as follows;
  - ☐ In line with WASA Act-1996, CWASA would be eligible for the implementation of the project plan under the condition of approval from CWASA executive board based on mutual agreement among related organizations
- Eventually, CWASA’s implementation is premised on the agreement of related organizations, and this means the eligibility of CWASA is far from adequate.
- Five new WASAs are currently in the process of being created in Borishal, Sylhet, Rangpur, Mymensingh, and Faridpur City Corporation, but these lengthy processes obviously indicate that the establishment of new WASA is very difficult.
- For these reasons, DPHE would be the appropriate agency. However, DPHE's capacity to carry out the project is not sufficient at present, and then the JICA Survey Team asked LGD, DPHE, and CWASA if they could employ a concession method at the stage of service supply after completion of the facility constructions. LGD, DPHE, and CWASA’ answers are as follows.
  - ☐ It is possible to adopt the concession method because Bangladesh has already incorporated PFI and PPP project system.
  - ☐ According to LGD, the EZ project in the northern part of Chattogram Province has received an application from a Korean company to participate in an industrial and domestic water and sewage service project through the concession method.

  Therefore, it was found that the concession method can be adopted to provide services at the operational phase, and DPHE was found to be a possible project entity.
- Depending on CWASA's capability at the time, it would be able to perform a role of developing facilities (construction management) at the construction stage through receipt of order from DPHE

and operation service supply at the operation stage by way of concession from DPHE.

- As described above, CWASA submitted the proposal containing the entrustment of the water supply and sewerage works project to Korean company by the concession method and the Prime Minister's Office is considering to adopt the proposal. According to LGD, DPHE is the appropriate owner of the entire project of the industrial water works and domestic water and sewerage works in the Moheshkhali/Matarbari region as proposed by the JICA Survey Team because CWASA's capacity is too limited to carry out the project in the region.

(iii) Proposals for legal systems for the future project promotion

- A large-scale water resources development project for municipal water supply is the first project for Bangladesh and BWDB as well, and there are many issues to overcome in terms of technology, organization, and legal system, and thus it is urgent to set various challenges to resolve these issues. Based on this situation, the following legal system reforms or establishments should be prioritized.
  - ☐ BWDB currently is able to handle only irrigation water and does not have the authority to handle municipal water. The BWDB Act 2000 needs to be reformed immediately so as to install BWDB the power to handle municipal water.
  - ☐ Water resources development requires river management techniques at low water level during the certain drought term, but BWDB has no experiences of such river water management and does not have such techniques. A law corresponding to Japanese River Act is needed to be enacted for the low water level management and high water management as well, etc. including stipulation of river water occupancy, river area and its occupancy. The rivers in the Chattogram Division are generally similar to the characteristics of Japanese rivers, and it is effective to establish a legal system based on the Japanese River Act.
  - ☐ Coordination with stakeholders in the formation of construction projects and subsequent management operations for both flood control and water utilization are urgent issues, especially the establishment of a legal system, including how to determine the appropriate cost sharing among multiple beneficiaries of projects and operations and to ensure compliance with such decisions.

    Japan, which had experienced severe water shortages in several big cities due to rapid economic growth more than 60 years ago, has an experience in dealing with and overcoming these issues. It would be effective to establish a legal system with reference to the Water Resources Development Promotion Act (1961) and the Water Resources Development Public Corporation Act (1962, now the Water Resources Agency Act (2002)).

- In this interview survey, it was pointed out by the interviewees that the JICA Survey Team should hold a meeting to coordinate the proposed project forwarding with relevant stakeholders. The JICA Survey Team conversely asked them about existing proper organizations for project formulation, coordination, monitoring and evaluation, etc., and several organizations were identified. The JICA Survey Team believes that efforts will be made by Bangladesh to set up the necessary institutions and legal systems, starting with the project implementation in the Moheshkhali/Matarbari region.

4.1.11 Selection of Basic Plan for Water Resources Development in the Short Term

Regarding water resources development plan in a short term for the demand areas of the Moheshkhali/Matarbari region and Chakaria City, several ideas and alternatives of water source and water-use facilities were conceived, compared and evaluated mainly from the following viewpoints, as explained in the foregoing Subsections 4.1.1 to 4.1.6:

- Target year (2026) of development plan in short term,
- Reliabilities of surface water and ground water as future water sources to be developed for the demand areas,
- Preliminary estimates of cost related to water-use facilities construction, and
- Institutional arrangements.

In due consideration of the study outcomes discussed in the said subsections, the development candidate which is to use the Matamuhuri River water as a surface water source and to be composed of the following facilities from a intake site to water demand areas, is selected in the Survey as a basic plan for water resources development in a short term. Table 4.1.22 explains the flow of the said selection.

- Pump type intake: on left river bank 3.6km upstream of Matamuhuri River Bridge on National Highway "N-1" (Chakaria),
- Headrace: Pipeline along Chattogram - Cox's Bazar Highway (under construction) and Matarbari Port Access Road (under planning),
- Regulation pond, water treatment plant and distribution pump station: Palakata area (Cox's Bazar), and
- Distribution pipelines to and distribution facilities in water demand areas.

Table 4.1.22 Work Flow to Formulate Candidate of Basic Short-term Plan for Water Resources Development

Work Items		Notable Outputs
1. Map study	1.1 To set up basic approaches towards alternative plans for water resources development	• The first priority for the short-term development plan is given to the **Matamuhuri River basin** where the Moheshkhali/ Matarbari region (major water demand center) is located.
	1.2 To study availability of surface water in the Matamuhuri River basin to secure water sources for new water demands	• It is essential to temporarily store the rainy season river water into **storage facilities** to provide a stable water supply for demand areas throughout the year.
	1.3 To examine alternatives of water resources development (1) Short term : S1, S2 and S3*	

Table 4.1.22 Work Flow to Formulate Candidate of Basic Short-term Plan for Water Resources Development

Work Items		Notable Outputs
		• Short term : **S1** (**intake** + **regulation pond**)is more feasible than each of S2 and S3.
3.Formulation of alternative plans in short term	To examine alternatives regarding **S1**, incorporating findings from "**2. Field Reconnaissance**"	
	(1) Intake sites and pipeline routes to regulation pond - 2 cases of pipeline routes along "existing and new roads"	• The pipeline route along **new roads** (Chattogram-Cox's Bazar Highway and Matarbari Port Access Road) is preferable from economic and social viewpoints.
	(2) Regulation pond (including "**4. Water Balance Study**") 1) First step : 3 cases with combination of water supply demands	• The regulation pond was roughly located in the **Palakata area**, Cox's Bazar.
	2) Second step : 12 cases** of a) 6 cases with combination of water supply demands "x(times)" b) 2 cases of "with and without ground water use"	• Cases of "**domestic + industrial water supply without ground water use**" are considered to be promising for the highest priority plan.
5. Selection of candidate of basic plan in short term	To select candidate of basic short-term plan, based on the above study outputs	• **Water source** : **Matamuhuri River** water as surface water • **Water-use facilities** : from intake site to water demand areas (1) Pump-type intake (Chakaria) : Left bank of the **Matamuhuri River**, 3.6km upstream of the Matamuhuri River Bridge on "N-1", (2) Headrace : Pipeline along **new roads** (Chattogram-Cox's Bazar Highway and Matarbari Port Access Road), (3) **Regulation pond**, Water treatment plant & Distribution pump station: **Palakata area** (Cox's Bazar), and (4) Distribution pipelines and Distribution facilities

Notes: * See "Sub-section 4.1.1 (4)". ** See "Sub-section 4.1.4 (3)".
Source: JICA Survey Team,

4.2 Recommendation on Improvement Plan of Kaptai Dam Operation

The Kaptai Dam has a vast reservoir capacity of about 200 million m^3 per meter of water depth (near the lowest water level of the dam). By improving dam operation, for example by increasing the water level drawdown by 10 cm as a new water source, it is possible to expect an increase in water resources (storage capacity) of 20 million m^3. Therefore, based on the data and information collected, the following dam operation improvement plan is preliminarily studied and proposed.

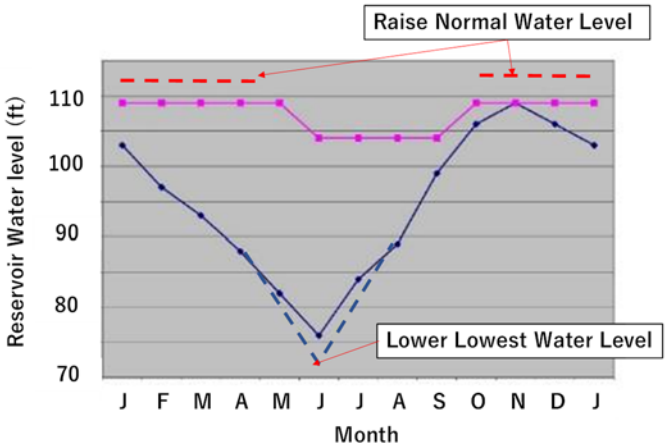
4.2.1 Study on Dam Operation Rule

(1) General

Figure 4.2.1 shows an example of examining the rule curve for dam operation. A study is carried out concerning the applicability of the following ideas;

i) To secure a new water source development capacity in the reservoir by increasing its drawdown range by lowering the minimum water level or rising the normal one, and

ii) To reallocate the existing water storage capacity by expanding the discharge facilities or introducing pre-release procedure.



Source: JICA Survey Team

Figure 4.2.1 Study on Kaptai Dam Operation Rule (Example)

Concerning the idea i), it is necessary to confirm the negative impact on reservoir-side residents due to water level increase and the intake structure due to lowering the minimum water level (designed minimum depth above the intake, sediment suction, etc.). As for the idea ii), any existence of inundation in the past due to dam release and the river channel flow capacity need to be confirmed so as to evaluate impacts on the downstream.

(2) Methodology

The possibility of water resources development (increase in dam discharge during the dry season) is examined by changing the rule curve with reference to the past dam operation data of the Kaptai Dam. At the same time, the impact on the change of power generation is roughly evaluated.

(3) Basic Conditions

1) Collected Data

The basic data and information of the Kaptai Dam collected through the survey are presented below:

- Water Level (WL): Daily WL (1990, 2003-2011, 2019-20) and Hourly WL (1991-2002, 2012-18),
- Discharge (Q): Daily turbine discharge (m^3/s) and spillway discharge (m^3/s),
- Evapotranspiration (mm) and rainfall (mm) of the Rangamati station, and

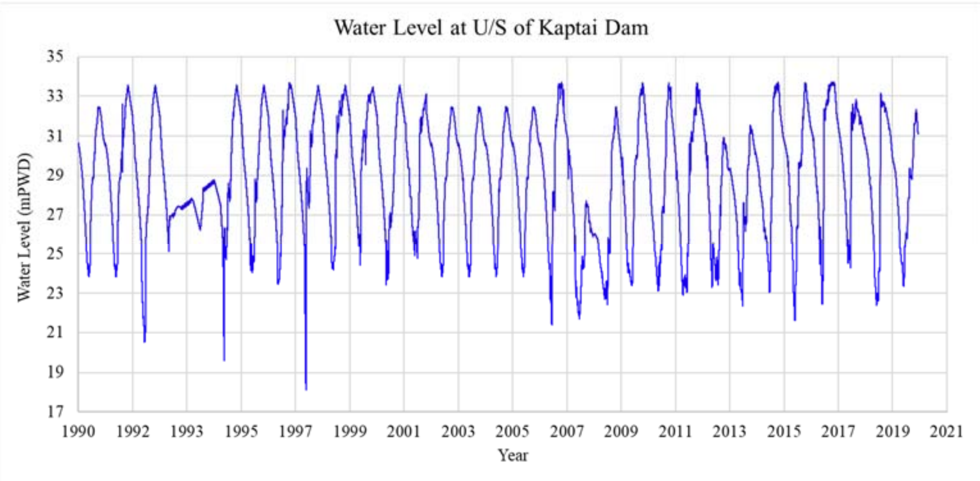
- Elevation-Storage Curve (Social Impact Assessment (SIA) study for Kaptai Hydro Electric Power Plant Extension Project (6th and 7th Units)).

2) Reservoir Water Level

The BPDB maintains a water level gauge station at the upstream side of the Kaptai Dam, as shown in Figure 4.2.2. Water level data for the station is available from 1991 to 2020, as shown in Figure 4.2.3.

Source: JICA Survey Team

Figure 4.2.2 Kaptai Water Level Gauge Station at Upstream of Kaptai Dam

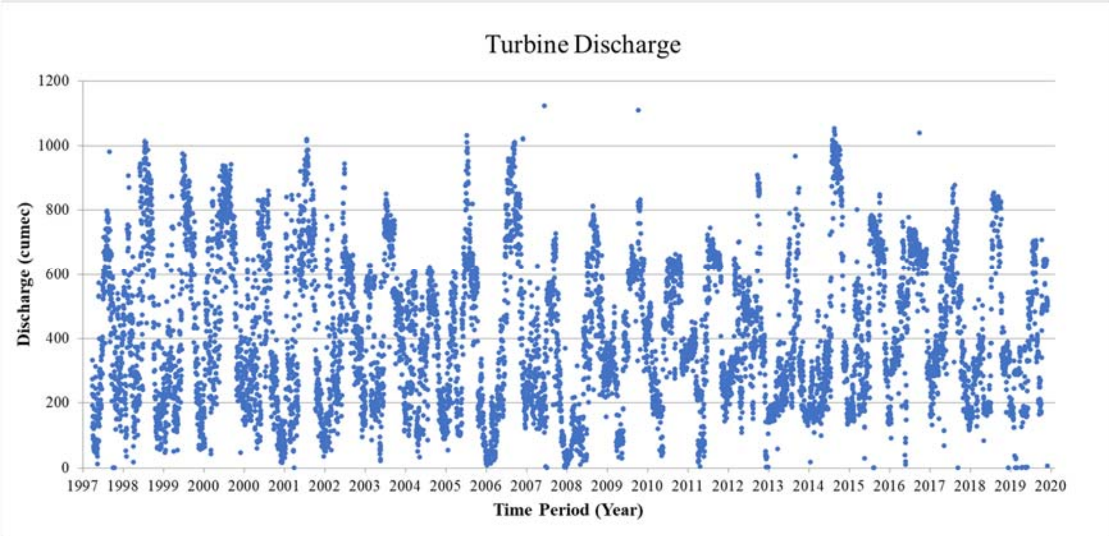


Source: BPDB data

Figure 4.2.3 Water Level Data of Kaptai Lake

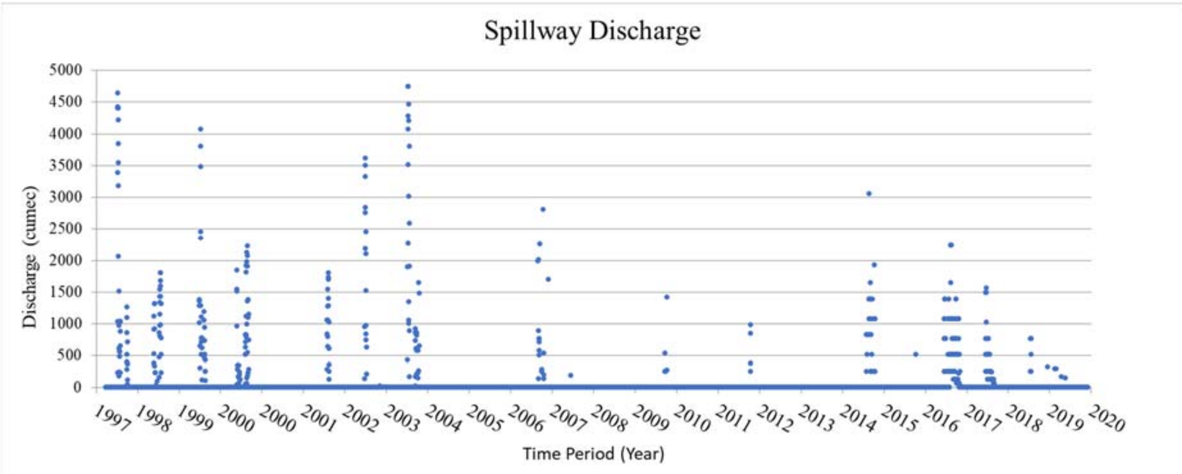
3) Turbine discharge and spillway discharge

The BPDB maintains the record of discharge through the turbine and spillways of the Kaptai Dam, as shown in **Figure 4.2.4.**



Source: BPDB data

Figure 4.2.4 Turbine Discharge of Kaptai Dam



Source: BPDB data

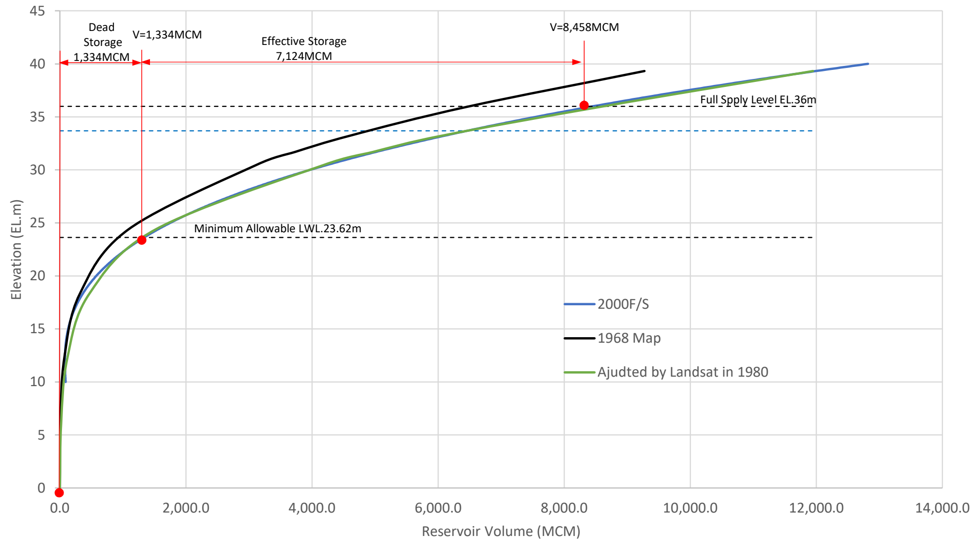
Figure 4.2.5 Spillout Discharge of Kaptai Dam

4) Reservoir storage capacity curve

The reservoir storage capacity curves of the Kaptai Reservoir established in 1968 Study and 2000 F/S are presented in Figure 4.2.6.

In 1980, the reservoir storage capacity was re-evaluated using LANDSAT photographs and power plant operation records. As a result, it was found that the reservoir surface area was slightly larger than the value calculated from the map created in 1968. It was also found that the effective storage capacity had hardly changed since 1968. From these results, it was considered that the amount of sedimentation in the reservoir above the minimum water level was very small and did not affect the effective capacity of the reservoir.

