JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

ECONOMIC RELATIONS DIVISION, MINISTRY OF FINANCE
DEPARTMENT OF PUBLIC HEALTH ENGINEERING, MINISTRY OF LOCAL GOVERNMENT, RURAL DEVELOPMENT & COOPERATIVES
THE GOVERNMENT OF THE PEOPLE'S REPUBLIC OF BANGLADESH

THE STUDY ON THE GROUND WATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

FINAL REPORT

MAIN REPORT BOOK 1

DECEMBER 2002

KOKUSAI KOGYO CO., LTD.
MITSUI MINERAL DEVELOPMENT ENGINEERING CO., LTD.

PREFACE

In response to the request from the Government of People's Republic of Bangladesh, the Government of Japan decided to conduct the Study on Ground Water Development of Deep Aquifers for Safe Drinking Water Supply to Arsenic Affected Areas in Western Bangladesh and entrusted the study to Japan International Cooperation Agency (JICA).

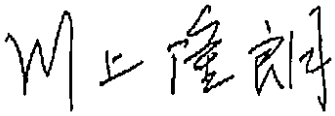
JICA dispatched a study team headed by Dr. Akira Kamata of Kokusai Kogyo Co., Ltd. and Mitsui Mineral Development Engineering Co., Ltd. to Bangladesh, four times between May 2000 and November 2002. In addition, JICA set up an Advisory Committee headed by Mr. Hisao Ushiki of JICA expert between May 2000 and November 2002, which examined the study from specialist and technical point of view.

The study team held a series of discussions with the officials concerned of the Government of Bangladesh and conducted field surveys in the study area and laboratory tests in Bangladesh and in Japan. After completion of the fieldworks, the study team conducted further studies and prepared this final report in Japan.

I hope that the report will contribute to the promotion of this project and to the enhancement of friendly relationship between our two countries.

Finally, I wish to express my sincere appreciation to the officials concerned of the Government of Bangladesh for their close cooperation extended to the study team.

December 2002



Takao Kawakami
President
Japan International Cooperation Agency

Mr. Kawakami Takao
President
Japan International Cooperation Agency
Tokyo, Japan

LETTER OF TRANSMITTAL

Dear Sir:

We are pleased to officially submit herewith the final report of "The Study on the Ground Water Development of Deep Aquifers for Safe Drinking Water Supply to Arsenic Affected Areas in Western Bangladesh".

This report compiles the results of the study which was undertaken in the People's Republic of Bangladesh, from May 2000 to November 2002 by the Study Team, organized by Kokusai Kogyo Co., Ltd. and Mitsui Mineral Development Engineering Co., Ltd.

