

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).

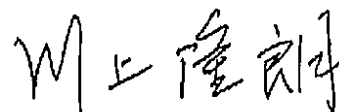
JICA dispatched a study team headed by Dr. Akira Kamata of Kokusai Kogyo Co., Ltd. and Mitsui Mineral Development Engineering Co., Ltd. to Bangladesh, four times between May 2000 and November 2002. In addition, JICA set up an Advisory Committee headed by Mr. Hisao Ushiki of JICA expert between May 2000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

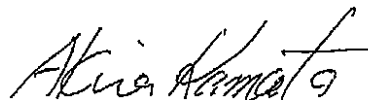
This report compiles the results of the study which was undertaken in the People's Republic of Bangladesh, from May 2000 to November 2002 by the Study Team, organized by Kokusai Kogyo Co., Ltd. and Mitsui Mineral Development Engineering Co., Ltd.

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.

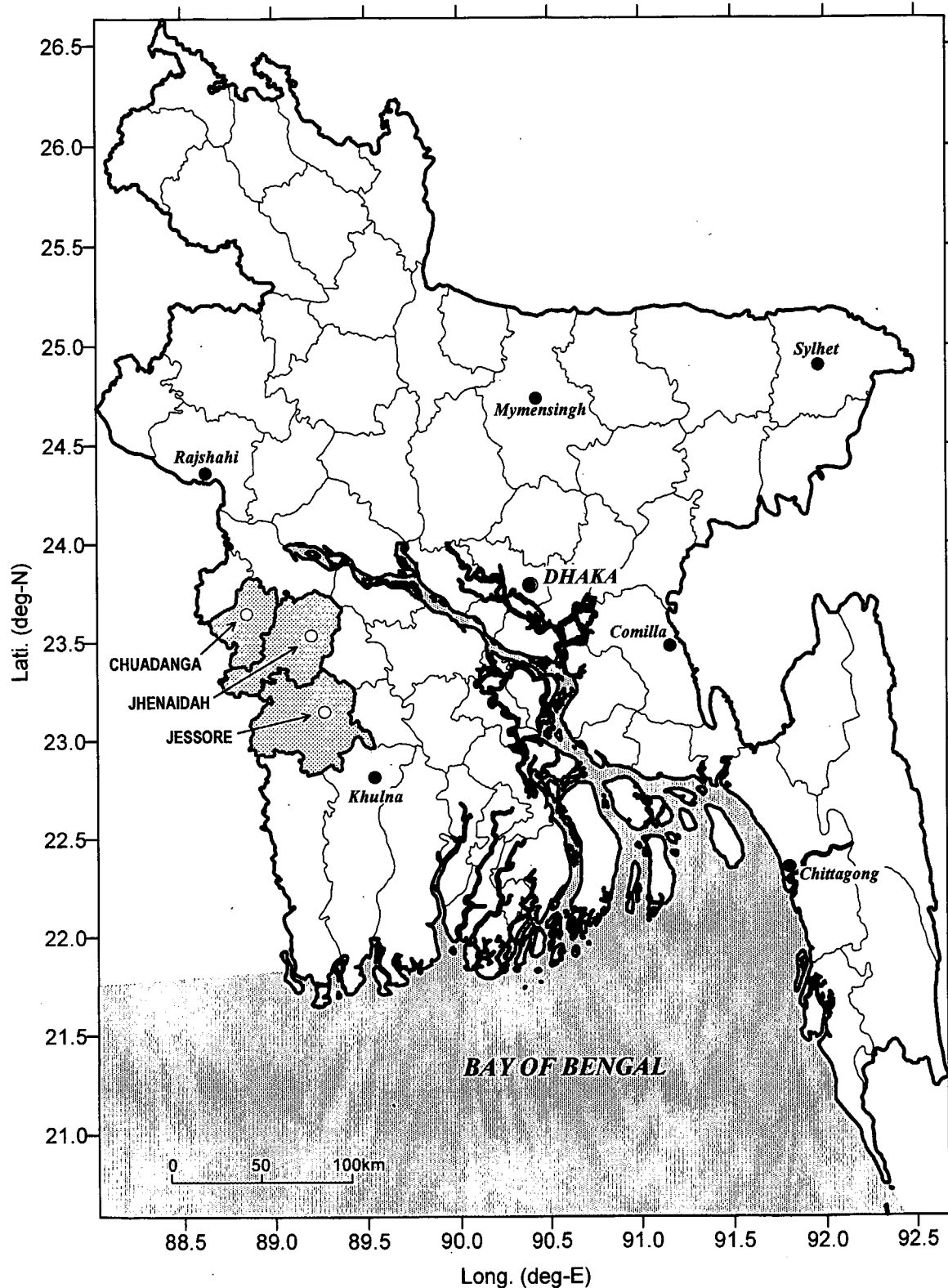
We also acknowledge and appreciate greatly the excellent support given by your agency, the JICA Advisory Committee and the Embassy of Japan in the People's Republic of Bangladesh.

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-HCO₃ 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 m²/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 1 will 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 1 and 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 670km² 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 1,221km² 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

PREFACE	
LETTER OF TRANSMITTAL	
LOCATION MAP	
ABBREVIATIONS	
EXECUTIVE SUMMARY	

CONTENTS

BOOK 1

CHAPTER 1 INTRODUCTION

1.1	Background of the Study	1-1
1.2	Objectives of the Study	1-3
1.3	Study Area.....	1-3
1.4	Study Implementation.....	1-3
1.5	Study Team	1-4

CHAPTER 2 NATURAL ENVIRONMENT OF THE STUDY AREA

2.1	Climate	2-1
2.1.1	Overview of Climatic Conditions	2-1
2.1.2	Rainfall and Evaporation in the Study Area.....	2-4
2.2	Hydrology	2-37
2.2.1	Drainage Pattern	2-37
2.2.2	River Flow	2-37
2.3	Topography and Geology	2-43
2.3.1	Topography	2-43
2.3.2	Geology.....	2-43
2.4	Groundwater	2-51

CHAPTER 3 SOCIO-ECONOMY AND WATER SUPPLY

3.1	Socio-Economy	3-1
3.1.1	Population	3-1

3.1.2	Socio-Economy	3-2
3.1.3	National Account	3-11
3.1.4	Water Supply and Sanitation Sector in the Current Fifth Five-Year Plan	3-15
3.2	Water Supply Conditions.....	3-25
3.2.1	Water Sources in the Study Area	3-25
3.2.2	Urban Water Supply	3-27
3.2.3	Rural Water Supply	3-34
3.3	Village Conditions in the Study Area	3-42
3.3.1	Methodology of Information Collection.....	3-42
3.3.2	Village Conditions	3-42

CHAPTER 4 ACTUAL CONDITION OF ARSENIC CONTAMINATION IN GROUNDWATER

4.1	Present Conditions of 300 Existing Wells	4-1
4.1.1	Objective of the Survey	4-1
4.1.2	Selection of the 300 Existing Wells	4-1
4.1.3	Well Structure.....	4-5
4.1.4	Groundwater Level.....	4-8
4.2	Arsenic Contamination in Rainy Season.....	4-31
4.2.1	Arsenic Analysis by AAS	4-31
4.2.2	Arsenic Analysis by Field Kit	4-32
4.2.3	Groundwater Quality	4-33
4.3	Arsenic Contamination in Dry Season	4-54
4.3.1	Arsenic Analysis by AAS	4-54
4.3.2	Arsenic Analysis by Field Kit	4-56
4.3.3	Groundwater Quality	4-57
4.3.4	Comparison of FK and AAS	4-59
4.4	General Water Quality.....	4-89
4.4.1	Trilinear Diagram Analysis.....	4-89
4.4.2	Stiff Diagram Analysis	4-90

CHAPTER 5 INVESTIGATION OF DEEP AQUIFERS

5.1	Core Borings	5-1
5.1.1	Purpose.....	5-1
5.1.2	Locations.....	5-1

5.1.3	Methodology.....	5-2
5.1.4	Subsurface Geology.....	5-3
5.1.5	Hydrogeological Classification	5-6
5.2	Drilling of Observation Wells/Holes.....	5-23
5.2.1	Purpose of Drilling.....	5-23
5.2.2	Site Selection	5-24
5.2.3	Drilling Configuration.....	5-24
5.2.4	Result of Drilling	5-25
5.3	Pumping Test	5-78
5.3.1	Purpose of Pumping Test	5-78
5.3.2	Methodology.....	5-78
5.3.3	Results of Step-Drawdown Test	5-80
5.3.4	Results of Continuous Pumping Test	5-81
5.3.5	Results of Recovery Test	5-84
5.3.6	Results of Pumping Test at Observation Holes	5-86
5.4	Arsenic Concentration.....	5-136
5.4.1	Purpose.....	5-136
5.4.2	Methodology.....	5-136
5.4.3	Arsenic Concentrations during Pumping Test	5-137
5.4.4	Arsenic Concentrations during Monitoring	5-139
5.5	General Water Quality.....	5-181
5.5.1	Purpose.....	5-181
5.5.2	Methodology.....	5-181
5.5.3	General Characteristics of Groundwater Quality.....	5-184
5.5.4	Monitoring Results of General Groundwater Quality.....	5-191
5.5.5	Relations between Arsenic and General Quality Parameters	5-200
5.5.6	Comparison with Bangladesh Standard and WHO Guideline	5-202
5.5.7	Re-Analysis of Water Quality for Observation Holes of which Hand Pumps are to be Installed, and Instruction on Their Use	5-215
5.5.8	Evaluation of General Water Quality.....	5-218
5.6	Core Sample Analysis.....	5-309
5.6.1	Geological Features of Core Samples	5-309
5.6.2	Core Sample Collection for Arsenic Analysis	5-319
5.6.3	Methodology of Core Sample Analysis	5-319
5.6.4	Results of Arsenic Analysis in Core Samples.....	5-321
5.6.5	Evaluation of Arsenic Analysis	5-324
5.7	Evaluation of Deep Aquifers.....	5-365

5.7.1	Quantitative Evaluation	5-365
5.7.2	Qualitative Evaluation	5-367
5.8	Regional Hydrogeologic Structures.....	5-385
5.8.1	Geological Profiles	5-385
5.8.2	Isopach Map of Clayey Layers.....	5-388

BOOK 2

CHAPTER 6 STUDY IN MODEL RURAL AREAS

6.1	Selection of Model Rural Areas.....	6-1
6.1.1	Definition of Model Rural Areas.....	6-1
6.1.2	Planned Activities in Model Rural Areas.....	6-1
6.1.3	Process of Model Rural Area Selection.....	6-3
6.1.4	Selected Villages for Model Rural Areas.....	6-4
6.1.5	Features of the Model Rural Areas	6-6
6.2	Overview of Socioeconomic Conditions in the Model Rural Area	6-12
6.2.1	General Characteristics of the Model Rural Areas	6-12
6.2.2	Water Fetching and Consumption.....	6-14
6.2.3	Arsenic Problems	6-16
6.3	Water Quality	6-18
6.3.1	Groundwater Quality	6-18
6.3.2	Pond Water Quality	6-23
6.4	Identification of Arsenicosis Patients.....	6-71
6.4.1	Preliminary Diagnosis of Arsenicosis Patients	6-71
6.4.2	Formal Diagnosis of Arsenicosis Patients	6-71
6.4.3	Tubewells Used by Arsenicosis Patients.....	6-72
6.4.4	Characteristics of Arsenicosis Patients	6-73
6.4.5	Treatment and Management of Patients.....	6-75
6.5	Awareness Raising Activities in the Model Rural Areas	6-80
6.5.1	Community Organization.....	6-80
6.5.2	Raising Awareness of Arsenic Problems.....	6-83
6.5.3	Awareness toward Arsenic Problems and Change in Water Sources.....	6-87
6.5.4	Awareness Raising Programs for the Future	6-89
Annex 6.5.1	Communication Material.....	6-96
Annex 6.5.2	Questionnaire for the Follow-up Interview	6-98
Annex 6.5.3	Information on Arsenic-Safe Water.....	6-99

