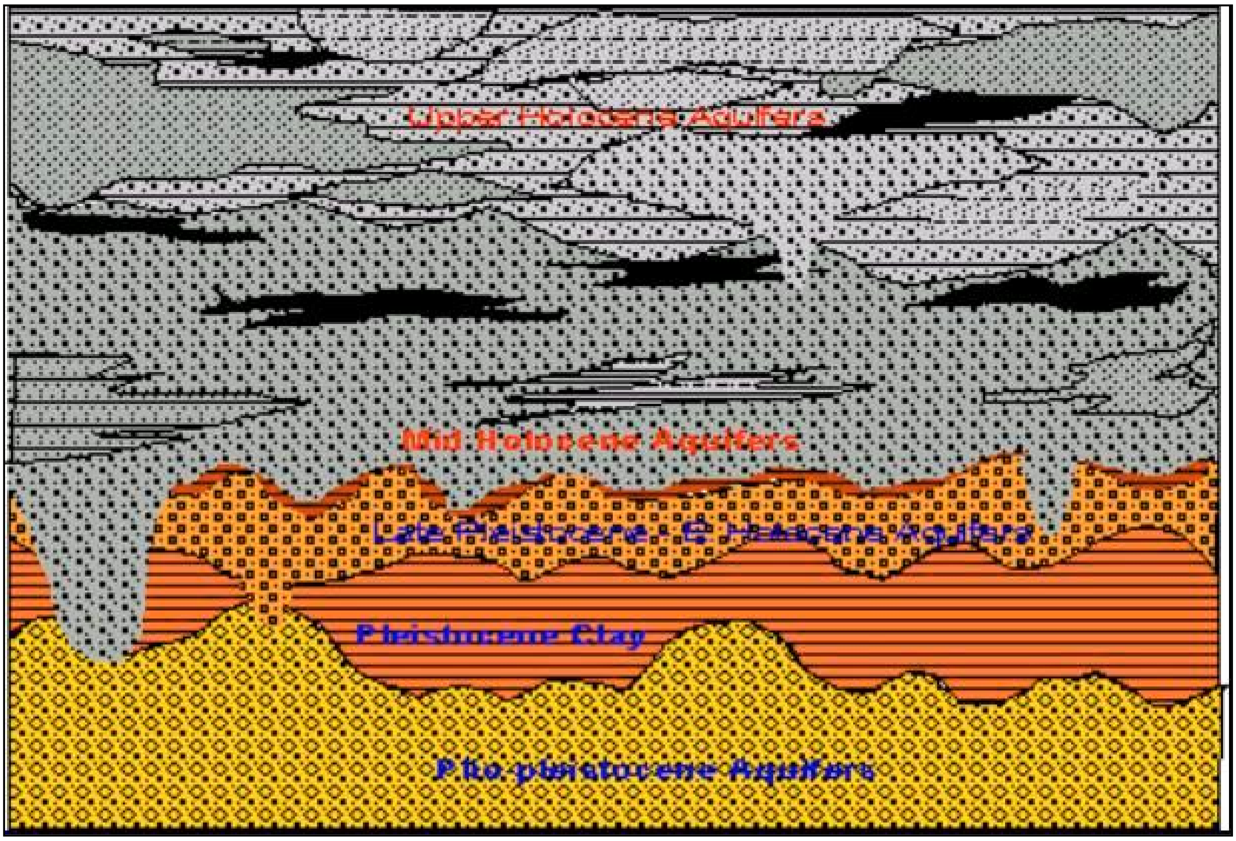
Government of the People's Republic of Bangladesh
Ministry of Local Government, Rural Development & Co-operatives,
Local Government Division

Report

of the



Ground Water Task Force

July, 2002

Presentation of the Report

A Task Force was formed by the Ministry of Local Government, Rural Development & Cooperatives, Local Government Division vide a Notification, No. LGD/WS-3/Arsenic/Option-1/2000/127 dated 06-08-2001 to collect and collate relevant hydro-geological information available with various agencies and organizations of the country, develop future plan of action related to availability of arsenic free water and other related matter. The final report of the Task Force is enclosed herewith.

July 21, 2002

(S.K.M. Abdullah)
Chairman
Former Director General,
Geological Survey of Bangladesh

(M. Nazrul Islam), Member
Director General,
Geological Survey of Bangladesh

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(L.R. Chowdhury), Member
General Manager, Laboratory Division
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Hydro-geologist
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CHAPTER I

Introduction

In the last few years the magnitude of the arsenic contamination of the ground water used for drinking and cooking purpose has been well established. Secretary, Ministry of Local Government, Rural Government & Co-operatives, Local Government Division called a meeting on July 29, 2001 of all the agencies involved in the development, planning or research on ground water use in the country. In addition, a representative from Bangladesh Petroleum Exploration Company, that has a large amount of subsurface geological information acquired during exploration for oil and natural gas, and the concerned officials from the Ministry and the Bangladesh Arsenic Mitigation Water Supply Project were also present.

Mr. Badiur Rahman, Secretary to the Ministry gave a detailed account of the threat to public health because of the contamination of ground water by arsenic and the steps being taken by the Government on this issue. He emphasized the role of the local experts in solving the problems as well as in drawing up a future road map for the government.

Different aspects of ground water issues were discussed and it was decided to form a 'Task Force' to collect all the available information and data on ground water in Bangladesh and suggest the areas where arsenic safe ground water can still be used for household purposes.

Following the meeting a notification (No. LGD/WS-3/Arsenic /Optin-1/2001/127 dated 6/8/2001) was issued forming the 'Task Force' along with the Terms of Reference .In summary the composition and the TOR were as follows.

1.1 Composition of the Task Force

i.	S.K.M.Abdullah, Chairman, Technical Advisory Group, BAMWSP	Chairman
ii.	Director General, Geological Survey of Bangladesh	Member
iii.	Director General, Water Resources Planning Organization	Member
iv.	Managing Director, Bangladesh Petroleum Exploration and Production Limited	Member
v.	Chief Engineer, (Irrigation), Bangladesh Agricultural Development Corporation	Member
vi.	Project Director, BAMWSP	Member
vii.	Director (Ground Water Hydrology), Bangladesh Water Development Board	Member
viii.	Executive Engineer, (R & D), Department of Public Health Engineering	Member
ix.	Hydro-Geologist, BAMWSP	Member-Secretary

ANNEX I

MINISTRY OF LOCAL GOVERNMENT, RURAL DEVELOPMENT & COOPERATIVES
LOCAL GOVERNMENT DIVISION
GROUND WATER TASK FORCE

INTERIM REPORT NO. 1

Geological Setting Of The Areas of Arsenic Safe Aquifers

Md. Munir Hussain and S.K.M. Abdullah
Ground Water Task Force
October, 2001

Table 5.2 Summary Statistics of Available Laboratory Analysis Result (Source: BGS- DPHE, 1999)

Source/ Ref	Year	Study Area	Well Types	Sampling Strategy	Analytical Technique	Number of Analysis	Statistical Parameters										
							Arsenic Concentration (mg/l)					Range (mg/l) < 0.01; 0.01-0.05 ; >0.05					
							Max	Min	Av	Medi-an	Std Dev.	Nr	%	Nr	%	Nr	%
DCH/SOES		All Bangladesh	Different types of water supply wells	Patient based survey	HG-AAS	3673	4.727	<0.003	0.140	0.019	0.314	1598	44	628	18	1393	38
DPHE	1998	All Bangladesh	Different types of water wells	From known Hot Spots	SDDC	2464	2.50	0	0.074	0.010	0.195	960	39	856	35	648	26
DPHE/ISDTP	1997	18 District Towns	Town water supply wells	Agency	HG-AAS	149	0.18	<0.002	0.022	0.067	0.035	83	56	46	31	20	13
Ahmed et al (BUET/NEMIP)	1997	NE Bangladesh	Irrigation wells	Random	SDDC	1210	0.268	<0.001	0.044	0.023	0.053	471	39	337	28	402	33
BCSIR/NEMIP	1997	NE Bangladesh	Irrigation wells	Random	AAS-HG	751	0.85	<0.001	0.055	0.0340	0.0805	200	27	239	32	312	41
NRECA	1997	Bangladesh	Wells in and around REB installations	Clustered	SDDC	456	0.788	0	0.061	0.026	0.108?	151	33	160	35	145	32
Safiula	1998	Faridpur Municipality	Water supply wells	Random	SDDC	166	1.87	0	0.187	0.0645	0.298	17	10	68	41	81	49
DANIDA/DPHE	1998	Noakhali Municipality	Water supply wells	Random	SDDC	216	0.992	<0.010	0.140	0.105	0.133	6	3	31	14	179	83
Talukder	1997	All Bangladesh	Water supply wells	From known Hot Spots	HPLC-ICP-MS,ICP-MS AAS-HG HLPC-AAS-GF SDDC	67	1.67	0.005	0.266	0.135	0.334	8	12	19	28	40	60
Nickson	1997	Central Bangladesh	Water supply wells	Transit along a line	HG-AAS	46	0.335	<0.0001	0.067	0.0338	0.0847	24	52	8	17	14	30
BGS	1997	Ch. Nawabganj Municipality	Water supply wells	Known Hot Spots	HG-ICP-AES	29	2.40	<0.004	0.382	0.141	0.553	13	45	8	27.5	8	27.5
BWDB/GWC	1995	Western Bangladesh	Water supply wells	Known Hot Spots	HG-AAS	20	0.048	<0.026	0.026	0.023	0.01	14	70	6	30	0	0
DWASA	1990	Dhaka City	WASA DTWs	Random	Not Known	3	All Bellow Detection Limit (0.01)					3	100	0	0	0	0
DPHE/18DTP	1997	Dhaka City	WASA Deep Wells and HTws	Random	ICP-MS	21	All Bellow Detection Limit (0.02)					21	100	0	0	0	0
BAMWSP	2002	41 Upazila	All types of water wells	All tube wells	Mark Test Kit	625041	> 3.0	0.05	-	- -		- -	-	-	-	-	-
UNICEF	2002	20 Upazila	All types of water wells	All tube wells	Mark Test Kit	403096	> 3.0	0.05	-			- -	-	-	-	-	-
					All data	1037408						3569	39	2460	26	3242	35

Chapter I

READING AND PRINTING INSRUCTIONS

The report is presented in 7 files as described below:

1- Cover page: This is the cover page.

2- Presentation: This is the page with signatures of the members of the Task Force.

3- Contents + EXECSUM: The table of contents and the Executive Summary in presented in this file.

4- Main Report: The main report in VIII chapters is presented in this file.

5. GWTF Annex: Annex I to III B are presented in this file.

6. Annex Landscape p-A-30: This page is number A-30 of Annex II. This is typed in landscape format. While reading this page should be read as page number A-30. If the report is printed this page should be placed in its proper place.

7-Chapter covers: Each chapter has a cover page without numbers. If the whole report is printed these pages should go in their proper places.

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Annex IIIB

Geological Setting of the Areas of Arsenic Safe Aquifers

October, 2001

Md. Munir Hussain [1] and S. K. M. Abdullah [2]

1. Hydrogeologist, BAMWSP & Member Secretary, GWTF
2. Former Director General, Geological Survey of Bangladesh and Chairman, Groundwater Task Force

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INTRODUCTION

All water below the earth surface may be called subsurface or underground or ground water. A hole penetrating the ground, initially passes through the zone of aeration (unsaturated zone), in which inter granular spaces are normally filled mainly with air. The hole then enters the saturated zone in which all inter granular spaces are filled with water. The upper surface of the saturated zone is called the water table and at any place it normally slopes toward the nearest stream. Very considerable amount of water occurs in more or less definite layers or rock formations that often extend at various angles for hundreds or thousands of meters into the earth. Such water bearing layers or rock formations are known as aquifers. An aquifer is usually bounded above and below by materials impervious to water.

In Bangladesh the most important environmental issue at present is the arsenic contamination in the ground water of the Holocene[1] aquifers of the Recent Alluvial deposits. The present paper deals with the aquifers of arsenic safe geological regions and superimposes them on the Upzila Map of Bangladesh. Lists of the Upzilas totally or partially belonging to this region are enclosed as Annex - 2 to Annex - 6.

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GEOMORPHOLOGY OF BANGLADESH

Topographically, Bangladesh is a plain land except the hills regions of east and northeast. The plain land mainly consists of fluvio-deltaic sediments deposited by the Ganges, the Brahmaputra and the Meghna river systems.

Geomorphologically, Bangladesh can be divided into four distinct regions each having distinguishing characters of its own.

1. The Holocene Floodplains of the Ganges, the Brahmaputra and the Meghna river systems.
2. The Bengal Delta
3. The Eastern and Northeastern Tertiary Hills Regions
4. The Pleistocene[2] Terrace or the Pleistocene Uplands

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1. An epoch of the Geological Time Scale, approximately 10,000 years ago, to the present time; also, the corresponding series of rocks and sediments deposits.
2. An Epoch in the Geological Time Scale that started about 1.8 million years ago and lasted until the start of the Holocene some 10,000 years ago, also, the corresponding series of rocks and sediments deposits.

The Flood plain and the Bengal Delta regions occupy seventy two(72) percent of the total land area of Bangladesh and the Pleistocene Terrace and the Tertiary Hills Regions cover rest 28%.

Regional geological setting reveal that the land forming sediments were transported by the great river systems from the Himalayan Mountains and the Shilling Plateau to the north, Arakan Yoma Belt of Mayanmar to the east and Rajmal Hills of India to the west, The open southern portion of Bengal Basin served as a depositional center for the sediments (Reimann 1993).

The geological structures and sedimentary depositional environmental process indicate that Mass-Flux (sediment + water) system and recyclic geo-environment played an important role during the land formation.

The floodplains of the Ganges, the Brahmaputra and the Meghna rivers cover approximately 40% of Bangladesh. The elevation of the major part of the floodplain ranges from 3 to 5 meters. As the floodplains approach the Himalayas from the northern part of the Pabna district the elevation rapidly increases to about 90 meters above the mean sea level at the northern end of the Panchagarh district (Fig. 1).

The Delta covers about 32% of Bangladesh. The present Delta is a combination of three deltas namely the Ganges delta, the Old Brahmaputra-Meghna delta and the Ganges-Jamuna (the present Brahmaputra)-Meghna delta. Moreover in the summer monsoon season when about 3 million cusecs of water passes through the delta, it behaves as a fluvial delta whereas in the winter when the volume of water passing through the delta drops to 250,000 to 300,000 cusecs it behaves as a tide dominated delta. These unusual features make this delta one the most complex in the world. Holocene or Recent sediments from a few hundred to thousands of meters cover the Flood plains and the Delta.

Arsenic contamination of the groundwater is mainly concentrated in the aquifers of the Flood plains and the Delta that covers about 72% of the country.

ARSENIC SAFE GEO-DISTRICTS OF BANGLADESH

A study of the geological map of Bangladesh shows that it can be quite safely assumed that water from shallow or deep aquifers are safe from arsenic contamination in some areas. Those assumptions are also confirmed from the analyses of tube-well water samples study done in the late 90′ s by the "British Geological Survey and Molt MacDonald Ltd."[3]

These arsenic safe areas can be divided in to the following regions, which cover about 28% of Bangladesh (Fig. 2). Most of these areas are sparsely populated compared to the average density of population per square kilometer in the country.

1. The Eastern and Northern Frontier Hilly Regions

- 1.1 Chittagong and Hill Tract Districts
- 1.2 Hill ranges of northeastern Sylhet District
- 1.3 Hills along the narrow frontier strip of Sylhet and Mymensingh District.

2. The Pleistocene[3] Terrace or the Pleistocene Uplands

- 2.1 The Barind Tract
- 2.2 The Madhupur Tract
- 2.3 The Lalmai Hills

1. The Eastern and Northern Frontier Hills Regions

1.1 Chittagong and Hill Tract Districts

High North-south striking hill ranges occupy wholly the districts of Chittagong, Cox's Bazar and the three Hill Tract districts. The anticlines form the hills and synclines the valleys. The lowest ranges generally follow the eastern coast of the Bay of Bengal from Feni River to Naf River and continue southwards across the Mayanmar border. Most of Moheskhali Island belongs to this hilly area. A narrow strip of coastal plain about 96.5 km long averaging about 9.66 km wide, developed due to a fault along the Sitakund anticline. Chokoria Sundarban and the associated Mud Flat area are small deltas of the Matamuhuri River. There is a very narrow strip of less than 100 meter beach from Cox's Bazar to Teknaf, between the hills and the Bay of Bengal.

Towards the east, the ranges get higher and the slope steeper until they reach the highest hill range in the east that marks the boundary between Bangladesh, Mayanmar and India. The hills are

3. Ground Water Studies For Arsenic Contamination in Bangladesh. Phase 1: Rapid Investigation Phase, Final Report, Main Report by British Geological Survey & Mott Macdonald, Jan. 1999.

composed of alternating beds of sandstone, siltstone and claystone. The age of the rocks range from Early Miocene[4] to Pleistocene (Annex -1).

1.2 Hill Ranges of Northeastern Sylhet District

Some of the hill ranges of the Chittagong and The Hill Tract districts continue northward across the Indian State of Tripura and form the hill ranges of northeastern Sylhet region. These hill ranges attain a much lower elevation and slope more gently than their continuation in The Chittagong and The Hill Tract Districts.

1.2 Hills along the narrow frontier strip of Sylhet and Mymensingh Districts.

The narrow strip of discontinuous low hill ranges extends from Jaflong in the east to the Brahmaputra River in the west. The Jaflong hill attains a maximum height of 61 meter above sea level, with the elevations of the hills decreasing westward. These hills do not form continuous range, but constitute a chain of circular and elongated hillocks separated by Recent alluvial valleys. Rocks older than those of Chittagong hills occur in the eastern part near Jaflong and Bagalibazer. Along the frontier of greater Mymensingh these hills form series of circular and elongated hillocks.

All the above hilly areas, in total occupy about 18% of Bangladesh.

2. The Pleistocene Terrace or The Pleistocene Uplands

2.1. The Barind Tract

The Barind Tract is located in the west of the Brahmaputra River. If falls in the central part of north Bengal and covers an area of 7680 sq. km in the Rajshahi division. The area comprises of six north south elongated isolated exposures of reddish brown deposits.

The Barind Tract is the product of vertical movements of Pleistocene period and reaches as maximum height of 20 m above modern flood plains.

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4. An Epoch in the Geological Time Scale that started about 23.8 million years ago and lasted until the Pliocene Epoch 5.3 million years ago, also the corresponding series of rocks and sediments deposited.

2.2 The Madhupur Tract

The Madhupur Tract is situated in the east of the Barhmaputra River. It looks like a chain of isolated circular to elongated low hillocks standing at a higher level than the surrounding flat alluvial plain and is affected by a series of faults.

This area of about 4,058 sq. km. extends in Dhaka, Mymensingh and Tangail districts. In the Madhupur Tract, reddish brown clay deposits are exposed on some north south trending elongated flat landmass abruptly elevated from the surrounding floodplains. In Madhupur Tract the landmass reaches a maximum height of 17 m from sea level.

In some places, there is a thin layer of white to grayish volcanic ash layer over the clay layer of the Uplands. The age of this ash layer which derive from the Toba Volcanic explosion of Sumatra, is 75,000 years BP (Before Present), which has been confirmed by radioactive dating. The Madhupur clay layer is thicker than those of the Barind Tract. Earlier it was thought that both the Barind Tract and the Madhupur Tract are of the same age. But recent studies based on Be^{10} [5] show that the Barind Tract is about 25,000 years old compared to that of Madhupur which is about 110,000 years old.

The Pleistocene Uplands cover an area of about 10% of Bangladesh. Determination of the concealed Pleistocene red clay that composes the rock type in the immediate surrounding of the Barind and the Madhupur Tracts should increase their areas considerably.

2.3. Lalmai Hills

The Lalmai Hills are situated in the Comilla district and are composed of reddish brown clay. The Lalmai Hills represent a north-south elongated low hill range of about 16 km long and about 2-3 km wide. It covers an area of about 33 sq. km. The hill range runs through the middle of Comilla district and is about 3 km from the Town. The average height is about 12 m that reaches a maximum of 40 meter above the mean sea level. The reddish brown deposits exposed in the

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5. J.W. Whitney, M.J. Pavich, Md. Anwarul Huq & A.K.M. Khorshed Alam, 1999, The Age and Isolation of the Madhupur and Barind Land Tracts, Ganges-Brahmaputra Delta Bangladesh; Abstract Volume, International Seminar on Quaternary Development and Coastal Hydrodynamics of the Ganges Delta in Bangladesh, 20-24 Sept., 1999, Organized by the Geol Survey of Bangladesh, p. 11.

Lalmai Hills area is considered as the extension of the reddish brown deposits of the Madhupur area of Pleistocene age.

IMPACTS OF SEA LEVEL CHANGES ON THE AQUIFERS

Most of Bangladesh had low elevation throughout it's geological history that made it very much sensitive to the sea-level changes which influenced the geological processes of weathering, erosion and deposition of sediments. Fairbridge[6] made a curve of sea level changes at different geological time. S.K. Acharyya[7] presented a summary of the history of sea level changes in South Asian Region from the great Ice Age of the Late Pleistocene to the present time. During the Late Pleistocene and Earliest Holocene the sea level was in the lowest stand when the Pleistocene sediments were exposed, weathered and was eroded and incised by the rivers. He divided the Holocene Deposits into three units, The Upper, The Middle and The Lower Units. The basal sand and gravel beds, comprising the lower unit of the Holocene sequence, were deposited in the incised channels of the proto Ganges-Brahmaputra rivers. During 18,000 to 12,000 yr. BP., sea level continued to rise resulting transgressional onlapping sedimentation and filling up of entranced valleys by fluvial or fluvio-deltaic sand with silt and clay. These sediments constitute the upper section of the lower unit, which is also free of arsenic problem, at least in the upper reaches of the delta. Most arseniferous tube wells generally tap the aquifers in the middle unit. This unit was deposited around 10,000 to 7,500 yr.BP. The deposition of the upper unit commenced when the sea level started rising rapidly during 7,000 - 5,000 yr. BP., and reached higher than 2 m than the present level. There was extensive development of marine and fresh water peat. After this post-glacial optimum, the sea level dropped initiating a phase of subdued marine regression and migration of shoreline to the present configuration. The upper unit sediments are also enriched in arsenic in most places.

THE WATER QUALITY OF THE SAFE AQUIFERS

The arsenic safe areas are outside the Floodplain of the Ganges, the Brahmaputra and the Meghna rivers and the Delta complex of the Ganges-Brahmaputra-Meghna rivers. All the tube well water samples from these areas did not show any arsenic contamination till now. As far as amount of widrawl of water is concerned Dhaka City can be cited as an example. With more than 370 deep tube wells, Dhaka WASA is widrawing 1.2 billion liters of water per day. This probably is the

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6. Fairbridge, R.W., 1961, Eustatic Changes in the Sea Level. Physics and Chemistry of the Earth, Vol. 4, p. 99-185
7. S.K. Acharyya, 1999, Ganges Delta Development During he Quaternary in the Bengal Basin and its Relation to Arsenic Toxicity in ground Water; Abstract Volume, International Seminar on Quaternary Development and Coastal Hydrodynamics of the Ganges Delta in Bangladesh, 20-24 Sept., 1999, Organized by the Geological Survey of Bangladesh, p. 17.

highest rate of widrawl in the country per sq. km. But till now water samples from any of the tube well in Dhaka City does not have any arsenic contamination.

Upazilas and part of Upazilas having water from all aquifers expected to be safe from arsenic contamination is listed below (Map enclosed).

A. The areas covered by Barind Residual Deposits of the Pleistocene Age.

A.1 Barind Residual Deposits cover an area of 7,680 sq. km of the central parts of Rajshahi Division.

Twelve Upazilas of Bogra, Joypurhat, Naogaon, Nowabganj and Rajshahi Districts (Annex-2) are completely covered by Barind Residual Deposits. Aquifers below the Red Clay of these Upazilas are safe from Arsenic pollution.

A.2. 32 Upazilas of Bogra, Dinajpur, Gaibandha, Joypurhat, Naogoan, Natore, Rangpur and Sirajganj Districts (Annex-3) partially belong to Barind Geological District of Residual Deposits.

B. The areas covered by Madhupur Residual Deposits of the Pleistocene Age.

B.1. Madhupur Residual Deposits cover an area of 4058 sq. km. 2 Upazilas of Mymensingh and Tangail Districts (Annex-4) are completely covered by Madhupur Clay deposits.

Aquifers of these Upazilas are safe from arsenic contamination.

B.2. 19 Upazilas of Comilla, Dhaka, Gazipur, Jamalpur, Mymensingh, Narayanganj, Narsingdi and Tangail Districts (Annex-5) are partly covered by Madhupur Clay deposits. Aquifers within the Madhupur Clay Deposits are still Arsenic safe.

C. The South Eastern Hills Region: Area covered by Pre-Holocene Sediments in the Chittagong and Hill Tract Districts.

C.1. All the Upazilas of Khagrachari, Rangamati, Bandarban, Cox's Bazar, and Districts of South Eastern Hills Regions (Annex-6) belong to Bedrock Districts and are completely covered by Bedrock Deposits.

C.2. Parts of 22 Upazilas of Chittagong, Sherpur, Habiganj, Maulivibazar, Sunamganj and Sylhet Districts (Annex-6) are situated within Bedrock Districts.