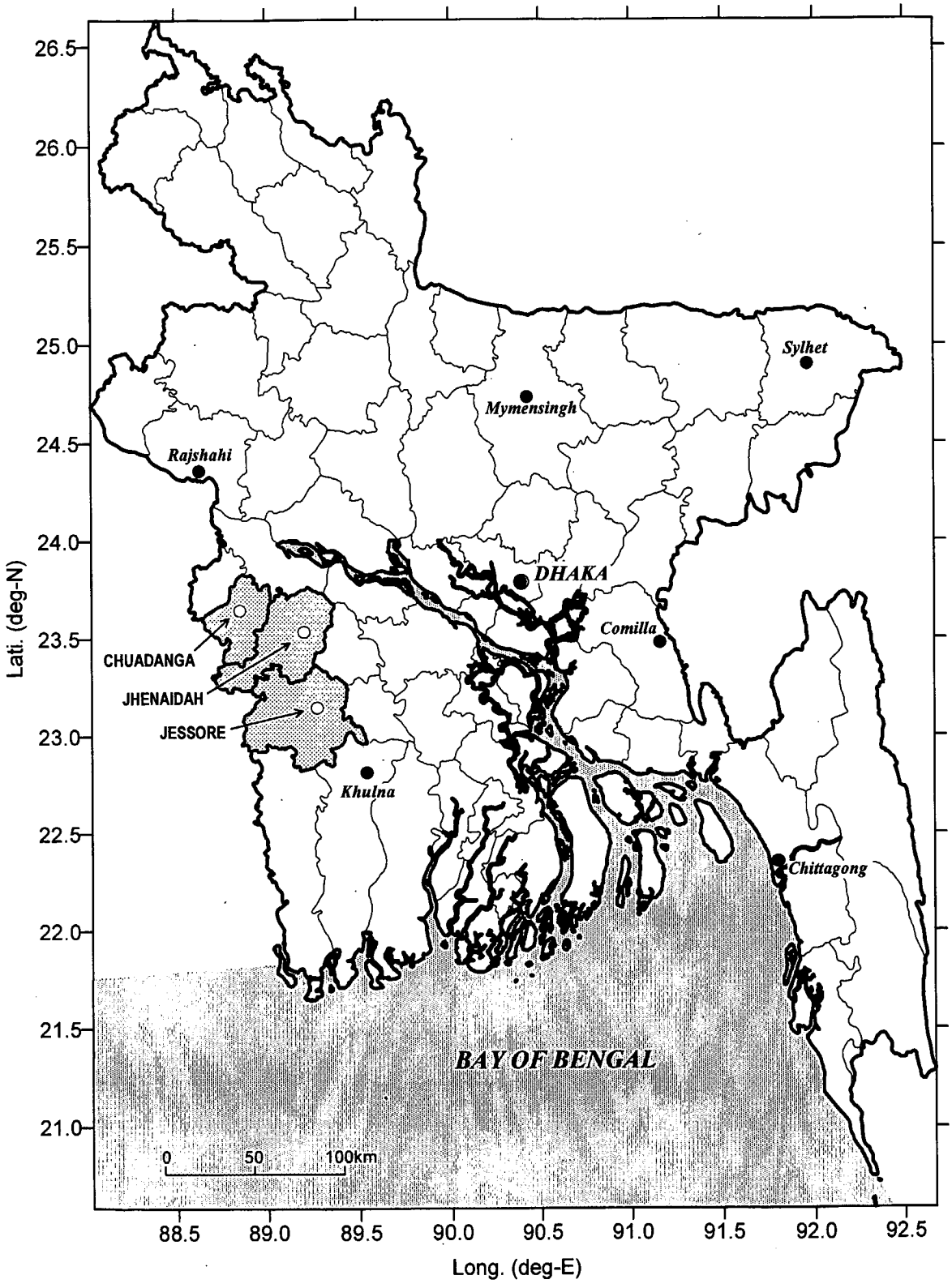
We would like to express our deep appreciation and sincere gratitude to all those who extended their kind assistance and cooperation to the Study Team, particularly the officials concerned of the Department of Public Health Engineering and other members of the Bangladesh Counterpart Team.

We also acknowledge and appreciate greatly the excellent support given by your agency, the JICA Advisory Committee and the Embassy of Japan in the People's Republic of Bangladesh.

We sincerely hope that this report will be of help for the socio-economic development of the country as a whole.

Very truly yours,

Kamata Akira
Team Leader
The Study Team for the Study on
Groundwater Development in Central
Cambodia



STUDY AREA

LOCATION MAP

THE STUDY ON THE GROUNDWATER DEVELOPMENT OF DEEP AQUIFERS FOR SAFE DRINKING WATER SUPPLY TO ARSENIC AFFECTED AREAS IN WESTERN BANGLADESH

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

Exchange Rate

(March 1, 2002)

US$ 1.00 = 55.26 Taka = 134.45 Yen

1 Taka = 2.433 Yen = US$ 0.01810

1 Yen = US$ 0.007438 = 0.4110 Taka

List of Abbreviations

AAN	Asia Arsenic Network
AAS	Atomic Absorption Spectrophotometer
ADP	Annual Development Program
ARD	Arsenic Removal Device
BADC	Bangladesh Agricultural Development Corporation
BAMWSP	Bangladesh Arsenic Mitigation Water Supply Project
BBS	Bangladesh Bureau of Statistics
BGS	British Geological Survey
BMD	Bangladesh Meteorological Department
BWDB	Bangladesh Water Development Board
DANIDA	Danish International Development Assistance
DCH	Dhaka Community Hospital
DFID	Department for International Development (UK)
DOEH	Department of Occupational & Environmental Health
DPHE	Department of Public Health Engineering
DTW	Depth To Groundwater Level from the ground surface
DWL	Dynamic Water Level
EC	Electric Conductivity
EIRR	Equity Internal Rate of Return
FIRR	Financial Internal Rate of Return
FK	Field Kit
FY	Fiscal Year
GHCN	Global Historical Climatology Network
GIS	Geographic Information System
GSB	Geological Survey of Bangladesh
GW	Groundwater
GWL	Groundwater Level