As shown in the following subsection, even in the latest bathymetric survey results, no significant progress of sedimentation in the reservoir has been confirmed. Detailed data on dam reservoir capacity needs to be investigated in the future, but in this survey, based on the above situations, the reservoir capacity curve is adopted with reference to the 2000 data as below.



Source: 2000F/S

Figure 4.2.6 Elevation- Storage Curves of Kaptai Reservoir

5) Calculation of dam inflow

The dam inflow data from 1969 to 1997 is summarized in the 2000 F/S. As for the data after 1997, since there is no observation data of the dam inflow, it is calculated by the following formula referring to the collected data of the reservoir water level fluctuation, turbine discharge, spillway discharge, and evapotranspiration.

i) Reservoir storage corresponding to daily WL (8:00 AM) = S1

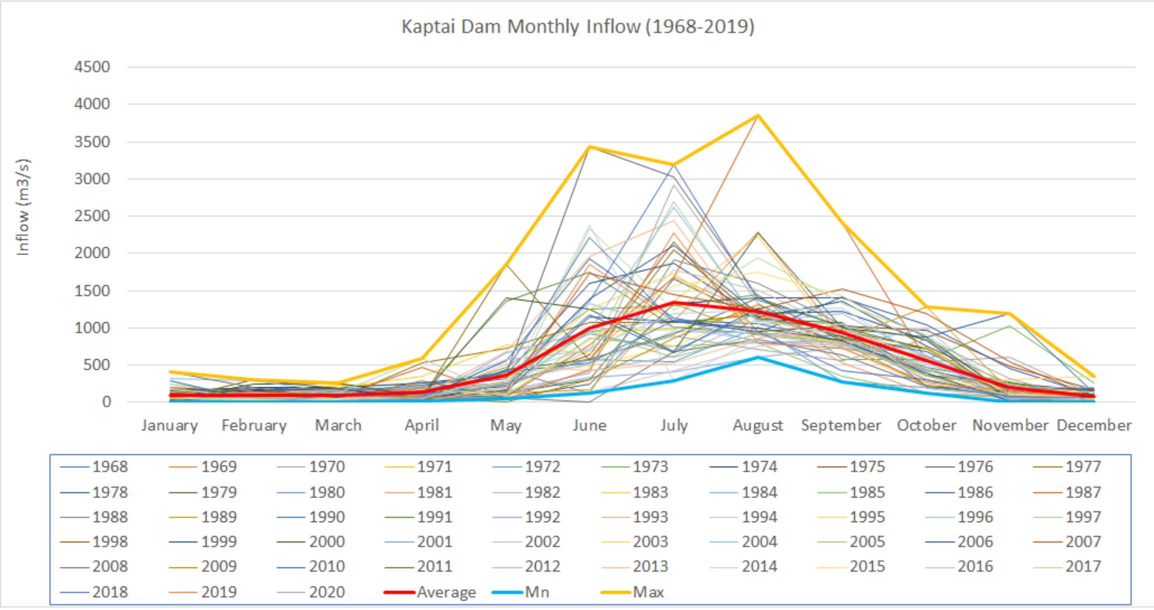
ii) Reservoir storage corresponding to following day WL (8:00 AM) = S2

iii) Change of storage, Δs (m^3) =S2-S1 (may be positive or negative)

iv) Evapotranspiration loss, ΔET (m^3) = ETo * Surface area

v) Daily inflow to reservoir, Qinflow (m^3) = Turbine discharge (m^3) + Spillway discharge (m^3) + Δs (m^3) + ΔET (m^3)

Based on the above, the calculated dam inflow data from 1969 to 2019 is presented in Figure 4.2.7.

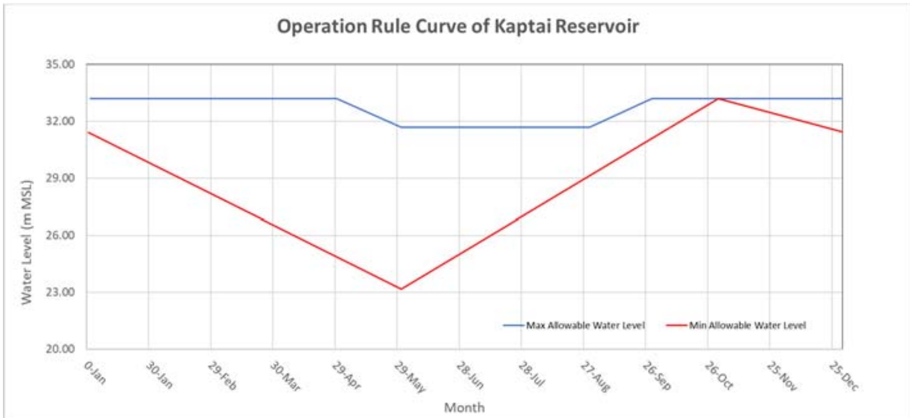


Source: JICA Survey Team

Figure 4.2.7 Calculated Dam Inflow to Kaptai Dam

6) Operation rule curve

In the Kaptai Dam, the operation rule curve has been revised once. The one collected this time is referred to in this study.



Source: BPDB

Figure 4.2.8 Operation Rule Curve of Kaptai Dam

(4) Procedures of reservoir operation simulation

Reservoir operation simulation is carried out applying the following procedures used for the Kaptai Dam power generation simulation in the 2000 F/S. The monthly dam outflow discharge and power generation are calculated, as stated below.

i) Dam inflow (Qin(t)) for the month is obtained from the monthly dam inflow data during the above period.

ii) Dam outflow discharge (Qout(t)) for the month is calculated applying the rule curve.

iii) If the dam outflow discharge calculated in (ii) exceeds the designed maximum turbine discharge (Qpmax), the excess water volume is stored in the reservoir and the dam outflow discharge is corrected to the Qpmax. In case the calculated dam outflow discharge is less than zero, the dam discharge is corrected to 0.

iv) Reservoir water level of the following month (RWL (t+1)) is calculated from the above-mentioned dam inflow (Qin (t)) and outflow (Qout (t)), reservoir water level data (RWL (t)) for the month., and H-V curve data

v) If the reservoir water level for the following month exceeds the elevation of the spillway crest, the spillway discharge is calculated, and the reservoir water level is corrected to the elevation of the spillway crest level.

vi) Power generation amount (P(t)) for the month is calculated based on the above dam outflow (turbine discharge), reservoir water level and effective head and power generation efficiency which can be converted from them.

(5) Result of reservoir operation simulation

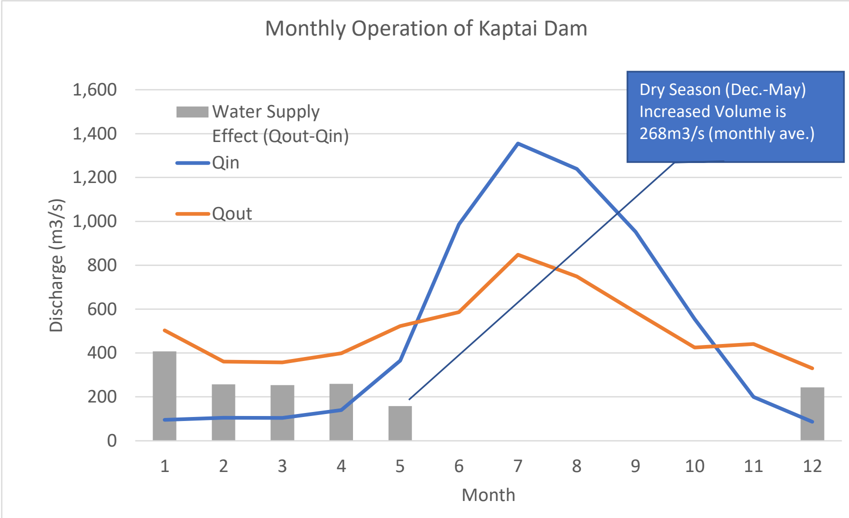
1) Present Condition（Case 0）

As the result of simulation under the present operation rule curve, obtained are dam inflow, dam outflow (turbine discharge), regulated discharge by the dam in the dry season (difference between dam outflow and dam inflow) and power generation, as shown below.

Figure 4.2.1 Result of Reservoir Operation Simulation under Present Operation Rule Curve

Month	Dam Inflow	Power Discharge	Regulated Discharge by Dam in Dry Season	Power Generation
	(m^3/s)	(m^3/s)	(m^3/s)	(GWh)
Jan.	96	503	407	83
Feb.	104	361	257	50
Mar.	104	357	253	51
Apr.	139	399	259	51
May	365	523	158	62
Jun.	987	586	—	62
Jul.	1,356	848	—	111
Aug.	1,239	749	—	114
Sep.	952	586	—	96
Oct.	555	425	—	75
Nov.	200	440	240	76
Dec.	87	330	244	57
Average	515	509	260	74
Total	-	-	-	887

Source: JICA Survey Team



Source: JICA Survey Team

Figure 4.2.9 Result of Reservoir Operation Simulation under Present Operation Rule Curve

2) Case Study of Revised Operation Rule Curve

In order to meet the future increase in water demands, the following two cases are examined as revised operation rule curves to increase the dry season regulated discharge by the Kaptai Dam.

(Case 1) Minimum reservoir water level of the rule curve is lowered by 1 m

(Case 2) Minimum reservoir water level of the rule curve is lowered by 2 m

As an alternative case, " to raise the maximum reservoir water level of the rule curve", which was originally considered, is conceivable. However, in the process of data collection in this survey, it was confirmed that (i) a hydraulic impact by backwater on the drainage and (ii) a negative social impact on land use in the surrounding areas of reservoir in connection with the raising of reservoir water level. Taking into account such impacts, this case is not considered in this comparative study.

3) Results of simulation of each case

The simulation result of each case is presented in Table 4.2.2and Annex 4.2-1.

Table 4.2.2 Result of Reservoir Operation Simulation under Revised Operation Rule Curve

Item	Unit	Present	Case 1	Case 2	Case 1 (diff.)	Case 2 (diff.)
Annual dam inflow	m^3/s	515.2	515.2	515.2	0.0	0.0
Annual dam outflow	m^3/s	509.0	509.6	510.1	0.6	1.1
Regulated discharge in dry season	m^3/s	263.1	268.8	272.2	5.7	9.1
Annual power generation	GWh	887.4	887.2	847.3	-0.2	-40.1

Source: JICA Survey Team

The increase in regulated discharge in the dry season (from December to May) is about 5.7 m^3 /s in Case 1 and about 9.1 m^3/ s in Case 2. By lowering the lowest water level of the rule curve, additional water resources development can be expected.

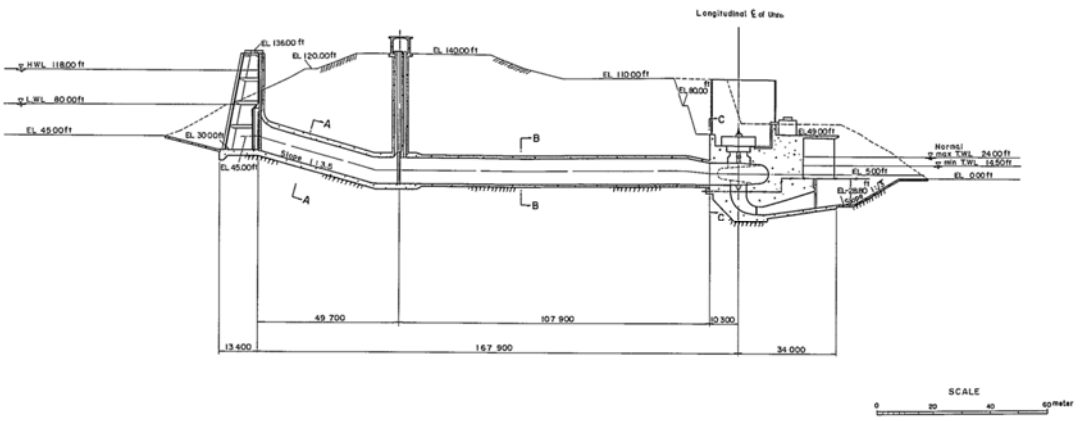
On the other hand, regarding the impact on hydroelectric power generation at the Kaptai Dam, the effective head would decrease by lowering the lowest level of dam operation, but the amount of water used for power generation would increase, thereby the respective effects would be offset and the extent of the impact would be small. As a result, Case 1 reduces the current annual power generation by 0.2GWh, and Case 2 reduces it by 40.1Gwh.

(6) Study of intake structure in case of lowering the low water level

The longitudinal section of the waterway of the Kaptai Dam is shown in Figure 4.2.10. The current low water level (LWL) is set at EL.24.38m. Compared to the current minimum water level, the covered water depth above the waterway at the intake is about 7.89m. If the LWL is lowered by 1 to 2 m due to change in dam operation, the covered water depth would be 5.89 to 6.89 m, but the design conditions required for the design of the pressure type intake (cover water depth ≥ waterway inner diameter (2.77 m)) are still satisfied.

However, it is to be considered if the hydraulic conditions and effect of sediment suction of the intake would be affected due to the change in the LWL. It is recommended to carry out a detailed bathymetric survey and hydraulic model test to examine in front of the intake, as required.

Lowe Water Level	(LWL)	24.38	EL.m	
Bed Level of Waterway	(Elb)	13.72	EL.m	
Diameter of Waterway	(D)	2.77	m	
Covered Water Depth	(hd)	7.89	m	LWL-Elb-D ≧ D



Source: 1980JICA F/S

Figure 4.2.10 Longitudinal Section of Kaptai Dam Waterway

(7) Plan to reallocate existing storage capacity by improving spillway structures and introducing pre-releasing

Regarding the plan to reallocate the existing storage capacity by improving the spillway structures and lowering the controlled water level by pre-releasing, the existing water storage area of the Kaptai Dam is huge and the water level reduction effect is small.

Although the flood control effect of the Kaptai Dam has not been quantitatively evaluated in the original development plan, its natural flood control effect is considerably high owing to its vast water storage capacity. The Kaptai Dam plays a very important role of flood discharge mitigation in the lower reaches of the Karnafuli River.

4.2.2 Confirmation of Present Sedimentation Situation and Study on Necessity of Countermeasure against Sedimentation

It was reported that there was almost no decrease in effective storage between 1962-1980 in the JICA study in 1980. However, it is said that sedimentation in the Kaptai Reservoir has progressed, and the storage capacity has greatly decreased recently.

During the period for collection of basic information, the latest reservoir sedimentation was confirmed based on the simple survey by the sub-contracted local consultant, as discussed hereunder.

(1) Existing Data of Reservoir Sedimentation

1) Original Plan

As shown in “Subsection 3.2.2”, the sedimentation storage capacity of the Kaptai Dam is 11.26 m PWD or less. This capacity is 1,800 x MCM.

2) Review of 1980F/S

The relation curve between reservoir water level, reservoir area and storage capacity of the Kaptai Reservoir was established in 1968. Then, JICA Study in 1980 evaluated the reservoir storage capacity using LANDSAT photographs and power plant operation records.

As a result, it was found that the reservoir surface area was slightly larger than the value calculated from the map created in 1968. It was also found that the effective storage capacity had hardly changed since 1968. From these results, it was considered that the amount of sedimentation in the reservoir above the minimum water level was very small and did not affect the effective capacity of the reservoir.

However, it is needed to clarify the current state of the reservoir sedimentation by bathymetric survey to measure the actual thickness of sedimentation.

In addition, it is said that the effective capacity can be secured much safely in the future for the following reasons.

- The riverbed slope of the Karnafuli River is as gentle as 1/10,000. Since its flow velocity is generally very slow, erosion on the riverbed and banks of the river rarely occurs.
- Most of the upstream basin of the Karnafuli River is gently sloping and covered with jungle, and there is no high mountain near the river. In such conditions, it can be said that the entire basin forms a stable terrain.
- This area is located over a typical monsoon zone, and after a long geological transition, it has formed a local terrain that can withstand harsh weather conditions. Therefore, there will be less sedimentation in the reservoir that affect the generation of electricity in the future.

3) Review of 2000F/S

The Kaptai Dam project was commissioned in 1962 with units 1 and 2 and the life period was assessed between 272 – 300 years. The estimated silt load was considered 1000 ppm with a 50% addition of bed load. The dry unit weight of settled deposit was assumed to be 60 pounds per cubic feet (0.961 tons/m^3) referring to Report on 2000 F/S Siltation Survey of Kaptai Reservoir, 2000.

The sedimentation survey near Kaptai and Rangamati was carried out in 1978, 1980, 1983, 1986 and 2000. Most of the reports are not properly documented and available. The report on the sedimentation survey carried out in 2000 has been collected from the KHPP Authority. In the report, the sedimentation conditions of 1983, 1986 and 2000 have been calculated and compared. The cause of sedimentation has been apprehended as follows:

- Rain washed silt carried by rainwater from huge catchment area,
- Erosion from reservoir banks, and
- Landslide in the adjoining hills.

However, detailed sedimentation survey in the main reservoir and fringe areas was not ultimately executed. It was said in the report that quantification of sedimentation under this circumstance without proper measurement was very difficult and would not be the true reflection of real situation.

In addition to this, the social impact assessment (SIA) study for Kaptai Hydro Electric Power Plant Extension Project (6^{th}/7th Units) in 2000 reported that considerable sedimentation occurred in the reservoir particularly in the northern areas. A sedimentation survey conducted by BWDB for BPDB in 2000 showed that 222,000 cft (62,782m^3) of sedimentation occurred between 1983 and 2000 in this area.