CHAPTER 7 ARSENIC CONTAMINATION MEASURES

7.1	Improvement of Urban Water Supply.....	7-1
7.1.1	Problem of Existing Water Supply Facilities.....	7-1
7.1.2	Improvement Plan of Pourashava Water Supply Systems in Arsenic Affected Areas.....	7-3

7.1.3	Improvement of Pourashava Water Supply Systems.....	7-4
7.1.4	Organization and Management.....	7-7
7.2	Arsenic Removal Equipment.....	7-9
7.2.1	Objective	7-9
7.2.2	Basic Approach for Arsenic removal experiment.....	7-9
7.2.3	Design of Arsenic Removal Equipment.....	7-11
7.2.4	Site Selection and Installation	7-16
7.2.5	Field Test.....	7-24
7.2.6	Evaluation and Conclusion.....	7-47
7.3	Improved Deep Well.....	7-51
7.3.1	Necessity of the Improved Deep Well	7-51
7.3.2	Type of Improved Deep Well.....	7-52
7.3.3	Construction Methods of Improved Deep Well.....	7-53
7.3.4	Results of Improved Deep Well Construction.....	7-61
7.3.5	Comparison of Improved Deep Well Types.....	7-71
7.3.6	Technological Transfer	7-74

CHAPTER 8 MECHANISM OF ARSENIC CONTAMINATION AND DEEP AQUIFER VALUATION

8.1	Review of Hypothesis on Arsenic Contamination Mechanism	8-1
8.1.1	Research History.....	8-1
8.1.2	Stage of Arsenic Contamination	8-3
8.1.3	Accumulation (Source) of Arsenic.....	8-3
8.1.4	Dissolution of Arsenic.....	8-5
8.1.5	Transport of Arsenic	8-6
8.1.6	Arguments on Mechanism Hypotheses	8-6
8.1.7	Evaluation of Mechanism Hypotheses	8-7
8.1.8	Cause of Contamination (Natural or Artificial?)	8-9
8.2	Hydrogeologic Structure and Contamination Mechanism	8-15
8.2.1	Occurrence of Arsenic Source	8-15
8.2.2	Arsenic Source and Hydrogeologic Structure	8-16
8.2.3	Contamination Mechanism.....	8-17
8.3	Simulation of Groundwater Contamination	8-21
8.3.1	Purpose of Groundwater Simulation	8-21
8.3.2	Methodology.....	8-21
8.3.3	Vertical 2-D Local Model	8-23

8.3.4	3-D Regional Model	8-59
8.3.5	Vertical 2-D Regional Model.....	8-170
8.4	Evaluation on Possibility of Deep Groundwater Development.....	8-182
8.4.1	Evaluation of Present Groundwater Flow Conditions.....	8-182
8.4.2	Impact of Future Deep Groundwater Development	8-183
8.4.3	Necessary Measures to Use Deep Groundwater.....	8-184
8.4.4	Necessary Research to Confirm Deep Groundwater Safety.....	8-184

CHAPTER 9 MASTER PLAN

9.1	Basic Policy.....	9-1
9.2	Zoning of Arsenic Contaminated Area.....	9-3
9.3	Screening and Mapping	9-6
9.4	Arsenic Contamination Mechanism and Direction for Measures	9-7
9.5	Master Plan Framework	9-8
9.5.1	Study	9-8
9.5.2	Measures for Rural Area	9-10
9.5.3	Measures for Urban Areas	9-12
9.5.4	Research& Development and Monitoring	9-14
9.6	Operation & Maintenance and Dissemination Activities.....	9-16
9.6.1	Operation & Maintenance Plan	9-16
9.6.2	Dissemination Activities.....	9-16

CHAPTER 10 PRE-FEASIBILITY STUDY OF THE PRIORITY PROJECTS

10.1	Rural Water Supply for Keshabpur by Groundwater from Deep Aquifers.....	10-1
10.1.1	Background of Project.....	10-1
10.1.2	Summary of Plan.....	10-1
10.1.3	Target Area of the Project.....	10-2
10.1.4	Screening	10-2
10.1.5	Public Education	10-2
10.1.6	Capacity Building	10-3
10.1.7	Water Supply Facility.....	10-4
10.1.8	Operation Cost.....	10-6
10.1.9	Implementation of the Project	10-7
10.1.10	Work Schedule.....	10-8

10.1.11	Operation and Maintenance.....	10-10
10.1.12	Water Quality Monitoring.....	10-12
10.1.13	Alternative Plans for Water Supply Facility / Maintenance.....	10-13
10.1.14	Feasibility Study	10-15
10.1.15	Proposal for Feasibility Study.....	10-16
10.2	Urban Water Supply Facilities Improvement and Expansion Project	10-17
10.2.1	Background.....	10-17
10.2.2	General Condition of Three Pourashavas and Content of Plan	10-17
10.2.3	Preliminary Construction Cost.....	10-24
10.2.4	Annual Operation and Maintenance Cost	10-25
10.2.5	Construction Period.....	10-25
10.3	Provision of Arsenic Free Water to Socially Vulnerable Sectors by Rainwater Harvesting and Solar Distillation (RWH/SD) System	10-26
10.3.1	Objective and Justification	10-26
10.3.2	Project Description	10-26
10.3.3	Scope for Feasibility Study.....	10-28
10.4	Establishment of Thana Arsenic Mitigation Promotion Center	10-31
10.4.1	Objective and Justification	10-31
10.4.2	Project Description	10-32
10.4.3	Scope for Feasibility Study.....	10-32
10.5	Project Appraisal	10-35
10.5.1	Project Appraisal of Rural Water Supply for Keshabpur by Groundwater from Deep Aquifers.....	10-35
10.5.2	Project Appraisal of Piped Arsenic Free Water Supply in the Urban Area.....	10-40
10.5.3	Preliminary Project Appraisal of Arsenic Free Water Supply to Socially Vulnerable Sectors by Rainwater Harvesting and Solar Distillation (RWH/SD) System	10-43
10.5.4	Preliminary Project Appraisal of Thana Arsenic Mitigation Promotion Center	10-44
10.6	Regional Rural Water Works.....	10-45
10.6.1	Purpose and Design Criteria	10-45
10.6.2	Water Supply Facilities Plan.....	10-47
10.6.3	Preliminary Construction Cost Estimate.....	10-48

CHAPTER 11 SUPPLEMENTARY SURVEY IN KESHABPUR AREA

11.1	Screening Survey.....	11-2
------	-----------------------	------

11.1.1	Site Selection	11-2
11.1.2	Survey Items and Method	11-4
11.1.3	Results	11-4
11.2	Well Drilling and Pumping Test.....	11-62
11.2.1	Observation Well.....	11-62
11.2.2	Pumping Test	11-64
11.2.3	Hydrogeological Structure in Keshabpur Area	11-65
11.3	Results of Socio-Economic Study	11-79
11.3.1	General Features of Mauza	11-79
11.3.2	General Features of Households	11-79
11.3.3	Consideration on Sustainability of Improved Water Supply System	11-80
11.4	Water Supply Facilities Plan.....	11-81
11.4.1	Arsenic Mitigation Strategy.....	11-81
11.4.2	Selection of Water Supply System.....	11-83
11.5	Water Supply Facilities and Construction Cost	11-85
11.5.1	Water Supply Area	11-85
11.5.2	Water Supplied Population and Water Consumption	11-85
11.5.3	Water Supply Facility.....	11-85
11.5.4	Total Project Cost	11-87
11.5.5	Implementation of the Project	11-87
11.5.6	Operation and Maintenance Cost	11-89
11.6	Issues on the Implementation of the Project	11-89
11.6.1	Implementation Body	11-89
11.6.2	Organization for O&M	11-90
11.6.3	Dissemination Activities.....	11-90
11.6.4	Monitoring	11-90

CHAPTER 12 CONCLUSIONS AND RECOMMENDATIONS

12.1	Conclusions.....	12-1
12.1.1	Arsenic Contamination	12-1
12.1.2	Arsenic Contamination by Depth.....	12-1
12.1.3	Hydrogeologic Unit and Aquifer Capacity.....	12-2
12.1.4	Arsenic Contamination Mechanism.....	12-3
12.1.5	Safety of Deep Groundwater.....	12-4
12.1.6	Technology for Arsenic Measures	12-5
12.1.7	Socio-economic Study in the Model Rural Area	12-7
12.1.8	Master Plan for Arsenic Measures	12-7

12.1.9	Priority Projects	12-9
12.1.10	Supplementary Survey in Keshabpur.....	12-10
12.2	Recommendations	12-11
12.2.1	Groundwater Development and Management	12-11
12.2.2	Investigation of Deep Aquifer	12-12
12.2.3	Water Supply Plan for Rural and Urban.....	12-12
12.2.4	Dissemination Activity on the Arsenic Problem	12-13
12.2.5	Arsenic Analysis Laboratory	12-13
12.2.6	Utilization of GIS	12-14

LIST OF TABLES

BOOK 1

Table 1.1	Administration Units, Population and Area of the Study Area.....	1-5
Table 2.1.1	List of meteorological stations in Bangladesh.....	2-6
Table 2.1.2	Average monthly precipitation in Bangladesh.....	2-7
Table 2.1.3	Monthly precipitation data at Jessore (WMO Station No.= 41936).....	2-8
Table 2.1.4	Monthly average temperature in Bangladesh	2-9
Table 2.1.5	Monthly average maximum temperature in Bangladesh	2-10
Table 2.1.6	Monthly average minimum temperature in Bangladesh	2-11
Table 2.1.7	Monthly average temperature at Jessore (WMO Station No.= 41936).....	2-12
Table 2.1.8	Monthly average maximum temperature at Jessore (WMO Station No.=41936)	2-13
Table 2.1.9	Monthly average minimum temperature at Jessore (WMO Station No.=41936)	2-14
Table 2.1.10	Computation of potential evapotranspiration at Jessore by Thornthwaite method	2-15
Table 2.1.11	Metrological Stations in the study area	2-16
Table 2.1.12	Monthly availability of daily meteorological data in the study area.....	2-16
Table 2.1.13	Monthly rainfall at Benapol	2-17
Table 2.1.14	Monthly rainfall at Chaugacha	2-17
Table 2.1.15	Monthly rainfall at Chuadanga.....	2-18
Table 2.1.16	Monthly rainfall at Jessore.....	2-18
Table 2.1.17	Monthly rainfall at Jhenaidah.....	2-19
Table 2.1.18	Monthly rainfall at Kaliganj	2-19
Table 2.1.19	Monthly rainfall at Keshabpur	2-20
Table 2.1.20	Monthly rainfall at Sailkupa	2-20
Table 2.1.21	Monthly evaporation at Jessore.....	2-21
Table 2.1.22	Monthly average of daily evaporation at Jessore.....	2-21
Table 2.2.1	Mean monthly flows in the Padma River at Hardinge Bridge	2-39
Table 3.1.1	Major population and demographic indicators in Bangladesh.....	3-1
Table 3.1.2	Comparison of key demographic indicators among the three	