IRP	Iron Removal Plant
JICA	Japan International Cooperation Agency
LGED	Local Government Engineering Department
LLDC	Least-Less Developed Countries
MLD	Million Liters per Day
MLGRD&C	Ministry of Local Government, Rural Development & Cooperatives
masl	meter above sea level
MCM	Million Cubic Meter
MoF	Ministry of Finance
MoHFW	Ministry of Health & Family Welfare
mS/m	1 mS/m = 10 microS/cm
M/M	Minutes of Meeting
NGO	Non-governmental organizations
NIPSOM	National Institute of Preventive and Social Medicine
NPV	Net Present Value
OHT	Over Head Tank
OJT	On the Job Training
OM	Operation and Maintenance
ORP	Oxidation-Reduction Potential
PETP	Potential Evapotranspiration
PSF	Pond Sand Filter
RGAG	Research Group for Applied Geology
RWH	Rain Water Harvesting
PWSS	Pourashava Water Supply System
SOB	Survey of Bangladesh
SWL	Static Water Level
S/W	Scope of Work
TRT	Trainer’s Training
UNDP	United Nations Development Program
UNICEF	United Nations Children’s Fund
USGS	United States Geological Survey
WASA	Water and Sewerage Authority
WHO	World Health Organization
WTP	Willingness To Pay

EXECUTIVE SUMMARY OF THE FINAL REPORT

This Executive Summary of the Final Report on the Study on the Groundwater Development of Deep Aquifers for Safe Drinking Water Supply to Arsenic Affected Areas in Western Bangladesh describes all of the results of the study carried out from May 2000 to November 2002.

CHAPTER 1 INTRODUCTION

The overall objectives of the study are 1) to formulate the master plan for the development of groundwater resources in arsenic affected areas in western Bangladesh, 2) to conduct a pre-feasibility study on the projects with higher priority, and 3) to transfer technology to counterpart personnel in the course of the study. The study area covers three districts, Jessore, Jhenaidah and Chuadanga. The study is composed of an intensive hydrogeological survey, a field examination of arsenic measures, such as arsenic removal devices and improved deep wells, a detailed survey in the model rural areas and preparation of the master plan and pre-feasibility study of the priority projects.

CHAPTER 2 NATURAL ENVIRONMENT OF THE STUDY AREA

The natural conditions of Bangladesh and the situation of the study area are reviewed. The climate of the study area is characterized by relatively low precipitation, high temperatures, and high evapotranspiration. The daily rainfall and evaporation data in the study area were collected and analyzed.

The ground elevation of the study area ranges from 0.5 to 15 m above mean sea level. The area occupies a part of the Ganges Delta. The surface geology is comprised of deltaic sediment from the Holocene age. Most of the study area is underlain by a shallow clayey layer. The subsurface geology consists mainly of sandy and gravelly layers in the northern part and sandy and clay layers in the southern part.

The aquifers in the study area can be divided into shallow aquifers and deep aquifers based on the existing drilling records and drilling results of the study. The aquitard that separates the deep aquifers from the shallow aquifers clearly occurs in the southern part but does not clearly exist in the northern part. The thickness of the aquitard increases toward south.

The arsenic problem in the study area is characterized not only by high concentrations of arsenic in shallow groundwater but also by many arsenicosis patients based on the existing information and the results of the study.

CHAPTER 3 SOCIO-ECONOMY AND WATER SUPPLY

The population of the study area is 4.27 million. The GDP of Jessore district is approximately 31 billion Tk at a constant price. The district GDP per capita is about 11,511 Tk in FY 1997/98, which is slightly higher than the national level of FY 1996/97. The major economic activity in the study area is agriculture. The manufacturing industry is still very limited in the study area.

Water from tube wells is the main and sometimes the only source of drinking water for most of the households in the study area. Especially in the rural area, water from tube wells is almost the only source of drinking water while tap water is partially supplied to the households in the urban centers of the study area. The on-going Fifth Five-Year Plan sets out the targets and programmes to improve water supply and sanitation as well as the undertaking of the study and remedial measures for the arsenic affected areas.

Based on the questionnaire survey on the conditions of the 260 selected villages in the study area, general features, water use and arsenic problems in the rural area were clarified in detail.

CHAPTER 4 ACTUAL CONDITION OF ARSENIC CONTAMINATION IN GROUNDWATER

The survey was carried out to obtain arsenic concentrations at 300 existing wells in the rainy season (June to July 2000) and in the dry season (December 2000 to January 2001). A total of 260 DPHE shallow tubewells and 40 Pourashava production wells were selected for the survey. Selection criteria of target shallow wells were set so as to allocate the target wells uniformly in the study area. The arsenic concentration was analyzed by the AAS in the laboratory set up at the DPHE Jhenaidah office.