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Annex - 1

EXPOSED GEOLOGICAL SUCCESSION OF BANGLADESH

ERA	PERIOD	EPOCH	GROUP	FORMATION	LITHOLOGY	THICKNESS (in Meter)
CENOZOIC	Quaternary	Holocene (Up to 0.01 Ma*)		Alluvium	Sand, Silt, clay, peat, Corals	Highly Variable
		....		....Unconformity.....	....	....
		Pleistocene (0.01 to 1.8 Ma)		Madhupur Clay	Red & yellow clay with ferruginous & calcareous nodules	32+
				St. Martin's Limestone	Shelly sandstone, limestone & coral clusters	1.7
		....		.....Unconformity........	....	....
	TERTIARY – NEOGENE	Pliocene (1.8 Ma to 5.3 Ma)		Dihing	Silty Sandstone, Claystone, Sandstone containing abundant ferrugenous concretions, boulder bed, yellowish brown.	129
				....Unconformity.....	....	....
				Dupi Tila Claystone	Claystone, siltstone, sub - ordinate sandstone with ferruginous bands, gravels in places	1798
		....				
		Late Miocene (5.3 Ma to 11.2 Ma)		Dupi Tila Sandstone	Medium to coarse grained, gray to yellow sandstone with clay balls and quartz pebbles, traces of coal lenses.	914
			....	.....Unconformity....	....	....
		Middle Miocene (11.2 Ma to 16.4 Ma)	Tipam	Girujan Clay	Claystone, silty shale, and subordinate sandstone.	1067
				Tipam Sandstone	Massive sandstone with subordinate shale	1203
			....	....	....	....
				Boka Bil	Alternation of well bedded slltstone and shale with subordinate sandstone	1710
		Early Miocene (16.4 Ma to 23.8 Ma)	Surma	Upper Bhuban	Siltstone with subordinate shale and sandstone	1953
				Middle Bhuban	Silty and sandy shale	928
				Lower Bhuban	Sandstone and sandy shale	980

* Million Years Ago
** Maximum Possible Thickness

Annex-2

Upzilas Completely Covered by Safe Aquifers in Barind Region

12 Upazilas of Bogra, Joypurhat, Naogoan, Nowabganj and Rajshahi Districts are completely covered by Barind Clay Residuum/Residual Deposits. Aquifers of these Upazilas are safe from Arsenic pollution.

Division	District	Upazila
Rajshahi	Bogra	Dhubchachia
		Kahalu
		Nandigram
	Joypurhat	Akkelpur
		Kalai
		Khetlal
	Naogaon	Niamatpur
		Patnitala
		Sapahar
	Nawabganj	Nachole
	Rajshahi	Godagare
		Tanore

Annex-3

Upzilas Partially Covered by Safe Aquifers in Barind Region

32 Upazilas of Bogra, Dinajpur, Gaibandha, Joypurhat, Naogoan, Natore, Rangpur and Sirajganj Districts are partially belong to Geologic District of Residual Deposits Aquifers located within above Geo-district are safe from Arsenic contamination.

Division	District	Upazila
Rajshahi	Bogra	Adamdighi (Except South west corner)
		Bogra Sadar (Western part)
		Dhunot (Eastern part)
		Sherpur (Western part)
		Shibganj (Western part)
	Dinajpur	Birampur (Eastern and Western corner)
		Birganj (North west and South west part)
		Birol (South east corner)
		Bochaganj (Southern part)
		Chirirbandar (Southern half)
		Dinajpur Sadar (Southern half)
		Ghoraghat (South and South west part)
		Hakimpur (Except North west corner)
		Kaharol (North east part)
		Nawabganj (South west part)
		Phulbari (Western half and part of North east)
		Parbatipur (Central North South)
	Gaibanda	Gobindaganj (Western part)
		Sadullapur (South west part)
	Joypurhat	Joypurhat Sadar (Eastern part)
		Panchbibi (North east and South east part)
	Naogaon	Badalgachhi (Western part)
		Dhamorihat (Except North east and Central part)
		Naogaon Sadar (North west part)
		Porsha (Except North west part)
		Raninagar (Eastern part)
	Natore	Sihingra (North east part)
	Rangpur	Badarganj (North west and South west part)
		Mithapukur (Western part)
		Pirganj (Western part)
	Sirajganj	Raiganj (North west part)
		Taras (North east part)

Annex- 4

Upzilas Completely Covered by Safe Aquifers in Madhupur Region

2 Upazilas of Mymensingh and Tangail Districts are completely covered by Madhupur Clay deposits. Aquifers of these Upazilas are safe from arsenic contamination.

Division	District	Upazila
Dhaka	Mymensingh	Bhaluka
	Tangail	Shakhipur

Annex- 5

Upzilas Partially Covered by Safe Aquifers in Madhupur Region

19 Upazilas of Comilla, Dhaka, Gazipur, Jamalpur, Mymensingh, Narayanganj, Narsingdi and Tangail Districts are partly covered by Madhupur Clay deposits. Aquifers within the Madhupur Clay Deposits are still Arsenic safe.

Division	District	Upazila
Chittagong	Comilla	Comilla Sadar (Part of Western side)
Dhaka	Dhaka	Dhaka Metro (Except Eastern part)
		Savar (Except extreme Southern and Eastern part)
	Gajipur	Gajipur Sadar (North west and South east part)
		Kapasia (Except South east part)
		Kaliakoir (Except South west corner)
		Sreepur (Except North east and Southern part)
	Jamalpur	Jamalpur (South east corner)
	Mymensingh	Gafargaon (Western part)
		Muktagacha (North west corner)
		Phulbaria (Eastern part and part of South)
		Trishal (South and South west part)
	Narayonganj	Rupganj (Only central part)
	Narsingdi	Belabo (North west and South west part)
		Palas (North west part)
		Shibpur (North east part)
	Tangail	Ghatail (Central and Eastern part)
		Madhupur (Eastern part and part of due South)
		Mirgapur (North east corner)

Annex- 6

Upzilas Completely and Partially Covered by Bed Rock and with Safe Aquifers in Hills Region

All the Upazilas of Bandarban, Cox's Bazar, Khagrachhari and Rangamati Districts of South Eastern Hilly Regions belong to Bedrock Districts and are completely covered by Bedrock Deposits. Aquifers of these areas are safe from arsenic contamination.

Parts of 20 Upazilas of ,Sherpur, Habiganj, Moulivibazar, Sunamganj and Sylhet Districts are situated within Bedrock Districts. The valleys within the hill area are also safe from arsenic contamination.

Division	District	Upazila
Chittagong	Chittagong	All Upzilas except he coastal plain areas of the Mirersharai and the Sitakund Upzilas.
	Khagrachari, Rangamati, and Bandarban	All Upzilas of these Districts.
Dhaka	Sherpur	Jhenaigati (Northern part)
		Nalitabari (Northern part)
		Sribardi (North east part)
Sylhet	Habiganj	Bahubal (Central part along North west direction)
		Chunarughat (North west, South west and Part of South east)
		Nabiganj (South east part)
	Maulavivazar	Barlekha (Eastern part fully)
		Kulaura (Western part and part of Eastern side)
		Kamalganj Western and Eastern part)
		Ragnagar (Eastern part)
		Srimangal (North South central part and South east corner)
	Sunamganj	Bishwambarpur (North east part)
	Sylhet	Beanibazar (Central part)
		Fenchuganj (Southern end)
		Golapganj (North east part)
		Gowainghat (South east part)
		Jaintapur (Northern part)
		Kanaighat (Eastern part)
		Sylhet Sadar (North east and South west corner)
		Zokiganj (North eastern portion)

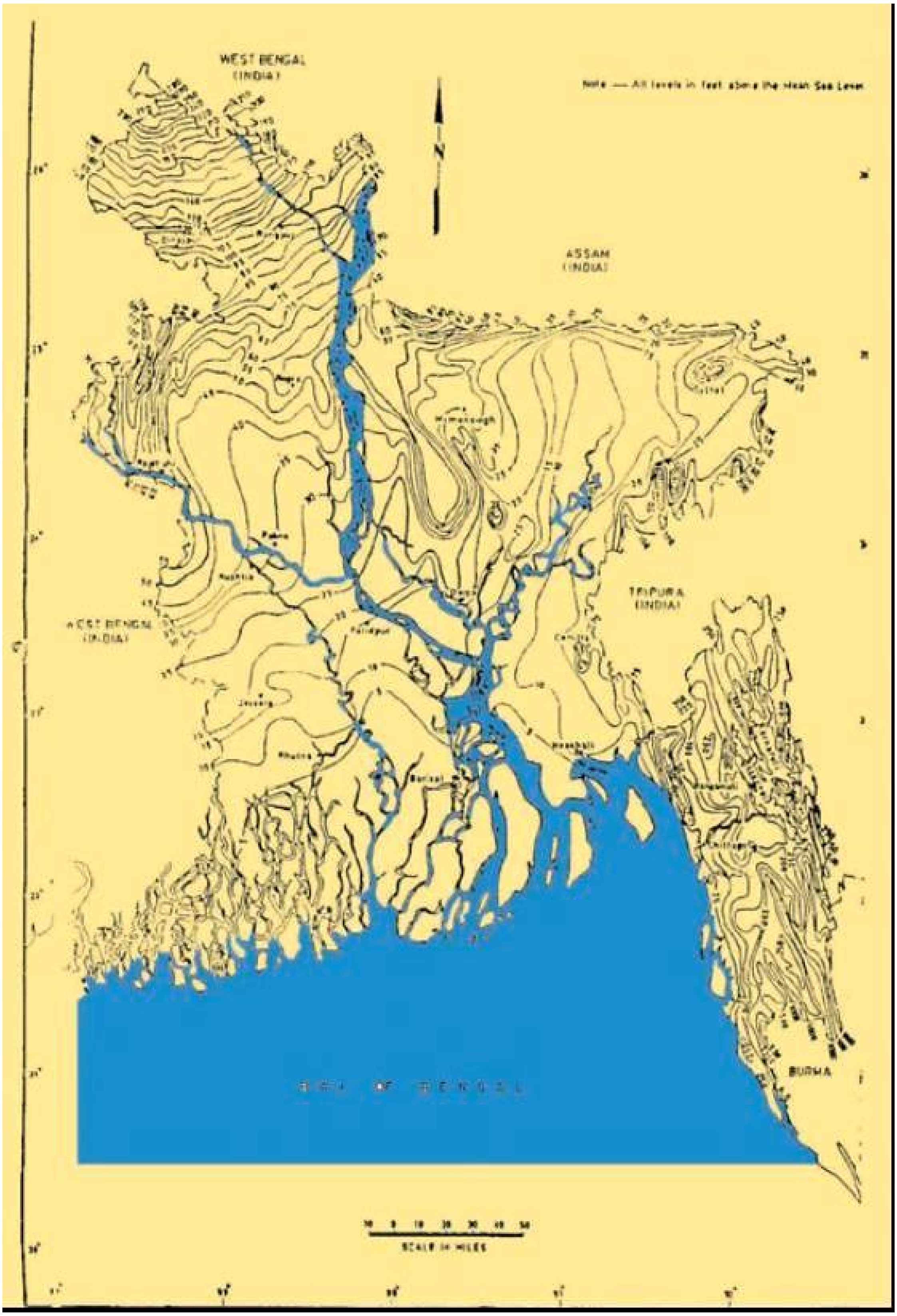

Fig. 1 Contour map of Bangladesh (Source-: Gulam Kibria, 1966)

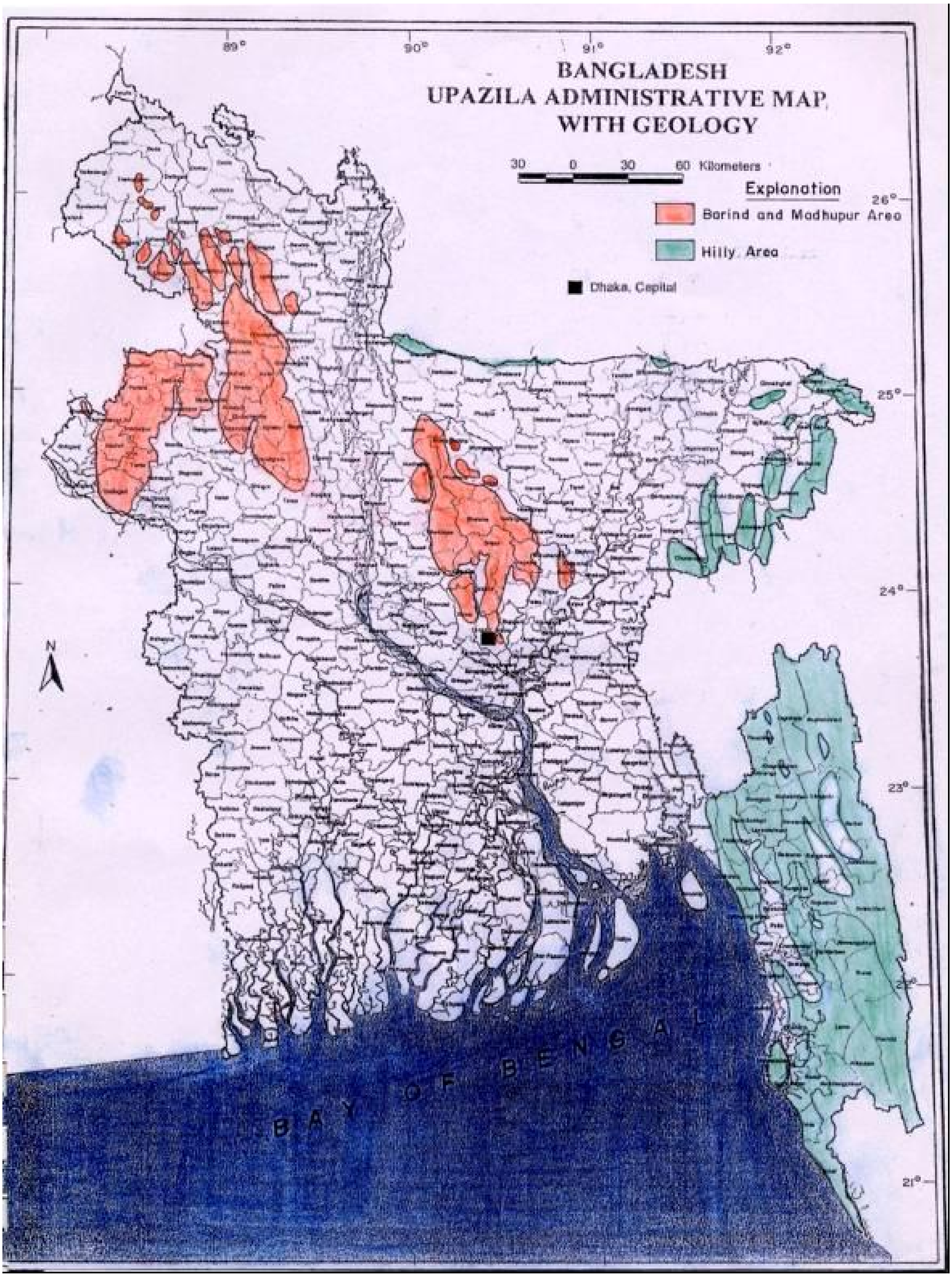

Fig 2. Map showing the area of arsenic safe aquifers.

Annex II

Table 4.1 Summarised Description of the Groundwater Development Zones in Bangladesh

Name of the zone	AREA	LITHOLOGY	Aquifer characters	Remarks
A	Rangpur, parts of Bogra & Jamalpur	Coarse sediments	T= 1000 to 7000 sq. m/day	Highest transmissivity
B	South-central part of the country	Clay, silt in the upper part	T=3500 sq.m/day	Potential for deep wells.
C	Kustia and most of Pabna	Floodplain of Ganges (sand, silt, clay)	2-3 cusecs for deep wells	
D	Most northwestern region (Dinajpur)	Coarse detrital piedmont deposits, top silt clay	T= high	Suitable for groundwater development
E	Bogra and Rajshahi	Older alluvial clay	1-2 cusecs for deep wells	
F	Southern and western parts of Rajshahi	Same as zone C		Lowest recharge
G	Southwestern section of Comilla & northern part of Noakhali	Floodplain deposits of Meghna	2 cusecs for deep wells	Suitable for deep wells
H	Most of Mymensingh, eastern Jamalpur & small part of NW Dhaka	Floodplain deposit of old Brahmaputra	2 cusecs for deep wells	Suitable for deep wells; high recharge
I	Plains of Sylhet district	Top part silt & clay	One cusec for deep wells	High rain fall, high recharge
J	Parts of Dhaka. Tangail & Mymensingh	Top part Madhupur Clay	1-2 cusec (200 mm recharge /Year)	Suitable for deep wells
K	Eastern part of Comilla	Estuarine silt	2 cusec	Suitable for deep wells
L	Chittagong & Noakhali	Piedmont deposits & estuarine deposits	T= 400 sq.m/day	Not favouable for extensive withdrawal
M	Hilly areas of Sylhet & Mymensingh & Ctg. Hill tracts	Tertiary sediments	Low transmissivity	Not favouable for extensive withdrawal
N	Coastal areas of Barishal, Patuakhali , most of Khulna, Noakhali, & Chittagong	Flood plains of GBM	-	Brackish & saline water problems
O	Western Rajshahi District	Thick Madhupur clay on the top part with thin sand layers	-	Limited scope for development

Source: UNDP, 1982

Table 4.2 Aquifer Types and Characteristics of the Groundwater Regions of Bangladesh

Aquifer Unit Area (Km.²) Relief / Physiographic Unit	Greater District	Lithology	Thickness of Aquifer (m.)/Depth to Main Aquifer (m.)	Type of the Aquifer
1	**2**	**3**	**4**	**5**
I. NW REGION: Unit-1: Northern Piedmont (3594). Piedmont Plain: broad ridges and depressions.	Dinajpur	Dominantly medium to course grained, poorly sorted sands and gravels with thin surface clays : 10m. thick clay occur in the south.	Aquifer thickness in excess of 100m. Range: 1-30m. Average: 5m.	Extensive unconfined, can be locally semi-confined.
Unit-2: Teesta (3279). Old Teesta floodplain, active alluvium: typically ridge and basin topography.	Dinajpur / Rangpur	Continuation of piedmont deposits containing a higher proportion of clays and silts with average thickness of 2m. or so followed by fine, medium and coarse sands, clay lenses persistently occur in sands.	Unknown but exceeds 60m. over most of the area. Range: 5-50m. Average: 20m.	Extensive unconfined.
Unit-3: Kurigram (1335). Old Teesta floodplain: typically ridge and topography.	Rangpur	Surface lays a finer materials and up to 15m. thick below 25m. coarse sands and gravels constitute over 50 percent of the aquifer materials.	Unknown but assumed to be 60m. Range: 5-50m. Average: 20m.	Extensive unconfined, locally semi-confined.
Unit-4: Dinajpur (1758). Barind with some Piedmont and old Teesta floodplain: ridge and basin topography.	Dinajpur	Surface clay varies in thickness from 2 to 15m., clays extensive throughout the penetrated sequence, becoming dominant below 80m. Sands uniform but gravels tend to be mixed with finer materials.	Unknown but could be 80m. Range: 15-60m.	Multiple, dominantly semi-confined.
Unit-5: Gaibandha (Jamuna floodplain in NE) (3929). Old Teesta floodplain: typically ridge and basin topography.	Rangpur and Bogra	Well developed surface clays with average thickness of 6m. with increasing depth fine sends under lying the silts rapidly give way to well sorted medium to coarse sands with gravel and clay lenses.	Not known. Range: 5-50m.	Extensive unconfined aquifer, semi-confined in places.
Unit-6: Northern Barind (2434). NE Barind and Barind: deeply dissected uplifted areas; soils developed from weathered Madhupur clay.	Dinajpur and Bogra	Surface covered by about 6m. Madhupur clay which is underlain by fine sands and silts which dominate the top 16m. and can locally extend to 30m.	Aquifer thickness ranges from 50-60m. Range: 3-40m. Average: 10m.	Dominantly semi-confined.
Unit-7: Shibganj (1200). Ganges and lower Mohananda floodplain: typical meander floodplain.	Rajshahi	Thin (6m.) clay overlies finer materials which rapidly coarsen to coarse sand, and gravels. Thin laterally persistent clays interlayer with sand.	Average aquifer thickness 100m. Range: 10-60m. Average: 30m.	Semi-confined.
Unit-8: High Barind (3634). Barind tracts: uplifted area, locally faulted and is highly dissected. fault depression contain thick (40m.) clay.	Rajshahi	Madhupur clay attains greatest thickness (21m.) underlying clays and silts on increase the depth to aquifer to 60m. Within the clays, thin lenses of fine sand occur but in the east medium to coarse sands occur and give rise to an aquifer. The aquifer materials thin westward.	Unknown but could be over 80m. Unknown but there may be no significant aquifer materials within 300m.	Upper part unconfined, becoming semi-confined to the south.
Unit-9: Little Jamuna (980). Little Jamuna Flood Plain, Lower Atrai and Ganges floodplain	Rajshahi Bogra	Two district fining up sequences separated by middle clays of 3 to 10m. thick lower aquifer relatively uniform with coarse sands and gravels at the base fining up to the dividing clay upper aquifer less uniform. Upper clay is 3 to 9m. thick and is underlain by silts to 14m.	Unknown but could be 30m. or 50m. Range : 10-65m. Average : 25m.	Upper part unconfined becoming semi-confined to the south.
Unit-10: Southern Barind (2189). Barind Tract uplifted highly dissected area	Bogra	Surface covered by weathered Madhupur clay of 6 m. thick underlain by silts and fine sands to varying depth from where sediments coarsen to coarse sands and gravels.	Unknown but could be as such as 50m. or more. Range : 10-64m. Average : 30m.	Mainly semi-confined.

Continued next page

1	2	3	4	5
Unit-11: Sherpur Platform (1546). Barind and lower Jamuna floodplain highly dissected uplifted area in the Barind and ridges and basin in the flood plain	Bogra	Fairly thin (not exceeding 10m.) surface clays and silts sorted sequence of sands to depth of 30m. or more followed by gravels. Basal clay of 30m. thick occurs to a depth of 106m.	Average thickness 30m. or more. Range : 15-60m. Average : 30m.	Semi-confined.
Unit-12: Ganges (3152). Ganges floodplain broad ridges and basin.	Rajshahi Pabna	Silty clay bands occur to over 30m. in places thin sand lenses common with small aquifer potential. Below 30m. coarser sediments with 70m. or more thickness.	Average thickness 70m. Range : 10-70m. Average : 35m.	Semi-confined.
Unit-13: Natore (1783) Ganges flood plain, ridges and basins	Rajshahi Pabna	Surface clays 12-24m. thick underlain by silts and fine sands to about 30m. this is followed by coarser materials forming an aquifer.	Unknown but could be 30 m. or more. Range: 10-70m. Average: 30m.	Semi-confined.
Unit-14: Tarash (1301) Lower Jamuna flood plain typified by ridges and basins	Pabna and Bogra	10m. of clays overlie a silty unit to 18m. below which medium to coarse grained sands	Aquifer thickness not proven. Range: 10m. or 50m.	Semi-confined.
<u>II. NE REGION:</u> Unit-15: Eastern piedmont (1690) Generally slopping piedmont alluvial plains, sandy near the hills but becomes clayey down slope.	Jamalpur and Mymen-singh	Surface clays 15 25m. thick with sands and silt leases overlying inter calculated coarse sands and cays to 50m. Sand aquifer coarsening downwards 40 to 75m with significant clays again 75m. to 110m.	Limited thickness and extent considerable reduction in aquifer materials within 100m. because of presence of extensive aquiclude clays. Range : 16-80m. Average : 40m.	Dominantly semi-confined.
Unit-16: Brahmaputra Floodplain (116) Old Brahmaputra flood plain with ridge and basin relief predominating in the meander flood plain, soil are well.	Jamalpur	Thin surface clays and silts which overlie a rapidly coarsening series of sediments containing fine sand bands. Sediments are coarsest is the west and become finer in the east with thickening of surface clays.	Estimated aquifer thickness 30 m. or 50m. Range: 5-50m. Average: 20m.	Semi-confined to unconfined
Unit-17: Old Brahmaputra Channel (1048) Active flood plain typified by ridges and basin with silts in the ridges and clays in the basins.	Jamalpur Mymen-singh and Kishore-gonj	3 to 9m. surf ace clays overlying micaceous, silty fine sands coarsening downwards to uniform medium sands.	Aquifer thickness ranges from 30 – 50m. Range: 15-80m. Average: 40m.	Generally unconfined
Unit-18: Palaeo Brahmaputra (2011) Old and oldest Brahmaputra flood plain characterized by ridges and basins.	Mymen-singh and Kishor-gonj	Generally 10-15m. of surface clays overlying uniform medium to coarse sands, sub-divisible into two sub units one with inter- mediate aquiclude absent and the other with present.	Thickness of aquifer not ascertained fully but exceeds 100m. Range: 15-80m Average: 40m	Unconfined to mainly semi-confined
Unit-19: Sylhet Basin (4056) Sylhet Basin a subsided area subjected to deep flooding	Sylhet and Mymen-singh	Very little in known about sub-surfaces geology sedimentary survey indicates total sedimentary thickness over 10 m. the areas is actively subsiding with the risibility that large thickness of silts and clays being deposited.	Not known	Not known but probably semi-confined to confined.
Unit-20: Surma Basin (9222). Eastern Surma basin: smooth relief with broad, almost level, ridges and basins. Grey silty soils occuron the ridges and clay in the basins.	Sylhet	Deep subsurface geology known seismic survey which indicates total sediments exceeding 10 .. few tube wells drilled in the northern fringe of the unit indicate varying thickness of silts and clays over lying a reasonable aquifer.	Not known	Not ascertained but probably semi-confined to confined.
				Continued next page

1	2	3	4	5
Unit-21: Madhupur Transition (1944). Old Brahmaputra and lower Jamuna floodplain with broad ridges and basins.	Tangail and Dhaka	10m. or so surface clays overlie gray fine sands followed by brown sands of various grain sizes to various depths.	Not known Range: 10-70m. Average: 45m.	Semi-Confined to unconfined
Unit-22: Madhupur Dhaka (4394). Madhupur tract a fault bounded zone distinguished by poorly drained level highland areas and well drained highland areas. The landscape is dissected in places.	Tangail and Dhaka	Madhupur clay with thickness up to 20m. or over occurs extensively throughout the region. Under the clay, medium to coarse sands with this hands of the fine waterfalls are encountered.	Aquifer thickness could be as such as 60 m. 0r more. Range: 15-90m. Average: 40m.	Semi-Confined
Unit-23: Mymensingh Trough (3008). Old and oldest Brahmaputra floodplain and part of Madhupur tract.	Mymen-singh and Kishor-ganj.	Part of place Brahmaputra Unit, but down faulted resulting in 40-50m. of recent fine sands over Pleistocene sands and gravels.	Thickness not ascertained but could be over 50m. Range: 15-90m. Average: 40m.	Semi-Confined
Unit-24: Old Meghna floodplain and Sylhet basin.	Sylhet, Comilla and Dhaka.	Unit is a southern extension of the Sylhet Basin Limited data do not allow assessment of lithology in the north, but existing wells in the south indicate a thin (ca. 3m.) layer of surface clay/silt overlying a sequence of fine sands which coarsen with depth.	Thickness of aquifer not ascertained. Range: 20-80m. Average: 45m.	Semi-Confined to confined
Unit-25: Eastern Hills (3194): Eastern hills NS and EW trending Dupi Tilla sediments; deep red brown terraces soils; southern piedmont deposits having a lower proportion of basin clays and a higher silt content.	Sylhet	Unit consists of folded tertiary sediments- Dupi Tilla sandstones constitute surface sediments.	Aquifer thickness not ascertained. Not known	Semi-Confined to confined multiple
Unit-26: Padma (2366). Lower Jamuna and Ganges floodplains with broad ridges and basins.	Tangail and Dhaka	Very little is known about the subsurface geology. Limited data indicate that the unit is similar to the Atrai basin and presumed that relatively thick occur, underlain by a sandy aquifer.	Not known. Range: 10-75m.	Unknown, but probably semi-confined to confined.
Unit-27: Young Meghna (3211). Young Meghna floodplain with ridges and predominating and old Meghna floodplain with dominantly level surface.	Dhaka and Comilla.	Little data exists on the subsurface geology. Limited data indicate that clays, 3 to 20m. thick are underlain by a mixture of sands and silts.	Not known. Range: 16-100m. Average: 60m.	Unknown, but likely to be semi-confined to confined.
<u>III. SW REGION:</u> Unit- SW-1: Old Gangetic Floodplain. Part of Gangetic moribund delta with linear ridges comprising of level to very gently undulating levees, inter ridge depressions and stream beds of dominant topographic elements.	Kushtia, Jessore, Faridpur and Khulna.	Predominantly medium to coarse grained, well sorted sand grading upward to fine sand to silty sand and clay with distinct fining up sequences. Capped by 10 to 60m. stlty/sandy surface clay.	Aquifer thickness is around 100m.; base rarely reached. 10 to 60m. with an average of 30m.	Extremely unconfined, locally semi-confined and confined.
Unit SW-2: Young Gangetic Floodplain. The unit comprises meander floodplains landscape of ridges, young channels and widespread development of past basins.	Faridpur, Khulna and Barisal.	Medium to fine grained sand constitutes the suffer materials. 30-60m. of surface clay with abundant peat layers covers the aquifer.	Aquifer thickness average 55m. Depth to the main aquifer averages 40m.	Semi-confined to unconfined, locally multiple.