	districts.....	3-2
Table 3.1.3	Net primary school enrollment rate in the study area.....	3-6
Table 3.1.4	Comparison of key indicators on primary education among the three districts.....	3-6
Table 3.1.5	Comparison of adult literacy rate.....	3-7
Table 3.1.6	Comparison on the levels of medical facilities and human resources.....	3-7
Table 3.1.7	Current conditions of household latrine.....	3-8
Table 3.1.8	Percentage of the households with electricity in rural and urban areas of three districts.....	3-10
Table 3.1.9	Resources and allocation of the state budget in FY 2000/01.....	3-11
Table 3.1.10	Broad details of revenue receipts.....	3-12
Table 3.1.11	Allocation of non-development budget.....	3-13
Table 3.1.12	Resources for annual development programme.....	3-14
Table 3.1.13	Major achievements of water supply and sanitation sector in selected years (1990 to 1997).....	3-17
Table 3.1.14	Projections of development in water supply and sanitation sector for fifth plan (1997 to 2002).....	3-18
Table 3.2.1	General information on water sources in the study area.....	3-27
Table 3.2.2	Existing urban water supply system in the study area.....	3-29
Table 3.2.3	Operation & maintenance staffs of Pourashava water supply system.....	3-31
Table 3.2.4	Water supply system service time & service charge.....	3-32
Table 3.2.5	Average monthly financial statement for operation & maintenance of water supply system in the study area (TAKA).....	3-33
Table 3.2.6	General usage of water sources in the study area.....	3-34
Table 3.2.7	Existing DPHE tube wells in the study area.....	3-35
Table 3.2.8	Comparison of hand pumps.....	3-37
Table 3.2.9	DPHE standard for platform construction.....	3-37
Table 3.2.10	Existing arsenic mitigation technologies for rural water supply	3-38
Table 3.2.11	DPHE organizations in the study area.....	3-40
Table 3.2.12	DPHE organizational chart.....	3-41
Table 3.3.1	Population size of the villages.....	3-43
Table 3.3.2	Active local NGOs.....	3-45
Table 3.3.3	Daily water consumption for cooking and drinking by	

	household	3-46
Table 3.3.4	Number of users per well	3-47
Table 3.3.5	Community groups to manage communal wells for domestic water use	3-47
Table 3.3.6	Communal wells for agricultural use in village	3-48
Table 3.3.7	Community groups to manage communal wells for agricultural use.....	3-48
Table 3.3.8	Arsenic patients reported from village leaders.....	3-49
Table 3.3.9	Community meeting on arsenic problems.....	3-51
Table 3.3.10	Actions to tackle with arsenic problems in the villages.....	3-51
Table 3.3.11	Actions taken by villages based on the community discussions	3-52
Table 3.3.12	NGO's activity related to arsenic problems.....	3-55
Table 4.1.1	Allocation of target wells to the 3 districts	4-2
Table 4.1.2	List of 300 existing wells surveyed by the study	4-10
Table 4.1.3	Results of well structure survey for production wells in Jessore Pourashava	4-16
Table 4.1.4	Results of well structure survey for production wells in Jhenaidah district	4-17
Table 4.1.5	Results of well structure survey for production wells in Chuadanga Pourashava.....	4-18
Table 4.2.1	Results of 300 existing wells survey in rainy season [June to July 2000].....	4-36
Table 4.3.1	Results of 300 existing wells survey in dry season [December 2000 to January 2001].....	4-60
Table 5.1.1	Characteristics of stratigraphy in study area.....	5-8
Table 5.2.1	List of Drilled Observation Deep Wells/Holes and Their Specifications	5-37
Table 5.3.1	Results of Step-Drawdown Tests Performed at JICA Observation Deep Wells.....	5-92
Table 5.3.2	Results of Continuous Pumping Tests and Recovery Tests	5-93
Table 5.5.1	Analytical parameters and the standard numbers.....	5-183
Table 5.5.2	Results of Observation Well and Hole	5-222
Table 5.5.3	Results of Core Boring	5-229
Table 5.5.4	Results of Improved Deep Tubewell	5-230
Table 5.5.5	Results of 300 Existing Well Survey (Rainy season)	5-232
Table 5.5.6	Results of 300 Existing Well Survey (Dry season)	5-233

Table 5.5.7	Results of Baseline Survey (Existing Well)	5-234
Table 5.5.8	Results of Baseline Survey (Pond)	5-235
Table 5.5.9	Summarized results of Observation Wells and holes in Pourashava exceeding Bangladesh and WHO guideline.....	5-236
Table 5.5.10	Summarized results of Observation Wells and holes in Model Rural Areas exceeding Bangladesh and WHO guideline	5-242
Table 5.5.11	Results of improved wells exceeding Bangladesh standard and WHO guideline	5-244
Table 5.5.12	Results of existing wells exceeding Bangladesh standard and WHO guideline	5-244
Table 5.5.13	Results of existing wells in model rural areas exceeding Bangladesh standard and WHO guideline.....	5-245
Table 5.5.14	Results of pond water in the model rural areas exceeding Bangladesh standard and WHO guideline.....	5-245
Table 5.5.15	Deep wells (300m in depth) – explanation of samples containing general water quality parameters exceeding standard values.....	5-246
Table 5.5.16	Deep wells (300m in depth) – explanation of samples containing general water quality parameters exceeding standard values.....	5-248
Table 5.5.17	Results of observation holes (re-analysis)	5-249
Table 5.6.1	Characteristics of stratigraphy in each core boring site.....	5-325
Table 5.6.2	Number of core samples collected for arsenic analysis	5-328
Table 5.6.3	Result of core analysis at girls college, Chuadanga	5-329
Table 5.6.4	Result of core analysis at Bara Dudpatila, Damurhuda.....	5-331
Table 5.6.5	Result of core analysis at Arabpur, Jhenaidah Pourashava	5-333
Table 5.6.6.	Result of core analysis at Krishna Chandrapur.....	5-335
Table 5.6.7	Result of core analysis at Kharki, Jessore Pourashava	5-337
Table 5.6.8	Result of core analysis at Rajnagar Bankabarsi, Keshabpur	5-339

BOOK 2

Table6.1.1	Number of model rural area	6-3
Table6.1.2a	List of prospect villages for model rural area in Chuadanga	6-6
Table6.1.2b	List of prospect villages for model rural area in Jessore	6-7
Table6.1.2c	List of prospect villages for model rural area in Jhenaidah	6-7
Table6.1.3	Features of model rural areas	6-8
Table6.1.4	Socioeconomic conditions of model rural areas	6-9
Table6.2.1	General characteristics of the model rural areas and their implications to arsenic problem	6-12
Table6.2.2	Water fetching and consumption practices and their implications to arsenic problems	6-14
Table6.2.3	Characteristic of arsenic problems and their implications to mitigation measures	6-16
Table6.3.1	Groundwater quality in Bara Dudpatila village in October 2000	6-26
Table6.3.2	Groundwater quality in Krishna Chandrapur village in October 2000	6-29
Table6.3.3	Groundwater quality in Rajnagar Bankabarsi village in October 2000	6-31
Table6.4.1	Number of arsenicosis patients by sex	6-72
Table6.4.2	Population at risk of arsenicosis	6-74
Table6.5.1	NGOs assisting the model rural areas	6-81
Table6.5.2	Community organization in the model rural area	6-81
Table6.5.3	Community activities in Bara Dudpatila(Chuadanga)	6-82
Table6.5.4	Community activities in Rajnagar Bankabarsi(Jessore)	6-82
Table6.5.5	Community activities in Krishna Chandrapur(Jhenaidah)	6-83
Table6.5.6	Training program on raising awareness of arsenic	6-84
Table6.5.7	Awareness raising activity in model rural area	6-85
Table6.5.8	Ratio of the households harvesting rainwater	6-86
Table6.5.9	Change in water fetching time in Rajnagar Bankabarsi	6-87
Table6.5.10	Steps of awareness raising activities	6-90
Table7.1.1	Present population and coverage	7-5
Table7.1.2	Daily service time(Hour/day)	7-6
Table7.1.3	Average monthly financial statement for O&M in TAKA	7-7
Table7.2.1	Four categories of arsenic removal technologies	7-10
Table7.2.2	Summary of arsenic removal experiment plan	7-11

Table7.2.3	Large scale solar distillation units.....	7-14
Table7.2.4	Site selected for arsenic removal equipment, Bara Dudpatila.....	7-18
Table7.2.5	Intallation of arsenic removal equipment, Bara Dudpatila.....	7-20
Table7.2.6	Site selected for arsenic removal equipment, Krishna Chandrapur.....	7-21
Table7.2.7	Intallation of arsenic removal equipment, Krishna Chandrapur.....	7-22
Table7.2.8	Site selected for arsenic removal equipment, Rajnagar Bankabarsi.....	7-23
Table7.2.9	Intallation of arsenic removal equipment, Rajnagar Bankabarsi.....	7-23
Table7.2.10	Water quality of three villages	7-25
Table7.2.11	Initial Field Test of double bucket system	7-26
Table7.2.12	Test data of increased chemical dosing.....	7-27
Table7.2.13	Test data of tablet form.....	7-28
Table7.2.14	Test data of increased chemical dosing -2-.....	7-29
Table7.2.15	Test data of increased dosing of chemical and additional filtration	7-30
Table7.2.16	Test data of passive sedimentation in three villages	7-33
Table7.2.17	Test data of passive sedimentation by chemical oxidation.....	7-36
Table7.2.18	Monitoring of passive sedimentation units	7-38
Table7.2.19	Test data of activated alumina.....	7-40
Table7.2.20	Effect of increased activated alumina at Rajanagar Bankabarsi.....	7-40
Table7.2.21	Monitoring of activated alumina units	7-41
Table7.2.22	Test data of basin type solar distillation	7-42
Table7.2.23	Monitoring of basin type solar distillation units.....	7-44
Table7.2.24	Test data of vacuum type solar distillation unit.....	7-46
Table7.2.25	Evaluation of five technologies	7-48
Table7.3.1	Summary of drilling improved deep wells at Rajnagar Bankabarsi.....	7-63
Table7.3.2	Geologic log at Rajnagar Bankabarsi vil.....	7-64
Table7.3.3	Summary of drilling improved deep wells at Krishna Chandrapur.....	7-66
Table7.3.4	Geologic log at Krishna Chandrapur vil.	7-67
Table7.3.5	Summary of drilling improved deep wells at Bara Dudpatila	7-69
Table7.3.6	Geologic log at Bara Dudpatila village.....	7-70

Table7.3.7	Results of simple pumping tes.....	7-70
Table7.3.8	Characteristic and evaluation of improved deep well.....	7-73
Table8.3.1	Groundwater simulation models and programs used in the study	8-22
Table8.3.3.1	Assumed hydrogeologic conditions for vertical 2-D local model	8-25
Table8.3.4.1	Hydrogeological modeling for 3-D regional model	8-59
Table8.3.4.2	Type of groundwater pumpage data	8-63
Table8.3.4.3	Estimated annual water balance in the study area	8-64
Table8.3.4.4	Future ground water pumpage scenarios and cases	8-67
Table8.3.5.1	Identified input paramaters for vertical 2-D regional model.....	8-172
Table8.3.5.2	Future groundwater pumpage scenarios and cases used for the future simulation by vertical 2-D regional model	8-174
Table9.2.1	Classification of arsenic contaminated area	9-2
Table9.2.2	Population(coverage), number of wells and arsenic concentration	9-3
Table9.2.3	Zoning of arsenic contaminated area	9-4
Table10.1.1	Summary of water supply facility	10-6
Table10.2.1	General condition of three Pourashava water supply facilities	10-18
Table10.2.2	Population forecast	10-19
Table10.2.3	Unit water demand	10-19
Table10.2.4	Water demand forecast	10-19
Table10.2.5	Outline of the water supply facilities plan (Chuadanga)	10-21
Table10.2.6	Outline of the water supply facilities plan (Jhenaidah)	10-22
Table10.2.7	Outline of the water supply facilities plan (Moheshpur).....	10-23
Table10.2.8	Target year 2005	10-24
Table10.2.9	Target year 2010	10-24
Table10.2.10	Annual operation and maintenance cost	10-25
Table10.5.1	Outline of the project	10-35
Table10.5.2	Allocation of initial investment in construction period.....	10-36
Table10.5.3	Annual operation cost of the facility	10-36
Table10.5.4	Estimation of the water bill to cover O/M cost of the planned facilities	10-37
Table10.5.5	Outline of the rural water supply project by hand pump installation	10-38
Table10.5.6	Construction cost of the project.....	10-38
Table10.5.7	O/M cost of the facilities	10-39