(2) Reservoir sedimentation data collected by subcontracting works

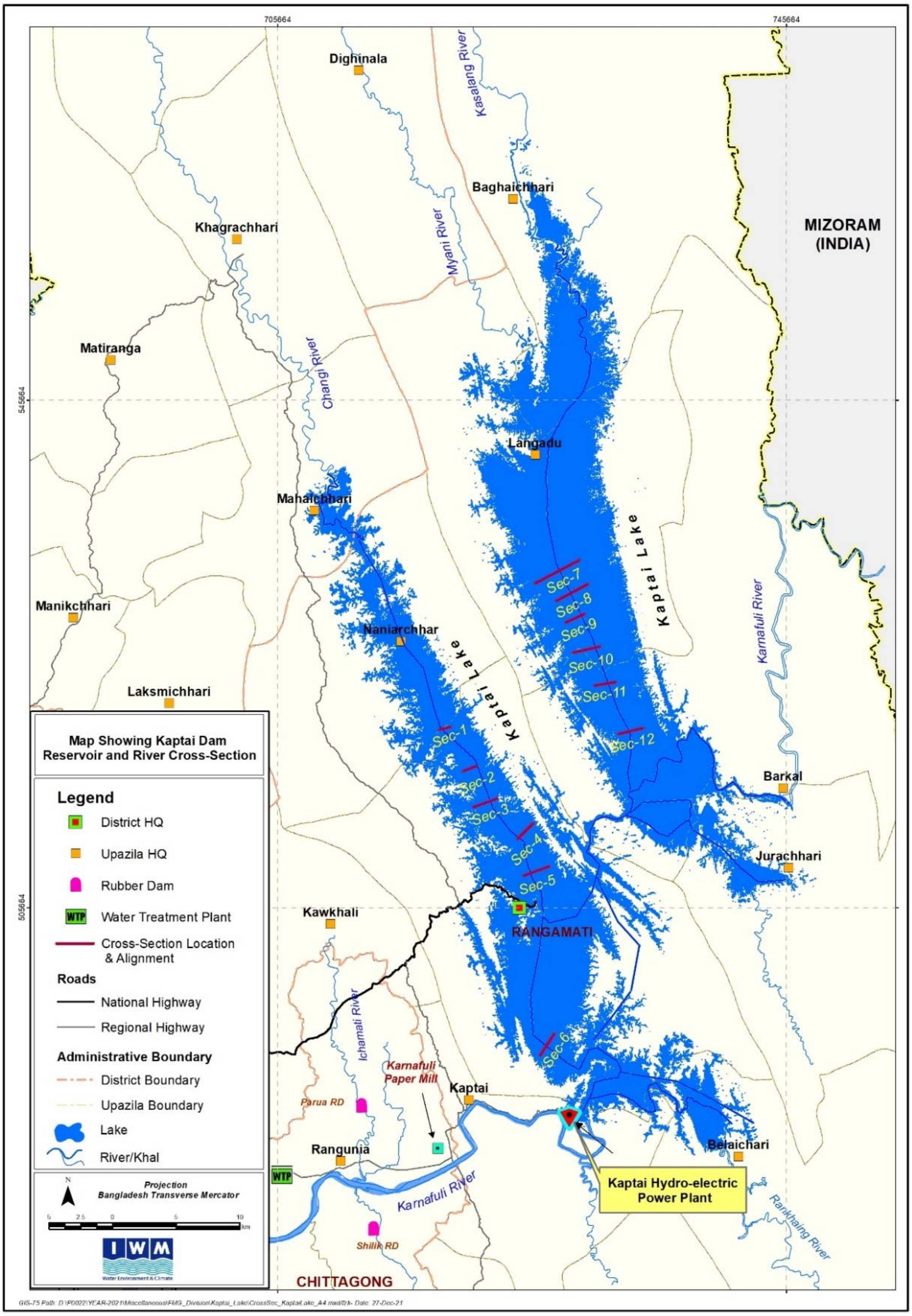
The following reservoir bathymetric survey data of the Kaptai Reservoir were collected through the subcontracting work.

- Results of bathymetric survey (12 survey lines) in 2012
- Results of bathymetric survey (12 survey lines) in 2019 (for same cross sections of 2012 survey)

The locations of the cross sections and their alignments are shown in Figure 4.2.11. Comparison of the cross sections is shown in Figures 4.2.12 and 4.2.13.

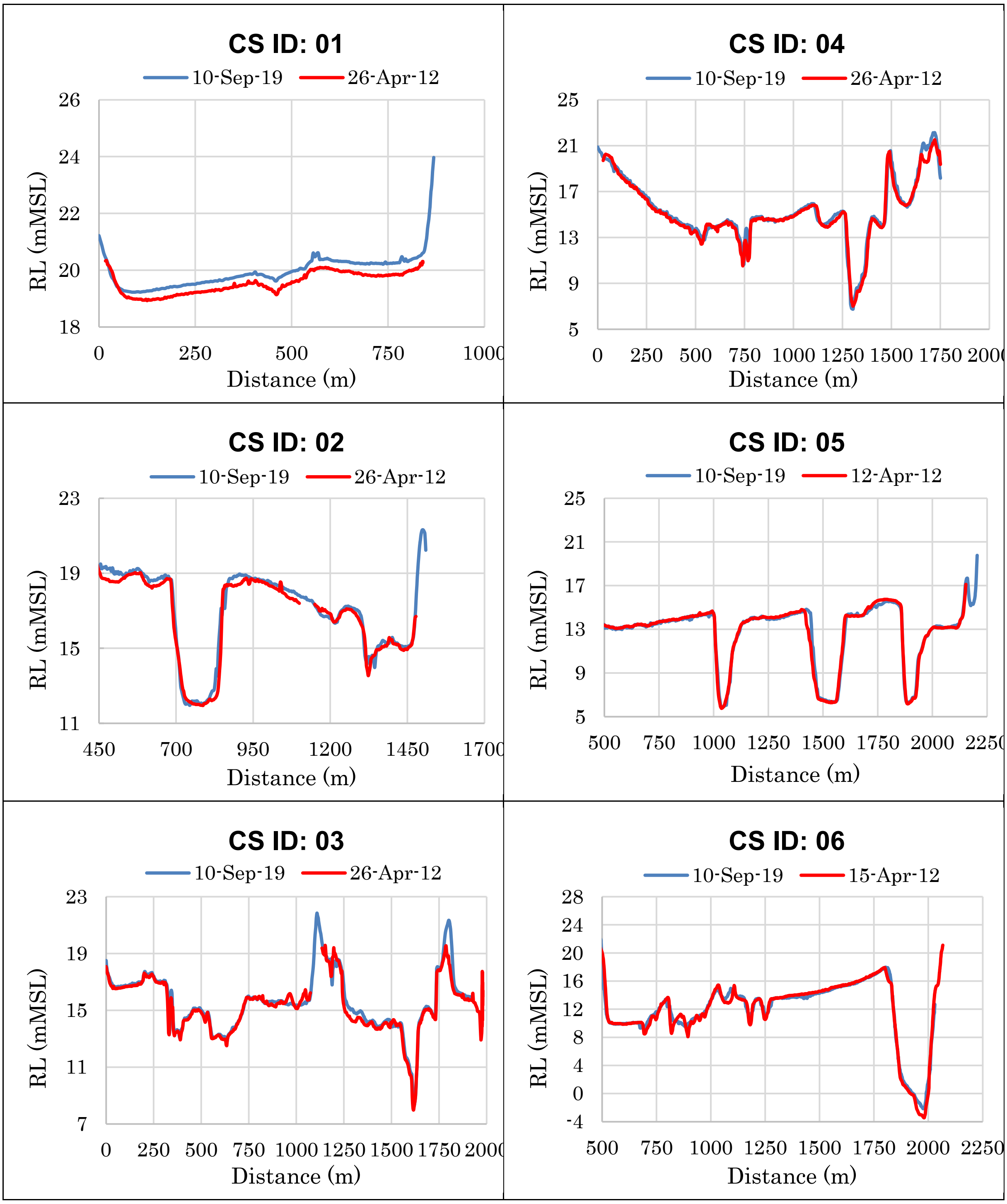
These surveys were carried out in the central part of the reservoir, but no progress of sedimentation was observed in the cross sections other than the upstream section (CS-ID01).

Therefore, as described above, although sedimentation is partially progressing in the fringe area of the reservoir, the progress rate of sedimentation is considered to be slow in the central part of the reservoir. It is estimated that the reservoir effective storage for power generation and water resource utilization would not be affected by sedimentation for the time being.



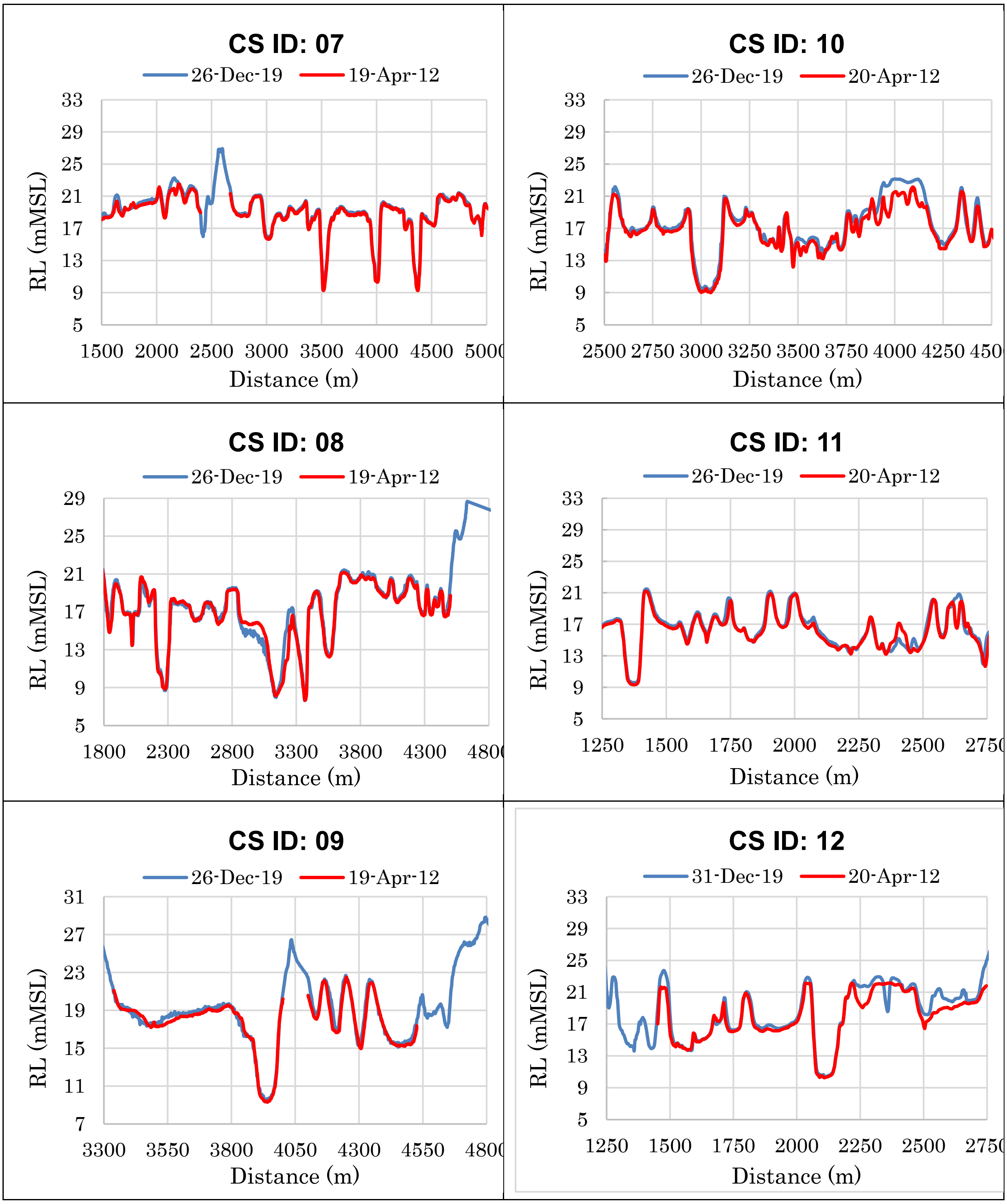
Source: JICA Survey Team

Figure 4.2.11 Location Map of Bathymetric Survey



Source: JICA Survey Team

Figure 4.2.12 Comparison of Surveyed Reservoir Cross Sections between 2012 and 2019 (1/2)



Source: JICA Survey Team

Figure 4.2.13 Comparison of Surveyed Reservoir Cross Sections between 2012 and 2019 (2/2)

4.3 Preliminary Study on Recommended Water Resources Development Options

4.3.1 Formulation of Alternative Plans for Long-term Water Resources Development

(1) Approach for study for long term plan

As mentioned in “Sub-section 4.1.1”, it is confirmed that there is a shortage for water supply to the Moheshkhali/Matarbari region, comparing with the present water resources potential in the Matamuhuri River basin. The development policy is to aim at water resources management which takes one river basin as a basic unit for the integrated water resources management in accordance with the philosophy of integrated water resources management. The first priority for the development is given to the Matamuhuri River basin where the Moheshkhali/Matarbari region is located.

On the other hand, there would be some restrictions to develop water resources in the Matamuhuri River basin due to social and environmental issues. Therefore, inter-basin water transfer from the Karnafuli and the Sangu River basins to the Matamuhuri River basin is also to be considered as phased development of water sources.

Following premises are considered for alternative study on the long-term plan:

- There is a shortage for water supply to the Moheshkhali/Matarbari region, comparing with the present water resources potential in the Matamuhuri River basin.
- For the short-term plan, the aforementioned water resources development plan by the pond is applied.
- Based on the water balance analysis including the short-term plan, the shortage of the long-term plan is calculated, through which the development scale is determined.

(2) Setting of long-term alternatives

Based on the above-mentioned approach, the following four (4) alternatives are established for the long term measures.

<Plan to supply water demands with self-water potential in the Matamuhuri River basin>

- M1; short-term alternative (S1) + pond expansion
- M2-1; short-term alternative (S1) + dam/reservoir in the Matamuhuri River basin

<Plan of inter-basin water transfer>

- M2-2; short-term alternative (S1) + dam/reservoir in the Sangu River basin
- M3; inter-basin water transfer alternative (Lake Kaptai water supply pipeline)

The long-term alternatives are to satisfy the required water demands by increasing the water storage capacity of the short-term alternative or by inter-basin water transfer from other river basins. The advantages and disadvantages of each alternative are shown in Table 4.3.1.

Table 4.3.1 Long Term Alternatives

Number	M1	M2-1	M2-2	M3
Alternatives	Pond Expansion	Dam construction on Matamuhuri River	Dam construction on Sangu River	Kaptai Dam Pipeline
Features	• Expansion pond will be constructed on the soft ground of the floodplain adjacent to short term pond. • The expansion pond will secure 173.7MCM in addition to the short term volume of 16 MCM. • Raw water is conveyed to a Pond after being taken at an additional river pumping station. • The water purification plant will be constructed adjacent to the pond and pumped to the demand area. • It is expected that the issues such as compensation for the floodplains, measures for soft ground, and measures for pond water quality.	• Secure the shortage volume for the long term demand by a dam construction on the Matamuhuri River. • By using dam outlet, to discharge the demand amount to the river. • The discharged water will be pumped at S1 intake and conveyed to the water purification plant. • It is expected that the issues such as relocation of inundation villages, road replacement, and environmental conservation.	• Secure the shortage volume for the long-term demand by a dam construction on the Sangu River. • Basi structures are same as M2-1 • In case of Sangu River dam, the intake point assumed to be "Dahazari" Bridge. However, the pumping distance from the intake to the W.T.P is approx.58km. Therefore, the pumping running cost is high[*1]. • It is proposed that the short cut route from the Sangu River to the Matamuhuri River by waterway tunnel than “Dohazari route”.	• Using the reservoir of the existing Kaptai Dam on the Karnafuli River. • The water will convey to the demand area by pipeline from Kaptai Dam. • A pressure-type intake will be constructed at Kaptai Dam, and non-pressure water will be conveyed approx. 95 km to the right bank Matamuhuri water purification plant (W.T.P). • It is expected the following issues such as; ✓ The establishment of a 100km canal route ✓ Securing of the land ✓ Whether or not the dam operation rules could be changed due to the addition of unspecified water supply business to the existing electric power business.

Note: *1 Refer to **Annex 4.3-1**

Source; JICA Survey Team

As mentioned in “Sub-section 4.1.4”, "Seawater desalination plan", "Groundwater utilization plan" and “Water demand management plan” are considered as supplemental measures.

- For "Seawater desalination plan", it is expected to need large scale facilities to meet the short term demand, and it is assumed that it would be difficult to implement the water supply project by “Seawater desalination plan” only. This is treated as supplemental measures in the case of local and small scale water demands.
- For "Groundwater utilization plan", currently there is a policy where groundwater use is to be limited in Bangladesh, and there are many uncertainties about its potential for the time being. The groundwater is treated as supplemental measure in the case of local and small scale water demands.
- For “Water demand management plan”, it can be implemented with main structural measures. This is treated as supplemental measures.

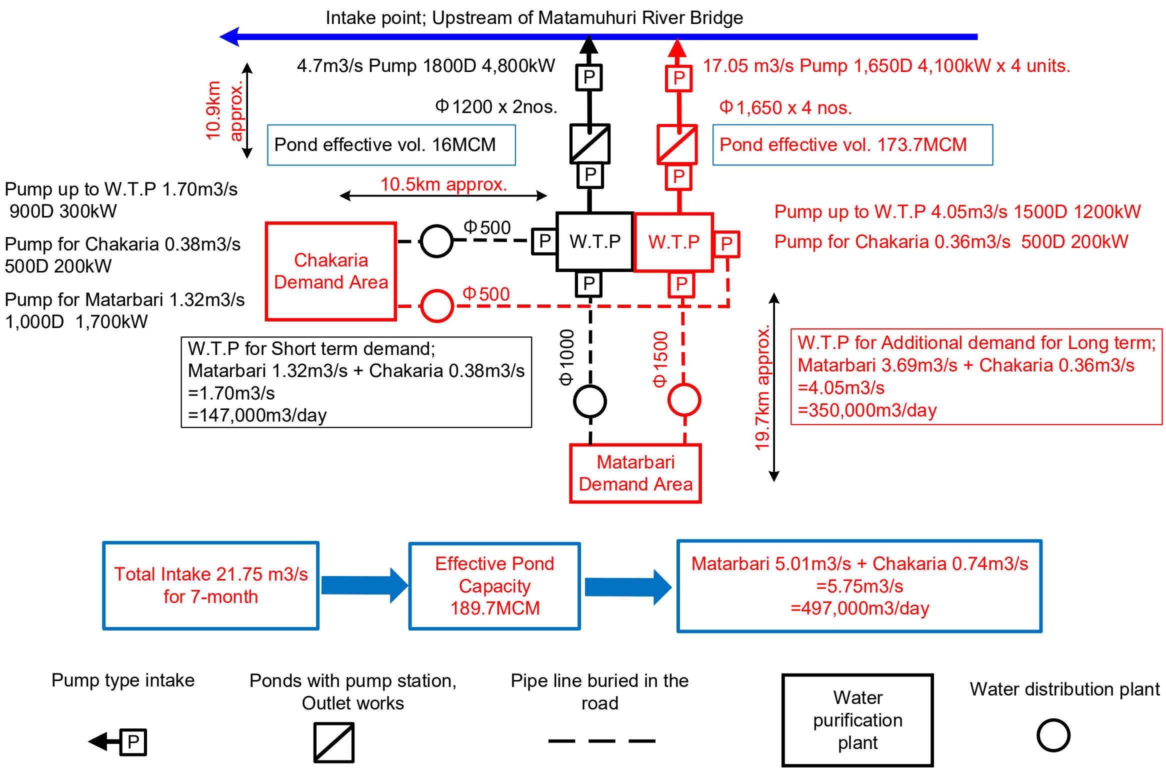
(3) Map study for long term alternatives

The long-term alternatives aim to satisfy the water demand by “Expanding short-term pond (M1)”, “Short-term pond+ Dam/reservoir (M2-1, M2-2), and/or “Kaptai Dam Pipeline (M3; existing lake water conveyance to demand area by pipeline)”.