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1	2	3	4	5
Unit SW-3: Coastal Plain. Coastal deltaic plain with mangrove forest.	Khulna, Barisal and Patu-akhali	Extensive thick surface clay with thickness up to 90m., locally up to 150m. shallow aquifer made up of medium to fine sand. Well defined aquifer of coarse to medium sand locally occurs at depths between 225 to 325m. with extensive clay cover.	Not well known.	Confined and multiple.
IV. SE REGION: Unit SE-1: Eastern Piedmont. Piedmont plains of the Tippera hills, lying along the border belt of Comilla and Noakhali.	Comilla, Noakhali.	Predominantly medium sand with subordinate fine sand at the bottom. Sorting in the sand is poor. Sandy materials are covered with a clay bed of more than 20m. thick.	Not precisely known, around 50m. Range: 40-60m. Average: 50m.	Extensive unconfined with local semi-confined to confined and multiple.
Unit SE-2: Old Meghna Floodplain. Formed by the Meghna and its tributaries and dis-tributaries. Typically flat, shallowly to intermittently flooded.	Comilla, Noakhali.	Predominantly medium sand with subordinate fine sand at the bottom. About 20m. clay covers the aquifer materials.	Known thickness of the main aquifer is around 10m. Range: 30-60m. Average: 50m.	Mainly unconfined.
Unit SE-3: Lower Meghna Floodplain. Formed by the present day Meghna. Deeply flooded.	Comilla, Noakhali.	25 to 40m. upper clay covers a layer of fine to medium sand. This is followed by occurrence of a second clay layer beneath which the main aquifer of medium to coarse sand lies.	The aquifer at the top (composite one) is about 60m. thick, thickness of the main aquifer is not known. 1st Aquifer : Range: 50-70m. Average: 60m.	Semi-confined to confined multiple.
Unit SE-4: Coastal Plains and Offshore Islands of Noakhali formed at the Meghna estuary.	Noakhali.	A 50-100m. or more clay materials cover a sandy sequence with a heterogeneous mixture of clay and silt. In some of the coastal islands, fine to medium sand found at the top which is followed by thick layer of silt and clay. Sandy materials are predominantly fine with subordinate medium and coarse materials at greater depths.	A shallow aquifer of about 20-30m. thickness exists. Thickness of the main aquifer is not known. Shallow aquifer exists at around 50-100m. depth. Main aquifer is deep seated.	Semi-confined to confined.
Unit SE-5: Complex Geology Area. Hills and Hill rages of Chittagong and Chittagong Hill Tracts characterized by high summits and deep valleys.	Chitta-gong, Chittagong Hill Tracts.	Surface clay of variable thickness covers the sandy materials, which are exposed or found at shallow depths in the hill ranges, and occurs at greater depths in the valley. Nature of thickness of the sandy materials is also variable.	Highly variable, ranges from few tens of meters to more than 100 meters. A composite aquifer exists at shallower depth. The main aquifer is deep seated.	Extensive folding of the beds results into confined aquifer. Deep seated ones may be semi-confined, even unconfined.
Unit SE-6: Coastal Plains of Chittagong. Plains that exists in between the folded hill ranges in the east and coastline in the west; characteristically flat and plain.	Chitta-gong	A 25 to 30 m. thick zone of silt and clay covers the aquifer materials. Clay thickness gradually increases towards the Bar. Sandy materials are predominantly medium to coarse.	A shallow aquifer of about 20-50m. thickness exists near the surface. Main aquifer is deep seated whose nature and extent are not known. Shallow aquifer exists at a depth of about 50m. the depth to the main aquifer is not precisely known	Semi-confined to confined.

Source: MPO, Technical Report No.5 - June,1987

Table 4.3 The Main Aquifers in Bangladesh, Their Lithologies, Relative Ages and Transmissivities (UNDP, 1982)

Aquifer	Lithology	Age	Transmissivity (m^2d^{-1})
Brahmaputra-Tista Fan and Brahmaputra basal gravels	Grey coarse sand, gravel and cobbles	Late Pleistocene and Holocene	3500-7000
Ganges, Lower Brahmaputra and Meghna main channels	Grey coarse to medium sands and gravel	Late Pleistocene and Holocene	3000-5000
Deeper cyclic aquifers of main delta and coastal areas	Grey medium to coarse sands	Early to Mid Pleistocene	1000-3000
Old Brahmaputra and Chandina fluvial aquifers and fine silts of the Sylhet basin	Red-brown medium to fine-grained weathered sands	Early to Mid Pleistocene (Dupi Tila?)	300-3000
Madhupur and Barind Tract weathered fluvial aquifers beneath surface clay residuum	Red-brown to Grey medium to coarse sands and inter bedded clays	Early to Mid Pleistocene (Dupi Tila?)	500-3000

Table 4.4 Relationship Between Average Aquifer Test Results and Geological Formation (BGS-DPHE 2001)

Aquifer Type/District or Region	Transmissivity (m^2d^{-1})	Storage coefficient	Ref
Deep Aquifer semi-confined by Upper Shallow Aquifer (Chandina Formation)			
Comilla District	1200	$1.3X10^{-3}$	1
Noakhali District	617		6
Sylhet Floodplains	460	$5.6X10^{-4}$	4
Lower Shallow Aquifer (Dhamrai Formation)			
Dhaka (Dhamrai)	3480	$8.5X10^{-4}$	7
Manikganj	4211	$3.9X10^{-4}$	7
Tangail	2803	$2.9X10^{-3}$	1
Upper Shallow Aquifer (Highstand Alluvium)			
Bogra District	2380	$1.1X10^{-3}$	1
Dinajpur District	2755	$2.8X10^{-3}$	1
Nawabganj	3172	$6.7X10^{-3}$	9
Pabna District	4316		1
Rangpur	4384	$2.6X10^{-3}$	1
Jessore District	3660	$1.9X10^{-3}$	1
Kushtia District	3780	$2.0X10^{-3}$	1
Deep Aquifer (Old Deep Aquifer Alluvium)			
Khulna District	3100	$1.0X10^{-3}$	5
Deep Aquifer (Dupi Tila Formation)			
Dhaka City	1333	$8.3X10^{-4}$	8
Madhupur Tract	1161	$1.7X10^{-3}$	1,3,4
Sylhet Hills	249	$1.3X10^{-5}$	2
Barind Tract	1835	$1.6X10^{-2}$	9

References: 1 UNDP (1982); 2 HTS/MMP (1967); 3 MMP/HTS (1982); 4 MMI (1992); 5 Rus (1985); 6 MMI (1993); 7 Baker et al. (1989); 8 EPC/MMP (1991); 9 Ahmed (1994).

Table 4.5 Correlation of Lithology With Hydraulic Conductivity and Specific Yield (MMP/HTS, 1982; Davies and Herbert, 1990)

Lithology	Characteristic Hydraulic Conductivity ($m\ d^{-1}$)		Characteristic Specific Yield (%)	
	Terraces	Floodplains	Terraces	Floodplains
Clay	-	-	0.5	3
Silt	-	0.4	4	5
Very fine sand	8	-	-	-
Fine sand	13	12	8	16
Fine-medium sand	17	26	-	-
Medium-fine sand	21	43	-	-
Medium sand	25	57	20	20
Medium-coarse sand	34	61	-	-
Coarse-medium sand	38	63	-	-
Coarse sand	46	95	25	25
Gravel (clayey)	25	40	30	30

Source: BGS-DPHE (2001)

Table 4.6 Region-Wise Abstract of Aquifer Test Analysis Results Conducted by BWDB

Sl. no.	Regions	Transmissivity (T) m^2/day		Storativity (S)		Permeability (K) m/day	
		max.	min.	max.	min.	max	min.
1	2	3	4	5	6	7	8
01	North-Eastern	3000	200	0.10	0.002	90	3
02	North-Western	4000	300	0.23	0.003	114	12
03	South-Western	3200	900	0.15	0.01	65	11
04	South-Eastern	1900	140	0.07	0.0007	23	5

Source: BWDB

Table 4.7 District-wise Aquifer Test Analysis Results Conducted by BWDB

Sl. no.	Administrative District	Transmissivity (T) m^2/day		Storativity (S)		Permeability (K) m/day	
		max.	min.	max.	min.	max	min.
1	2	**3**	**4**	**5**	**6**	**7**	**8**
01	Thakurgaon	1300	1900	0.095	0.12	23	40
02	Dinajpur	850	2500	0.01	0.15	17	48
03	Kurigram	1032.4	2000	0.08	0.143	20	37
04	Rangpur	259.76	2500	0.021	0.226	24	113
05	Gaibanda	884.27	3300	0.037	0.20	66	102
06	Lalmonirhat	499.96	1479.63	0.02	0.633	27	51
07	Nilphamari	500	1300	0.08	0.13	12	20
08	Rajshahi	418	2399	0.0003	0.10	14	40
09	Naogaon	405	2000	0.0001	0.40	20	64
10	Natore	1200	2500	0.004	0.06	25	56
11	Ch. Nawabganj	223	2458	0.0002	0.20	12	100
12	Bogra	600	3000	0.01	0.09	35	75
13	Joypurhat	900	2360	0.003	0.08	40	64
14	Pabna	1200	4000	0.04	0.10	26	82
15	Sirajganj	1233.48	3500	0.02	0.10	33	114
16	Jessore	161.15	2300	0.0041	0.07	24	31
17	Jhenaidah	485.95	2500	0.0025	0.198	14	50
18	Magura	1000	2400	0.01	0.10	18	32

19	Kushtia	709.85	2500	0.0072	0.252	15	35
20	Meherpur	1900	3200	0.02	0.10	27	43
21	Chuadanga	1200	2900	0.02	0.07	28	65
22	Faridpur	900	2300	0.01	0.15	11	36
23	Rajbari	900	2200	0.03	0.10	16	29
24	Gopalganj	1300	1555.28	0.0007	0.08	17	-
25	Satkhira	1000	1300	0.01	0.04	22	40
26	Dhaka	155	1700	0.02	0.04	6	15
27	Gazipur	316	1100	0.03	0.05	12	20
28	Manikganj	700	1897.73	0.01	0.10	14	30
29	Narshingdi	300	1000	0.01	0.06	7	25
30	Narayanganj	250	300	0.01	0.04	10	50
31	Munshiganj	500	1055	0.02	0.02	18	25
32	Tangail	1100	3100	0.03	0.10	10	50
33	Mymensingh	400	1500	0.01	0.05	9	23
34	Sherpur	1300	1500	0.05	0.09	31	32
35	Kishoreganj	201.63	2500	0.02	0.02	10	17
36	Netrokona	500	900	0.01	0.04	8	16
37	Jamalpur	800	3000	0.01	0.10	9	90
38	Sylhet	163	1377.6	0.0013	0.03	7	26
39	Sunamganj	224	750	0.002	0.03	3	22
40	Moulavibazar	200	-	-	0.02	-	-
41	Habiganj	200	518.07	0.0202	0.04	3	-
42	Comilla	80	1900	0.001	0.07	5	21
43	Brahmanbaria	450	780	0.001	0.05	8	23
44	Chandpur	278.13	1200	0.01	0.07	7	15
45	Noakhali	820	-	0.002	-	10	-
46	Feni	292.71	1070	0.003	-	13	-
47	Chittagong	114	600	0.0007	0.03	3	10
48	Cox's Bazar	-	700	0.002	-	6	-
49	Panchagarh	318.4	554.78	0.011	0.014	-	-
50	Madaripur	675.07	1105.65	0.0016	0.0022	-	-
51	Narail	214.86	416.39	0.0201	0.466	-	-
52	Bagerhat	233.81	447.63	0.033	-	-	-

Source: BWDB

Table 4.8 Aquifer Test Results of Coastal Area Conducted by DANIDA

Location	**Transmissivity m^2/day**	**Storativity**
1	2	3
Eklaspur, Noakhali	400-4500	0.0006-0.004
Raipur, Laksmipur	2600	0.0004
Patuakhali sadar, Patuakhali	635-1500	$1.2 \times 10^{-4} – 2.3 \times 10^{-4}$
Amtali, Barguna, Patuakhali	975	0.00012
Kalapara, Patuakhali	760	0.0003
Galachipa, Patuakhali	1665	0.00057
Pathorghata, Barguna	304-1047	0.001-0.00085
Ramganj, Laksmipur	3050-6250	0.001-0.0004

Table 4.9 Summary of Aquifer Parameters for the Upper Shallow, Lower Shallow and Deep Aquifers at Faridpur.

Aquifer	**Upper shallow**	**Lower shallow**	**Deep**
Approx. age (kaBP)	5 to 8	8-23	>140
Gradient (m km^{-1})	0.08	0.08	0.08
Width (km)	18	18	18
Transmissivity (m^2d^{-1})	125-1870	40-5020	120-1830
Flow (m^3d^{-1})	1190	3287	6311
Thickness (m)	45-60	75-90	90
Porosity (-)	0.10-0.15	0.05-0.20	0.10-0.15
Time to replace one pore volume (ka)	12-185	10-321	2.3-114

Source: BGS-DPHE (2001)

Table 4.10 Estimate of Flow Rates and Time for Flushing for a Cross Section Through Faridpur

Layer	**Column A**	**Column B**	**Column C**	**Column D**
a. Block transmissivities (m^2d^{-1})				
1	1870	125	1230	150
2a	1140	920	5020	240
2b	780	780		40
3a	120	120	430	1720
3b	1830	1830	1830	1830
3c	940	940	940	940
3d	1220	1220	1400	1220
b. Block throughflow rates (m^3d^{-1})				
1	598.4	40	492	60
2a	364.8	294.4	2008	96
2b	249.6	249.6		
3a	38.4	38.4	172	688
3b	585.6	585.6	585.6	585.6
3c	300.8	300.8	300.8	300.8
3d	390.4	390.4	560	488
c. Time to replace block volume (a)				
1	12362	184932	12529	68493
2a	11265	11167	10233	14269
2b	10976	13172		321062
3a	114155	85616	27875	6969
3b	2339	4678	3509	3509
3c	5465	5465	5465	5465
3d	8772	10527	9173	8772

Source: BGS-DPHE (2001)

Table 4.11 Estimates of Flow and Time for Flushing for the Aquifer Units of the Brahmaputra Channel Between Faridpur and Dhamrai Under Present-day Gradients.

Aquifer	Upper shallow	Upper part of lower shallow	Lower shallow
Approx. age (kaBP)	5 to 8	~10	15 to 18
Gradient (m km^{-1})	0.08	0.08	0.08
Width (km)	45	45	45
Transmissivity (m^2d^{-1})	950	1325	2325
Flow (m^3d^{-1})	3420	4770	8370
Thickness (m)	45	55	40
Seepage velocity (m d^{-1})	$1.69X10^{-3}$	$1.93X10^{-3}$	$4.65X10^{-3}$
Porosity (-)	0.05	0.2	0.3
Darcy velocity (m d^{-1})	$3.38X10^{-2}$	$9.64X10^{-3}$	$1.55X10^{-2}$
Volume of groundwater (m^3)	$2.531X10^{11}$	$1.238X10^{11}$	$1.350X10^{11}$
Time to replace one pore volume (ka)	20	71	44

Source: BGS-DPHE (2001)

Table 4.12 Estimates Of Flow and Time for Flushing for the Aquifer Units of the Brahmaputra Channel Between Faridpur and Dhamrai Under Early Holocene Gradients.

Aquifer	Upper part of present day lower shallow	Lower shallow
Approx. age (kaBP)	~10	15 to 18
Gradient (m km^{-1})	0.28	0.28
Width (km)	45	45
Transmissivity (m^2d^{-1})	1325	2325
Flow (m^3d^{-1})	16695	29295
Thickness (m)	55	40
Seepage velocity (m d^{-1})	$6.75X10^{-3}$	$1.63X10^{-3}$
Porosity (-)	0.2	0.3
Darcy velocity (m d^{-1})	$3.37X10^{-2}$	$5.43X10^{-2}$
Volume of groundwater (m^3)	$1.238X10^{11}$	$1.350X10^{11}$
Time to replace one pore volume (ka)	20	13

Source: BGS-DPHE (2001)

Table 4.13 Estimates of Flow Rates and Time for Flushing for Upper Ganges, Lower Ganges and Mahananda Channel Sequences at Chapai Nawabganj Under Present-day Gradients.

Aquifer	Upper Ganges	Lower Ganges	Mahananda
Approx. age (kaBP)	2 - 5	5-15	2-5
Gradient (m km^{-1})	0.08	0.08	0.08
Width (km)	5	5	4
Transmissivity (m^2d^{-1})	570	2500	350
Flow (m^3d^{-1})	228	1000	112
Thickness (m)	40	80	40
Seepage velocity (m d^{-1})	$1.14X10^{-3}$	$2.5X10^{-3}$	$7.00X10^{-4}$
Porosity (-)	0.05	0.1	0.05
Darcy velocity (m d^{-1})	$2.28X10^{-2}$	$2.50X10^{-2}$	$1.40X10^{-2}$
Volume of groundwater (m^3)	$1.000X10^{9}$	$4.000X10^{9}$	$8.000X10^{9}$
Time to replace one pore volume (ka)	12	11	20

Source: BGS-DPHE (2001

Table 4.14 Long Term Mean Monthly Rainfall and Potential Evapotranspiration for Four Cities in Bangladesh

Months	Dhaka		Chittagong		Rajshahi		Khulna	
	Rainfall 1953-77	ET_0	Rainfall 1947-77	ET_0	Rainfall 1947-78	ET_0	Rainfall 1947-78	ET_0
January	9	89	7	73	13	72	8	88
February	20	110	15	113	10	93	19	107
March	55	169	53	153	29	135	36	150
April	114	188	119	178	81	170	93	162
May	265	188	242	177	266	168	184	171
June	375	133	589	133	520	133	350	115
July	463	144	759	146	439	134	393	118
August	323	140	547	141	319	129	286	113
Sept.	276	128	279	136	279	123	280	112
Oct.	166	120	60	125	160	110	161	120
Nov.	29	99	61	105	9	89	25	103
Dec.	0	94	10	93	1	73	15	88
Annual Total	***2095***	***1602***	***2741***	***1573***	***2126***	***1429***	***1850***	***1447***

Source: Rashid, 1991

Table 4.15 Flooded Areas 1954-1988

Year	Flooded area (km^2)	% total land area flooded
1954	36920	25.6
1955	50700	35.2
1956	35620	24.7
1960	28600	19.8
1961	28860	20.0
1962	37440	26
1963	43160	29.9
1964	31200	21.6
1965	28600	19.8
1966	33540	23.3
1967	25740	17.8
1968	37440	26
1969	41600	28.8
1970	42640	29.6
1971	36475	25.3
1972	20800	14.4
1973	29900	20.7
1974	52720	36.6
1975	16590	11.5
1976	28418	19.7
1977	12548	8.7
1978	10832	7.5
1980	33077	22.9
1982	3149	2.1
1983	11112	7.7
1984	28314	19.6
1985	11427	7.9
1986	4589	3.1
1987	57491	39.9
1988	82000	56.9

Source: Miah, 1988 and Brammer, 1990

Table 4.16 Approximate Wet Season Regional Groundwater Gradients

Location	Gradient (m km^{-1}) Maximum	Gradient (m km^{-1}) Maximum
North	2	0.5
Central	0.5	0.1
Southern	0.1	0.01

Source: BWDB (Unpublished)

Table 4.17 Summary of Change in Use of Irrigation Technologies, Expressed as a Percentage of the Overall Irrigation Volume

Mode of irrigation	1982-83	1996-97
Groundwater		
Shallow tube well	24	56
Deep tube well	15	13
Manual operated pump unit	1	1
Surface water		
Low-lift pump	22	15
Traditional	28	5
Canal	10	10

Source: BGS-DPHE (2001)

Table 4.18 Summary of Irrigation Abstraction Modes Operating in Bangladesh During 1996-1997

Aquifers	Technology	Units operating	Units non-operating	Total units
Highland Grey fine to medium sands within floodplains, with shallow (<5m) water table	Shallow tube wells (STW)	600,276	13,284	613,559
Fine to medium sands within floodplains, fairly deep (<7m) dry season water table	Deep set STW	26,245	615	26,860
Fine to medium sands within floodplains with deep (<10m) dry season water table	Very deep set STW	3,313	99	3,412
	All shallow tube wells	629,834	13,998	643,831
Grey or red-brown transgressive tract medium to fine sands with a deep water table	Force mode tube wells	201	18	219
Transgressive to lowstand Grey and red-brown coarse grained sediments	Deep tube wells	25,210	5,663	30,873
Very shallow aquifers and open bodies of water	Low lift pumps	62,875	2,949	65,824

Source: BGS-DPHE (2001)

Table 5.2 to be inserted from another file

Table 5.3 Summary of Pre-Existing Laboratory Data by District

Division	District	Wells < 10m			Wells 10-100 m			Wells 100-200 m			Wells >200 m		
		Nr of Tests	Wells >0.05 mg/l	%	Nr of Tests	Wells >0.05 mg/l	%	Nr of Tests	Wells >0.05 mg/l	%	Nr of Tests	Wells >0.05 mg/l	%
Barishal	Barguna										38	5	13
	Barishal				98	77	79	1	1		33	8	24
	Bhola				6	6	100				46	4	9
	Jhalokhati	1	0		26	5	19				16	0	0
	Patuakhali					0		2	0		24	1	4
	Pirojpur	6	3		49	12	24				7	0	
Chittagong	Brahmanbaria				30	14	47						
	Chandpur				125	90	72	1	1		1	0	
	Chittagong	3	1		15	0	0	5	1		4	0	
	Comilla				36	21	58	1	0				
	Feni				31	10	32	2	0				
	Laksmipur	44	35	80	165	143	87	1	1		11	2	18
	Noakhali	16	11	69	155	132	85				3	2	
Dhaka	Dhaka				39	2	5	1	0				
	Faridpur	5	1		188	55	29	2	1		1	1	
	Gazipur				29	0	0				1	0	
	Gopalganj	1	0		84	38	45						
	Jamalpur				6	4		4	1				
	Kishoreganj	10	2	20	379	124	33	6	2				
	Madaripur				56	51	91		0		1	1	
	Manikganj				83	34	41	1	0				
	Munshiganj				35	26	74	4	0				
	Mymensingh	1	0		28	5	18		0				
	Narayanganj	2	2		133	92	69	2	1				
	Narshingdi	3	0		69	34	49	1	1		1	0	
	Netrokona	5	0		337	89	26	13	4	31			
	Rajbari	5	1		55	10	18		0				
	Shariatpur				44	17	39	7	0		16	1	6
	Sherpur				10	0	0	2	0				
	Tangail				19	2	11		0				
Khulna	Bagerhat	3	2		117	57	49		0		11	0	0
	Chuadanga	1	0		57	21	37	3	0				
	Jessore	7	1		383	215	56	8	0		4	0	
	Jhenaidah				39	10	26		0				
	Khulna	2	0		311	50	16	28	0	0	34	4	12
	Kushtia	2	0		270	60	22	3	1		7	0	
	Magura				35	11	31	9	0				
	Meherpur	3	1		106	26	25	10	2	20	3	0	
	Narail				56	9	16		0				
	Satkhira	2	0		139	37	27	3	2				
Rajshahi	Bogra	6	0		61	4	7						
	Dinajpur	8	0		35	4	11	5	0				
	Gaibanda	7	0		24	5	21	11	2	18			
	Joypurhat	1	0		61	5	8						
	Kurigram	9	0		23	1	4						
	Lalmonirhat	4	0		15	1	7						
	Naogaon				50	4	8						
	Natore				67	3	4	1	1				
	Ch. Nawabganj	3	0		175	62	35						
	Niphamari	11	0	0	46	1	2						
	Pabna				320	78	24						
	Panchagarh	2	0		71	1	1						
	Rajshahi	7	0		104	19	18	1	0				
	Rangpur	39	1	3	16	0	0						
	Sirajganj	1	0		50	3	6						
	Thakurgaon	3	0		61	1	2						
Sylhet	Habiganj				284	71	25					1	1
	Maulavibazar	3	0		307	69	22	11	5	45		1	0
	Sunamganj	3	2		117	52	44	213	140	66		1	1
	Sylhet	2	0		438	151	34	9	1			1	0
Total		**231**	**63**	**27**	**6168**	**2124**	**34**	**371**	**168**	**45**	**266**	**31**	**12**