Table10.5.8	Result of estimating key financial feasibility indicators.....	10-39
Table10.5.9	Outline of the project	10-40
Table10.5.10	Annual allocation of project cost (construction cost)	10-41
Table10.5.11	O/M cost of the facilities	10-41
Table10.5.12	Target number of house connection	10-41
Table10.5.13	Estimated project income in 2005 and 2010 (Meter Rate)	10-42
Table10.5.14	Estimated project income in 2005 and 2010 (Flat + Meter Rate)	10-42
Table10.5.15	Result of estimating key project feasibility indicators	10-43
Table10.5.16	Outline of the project	10-44
Table10.5.17	Outline of the project	10-44
Table10.6.1	Target Thanas, population and water demand.....	10-45
Table10.6.2	Designed water volume and average receiving capacity	10-47
Table10.6.3	Number of facilities.....	10-47
Table10.6.4	Preliminary construction cost estimate	10-48
Table11.1.1	List of 16 mouzas in Keshabpur area on supplementary survey	11-2
Table11.1.2	Results of screening survey (Ramlhandrapur: No.1 to No.122)	11-7
Table11.1.3	Results of screening survey (Byasdanga: No.1 to No.47).....	11-9
Table11.1.4	Results of screening survey (Brahmakati: No.1 to No.109)	11-10
Table11.1.5	Results of screening survey (Khatiakhali: No.1 to No.66)	11-12
Table11.1.6	Results of screening survey (Maguradanga: No.1 to No.89)	11-13
Table11.1.7	Results of screening survey (Baliadanga: No.1 to No.303).....	11-15
Table11.1.8	Results of screening survey (Sujapur: No.1 to No.100)	11-19
Table11.1.9	Results of screening survey (Altapol: No.1 to No.911).....	11-21
Table11.1.10	Results of screening survey (Surfabad: No.1 to No.50)	11-31
Table11.1.11	Results of screening survey (Bajitpur: No.1 to No.72)	11-32
Table11.1.12	Results of screening survey (Sabdia: No.1 to No.192)	11-34
Table11.1.13	Results of screening survey (Kesabpur: No.1 to No.226)	11-37
Table11.1.14	Results of screening survey (Madhyakul: No.1 to No.253)	11-40
Table11.1.15	Results of screening survey (Habaspol: No.1 to No.56)	11-44
Table11.1.16	Results of screening survey (Bhagati Narendrapur: No.1 to No.367)	11-45
Table11.2.1	Location of drilling site.....	11-62
Table11.2.2	Items of observation well.....	11-64
Table11.2.3	Results of step-drawdown test in Brahmakati.....	11-67

Table11.2.4	Results of continuous pumping test in Brahmakati	11-68
Table11.5.1	Water consumption for 16 mouza.....	11-85
Table11.5.2	Required water supply system by improved level 1	11-86
Table11.5.3	Total project outlay (Improved level 1 water supply facility)	11-87
Table11.5.4	Project implementation schedule.....	11-88
Table11.5.5	Operation & maintenance cost (per House hold)	11-89

LIST OF FIGURES

BOOK 1

Figure 2.1.1	Location of Meteorological Stations in Bangladesh.....	2-22
Figure 2.1.2	Distribution of Average annual precipitation in Bangladesh	2-23
Figure 2.1.3	Average monthly precipitation in Bangladesh.....	2-24
Figure 2.1.4	Average monthly temperature in Bangladesh.....	2-25
Figure 2.1.5	Average monthly potential evapotranspiration in Bangladesh.....	2-26
Figure 2.1.6	Correlation of annual rainfall(1)[Jessore-Faridpur, Jessore-Dhaka].....	2-27
Figure 2.1.7	Correlation of annual rainfall(2) [Jessore-Khulna, Jessore-Satkhira].....	2-28
Figure 2.1.8	Correlation of annual rainfall(3) [Jessore-Calcutta, Khulna-Satkhira].....	2-29
Figure 2.1.9	Probability analysis of annual rainfall [Jessore, Khulna]	2-30
Figure 2.1.10	Long-Term rainfall analysis(Calcutta, 1829 to 1990).....	2-31
Figure 2.1.11	Rainfall and evaporation stations in the study area	2-32
Figure 2.1.12	Average annual rainfall in the study area.....	2-33
Figure 2.1.13	Average monthly rainfall in the study area.....	2-34
Figure 2.1.14	Daily rainfall and evaporation in Jessore (1990-1992).....	2-35
Figure 2.1.15	Daily rainfall and evaporation in Jessore (1993-1994).....	2-36
Figure 2.2.1	River map of Bangladesh.....	2-40
Figure 2.2.2	Rivers and water bodies in the study area.....	2-41
Figure 2.2.3	Mean monthly flows in the Padma River at Hardinge Bridge	2-42
Figure 2.3.1	LANDSAT imagery of the study area.....	2-46
Figure 2.3.2	Ground elevation of the study area	2-47
Figure 2.3.3	Simplified geological map of Bangladesh	2-48
Figure 2.3.4	Geological sections in Jhenaidah district.....	2-49
Figure 2.3.5	Geological sections in Jessore district.....	2-50
Figure 2.4.1	Stratigraphy and aquifer unit classification in Samta, Jessore	2-52
Figure 3.1.1	Structure of GDP by industrial sector in Bangladesh (1990/91-1996/97).....	3-3
Figure 3.1.2	Structure of GDP by industrial sector in Jessore (1990/91-1997/98).....	3-4
Figure 3.1.3	Annual change of district GDP and agricultural sector.....	3-5

Figure 3.1.4	Sources of drinking water in rural areas of the three districts.....	3-8
Figure 3.1.5	Sources of drinking water in urban areas of the three districts.....	3-8
Figure 3.1.6	Conditions of toilet facilities in the rural areas of the three districts	3-9
Figure 3.1.7	Conditions of toilet facilities in the urban areas of the three districts.....	3-9
Figure 3.1.8	Sources of income by rural households in the three districts	3-10
Figure 3.1.9	Sources of income by urban households in the three districts	3-10
Figure 3.3.1	Population size of the 260 villages	3-61
Figure 3.3.2	Ratio of villages by region	3-61
Figure 3.3.3	Village ratio by prevalence of roof materials	3-62
Figure 3.3.4	Ratio of villages with daily food intake	3-62
Figure 3.3.5	Ratio of villages with community groups.....	3-63
Figure 3.3.6	Ratio of villages with mass media	3-63
Figure 3.3.7	Ratio of villages by common communication tools	3-64
Figure 3.3.8	Main sources of water	3-65
Figure 3.3.9	Water container & carrying tool	3-66
Figure 3.3.10	Activity of caretaker (communal wells for domestic water).....	3-66
Figure 3.3.11	Reward to management (communal well for domestic water use).....	3-67
Figure 3.3.12	Activity of community group/caretaker (communal wells for agricultural water use).....	3-67
Figure 3.3.13	Reward to management (communal well for agricultural water use).....	3-68
Figure 3.3.14	Medical treatment of arsenic patients	3-68
Figure 3.3.15	Unfair social attitude toward arsenic patients.....	3-69
Figure 3.3.16	Access to the nearest medical facility	3-69
Figure 3.3.17	Knowledge about symptoms of arsenic poisoning	3-70
Figure 3.3.18	Known symptoms of arsenic poisoning	3-70
Figure 3.3.19	Actions to obtain arsenic safe water	3-71
Figure 3.3.20	Villages with NGOs activity related to arsenic problems	3-72
Figure 4.1.1	Process of target well selection	4-19
Figure 4.1.2	Process of target well selection for general water quality analysis	4-20
Figure 4.1.3	Location of 300 existing wells.....	4-21
Figure 4.1.4	Well depth of 260 existing DPHE shallow wells by district	4-22
Figure 4.1.5	Distribution of specific capacity(S_c) obtained from existing	

	production wells	4-23
Figure 4.1.6	DTW measured at 300 existing wells in rainy season.....	4-24
Figure 4.1.7	GWL measured at 300 existing wells in rainy season.....	4-25
Figure 4.1.8	Groundwater flow vectors in rainy season.....	4-26
Figure 4.1.9	DTW measured at 300 existing wells in dry season	4-27
Figure 4.1.10	GWL measured at 300 existing wells in dry season.....	4-28
Figure 4.1.11	Groundwater flow vectors in dry season.....	4-29
Figure 4.1.12	Changes in GWL at 300 existing wells between rainy season and dry season	4-30
Figure 4.2.1	As concentrations by district in rainy season analyzed by AAS.....	4-42
Figure 4.2.2	As concentration in rainy season analyzed by AAS	4-43
Figure 4.2.3	As concentrations by district in rainy season by AAN field kit	4-44
Figure 4.2.4	As concentration in rainy season analyzed by AAN field kit.....	4-45
Figure 4.2.5	Iron(Fe^{2+}) concentrations measured at 300 existing wells in rainy season.....	4-46
Figure 4.2.6	pH values measured at 300 existing wells in rainy season	4-47
Figure 4.2.7	Eh values measured at 300 existing wells in rainy season	4-48
Figure 4.2.8	Electric conductivity (EC) measured 300 existing wells in rainy season.....	4-49
Figure 4.2.9	Eh-pH plots of 300 existing wells measured in rainy season	4-50
Figure 4.2.10	Relationship between Eh and pH by district in rainy season.....	4-51
Figure 4.2.11	Eh-pH-As relations of 300 existing wells measured in rainy season	4-52
Figure 4.2.12	Eh-pH- Fe^{2+} relations of 300 existing wells measured in rainy season	4-53
Figure 4.3.1	As concentrations by district in dry season analyzed by AAS	4-67
Figure 4.3.2	Comparison of As concentrations by district analyzed by AAS	4-68
Figure 4.3.3	As concentration in dry season analyzed by AAS.....	4-69
Figure 4.3.4	Changes in As concentration between rainy season and dry season	4-70
Figure 4.3.5	Changed ratio of As concentration from rainy season and dry season	4-71
Figure 4.3.6	Comparison of As concentrations by district measured by AAN field kit	4-72
Figure 4.3.7	As concentration in dry season analyzed by AAN field kit.....	4-73
Figure 4.3.8	Iron(Fe^{2+}) concentrations measured at 300 existing wells in	

	dry season	4-74
Figure 4.3.9	Changes in Iron(Fe^{2+}) concentration between rainy season and dry season	4-75
Figure 4.3.10	pH values measured at 300 existing wells in dry season.....	4-76
Figure 4.3.11	Changes in pH value between rainy season and dry season.....	4-77
Figure 4.3.12	Eh values measured at 300 existing wells in dry season.....	4-78
Figure 4.3.13	Changes in Eh value between rainy season and dry season.....	4-79
Figure 4.3.14	Electric conductivity (EC) measured at 300 existing wells in dry season	4-80
Figure 4.3.15	Changes in EC value between rainy season and dry season	4-81
Figure 4.3.16	Eh-pH-As relations of 300 existing wells measured in dry season	4-82
Figure 4.3.17	Eh-pH-As relations of Chuadanga in rainy season and dry season	4-83
Figure 4.3.18	Eh-pH-As relations of Jhenaidah in rainy season and dry season	4-84
Figure 4.3.19	Eh-pH-As relations of Jessore in rainy season and dry season	4-85
Figure 4.3.20	Eh-pH- Fe^{2+} relations of 300 existing wells measured in dry season	4-86
Figure 4.3.21	Comparison of As concentrations measured by FK and AAS by Log-Log plot in rainy season.....	4-87
Figure 4.3.22	Comparison of As concentrations measured by FK and AAS by Log-Log plot in dry season	4-88
Figure 4.4.1	Trilinear diagram of shallow groundwater by district in rainy season	4-91
Figure 4.4.2	Trilinear diagram of shallow groundwater by district in dry season	4-92
Figure 4.4.3	Trilinear diagram of groundwater from production wells in rainy season.....	4-93
Figure 4.4.4	Trilinear diagram of groundwater from production wells in dry season	4-94
Figure 4.4.5	Stiff diagram of groundwater taken from existing shallow tubewells in rainy season	4-95
Figure 4.4.6	Stiff diagram of groundwater taken from existing shallow tubewells in dry season	4-96
Figure 4.4.7	Stiff diagram of groundwater taken from Pourashava	