The map study was conducted by obtaining information of land use, aerial photographs, topographic conditions from Google Earth. Regarding dam candidate sites, careful attention was given to the residential houses, land use, and rare species.

1) Pond expansion plan (M1)

The schematic diagram for pond expansion plan is shown in Figure 4.3.1.



Source: JICA Survey Team

Figure 4.3.1 Expansion of Pond Plan for Long-term Water Demands

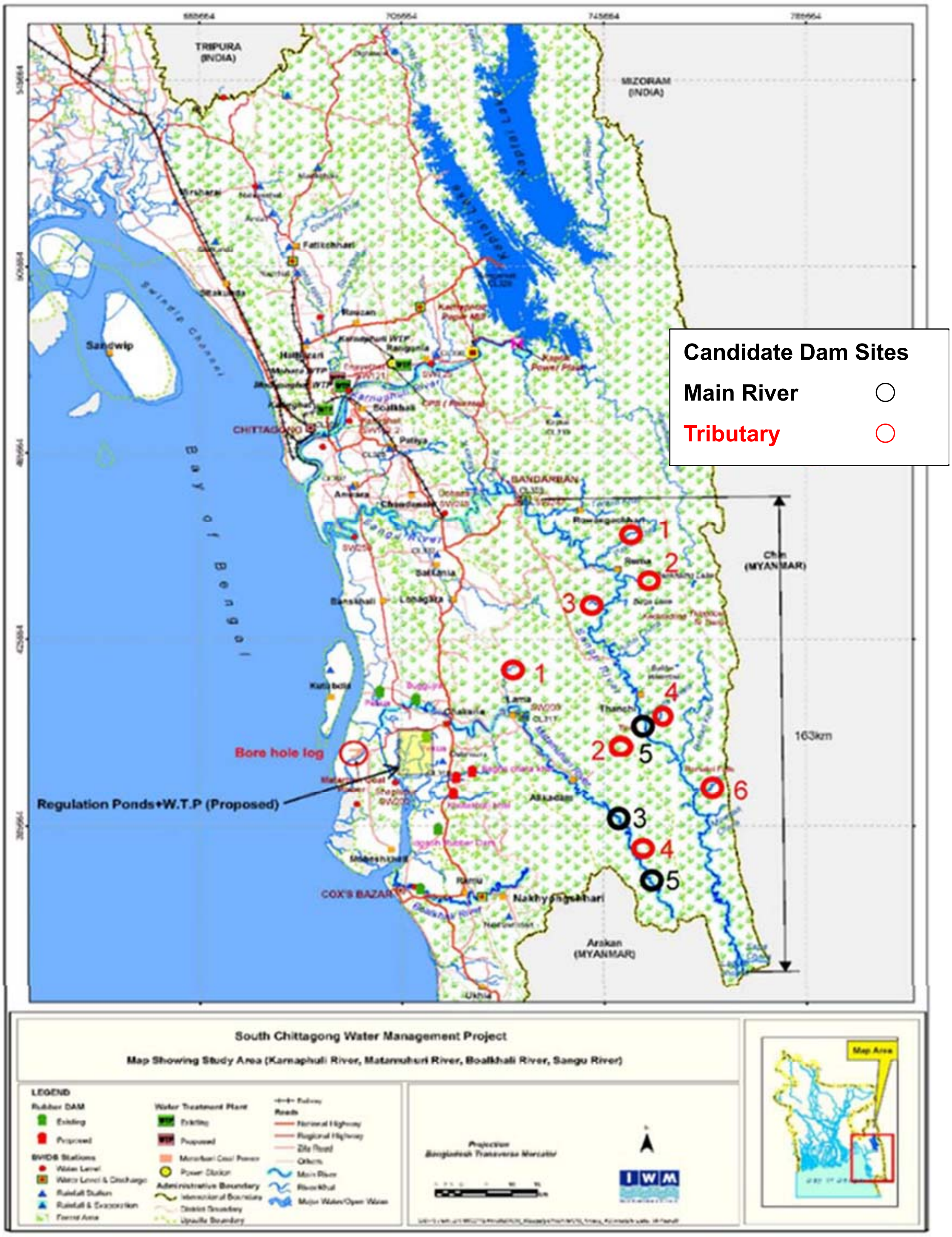
2) Dam/reservoir plan (M2-1, M2-2)

(a) Candidate dam sites

The candidate sites of the dams in the Matamuhuri and Sang River basins are shown in Figure 4.3.2. The dams are examined as water utilization dams with no flood control capacity in careful consideration of the following, among others:

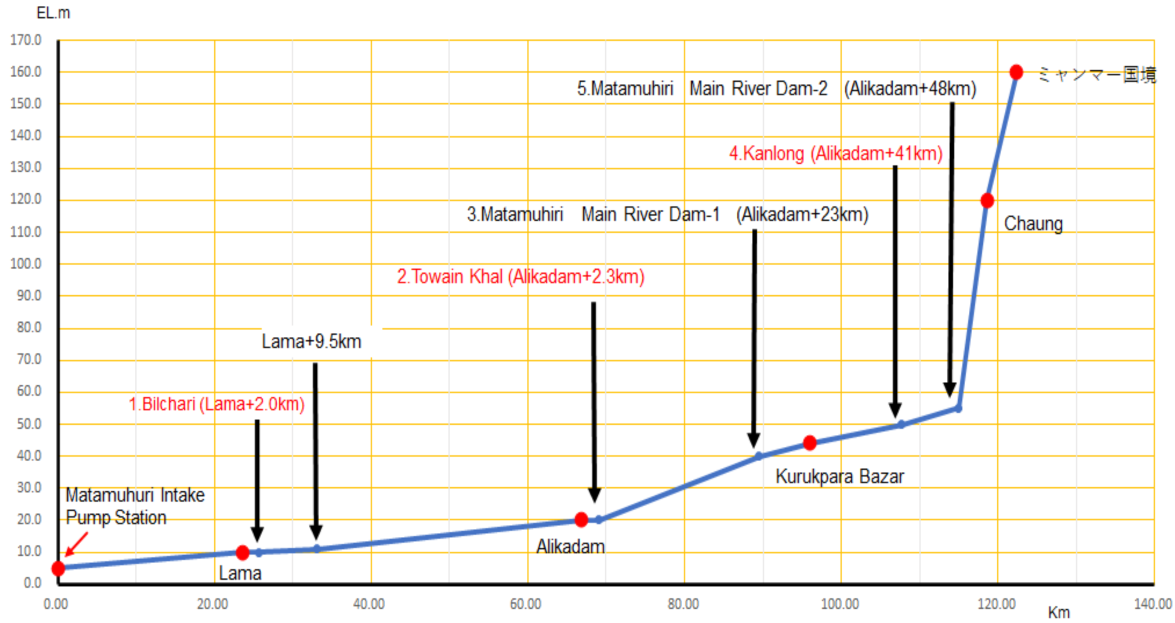
- Maintaining river functions before construction of dam,
- Operation of reservoir water release during floods based on weather information in the river basin so as to minimize negative impacts in the downstream areas, and

- Measures to minimize environmental changes, land acquisition, resettlement areas, etc.



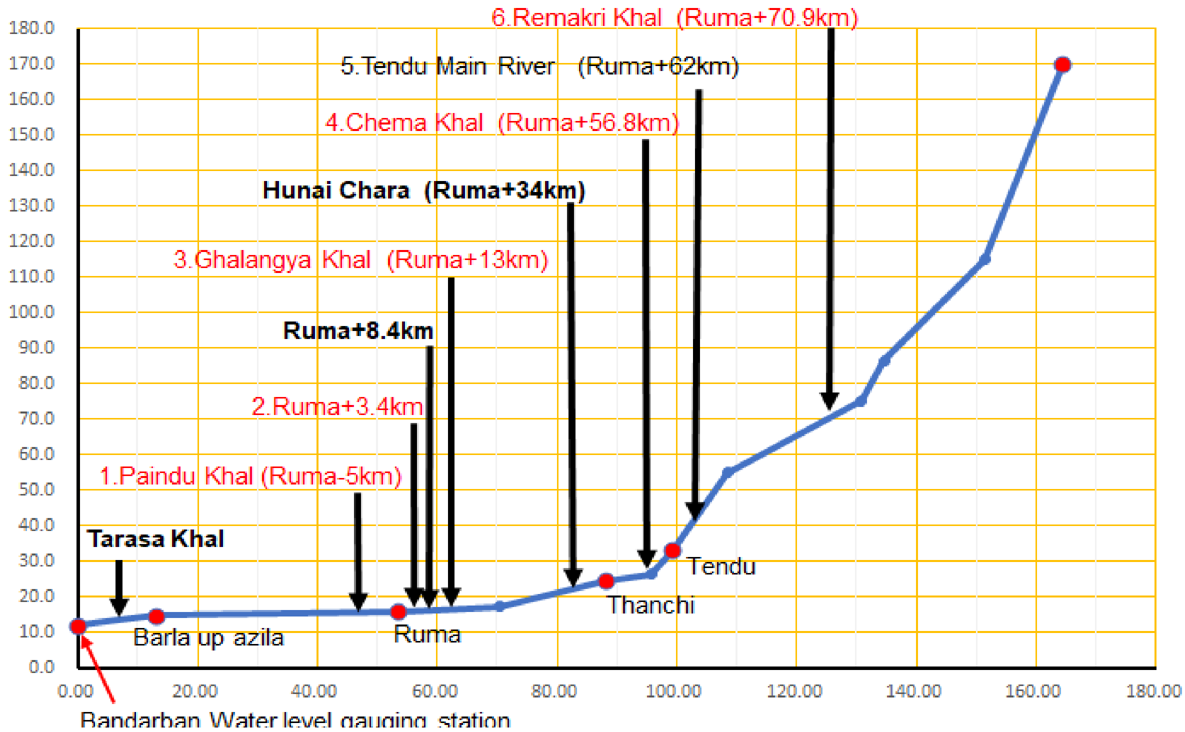
Source: JICA Survey Team   Note:The numbers at the circles correspond to those in the next figures.

Figure 4.3.2   Candidate Dam Sites on Matamuhuri and Sangu River Basins



Source: JICA Survey Team

Figure 4.3.3 Matamuhuri River Profile (Upstream of Matamuhuri Bridge)



Source: JICA Survey Team, Note: See Figure-4.3.2 for the dam site numbers.

Figure 4.3.4 Sangu River Profile (Upstream of Bandarban Water Level Gauging Station)

(b) Proposed candidate dam sites

The alternative dam sites in the Matamuhuri and Sangu River basins are shown in Tables 4.3.2 and 4.3.3, which were compared in terms of catchment area, distribution of settlements, reserve efficiency, and capacity to reserve water.

As the result, the following 4 dam sites are proposed.

- Matamuhuri River basin: - Main River Dam-1 Bit Phar (3), - Main Dam-2 (5)
- Sangu River basin: - Ghalangya Khal (3), - Chema Khal (4)

Table 4.3.2 Comparison of Dam Sites in Matamuhuri River Basin

Items		Matamuhiri River Basin					
		Bilchari	Upstream Lama	Upstream Alikadam			
Tributary, Location, and Riverbed elevation (Refer; Figure 4.1.10)		Lama+2km	Lama +9.5km	2.3km	41km	23km	48km
		Right tributary River bed EL.45(at dam site)	Right tributary EL.20 (at tributary junction)	Right tributary Towain Khal EL.40(at dam site)	Right tributary Kanlong EL.50(at dam site)	Main River Dam-1 Bit Phar EL.40(at dam site)	Main River Dam-2 8km to Myanmar border EL.50 (at dam site)
Distribution of Villages Existence of dam site [*1]		**No dam site** (Villages continuous in upstream 33km section) **Dam site available** (Villages scatted upstream of the above section) Village EL.50～60 approx.)	**No dam site** (Villages EL.20~100 continuous to the end of the tributary, The existing road may inundate)	**No dam site** (Approx. 17km upstream of the tributary, there is no reservoir terrain) **Dam site available** (At the upstream of tributary junction, The villages scatted on right tributary tributary)	**Dam site available** (The villages scatted in upstream tributary at EL.65.80.90. 115)	**Dam site available** (The villages scatted in upstream tributary at EL.40.45.50.55.60.65.100.130.150)	**Dam site available** (The villages scatted in upstream tributary at El.55,65,70,80,90,100,120)
Figure for Distribution of Villages (Google Earth)		Figure 3.3.1 (Figure shows in appendix)	Figure 3.4.1	Figure 3.5.1	Figure 3.6.1	Figure 3.1.1	Figure 3.2.1
Catchment Area[*2] C.A (km^2)		11.4	----	96.3	33.0	328	128
Approx. Dam Volume[*2] V (MCM)		1.36		0.13	0.42	0.11	0.15
Reserve Efficiency [*2] α=Reserve amount / V		57		592	183	700	513
Assumed storage capacity during drought[*3] (MCM)		7	----	63	22	213	83
Assumed storage capacity in normal stage season[*3] (MCM)		14	----	116	40	397	155
Dam site Evaluation	Villages inundation	Occur △	----	Occur △	Occur △	Occur △	Occur △
	Reserve Efficiency	Bad ×		Medium ○	Medium △	Good ○	Good ○
	Ability to reserve water	Low ×		Medium △	Low ×	Heigh ○	Medium △
Proposed dam site for Matamuhuri River basin (draft)		● **In technical viewpoints, Main River Dam-1 Bit Phar (Alikadam+23km) , Main River Dam-2 (Alikadam+48km) is recommended.** ● Due to the large catchment area, ability to reserve water may [Good]. ● However, village inundation occurs same as the other tributaries.					

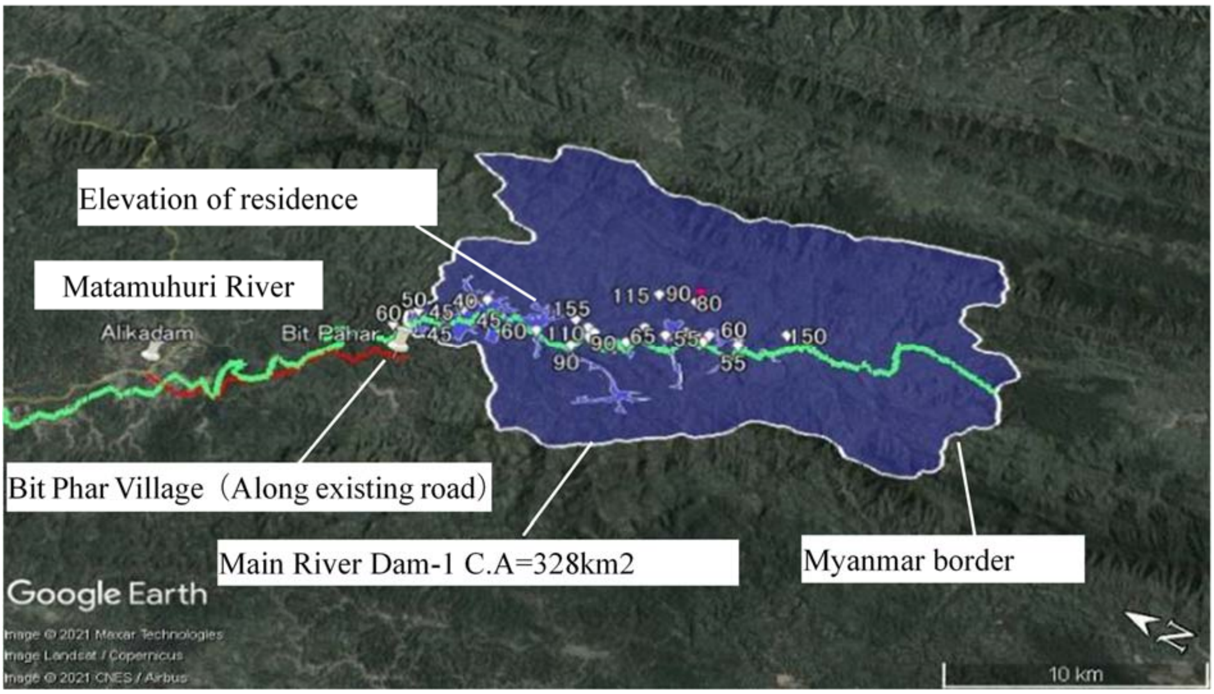
Source: JICA Survey Team

Table 4.3.3 Comparison of Dam Sites in Sangu River Basin

Items	Sangu River Basin								
	Tarasa Khal	Paindu Khal	Upstream Ruma			Humai Chara	Humai Chara 上流		Tendu
Tributary, Location, and Riverbed elevation (Refer; Figure 4.1.11)	Badraban +8.1km	Ruma -5.0km	3.4km	8.4km	13km	Ruma +34km	Ruma +56.8km	Ruma +70.9km	Ruma +62km
	Right tributary EL.10 (at tributary junction)	Right tributary EL.40 (at dam site)	Right tributary EL.72 (at dam site)	Right tributary EL.17 (at tributary junction)	Left tributary Ghalangya Khal EL.22 (at dam site)	Right tributary EL.40 (at tributary junction)	Right tributary Chema Khal EL.40 (at dam site)	Right tributary Remakri Khal EL.60 (at dam site)	Main river EL.40 (at dam site)
Distribution of Villages Existence of dam site *1	**No dam site** (Villages continuous to the end of the tributary	**No dam site** (Villages of EL.40 under scattered upstream 10km of the tributary) **Dam site available** (No villages from 10km to the end of the tributary)	**No dam site** (Villages of EL.70 under scattered upstream 10km of the tributary) **Dam site available** (No villages from 10km to the end of the tributary)	**No dam site** (Villages scattered EL.30,60,120,140 ,200)	**Dam site available** (Villages scattered at EL.46, 87, 105, 148,159)	**No dam site** (Villages EL.40~190 continuous to the end of the tributary)	**Dam site available** (Villages scattered at EL.55,60,95,150, 220,250, Houses scattered at EL.57,65,100~106,130)	**Dam site available** (Villages at EL.100 scattered in the left tributary. Villages at EL.80~160 scattered in right tributary.)	**Dam site available** (Villages scattered upstream of the sit e. And [Remakri] should not be inundated.)
Figure for Distribution of Villages (Google Earth figure shows in Appendix)	Figure 3.9.1	Figure 3.9.1	Figure 3.10.1	Figure 3.11.1	Figure 3.12.1	Figure 3.13.1	Figure 3.14.1	Figure 3.15.1	Figure 3.7.1
Catchment Area*2 C.A (km^2)	----	62	26.4	----	26.7	----	59	193.8	500
Approx. Dam Volume*2 V (MCM)		1.00	2.30		0.20		0.17	0.44	----
Reserve Efficiency *2 α=Reserve amount / V		77	33		385		453	175	----
Assumed storage capacity during drought*3 (MCM)	----	40	17	----	17	----	38	126	325
Assumed storage capacity in normal stage season*3 (MCM)	----	75	32	----	32	----	71	234	604
Dam site Evaluation: Villages Inundation	----	Occur △	Occur △	----	Occur △	----	Occur △	Occur △	The storage capacity is limited in 18 MCM due to avoiding inundation of Remakri.
Dam site Evaluation: Reserve Efficiency		Bad ×	Bad ×		Good ○		Good ○	Medium ○	
Dam site Evaluation: Ability to reserve water		Medium △	Low ×		Low ×		Medium △	Medium △	
Proposed dam site for Sangu River basin (draft)	● **In technical viewpoints, Ghalangya Khal（Ruma+13km）, Chema Khal(Ruma+56.8km) is recommended.** ● The above sites, ability to reserve water may be [Low] however, it is expected to be shared with short term facilities for long term demand. ● It is proposed that the conveyance water from Sangu river to Matamuhiri river is recommend the shortcut route by the tunnel waterway.								