Table. 5.4 Summary of Regional Arsenic Survey by District

Division	District	Nr of Wells		Average Depth (m)	Max. As (mg/l)	>BGD Std		>WHO Guideline	
		All	Deep			Nr	%	Nr	%
Barisal	Barguna	32	30	284	0.011	0	0	1	3
	Barisal	91	47	166	0.862	28	31	39	43
	Bhola	48	45	286	0.239	2	4	2	4
	Jhalokhati	33	19	188	0.550	2	6	8	24
	Patuakhali	40	37	269	0.017	0	0	3	8
	Pirojpur	47	14	96	0.270	8	17	16	34
Chittagong	Brahmanbaria	51	0	42	0.735	19	37	24	47
	Chandpur	58	4	43	1.086	52	90	53	91
	Chittagong	43	7	70	0.344	7	16	14	33
	Comilla	110	0	38	0.698	72	65	78	71
	Cox's Bazar	43	7	81	0.070	1	2	2	5
	Feni	50	4	49	0.420	17	34	27	54
	Laksmipur	34	5	54	0.816	19	56	26	76
	Noakhali	48	5	40	0.649	34	71	41	85
Dhaka	Dhaka	38	0	58	0.262	14	37	19	50
	Faridpur	63	1	44	0.924	41	65	48	76
	Rajbari	34	0	40	0.359	8	24	16	47
	Gopalganj	40	6	79	0.602	32	80	34	85
	Madaripur	36	9	89	0.627	25	69	25	69
	Manikganj	47	0	42	0.089	7	15	30	64
	Munshiganj	46	0	55	0.529	38	83	42	91
	Narayanganj	30	0	48	0.324	7	23	9	30
	Shariatpur	49	8	72	0.590	32	65	37	76
Khulna	Bagerhat	62	6	46	0.635	37	60	50	81
	Chuadanga	34	0	45	0.538	15	44	28	82
	Jhenaidah	54	1	53	0.557	14	26	34	63
	Jessore	69	1	57	0.355	33	48	49	71
	Khulna	76	20	124	0.538	17	22	29	38
	Kushtia	47	0	47	1.665	13	28	19	40
	Magura	32	0	60	0.216	6	19	12	38
	Meherpur	15	0	49	0.483	9	60	14	93
	Narail	24	1	62	0.255	10	42	15	63
	Satkhira	61	5	59	0.509	41	67	49	80
Rajshahi	Natore	43	0	36	0.018	0	0	2	5
	Ch. Nawabganj	45	0	38	0.064	2	4	5	11
	Pabna	78	0	35	0.493	13	17	20	26
	Rajshahi	78	0	36	0.092	5	6	14	18
Sylhet	Habiganj	43	0	56	0.050	0	0	16	37
	Maulavibazar	52	0	55	0.254	6	12	19	37
	Sunamganj	22	0	128	0.246	5	23	20	91
	Sylhet	77	1	60	0.157	14	18	35	45
Total	**41**	**2023**	**283**		**1.67**	**705**	**35**	**1024**	**51**

Source: BGS-DPHE, 1999

Table 5.5 Arsenic Results of Representative Upazilas Under Coastal Beach Geo-district

Sl. No.	Location	Max. As mg/l	All Wells (< 200 m)			Deep Wells (> 200m)	
			Nr	Contaminated	%	Nr	Contaminated
01.	U.Z : Sitakunda Dist: Chittagong	0.052	59	41	69	1	0
02.	U.Z : Sadar (Patenga) Dist: Chittagong	0.010	09	0	0	0	0
03.	U.Z :Banskhali Dist: Chittagong	0.000	00	0	0	0	0

Table 5.6 Arsenic Results of Representative Upazilas Under Deltaic Swamp Geo-district

Sl. No.	Location	Max. As mg/l	All Wells (< 200 m)			Deep Wells (> 200m)	
			Nr	Contaminated	%	Nr	Contaminated
01.	U.Z : Mongla Dist: Bagerhat	0.015	22	0	0	0	0

Table 5.7 Arsenic Results of Representative Upazilas Under Deltaic Tidal Geo-district

Sl. No.	Location	Max. As mg/l	All Wells (< 200 m)			Deep Wells (> 200m)	
			Nr	Contaminated	%	Nr	Contaminated
01.	U.Z : Devhata Dist: Satkhira	0.330	157	96	61	7	2 (29%)
02.	U.Z : Asasuni Dist : Satkhira	0.288	111	29	26	0	0
03.	U.Z : Bhola Dist : Bhola	0.224	80	2	3	64	1 (2%)
04.	U.Z : Laksmipur Dist : Laksmipur	1.240	220	169	77	2	0

Table 5.8 Arsenic Results of Representative Upazilas Under Deltaic Fluvial Geo-district

Sl. No.	Location	Max. As mg/l	All Wells (< 200 m)			Deep Wells (> 200m)	
			Nr	Contaminated	%	Nr	Contaminated
01.	U.Z : Madaripur Dist: Madaripur	0.833	127	86	68	0	0
02.	U.Z : Satkhira Dist : Satkhira	0.370	297	151	51	0	0
03.	U.Z : Meherpur Dist : Meherpur	0.781	227	68	30	3	0

Table 5.9 Arsenic Results of Representative Upazilas Under Paludal Geo-district

Sl. No.	Location	Max. As mg/l	All Wells (< 200 m)			Deep Wells (> 200m)	
			Nr	Contaminated	%	Nr	Contaminated
01.	U.Z : Baniachong Dist: Habiganj	0.268	41	11	27	0	0
02.	U.Z : Gopalganj Dist : Gopalganj	0.960	81	54	67	0	0
03.	U.Z : Rupsha (Daulatpur) Dist : Khulna	0.650	94	30	32	0	0

Table 5.10 Arsenic Results of Representative Upazilas Under Alluvial Geo-district

Sl. No.	Location	Max. As mg/l	All Wells (< 200 m)			Deep Wells (> 200m)	
			Nr	Contaminated	%	Nr	Contaminated
01.	U.Z : Godagari Dist: Rajshahi	0.015	61	3	5	0	0
02.	U.Z : Manikganj Dist : Manikganj	0.095	201	44	22	0	0
03.	U.Z : Faridganj Dist : Chandpur	1.200	209	157	75	1	0

Table 5.11 Arsenic Results of Representative Upazilas Under Chandina Geo-district

Sl. No.	Location	Max. As mg/l	All Wells (< 200 m)			Deep Wells (> 200m)	
			Nr	Contaminated	%	Nr	Contaminated
01.	U.Z : Kachua Dist: Chandpur	-	83	82	99	0	0
02.	U.Z : Sonagazi Dist : Feni	-	26	15	58	2	0

Table 5.12 Arsenic Results of Representative Upazilas Under Valley Alluvial Geo-district

Sl. No.	Location	Max. As mg/l	All Wells (< 200 m)			Deep Wells (> 200m)	
			Nr	Contaminated	%	Nr	Contaminated
01.	U.Z : Satkania Dist: Chittagong	-	0	0	0	0	0
02.	U.Z : Rauzan Dist : Chittagong	-	0	0	0	0	0
03.	U.Z : Patia Dist : Chittagong	0.013	6	0	0	2	0

Table 5.13 Arsenic Results of Representative Upazilas Under Alluvial Fan Geo-district

Sl. No.	Location	Max. As mg/l	All Wells (< 200 m)			Deep Wells (> 200m)	
			Nr	Contaminated	%	Nr	Contaminated
01.	U.Z : Hatibandha Dist: Lalmonirhat	0.002	53	0	0	0	0

Table 5.14 Arsenic Results of Representative Upazilas Under Residual Geo-district

Sl. No.	Location	Max. As mg/l	All Wells (< 200 m)			Deep Wells (> 200m)	
			Nr	Contaminated	%	Nr	Contaminated
01.	U.Z : Mirzapur Dist: Tangail	0.066	27	1	4	0	0
02.	U.Z : Ghatail Dist : Tangail	0.000	3	0	0	0	0
03.	U.Z : Shibganj Dist : Bogra	0.040	103	0	0	0	0

Table 5.15 Arsenic Results of Representative Upazilas Under Bedrock Geo-district

Sl. No.	Location	Max. As mg/l	All Wells (< 200 m)			Deep Wells (> 200m)	
			Nr	Contaminated	%	Nr	Contaminated
01.	U.Z : Baghaichari Dist: Rangamati	-	0	0	0	0	0
02.	U.Z : Khagrachari Dist : Khagrachari	-	0	0	0	0	0
03.	U.Z : Lama Dist : Bandarban	-	0	0	0	0	0

Table 5.16 Arsenic Statistics for the Twelve Most Contaminated Districts

District	Number of well sampled	Average As concentration (µg L^{-1})	Mean As Concentration deep/shallow(µg L^{-1})	% of wells in given As concentration class (µg L^{-1})				% of wells exceeding 50 µg L^{-1}
				<10	10-50	50-200	>200	
Chandpur	59	366	2/51	8	2	10	80	90
Madaripur	36	191	1/<1	31	0	31	39	69
Munshiganj	46	189	3/2	9	9	41	41	83
Gopalganj	42	187	21/<1	17	5	43	36	79
Lakshmipur	34	179	2/<1	24	21	26	29	56
Noakhali	49	162	4/2	16	14	37	33	69
Bagerhat	62	156	<1/<1	19	21	34	29	60
Shariatpur	49	151	2/<1	24	10	35	31	65
Comilla	110	142	<1/<1	29	5	37	28	65
Faridpur	63	140	<1/5	24	11	35	30	65
Satkhira	61	133	2/<1	18	15	41	26	67
Meherpur	15	116	<1/-	7	33	40	20	60

Table : 5.17 Arsenic Statistics for the Twelve Least Contaminated Districts

District	Number of wells sampled	Average As Concentration (µg L^{-1})	Maximum As Concentration (µg L^{-1})	% of wells in given As concentration class (µg L^{-1})				% of wells exceeding 50 µg L^{-1}
				<10	10-50	50-200	>200	
Thakurgaon	46	1	6	100	0	0	0	0
Natore	51	1	18	96	4	0	0	0
Barguna	33	1	11	97	3	0	0	0
Jaipurhat	40	1	13	98	3	0	0	0
Lalmonirhat	39	1	16	97	3	0	0	0
Nilphamari	53	2	23	94	6	0	0	0
Panchagarh	39	3	34	95	5	0	0	0
Patuakhali	42	3	17	93	7	0	0	0
Dinajpur	94	3	54	95	3	2	0	2
Cox's Bazar	43	3	70	95	2	2	0	2
Gazipur	44	4	155	98	0	2	0	2
Naogaon	92	6	244	95	3	1	1	2

Table 5.18 List Of Arsenic Prone Upazilas (268)

Sl #	DIVISION	DISTRICT	UPAZILA	As Conc. (BGS Report May 2000)	Pourashava	# of Union	# of Village	# of Household (Projected 2000)	# of Population (Projected 2000)
1.	BARISAL	BARISAL	Agailjhara	0.3190		5	95	39728	176812
2.	BARISAL	BARISAL	Babuganj	0.7350		6	87	32687	163086
3.	BARISAL	BARISAL	Bakerganj	0.1370	*	18	171	82130	404047
4.	BARISAL	BARISAL	Banaripara	0.3890	*	11	77	34706	172590
5.	BARISAL	BARISAL	Barisal	0.3850	*	20	128	97664	497137
6.	BARISAL	BARISAL	Gaurnadi	0.3590	*	7	124	41081	205922
7.	BARISAL	BARISAL	Mehendiganj	0.8620	*	13	161	71666	350923
8.	BARISAL	BARISAL	Muladi	0.6670		7	108	42270	206338
9.	BARISAL	BARISAL	Ujirpur	0.2570		9	117	57824	272538
10.	BARISAL	BHOLA	Bhola	0.1630	*	16	123	80655	422009
11.	BARISAL	BHOLA	Lalmohan	0.2390	*	9	76	58457	302996
12.	BARISAL	JHALAKATI	Jhalakati	0.0687	*	12	176	47455	234743
13.	BARISAL	JHALAKATI	Nalchiti	0.5500	*	13	150	49408	244276
14.	BARISAL	PIROJPUR	Bhandaria			7	37	36360	174280
15.	BARISAL	PIROJPUR	Mathbaria	0.1590	*	11	92	62581	304698
16.	BARISAL	PIROJPUR	Nazirpur	0.2700		8	142	41421	199217
17.	BARISAL	PIROJPUR	Nesarabad	0.0532	*	10	137	53030	243024
18.	BARISAL	PIROJPUR	Pirojpur	0.2460	*	13	143	54461	270187
19.	CHITTAGONG	BANDARBAN	Bandarban		*	8	199	12975	59653
20.	CHITTAGONG	BRAHMANBARIA	Akhaura	0.1100	*	5	125	24418	135578
21.	CHITTAGONG	BRAHMANBARIA	Banchharampur	0.7350		13	118	55968	310045
22.	CHITTAGONG	BRAHMANBARIA	Brahmanbaria	0.3820	*	31	398	141787	791339
23.	CHITTAGONG	BRAHMANBARIA	Kasba	0.1050	*	10	236	53171	292600
24.	CHITTAGONG	BRAHMANBARIA	Nabinagar	0.4060	*	19	198	82720	454247
25.	CHITTAGONG	BRAHMANBARIA	Nasirnagar	0.3570		13	129	53192	280908
26.	CHITTAGONG	BRAHMANBARIA	Sarail	0.3160		10	146	57010	305377
27.	CHITTAGONG	CHANDPUR	Chandpur	0.6410	*	18	114	91551	476246
28.	CHITTAGONG	CHANDPUR	Faridganj	0.6440		16	175	81030	417937
29.	CHITTAGONG	CHANDPUR	Haimchar	0.5290	*	6	64	27230	135967
30.	CHITTAGONG	CHANDPUR	Hajiganj	0.5860	*	13	147	57655	304868
31.	CHITTAGONG	CHANDPUR	Kachua	0.4140	*	12	238	65341	352420
32.	CHITTAGONG	CHANDPUR	Matlab	0.6440	*	22	407	99146	534728
33.	CHITTAGONG	CHANDPUR	Shahrasti	1.0900	*	9	176	40576	216772
34.	CHITTAGONG	CHITTAGONG	Mirsharai	0.3440	*	16	207	72502	390854
35.	CHITTAGONG	CHITTAGONG	Sitakunda	0.1960	*	10	107	62485	329884
36.	CHITTAGONG	COMILLA	Barura	0.3200	*	15	332	68706	372934
37.	CHITTAGONG	COMILLA	Brahmanpara	0.1590		8	65	34441	194287
38.	CHITTAGONG	COMILLA	Burichang	0.0632		8	171	49061	274175
39.	CHITTAGONG	COMILLA	Chandina	0.4070	*	12	232	60913	323854
40.	CHITTAGONG	COMILLA	Chauddagram	0.1380		14	418	74666	398466
41.	CHITTAGONG	COMILLA	Daudkandi	0.6980	*	22	467	100233	550204
42.	CHITTAGONG	COMILLA	Meghna						
43.	CHITTAGONG	COMILLA	Debiduar	0.4520		16	201	72305	404252
44.	CHITTAGONG	COMILLA	Homna	0.2130		10	207	47858	253876
45.	CHITTAGONG	COMILLA	Laksham	0.5250	*	25	504	114482	615743
46.	CHITTAGONG	COMILLA	Muradnagar	0.4120		21	301	94016	500645
47.	CHITTAGONG	COMILLA	Nangalkot	0.6680		11	285	63015	331182
48.	CHITTAGONG	COX'S BAZAR	Ukhia	0.0701		5	54	24946	145817
49.	CHITTAGONG	FENI	Daganbhuiya	0.4200	*	8	126	45175	245970
50.	CHITTAGONG	FENI	Feni	0.1640	*	16	133	74530	414961
51.	CHITTAGONG	FENI	Sonagazi	0.1660		9	93	48339	258146
52.	CHITTAGONG	LAKSMIPUR	Laksmipur	0.2560	*	21	252	124363	630226
53.	CHITTAGONG	LAKSMIPUR	Raipur	0.7440		7	82	52803	256288
54.	CHITTAGONG	LAKSMIPUR	Ramganj	0.8160	*	13	126	57194	286000

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55.	CHITTAGONG	LAKSMIPUR	Ramgati	0.0993	*	12	69	77203	402292
56.	CHITTAGONG	NOAKHALI	Begumganj	0.5300		29	343	153869	811402
57.	CHITTAGONG	NOAKHALI	Chatkhil	0.6490	*	9	136	43982	233022
58.	CHITTAGONG	NOAKHALI	Companiganj	0.0956		11	41	40101	220021
59.	CHITTAGONG	NOAKHALI	Noakhali	0.2640	*	24	287	149929	781944
60.	CHITTAGONG	NOAKHALI	Senbag	0.4780		9	111	49487	259571
61.	DHAKA	DHAKA	Dhamrai	0.1070	*	16	398	74486	375332
62.	DHAKA	DHAKA	Dohar	0.2620	*	8	39	41139	211010
63.	DHAKA	DHAKA	Keraniganj	0.0984		11	399	123195	636209
64.	DHAKA	DHAKA	Nawabganj	0.2620		14	305	61634	323027
65.	DHAKA	FARIDPUR	Alfadanga	0.3460		6	118	21553	109048
66.	DHAKA	FARIDPUR	Bhanga	0.4680	*	12	227	53901	257642
67.	DHAKA	FARIDPUR	Boalmari	0.1810	*	11	255	45861	228191
68.	DHAKA	FARIDPUR	Char Bhadrasan	0.4270		4	129	16140	83851
69.	DHAKA	FARIDPUR	Faridpur	0.2450	*	14	298	78590	402463
70.	DHAKA	FARIDPUR	Madhukhali	0.2280		9	238	37961	198526
71.	DHAKA	FARIDPUR	Nagarkanda	0.9240	*	17	335	66321	320632
72.	DHAKA	FARIDPUR	Sadarpur	0.2900		9	287	40435	206471
73.	DHAKA	GAZIPUR	Kaliganj	0.1550		6	105	42364	211098
74.	DHAKA	GOPALGANJ	Gopalganj	0.6020	*	24	196	67119	349691
75.	DHAKA	GOPALGANJ	Kasiani	0.3800		14	161	48055	246715
76.	DHAKA	GOPALGANJ	Kotalipara	0.5210	*	12	196	48884	247434
77.	DHAKA	GOPALGANJ	Muksudpur	0.5880	*	17	260	64955	323387
78.	DHAKA	GOPALGANJ	Tungipara	0.3150	*	5	67	20839	105722
79.	DHAKA	JAMALPUR	Bakshiganj	0.1130		7	196	41609	188884
80.	DHAKA	JAMALPUR	Jamalpur	0.0506	*	19	333	133351	602309
81.	DHAKA	JAMALPUR	Sarishabari	0.2300	*	11	179	77030	346927
82.	DHAKA	KISHOREGANJ	Ashtagram	0.0775		7	73	27400	158764
83.	DHAKA	KISHOREGANJ	Bajitpur	0.5730	*	13	178	45566	236497
84.	DHAKA	KISHOREGANJ	Bhairab	0.5050	*	11	79	44745	230938
85.	DHAKA	KISHOREGANJ	Hossainpur	0.1950		6	101	38332	177634
86.	DHAKA	KISHOREGANJ	Itna	0.0814		8	117	31126	159538
87.	DHAKA	KISHOREGANJ	Karimganj	0.1760		11	184	56479	284586
88.	DHAKA	KISHOREGANJ	Kishoreganj	0.1720	*	15	203	72576	360404
89.	DHAKA	KISHOREGANJ	Kuliarchar	0.2170	*	7	131	33986	159992
90.	DHAKA	KISHOREGANJ	Nikli	0.0983		6	122	28610	133094
91.	DHAKA	KISHOREGANJ	Pakundia	0.2730		10	170	51901	252426
92.	DHAKA	MADARIPUR	Kalkini	0.4660	*	15	190	60208	301099
93.	DHAKA	MADARIPUR	Madaripur	0.5520	*	18	185	71052	369386
94.	DHAKA	MADARIPUR	Rajoir	0.6270		10	177	49070	245227
95.	DHAKA	MADARIPUR	Sibchar	0.2890	*	18	467	75511	367298
96.	DHAKA	MANIKGANJ	Ghior	0.0890		7	183	31737	153025
97.	DHAKA	MANIKGANJ	Harirampur	0.0888		13	253	39177	187591
98.	DHAKA	MANIKGANJ	Manikganj	0.0519	*	13	308	59788	285325
99.	DHAKA	MANIKGANJ	Saturia	0.0628		9	215	35326	168258
100.	DHAKA	MUNSHIGANJ	Gozaria	0.3120		8	120	28747	154042
101.	DHAKA	MUNSHIGANJ	Lohajang	0.3470		12	133	34541	184120
102.	DHAKA	MUNSHIGANJ	Munshiganj	0.0761	*	12	219	65792	353788
103.	DHAKA	MUNSHIGANJ	Serajdikhan	0.5290		14	177	49912	274902
104.	DHAKA	MUNSHIGANJ	Srinagar	0.5170		14	147	47247	246956
105.	DHAKA	MUNSHIGANJ	Tongibari	0.2920		12	160	40750	212257
106.	DHAKA	MYMENSINGH	Dhobaura	0.2000		7	158	39638	188432
107.	DHAKA	MYMENSINGH	Gouripur	0.1090	*	13	278	62891	297534
108.	DHAKA	MYMENSINGH	Haluaghat	0.0786		12	205	64376	290807
109.	DHAKA	MYMENSINGH	Muktagachha	0.0656	*	13	273	83257	386111
110.	DHAKA	MYMENSINGH	Mymensingh	0.0594	*	20	173	135937	679642
111.	DHAKA	MYMENSINGH	Nandail	0.0608	*	13	272	81293	394616

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112.	DHAKA	MYMENSINGH	Phulpur	0.0765		20	411	115320	550855
113.	DHAKA	NARAYANGANJ	Araihazar	0.1800		12	315	68852	359826
114.	DHAKA	NARAYANGANJ	Sonargaon	0.3240		11	473	57727	314257
115.	DHAKA	NARSINGDI	Belabo	0.1630		7	97	36143	174850
116.	DHAKA	NARSINGDI	Manohardi	0.0686		11	169	61616	276034
117.	DHAKA	NARSINGDI	Narsingdi	0.1920	*	17	270	106314	541602
118.	DHAKA	NARSINGDI	Palas	0.0519	*	5	98	40755	208848
119.	DHAKA	NARSINGDI	Raipura	0.2840		24	231	99460	496519
120.	DHAKA	NARSINGDI	Sibpur	0.0713		9	196	57675	284695
121.	DHAKA	NETRAKONA	Atpara	0.2160		7	175	30414	144589
122.	DHAKA	NETRAKONA	Durgapur	0.1760	*	7	215	41919	202962
123.	DHAKA	NETRAKONA	Kalmakanda	0.2620		8	343	51058	251232
124.	DHAKA	NETRAKONA	Kendua	0.0795	*	13	311	66587	318754
125.	DHAKA	NETRAKONA	Khaliajuri	0.1350		6	66	16774	90961
126.	DHAKA	NETRAKONA	Madan	0.1540		8	120	28350	141136
127.	DHAKA	NETRAKONA	Mohanganj	0.1450	*	10	163	31214	155298
128.	DHAKA	RAJBARI	Goalanda	0.3140	*	4	206	20402	110010
129.	DHAKA	RAJBARI	Pangsha	0.1580	*	20	316	70751	380102
130.	DHAKA	RAJBARI	Rajbari	0.3590	*	17	203	63067	316266
131.	DHAKA	SHARIATPUR	Bhedarganj	0.2000	*	10	331	47515	248710
132.	DHAKA	SHARIATPUR	Damudya	0.5900	*	7	124	23793	114791
133.	DHAKA	SHARIATPUR	Goshairhat	0.5760		7	199	29778	139058
134.	DHAKA	SHARIATPUR	Janjira	0.5400	*	12	177	37331	188779
135.	DHAKA	SHARIATPUR	Naria	0.2980	*	15	211	52313	257933
136.	DHAKA	SHARIATPUR	Shariatpur	0.5400	*	13	147	39611	194354
137.	DHAKA	SHERPUR	Nakla	0.0544		9	117	43527	195542
138.	DHAKA	SHERPUR	Nalitabari	0.1370	*	7	138	55507	271598
139.	DHAKA	SHERPUR	Sherpur	0.1150	*	16	180	104118	457703
140.	DHAKA	SHERPUR	Sribardi	0.1680		10	156	62270	273833
141.	DHAKA	TANGAIL	Basail	0.0926		6	107	35725	178266
142.	DHAKA	TANGAIL	Delduar	0.1530		8	166	42505	210821
143.	DHAKA	TANGAIL	Mirzapur	0.1310	*	13	219	79923	404995
144.	DHAKA	TANGAIL	Nagarpur	0.1490		11	233	58315	286106
145.	DHAKA	TANGAIL	Tangail	0.1440	*	16	277	90718	456622
146.	KHULNA	BAGERHAT	Bagerhat	0.6350	*	12	167	59185	283018
147.	KHULNA	BAGERHAT	Chitalmari	0.4800		7	121	31598	153029
148.	KHULNA	BAGERHAT	Fakirhat	0.5710		8	87	31572	148747
149.	KHULNA	BAGERHAT	Kachua	0.1770		7	96	24119	111899
150.	KHULNA	BAGERHAT	Mollahat	0.3170		7	102	27905	140075
151.	KHULNA	BAGERHAT	Mongla		*	9	76	35350	165536
152.	KHULNA	BAGERHAT	Morelganj	0.4720	*	16	184	79573	385384
153.	KHULNA	BAGERHAT	Rampal	0.5050		11	149	43055	200484
154.	KHULNA	BAGERHAT	Sarankhola	0.0601		7	44	25464	129427
155.	KHULNA	CHUADANGA	Alamdanga	0.5380	*	15	191	58109	294629
156.	KHULNA	CHUADANGA	Chuadanga	0.0997	*	9	129	53476	267896
157.	KHULNA	CHUADANGA	Damurhuda	0.4970	*	10	102	48463	255949
158.	KHULNA	CHUADANGA	Jibannagar	0.0987	*	4	89	29416	150122
159.	KHULNA	JESSORE	Abhoynagar	0.3550	*	8	121	47935	245585
160.	KHULNA	JESSORE	Bagherpara	0.1520		9	191	37280	202726
161.	KHULNA	JESSORE	Chaugachha	0.0867		11	166	43895	218195
162.	KHULNA	JESSORE	Jessore	0.1720	*	18	250	122652	636698
163.	KHULNA	JESSORE	Jhikorgachha	0.2010	*	11	179	56471	283058
164.	KHULNA	JESSORE	Keshabpur	0.3080	*	9	143	48767	240275
165.	KHULNA	JESSORE	Manirampur	0.2240	*	17	249	77500	391312
166.	KHULNA	JESSORE	Sarsa	0.0573		11	172	59909	310547
167.	KHULNA	JHENAIDAH	Harinakundu	0.1350		8	129	35630	194494
168.	KHULNA	JHENAIDAH	Jhenaidah	0.1480	*	20	283	78330	399830