The As concentration map both in the rainy season and dry season shows that the highly contaminated areas above 0.1 mg/l are mainly distributed in the western part of the study area. On the other hand, less contaminated areas are distributed in the eastern part. The distribution pattern of arsenic concentration in the dry season is similar to that in the rainy season. However, As concentrations slightly increased in the dry season in wide areas in the northern part of Chuadanga district, northwestern and southwestern parts of Jhenaidah district, and central part of Jessore district. While As concentrations decreased in the area from western Jhenaidah district to western Jessore district.

Higher concentrations of Fe^{2+} and lower values of Eh are found in the areas where As concentrations are high in the rainy season. In the dry season, the Eh values increased in the central to western part of Jessore district. But the maximum Eh value in the dry season is lower than that in the rainy season. The EC values in the southeastern part of Jessore district are higher than 150 mS/m both in the rainy season and the dry season, indicating that the shallow groundwater is influenced by saline water. In the dry season, the EC values increased in the

higher EC zone from Keshabpur thana to Jessore Sadar thana.

General water quality samples were collected from 30 existing wells. The results of 23 existing shallow wells show that the chemical composition of groundwater from Chuadanga district to central Jessore district is characterized by Ca-HCO_3 type. However, the shallow groundwater in the southern part of Jessore district shows Na-Cl type.

CHAPTER 5 INVESTIGATION OF DEEP AQUIFERS

1) Drilling Sites

Six core borings with depths of 300 m were drilled at two sites each in Chuadanga, Jhenaidah and Jessore Districts. The observation wells (depth = 300 m) and observation holes (depth = 50 to 300 m) were also constructed at two sites each in Chuadanga, Jhenaidah and Jessore Pourashava. In addition, one deep observation well was drilled at Keshabpur thana, Jessore district in order to confirm productivity and water quality of the deep aquifer.

2) Subsurface Geology and Aquifer Classification

In the districts of Chuadanga and Jhenaidah, the subsurface geology up to 300 m in depth consists mainly of fine to medium sand in the shallow zone (A and B formations), medium sand to gravel in the middle zone (C formation), and fine to medium sand with silt in the deeper zone (D and E formations). These aquifers are named as First Aquifer (Shallow Aquifer, A and B formations), Second Aquifer (Middle Aquifer, C formation), and Third Aquifer (Deep Aquifer, D and E formations), respectively. The former two aquifers can be correlated with Shallow aquifers used by BGS and DPHE (2001) and the latter one aquifer corresponds to Deep Aquifer by BGS and DPHE (2001). There is no thick clay layer between the Shallow-Middle Aquifers and Deep Aquifer. On the other hand, the sediment is generally fine in grain size in the southern part of the study area. A thick clayey layer occurs in C formation in the southern and western parts of Jessore district. The thickness of the clayey layer increases towards the south. This clayey layer contributes as an aquiclude, which separates the Deep Aquifer from the Shallow Aquifer. In the southern part of the study area, Second Aquifer (Middle Aquifer) does not occur because of the clayey facies of C formation.

3) Results of Core Boring and Geophysical Logging

The resistivity logs at CH-2 site in Chuadanga Pourashava clearly show that Second Aquifer has high resistivity values. On the other hand, Third Aquifer (= Deep Aquifer) has lower resistivity. The bottom depths of Second Aquifer are about 160 m in Chuadanga Pourashava, about 190 m in Jhenaidah Pourashava, and about 220 m in Jessore Pourashava.

According to the core boring and the test well drilled in Keshabpur thana in Jessore district, the upper part of A formation consists of clay and peat. The shallow aquifer is distributed from

about 50 to 100 m in depth. A clayey layer occurs at depths from 90 to 219 m. The deep aquifer is distributed below 220 in depth.

4) Arsenic in Soil and Groundwater

Arsenic in soil and groundwater was examined at three sites in the study area. The total arsenic content in the core samples at depths shallower than 200 m are not high, showing less than 10 ppm at CH-2 site in Chuadanga Pourashava. The result of the leachate test also shows the arsenic released by the test was very small in the shallower portion. However, the arsenic concentration at depths from 44.5 to 53.5 m at Ch-2-1 hole shows groundwater highly contaminated by arsenic ranging from 0.12 to 0.23 mg/l. The arsenic concentration in groundwater decreases with depth. In the deeper portion below 200 m in depth, the highest total arsenic content of 117.3 ppm was found in silty clay sample at depths from 207.50 to 207.72 m and the values from 20 to 50 ppm were also found at depths from 210 to 250 m. However, the arsenic concentrations in groundwater measured in Ch-2 well and Ch-2-4 hole were very small, showing below 0.002 mg/l.