*1 Villages and roads visible on Google Earth
*2 C.A; Catchment area, V; Dam volume (Approx. vol. having 70MCM effective water storage（million m^3）)
α ; Reserve efficiency= Effective water storage / Dam Vol.
*3 Ability to reserve water; Comparison of the following possible storage capacity to required volume
Possible storage capacity in drought=0.65m x C.A(km^2)
Possible storage capacity in normal season=1.209m x C.A(km^2)
Source: JICA Survey Team

Among the candidate dam sites, the mainstream dam candidate site near Bit Phar on the Matamuhuri River is shown below.



Source: JICA Survey Team

Figure 4.3.5 Matamuhuri Main River Dam-1: Catchment Area and Distribution of Residences

3) Kaptai Dam pipeline（M3）

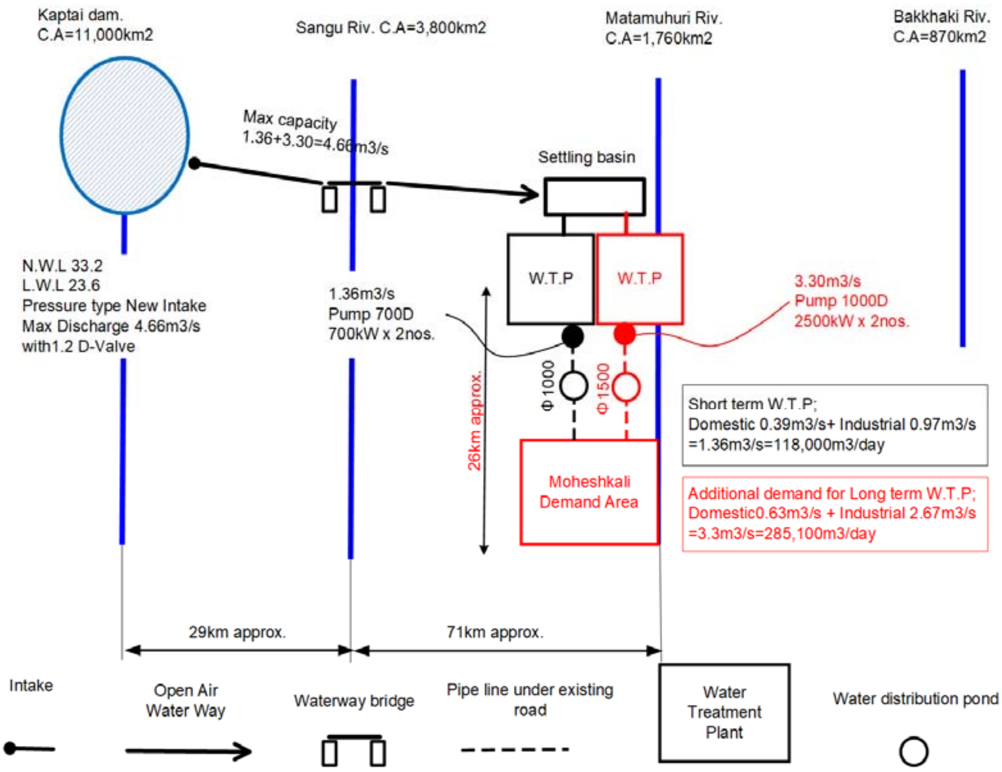
This alternative is expected to use the water under L.W.L (23.60m) at the existing Kaptai Dam reservoir by changing the current reservoir operation rule. The non-pressure water is conveyed approx. 95.93km to the W.T.P near Chakaria by an open channel from the Kaptai Dam.

The waterway configuration is as follows.

- A pressure type intake is provided at the Kaptai Dam.
- The amount of water 4.66 m^3/s (total demand of domestic and industrial water in long term) is conveyed with an open channel.
- Open channel; concrete lining 3.0 Bx2.0 H, side slope1:3.0, gradient=1/6,300, L=92.87 km
- Tunnel (NATM); 4.0 B x 3.0 H, L=2.0 km in total
- Waterway bridge; Pipe beam bridge 2.8 D, L=1.06 km in total
- Water treatment plant (W.T.P); Matamuhuri River right bank (adjacent to Road N-1)
- W.T.P to demand area; approx. 26km pumped pipeline under existing road (short term: 1.0m D, long term: 1.5m D)

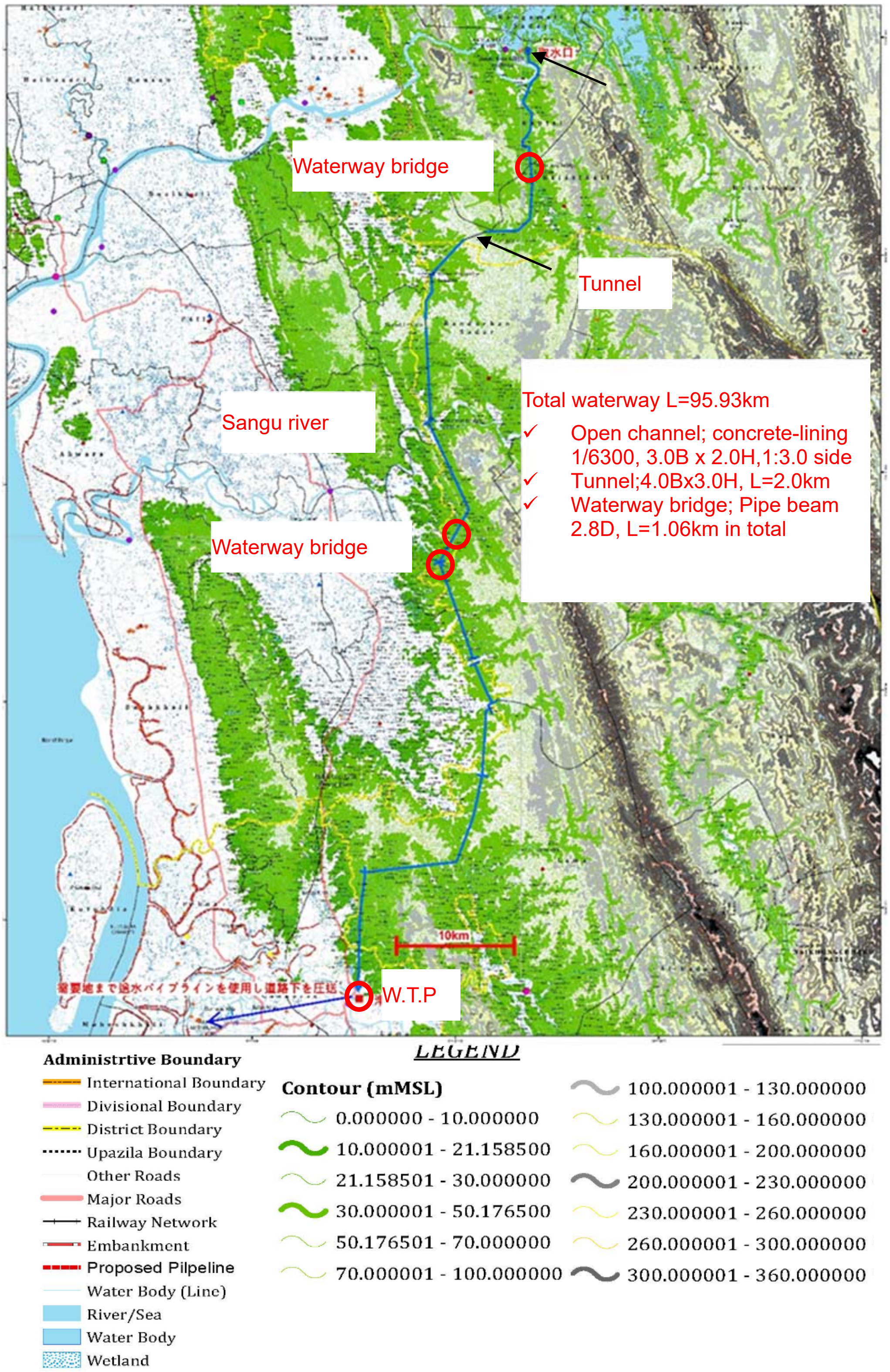
Notes;
The open channel water way shall pass through the EL.20m~10m zones (green color zones in Figure 4.3.7). The water way route is subject to change due to the site conditions. In the case

where the non-pressure waterway route could not be found, the route and the facilities should be changed for a pressure type waterway.



Source: JICA Survey Team

Figure 4.3.6 Water Conveyance Plan from Kaptai Dam



Source; JICA Survey Team

Figure 4.3.7 Map Study on Kaptai Dam Pipeline

(4) 1st Screening of long-term alternatives

In order to select the options subject to the water balance analysis in "Sub-section 4.3.2", the preliminary evaluation (1st screening) was made based on the preliminary study in term of feasibility of cost, social, environmental, and technical aspects.

Table 4.3.4 Primary Evaluation of Long-term Alternatives Based on Map Study

Long-term alternatives	M1	M2-1	M2-2	M3
Features	Expansion short-term Pond	Dam construction in Matamuhuri River	Dam construction in Sangu River	Water Conveyance from Kaptai Dam
Major facilities (Short-term plan)	・Pond：Effective vol.16 MCM、Area in F.S.L320 ha ・Intake：Design amount 4.7 m^3/s ・Water Treatment Plant：Plant capacity1.7 m^3/s ・Headrace, Tailrace length (km)：Intake ~ Pond 10.9 km、 Pond ~ Matarbari demand area 19.7 km、 Pond ~ Chakaria demand area 10.5 km			
Major facilities (Additional facilities for long-term demand)	・Expansion pond ・Expansion of water treatment plant ・Expansion pipe line	・Dam reservoir ・Expansion of water treatment plant ・Expansion pipe line	・Headrace tunnel（Sangu ~ Matamuhuri River basin 21 km） ・Dam reservoir ・Expansion of water treatment plant ・Expansion pipe line	Headrace waterway (Kaptai Dam ~Matamuhuri 95km) ・Dam reservoir ・Expansion of water treatment plant ・Expansion pipe line
Technical aspect	◎	◎	○ Long length headrace tunnel could be constructed technically	○ Long length waterway could be constructed technically
Cost ratio	2.5 （there is a cost issues for headrace, tailrace）	1.0＋α （compensation, land for related to dam are issues）	1.1＋α （compensation, land for related to dam are issues）	1.3＋α （there is o cost issues for long water way）
Environmental aspect	△	△	△	△
Social aspect	○ Land acquisition & resettlement for pond construction	○ Land acquisition & resettlement for dam/reservoir construction	△ Land acquisition & resettlement for dam/reservoir & headrace waterway construction (Large)	△ Land acquisition for headrace waterway construction (Large)
Integrated water management	◎ Self-basin development	◎ Self-basin development	△ Need to conduct water from outside the basin	△ Need to conduct water from outside the basin
Primary evaluation (for water balance calculation)	Adopt	Adopt	Adopt	Not Adopted (The cost including the compensation at the site is large)

Source: JICA Survey Team

As the result of evaluation, M1, M2-1, and M2-2 are selected as the options for the water balance analysis of the long term plan in "Subsection 4.3.2".

(5) Basic specifications for long-term alternatives

Basic specifications for long-term alternatives are determined by the results of water balance analysis as compiled in Table 4.3.5.

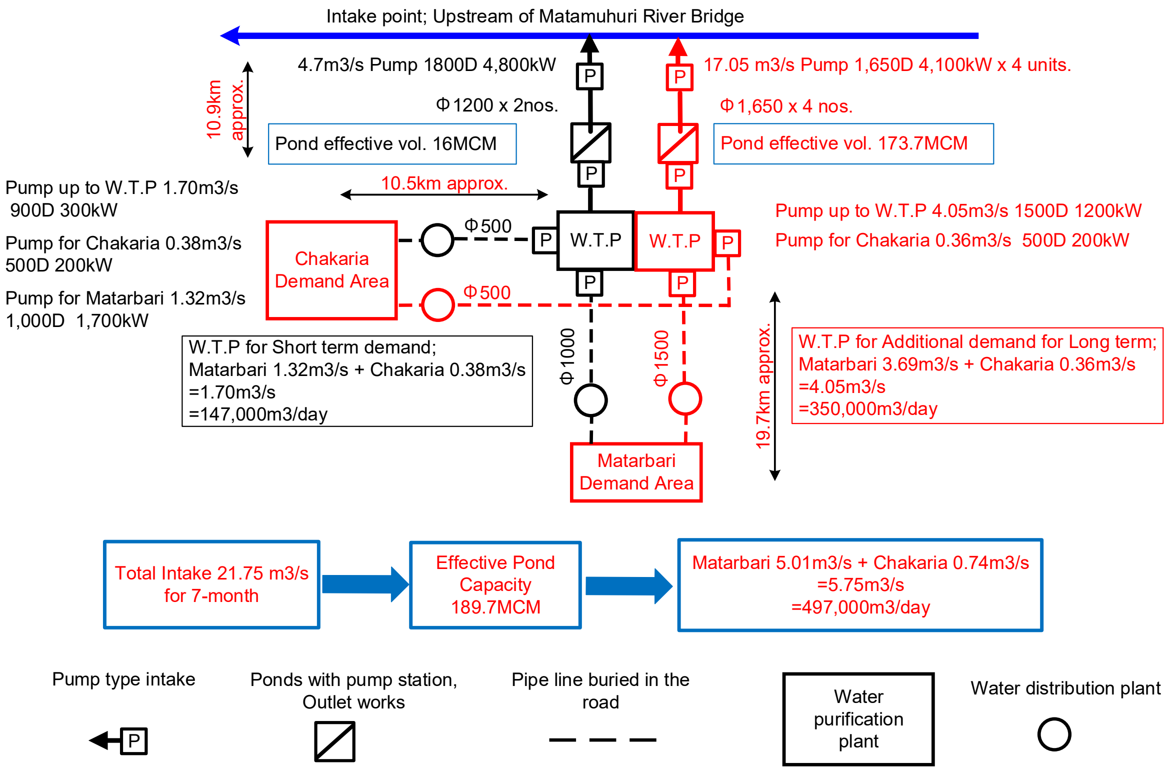
1) Expansion Pond（M1）

Table 4.3.5 Basic Specifications of Expansion Pond

Items		Contents		Remarks
		Short-term Plan	Long-term Plan	
1. Intake	Location	Upstream of Matamuhuri Bridge≒3.6km		
	Type	Pressure type		Non pressure type intake may require checking of social cost.
	Amount	4.7 m³/s	17.05 m³/s	
	Intake level	L.W.L 3.0 m		
2. Headrace, tailrace				
Section-1（Intake ~Pond）	Length	10.9km		Headrace
	Type	Pressure type, ductile steel pipe		
	Scale	Q=4.7 m³/s, Φ1.2 m、2-units	Q=17.05 m³/s, Φ1.65 m、4-units	
Section-2（Pond ~Matarbari demand area）	Length	19.7 km		Tailrace
	Type	Pressure type, ductile steel pipe		
	Scale	Q=1.32 m³/s, Φ1.0 m、1-unit	Q=3.69 m³/s, Φ1.5 m、1-unit	
Section-3（Pond ~Chakaria Demandarea）	Length	10.5 km		Tailrace
	Type	Pressure type, ductile steel pipe		
	Scale	Q=0.38 m³/s, Φ0.5 m、1-unit	Q=0.36 m³/s, Φ0.5 m、1-unit	
3.Pond	Effective capacity	16 MCM	173.7 MCM	
	Area in F.S.L	320 ha	3,470 ha	
4. Water Treatment Plant	Capacity	1.7 m³/s	4.05 m³/s	
	Treatment type	Sun-drying type		
	Land	Adjacent pond		
5. Ancillary Equipment	Distribution pond	Matarbari; 9,500 m³ Chakaria; 2,700 m³	Matarbari; 26,600 m³ Chakaria; 2,600 m³	Assuming 2-hour capacity of water supply amount

Source: JICA Survey Team

The schematic diagram of the expanded pond for the long term plan is presented in Figure 4.3.8.