	production wells in October 2000	4-97
Figure 4.4.8	Stiff diagram of groundwater taken from Pourashava production wells in dry season	4-98
Figure 5.1.1	Location of core boring sites	5-9
Figure 5.1.2	Location of core boring site in Chuadanga Pourashava.....	5-10
Figure 5.1.3	Location of core boring site in Jhenaidah Pourashava	5-11
Figure 5.1.4	Location of core boring site in Jessore Pourashava	5-12
Figure 5.1.5	Location of core boring site in Bara Dudpatila Village.....	5-13
Figure 5.1.6	Location of core boring site in Krishna Chandrapur Village	5-14
Figure 5.1.7	Location of core boring site in Rajnagar Bankabarsi Village	5-15
Figure 5.1.8	Correlation of subsurface geology based on core boring.....	5-16
Figure 5.1.9	Photograph and sketch of core sample with laminated structure (Jenaidah, JH-1, 15-16m).....	5-17
Figure 5.1.10	Photograph and sketch of core sample with biogenic disturbed sedimentary structure by bioturbation (Moheshpur, JH-KC, 19-20m).....	5-18
Figure 5.1.11	Photograph and sketch of core sample with shell fragment (Chuadanga, CH-2, 119-120m)	5-19
Figure 5.1.12	Photograph and sketch of core sample with trace fossil (Moheshpur, JH-KC, 87-88m).....	5-20
Figure 5.1.13	Photograph and sketch of core sample with Wooden fragment (Jhenaidah, JH-1, 16-17m).....	5-21
Figure 5.1.14	Photograph and sketch of core sample with block (Jhenaidah, JH-1, 69-70m)	5-22
Figure 5.2.1	Schematic drilling plan of observation wells and bore holes	5-38
Figure 5.2.2	Location of existing production wells and new drilling sites in Chuadanga Pourashava	5-39
Figure 5.2.3	Location of existing production wells and new drilling sites in Jhenaidah Pourashava.....	5-40
Figure 5.2.4	Location of existing production wells and new drilling sites in Jessore Pourashava	5-41
Figure 5.2.5	Drilling site map of CH-1 (Poshu Hat, Chuadanga Pourashava).....	5-42
Figure 5.2.6	Drilling site map of CH-2 (Girls college, Chuadanga Pourashava).....	5-43
Figure 5.2.7	Drilling site map of JH-1 (Arabpur, Jhenaidah Pourashava)	5-44

Figure 5.2.8	Drilling site map of JH-2 (Hamdah, Jhenaidah Pourashava)	5-45
Figure 5.2.9	Drilling site map of JS-1 (Ghop, Jessore Pourashava)	5-46
Figure 5.2.10	Drilling site map of JS-2 (Kharki, Jessore Pourashava)	5-47
Figure 5.2.11	Drilling site map of CH-BD (Bara Dupatila, Damurhuda Upazila)	5-48
Figure 5.2.12	Drilling site map of JH-KC (Krishna Chandrapur, Moheshpur)	5-49
Figure 5.2.13	Drilling site map of JS-RB (Rajnagar Bankabarsi, Keshabpur)	5-50
Figure 5.2.14	Results of geophysical logging at CH-1 Site [Poshu Hat, Chuadanga Pourashava]	5-51
Figure 5.2.15	Results of geophysical logging at CH-2 Site [Girls college, Chuadanga Pourashava]	5-52
Figure 5.2.16	Results of geophysical logging at CH-BD Site [Bara Dudpatila, Damurhuda]	5-53
Figure 5.2.17	Results of geophysical logging at JH-1 Site [Arabpur, Jhenaidah Pourashava]	5-54
Figure 5.2.18	Results of geophysical logging at JH-2 Site [Hamdah, Jhenaidah Pourashava]	5-55
Figure 5.2.19	Columnar section and Geophysical logging at JH-KC Site [Krishna Chandrapur, Moheshpur]	5-56
Figure 5.2.20	Results of geophysical logging at JS-1 Site [Ghop, Jessore Pourashava]	5-57
Figure 5.2.21	Results of geophysical logging at JS-2 Site [Kharki, Jessore Pourashava]	5-58
Figure 5.2.22	Results of geophysical logging at JS-RB Site [Rajnagar Bankabarsi, Keshabpur]	5-59
Figure 5.2.23	Columnar section and geophysical logging at CH-1 Site [Poshu Hat, Chuadanga Pourashava]	5-60
Figure 5.2.24	Columnar section and geophysical logging at CH-2 Site [Girls college, Chuadanga Pourashava]	5-61
Figure 5.2.25	Columnar section and geophysical logging at CH-BD Site [Bara Dudpatila, Damurhuda]	5-62
Figure 5.2.26	Columnar section and geophysical logging at JH-1 Site [Arabpur, Jhenaidah Pourashava]	5-63
Figure 5.2.27	Columnar section and geophysical logging at JH-2 Site [Hamdah, Jhenaidah Pourashava]	5-64
Figure 5.2.28	Columnar section and geophysical logging at JH-KC Site [Krishna Chandrapur, Moheshpur]	5-65

Figure 5.2.29	Columnar section and geophysical logging at JS-1 Site [Ghop, Jessore Pourashava]	5-66
Figure 5.2.30	Columnar section and geophysical logging at JS-2 Site [Kharki, Jessore Pourashava].....	5-67
Figure 5.2.31	Columnar section and geophysical logging at JS-RB Site [Rajnagar Bankabarsi, Keshabpur].....	5-68
Figure 5.2.32	Casing program of observation deep well & holes at CH-1 Site (Poshu Hat, Chuadanga Pourashava).....	5-69
Figure 5.2.33	Casing program of observation deep well & holes at CH-2 Site (Girls college, Chuadanga Pourashava).....	5-70
Figure 5.2.34	Casing program of observation hole at CH-BD Site (Bara Dudpatila).....	5-71
Figure 5.2.35	Casing program of observation deep well & holes at JH-1 Site (Arabpur, Jhenaidah Pourashava).....	5-72
Figure 5.2.36	Casing program of observation deep well & holes at JH-2 Site (Hamdah, Jhenaidah Pourashava).....	5-73
Figure 5.2.37	Casing program of observation hole at JH-KC Site (Krishna Chandrapur).....	5-74
Figure 5.2.38	Casing program of observation deep well & holes at JS-1 Site (Ghop, Jessore Pourashava).....	5-75
Figure 5.2.39	Casing program of observation deep well & holes at JS-2 Site (Kharki, Jessore Pourashava).....	5-76
Figure 5.2.40	Casing program of observation hole at JS-RB Site (Rajnagar Bankabarsi)	5-77
Figure 5.3.1	Results of step-drawdown test at Ch-1 observation well.....	5-94
Figure 5.3.2	Results of step-drawdown test at Ch-2 observation well.....	5-95
Figure 5.3.3	Results of step-drawdown test at Jh-1 observation well	5-96
Figure 5.3.4	Results of step-drawdown test at Jh-2 observation well	5-97
Figure 5.3.5	Results of step-drawdown test at Js-1 observation well.....	5-98
Figure 5.3.6	Results of step-drawdown test at Js-2 observation well.....	5-99
Figure 5.3.7	Results of continuous pumping test at CH-1 site, Chuadanga	5-100
Figure 5.3.8	Results of continuous pumping test at CH-2 site, Chuadanga	5-101
Figure 5.3.9	Results of continuous pumping test at JH-1 site, Jhenaidah.....	5-102
Figure 5.3.10	Results of continuous pumping test at JH-2 site, Jhenaidah.....	5-103
Figure 5.2.11	Results of continuous pumping test at JS-1 site, Jessore	5-104
Figure 5.3.12	Results of continuous pumping test at JS-2 site, Jessore.....	5-105
Figure 5.3.13	Results of recovery test at CH-1 site, Chuadanga	5-106

Figure 5.3.14	Results of recovery test at CH-2 site, Chuadanga	5-107
Figure 5.3.15	Results of recovery test at JH-1 site, Jhenaidah	5-108
Figure 5.3.16	Results of recovery test at JH-2 site, Jhenaidah.....	5-109
Figure 5.3.17	Results of recovery test at JS-1 site, Jessore.....	5-110
Figure 5.3.18	Results of recovery test at JS-2 site, Jessore.....	5-111
Figure 5.3.19	Results of simple pumping test at Ch-1-1 observation hole, Chuadanga	5-112
Figure 5.3.20	Results of simple pumping test at Ch-1-2 observation hole, Chuadanga	5-113
Figure 5.3.21	Results of simple pumping test at Ch-1-3 observation hole, Chuadanga	5-114
Figure 5.3.22	Results of simple pumping test at Ch-1-4 observation hole, Chuadanga	5-115
Figure 5.3.23	Results of simple pumping test at Ch-2-1 observation hole, Chuadanga	5-116
Figure 5.3.24	Results of simple pumping test at Ch-2-2 observation hole, Chuadanga	5-117
Figure 5.3.25	Results of simple pumping test at Ch-2-3 observation hole, Chuadanga	5-118
Figure 5.3.26	Results of simple pumping test at Ch-2-4 observation hole, Chuadanga	5-119
Figure 5.3.27	Results of simple pumping test at Jh-1-1 observation hole, Chuadanga	5-120
Figure 5.3.28	Results of simple pumping test at Jh-1-2 observation hole, Chuadanga	5-121
Figure 5.3.29	Results of simple pumping test at Jh-1-3 observation hole, Chuadanga	5-122
Figure 5.3.30	Results of simple pumping test at Ch-1-4 observation hole, Chuadanga	5-123
Figure 5.3.31	Results of simple pumping test at Jh-2-1 observation hole, Chuadanga	5-124
Figure 5.3.32	Results of simple pumping test at Jh-2-2 observation hole, Chuadanga	5-125
Figure 5.3.33	Results of simple pumping test at Jh-2-3 observation hole, Chuadanga	5-126
Figure 5.3.34	Results of simple pumping test at Jh-2-4 observation hole, Chuadanga	5-127

Figure 5.3.35	Results of simple pumping test at Js-1-1 observation hole, Jessore	5-128
Figure 5.3.36	Results of simple pumping test at Js-1-2 observation hole, Jessore	5-129
Figure 5.3.37	Results of simple pumping test at Js-1-3 observation hole, Jessore	5-130
Figure 5.3.38	Results of simple pumping test at Js-1-4 observation hole, Jessore	5-131
Figure 5.3.39	Results of simple pumping test at Js-2-1 observation hole, Jessore	5-132
Figure 5.3.40	Results of simple pumping test at Js-2-2 observation hole, Jessore	5-133
Figure 5.3.41	Results of simple pumping test at Js-2-3 observation hole, Jessore	5-134
Figure 5.3.42	Results of simple pumping test at Js-2-4 observation hole, Jessore	5-135
Figure 5.4.1	Changes in water quality during step-drawdown test at CH-1 Site, Chuadanga	5-147
Figure 5.4.2	Changes in water quality during step-drawdown test at CH-2 Site, Chuadanga	5-148
Figure 5.4.3	Changes in water quality during step-drawdown test at JH-1 Site, Jhenaidah	5-149
Figure 5.4.4	Changes in water quality during step-drawdown test at JH-2 Site, Jhenaidah	5-150
Figure 5.4.5	Changes in water quality during step-drawdown test at JS-1 Site, Jessore	5-151
Figure 5.4.6	Changes in water quality during step-drawdown test at JS-2 Site, Jessore	5-152
Figure 5.4.7	Changes in water quality during continuous pumping test at CH-1 Site, Chuadanga	5-153
Figure 5.4.8	Changes in water quality during continuous pumping test at CH-2 Site, Chuadanga	5-154
Figure 5.4.9	Changes in water quality during continuous pumping test at JH-1 Site, Jhenaidah	5-155
Figure 5.4.10	Changes in water quality during continuous pumping test at JH-2 Site, Jhenaidah	5-156
Figure 5.4.11	Changes in water quality during continuous pumping test at	