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169.	KHULNA	JHENAIDAH	Kaliganj	0.0909	*	14	196	49841	262951
170.	KHULNA	JHENAIDAH	Kotchandpur	0.1310	*	8	79	25705	128632
171.	KHULNA	JHENAIDAH	Maheshpur	0.5570	*	15	194	54594	295620
172.	KHULNA	JHENAIDAH	Sailkupa	0.2810	*	17	258	67074	352009
173.	KHULNA	KHULNA	Batiaghata	0.5380		7	158	30807	153821
174.	KHULNA	KHULNA	Dighalia	0.1680		4	41	26998	129408
175.	KHULNA	KHULNA	Dumuria	0.0657		14	230	60126	307804
176.	KHULNA	KHULNA	Dacope			9	107	32990	171757
177.	KHULNA	KHULNA	Paikgachha	0.1300	*	10	212	53552	270102
178.	KHULNA	KHULNA	Phultala	0.2590		3	25	16727	81516
179.	KHULNA	KHULNA	Rupsha	0.1370		5	72	36106	180222
180.	KHULNA	KHULNA	Terakhada	0.1140		6	96	23884	123566
181.	KHULNA	KUSHTIA	Bheramara	1.6600	*	9	74	34299	173065
182.	KHULNA	KUSHTIA	Daulatpur	0.6650		14	242	86423	432847
183.	KHULNA	KUSHTIA	Kumarkhali	0.3770	*	15	216	62903	322810
184.	KHULNA	KUSHTIA	Kushtia	0.0616	*	18	157	86823	442529
185.	KHULNA	KUSHTIA	Mirpur	1.0300	*	13	197	62680	319255
186.	KHULNA	MAGURA	Magura	0.1060	*	16	252	65053	344310
187.	KHULNA	MAGURA	Mohammadpur	0.1680		8	182	36605	192408
188.	KHULNA	MAGURA	Salikha	0.2160		7	118	28872	158749
189.	KHULNA	MEHERPUR	Gangni	0.0625		9	136	57099	274966
190.	KHULNA	MEHERPUR	Meherpur	0.4280	*	18	117	63756	315335
191.	KHULNA	NARAIL	Kalia	0.2550	*	15	184	47304	236096
192.	KHULNA	NARAIL	Lohagara	0.2480		12	224	47909	249898
193.	KHULNA	NARAIL	Narail	0.2030	*	16	228	58131	300870
194.	KHULNA	SATKHIRA	Asasuni	0.3300		9	241	52956	265148
195.	KHULNA	SATKHIRA	Debhata	0.3150		5	116	23041	118882
196.	KHULNA	SATKHIRA	Kalaroa	0.4530	*	15	136	46118	228865
197.	KHULNA	SATKHIRA	Kaliganj	0.1000		12	249	53511	270715
198.	KHULNA	SATKHIRA	Satkhira	0.5010	*	17	235	80391	413333
199.	KHULNA	SATKHIRA	Shyamnagar	0.5090		13	216	60570	318005
200.	KHULNA	SATKHIRA	Tala	0.3190		12	228	61612	301666
201.	RAJSHAHI	BOGRA	Dhunot	0.0759		10	209	63571	296381
202.	RAJSHAHI	BOGRA	Gabtali	0.6320		10	213	68617	319111
203.	RAJSHAHI	BOGRA	Shariakandi	0.1500	*	13	190	60325	275476
204.	RAJSHAHI	BOGRA	Shibganj	0.0917		12	436	82837	375328
205.	RAJSHAHI	CHAPAI NAWABGANJ	Shibganj	0.0639	*	18	367	87112	506816
206.	RAJSHAHI	CHAPAI NAWABGANJ	Bholahat						
207.	RAJSHAHI	CHAPAI NAWABGANJ	Gomastapur		*	8	235	44364	230366
208.	RAJSHAHI	CHAPAI NAWABGANJ	Nachol			4	190	22022	116543
209.	RAJSHAHI	CHAPAI NAWABGANJ	Nawabganj		*	19	192	84705	467429
210.	RAJSHAHI	DINAJPUR	Birganj	0.0542		11	186	55020	277566
211.	RAJSHAHI	GAIBANDHA	Gabindaganj	0.0544	*	17	387	103303	497509
212.	RAJSHAHI	GAIBANDHA	Palashbari	0.0840		9	160	54062	252967
213.	RAJSHAHI	GAIBANDHA	Sadullapur	0.0841		11	172	61233	291614
214.	RAJSHAHI	GAIBANDHA	Sundarganj	0.7080		15	178	91215	432811
215.	RAJSHAHI	JOYPURHAT	Joypurhat		*	11	192	59129	270325
216.	RAJSHAHI	KURIGRAM	Nageshwari	0.0629		15	367	67456	335730
217.	RAJSHAHI	KURIGRAM	Rajarhat	0.4200		7	180	35564	190378
218.	RAJSHAHI	KURIGRAM	Ruhumari	0.0710		5	193	33885	164448
219.	RAJSHAHI	KURIGRAM	Ulipur	0.1870	*	14	418	82181	414246
220.	RAJSHAHI	NAOGAON	Manda	0.2440		14	286	76041	397194
221.	RAJSHAHI	NAOGAON	Porsha			6	242	23461	116735
222.	RAJSHAHI	NATOR	Bagatipara			4	142	25678	129533

Sl #	DIVISION	DISTRICT	UPAZILA	As Conc. (BGS Report May 2000)	Pourashava	# of Union	# of Village	# of Household (Projected 2000)	# of Population (Projected 2000)
223.	RAJSHAHI	NATOR	Lalpur		*	10	228	51282	260368
224.	RAJSHAHI	PABNA	Bera	0.0807	*	10	157	45956	250676
225.	RAJSHAHI	PABNA	Ishwardi	0.4930	*	10	113	50846	284190
226.	RAJSHAHI	PABNA	Santhia	0.3410	*	11	253	60769	340156
227.	RAJSHAHI	PABNA	Sujanagar	0.0578	*	10	195	46977	256958
228.	RAJSHAHI	RAJSHAHI	Bagha		*	6	101	37773	184717
229.	RAJSHAHI	RAJSHAHI	Bagmara			15	362	74978	339024
230.	RAJSHAHI	RAJSHAHI	Boalia			30	0	66382	352867
231.	RAJSHAHI	RAJSHAHI	Charghat		*	6	129	40039	196634
232.	RAJSHAHI	RAJSHAHI	Durgapur			7	122	36050	165168
233.	RAJSHAHI	RAJSHAHI	Godagari		*	9	396	52014	261373
234.	RAJSHAHI	RAJSHAHI	Mohanpur	0.0582		6	154	32276	151675
235.	RAJSHAHI	RAJSHAHI	Paba	0.0918		9	261	52000	256055
236.	RAJSHAHI	RAJSHAHI	Puthia	0.0638		6	183	39629	191286
237.	RAJSHAHI	RAJSHAHI	Tanor		*	6	207	35668	165618
238.	RAJSHAHI	RANGPUR	Pirgachha	0.2980		9	189	68162	307888
239.	RAJSHAHI	SIRAJGANJ	Belkuchi	0.0536		6	132	55137	294197
240.	RAJSHAHI	SIRAJGANJ	Kamarkhanda	0.0925		4	92	24935	127196
241.	RAJSHAHI	SIRAJGANJ	Kazipur	0.3840	*	11	182	60061	281765
242.	RAJSHAHI	SIRAJGANJ	Raiganj	0.0501		9	269	54421	270034
243.	RAJSHAHI	SIRAJGANJ	Shahzadpur	0.1950	*	16	279	92297	504542
244.	RAJSHAHI	SIRAJGANJ	Sirajganj	0.1180	*	18	282	92964	466992
245.	RAJSHAHI	SIRAJGANJ	Taras			8	243	34130	162522
246.	SYLHET	HABIGANJ	Ajmiriganj	0.1360		5	79	19127	104172
247.	SYLHET	HABIGANJ	Baniyachang	0.3200		15	337	51761	283026
248.	SYLHET	MOULVI BAZAR	Kamalganj	0.2540	*	9	276	48246	230006
249.	SYLHET	MOULVI BAZAR	Kulaura		*	16	486	76548	407608
250.	SYLHET	MOULVI BAZAR	Moulvi Bazar	0.1330	*	15	419	52745	287254
251.	SYLHET	MOULVI BAZAR	Rajnagar	0.0910		8	255	38097	209136
252.	SYLHET	SUNAMGANJ	Bishambarpur	0.0574		3	175	25617	127418
253.	SYLHET	SUNAMGANJ	Chhatak	0.2460	*	13	530	56845	327784
254.	SYLHET	SUNAMGANJ	Derai	0.0941	*	9	233	39053	222341
255.	SYLHET	SUNAMGANJ	Dharmapasha	0.1450		10	313	36878	196957
256.	SYLHET	SUNAMGANJ	Dwarabazar	0.2040		7	294	35246	188688
257.	SYLHET	SUNAMGANJ	Jamalganj	0.0718		5	165	23555	129325
258.	SYLHET	SUNAMGANJ	Sulla	0.0706		4	113	18045	107929
259.	SYLHET	SUNAMGANJ	Sunamganj	0.0607	*	17	424	65863	363784
260.	SYLHET	SUNAMGANJ	Tahirpur	0.0680		7	234	28583	160283
261.	SYLHET	SYLHET	Balaganj	0.1570		14	467	47995	277038
262.	SYLHET	SYLHET	Beani Bazar	0.0519		11	176	35216	217856
263.	SYLHET	SYLHET	Bishwanath	0.0530		8	432	34250	203676
264.	SYLHET	SYLHET	Companiganj	0.0730		3	131	17706	102203
265.	SYLHET	SYLHET	Golapganj			11	254	45384	274889
266.	SYLHET	SYLHET	Gowainghat	0.0614		8	264	35484	203924
267.	SYLHET	SYLHET	Kanaighat	0.1510		9	288	38438	214385
268.	SYLHET	SYLHET	Zakiganj	0.0833	*	9	286	38787	208846
				Total	**131**	**3171**	**53118**	**15098457**	**76811678**

Source – BGS Report May 2000,Survey of BAMWSP, UNICEF, WPP, DPHE-DANIDA and WVI

ANNEX IIIB

Geological Survey of Bangladesh\
Geochemistry and Arsenic Investigation Branch

Summary Of Arsenic Pollution Field Investigation

Surveyed area

Brahmanpara Upazila, Comilla District
Debidwar Upazila, Comilla District
Daudkandi Upazila, Comilla District

Field Instrument

Arsenic Test kit Merck Germany
pH Meter
EC Meter
Temperature
GPS

Upazila: Daudkandi; District Comilla

Total area of Upazila	376.2 sq. km.
Total Population of the Upazila	4,58,503
No. of Female	2,27,218
No. of Male	2,31,285
Total No of the tube well screened	221
Total No of arsenic free tube wells	55
Number of Affected tube well	166
Percentage of affected tube well	75.7%
Arsenic concentration level	>0.05 – 1.00 mg/l
Geological set up of the area	Flood plain deposit of Gumti, and Meghna rivers; Geomorpholgically the area is
Comment	within part of Chandina Deltaic plain. The maximum concentration is within 14-70m. There is an Impervious layer between the upper and lower aquifer (60-70m) .Below this layer the aquifer is not found contaminated.

Upazila: Debidwar; District Comilla

Total area of Upazila	232 sq. km.
Total Population of the Upazila	-
No. of Female	-
No. of Male	-
Total No of the tube well screened	313
Total No of arsenic free tube wells	24
Number of Affected tube well	289
Percentage of affected tube well	92.33%
Arsenic concentration level	>0.05 – 0.82 mg/l
Geological set up of the area	Flood plain deposit of Gumti, Buri,Salda and Meghna rivers; Geomorpholgically the
Comment	area is within Chandina Deltaic plain. The maximum concentration is within 14-37m. There is an Impervious layer between the upper and lower aquifer (30-40m) .Below this layer the aquifer is not found contaminated.

Upazila: Brahmanpara, District: Comilla

Total area of Upazila	128.49 sq. km.
Total Population of the Upazila	140296
No. of Female	67707
No. of Male	72589
Total No of the tube well screened	83
Total No of arsenic free tube wells	25
Number of Affected tube well	58
Percentage of affected tube well	69.87%
Arsenic concentration level	>0.05 – 0.5 mg/l
Geological set up of the area	Flood plain of Gumtai Salda and Meghna rivers, Eastern part hilly
Comment	Eastern hilly region not contaminated .The maximum concentration is within 14-30m.There is an Impervious layer between the upper and lower aquifer (30-40m) Below this layer the aquifer is not contaminated .

Surveyed area

Akhura Upazila, Brahmanbaria District
Brahmanbaria Upazila, Brahmanbaria District
Sarail Upazila Brahmanbaria District
Kasba Upazila, Brahmanbaria District.

Field Instrument

Arsenic Test kit Merck Germany
pH Meter
EC Meter
Temperature

Upazila: Akhaura, Brahmanbaria Sadar and Sarail; & Kasba; District: Brahmanbaria

Total area of Upazila	818 + 202 (Kasba) = 1020 Sq. km
Total Population of the Upazila	-
No. of Female	-
No. of Male	-
Total No of the tube well screened	553 +123 (Kasba)= 676
Total No of arsenic free tube wells	55 + 74 (Kasba)
Number of Affected tube well	237 + 49 (Kasba)
Percentage of affected tube well	42.3%
Arsenic concentration level	>0.05 – 1.00 mg/l
Geological set up of the area	Flood plain deposit of Titas and Meghna rivers; Eastern hilly belt.
Comment	The maximum concentration is within 14-66m. There is an Impervious layer between the upper and lower aquifer (60-70m) at places. Hilly belt is found free from contamination. A oxidized zone at a depth of~1.5m is found to contain 333ppm As in the sediment.

Field Instrument

Arsenic Test kit Merck Germany
pH Meter
EC Meter
Temperature

Upazila: Senbag; District: Noakhali

Total area of Upazila	:158 Sq. km
Total Population of the Upazila	: 241979
No. of Female	: 127669
No. of Male	: 114310
Total No of the tube well screened	: 182
Total No of arsenic free tube wells	: 17
Number of Affected tube well	: 165
Percentage of affected tube well	:90.66%
Arsenic concentration level	:>0.05 – 1.00 mg/l
Geological set up of the area	:
Comment	: Most of the shallow tube wells are arsenic affected.

South West Bangladesh

Surveyed Area
Mirpur, Khustia
Jhikorgacha, Jessore
Dumuria, Khulna
Salika, Magura

Field Instrument

Merk Kit
Arsenic Test (Sensitive)
Method- Analytical Test strips
Store Cool-15-25 degree Celcious and Dry
Merk KgaA, 64271, Darmastaat, Germany

PH Meter
EC Meter
Temperature
GPS

Mirpur Upazila, Kustia District

Part of inactive Ganges Delta
Hydrology is mainly controlled by the Padma River
Areas adjacent to the Padma river is normally arsenic free
Arsenic contaminated tube wells 40%
Up to 150 feet tube wells are As contaminated
Above 200 ft normally As free, in many cases very shallow tube wells (40ft) are As free
Generalized stratigraphic succession of As contaminated area, Top 15 feet silty clay, Middle 70 ft clay and lower 35 ft sand

Jhikorgach Upazila, Jessore District

Part of inactive Ganges Delta adjacent to the Indian Border
Hydrology is mainly controlled by the rain fall and subsurface water
Arsenic contamination tube wells 60%
Up to 200 feet tube wells are As contaminated exceptionally some very shallow tube wells As free
Above 200 ft normally As free, in many cases very Deep tube wells (40ft) are As contaminated
Generalized stratigraphic succession of As contaminated area, Top 40 feet silty clay, clay and organic clay, lower 80 ft mainly sand
Generalized stratigraphic succession of As free area, from Top to 90 feet mainly sand

Dumuria Upazila, Khulna District

Part of inactive Ganges Delta and tidal Ganges delta
Hydrology is mainly controlled by both tidal and upland frees water
Arsenic contaminated tube wells more than 60%
Mostly shallow tube wells (250) are As contaminated exceptionally some very shallow tube wells As free
Above 300 ft normally As free, in many cases very Deep tube wells (40ft) are also As contaminated
Generalized stratigraphic succession of As contaminated area, Top 65 feet peat and peaty clay, lower 125 ft mainly sand
Tidal area more As affected than non tidal area
Bayersinga area of Shovna Union most of the Deep tube wells are As affected

Salika Upazila, Magura District

Part of inactive Ganges Delta
Hydrology is mainly controlled by rian fall and subsurface water
Arsenic contaminated tube wells more than 50%
Mostly shallow tube wells (120) are As contaminated exceptionally some very shallow tube wells As free
Some Deep tube wells are also As contaminated
Generalized stratigraphic succession of As contaminated area, Top 55 feet clay and organic clay, lower 135 ft mainly sand
Arpara Sadar area most of the Deep tube wells are As affected

Conclusion

Shallow aquifers are normally As contaminated (230ft)
In many cases very shallow aquifers less than 60 ft are As free
As contamination is not uniform all over the area even within 10 feet it varies considerably
Low hydraulic gradient, insignificant water flow and inhomogeniety of sedimentation pattern probably responsible for the local As contamination variation
Geology has a strong relation with As contamination, Clay, Silt, Organic Clay and Peat are the probable sources of As
In many cases geomorphology shows some relation with As contamination but not constant
Deep tube wells Dumuria Upzila, Shovna, Bayersinga Village are As contaminated (Depth-1020ft. As level 0.1-0.2 PPM; Depth-1560 ft. As level 0.05 PPM and Depth-580 ft. As level <0.05PPM sunk by DPHE)
Similarly Arpara Sadar area of Salika Upzila some Deep tube wells are As contaminated(Depth-780 ft. As level 0.1- PPM; Depth-820 ft. As level 0.05 PPM and Depth-760 ft. As level< 0.05 PPM sunk by DPHE)
Probable main causes of deep tube well contamination are leakage of contaminated water from the top layer to bottom layer.

The Task Force was allowed to co-opt member(s) and/or seek guidance from any others.

1.2 Terms of Reference

i. To collect and evaluate geological and hydro-geological data presently lying with different government and academic institutions;
ii. To identify areas/locations, suitable for sinking tube wells at deep depths on the basis of reliable and authentic hydro-geo-chemical data;
iii. To develop a guideline for protecting the arsenic safe aquifers from future contamination, especially drilling procedures to be followed;
iv. To identify gaps in available knowledge or data regarding the deep aquifers;
v. To develop a comprehensive Terms of Reference for hydro-geo-chemical investigation in arsenic prone areas, where concrete knowledge is still lacking;
vi. To identify specific activities to be undertaken and identify and recommend to concerned departments/agencies to undertake the activity;
vii. Any other related matter.

1.3 Meetings of the Task Force

1.3.1 The Task Force held its first meeting on August 06, 2001 where all the members except the Managing Director (BAPEX), who was represented by Mr. L.R. Choudhary, General Manager (Laboratories Division) of BAPEX, and Director General, Water Resources Planning Organization who was represented by Mr. H.S.M. Faruque, Director, was present. In that meeting BAMWSP presented the results of screening program so far completed and it was decided that a strategic criteria would be developed after obtaining as much as possible geo-hydro-chemical information of some selected hot spot areas. It was also decided that the Geological Survey of Bangladesh would present a simplified map showing the geo-districts of the country and two upazilas from each of those geo-districts would be selected for detailed study. In addition, the procedural matters of future meetings were also decided. In continuation of this, a letter was written to the Secretary, Local Government Division to write letters to the Secretaries of the Ministries of Water Resources, Agriculture, and Energy and Mineral Resources to request concerned agencies under those ministries for making information on the subject available to the Task Force. The Secretary, Local Government Division was kind enough to write D.O. letters to those Secretaries and in turn they were prompt to communicate to the agencies about releasing all available data to the Task Force. The agencies made the data available free of cost except that some of the reports of the BWDB were to be purchased.

1.3.2 DG, GSB submitted a map simplifying the geological units of the country into eleven geo-districts in the 2nd meeting of the Task Force. A committee comprising the DG, GSB, Director (Ground Water Hydrology), BWDB, and the Member Secretary of the Task force was given the responsibility to select two upazilas from each of the geo-districts for detailed studies. The Task Force selected six upazilas from that list in the next meeting. Efforts were made to collect as much information as possible on those upazilas.

1.3.3 After all the data of the six upazilas were obtained and analyzed, it was found that the information available was not enough to write a comprehensive report on the groundwater based on the data available. It was also realized that the committee was not in a position to arrange field work by concerned technical people to collect enough information to write such a report. It was realized that the BGS-DPHE (2002) study took years to complete and the JICA study of three upazilas only took three years.

1.3.4 Considering the above facts it was decided that instead of studying a few upazilas in detail, the Task Force would attempt to develop a conceptual model about the Late Pleistocene-Holocene geology of the country and also attempt to correlate the geological formations with the aquifers from which most of the ground water used in the country is withdrawn. This may give us an understanding of the arsenic contamination of the aquifers and their geological relationships. This would also help in discussing countrywide distribution of the aquifers not yet contaminated and relate the geological age of the sediments containing those aquifers. By this time the BGS-DPHE, 2001 study was available which is an excellent compilation of all the previous work on the aquifers in the country and also contains all the hydro-geological data available till 1999. Along with these data of the 41 upazilas obtained by BAMWSP and the recent data available from DANIDA-DPHE and BWDB could be used to develop the conceptual models for future studies and to prepare a road map in continuing the studies in identifying the areas of arsenic safe aquifers as well as the studies needed in understanding the problems of the mobilization of arsenic in the groundwater. An interim report on the arsenic safe areas prepared by Mr. Munir Hussain and Mr. S.K.M.Abdullah was submitted to the Secretary, LGRD, Local Government Division in November, 2001(Annex 1). Representatives from BAMWSP, Geological Survey, BWDB and DPHE were nominated to prepare a draft of the final report to be submitted to the Government.

1.3.5 In the mean time the new government came to power in October 2001, and in her first speech to the nation the Prime Minister announced that an International Seminar would be held within 100 days of her government. The group working on the Task Force report was also given the responsibility to prepare the Country Paper of the Geo-hydrology Section of that International Workshop. This also gave the Task Force an immense opportunity to present the conceptual models of the Late Pleistocene-Holocene geology of Bangladesh and the concept to classify the aquifers on that basis to the most eminent experts from home and abroad.

1.3.6 It is important to note that most of the national as well as international experts agreed that future work on geo-hydro-chemical studies should keep in mind the conceptual models of the Late Pleistocene-Holocene geology as well as the classification of the aquifers based on that model. The recommendations of this report were prepared keeping in mind the discussions during the three-day period of the International Workshop on arsenic issues in Bangladesh in January 2002.

1.4 Preparation of the report

1.4.1 Initial drafts of the report was prepared by the following persons:

i) Chapter 2 and 3 by Mr. Md. Nehal Uddin of the Geological Survey
ii) Chapter 4 by Mr. Arpan Kumar Mitra and Mr. Md. Anwar Zahid of BWDB
iii) Chapter 5 by Mr Munir Hussain of BAMWSP and Mr Anwar Zahid of BWDB.
iv) Chapters 6 and 7 by Mr. S.K.M. Abdullah and Mr. Md. Nehal Uddin

All the above chapters were edited and some of the chapters were re-written by Mr.S.K.M.Abdullah along with Mr. Md. Nehal Uddin.

1.4.2 Attempt was made to cover most of the points in the TOR. However, the guide line for protecting arsenic safe aquifers from arsenic contaminated water in the upper aquifers during its development was not covered (item iii of TOR). This needs specialized drilling and sealing procedures during well completion (tube wells) which requires expertise in drilling technology. This also needs field testing and monitoring by both chemical analyses and isotopic age dating of the water from the aquifer that have been developed.

Also item iv of the TOR was intentionally left out because it is the prerogative of the Government to decide which agency or combination of agencies will be most suitable to under take which part of the activities recommended.

1.5 Acknowledgement

1.5.1 The Task Force as well as the authors expresses their heartfelt gratitude to Mr. Abdul Quader Choudhary, Project Director, BAMWSP; Mr. M. Nazrul Islam, Director General, Geological Survey of Bangladesh; Mr. Alamgir Hossain, Director(Ground Water Hydrology), Bangladesh Water Development Board; Mr. Md. Abdul Halim, Member Director (MI), Bangladesh Agricultural Development Corporation; Mr. H.S.M. Faruque, Director, Water Resources Planning Organization; Mr. Ihtishamul Huq, Executive Engineer (Research & Development), Department of Public Health Engineering for allowing to consult, copy and use any information available in their respective offices for the purpose of writing this report. Thanks are due to Moqubul-E-Elahi, Managing Director, BAPEX for allowing Mr. L.R. Chowdhury to consult some raw data in their Data Center and made them available to the Task Force. Special thanks are due to the Project Director, BAMWSP for allowing Mr. Munir Hussain; the Director General, GSB for allowing Md. Nehal Uddin and the Director (Ground Water Hydrology), BWDB for allowing Mr. Arpan Kumar Mitra and Mr. Md. Anwar Zahid to give much of their time for many days in compiling the data and writing of this report.