Source: JICA Survey Team

Figure 4.3.8 Expansion of Pond Plan for Long-term Water Demands

2) Matamuhuri River Dam Plan（M2-1）

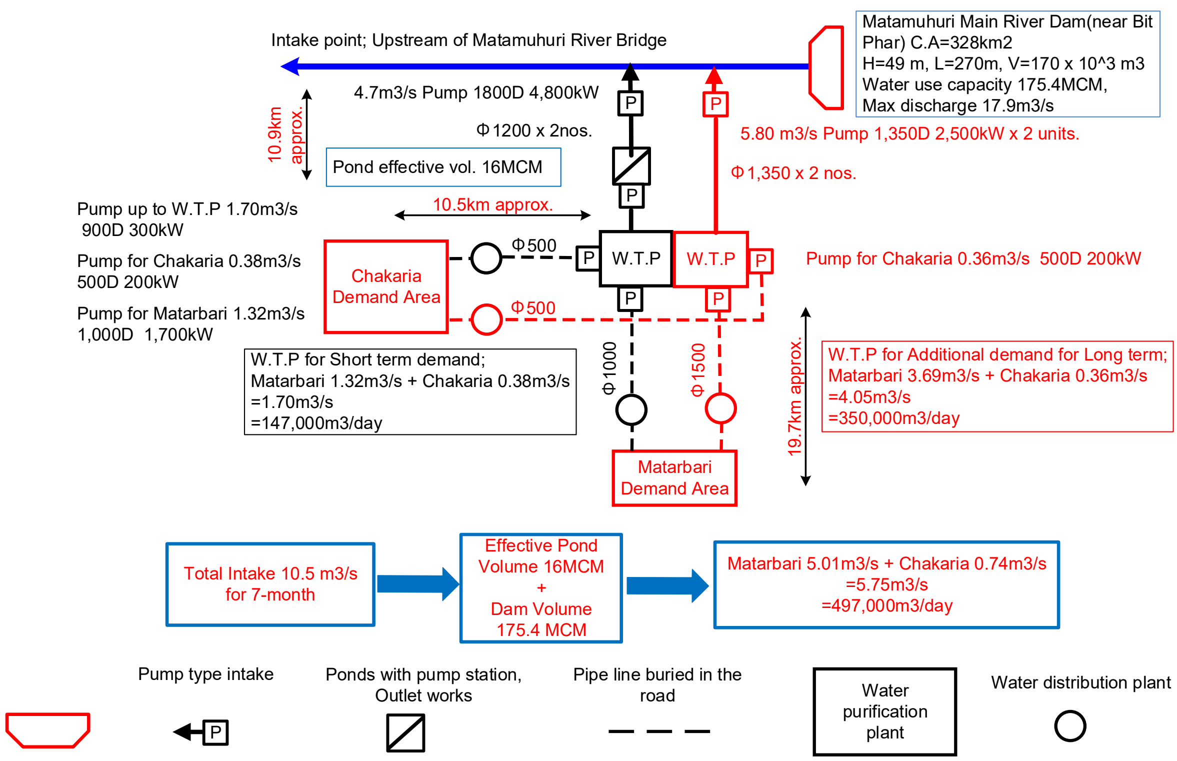
Table 4.3.6 Basic Specifications of Matamuhuri River Dam Plan

Items		Content		Remarks
		Short-term Plan	Long-term Plan	
1.Intake	Location	Upstream of Matamuhuri Bridge≒3.6 km		
	Type	Pressure type		Non pressure type intake may requires checking of social cost.
	Amount	4.7 m^3/s	5.8 m^3/s	
	Intake level	L.W.L 3.0 m		
2. Headrace, tailrace				
Section-1 (Intake ~Pond)	Length	10.9 km		Headrace
	Type	Pressure type、Ductile steel pipe		
	Scale	Q=4.7 m^3/s, Φ1.2 m、2-units	Q=5.8 m^3/s, Φ1.35 m、2-units	To directly W.T.P (in long term)
Section-2 (Pond ~ Matarbari demand area)	Length	19.7 km		Tailrace
	Type	Pressure type、Ductile steel pipe		
	Scale	Q=1.32 m^3/s, Φ1.0 m、1-unit	Q=3.69 m^3/s, Φ1.5 m、1-unit	From W.T.P(in long term)

Items		**Content**		**Remarks**
		Short-term Plan	**Long-term Plan**	
Section-3 (Pond ~Chakaria demand area)	Length	10.5 ㎞		Tailrace
	Type	Pressure type、Ductile steel pipe		
	Scale	Q=0.38 m³/s, Φ0.5 m、1-unit	Q=0.36 m³/s, Φ0.5 m、1-unit	From W.T.P (in long term)
3. Pond (short term) Dam (long term)	Effective capacity	16 MCM	175.5 MCM, 49 mH, 270 mL	Dam site is near Bit-phal
	Area in F.S.L	320 ha	1,800 ha	
4. Water Treatment Plant	Capacity	1.7 m³/s	4.05 m³/s	
	Treatment type	Sun-drying type		
	Land	Adjacent pond		
5. Ancillary Equipment	Distribution pond	Matarbari; 9,500 m³ Chakaria; 2,700 m³	Matarbari; 26,600 m³ Chakaria; 2,600 m³	Assuming 2-hour capacity of water supply amount

Source: JICA Survey Team

The schematic diagram of the construction of Matamuhuri River Dam for the long-term plan is shown in Figure 4.3.9.



Source: JICA Survey Team

Figure 4.3.9 Matamuhuri River Dam for Long-term Demand

4.3.2 Water Balance Study (Long-term Plan)

(1) Brief summary of water balance study in long-term plan

Water balance analysis models were developed for the following three conceivable structure plans in the long-term plan, and then storage capacity requirements and feasibility of the structures were studied.

- Long-term plan 1: Palakata regulation pond (Short-term) + Expansion of Palakata regulation pond
- Long-term plan 2: Palakata regulation pond (Short-term) + Matamuhuri main river dam
- Long-term plan 3: Palakata regulation pond (Short-term) + Sangu River dam and diversion

The conclusions of the water balance study are summarized in Table 4.3.7 and the process of the study is detailed hereunder.

Table 4.3.7 Brief Summary of Water Balance Study Results in Long-term Plan

Plan		Results of Water Balance Study
Long-term plan 1	Palakata regulation pond (Short-term) + Expansion of Palakata regulation pond	In addition to the storage capacity:16 MCM of regulation pond in the short-term plan, a capacity expansion of 173.7 MCM for the regulation pond is required.
Long-term plan 2	Palakata regulation pond (Short-term) + Matamuhuri main river dam	In addition to the storage capacity:16 MCM of regulation pond in the short-term plan, required is an effective storage capacity of 175.5 MCM at the Matamuhuri main river dam.
Long-term plan 3	Palakata regulation pond (Short-term) + Sangu River dam and diversion	Since water supply to the water demands even in the Sangu River basin is not satisfied through construction of the new Sangu River dam, water transfer by diversion channel from the Sangu to the Matamuhuri River basins is considered to be impossible.

Source: JICA Survey Team

(2) Primary rules of water balance analysis model (long-term Plan)

The primary rules of the water balance analysis model in the long-term plan are set as follows.

Primary rules of water balance analysis model (long-term Plan)

1) Whereas the priority of water supply for water demands is as stated below in general, conducted are multiple case studies that combine these demands.
   River Maintenance Flow ⇒ Domestic Water ⇒ Industrial Water ⇒ Agricultural Water
2) Water demands located downstream of the storage structure are targeted for water supply by the storage structure.
3) The water level of the storage structure should be restored within the range of surplus river water so as not to disturb the existing water rights.
4) The operation of the storage structure is to be conducted basically so as to recover its full capacity once at least in a rainy season.
5) A 1/10 drought year is adopted as the safety level of water use for the long-term plan (refer to "Subsection 4.1.5 (3)").

6) In the case of water transfer to other river basin, the water transfer is allowed only when surplus water is available in an original river basin after placing first priority on the development of water resources in the original river basin so as to avoid conflict between water users in both river basins.

(3) Development and analysis of water balance analysis model (Long-term Plan)

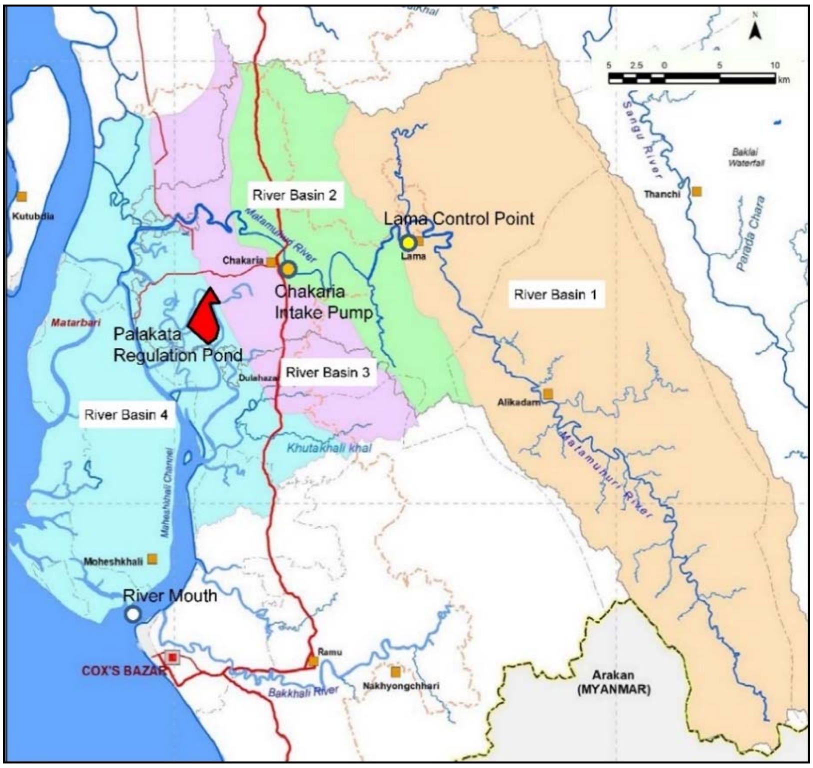
1) Long-term plan 1: Palakata regulation pond (Short-term) + Expansion of Palakata regulation pond

Expansion of Palakata regulation pond (storage capacity:16 MCM) in the short-term plan was studied. The specifications and map of the water balance analysis model are shown in Table 4.3.8 and Figures 4.3.10 to 4.3.11 (refer to “Annex 4.3-2” for water balance calculation procedures).

Table 4.3.8 Specifications of Water Balance Analysis Model
(Long Term: Expansion Plan of Palakata Regulation Pond)

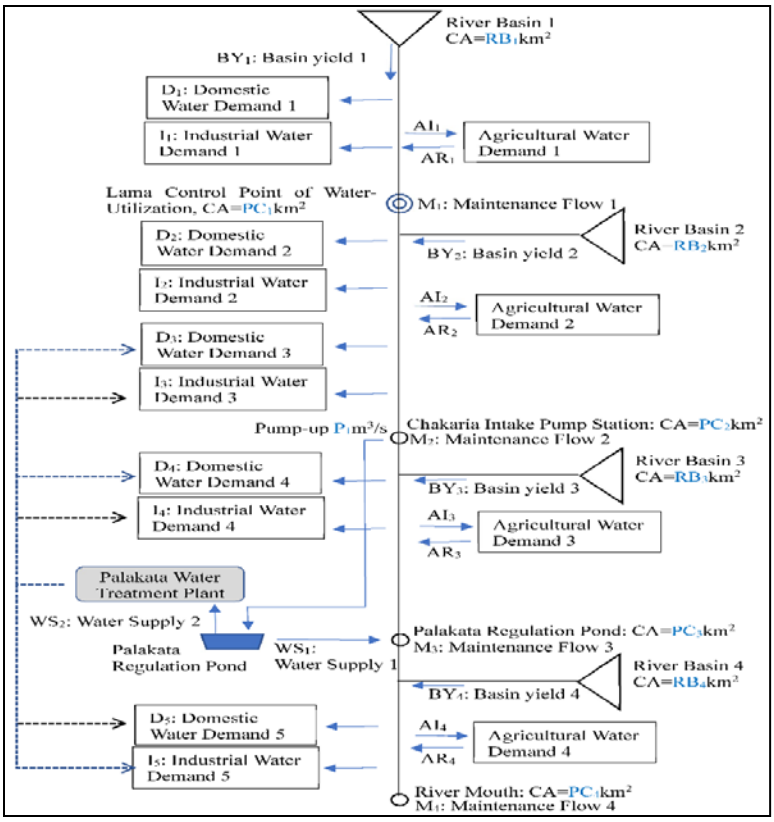
Item		Setting Conditions	Remarks
Basic Conditions	Data Target Period	1966.11－2019.10（53 years）	
	Target Year	Long Term: 2041	
	Target River Basin	Matamuhuri River basin: CA= 2,511 km^2	
	Control Point of Water Utilization	Lama control point	Water level gauge station
	Development Structure	Palakata Regulation Pond	
	Water Demand	Intake water from river of domestic, industrial and agricultural demands	
Model Parameter	Catchment Area of River Basin	River Basin 1: 1,201 km^2 River Basin 2: 289 km^2 River Basin 3: 278 km^2 River Basin 4: 744 km^2	
	Catchment Area at Check Point	Lama Control Point : 1,201 km^2 Chakaria Intake Pump Station : 1,490 km^2 Palakata Regulation Pond : 1,767 km^2 River Mouth Point : 2,511 km^2	
	Maintenance Flow	0.8 $m^3/s/100km^2$	
	Capacity of Chakaria Intake Pump Station	Trial calculation of minimum capacity of Chakaria Intake Pump for keeping full recovery of Palakata Regulation Pond each year	

Source: JICA Survey Team



Source: JICA Survey Team

Figure 4.3.10 Basin Map of Matamuhuri River
(Long Term: Expansion Plan of Palakata Regulation Pond)



Source: JICA Survey Team

Figure 4.3.11 Diagram of Water Balance Analysis Model
(Long Term: Expansion Plan of Palakata Regulation Pond)

The following 7 cases were set up for the combination of maintenance flow, domestic water, industrial water, and agricultural water as the objects of water supply by the Palakata regulation pond, and the required capacities of the Palakata regulation pond were calculated in each case.

■Combinations of water demands as objects of water supply (7 cases in total)
Case 1 : Maintenance Flow
Case 2-1 : Maintenance Flow + Domestic Water
Case 2-2 : Maintenance Flow* + Domestic Water
Case 3-1 : Maintenance Flow + Domestic Water + Industrial Water
Case 3-2 : Maintenance Flow* +Domestic Water + Industrial Water
Case 4-1 : Maintenance Flow + Domestic Water + Industrial Water + Agricultural Water
Case 4-2 : Maintenance Flow* + Domestic Water + Industrial Water + Agricultural Water
*: In case of no supply for maintenance flow by Palakata Regulation Pond

Table 4.3.9 shows the water supply objects in each case.

Table 4.3.9 Object Water Demands of Water Supply in Each Case (Long Term: Palakata Regulation Pond Plan)

Case No.	Water Supply	Maintenance	Domestic	Industrial	Agricultural	Remarks
Case 1	WS_1	M_3, M_4	—	—	—	
	WS_2	—	—	—	—	
Case 2-1	WS_1	M_3, M_4	—	—	—	
	WS_2	—	D_3, D_4, D_5	—	—	
Case 2-2	WS_1	—	—	—	—	
	WS_2	—	D_3, D_4, D_5	—	—	
Case 3-1	WS_1	M_3, M_4	—	—	—	
	WS_2	—	D_3, D_4, D_5	I_3, I_4, I_5	—	
Case 3-2	WS_1	—	—	—	—	
	WS_2	—	D_3, D_4, D_5	I_3, I_4, I_5	—	
Case 4-1	WS_1	M_3, M_4	—	—	—	
	WS_2	—	D_3, D_4, D_5	I_3, I_4, I_5	AI_4	
Case 4-2	WS_1	—	—	—	—	
	WS_2	—	D_3, D_4, D_5	I_3, I_4, I_5	AI_4	

Note (1): Structure of water resource and target of water supply
WS_1 : Water supply from Palakata Regulation Pond to the Matamuhuri River
WS_2 : Water supply from Palakata Regulation Pond to Palakata Water Treatment Plant
Note (2): Each mark M (Maintenance flow), D (Domestic water), I (Industrial water) and AI (Agricultural intake water) shows target water demand. The location of each mark with the number beside the one can be found by referring the figure of water balance model above.
Source: JICA Survey Team

The results of water balance calculation in the 7 cases are summarized in Table 4.3.10 (refer to "Appendix 4.3-3"). Since all water demands including river maintenance flow are the objects of water supply in the long-term plan, the storage capacity of 189.7 MCM in Case 4-1 is selected as a long-term plan. Then, the expansion capacity of 173.7 MCM for the Palakata regulation pond was estimated to be required in addition to the storage capacity:16 MCM in the short-term plan.

Table 4.3.10 Calculation Result of Water Balance Analysis (Long Term: Palakata Regulation Pond Plan)

Item		Case1	Case2-1	Case2-2	Case3-1	Case3-2	Case4-1	Case4-2
Chakaria Intake Pump		5.0 m3/s	6.0 m3/s	3.0 m3/s	10.0 m3/s	6.0 m3/s	16.0 m3/s	13.0 m3/s
Palakata Regulation Pond	5 yr	18,760,082 m3	35,436,203 m3	15,703,366 m3	81,788,430 m3	63,808,666 m3	169,988,458 m3	148,536,300 m3
	10 yr	32,888,143 m3	45,882,663 m3	17,294,688 m3	96,554,588 m3	72,418,540 m3	189,706,703 m3	164,628,479 m3

Note: Values of Chakaria intake pump indicate pump capacity for restoring regulation pond excluding maximum intake water 5.75m^3/s
Source: JICA Survey Team

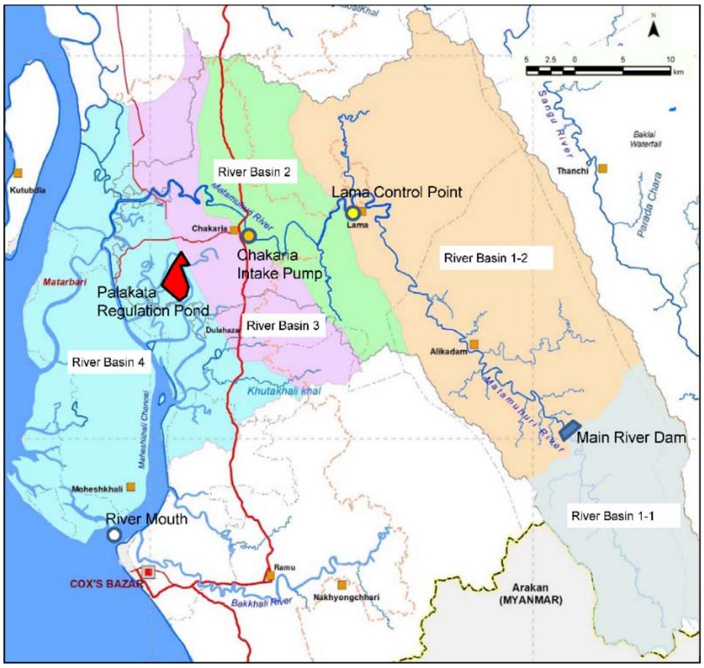
2) Long-term plan 2: Palakata regulation pond (Short-term) + Matamuhuri main river dam

In addition to the Palakata regulation pond in the short-term plan (Storage capacity:16 MCM), a new dam construction plan in the upper Matamuhuri River was studied. The specifications and map of the water balance analysis model are shown in Table 4.3.11 and Figures 4.3.12 to 4.3.13 (refer to "Annex 4.3-2" for water balance calculation procedures).