	JS-1 Site, Jessore	5-157
Figure 5.4.12	Changes in water quality during continuous pumping test at JS-2 Site, Jessore	5-158
Figure 5.4.13	Results of monthly groundwater monitoring at CH-1 Site [Poshu Hat, Chuadanga Pourashava]	5-159
Figure 5.4.14	Changes in groundwater level and groundwater quality at CH-1 Site, Chuadanga	5-160
Figure 5.4.15	Results of monthly groundwater monitoring at CH-2 Site [Girls college, Chuadanga Pourashava]	5-161
Figure 5.4.16	Changes in groundwater level and groundwater quality at CH-2 Site, Chuadanga	5-162
Figure 5.4.17	Results of monthly groundwater monitoring at CH-BD Site [Bara Dudpatila, Damurhuda]	5-163
Figure 5.4.18	Changes in groundwater level and groundwater quality at CH-BD Site, Chuadanga	5-164
Figure 5.4.19	Results of monthly groundwater monitoring at JH-1 Site [Arabpur, Jhenaidah Pourashava]	5-165
Figure 5.4.20	Changes in groundwater level and groundwater quality at JH-1 Site, Jhenaidah	5-166
Figure 5.4.21	Results of monthly groundwater monitoring at JH-2 Site [Hamdah, Jhenaidah Pourashava]	5-167
Figure 5.4.22	Changes in groundwater level and groundwater quality at JH-2 Site, Jhenaidah	5-168
Figure 5.4.23	Results of monthly groundwater monitoring at JH-KC Site [Krishna Chandrapur, Moheshpur]	5-169
Figure 5.4.24	Changes in groundwater level and groundwater quality at JH-KC Site, Jhenaidah	5-170
Figure 5.4.25	Results of monthly groundwater monitoring at JS-1 Site [Ghop, Jessore Pourashava]	5-171
Figure 5.4.26	Changes in groundwater level and groundwater quality at JS-1 Site, Jessore	5-172
Figure 5.4.27	Results of monthly groundwater monitoring at JS-2 Site [Kharki, Jessore Pourashava]	5-173
Figure 5.4.28	Changes in groundwater level and groundwater quality at JS-2 Site, Jessore	5-174
Figure 5.4.29	Results of monthly groundwater monitoring at JS-RB Site [Rajnagar Bankabarsi, Keshabpur]	5-175

Figure 5.4.30	Changes in groundwater level and groundwater quality at JS-RB Site, Jessore	5-176
Figure 5.4.31	Monthly monitoring results of improved deep wells in Bara Dudpatila Village, Chuadanga	5-177
Figure 5.4.32	Monthly monitoring results of improved deep wells in, Krishna Chandrapur Village, Jhenaidah	5-178
Figure 5.4.33	Monthly monitoring results of improved deep wells in Rajnagar Bankabarsi Village, Jessore	5-179
Figure 5.4.34	Eh-pH-As relations in groundwater of JICA observation wells/holes	5-180
Figure 5.5.1	EC data comparison between rainy season and dry season for existing wells	5-250
Figure 5.5.2	TDS data comparison between rainy season and dry season for existing wells	5-251
Figure 5.5.3	NA data comparison between rainy season and dry season for existing wells	5-252
Figure 5.5.4	Cl data comparison between rainy season and dry season for existing wells	5-253
Figure 5.5.5	NO ₃ data comparison between rainy season and dry season for existing wells	5-254
Figure 5.5.6	NO ₂ data comparison between rainy season and dry season for existing wells	5-255
Figure 5.5.7	Fe data comparison between rainy season and dry season for existing wells	5-256
Figure 5.5.8	NH ₄ data comparison between rainy season and dry season for existing wells	5-257
Figure 5.5.9	Ni data comparison between rainy season and dry season for existing wells	5-258
Figure 5.5.10	Zn data comparison between rainy season and dry season for existing wells	5-259
Figure 5.5.11	NO ₃ data comparison between pond water and shallow groundwater in the model rural areas	5-260
Figure 5.5.12	NO ₂ data comparison between pond water and shallow groundwater in the model rural areas	5-261
Figure 5.5.13	NH ₄ data comparison between pond water and shallow groundwater in the model rural areas	5-262
Figure 5.5.14	SO ₄ data comparison between pond water and shallow	

	groundwater in the model rural areas	5-263
Figure 5.5.15	K data comparison between pond water and shallow groundwater in the model rural areas	5-264
Figure 5.5.16	F data comparison between pond water and shallow groundwater in the model rural areas	5-265
Figure 5.5.17	Mg data comparison between pond water and shallow groundwater in the model rural areas	5-266
Figure 5.5.18	Fe data comparison between pond water and shallow groundwater in the model rural areas	5-267
Figure 5.5.19	Mn data comparison between pond water and shallow groundwater in the model rural areas	5-268
Figure 5.5.20	Hardness data comparison between pond water and shallow groundwater in the model rural areas	5-269
Figure 5.5.21	Ca data comparison between pond water and shallow groundwater in the model rural areas	5-270
Figure 5.5.22	COD data comparison between pond water and shallow groundwater in the model rural areas	5-271
Figure 5.5.23	Trilinear diagram of groundwater at CH-1 Site, Chuadanga	5-272
Figure 5.5.24	Trilinear diagram of groundwater at CH-2 Site, Chuadanga	5-273
Figure 5.5.25	Trilinear diagram of groundwater at JH-1 Site, Jhenaidah	5-274
Figure 5.5.26	Trilinear diagram of groundwater at JH-2 Site, Jhenaidah	5-275
Figure 5.5.27	Trilinear diagram of groundwater at JS-1 Site, Jessore	5-276
Figure 5.5.28	Trilinear diagram of groundwater at JS-2 Site, Jessore	5-277
Figure 5.5.29	Trilinear diagram of groundwater at Obs. Holes in model rural areas	5-278
Figure 5.5.30	Trilinear diagram of groundwater at improved deep wells in Bara Dudpatila Village, Chuadanga.....	5-279
Figure 5.5.31	Trilinear diagram of groundwater at improved deep wells in Krishna Chandrapur Village, Jhenaidah	5-280
Figure 5.5.32	Trilinear diagram of groundwater at improved deep wells in Rajnagar Bankabarsi Village, Jessore.....	5-281
Figure 5.5.33	Changes in groundwater level and groundwater quality at Ch-1 well, Chuadanga.....	5-282
Figure 5.5.34	Changes in groundwater level and groundwater quality(NH ₄ , Fe, Mn) at Ch-1 well, Chuadanga.....	5-283
Figure 5.5.35	Changes in groundwater level and groundwater quality at Ch-2 well, Chuadanga.....	5-284

Figure 5.5.36	Changes in groundwater level and groundwater quality(NH ₄ , Fe, Mn) at Ch-2 well, Chuadanga.....	5-285
Figure 5.5.37	Changes in groundwater level and groundwater quality at Jh-1 well, Jhenaidah	5-286
Figure 5.5.38	Changes in groundwater level and groundwater quality(NH ₄ , Fe, Mn) at Jh-1 well, Jhenaidah	5-287
Figure 5.5.39	Changes in groundwater level and groundwater quality at Jh-2 well, Jhenaidah	5-288
Figure 5.5.40	Changes in groundwater level and groundwater quality(NH ₄ , Fe, Mn) at Jh-2 well, Jhenaidah	5-289
Figure 5.4.41	Changes in groundwater level and groundwater quality at Js-1 well, Jessore.....	5-290
Figure 5.5.42	Changes in groundwater level and groundwater quality(NH ₄ , Fe, Mn) at Js-1 well, Jessore.....	5-291
Figure 5.5.43	Changes in groundwater level and groundwater quality at Js-2 well, Jessore.....	5-292
Figure 5.5.44	Changes in groundwater level and groundwater quality(NH ₄ , Fe, Mn) at Js-2 well, Jessore.....	5-293
Figure 5.5.45	Changes in groundwater level and groundwater quality(As,NH ₄ , Fe, Mn) at Ch-CB-2 Obs. Hole, Chuadanga	5-294
Figure 5.5.46	Changes in groundwater level and groundwater quality(As,NH ₄ , Fe, Mn) at Jh-CB-2 Obs. Hole, Jhenaidah	5-295
Figure 5.5.47	Changes in groundwater level and groundwater quality(As,NH ₄ , Fe, Mn) at Js-CB-2 Obs. Hole, Jessore	5-296
Figure 5.5.48	Changes in groundwater quality of improved deep wells in Bara Dudpatila Village, Chuadanga.....	5-297
Figure 5.5.49	Changes in groundwater quality of improved deep wells in Krishna Chandrapur Village, Jhenaidah	5-298
Figure 5.5.50	Changes in groundwater quality of improved deep wells, Ranjnagar Bankabarsi Village Jessore.....	5-299
Figure 5.5.51	Relations of bicarbonate to As, Fe, Eh, and pH in groundwater of JICA observation wells/holes	5-300
Figure 5.5.52	Relations of Dissolved iron to As, NH ₄ , Eh and pH in groundwater of JICA observation wells/holes	5-301
Figure 5.5.53	Relations of calcium to As, Mg, Eh and pH in Groundwater of JICA observation wells/holes.....	5-302
Figure 5.5.54	Relations of Ammonium to As, HCO ₃ , Eh and pH in	

	groundwater of JICA observation wells/holes	5-303
Figure 5.5.55	Relations of COD to As, NH ₄ , Eh and pH in Groundwater of JICA observation wells/holes.....	5-304
Figure 5.5.56	TDS data comparison between shallow and deep groundwater in Rajnagar Bankabarsi	5-305
Figure 5.5.57	NH ₄ data comparison between shallow and deep groundwater in Rajnagar Bankabarsi	5-306
Figure 5.5.58	Na data comparison between shallow and deep groundwater in Rajnagar Bankabarsi	5-307
Figure 5.5.59	Cl data comparison between shallow and deep groundwater in Rajnagar Bankabarsi	5-308
Figure 5.6.1	Geological columnar section	5-341
Figure 5.6.2	Geological columnar section	5-344
Figure 5.6.3	Geological columnar section	5-347
Figure 5.6.4	Geological columnar section	5-350
Figure 5.6.5	Geological columnar section	5-353
Figure 5.6.6	Geological columnar section	5-356
Figure 5.6.7	Results of arsenic content test and leachate test at CH-2 Site [Girls college, Chuadanga Pourashava]	5-359
Figure 5.6.8	Results of arsenic content test and leachate test at CH-BD Site [Bara Dudpatila, Damurhuda]	5-360
Figure 5.6.9	Results of arsenic content test and leachate test at JH-1 Site [Arabpur, Jhenaidah Pourashava]	5-361
Figure 5.6.10	Results of arsenic content test and leachate test at JH-KC Site [Krishna Chandrapur, Moheshpur]	5-362
Figure 5.6.11	Results of arsenic content test and leachate test at JS-2 Site [Kharki, Jessore Pourashava]	5-363
Figure 5.6.12	Results of arsenic content test and leachate test at JS-RB Site [Rajnagar Bankabarsi, Keshabpur]	5-364
Figure 5.7.1	Distribution of specific capacity at JICA drilling Sites	5-373
Figure 5.7.2	Depth-wise distribution of transmissivity by district	5-374
Figure 5.7.3	Depth-wise distribution of apparent Hydraulic Conductivity by district	5-375
Figure 5.7.4	Arsenic concentration and ground water quality at CH-1 Site [Poshu Hat, Chuadanga Pourashava]	5-376
Figure 5.7.5	Arsenic concentration and groundwater quality at CH-2 Site [Girls college, Chuadanga Pourashava]	5-377