Previous studies in Bangladesh show that the arsenic source mainly occurs in shallow portions within a depth of 100 m. However, in the study, the arsenic source was found not only in the shallow portion but also in the middle and deep portions (100 to 300 m in depth).

5) Arsenic Concentrations in Deep Groundwater

The arsenic concentrations in groundwater were monitored for more than 6 months at the newly constructed observation wells/holes. The groundwater in the deep aquifer is not contaminated by arsenic in most areas. Out of 15 observation wells/holes, the groundwater taken from Jh-CB-2 hole in Krishna Chandrapur village, Jhenaidah district was contaminated by arsenic, exceeding the Bangladeshi standard value (= 0.05 mg/l) in 5 out of 8 measurements.

6) Groundwater Quality of Deep Groundwater

A total of 27 water quality parameters including heavy metals were analyzed in a laboratory in Bangladesh.

The groundwater samples for the general groundwater quality analysis were taken during the pumping test at all the observation wells/holes except the observation holes in the model rural villages. The monthly groundwater quality monitoring was performed at observation wells in Pourashava areas and the model rural villages.

The chemical composition of deep groundwater is different from that of shallower groundwater even though there is no thick clayey layer between the Middle Aquifer and Deep Aquifer. The chemical composition of shallow groundwater within 150 m in depth are almost the same. It was found that the chemical composition of deep groundwater was different from the shallower

groundwater at all the Pourashava drilling sites.

The safety of deep groundwater for drinking purposes was examined by comparing sample values with the Bangladesh standard and the WHO guideline values. There is no sample exceeding both standard/guideline values in cadmium, total chromium, copper, cyanide, mercury, zinc, fluoride, sodium, chloride, sulfate, nitrate, and TDS (Total Dissolved Solids) concentrations. However, three samples taken from Jhenaidah Pourashava exceeded the WHO guideline value for lead (= 0.01 mg/l), but the values were lower than the Bangladesh standard (= 0.05 mg/l). The samples were taken during the pumping test. There is one sample from Js-CB2 observation hole exceeding the WHO guideline value for nickel (=0.02 mg/l). However, the value (= 0.037 mg/l) was lower than the Bangladeshi standard value of 0.1 mg/l.

Regarding the health impact, the most important parameter other than arsenic is manganese for deep groundwater used for drinking in the study area. The WHO health guideline value of manganese is 0.5 mg/l, whereas the guideline value that may give rise to complaints from consumers is 0.1 mg/l. The Bangladesh standard value of manganese is set at 0.1 mg/l. Out of 87 samples taken from the deep observation wells/holes, 50 samples exceeded 0.1 mg/l and 15 samples exceeded 0.5 mg/l. Among the 15 observation wells/holes, the manganese concentrations were almost continuously higher than 0.5 mg/l at Js-1 and Js-2 observation wells and Js-1-4 observation hole in Jessore Pourashava. It is necessary to treat manganese when the groundwater is used for drinking purposes.

7) TEM Survey and Hydrogeologic Structure

Transient electromagnetic survey (TEM) and electric prospecting using the Schlumberger electrode configuration were used for the geophysical survey. The TEM measurements were carried out at 200 points in the study area. The TEM results clearly show the occurrence of subsurface resistivity layers up to a depth of 400 m. The high resistivity layer, which corresponds to Second Aquifer (= Middle Aquifer) can be traced widely in most parts of the study area at depths from 100 to 200 m. However, the high resistivity layer cannot be found in the southern part of the study area because C formation mainly consists of clayey layers. In deeper zone with depths more than 200 m, the resistivity values are generally low, but there are some areas where high resistivity layers occur at depths from 250 to 300 m in Chuadanga district and the southern part of Jessore district.

CHAPTER 6 STUDY IN MODEL RURAL AREAS

Three model rural areas were selected based on the carefully considered criteria for conducting several activities to prepare the master plan to cope with the arsenic problem in the study area. One village per district was selected as the model rural area; those are Rajnagar Bankabarsi in

Keshabpur thana of Jessore District, Krishna Chandrapur in Moheshpur thana of Jhenaidah district, and Bara Dudpatila in Damurhuda thana of Chuadanga district.