Table 4.3.11 Specifications of Water Balance Analysis Model (Long Term: Matamuhuri Main River Dam Plan)

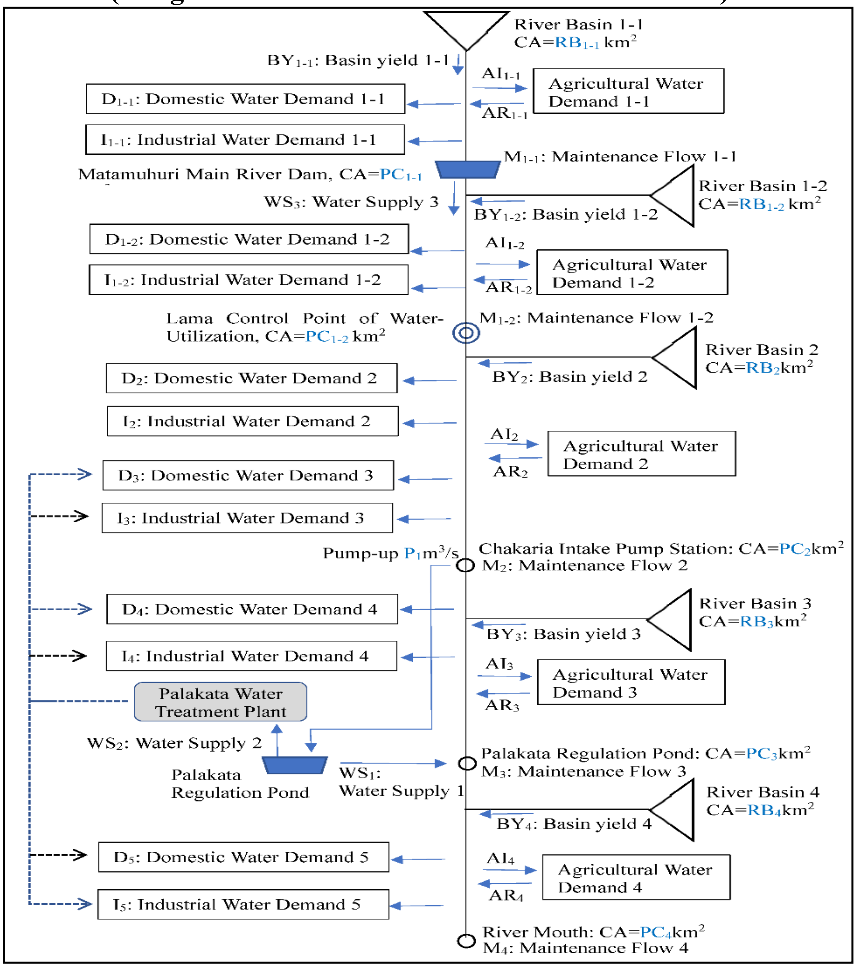
Item		Setting Condition	Remarks
Basic Conditions	Target Period	1966.11－2019.10（53 years）	
	Target Year	Long Term: 2041	
	Target River Basin	Matamuhuri RiverBasin: CA= 2,511 km^2	
	Control Point of Water Utilization	Lama control point	Water Level Gauge Station
	Development Structure	Palakata Regulation Pond (Planned in short term) + Dam upstream in Matamuhuri river	
	Water Demand	Intake water from river of domestic, industrial and agricultural demand	
Model Parameter	Catchment Area of River Basin	River Basin 1-1 : 349 km^2 River Basin 1-2 : 852 km^2 River Basin 2 : 289 km^2 River Basin 3 : 278 km^2 River Basin 4 : 744 km^2	
	Catchment Area at check point	Dam in the Matamuhuri River : 349 km^2 Lama Control Point : 1,201 km^2 Chakaria Intake Pump Station : 1,490 km^2 Palakata Regulation Pond : 1,767 km^2 River Mouth Point : 2,511 km^2	
	Maintenance Flow	0.8 m^3/s/100km^2	
	Capacity of Chakaria Intake Pump Station	3.0 m^3/s for restoring Palakata regulation pump, 1.7 m^3/s for intake water of domestic and industrial	

Source: JICA Survey Team



Source: JICA Survey Team

Figure 4.3.12 Basin Map of Matamuhuri River (Long Term: Matamuhuri Main River Dam Plan)



Source: JICA Survey Team

Figure 4.3.13 Diagram of Water Balance Analysis Model (Long Term: Matamuhuri Main River Dam Plan)

The following 7 cases were set up for the combination of maintenance flow, domestic water, industrial water, and agricultural water as the objects of water supply by the Palakata regulation pond and the Matamuhuri main river dam, and the required storage capacity of the Matamuhuri main river dam was calculated in each case.

■Combinations of water demands as the objects of water supply (7 cases in total)

Case 1 : Maintenance Flow
Case 2-1 : Maintenance Flow + Domestic Water
Case 2-2 : Maintenance Flow* + Domestic Water
Case 3-1 : Maintenance Flow + Domestic Water + Industrial Water
Case 3-2 : Maintenance Flow* +Domestic Water + Industrial Water
Case 4-1 : Maintenance Flow + Domestic Water + Industrial Water + Agricultural Water
Case 4-2 : Maintenance Flow* + Domestic Water + Industrial Water + Agricultural Water
*: In case of no supply for maintenance flow by Palakata Regulation Pond

Table 4.3.12 shows the objects of water supply (maintenance flow, domestic water, industrial water, agricultural water) in each case. For comparing to “Long-term plan 1 (expansion plan of Palakata regulation pond)”, the river stretch downstream of the Palakata regulation pond was defined as the stretch of water supply, excluding the water supply from the Matamuhuri main river dam to Palakata regulation pond).

Table 4.3.12 Object Water Demands of Water Supply in Each Case (Long Term: Matamuhuri Main River Dam Plan)

Case No.	Water Supply	Maintenance	Domestic	Industrial	Agricultural	Remarks
Case 1	WS_1	—	—	—	—	
	WS_2	—	—	—	—	
	WS_3	M_3, M_4	—	—	—	
Case 2-1	WS_1	—	—	—	—	
	WS_2	—	D_3, D_4, D_5	—	—	
	WS_3	M_3, M_4	D_3, D_4, D_5	—	—	
Case 2-2	WS_1	—	—	—	—	
	WS_2	—	D_3, D_4, D_5	—	—	
	WS_3	—	D_3, D_4, D_5	—	—	
Case 3-1	WS_1	—	—	—	—	
	WS_2	—	D_3, D_4, D_5	I_3, I_4, I_5	—	
	WS_3	M_3, M_4	D_3, D_4, D_5	I_3, I_4, I_5	—	
Case 3-2	WS_1	—	—	—	—	
	WS_2	—	D_3, D_4, D_5	I_3, I_4, I_5	—	
	WS_3	—	D_3, D_4, D_5	I_3, I_4, I_5	—	
Case 4-1	WS_1	—	—	—	—	
	WS_2	—	D_3, D_4, D_5	I_3, I_4, I_5	—	
	WS_3	M_3, M_4	D_3, D_4, D_5	I_3, I_4, I_5	AI_4	
Case 4-2	WS_1	—	—	—	—	
	WS_2	—	D_3, D_4, D_5	I_3, I_4, I_5	—	
	WS_3	—	D_3, D_4, D_5	I_3, I_4, I_5	AI_4	

Source: JICA Study Team

Note (1): Structure of water resource and target of water supply

WS_1 : Water supply from Palakata Regulation Pond to the Matamuhuri River
WS_2 : Water supply from Palakata Regulation Pond to Palakata Water Treatment Plant
WS_3 : Water supply from the Matamuhuri Main River Dam to downstream of the Matamuhuri River

Note (2): Each mark M (Maintenance flow), D (Domestic water), I (Industrial water) and AI (Agricultural intake water) shows target water demand. The location of each mark with the number beside the one can be found by referring the figure of water balance model above.

Note (3): Water supply rule at overlapping points

D_3,D_4,D_5,I_3,I_4,I_5: Shortage of water demand at overlapping points by water storage facilities more than one is supplied by the Palakata Regulation Pond first, then remain shortage of water supply is supplied by the Matamuhuri Main River Dam.

The results of water balance calculation in the 7 cases are summarized in Table 4.3.13 (refer to "Appendix 4.3-3"). Since all water demands including river maintenance flow are the objects of water supply in the long-term plan, the storage capacity of 175.5 MCM in Case 4-1 was estimated for the Matamuhuri main river dam in the long-term plan.

Table 4.3.13 Calculation Result of Water Balance Analysis (Long Term: Matamuhuri Main River Dam Plan)

Item		Case1	Case2-1	Case2-2	Case3-1	Case3-2	Case4-1	Case4-2
Dam upstream in Matamuhuri river	5 yr	18,759,776 m3	19,435,807 m3	–	65,787,948 m3	47,808,515 m3	155,286,289 m3	135,494,726 m3
	10 yr	32,887,816 m3	32,887,816 m3	1,294,688 m3	80,554,030 m3	56,418,427 m3	175,445,485 m3	151,657,009 m3

Source: JICA Study Team

3) Long-term plan 3: Palakata regulation pond (Short-term) + Sangu River dam and diversion

In addition to the Palakata regulation pond in the short-term plan, a plan with new dam construction in the Sangu River basin and water transfer by diversion channel from the Sangu to the Matamuhuri River basins was studied. As mentioned in "(2) Primary rules of water balance analysis model (Long-term Plan)", in the case of water transfer to other river basin, the transfer is allowed only when surplus water is available in an original river basin after placing first priority on the development of water resources in the original river basin so as to avoid conflict between water users in both river basins. As the first step, therefore, the water balance analysis model was developed only for the Sangu River basin in order to examine the possibility in water transfer to other river basin from the Sangu River. The specifications and map of the water balance analysis model are shown in Table 4.3.14 and Figures 4.3.14 to 4.3.15 (refer to "Annex 4.3-2" for water balance calculation procedures).

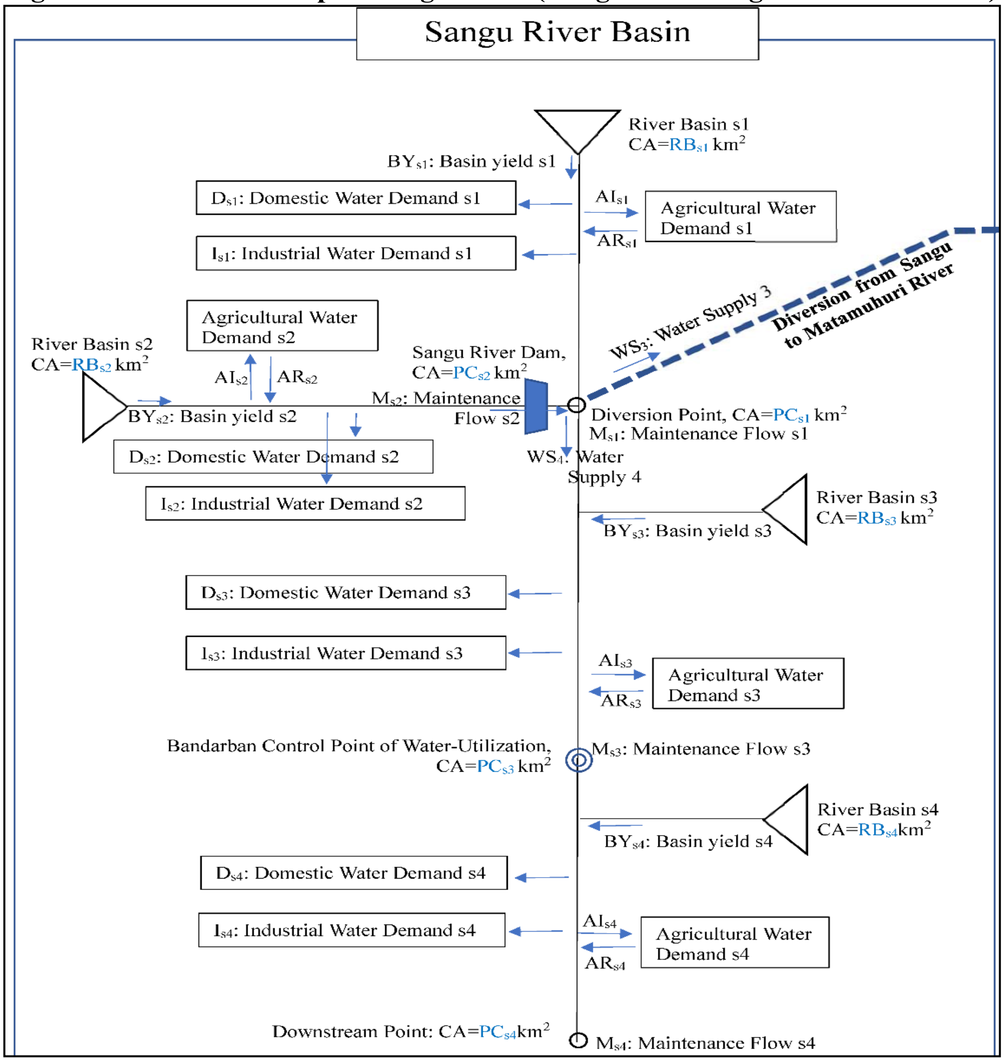
Table 4.3.14 Specifications of Water Balance Analysis Model (Long Term: Sangu River Dam Plan)

Item		Setting Conditions	Remarks
Basic Conditions	Target Period	1966.11－2019.10（53 years）	
	Target Year	Long Term: 2041	
	Target River Basin	Sangu RiverBasin: CA= 3,663 km^2	
	Control Point of Water Utilization	Bandarban control point	Water level gauge station
	Development Structure	Dam in SanguRriver	
	Water Demand	Intake water from river of domestic, industrial and agricultural demand	
Model Parameter	Catchment Area of River Basin	River Basin s1 : 802 km^2 River Basin s2 : 59 km^2 River Basin s3 : 1,305 km^2 River Basin s4 : 1,498 km^2	
	Catchment Area at Check Point	Diversion Point : 861 km^2 Dam in the Sangu River : 259 km^2 Bandarban Control Point : 2,165 km^2 Downstream Point : 3,663 km^2	
	Maintenance Flow	0.8 m^3/s/100km^2	

Source: JICA Study Team

Source: JICA Study Team

Figure 4.3.14 Basin Map of Sangu River (Long Term: Sangu River Dam Plan)



Source: JICA Study Team

Figure 4.3.15 Diagram of Water Balance Analysis Model
(Long Term: Sangu River Dam Plan)

The following 7 cases were set up for combinations of maintenance flow, domestic water, industrial water, and agricultural water as the objects of water supply by the Sangu River dam, and required storage capacities of the Sangu River dam were calculated in each case.

■Combinations of water demands as the objects of water supply (7 cases in total)

Case 1 : Maintenance Flow
Case 2-1 : Maintenance Flow + Domestic Water
Case 2-2 : Maintenance Flow* + Domestic Water
Case 3-1 : Maintenance Flow + Domestic Water + Industrial Water
Case 3-2 : Maintenance Flow* +Domestic Water + Industrial Water
Case 4-1 : Maintenance Flow + Domestic Water + Industrial Water + Agricultural Water
Case 4-2 : Maintenance Flow* + Domestic Water + Industrial Water + Agricultural Water
*: In case of no supply for maintenance flow by Palakata Regulation Pond

Table 4.3.15 shows the objects of water supply in each case.

Table 4.3.15 Object Water Demand of Water Supply in Each Case
(Long Term: Sangu River Dam Plan)

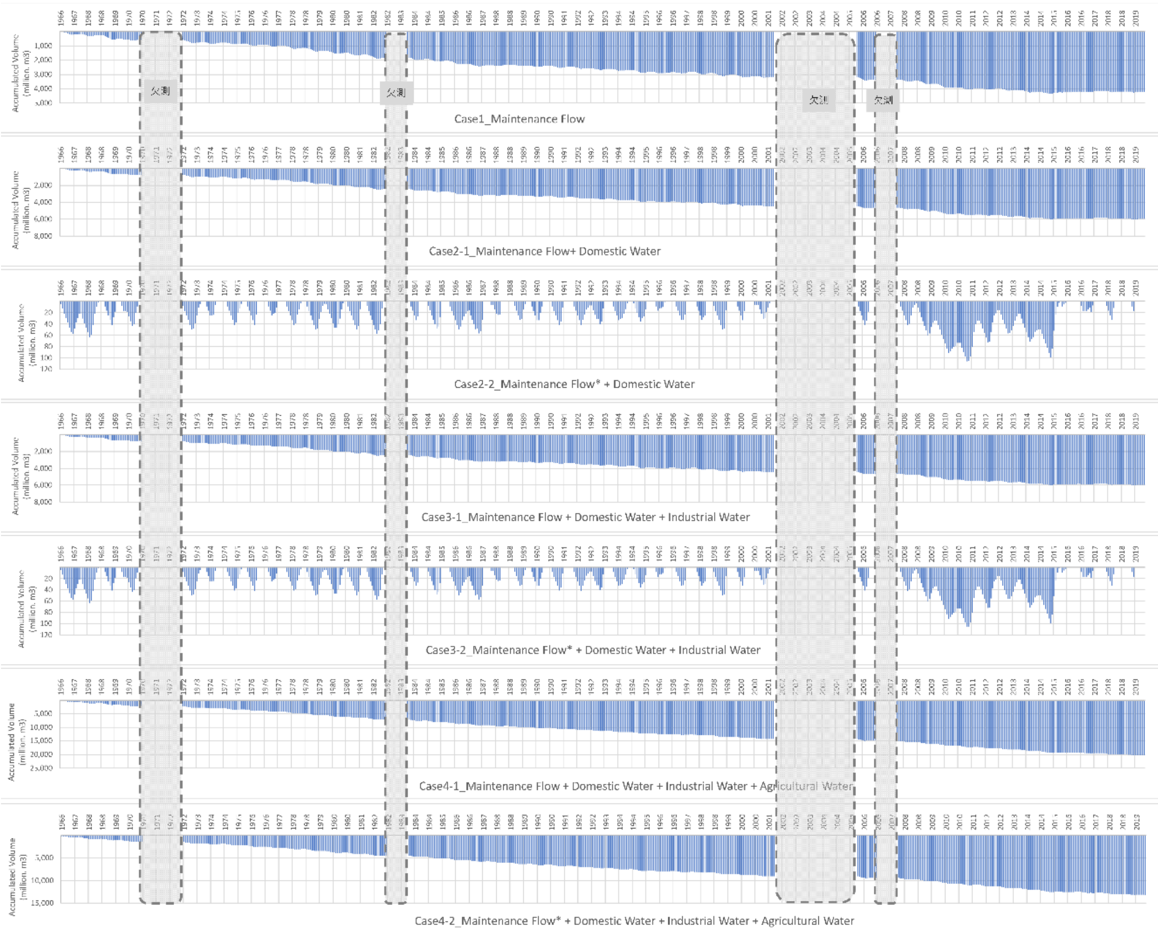
Case No.	Water Supply	Maintenance	Domestic	Industrial	Agricultural	Remarks
Case 1	WS_1	–	–	–	–	
	WS_2	–	–	–	–	
	WS_3	–	–	–	–	
	WS_4	M_{s1}, M_{s2}, M_{s3}, M_{s4}	–	–	–	
Case 2-1	WS_1	–	–	–	–	
	WS_2	–	–	–	–	
	WS_3	–	–	–	–	
	WS_4	M_{s1}, M_{s2}, M_{s3}, M_{s4}	D_{s3}, D_{s4}	–	–	
Case 2-2	WS_1	–	–	–	–	
	WS_2	–	–	–	–	
	WS_3	–	–	–	–	
	WS_4	–	D_{s3}, D_{s4}	–	–	
Case 3-1	WS_1	–	–	–	–	
	WS_2	–	–	–	–	
	WS_3	–	–	–	–	
	WS_4	M_{s1}, M_{s2}, M_{s3}, M_{s4}	D_{s3}, D_{s4}	I_{s3}, I_{s4}	–	
Case 3-2	WS_1	–	–	–	–	
	WS_2	–	–	–	–	
	WS_3	–	–	–	–	
	WS_4	–	D_{s3}, D_{s4}	I_{s3}, I_{s4}	–	
Case 4-1	WS_1	–	–	–	–	
	WS_2	–	–	–	–	
	WS_3	–	–	–	–	
	WS_4	M_{s1}, M_{s2}, M_{s3}, M_{s4}	D_{s3}, D_{s4}	I_{s3}, I_{s4}	AI_{s3}, AI_{s4}	
Case 4-2	WS_1	–	–	–	–	
	WS_2	–	–	–	–	
	WS_3	–	–	–	–	
	WS_4	–	D_{s3}, D_{s4}	I_{s3}, I_{s4}	AI_{s3}, AI_{s4}	