Figure 5.7.6	Arsenic concentration and groundwater quality at JH-1 Site [Arabpur, Jhenaidah Pourashava]	5-378
Figure 5.7.7	Arsenic concentration and groundwater quality at JH-2 Site [Hamdah, Jhenaidah Pourashava]	5-379
Figure 5.7.8	Arsenic concentration and groundwater quality at JS-1 Site [Ghop, Jessore Pourashava]	5-380
Figure 5.7.9	Arsenic concentration and ground water quality at JS-2 Site [Kharki, Jessore Pourashava].....	5-381
Figure 5.7.10	Arsenic in soil and groundwater at CH-2 Site [Girls college, Chuadanga Pourashava].....	5-382
Figure 5.7.11	Arsenic in soil and groundwater at JH-1 Site [Arabpur, Jhenaidah Pourashava].....	5-383
Figure 5.7.12	Arsenic in soil and groundwater at JS-2 Site [Kharki, Jessore Pourashava].....	5-384
Figure 5.8.1	Location Map of Geological Profile and Geological Log.....	5-389
Figure 5.8.2	Geological Profile (A-A')	5-390
Figure 5.8.3	Geological Profile (B-B')	5-391
Figure 5.8.4	Geological Profile (C-C').....	5-392
Figure 5.8.5	Geological Profile (D-D').....	5-393
Figure 5.8.6	Geological Profile (E-E')	5-394
Figure 5.8.7	Geological Profile (F-F')	5-395
Figure 5.8.8	Geological Profile (G-G')	5-396
Figure 5.8.9	Isopach map of clayey layers in C formation	5-397

BOOK 2

Figure 6.1.1	Process of model rural area selection within district	6-10
Figure 6.1.2	Location of model rural areas and core drilling sites in Pourashavas with As concentration.....	6-11
Figure 6.3.1	Location map of existing tubewells in Bara Dudpatila village	6-33
Figure 6.3.2	Location map of existing tubewells in Krishna Chandrapur village.....	6-34
Figure 6.3.3	Location map of existing tubewells in Rajnagar Bankabarsi village.....	6-35
Figure 6.3.4	Arsenic concentrations of existing wells in modern rural areas analyzed by AAS	6-36
Figure 6.3.5	Arsenic concentration map of Bara Dudpatila village (October 2000).....	6-37
Figure 6.3.6	Arsenic concentration map of Krishna Chandrapur village (October 2000).....	6-38
Figure 6.3.7	Arsenic concentration map of Rajnagar Bankabarsi village (October 2000).....	6-39
Figure 6.3.8	Arsenic concentration map of Bara Dudpatila village by field kit (October 2000)	6-40
Figure 6.3.9	Arsenic concentration map of Krishna chandrapur village by field kit (October 2000).....	6-41
Figure 6.3.10	Arsenic concentration map of Rajnagar Bankabarsi village by field kit (October 2000).....	6-42
Figure 6.3.11	Comparison of As concentrations measured by FK and AAS in the model rural areas.....	6-43
Figure 6.3.12	Electric conductivity of existing wells in the model rural areas	6-44
Figure 6.3.13	EC map of Bara Dudpatila village (October 2000)	6-45
Figure 6.3.14	EC map of Krishna Chandrapur village (October 2000).....	6-46
Figure 6.3.15	EC map of Rajnagar Bankabarsi village (December 2000).....	6-47
Figure 6.3.16	Fe ²⁺ concentration of existing wells in the model rural areas.....	6-48
Figure 6.3.17	Fe ²⁺ map of Bara Dudpatila village (October 2000).....	6-49
Figure 6.3.18	Fe ²⁺ map of Krishna Chandrapur village (October 2000)	6-50
Figure 6.3.19	Fe ²⁺ map of Rajnagar Bankabarsi village (October 2000)	6-51
Figure 6.3.20	pH values of existing wells in the model rural areas	6-52
Figure 6.3.21	pH map of Bara Dudpatila village (October 2000)	6-53
Figure 6.3.22	pH map of Krishna Chandrapur village (October 2000)	6-54

Figure 6.3.23	pH map of Rajnagar Bankabarsi village (October 2000).....	6-55
Figure 6.3.24	Eh values of existing wells in the model rural areas	6-56
Figure 6.3.25	Eh map of Bara Dudpatila village (October 2000).....	6-57
Figure 6.3.26	Eh map of Krishna Chandrapur village (October 2000)	6-58
Figure 6.3.27	Eh map of Rajnagar Bankabarsi village (October 2000)	6-59
Figure 6.3.28	Trilinear diagram of shallow groundwater in the model rural areas.....	6-60
Figure 6.3.29	Stiff diagram of shallow groundwater in Bara Dudpatila village	6-61
Figure 6.3.30	Stiff diagram of shallow groundwater in Krishna Chandrapur village.....	6-62
Figure 6.3.31	Stiff diagram of shallow groundwater in Rajnagar Bankabarsi village.....	6-63
Figure 6.3.32	Pond water quality in Bara Dudpatila village.....	6-64
Figure 6.3.33	Pond water quality in Krishna Chandrapur village	6-65
Figure 6.3.34	Pond water quality in Rajnagar Bankabarsi village	6-66
Figure 6.3.35	Trilinear diagram of pond water in the model rural areas.....	6-67
Figure 6.3.36	Stiff diagram of pond water in Bara Dudpatila village.....	6-68
Figure 6.3.37	Stiff diagram of pond water in Krishna Chandrapur village	6-69
Figure 6.3.38	Stiff diagram of pond Water in Rajnagar Bankabarsi village	6-70
Figure 6.4.1	Number of arsenicosis patients by age.....	6-76
Figure 6.4.2	Number of arsenicosis patients by stage	6-76
Figure 6.4.3	Ratio of the tubewells used by arsenicosis patients to the total number of tubewells whose arsenic concentration is in a corresponding arsenic concentration range.....	6-77
Figure 6.4.4	Ratio of households reducing arsenic or obtaining arsenic safe water	6-78
Figure 6.4.5	Carrying method of water pots	6-78
Figure 6.5.1	Ratio of households having heard about arsenicosis.....	6-92
Figure 6.5.2	Ratio of households with knowledge about symptoms of arsenicosis (dark spots on the skin)	6-92
Figure 6.5.3	Ratio of households with knowledge about the cause of arsenicosis	6-93
Figure 6.5.4	Ratio of households with knowledge about prevention methods of arsenicosis (not to drink arsenic contaminated water).....	6-93
Figure 6.5.5	Rainwater collection by locally available goods (sari & colshi).....	6-94

Figure 6.5.6	Change in water sources in Rajnagar Bankabarsi	6-94
Figure 6.5.7	Change in water sources by initial water source in Rajnagar Bankabarsi between Oct. '00 and Mar. '01	6-95
Figure 6.5.8	Change in awareness of the former STW users who switched to the DPHE DTW or JICA DTW	6-95
Figure 6.5.9	Water sources in model rural areas as of October 2001	6-96
Figure 7.2.1	Tubewell platform for passive sedimentation unit	7-19
Figure 7.2.2	Correlation of EC and As removal %	7-26
Figure 7.2.3	Variation of arsenic and EC by sampling date	7-28
Figure 7.2.4	pH and ORP monitoring of passive sedimentation units	7-31
Figure 7.2.5	Result of passive sedimentation units.....	7-34
Figure 7.2.6	Histogram of removal rate by passive sedimentation units	7-35
Figure 7.2.7	Water quality parameter for passive sedimentation	7-37
Figure 7.2.8	Yield of basin type solar distillation at Bara Dudpatila.....	7-43
Figure 7.2.9	Yield of basin type solar distillation at Krishna Chandrapur	7-44
Figure 7.3.1	Arsenic contamination of a deep well due to no sealing	7-52
Figure 7.3.2	Structure of improved deep well	7-52
Figure 7.3.3	Ø38mm screen	7-53
Figure 7.3.4	Cutter with diamond tips.....	7-54
Figure 7.3.5	Construction method of type A	7-54
Figure 7.3.6	Drilling by donkey method.....	7-55
Figure 7.3.7	Construction method of type B	7-57
Figure 7.3.8	Wrapping of the casing with the Nice Seal	7-58
Figure 7.3.9	Construction method of type C	7-59
Figure 7.3.10	Metal-petal-basket.....	7-60
Figure 7.3.11	Location of improved deep wells at Rajnagar Bankabarsi	7-62
Figure 7.3.12	Arrangement of improved deep wells at Rajnagar Bankabarsi	7-62
Figure 7.3.13	Location of improved deep wells at Krishna Chandrapur.....	7-65
Figure 7.3.14	Arrangement of improved deep wells at Krishna Chandrapur.....	7-65
Figure 7.3.15	Location of improved deep well at Bara Dudpatila	7-68
Figure 7.3.16	Arrange of improved deep well at Bara Dudpatila.....	7-68
Figure 7.3.17	Comparison of transmissivity.....	7-71
Figure 7.3.18	Cost comparison of improved deep wells (depth:150m)	7-71
Figure 8.3.3.1	Conceptual diagram of vertical 2-D local model	8-24
Figure 8.3.3.2	Model conditions and simulated Piezometric Heads (case-01,no well).....	8-39
Figure 8.3.3.3	Simulated arsenic concentrations(case-01,no well).....	8-40

Figure 8.3.3.4	Model conditions and simulated Piezometric Heads (case-02, irrigation wells)	8-41
Figure 8.3.3.5	Simulated arsenic concentrations (case-02, irrigation wells)	8-42
Figure 8.3.3.6	Model conditions and simulated Piezometric Heads(case-03, case-02 with A deep domestic well)	8-43
Figure 8.3.3.7	Simulated arsenic concentrations (case-03, case-02, with A deep domestic well)	8-44
Figure 8.3.3.8	Model conditions and simulated Piezometric Heads(case-04, case-03 with A deep irrigation well)	8-45
Figure 8.3.3.9	Simulated arsenic concentrations (case-04, case-03, with A deep irrigation well)	8-46
Figure 8.3.3.10	Model conditions and simulated Piezometric Heads(case-05, case-04 with thin clay layers)	8-47
Figure 8.3.3.11	Simulated arsenic concentrations (case-05, case-04, with thin clay layers)	8-48
Figure 8.3.3.12	Model conditions and simulated Piezometric Heads (case-06, case-04 with thick clay layers)	8-49
Figure 8.3.3.13	Simulated arsenic concentrations (case-06, case-04, with thick clay layers)	8-50
Figure 8.3.3.14	Model conditions and monitoring points for transient simulation	8-51
Figure 8.3.3.15	Simulated Piezometric Heads in dry season and rainy season by transient simulation	8-52
Figure 8.3.3.16	Simulated arsenic concentrations by steady-state simulation and transient simulation	8-53
Figure 8.3.3.17	Comparison of arsenic concentrations by steady-state simulation and transient simulation	8-54
Figure 8.3.3.18	Simulated Piezometric Heads and arsenic concentrations at Obs-1/#1, #2, and #3 points	8-55
Figure 8.3.3.19	Simulated Piezometric Heads and arsenic concentrations at Obs-2/#1, and Obs-3/#1 points	8-56
Figure 8.3.3.20	Simulated arsenic concentrations (transient simulation, remove arsenic sources)[1/2]	8-57
Figure 8.3.3.21	Simulated arsenic concentrations (transient simulation, remove arsenic sources)[2/2]	8-58
Figure 8.3.4.1	Model grid for 3-D regional model	8-79
Figure 8.3.4.2	Top and bottom elevations and thickness of layer-1	8-80