The groundwater quality of all the existing wells and selected pond water quality were tested. The result of arsenic analysis of groundwater measured in October 2000 shows that the degree of arsenic contamination in the existing wells varies by village. About 2/3 of the wells in Bara Dudpatila are contaminated. In Krishna Chandrapur, about 3/4 of the wells are contaminated. All the tubewells except the DPHE deep tubewell in Rajnagar Bankabarsi village are contaminated. The second arsenic measurements were carried out in December 2000. The distribution patterns of arsenic concentration are similar to the patterns in October. There are minor increases/decreases in arsenic concentrations at each village. Most of the pond water samples show arsenic concentrations below 0.01 mg/l. The maximum arsenic level is 0.02 mg/l in Rajnagar Bankabarsi.

An intensive socio-economic study of the model rural areas was conducted. Bara Dudpatila has about 2,300 villagers and 515 households. All the households depend on shallow tubewells for their drinking water; there are 175 tubewells mainly owned by individuals. Seventy-three (73) arsenicosis patients have been diagnosed, and most of them are drinking water from the tubewells located in the center of the village.

Krishna Chandrapur has about 1,000 villagers and 220 households. All the households depend on shallow tubewells for their drinking water; there are 115 tubewells mainly owned by individuals. The tubewells with water containing higher arsenic concentrations are located to the east of the unpaved road dividing the village. About 80% of the 45 arsenicosis patients in the village are living in one para.

Rajnagar Bankabarsi has about 1,800 villagers and 380 households. About 70% of the households depend on the DPHE deep tubewell located at the edge of the village for their drinking water, and the remaining 30% on shallow tubewells. There are 23 arsenicosis patients diagnosed. Although almost all the tubewells have 0.05 mg/l or more of arsenic in the water, the ratio of arsenicosis patients to population at risk is lower compared to the other two villages.

One of the common features of the model rural areas is that the average household with five members is estimated to consume about 45 liter of water for drinking and cooking purposes (excluding washing dishes and pots) during the rainy season. Water consumption during the dry season would increase by 10 to 15%. Although there are only several hundred households in one village, a large gap in economic conditions exists among villagers. The annual cash income per capita is more than 11,000 Tk for wealthy households while less than 3,000 Tk for the other end.

The study team has encouraged villagers to form a community organization to lead community activities related to arsenic problems. Each model rural area has already set up an organization with about 20 members and held meetings to discuss the aforementioned subjects and awareness raising activity. The study team organized a training seminar for village representatives and

assisting NGO staff on raising villagers' awareness of arsenic problems. Door to door visits and courtyard meetings have been held and are still ongoing to educate villagers through a picture-story show about a rickshaw driver who is suffering from arsenicosis.

CHAPTER 7 ARSENIC CONTAMINATION MEASURES

Based on the various field works done by the study team, several arsenic mitigation measures were proposed and examined. For urban water supply, problems of existing water supply facilities were pointed out. Then an improvement plan of the Pourashava water supply systems was proposed.

Regarding the arsenic removal equipment, five arsenic removal technologies, i.e. double bucket system, aeration/sedimentation/filtration system, adsorption system by activated alumina, basin type solar still, and vacuum type solar still, were installed in the model rural areas. The monitoring of the arsenic removal technology was continued until November 2001.As a result, three technologies have been recommended. They are aeration/passive sedimentation and solar distillation combined with rain water harvesting and an adsorption based arsenic removal device.

The possibility, availability and feasibility of alternative water sources such as pond water and rain water harvesting are evaluated based on the actual conditions in the study area.

Three types of improved deep wells were constructed in each model rural area. The construction methods and effectiveness of sealing methods were evaluated. The monitoring of groundwater taken from the improved deep wells was continued until January 2002.

Summarizing the available information/data on the groundwater conditions in the study area, preparations for a groundwater development plan of deep aquifers was made. The merits and demerits of deep groundwater development were evaluated. Then the basic policies and preparations for the optimal development plan of deep aquifers were examined for sustainable use.

CHAPTER 8 MECHANISM OF ARSENIC CONTAMINATION AND DEEP AQUIFER EVALUATION

Many research works on the mechanism of arsenic contamination have been carried out since 1990's. This study reviewed source, dissolution and transportation of arsenic according to the papers published in the past 10 years.