Source: JICA Study Team
Note (1): Structure of water resource and target of water supply
WS_1 : Water supply from Palakata Regulation Pond to the Matamuhuri River
WS_2 : Water supply from Palakata Regulation Pond to Palakata Water Treatment Plant
WS_3 : Water supply from Sangu River Dam to downstream of Matamuhuri River through diversion
WS_4 : Water supply from Sangu River Dam to downstream of Sangu River

Note (2): Each mark M (Maintenance flow), D (Domestic water), I (Industrial water) and AI (Agricultural intake water) shows target water demand. The location of each mark with the number beside the one can be found by referring the figure of water balance model above.

Source: JICA Study Team

The results of water balance calculation in the 7 cases are shown in Figure 4.3.16. All the cases excluding Cases 2-2 and 3-2 show the trend that the accumulated water volume at the Sangu Reservoir continuously increases without restoration of reservoir water level, which means that the Sangu Reservoir has no restoration capacity due mainly to its rather small catchment area of 59 km^2. Eventually, there is no proper new dam site expected to meet water demands sufficiently in the Sangu River basin itself, and hence water transfer to the Matamuhuri River basin is considered difficult.



Source: JICA Study Team

Figure 4.3.16 Calculation Result Diagram of Water Balance Analysis (Long Term: Sangu River Dam Plan)

4.3.3 Evaluation of Alternative Plans for Long-term Water Resources Development

The following two (2) alternative plans of “M1” and “M2-1” for long-term water resources development were chosen for evaluation through the studies in the foregoing subsections “4.3.1” and “4.3.2” which aimed to (i) formulate alternative plans for long-term water resources development and (ii) examine practicality of water storage facilities in the alternatives from a hydrological viewpoint, respectively.

- **M1: Palakata Regulation Pond (Short Term: Storage capacity 16 MCM) + Expansion of Palakata Regulation Pond (Storage capacity 173.7 MCM)**
- **M2-1: Palakata Regulation Pond (Short Term: Storage capacity 16 MCM) + Matamuhuri Main River Dam (Reservoir storage capacity 175.5 MCM)**

The evaluation was made by using the Multi-Objective Analysis（MOA）Method, which is discussed hereunder.

A project has impacts on various parts in society after it is actually executed. The impacts are not only what the project aims to positively achieve but also what are caused against its will and the society does not necessarily expect, such as negative impacts on economy and environment. Therefore, the project impacts shall be carefully assumed and assessed in its earlier planning stage.

There are social impacts, environmental impacts, economic impacts, financial impacts, institutional impacts, technical impacts, etc. selected as the objectives for assessment of project impacts (in other words, “assessment objective”), dependent mainly on the contents of the project. Out of these objectives, economic and financial impacts have a unique index of “the value of money” for their assessment, while other objectives have no such index.

Therefore, the Multi-Objective Analysis（MOA）method is adopted as an evaluation method to deal with this problem. The MOA method expresses all the impacts in points, and uses the total point by summing up the points acquired for the objectives as one of indicators to evaluate the soundness and priority of the project.

The total acquired point demonstrates the magnitude of the impacts on objectives, and a project with a larger point than the other is more beneficial in general. However, there is a case where a high total point is acquired because the positive impact on one objective is very high, although there is an objective with a low point due to several negative impacts. In due consideration of the case, the method evaluates the balance of impacts to all the objectives as well, so as to lower the priority of such a project.

Eventually, the MOA method evaluates the total impacts and the balance of impact, as explained hereunder. The total acquired point indicates the positive impact of the project. Meanwhile, the generalized distance from the assumed iso-impacts line demonstrates the degree of unbalance. The total acquired point and degree of unbalance are assessed by using the following Equations (1) and (2).

<u>Gross Magnitude of Impacts (GMI)</u>

$$GMI = \sum_{i=1}^{n} \left\{ WOB(i) \times \sum_{j=1}^{m(i)} \left(WIT(i, j) \times P(i, j) \right) \right\} \quad (1)$$

where, *GMI*: Gross magnitude of impacts
WOB(i): Relative weight of objective (i)
WIT(i,j): Relative weight of assessment item (i, j)
P(i,j): Corresponding point of assessment item (i, j)
n: Number of objectives
m(i): Number of assessment items of objective (i)

<u>Balance of impacts</u>

$$GD = \sqrt{\sum_{i=1}^{n} \left\{ (IOB(i) - O) \right\}^2}$$

$$DUB = \frac{GD}{O} \quad (2)$$

Where, *GD*: Generalized distance of impacts
DUB: Degree of unbalance of impacts
IOB(i): Acquired point of objective (i)

$$= \sum_{j=1}^{m} \left(WIT(i, j) \times P(i, j) \right)$$

O: Coordinate of iso-magnitude of impacts

Through careful consideration of natural conditions and socio-economy in the survey area in addition to the contents of the alternative plans, the MOA adopted 5 assessment objectives and 21 assessment items in total, as tabulated below.

Table 4.3.16 Assessment Objectives and Items in MOA

Assessment Objectives	Items
Social issues	6
Environmental issues	3
Institutional issues	3
Financial issues	2
Technical considerations	7
Total	21

Note : The details are as referred to in **Annex4.3-4 (Table 1).**
Source: JICA Survey Team

The results of impact assessment in terms of the above objectives and items are detailed in Annex 4.3-4 (Table 2), and Table 4.3.17 presents the summary of MOA results.

Since it is essential and the most important in the planning and implementation stage that the water resources development project in the survey area cooperate closely with several organizations/institutions which cover extensively beyond each administrative division, "2" is given to "Institutional issues" as a relative weight of objective.

Table 4.3.17 Assessment of Alternative Plans by MOA

Alternative Plans		Total Score (GMI*)	Degree of Unbalance
M1	Palakata Regulation Pond (Short Term) + Expansion of Palakata Regulation Pond	33	38.1
M2-1	Palakata Regulation Pond (Short Term) + Matamuhuri Main River Dam	54	7.4

Note : The details are as referred to in Annex 4.3-4.
Source: JICA Survey Team

According to the results in the above table and Annex 4.3-4 (Table 2), both alternative plans are assessed as stated below.

1) As to the total score, which is translated into gross magnitude of impacts (GMI), the alternative M2-1 obtained a higher point, and the degree of unbalance of M2-1 results in a smaller value.

2) Regarding the construction cost, there is a large difference between both alternative plans, which makes a significant impact on the points of GMI.

3) The river maintenance flow to control in the river stretches downstream of the Matamuhuri Main Dam results in a better evaluation of the Environmental issues.

4) As for "Institutional issues" and "Technical considerations", there is no large difference presented between both alternatives.

In due consideration of the above-mentioned assessments, it is proposed to position the alternative plan of "**M2-1**" as the recommended water resources development option in the south Chattogram region, since "M2-1" is evaluated to have the higher soundness and priority recognized in terms of GMI and Degree of unbalance of impacts.

4.3.4 Preparation of Roadmap for Water Resources Development

The recommended option of water resources development plan in the survey area, which is to be considered for JICA's assistance in future, is outlined as compiled in Table 4.3.18, on the basis of the survey outcomes in and before "Subsection 4.3.3".

Table 4.3.18 Recommended Option of Water Resources Development Plan

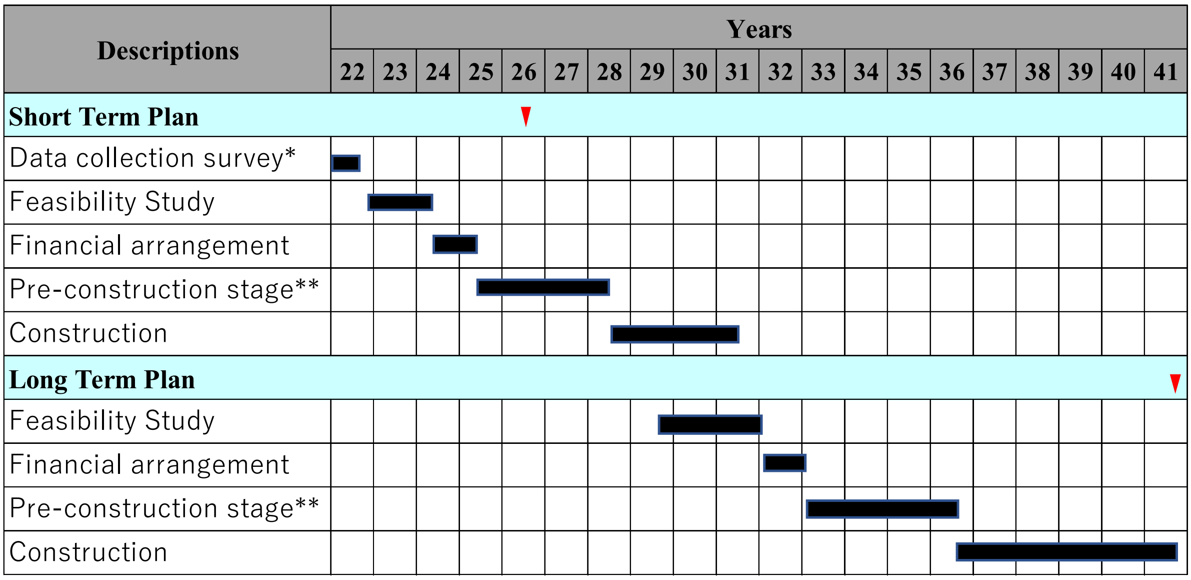
Item	Descriptions
Short Term Plan	
Project goal	Domestic and industrial water supply in Moheshkhali/Matarbari industrial areas and domestic water supply in Chakaria City
Target year	Year 2026*
Water source	Surface water : rainy season river water in the Matamuhuri River

Item	Descriptions
Major water-use facilities	• Pump type intake: on left riverbank, 3.6km upstream of the Matamuhuri River Bridge on National Highway "N-1" (Chakaria), • Headrace: Pipeline along Chattogram - Cox's Bazar Highway (under planning) and Matarbari Port Access Road (under design), • Regulation pond, water treatment plant and distribution pump station: Palakata area, Cox's Bazar • Distribution pipelines to and distribution facilities in water demand areas.
Social impact	It is supposed that there would be impacts caused on the people who have been running shrimp cultivation and salt refining due to the pond (storage area: about 3.2km^2) construction.
Construction cost**	99,800 x 10^6 (JPY) • Pump type intake: 4,600 x 10^6 (JPY) • Headrace: 700 x 10^6 (JPY) • Regulation pond, water treatment plant and distribution pump station: 32,500 x 10^6 (JPY) • Distribution pipelines to and distribution facilities in water demand areas: 62,000 x 10^6 (JPY)
Long Term Plan	
Project goal	• Project goal in short term plan • Agricultural, industrial and domestic water in South Chattogram region
Target year	Year 2041
Water source	Surface water : rainy season river water in the Matamuhuri River
Major water-use facilities	• Facilities in short-term plan • Matamuhuri Main River Dam (23km upstream of Alikadam)
Social impact	The Matamuhuri Reserved Forest, stipulated by Bangladesh Forest Act in 1927 for reserving forest environment, is situated upstream of the dam candidate site and it is supposed that there is a possibility that some small settlements (approx. 20 settlements) scattering in the upstream would be resettled due to implementation of the dam plan (reservoir area: about 25 km^2).
Construction cost**	110,000 x 10^6 (JPY) • Facilities in short-term plan: 99,800 x 10^6 (JPY) • Matamuhuri Main River Dam: 10,200 x 10^6 (JPY)

Notes:
1) * The year 2031 is assumed for completion of construction works in the roadmap presented below, because of delay of the Survey's progress due to COVID-19.
2) ** Calculated only for cost comparison to the other alternative plan, based on the following guideline and manual, excluding land acquisition/compensation costs, not the construction costs
   1. "Guideline for Calculating Facility Renewal Costs Related to Restructuring of Water Services, December 2011, (Waterworks Division, Health Bureau, Ministry of Health, Labor and Welfare)"
   2. "Civil Engineering Work Estimation Standard Manual 2020, (Ministry of Land, Infrastructure, Transport and Tourism, Japan)"

Source: JICA Survey Team

The roadmap for the above recommended option for short-term and long-term water resources development plans is proposed as presented in Figure 4.3.17, including several processes before implementation of project construction.



Notes :

1) ▼ Target years, * The completion of the Study was delayed due to COVID19.

2) ** including procurement of consultant, D/D, P/Q & Tender

3) The long term road map is to be reviewed in future state of developments in the Moheshkhali/ Matarbari region and its suburbs.

Source: JICA Survey Team

Figure 4.3.17 Roadmap of Recommended Option of Water Resources Development Plan

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

This Data Collection Survey has proposed the water resources development method of "**M2-1: Palakata Regulation Pond (Short term) + Matamuhuri Main River Dam**[1] (see Figure 5.1.1)", through a preliminary study on water resources development in the south Chattogram region, as a recommended water resources development option in the region, and drawn out the road map for "**M2-1**" as well.

Furthermore, a rough idea level study on sewage treatment is made in the Survey, as referred to in Annex 5-1.

Source: JICA Survey Team

Figure 5.1.1 Location Map of Facilities Adopted in Recommended Water Resources Development Option

This survey was repeatedly compelled to delay its progress and revise the work schedule due to the COVID-19 constraints, and somehow was completed by pushing the progress forward through partly incorporating remote work in Japan and also online discussions between the Japanese and Bangladeshi sides.

The Moheshkhali/Matarbari region is progressing as an important infrastructure base under the Japanese technical assistance based on "BIG-B", and hence it is required to develop the water resources

[1] While the recommended development option has a higher priority from a technical viewpoint, the dam site planned in the recommended option is located on the fringe of the reserved forest according to the basic environmental survey. Therefore, the practicability of the recommended option needs to be fully examined based on impacts of environmental and social consideration.

immediately as the measures to be taken for the growth of population in the region and its suburbs. In such a situation, for the next survey stage of the water resources development plan in the south Chattogram region, it is recommended that future actions be successively taken in due consideration of the following matters.

(1) Hydrological study in the Matamuhuri River basin

1) River maintenance flow: Accuracy improvement for river water utilization and environmental conservation by surveying study items such as protection of flora, fauna and fisheries, water quality and navigation, among others

2) Water balance analysis: Accuracy improvement by updating water balance analysis model such as change of calculation term (time step) from monthly to daily basis to more specifically design functions and capacities of water-use structures in the plan

(2) Water quality for use of the Matamuhuri River water

1) Detailed water quality inspection by taking samples back to Japan for further inspection, since heavy metals have been detected

2) Detailed water quality inspection of pesticides by bringing back samples to Japan, since no pesticide inspection has been conducted

(3) Municipal water demand forecast: The development of the Moheshkhali/Matarbari region is a national strategy and is expected to be developed stepwise in the short, medium, and long terms. On the other hand, it is necessary to take into account the economic situation in "the after-COVID19" scenario and other trends due to global policies such as low carbon and energy savings, among others.

1) To grasp the economic situation of "after-COVID19" scenario and the investment situation of each country in the future, and to monitor the development situation; and

2) To consider reduction of infrastructure costs for water supply by examining measures to control water demand on the development side, such as energy-saving measures and water-saving measures

(4) Environmental and social assessment, in particular on construction and operation of Parakata regulation pond.

1) To support the environmental and social impact assessment (ESIA) based on the Bangladesh regulations, and conduct an Environmental and Social Consideration Study based on the JICA Environmental and Social Consideration Guidelines

2) To survey and grasp the number of affected people due to loss of income in salt refining and shrimp cultivation

3) To prepare the draft income restoration program, referring to past good practices in Bangladesh

(5) To conduct topographic, geological and geotechnical surveys for planning water-use facilities in the short-term and long-term water resources development plan, and to coordinate the plan of the said water-use facilities, including headrace pipelines and transmission pipelines, with new roads and railways under planning/design in other MIDI-related projects,

(6) To continue the study on institutional arrangements for implementation of the short-term and long-term water resources development plan,

(7) To assess and confirm viability of the short-term and long-term water resources development plan through economic and financial analyses, and

(8) To make a study on additional projects which are expected to promote a synergy effect by using the vast water-surface and riparian areas in and around the Palakata regulation pond so that the short-term and long-term plan would add value to a whole of MIDI as one of the MIDI projects; for instance, under the following concepts:

- Adoption of floating solar power generation system for the electric power to use at the intake pump station, WTP, etc., and
- Creation of a tourist spot as well as a community place of recreation and relaxation.