Figure 8.3.4.3	Top and bottom elevations and thickness of lalyer-2	8-81
Figure 8.3.4.4	Top and bottom elevations and thickness of lalyer-3	8-82
Figure 8.3.4.5	Top and bottom elevations and thickness of lalyer-4	8-83
Figure 8.3.4.6	Top and bottom elevations and thickness of lalyer-5	8-84
Figure 8.3.4.7	Top and bottom elevations and thickness of lalyer-6	8-85
Figure 8.3.4.8	Isopach maps by facies of layer-1	8-86
Figure 8.3.4.9	Isopach maps by facies of layer-2	8-87
Figure 8.3.4.10	Isopach maps by facies of layer-3	8-88
Figure 8.3.4.11	Isopach maps by facies of layer-4	8-89
Figure 8.3.4.12	Isopach maps by facies of layer-5	8-90
Figure 8.3.4.13	Isopach maps by facies of layer-6	8-91
Figure 8.3.4.14	Identified geohydrologic parameters for layer-1	8-92
Figure 8.3.4.15	Identified geohydrologic parameters for layer-2.....	8-93
Figure 8.3.4.16	Identified geohydrologic parameters for layer-3.....	8-94
Figure 8.3.4.17	Identified geohydrologic parameters for layer-4.....	8-95
Figure 8.3.4.18	Identified geohydrologic parameters for layer-5.....	8-96
Figure 8.3.4.19	Identified geohydrologic parameters for layer-6.....	8-97
Figure 8.3.4.20	Historical groundwater pumpage input to 3-D regional model.....	8-98
Figure 8.3.4.21	Historical groundwater pumpage by user type and model layer.....	8-99
Figure 8.3.4.22	Distribution of groundwater pumpage in Dec.1983	8-100
Figure 8.3.4.23	Distribution of groundwater pumpage in Dec.1992	8-101
Figure 8.3.4.24	Distribution of groundwater pumpage in Dec.2001	8-102
Figure 8.3.4.25	Comparison of estimated monthly recharge with monthly rainfall	8-103
Figure 8.3.4.26	Correlation between estimated monthly recharge and monthly rainfall from 1990 to1999	8-104
Figure 8.3.4.27	Comparison of simulated Piezometric Heads with actual groundwater level at Jhenaidah Pourashava.....	8-105
Figure 8.3.4.28	Comparison of simulated Piezometric Heads with actual groundwater level at Jessore Pourashava.....	8-106
Figure 8.3.4.29	Simulated Piezometric Heads at model village from 1983 to 2001.....	8-107
Figure 8.3.4.30	Distribution of simulated Piezometric Heads in layer-3 in 2001 by historical simulation	8-108
Figure 8.3.4.31	Comparison of simulated Piezometric Heads with actual groundwater levels in January 2001	8-109

Figure 8.3.4.32	Concept of future groundwater pumpage scenarios	8-110
Figure 8.3.4.33	Future groundwater pumpage by scenario-1	8-111
Figure 8.3.4.34	Future groundwater pumpage by case-1, scenario-1	8-112
Figure 8.3.4.35	Simulated Piezometric Heads at Jessore Pourashava from 2002 to 2020 by case-1, scenario-1	8-113
Figure 8.3.4.36	Simulated Piezometric Heads at model villages from 2002 to 2020 by case-1, scenario-1	8-114
Figure 8.3.4.37	Distribution of simulated Piezometric Heads in layer-2 in 2020 by case-1, scenario-1	8-115
Figure 8.3.4.38	Distribution of simulated Piezometric Heads in layer-3 in 2020 by case-1, scenario-1	8-116
Figure 8.3.4.39	Distribution of simulated Piezometric Heads in layer-4 in 2020 by case-1, scenario-1	8-117
Figure 8.3.4.40	Distribution of simulated Piezometric Heads in layer-5 in 2020 by case-1, scenario-1	8-118
Figure 8.3.4.41	Future groundwater pumpage by case-2, scenario-1	8-119
Figure 8.3.4.42	Difference of simulated Piezometric Heads between case-1 and case-2, scenario-1 in Apr 2020	8-120
Figure 8.3.4.43	Simulated Piezometric Head difference between case-1 and case-2, Scenario-1 [Jessore district]	8-121
Figure 8.3.4.44	Simulated Piezometric Head difference between case-1 and case-2, Scenario-1 [Jhenaidah district]	8-122
Figure 8.3.4.45	Simulated Piezometric Head difference between case-1 and case-2, Scenario-1 [Chuadanga district]	8-123
Figure 8.3.4.46	Future groundwater pumpage by scenario-2	8-124
Figure 8.3.4.47	Linear projection of agricultural pumpage for scenario-2	8-125
Figure 8.3.4.48	Linear projection of domestic pumpage for scenario-2	8-126
Figure 8.3.4.49	Future groundwater pumpage by case-1, scenario-2	8-127
Figure 8.3.4.50	Simulated Piezometric Heads at Jessore Pourashava from 2002 to 2020 by case-1, Scenario-2	8-128
Figure 8.3.4.51	Simulated Piezometric Heads at model villages from 2002 to 2020 by case-1, Scenario-2	8-129
Figure 8.3.4.52	Distribution of simulated Piezometric Heads in layer-2 in 2020 by case-1, scenario-2	8-130
Figure 8.3.4.53	Distribution of simulated Piezometric Heads in layer-3 in 2020 by case-1, scenario-2	8-131
Figure 8.3.4.54	Distribution of simulated Piezometric Heads in layer-4 in	

	2020 by case-1, scenario-2	8-132
Figure 8.3.4.55	Distribution of simulated Piezometric Heads in layer-5 in 2020 by case-1, scenario-2	8-133
Figure 8.3.4.56	Difference of simulated Piezometric Heads between case-1, scenario-1 and case-1, scenario-2 in Apr 2020	8-134
Figure 8.3.4.57	Difference of simulated Piezometric Heads between case-1, scenario-1 and case-1, scenario-2 in Sep 2020	8-135
Figure 8.3.4.58	Future groundwater pumpage by case-2, scenario-2	8-136
Figure 8.3.4.59	Difference of simulated Piezometric Heads between case-1, and case-2, scenario-2 in Apr 2020	8-137
Figure 8.3.4.60	Simulated Piezometric Head difference between case-1 and case-2, scenario-2 [Jessore district]	8-138
Figure 8.3.4.61	Simulated Piezometric Head difference between case-1 and case-2, scenario-2 [Jhenaidah district]	8-139
Figure 8.3.4.62	Simulated Piezometric Head difference between case-1 and case-2, scenario-2 [Chuadanga district]	8-140
Figure 8.3.4.63	Modeled urgent areas and semi-urgent areas	8-141
Figure 8.3.4.64	Modeled Upazila areas	8-142
Figure 8.3.4.65	Distribution of groundwater pumpage from layer-5 in Dec.2020 by case-3, scenario-2	8-143
Figure 8.3.4.66	Future groundwater pumpage by case-3, scenario-2	8-144
Figure 8.3.4.67	Difference of simulated Piezometric Heads between case-1 and case-3, scenario-2 in Apr 2020	8-145
Figure 8.3.4.68	Simulated Piezometric Head difference between case-1 and case-3, scenario-2 [Chaugachha and Moheshpur]	8-146
Figure 8.3.4.69	Distribution of simulated Piezometric Heads in layer-5 in 2020 by case-3, scenario-2	8-147
Figure 8.3.4.70	Future groundwater pumpage by case-4, scenario-2	8-148
Figure 8.3.4.71	Distribution of simulated Piezometric Heads in layer-5 in 2020 by case-4, scenario-2	8-149
Figure 8.3.4.72	Simulated Piezometric Heads at Rajnagar Bankabarsi, Jessore from 2002 to 2020 by case-4, scenario-2	8-150
Figure 8.3.4.73	Difference of simulated Piezometric Heads between case-4, scenario-2 and case-1, scenario-2 in Apr 2020	8-151
Figure 8.3.4.74	Future groundwater pumpage by scenario-3	8-152
Figure 8.3.4.75	Future groundwater pumpage by case-1, scenario-3	8-153
Figure 8.3.4.76	Simulated Piezometric Heads at, Jessore Pourashava from	

	2002 to 2020 by case-1, scenario-3	8-154
Figure 8.3.4.77	Simulated Piezometric Heads at model villages from 2002 to 2020 by case-1, scenario-3	8-155
Figure 8.3.4.78	Distribution of simulated Piezometric Heads in layer-2 in 2020 by case-1, scenario-3	8-156
Figure 8.3.4.79	Distribution of simulated Piezometric Heads in layer-3 in 2020 by case-1, scenario-3	8-157
Figure 8.3.4.80	Distribution of simulated Piezometric Heads in layer-4 in 2020 by case-1, scenario-3	8-158
Figure 8.3.4.81	Distribution of simulated Piezometric Heads in layer-5 in 2020 by case-1, scenario-3	8-159
Figure 8.3.4.82	Difference of simulated Piezometric Heads between case-1, scenario-1 and case-1, scenario-3 in Apr 2020	8-160
Figure 8.3.4.83	Difference of simulated Piezometric Heads between case-1, scenario-1 and case-1, scenario-3 in Sep 2020	8-161
Figure 8.3.4.84	Future groundwater pumpage by case-2, scenario-3	8-162
Figure 8.3.4.85	Difference of simulated Piezometric Heads between case-1 and case-2, scenario-3 in Apr 2020.....	8-163
Figure 8.3.4.86	Simulated Piezometric Head difference between case-1 and case-2,scenario-3 Jessore district]	8-164
Figure 8.3.4.87	Simulated Piezometric Head difference between case-1 and case-2, scenario-3[Jhenaidah district]	8-165
Figure 8.3.4.88	Simulated Piezometric Head difference between case-1 and case-2, scenario-3[Chuadanga district]	8-166
Figure 8.3.4.89	Future groundwater pumpage by case-3, scenario-3	8-167
Figure 8.3.4.90	Difference of simulated Piezometric Heads between case-1 and case-3, scenario-3 in Apr 2020	8-168
Figure 8.3.4.91	Simulated Piezometric Head difference between case-1 and case-3, scenario-3[Chaugachha and Moheshpur]	8-169
Figure 9.2.1	Proposed priority project	9-5
Figure 9.5.1	Master plan frame work (Chuadanga, Jhenaidah, Jessore).....	9-15
Figure 10.6.1	Pipeline network of the regional rural waterworks plan	10-49
Figure 11.1.1	Relationship among each survey	11-1
Figure 11.1.2	Location map of 16 mouzas	11-3
Figure 11.1.3	Number of surveyed wells in 16 mouzas	11-50
Figure 11.1.4	Well density / 1000 persons of supplementary survey	11-51
Figure 11.1.5	Well depth classification in the study area	11-52

Figure 11.1.6	Arsenic concentration map at well points.....	11-53
Figure 11.1.7	Map arsenic concentration measured with field kits.....	11-54
Figure 11.1.8	Map arsenic concentration measured with AAS	11-55
Figure 11.1.9	Arsenic concentration map of the supplementary survey area.....	11-56
Figure 11.1.10	Histogram of pH value	11-57
Figure 11.1.11	Histogram of Eh value	11-58
Figure 11.1.12	EC values measured at the existing wells	11-59
Figure 11.1.13	Eh-pH-As relations of existing wells of supplementary survey	11-60
Figure 11.1.14	Comparison of As concentrations measured by FK and AAS by Log-Log plot	11-61
Figure 11.2.3	Drilling progress	11-63
Figure 11.2.1	Location map of observation well	11-69
Figure 11.2.2	Location map of observation well	11-70
Figure 11.2.4	Columnar section and geophysical logging at JS-OW-1 Site [Brahmakati, Keshabpur].....	11-71
Figure 11.2.5	Casing program (Brahmakati)	11-72
Figure 11.2.6	Results of step-drawdown test at Js-OW-1 observation well	11-73
Figure 11.2.7	Results of continuous pumping test and recovery test at Js-OW-1 well.....	11-74
Figure 11.2.8	Location map of geological profile	11-75
Figure 11.2.9	Geological Profile (A-B).....	11-76
Figure 11.2.10	Geological Profile (B-C).....	11-77
Figure 11.2.11	Geological Profile (D-E).....	11-78