CHAPTER II

Physiography of Bangladesh

2.1 Introduction

2.1.1 Bangladesh belong to South Asia and lies between $20^0$34´ and $26^0$38´ N, and $88^0$01´ and $92^0$41´ E. The area of the country is 147,570 square km with more than 700 km long coastlines.

2.1.2 About 80% of the land is flat, intersected by numerous rivers and their distributaries. The land area has a general slope of 1^0-2^0 from north to south (Fig. 2.1).

2.1.3 Physiographically Bangladesh can be divided into 7 divisions. Each of these divisions can be subdivided with distinguished characteristics of its own (Fig. 2.2).

i) Hilly Regions
   a) Chittagong Hill Tracts
   b) Hill Ranges of Northeastern Sylhet
   c) Hills along the Narrow Strip of Sylhet and Mymensingh Districts

ii) Pleistocene Uplands
   a) Barind Tract in the north western part
   b) Madhupur Tract in the central part
   c) Lalmai Hills

iii) Tippera Surface

iv) Tista Fan

v) Flood Plains
   a) Ganges Flood Plain
   b) Atrai Flood Plain
   c) Brahmaputra Jamuna Flood Plain
   d) Old Brahmaputra Flood Plain
   e) Meghna Flood Plain

vi) Delta Plain of the Ganges-Brahmaputra-Meghna Delta Complex
   a) Active Delta
   b) Inactive Delta
   c) Tidal Delta

vii) Sylhet Depression and Inland Marshes

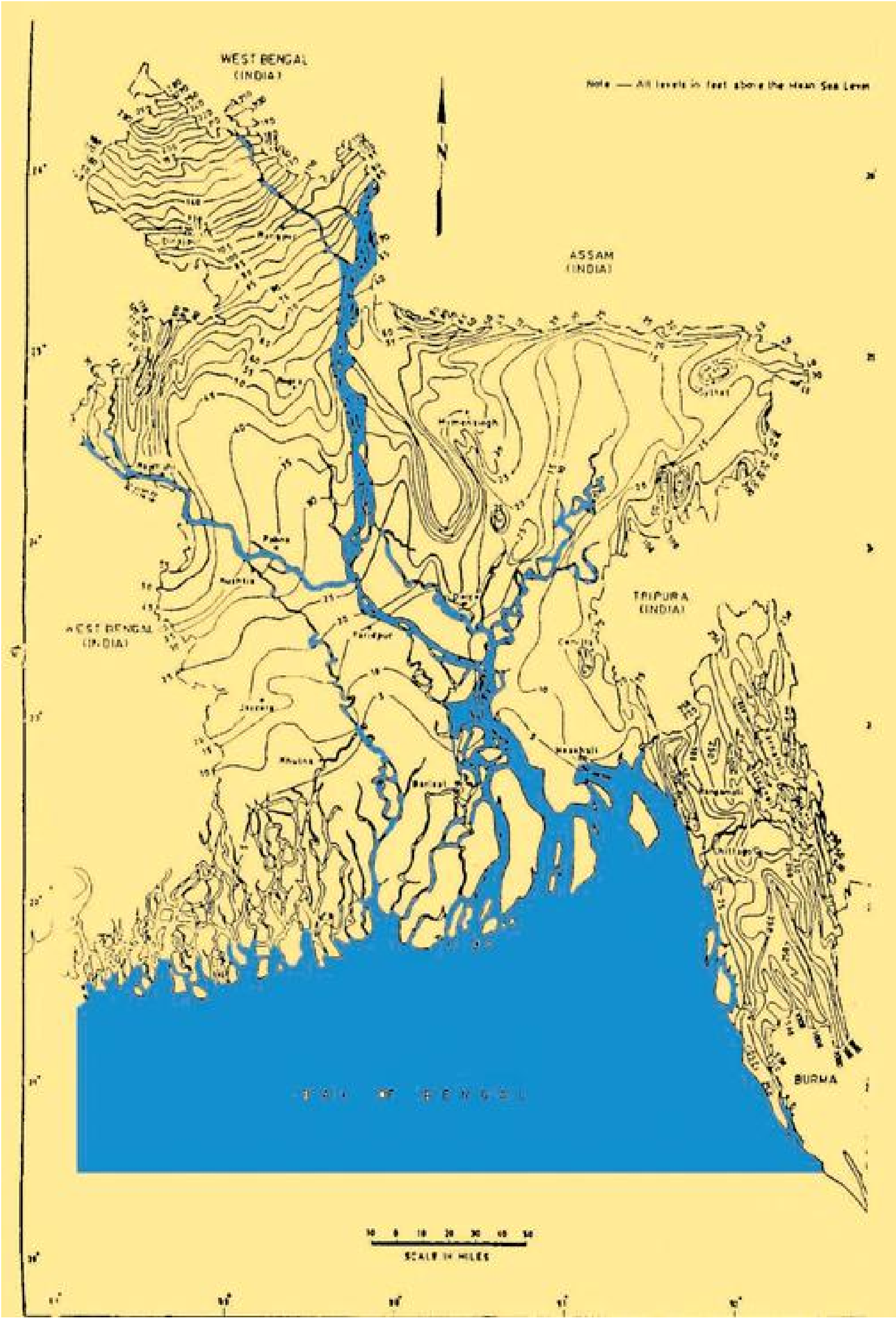

Fig. 2.1 Contour Map of Bangladesh (Source-: Gulam Kibria, 1966)

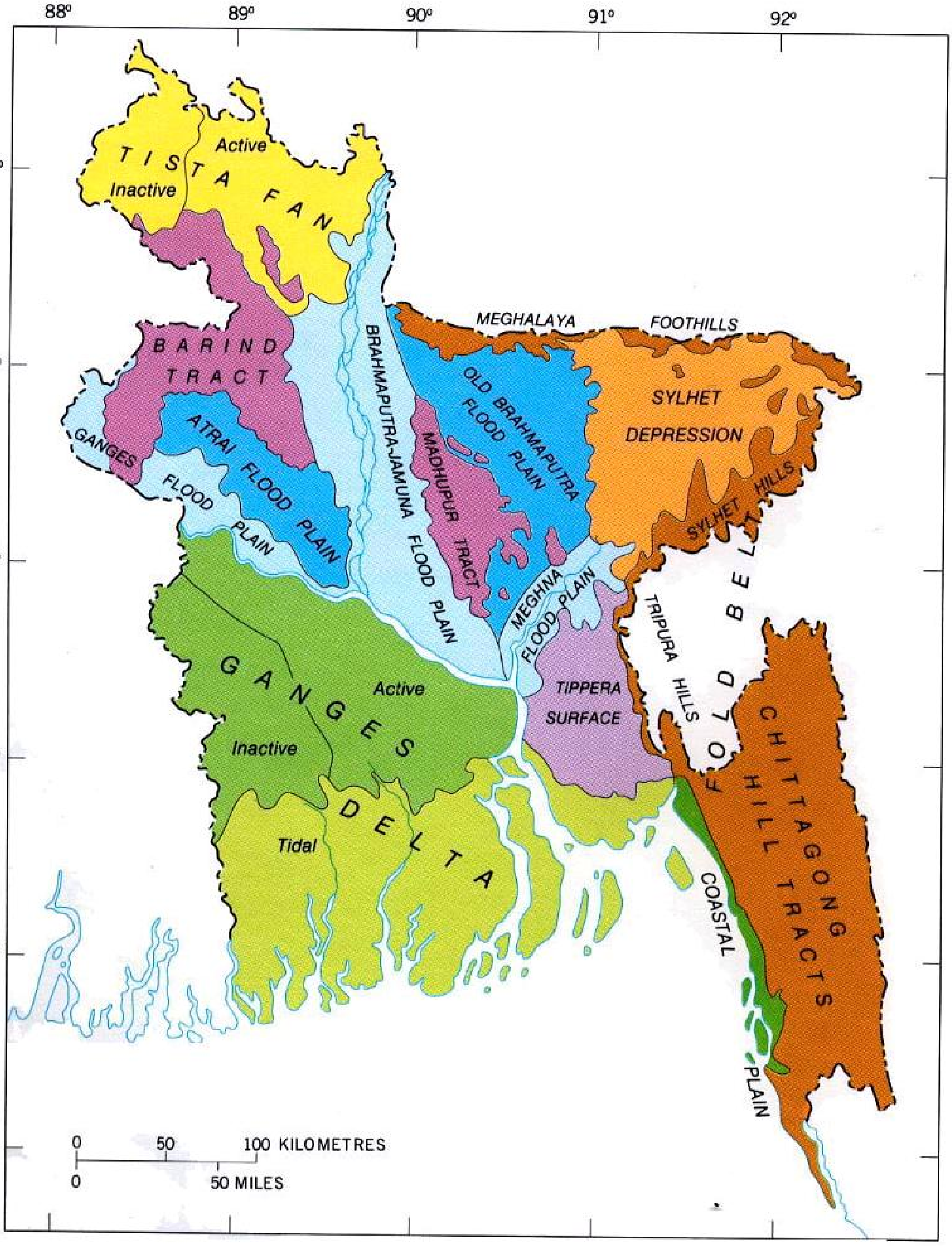

Fig. 2.2 Physiographic Map of Bangladesh (Alam, et al. 1991)

2.2. Hilly Regions:

2.2.1 Hilly areas occupy about 18% of Bangladesh. High north-south striking hill ranges occupy wholly the districts of Chittagong, Cox's Bazar and the three Hill Tract districts. The anticlines form the hills and synclines the valleys. The hills becomes higher towards east reaching a maximum height of 1003 m. The lowest ranges generally follow the eastern coast of the Bay of Bengal from Feni River to Naf River and continue southwards across the Mayanmar border. Most of Moheskhali Island belongs to this hilly area. There is a narrow strip of coastal plain in the Chittagong District and a very narrow strip of beach from Cox's Bazar to Teknaf, between the hills and the Bay of Bengal. Chokoria Sundarban and the associated Mud Flat area is a small delta of the Matamuhuri River. Towards the east, the ranges get higher and the slope steeper until they reach the highest hill range in the east that marks the boundary between Bangladesh, Mayanmar and India.

2.2.2 Some of the hill ranges of the Chittagong and the Hill Tract districts continue northward across the Indian State of Tripura and form the hill ranges of northeastern Sylhet region. These hill ranges attain a much lower elevation and slope more gently than their continuation in the Chittagong and the Hill Tract Districts.

2.2.3 The narrow strip of discontinuous low hill ranges extends from Jaflong in the east to the Brahmaputra River in the west. These hills do not form continuous range, but constitute a chain of circular and elongated hillocks separated by Holocene alluvial valleys. Along the frontier of greater Mymensingh these hills form series of circular and elongated hillocks.

2.3. Pleistocene Uplands

2.3.1 The Barind Tract

2.3.1.1 The Barind Tract is located in the west of the Brahmaputra River. It falls in the central part of north Bangladesh and covers an area of 7,680 sq. km in the Rajshahi division. The area comprises of six north-south elongated and isolated exposures of reddish brown deposits. The Barind Tract is the product of vertical movements of Pleistocene period and reaches maximum height of 20 m above modern flood plains.

2.3.2 The Madhupur Tract

2.3.2.1 The Madhupur Tract is situated in the east of the Barhmaputra River. It looks like a chain of isolated circular to elongated low hillocks standing at a higher level than the surrounding flat alluvial plain and is affected by a series of faults. This area of about 4,058 sq. km. extends in Dhaka, Mymensingh and Tangail districts. The Madhupur Tract reaches a maximum height of 17 m from sea level and is elevated during the same period as that of the Barind Tract.

2.3.3 The Pleistocene Uplands cover an area of about 10% of Bangladesh. Determination of the concealed Pleistocene red clay that composes the rock type in the immediate surrounding of the Barind and the Madhupur Tracts should increase their areas considerably.

2.3.4 Lalmai Hills

2.3.4.1 The Lalmai Hills are situated in the Comilla district and are composed of reddish brown clay. The Lalmai Hills represent a north-south elongated low hill range of about 16 km long and about 2-3 km wide. It covers an area of about 33 sq. km. The hill range runs through the middle of Comilla district. The average height is about 12 m that reaches a maximum of about 47 meter above the mean sea level. Comparable with the Barind and Madhupur the Lalmai Hills was uplifted at similar time and also displays a dendritic drainage pattern.

2.4 Tippera Surface

2.4.1 The area between the Meghna flood plain in the west and the Tripura Hills in the east was uplifted in Early Holocene times (Bakr, 1977). This physiographic unit is made up of estuarine sediments of Early to Middle Holocene age. The present day rectangular drainage pattern of this flat area was artificially developed for irrigation purposes. The western edge of the Tiperra Surface grades transitionally into the Meghna Flood Plain.

2.5 Tista Fan

2.5.1 The Tista Fan is at the northwestern part of Bangladesh. It is the extension of the Himalayan piedmont plain that slope southward from a height of 96 m to 33 m with a gradient of about 55 cm/km. The region is covered by the piedmont sand and gravel, which were deposited as alluvial fan of the Tista, Mahananda and Karatoya rivers and their distributaries issuing from the Terai area of the foothills of Himalayas. There was a major shift in the courses of these rives in 1887.

2.6 Flood Plains

2.6.1 The flood plains of the Ganges, the Atrai, the Brahmaputra-Jamuna, the Old Brahmaputra, and the Meghna rivers cover approximately 40% of Bangladesh. The elevation of the major part of the flood plain ranges from 3 to 5 meters. The flood plain covers the central, north and northeastern part of the country. The Brahmapura-Jamuna Flood Plain is located between the Barind and Madhupur Tracts. Elevation of this surface is 29 m in the north and about 6 m in the south. In 1887, a remarkable change in the course of the Brahmaputra took place. In that year, the river shifted from a course around the eastern edge to the western side of the Madhupur Tract and changed from a meandering river to a braided river. The Old Brahmaputra degenerated into a small seasonal channel and rarely spills over the previously built up levees. The Ganges Flood Plain extends from the western border of the country, south of the Barind Tract, as far east where it merges with the Jamuna Flood Plain. The Meghna Flood Plain merges with the southern part of the Old Brahmaputra Flood Plain in the northwest and with the Sylhet Depression in the north. Landform of the flood plain is characterized by natural levees distributed in a mottled pattern which forms shallow depressions and small ridges. The maximum height of the levees is 30 m above the sea level. There are numerous small depressions (beels/haors) in the flood plain. The levee of the rivers gently slopes towards these depressions. Silty clay, clay, sandy silt with local peat beds are the major constituents of the flood plain area.

2.7 Delta Plain of the Ganges-Brahmaputra-Meghna Delta Complex

2.7.1 The Active and the Inactive Delta

2.7.1.1 The Delta Complex covers about 32% of Bangladesh. The area south of a line drawn from Ganges-Padma as far as the lower course of the Feni river in the southeast belongs to the delta of the Ganges, Brahmaputra and Meghna river. The Ganges is the greatest builder of the delta (70-80%). The Ganges delta located in the south of the Barind and Madhupur Tract also includes part of West Bengal. The Bangladesh portion of the delta occupies about 46,620 sq. km. In the southwest, a part of the delta has been classified as the inactive delta but the major part in the south and southeast is very active. The elevation of the delta is about 15 to 20 m from the sea level in the northwest and 1 to 2 m in the south. The elevation increases within the upper reaches of the delta. Many swamps (depressions) have developed in the substantial part of the delta. Clay, silty clay and occasionally peat are the major constituent of the delta plain.

2.7.1.2 The present Delta is a combination of three deltas, namely the Ganges delta, the Old Brahmaputra-Meghna delta and the Ganges-Jamuna (the present Brahmaputra)-Meghna Delta. In some recent literature the name, "Ganges-Brahmaputra-Meghna Delta Complex” has been used. Also, in the summer monsoon season when about 3 million cusecs of water passes through the delta, it behaves as a fluvial delta whereas in the winter when the volume of water passing through the delta drops to 250,000 to 300,000 cusecs it behaves as a tide dominated delta. These unusual features make this delta one the most complex in the world. Holocene or Recent sediments from a few hundred to thousands of meters cover the Flood plains and the Delta.

2.7.2 Tidal Delta Plain

2.7.2.1 This is the southern part of the Delta plain. This area is tide dominated and is considered as the active part of the delta. The landforms are characterized by tidal low land with weakly developed natural levees distributed in an irregular pattern. Numerous rivers, channels, tidal creeks have criss-crossed the area. Swamps and depressions are also present in the area. Estuarine deposits of silt, silty clay dominates in this area. Mangrove swamps of the Sundarban and many salt fields and shrimp culture farms have developed in the area. The landforms in the area are temporal as they are changing due to the cyclones and other natural calamities.

2.8. Sylhet Depression and Inland Marshes

2.8.1 The Sylhet Depression is a tectonic basin subsiding at a very fast rate and is bounded by the hills of frontier strip of Sylhet and Netrokona Districts in the north and the northeastern Sylhet Hills in the east. Numerous lakes (beels) and large swamps (haors) cover the saucer shaped area of about 7,250 sq. km. The elevation of the central part of the depression is about 3 m above the sea level. The inland marshes are found scattered all over the country. Most of them are back swamps, oxbow lakes and abandoned channels formed due to the changes in the courses of the rivers.

CHAPTER III

Geology

3.1 Introduction

3.1.1 The oldest rocks exposed in Bangladesh belong to the Tertiary Era mainly from Miocene and later in age though in the subsurface rocks of Archean, Paleozoic and Mesozoic age have been identified. Quaternary sediments cover approximately 82% of the country and rocks from Paleocene to the Pleistocene are exposed in 18% of the area in the hilly region (Fig. 3.1). The largest submarine fan in the world lies in offshore Bangladesh. Curry and Moore (1971, 1974)) has included the Tertiary and the Quaternary areas of Bangladesh and West Bengal, India along with the Bengal Submarine fan as the Bengal Basin. Some authors include parts of Mayanmar and Assam, India also within the Bengal Basin (Bangladesh 48%, India 38%, Mayanmar 14%). The basin extends from the basin fault east of Chotonagpur Plateau in the west, Shillong Plateau in the north bounded by the Dauki Fault and Indo-Burmese thrust belt in the east and opens to the Bay of Bengal in the south up to 200 meter isobaths. (Fig. 3.2a). Two crustal sections along with North-south and Northwest-Southeast of the basin is shown in Fig. 3.2b.

3.1.2 Tectonically Bangladesh is divided broadly into the following divisions (Fig. 3.3).

I. Indian Platform and Shelf

a) Dinajpur slope (Himalayan Fore Deep); b) Rangpur Platform, c) Bogra Shelf,
d) Hinge Zone (Eocene slope break)

II. Bengal Fore Deep

a) Folded Flank, b) Basinal Area; i) Sylhet Trough, ii) Chandpur-Barisal Gravity High, iii) Faridpur Trough, iv) Patuakhali Depression (Hatia Trough)

3.1.3 Geological evolution of the Bengal Basin starting from Upper Paleozoic time is directly related with the break up of eastern Gondwanaland and collision of the Indian plate with the Asian plate, it can be divided into four major stages: I. Permo-carboniferous Pre-Breakup stage; II. Early Cretaceous Rift stage; III. Late Cretaceous-Eocene Plate or Drift stage, and IV. Oligocene-Recent Orogenic stage. The sedimentary cover of the basin with a maximum thickness of 20 km includes three major lithostratigraphic units separated by three major unconformities. The western part of Bangladesh is the platform shelf, whereas the folded belt represents the eastern part of the country. The central part representing the most subsided part of the basin comprises two major depressions at the north (Sylhet Trough) and south (Patuakhali Depression). The transition zone from the shelf to basin is represented by the hinge zone-a Eocene shelf/slope break. (Fig. 3.2, 3.3 and 3.4).

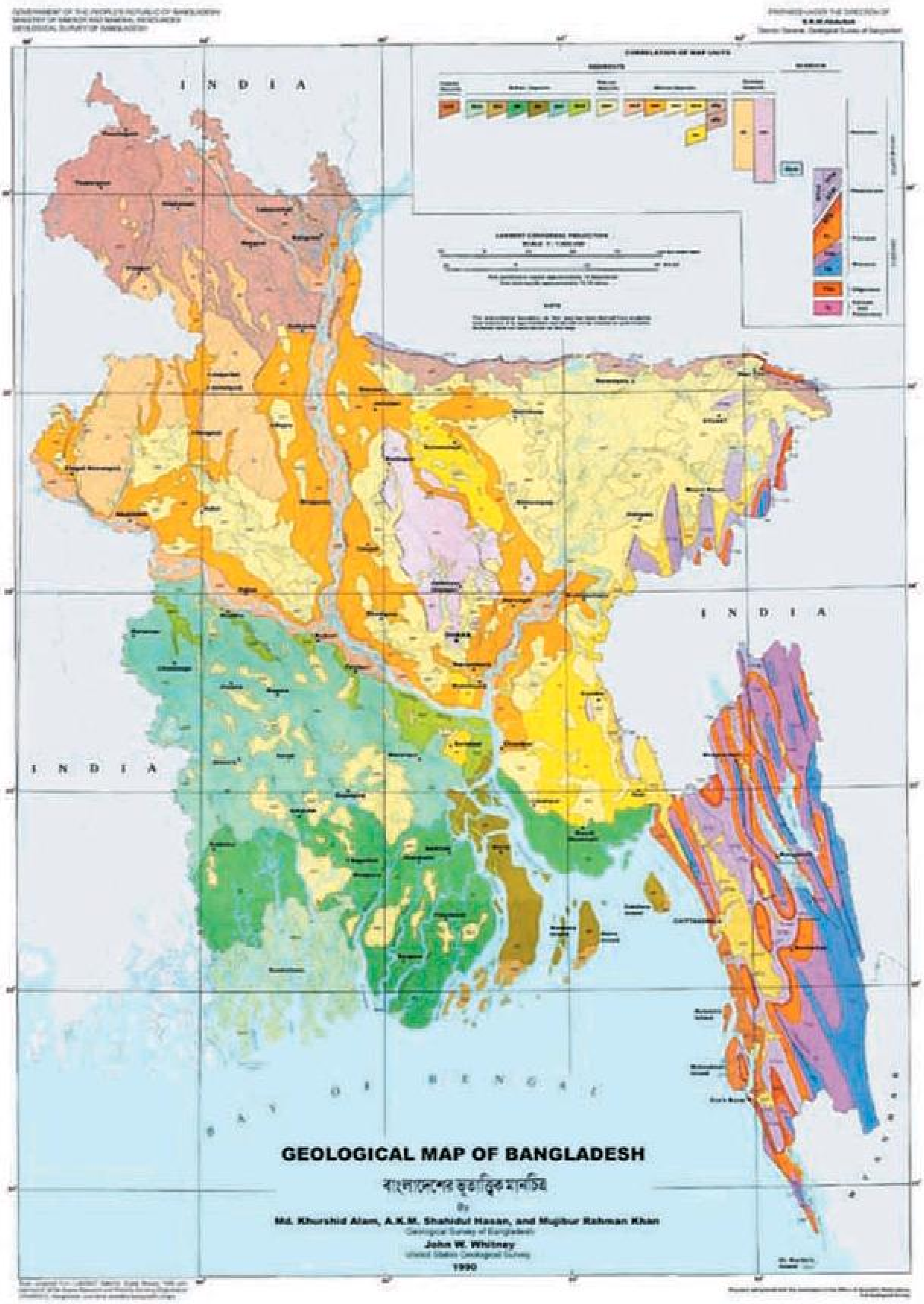

Fig. 3.1 Geological Map of Bangladesh (Alam, et al. 1990)

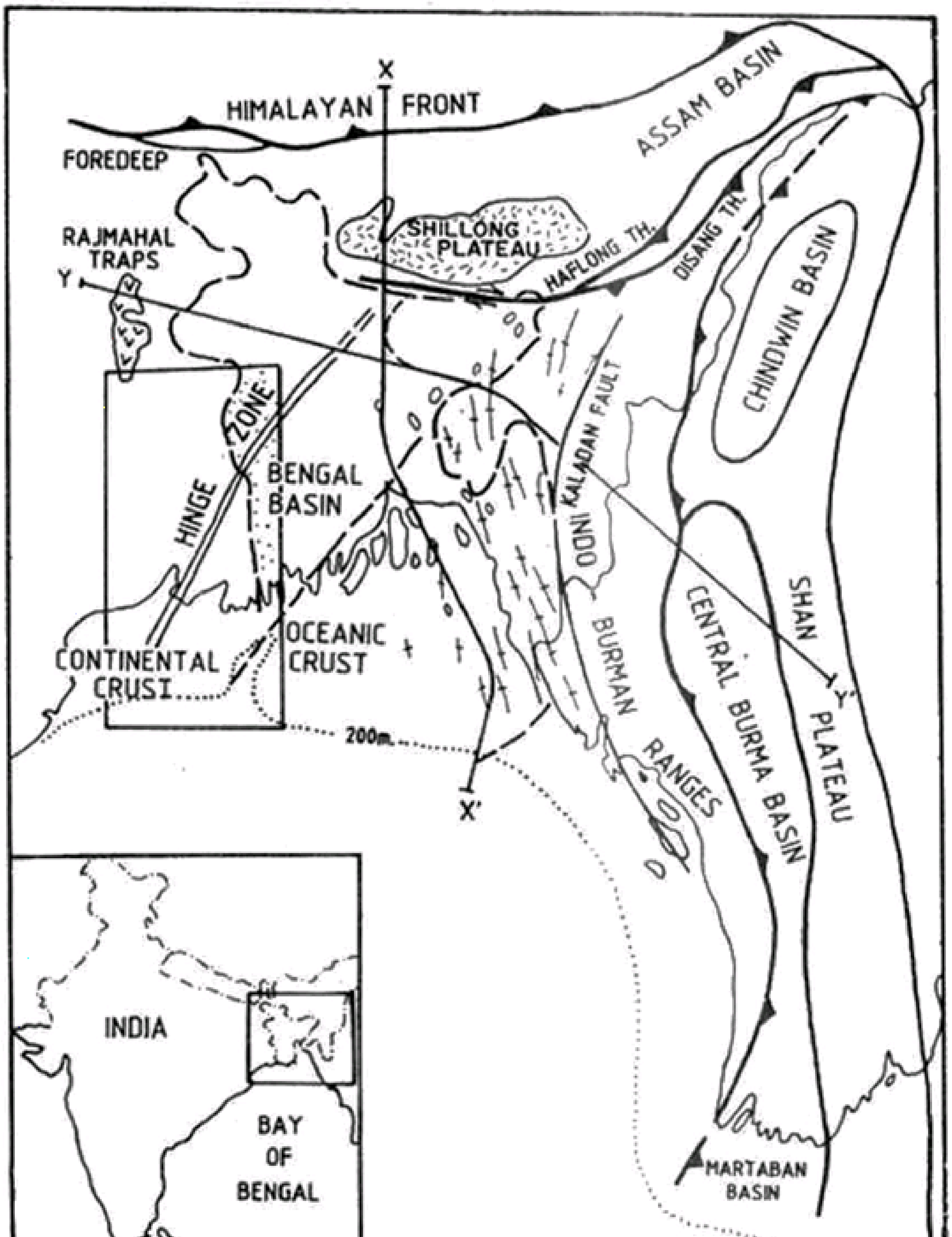

Fig. 3.2a Map Showing the Position of the Bengal Basin with Tectonic Elements, Crustal Cross Section Lines Along X-X/ and Y-Y/ (Source BOGMC, 1986).