The study revealed that the arsenic content of more than 30 mg/kg is contained not only in the shallow bed at 10 to 20 m depth but also in the deep bed at 200 to 300 m depth according to the core boring and its analysis at 6 sites in the study area. The arsenic in the shallow bed is thought

to be “active” and elution in the shallow bed is mainly concerned with contamination of groundwater.

The groundwater of the study area is characterized by low oxidation –reduction potential (Eh) and high iron concentration. Therefore, it is most likely that the dissociation of ferric oxyhydroxide and release of iron and arsenic ion into the groundwater occur under the reduction condition.

The dissolved arsenic migrates along with movement of groundwater. Groundwater pumpage increased since 1980’s especially in the irrigation wells in the study area. The pumpage of the year 2000 is estimated to be 15.1 MCM, which is 4.5 times of the pumpage in the year 1983. Such a huge amount of groundwater extraction caused groundwater decline and triggered leakage and squeeze of arsenic dissolved pore water from aquiclude.

A computer simulation study was conducted by using 2-D and 3-D groundwater flow and solute-transport model to simulate the movement of arsenic contaminated groundwater. The results of groundwater simulation revealed groundwater levels decline in the lower part of the shallow aquifer that was caused by the heavy pumping of the irrigation wells. Due to decline, arsenic contaminated groundwater of the upper part of the shallow aquifer is pulled into the depression zone. Regionally, groundwater flows toward the lower part of the shallow aquifer from the middle and the deep aquifer. However, the aquiclude prevents upward groundwater flow from the deep aquifer in the southern Jessore District. Moreover, the regional groundwater flow from the northern and southern part of the study area is prevented from flowing into the deep aquifer in the southern Jessore District because of the presence of the aquiclude (clay layer of C formation).

The deep groundwater in the southern part of Jessore district is free from arsenic and safe at present. However, groundwater levels will be declined by small amount of pumpage because the specific capacity and transmissivity is smaller than that of the shallow and the middle aquifers. Accordingly, safety of the deep groundwater is assured unless huge amount of groundwater is extracted by the irrigation wells, which may develop the deep aquifer in the future.

CHAPTER 9 MASTER PLAN

The master plan for arsenic mitigation in the study area has been prepared in accordance with the National Policy for Safe Water Supply & Sanitation 1998 of MLGRD&C. The objective of the master plan is to supply arsenic-safe drinking water to people mainly by the development of groundwater in deep aquifers. The target year of the master plan is 2010.

The master plan has been prepared based on the strategic viewpoints considering the hydrogeologic structures that control the groundwater flow in the study area. The study area is divided into Urgent Area, Semi-Urgent Area and Observation area based on the conditions of

groundwater contamination by arsenic in the shallow aquifer.

Prior to implementation of the master plan, the screening of all wells with mapping should be conducted and the countermeasures should be adopted by zoning of arsenic affected areas.

The master plan is composed of short-term, mid-term and long-term plans for the rural and urban water supplies. Facilities of the rural water supply plan consist of deep hand tube wells, a pond sand filter, a rainwater harvesting system and arsenic removal devices. Education for the residents is also included. Countermeasure for urban water supply consists of the construction of arsenic removal facilities, and the rehabilitation and expansion of existing water supply systems. In the presently unsupplied area, the foundation of water rickshaw corps, introduction of water tank truck, construction of overhead tank and pipeline with public stand post are planned.

The regional rural water supply system is proposed as one of the important mid-term mitigation measures by the study. The regional rural water supply system can be adapted to the northern urgent area and semi-urgent area where the clayey layer in C formation does not exist. The merits of this system are (1) utilizing exiting Pourashava water supply facilities in some thanas, (2) better operation and maintenance even in some case water treatment is necessary, and (3) better management and control of groundwater quality and quantity. This system could be a model of a safe drinking water supply using the deep groundwater resources for arsenic mitigation in Bangladesh.

CHAPTER 10 PRIORITY PROJECTS

Four priority projects were selected from the master plan. A pre-feasibility study was carried out. The cost was estimated on the basis of local prices in Bangladesh.

1) Deep Groundwater Development in Keshabpur Upazila

The project will supply arsenic safe deep groundwater to 61 mouzas (population about 84,000) of Keshabpur thana located in the Urgent Area in the southern part of Jessore district. The water supply system is composed of a deep well (depth: 300 m), an elevated tank, pipeline and public faucets constructed in the center of the village. The project cost is estimated at 624 million Tk. The O&M cost is 23.9 Tk per month per person. The alternative water supply facility is the level 1 system which is composed of a deep well with hand pump. In this alternative plan, the cost is estimated at 278 million Tk and the O&M cost is estimated at 3.7 Tk per month per person.