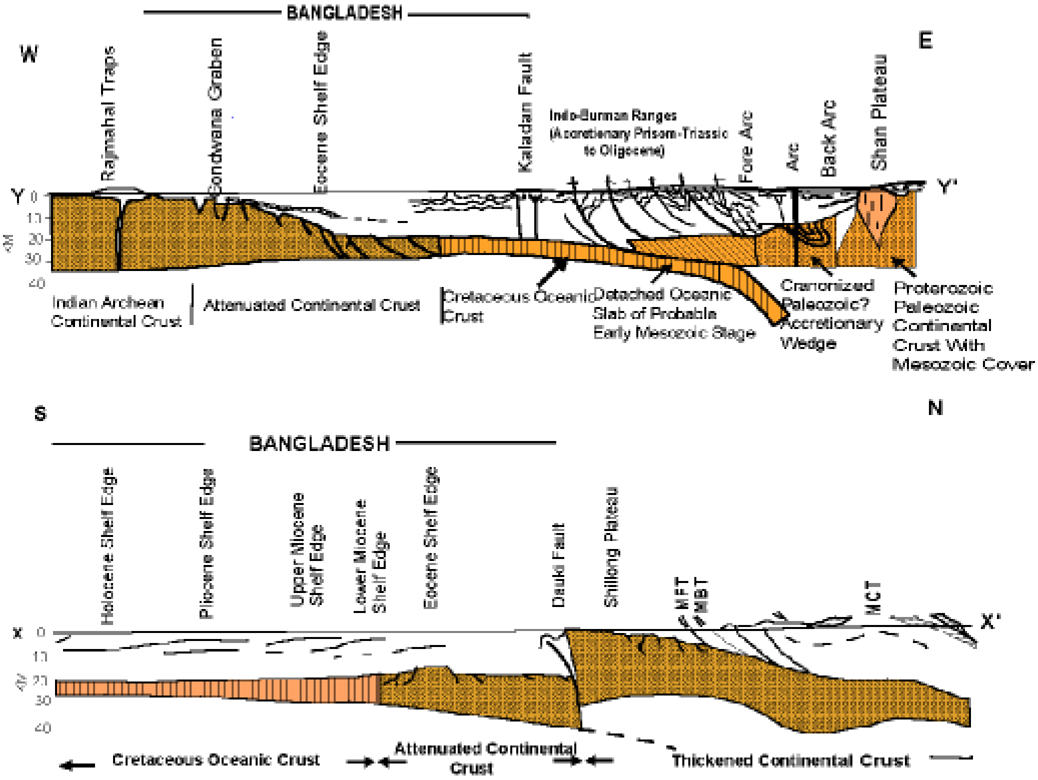

Fig. 3.2b. Schematic Crustal Cross Section Through the Line X-X/ and Y-Y/ Figure 3.2a (Source BOGMC, 1986).

3.1.4 Rapid subsidence of the foredeep of the Bengal Basin was compensated by the influx of huge amounts of detritus originating from the nearby sources of the basin. Shallow water conditions and deltaic environment persisted. In addition to the Western and Northern foreland shelves, which were source areas earlier, the rising chains of the Himalayas and the Indo-Burman Ranges were increasingly subjected to erosion and supplied much of the sediments since the Mid-Miocene in the basinal area (Shamsuddin and Abdullah, 1997).

3.1.5 Bangladesh contain thick sediment (up to 20 km in the southern part) sequences of Permian to Holocene (Fig. 3.4). The sediment thickness is shallowest in northern Bangladesh (114 m). Major part of the sediment is deposited by the Ganges-Brahmaputra-Meghna river systems during Miocene to Holocene time. In Bangladesh the oldest sediment is the Permian Gondwana rock that lies over the Pre-Cambrian Basement

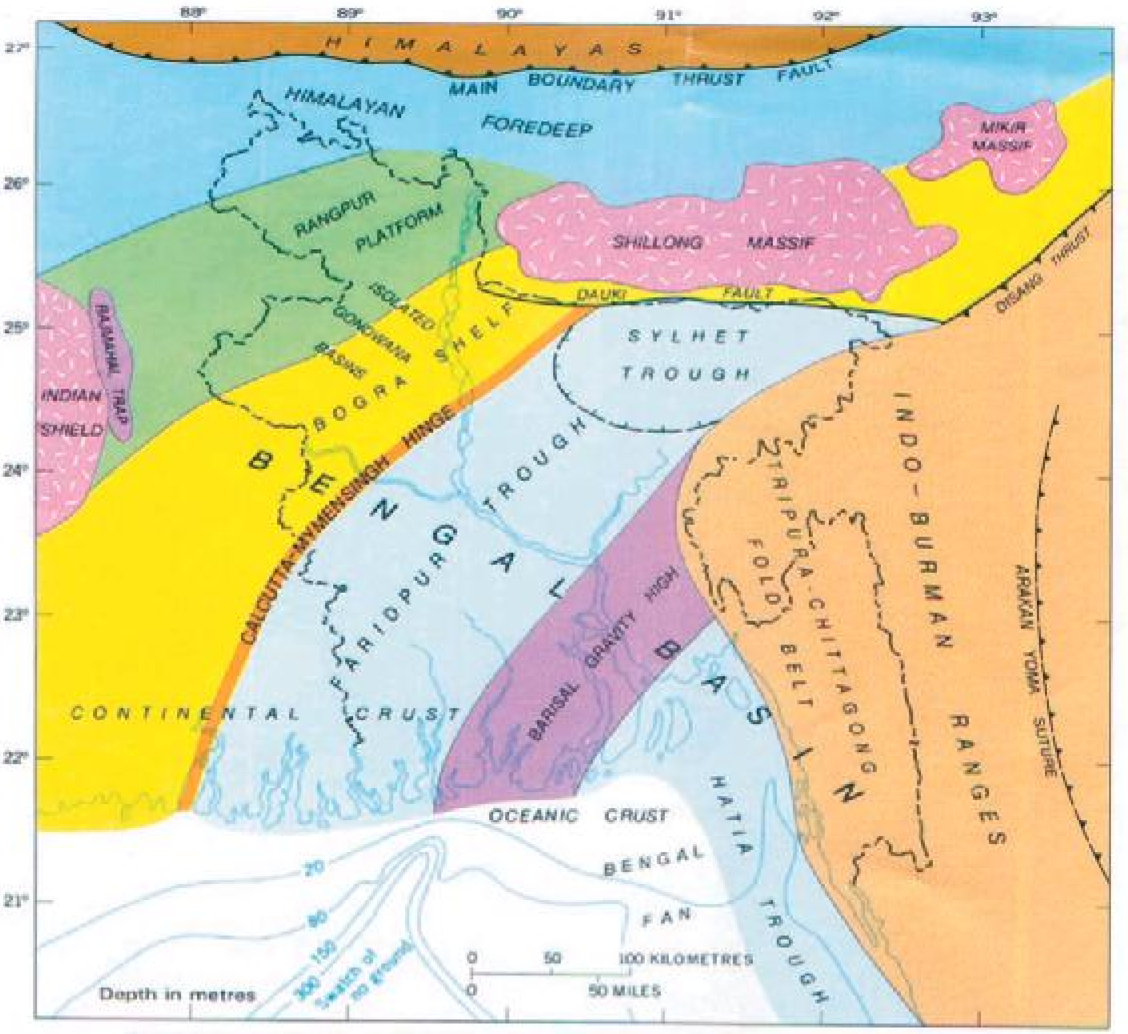

Fig.3.3 Generalized Tectonic Map of Bangladesh and Adjoining Areas (Alam, et al. 1990).

complex. Over the Gondwana rock successively lies the Cretaceous Rajmal Trap, Paleocene Tura Sandstone, Eocene Sylhet Limestone and Kopili Formation , Oligocene Barail Formation, Miocene Bhuban, Bokabil and Tipam Sandstone, Pli-Pleistocene Dupi Tila Sandstone, Pleistocene Dihing Formation and Madhupur Clay, and Holocene Alluvial sediments (Fig. 3.4, Table 3.1) This generalized sequence is not common in all parts of the country and in some places many formations are missing due to depositional, non-depositional, and post depositional erosion. The stratigraphic sequence in the Himalayan Foredeep is shown in Fig. 3.5. The stratigraphic sequence is also variable between the Basin Fore Deep area and the Shelf areas.

3.1.6 During the Pleistocene and Holocene time large volume of sediments were laid down in the Ganges-Brahmaputra-Meghna (GBM) Delta Complex by the mighty rivers

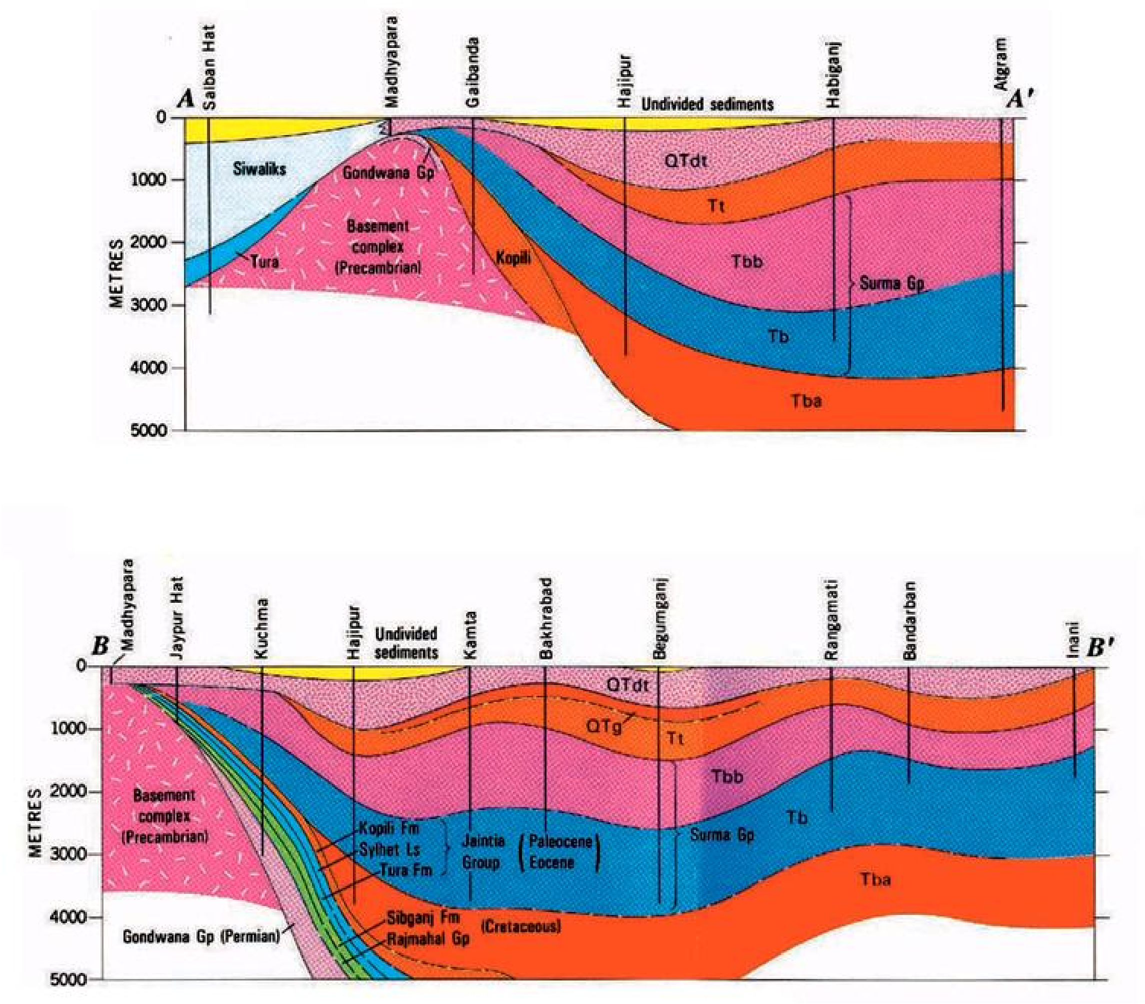

Fig. 3.4 Correlation of Stratigraphic Sections From the Himalayan Foredeep Across the Bengal Basin (Alam, et al., 1990)

that built up the delta and aquifer systems. The input of the sediments and their distribution was largely controlled by tectonic activities (rising Himalayas) and the climatic changes in the region. The unconsolidated sediments of the Late Pleistocene and Holocene unconformably lie over the Madhupur Clay Formation. The presence of Toba ash on top of the Madhupur Clay Formation of the Pleistocene Uplands indicates that these are older than 75,000 years.

3.1.7 In Bangladesh, the Quaternary sediments (including Plio-Pleistocene) of the GBM Delta Complex are the most important for groundwater withdrawal. Hence, these are described in some detail.

Table 3.1 Generalized Stratigraphic Sequence of Bangladesh.

Age	Formation / Group	Lithologic description	Comment
Holocene	Alluvium	Sand, silt and clay: Grey; layered and inter layered with peat and decomposed vegetal matters.	Top and Middle or Main Aquifers
Pleistocene	Madhupur Clay	Red clay with patches of sandstone: Deeply oxidized, variegated colors, Contains ferruginous nodules and laterite	Stable Paleosol
Pio-Pleistocene	Dihing	Sandstone: Variegated colors with pebbles and laterites.	
	Dupi Tila Sandstone	Sandstone with clay beds: Grey, oxidized to variegated colors, coarse, pebbles and petrified woods present	Deep Aquifers
Miocene	Tipam Sandstone	Top: Girujan Clay: Grey Bottom: Tipam Sandstone: Grey, Medium to coarse with lignite bands.	Very Deep Aquifers
	Bokabil	Sandstone and shale	Gas producing zone
	Bhuban	Sandstone and shale	
Oligocene	Barail	Sandstone	
Eocene	Kopili	Shale with sandstone and fossiliferous beds	
	Sylhet Limestone	Lime stone with sandstone beds	Limestone deposits
Paleocene	Tura Sandstone	Sandstone	Oldest exposed rock of BD
Cretaceous	Rajmahal Trap	Volcanic trap with sandstone and shale	
Permian	Gondwana	Sandstone with shale and coal beds	Coal deposits
Pre-Cambrian	Basement	Granite, Granodiorite, Gneiss and Schist	Igneous & metamorphic rock

(Source GSB)

3.2 Quaternary of the GBM Delta Complex

3.2.1 Most of Bangladesh had low elevation throughout it's geological history that made it very much sensitive to the sea-level changes which influenced geological processes of weathering, erosion and deposition of sediments. The Brahmaputra and the Ganges river systems are draining the northern and southern slope of the rising Himalayas. The terrigenous sediments is reworked and redistributed by the strong current from the Bay of Bengal. These processes were in operation throughout the Plio-Pleistocene and Holocene

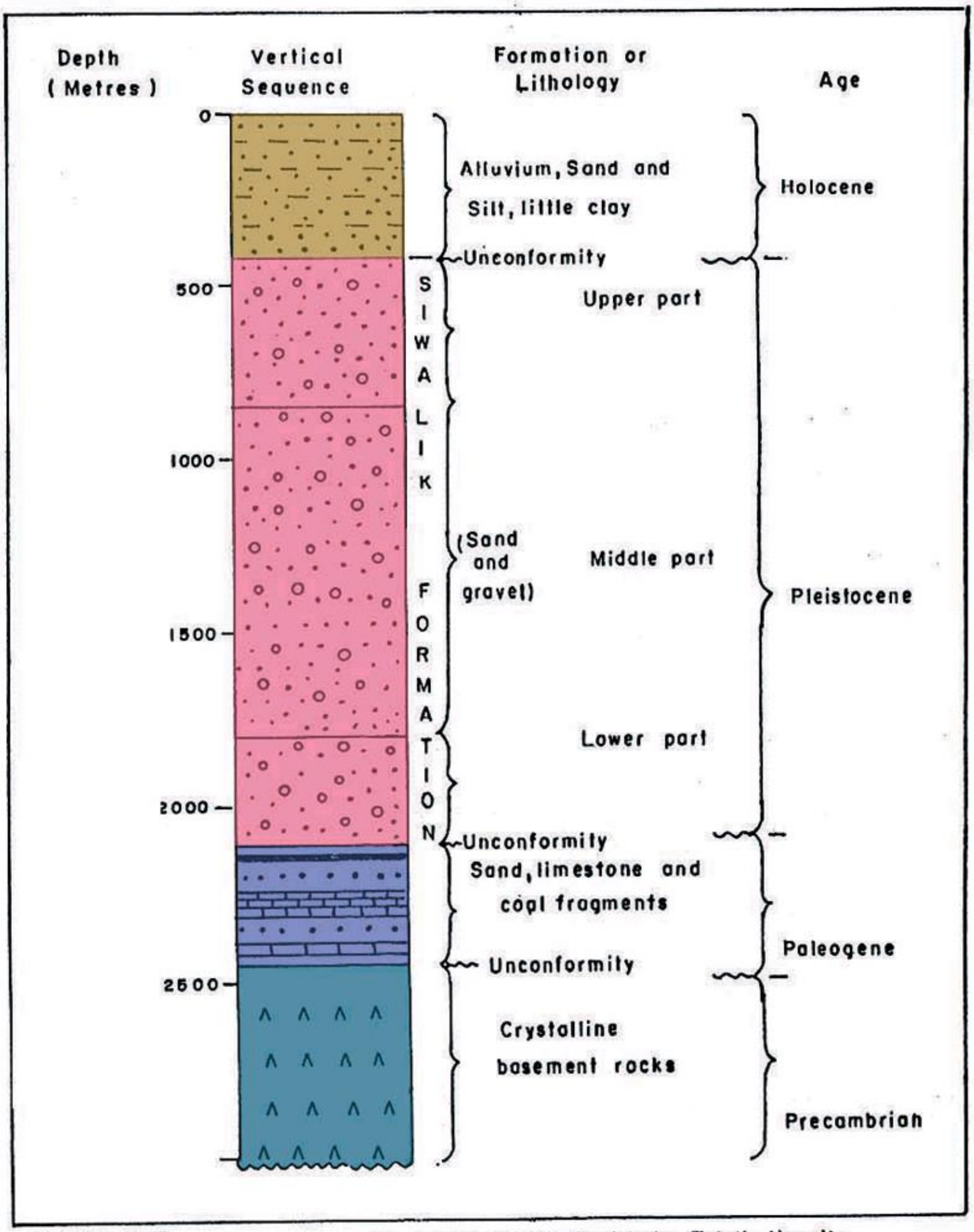

Fig. 3.5 Lithologic Column Showing Sediments Penetrated in Salban Hat Test Hole, Tetulia Upazila, Panchagarh District.

periods towards the making of the large delta and one of the largest deep sea fan in the world. The modern delta is a complex combination of three deltas as well as a complex of fluvial cum tidal delta. Immense sedimentation took place in the GBM delta complex during the Cenozoic time and more than half of it was deposited during the Plio-

Pleistocene and Holocene time leading to the southward growth and development of the Bengal Delta. Discharge of great volume of sediments from the Himalayas and subsidence of the Bengal basin floor are the major cause of this huge sedimentation (Biswas, 1992).

3.2.2 The Quaternary Period is important in the history of the Bengal Basin as well as of the world. The mighty Himalayas took its present shape during this time. Also there were many ups and downs in the earth's climatic condition during this period (Fig 3.6 and 3.7). The old terraces (Pleistocene terraces) of Barind and Madhupur Tract area were also uplifted during this time.

3.3 Quaternary Stratigraphy

3.3.1 The Quaternary stratigraphy of the Bengal Basin has not been well studied. Main problem being paucity of marker beds that can be used as correlative datum for long distances as well as little availability of absolute ages. Four geomorphic and morphostratigraphic units e.g. the Tertiary Hills, the Pleistocene Uplands, the Tippera Surface and the Young Flood Plains and the Delta Surface have been identified by Morgan and McIntire (1959) in Bangladesh. Later, substantial amount of subsurface data have accumulated as a by product of drilling for ground water and oil and gas (Coulson, 1940; Biswas, 1963; Sengupta, 1966; Chaterjee et al, 1969; Deshmukh et al 1979). Tertiary subsurface record has been analysed in detail by geologists engaged in oil exploration and a dependable model of tectonics and sedimentation has emerged (Shamsuddin & Abdullah 1997; Sengupta 1966). But the Quaternary sequence has been subjected to sedimentological analysis only in very restricted areas (Biswas & Roy 1976), and the regional framework of sedimentation has not been worked out. Paleontological researches on the Quaternary of the Bengal Basin are limited in extent. Palynological studies of Chanda and Mukherjee (1969), Mallick (1969), Visnu Mittre & Gupta (1971) and Mukherjee 1971) on Kolkata peat and Islam and Tooley (1999) on Khulna peat have thrown some light on the Holocene ecology and vegetation history.

3.3.2 The base of the Quaternary is difficult to identify, but in many boreholes a sequence dominantly of clay and sand having saline formation water and locally containing microfossils have been assigned Upper Pleistocene age (Sengupta, 1966). In West Bengal two stratigraphic units capped by laterite or red-mottled soil profile have been established representing the basal units of the Quaternary column (Niogy and Mallick, 1973,

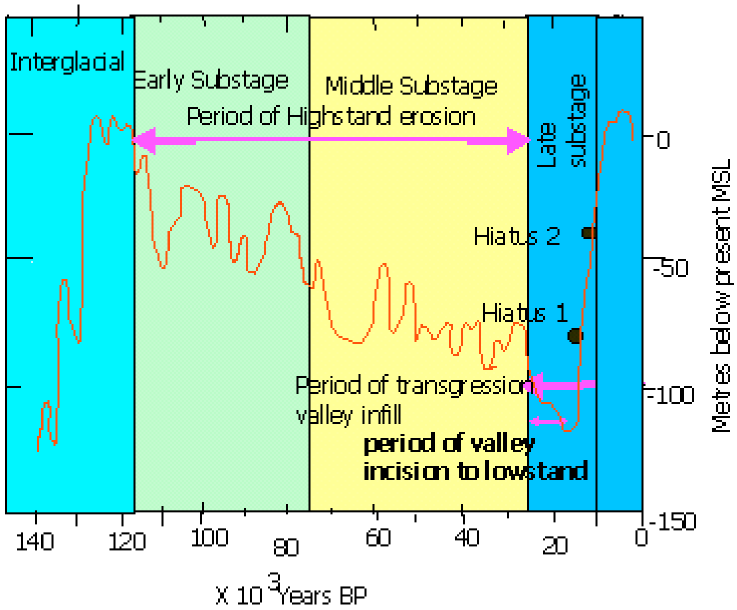

Fig. 3.6. Sea Level Changes During Last Interglacial Transition (After Pirazzoli, 1991)

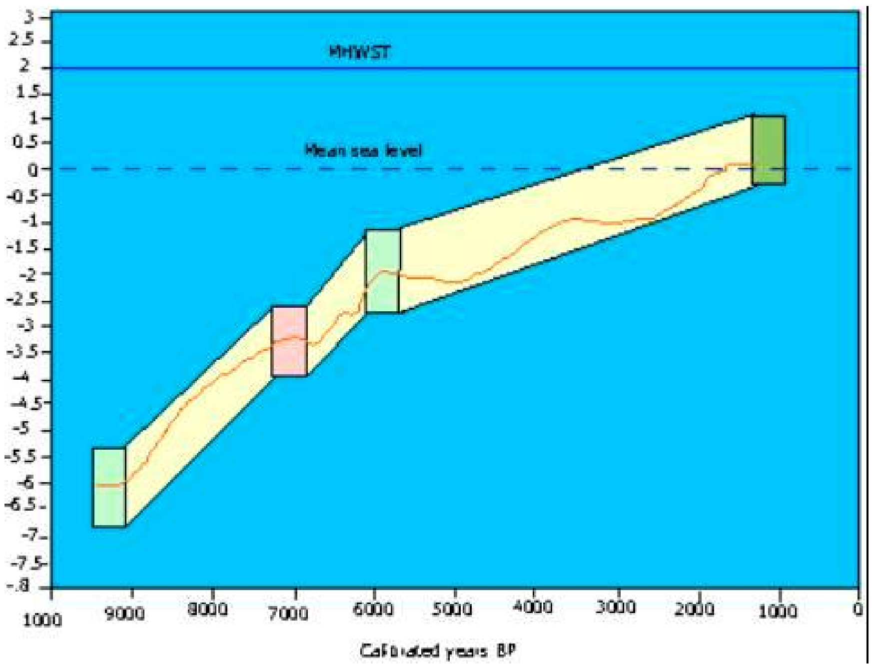

Fig. 3.7. A Sea Level Curve From Paniagati Based on the Age and Altitude of Radiocarbon Dated Samples , for Which Error Margins are Given. Within the Sea Level Band, Variations of The Curve are Derived From a Consideration of Changes in the Bio and Lithostratigraphy (After Islam and Tooley, 19991)

Bhatacharya and Banerjee 1979). Based on proximity of location, lithological organisational similarity, the Toba-Ash-Bed bearing basal Quaternary unit is tentatively correlated with the younger laterite topped Quaternary unit recognised in subsurface from the Western margin areas of the Bengal Basin (Acharyya et al 1999). In Bangladesh moderately oxidised Kalsi and Gouripur Beds, unconformably overlie the deeply oxidised deposits in the Mamhupur and Barind area respectively (Mansur 1995). The Gouripur and lower parts of Kalshi Beds have yielded reverse magnetic polarity corresponding to top of Matuyama Reverse Chron of 0.78 Ma, whereas, underlying and overlying formations show normal magnetic polarity (Mansur, 1995). Thus the Madhupur and Barind Tracts sediments broadly correspond to Early Pleistocene age (Mansur, 1995). The presence of Toba-Ash-Bed marker on top of the Pleistocene upland surfaces in West Bengal, India (Achryya and Basu 1993), Bangladesh (Abdullah and Hasan, 1991) and Bay of Bengal (Kudras et.al, 1999) indicates that these Pleistocene upland deposits are older than 75,000 years BP.