2) Rehabilitation and Expansion of 3 Pourashava Water Supply Systems (PWSS)

Three Pourashava water supply systems will be rehabilitated and expanded. Several production wells in the PWSS of Chuadanga , Jhenaidah and Moheshpur have already been contaminated

with arsenic. The deep well, elevated tank, treatment plant, pipeline and public stand post are rehabilitated and/or newly constructed. The project cost is estimated at 388 million Tk. On the other hand, the water charge to meet the O&M cost will be 200 Tk per month per connection.

The other two projects are: **Provision of arsenic free water to socially vulnerable sectors by Rain Water Harvesting** and **Solar Distillation (RWH/SD) system and the Establishment of Upazila arsenic mitigation promotion centers.** According to the preliminary financial and economical evaluation, these projects are feasible.

CHAPTER 11 SUPPLEMENTARY SURVEY IN KESHABPUR AREA

In order to examine the possibility of the deep groundwater development in the Keshabpur area, which is one of the four priority projects, a supplementary survey was conducted covering 16 mouzas in Keshabpur thana.

The number of existing shallow tube wells in the 16 mouzas totaled 3,037 excluding irrigation wells. Most of the study area shows arsenic concentrations at around 0.2 to 0.5 mg/l and lesser contaminated areas are observed in the western and southern parts.

An observation well was drilled at the center of Brahmakati mouza in order to confirm the hydrogeologic conditions and the arsenic concentrations in the deep aquifer. The borehole encountered a coarse sand and gravel layer at a depth of 287 m, which continues up to the bottom of the borehole, 298 m in depth. A step-drawdown test, continuous pumping test and recovery test were conducted after the completion of the well development, which resulted in the transmissivity of 2.450 m^2/day and storage coefficient of 5.87E-1. The aquifer capacity is not so high but it is considered to be sufficient for domestic water use. Groundwater samples were collected during the step-drawdown test and continuous test. The analysis with AAS showed all the samples were below the Bangladesh standard, 0.05 mg/l, which assures the deep aquifer is safe from arsenic in this area.

Social survey results indicate that villagers' willingness to pay (WTP) for safe water is 30 Tk per month per household. The survey results also suggest that the activities to raise villagers' awareness about arsenic poisoning are effective in raising villager's WTP.

Considering the physical conditions of settlements such as density and people's solvency, two types of water supply facilities were designed. A deep well with a hand pump (level 1) shall be installed for the rural areas and a deep well with an elevated tank and a motorized pump (improved level 1) for the urbanized areas in Keshabpur and Altapol mouzas. According to the estimation, a total of one hundred and eighty deep wells for the level 1 and three deep wells for the improved level 1will be required to supply water to all 16 mouzas. The project cost amounts to approximately 95 million Tk. The O&M cost is 16 Tk per month per household in the rural

areas with the level 1and 105 Tk in the urban areas with the improved level 1. In this case, peoples' WTP for the improved level 1 system must be studied further.

CHAPTER 12 CONCLUSIONS AND RECOMMENDATIONS

The arsenic contaminated areas are extended in the western part of the study area of 3 districts. The area of contamination of more than 0.1 mg/l (*Urgent Area*) occupies 670km^2 where about 510 thousand people are living in 319 mouza. In addition, the area of contamination of more than 0.05 mg/l and less than 0.1 mg/l (*Semi-Urgent Area*) reaches to 1,221km^2 and about 890 thousand people are living in 517 mouza. The study formulated a *Master Plan*, which is targeting the year-2010 and supplies arsenic safe water to rural populations in *Urgent and Semi-urgent Area* in order to dispel a risk of arsenic contamination and secure safe and sanitary water. Four *Priority Projects* are selected and studied at pre-feasibility basis. Based on the analysis, all the projects thought to be feasible. Further detailed feasibility study is required before implementation.

The following recommendations were presented based on the study.

(1) Groundwater development and management

(2) Investigation of deep aquifer

(3) Water supply plan for rural and urban

1) Early implementation of the project

2) Construction of regional rural water works

3) Improvement of Pourashava Water Supply System (PWSS)

(4) Dissemination activity on the arsenic problem

(5) Business plan for arsenic analysis laboratory established in Jhenaidah DPHE

(6) Utilization of GIS constructed and stored with software in the DPHE computer

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