3.3.3 In Bangladesh the Pleistocene deposit is characterized by deeply oxidized paleosol. The surface exposures in the Madhupur and Barind areas, there is not much difference between the deposits. The Clay is characterized by red clay at the top and mottled clay at the bottom. The red clay is red to brick red and yellow, massive, contains ferruginous nodules and laterite. The clay contains minor amount of sand. The mottled clay is bluish to earthy gray with mottlings of red, brown, yellow and orange colours. The massive and sticky clay contains ferruginous nodules. The concentration of the nodules varies from place to place. The thickness of the mottled clay is variable but generally it is about 15 m. Depending on the degree of oxidation and hydration, the colour of the clay alters from red to yellow, orange and brown. The clay contains small amount of sand that does not appreciably reduce its high plasticity. The clay becomes soft and muddy in contacts with water and unlike other clay dries quickly and becomes very hard.

3.3.4 Plio-Pleistocene Dupi Tila sandstone underlies the Pleistocene Red Clay and the Late Pleistocene-Holocene alluvial deposits overlies the Pleistocene Red Clay. The bottom of the Pleistocene Clay (top of the Dupi Tila Sandstone) is very much undulated and marked by a prominent unconformity (Khan, 1991).

3.4 late Pleistocene-Holocene in Bengal Basin

3.4.1 Late Pleistocene-Holocene has been dealt separately in this report because most of the groundwater withdrawn in Bangladesh is from the aquifers belonging to the sediments of this period.

3.4.2 Late Pleistocene-Holocene Sedimentation and Sea Level Changes

3.4.2.1 In recent years attempts have been made to analyze the atmospheric circulation system on a planetary scale. The parameters which are considered necessary for working out a general circulation model (GCM) are : (1) land-sea coverage, (2) the albedo of the earth, (3) the ice cover on land and sea, (4) surface temperature of the sea. From an evaluation of these variables and the existing GCM, a model of the surface of the earth during 18,000 BP, i.e., during the peak of the last glaciation (Wisconsin) has been constructed (Climap, 1976; Gates, 1976). This global model has been tested with reference to local/regional records to improve the theory. In fact, several studies have been made in this direction in Australia (Webster & Streten, 1978) and Africa (Butzer et al., 1978). A coherent picture of geological, climatic and ecological changes in the Bengal Basin since the last glacial stage is not available. Information of varying degree of credibility is scattered in the literature of diverse disciplines. Poddar et al. (!993) attempted to describe the changes in geography and climate of the Bengal Basin since the last glacial stage. Niyogi (1975) presented a model of paleogeographic changes due to shifts in shoreline. The bathymetric map of the Bay of Bengal and the Indian Ocean indicates a sharp break in submarine topography at -200 contour. Submarine canyons and wedges of relict coarse clastics have been recorded in the shelf away from the mouth of the present rivers. On these grounds the -200 contour has also been assumed by Podder et al. (1993) to be the coast line during the last glacial maximum. The reconstructed land-sea configuration of the Bengal Basin during that time is shown in (Fig. 3.8). It shows that the landmass of the GBM Delta Complex extended into the Bay of Bengal for more than 200 km.

3.4.2.2 Sea-level changes during the Late Pleistocene-Holocene time influenced the geological processes of weathering, erosion and deposition of sediments. Various authors (Fairbridge, 1961; Pirzzoli, 1991, Acharyya, 1999) presented sea level changes curves.

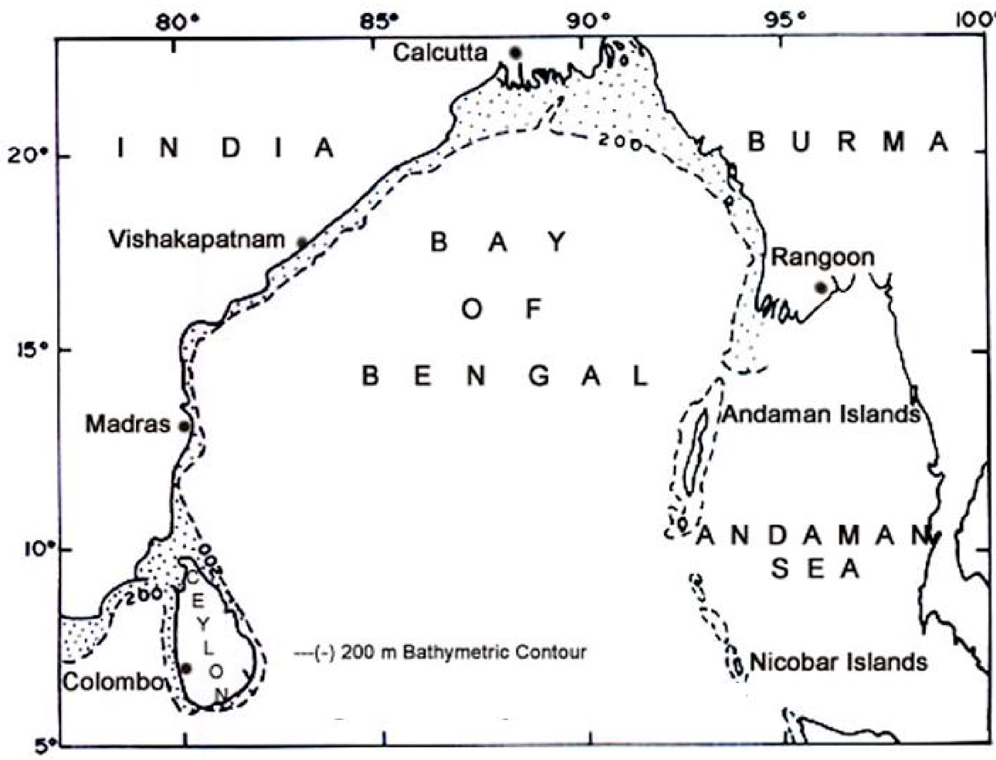

Fig. 3.8. Bathymetric Contour Map at Lowest Sea Level Stand (Podder et al. 1993)

The Late Pleistocene includes the last glacial-interglacial periods between 128 to 10 ka. (Fig. 3.6). The last glacial maximal was marked between 21 to 18 ka when the sea level was in the lowest stand. During the lowest stand of sea level the Pleistocene sediments were exposed, weathered and was eroded and incised by rivers. The basal sand and gravel bed found at different places of the Bengal Basin was deposited during this time in the incised channels of the proto Ganges-Brahmaputra rivers and flood plains. The sea level continued to rise from 18 ka to 12 ka resulting in transgression and onlapping of sedimentation and filling up of the entranced valleys by fluvial and or fluvio-deltaic sand with scattered gravel. From 12 to 10 ka there was a regression (sea level fall) and as a result the upper surface of these sediments were exposed to aerial oxidation (Umitsu, 1993 and Acharyya, 2000) in different parts of the country. BGS-DPHE (2001) mentions oxidized sediments from 45-70 meters depth in Faridpur and GSB (personal communication with Mr. Rashed Ekram Ali, 2002) indicates similar oxidized sediments from a number of drill holes at 45-50 meters in Bhola District.

3.4.2.3 From 10 to 6 ka, the sea level started rising again, and at ~6ka reached higher than 2 m than the present level. During this time there was an extensive development of marine and fresh water peat. After the post glacial optimum, the sea level dropped and initiated a phase of subdued marine regression and migration of shoreline to the present configuration. Islam and Tooley (1999) have recognized 5 transgressive phases in the Holocene sediments NW of Khulna City, each of which followed by a regressive phase.

3.4.3 Late Pleistocene-Holocene Stratigraphy

3.4.3.1 The red clay of the Early Pleistocene is overlain by the Late Pleistocene-Holocene alluvium deposits. In the Ganges-Brahmaputra-Meghna Delta complex, vertical and horizontal variations of the lithofacies in the Late Pleistocene-Holocene is very high (Fig. 3.9). It is difficult to correlate individual sediment layers from one place to another even at short distances. Inter fingering of the sediments are common. We must keep in mind that the Bengal Basin is one of the fastest subsiding regions of the world. The high rate of subsidence along with similar high rate of sediment deposition makes mapping of these units quite difficult. But the magnitude of the arsenic contamination of the ground water and time and necessity dictate that this problem is solved. Geologists of Bangladesh must initiate the work of detailed systematic mapping of these Late Pleistocene-Holocene sediments of the country.

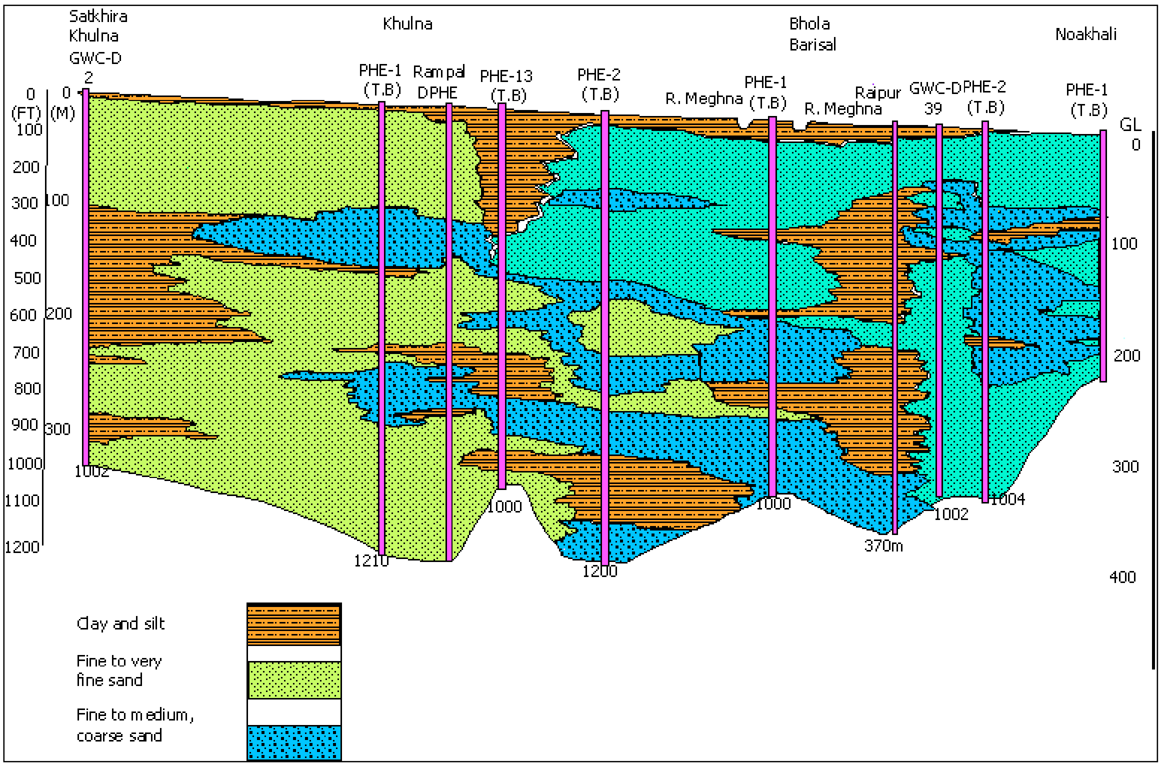

Fig. 3.9. Geological Cross Section Across the Coastal Area (E-W), (Source Aggarwal With Others, 2000)

3.4.3.2 The stratigraphy of the Late Pleistocene-Holocene sediments beneath the present Delta Surface has been mainly inferred from limited subsurface data (Fig. 3.10a,b). Based on generalised lithology inferred from ground water drilling and heavy mineral content, the subsurface sediments beneath the Younger Delta Plain from the northern and southern arsenic affected areas in Bhagirathi-Ganga flood-delta plains, West Bengal, have been tentatively classified into three broad stratigraphic zones (Deshmukh, et al., 1973; Biswas and Roy, 1976; Anon, 1999; Acharyya 1999). Most arseniferous tube wells generally tap the aquifers in Unit 2, which is dominantly made up of fine sand and clay, whereas, Unit 1 is coarse and sandy. A similar homotaxial sequence of five Holocene units has been established in Bangladesh from the Brahmaputra-Jamuna braided river floodplain and southern parts of the Present Delta Plain (Umitsu, 1993) (Fig. 3.10b).

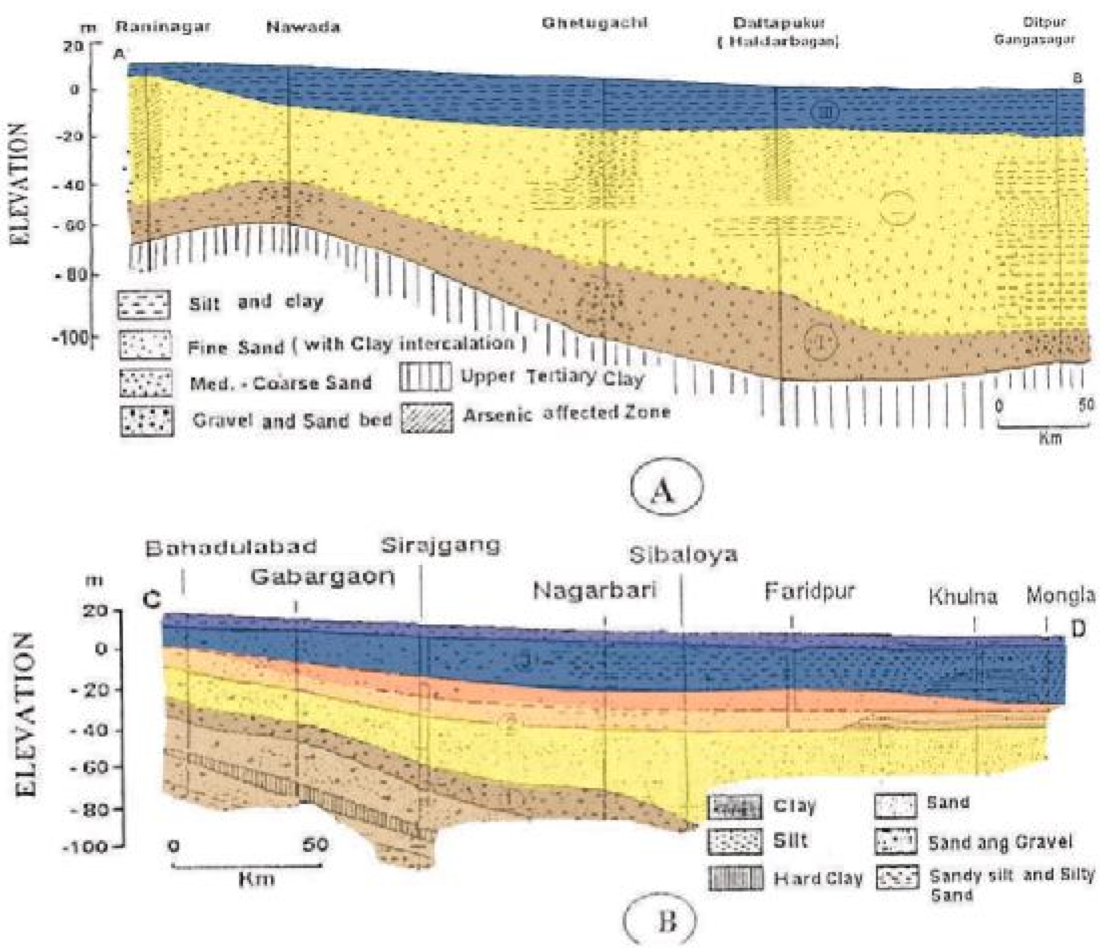

Fig. 3.10 a,b. Profiles of Holocene Sediments. A) Section A-B Across the Ganges Delta in West Bengal, B) Section C-D Across Jamuna Floodplains and Ganges Delta in Bangladesh. I-III and 1-3 are Broad Stratigraphic Units

3.4.3.3 C^{14} age of fossil wood from the basal part of Unit 1 from Brahmaputra-Jamuna floodplain yielded 48,000 and 28,000 BP respectively (Umitsu, 1993; Anon, 1999).

Organic matter from the uppermost part of Unit 1 at a depth of 48 m (46 m b.s.l.) from Khulna area, has yielded 12,300 BP. At Khulna, the thickness of Oxidised sediments at the top of Unit 1 is about 15 m. The top sandy section of Unit 1 is also oxidised at places in West Bengal (Poddar et al., 1993). Clay beds inter bedded with gravel and overlying a 6+ m medium grained sand bed from Digha, West Bengal located at the western boundary of Bengal Basin and on the present coast line has yielded an age of 22,360 BP (Hait et al., 1996). Likewise a similar sand bed with calcrets, silt and clay layers from Diamond Harbour in West Bengal has yielded an age of 14,460 BP (Hait et al., 1996). These beds may also be correlated to Unit 1 of Acharyya et al. (2000) (Fig. 3.10a)

3.4.3.4 These ages broadly corroborate that the basal sand with gravel unit, recorded from Brahmaputra-Jamuna floodplain and those in the present Active Delta, was deposited as entrenched valley fill/fan during the latest Pleistocene and earliest Holocene under prevailing low stand of sea level. On the other hand, Unit 3 ~7000 BP., and younger in age, from the Active Delta in Bangladesh and West Bengal part are lithologically similar and comparable. The uppermost unit often has extensive development of peat layers in the basal part in southern parts of the Active Delta in Bangladesh and West Bengal (Acharyya, 1999). The presence of typical estuarine sediments ranging from swampy mangrove to tidal mangrove in brackish to fresh water mixed sediments is recorded by Banerjee and Sen (1987) from Bhagirathi delta, West Bengal. These sediments occur at 7 m to 2 m b.s.l. depth and are located in areas 80 to 120 km inward from the present sea shore. Based on C^{14} dates these high stand sea-level sediments are tentatively dated 7,000 to 6,000 BP There was widespread development of marine and fresh water peat layers around Kolkata during 6,500 to 2,000 BP (Banerjee & Sen, 1987). Islam and Tooley (1999) also mentions such peat developments around Khulna in Bangladesh. Aquifers in this unit are also arsenic contaminated.

3.4.3.5 Thus the middle unit that contains most of the arsenic contaminated aquifers from Bangladesh and West Bengal is also broadly correlated. Based on C^{14} ages from organic matters from various levels of Unit 2 and base of Unit 3, the age of Unit 2 has been broadly inferred to be 10,000 - 7,000 BP (Umitsu, 1993; Hait et al., 1996). This is also supported by Nelson and Bray (1970). From the cores at Khulna, fossil mollusks and marine planktonic diatoms recorded from depths ranges of 20 - 30 m from Unit 2 nearly covering the entire unit indicate relatively strong marine influence. Thus the coast line of the delta was located to the north of Khulna and Kolkata during deposition of the highly arsenic contaminated Unit 2.

3.4.3.6 Some of the available absolute age dates from different parts of the Bengal Basin are given in table 3.2.

Table 3.2 Showing Some Absolute Age Dates From Different Parts of Bengal Basin

Name of the place	Type sample and depth	Age of the sample	Remarks
Kharampur; Near Akhaura Railway station ($91^{0}13^{/}$E & $23^{0}52^{/}$N)	Peat (Top bed); Peat (Bottm bed) 1-2 m below surface	5580+/- 75BP 5620+/-75 BP	Hasan, 1986 Chandina deltaic plain;
Kachpur (near Dhaka city) ($90^{0}30^{/}$ & $23^{0}41^{/}$)	Peat (top layer), 0.5 m below surface Peat (lower layer) Peat (lower layer), 2.5 -3.0 m below the surface	3670+/-60 BP 6060+/-75 BP 6460+/-80 Bp	Two dipping beds on the top of red clay
Near Kachpur (Dhaka)	Peat (at the top of red clay) ~4m below surface	6390+/-80BP	Hasan 1986
Eastern Dhaka	Peat layers from Bashabo Formation	4040 +/-70 to 1278 ?+/- 140 BP	Monsur,1994
Sirajganj	Wood	28,300 BP	JICA (1976)
Brahmaputra-Jamuna Floodplain	Fossil wood from basal part of unit 1	48,500 and 28,300 BP	Umitsu, 1999
Khulna area; southern part of Ganges delta	Organic matter from uppermost part of unit -1 at 48 m.	12,300 BP	Do
Dighia, western boundary of Bengal Basin	Clay beds interbedded with gravel. Top 6 m medium sand	22,360 BP	Hait, et al 1996
Diamond harbour	Sand beds with calcrets silt and clay	14, 460 BP	Hait etal 1996
In between Madhupur and Barind tracts	Upper Unit coarse sand to micaceous silt 26 m 32 m lower unit 62 m	 6,400 BP 6290 BP >48,500 BP	Davies and Exley, 1992
Faridpur DPHE/BGS Test bore hole	6.2 m Micaceous silt 9.2m and fine sand 9.8m 10.2m 44.5m Peaty clay 55.2m Med. F. sand 73.2m basal coarse sand 91.4m & gravel 125m c. sand & gravel	106.6+/-.58 3085+/-50 960+/-45 855+/-45 8260+/-75 11890+/-80 18560+/-130 22690+/-190 9925+/-70	BGS-DPHE, 2001 Brown med. to fine sand at 134 to 155 m
Laxmipur Test bore hole (LPW-6)	10.7 m Intertidal thin micaceous silt with v. fine sands with peat 35 m Fluvial M - fine & M. sand 38.7 m Do 46.3 m Do 73.2 m Do 91.7 m Do 116.10 m Micaceous clay & silt aquiclude 137.5 m Silty fine to M. sand inter bedded with med. to coarse sand	 110+/-0.58 6920+/-50 10020+/-85 9155+/-70 8855+/70 11320+/-75 6525+/60 12585+/-95	BGS-DPHE (2001)

3.4.4 Proposed Divisions of the late Pleistocene-Holocene in Bangladesh

3.4.4.1 A proposal to map the Late Pleistocene-Holocene sediments based on their deposition during their transgressive and regressive phases of the sea level changes is presented in this report. Umitsu (1993) divided the Late Pleistocene-Holocene sediments in the Brahmaputra-Jamuna floodplain and the southwestern part of the Active Delta Plain in Bangladesh into 5 members on the basis upward coarsening or fining of grain size. These five members have been broadly divided into Lower, Middle and Upper members by Acharrya et.al (2000) in West Bengal and southern part of Bangladesh.(Fig. 3.10a). BGS-DPHE (2001) also divided these sediments into 3 major units. Considering all the above, three major divisions of the Late Pleistocene-Holocene sediments are proposed in the report and a proposal to map the Late Pleistocene-Holocene sediments based on their deposition during the transgressive and regressive phases of the sea level changes is presented below. These suggested divisions have been shown in Table 3.3.

3.4.4.2 Following is a brief description of the proposed divisions of the Late Pleistocene-Holocene sediments in the floodplain and the deltaic regions of Bangladesh. It must be remembered that these divisions are made on the basis of lithological variations in the almost continuous cyclic deposits of fluvio-deltaic sediments with occasional shallow marine and or tidal deposits. Each individual sand, silt or clay layer may not continue for long distances (even for kilometers) but the divisions are made on the basis of depositional nature of a zone in the sediment column. The boundaries among the divisions are not easily recognisable. Though some sedimentological studies have been done in West Bengal, India such studies are rare in Bangladesh. Bio-stratigraphic work based on palynofacies studies is also rare. Scarcity of absolute age dates has already been mentioned earlier. Number of workers both in Bangladesh and West Bengal, India have recognised the sediments of the transgressive and the regressive phases of the thick Late Pleistocene-Holocene sediment column. Most workers have also acknowledged the three divisions of the Late Pleistocene-Holocene sediments.

Table 3.3. Comparative Divisions of the Late Pleistocene-Holocene Sediments in Bangladesh and West Bengal

Proposed divisions	West Bengal & Southern Bangladesh (Acharyya et al, 2000)	Bangladesh (Umitsu, 1993)	BGS-DPHE report Bangladesh (2001)
Upper Holocene	Unit I : fine sand clay, peaty material	Upper most Unit: (5/6-0 ka); fine silt and clay, peaty material	
Middle Holocene Wide spread peat layers at the upper part.		Upper Unit: (10/8-5/6 ka); fine sand and silt at bottom and upper, coarser at middle	18-5ka: Rapid base level rise; Upward finings; Coarse sediments at the bottom and fine upwards.
	Unit II (10-7k); fine to medium sand with clay intercalations	Middle Unit: (12-10ka); coarse sand, silt in the upper, fine sand, silt and clay at the bottom	
Late-Pleistocene-Early Holocene Gravel Bed at the bottom, upper Part oxidized.		Lower Unit:(12-18ka); Sand with scattered gravel; upper part oxidized	
	Unit III (23.37 ka*); Sand with scattered gravel	Lower most Unit:(~18 ka); gravel bed, ~ 10 m thick	21-18ka; Lowest strand of sea level; Coarse material deposition
			28-21 ka: Rapid fall in base level; Rapid valley incision. Coarse sediment deposition.
Older			128-28 ka: steady decline of sea level. Slow erosion

* Hait & others, 1996

3.4.4.3 Bangladesh face the greatest environment problem in the history because of arsenic contamination of its vast ground water resources. A relationship between the arsenic contamination and the geological history of the sediments are gradually becoming clear. This make it essential that geologists in Bangladesh must give all their efforts for detailed sedimentological, mineralogical, biological including trace fossils studies backed by absolute age dating by C^{14} and all other isotopic studies to describe the boundaries of these divisions for easy recognition by all concerned engaged in ground water studies or development.

3.4.4.4 Late Pleistocene –Early Holocene (18 –10 ka) is recognized by the basal gravel bed with an average thickness of 10 meter. This gravel bed has a gradient of 3/10,000 towards south. This bed was deposited in valleys/fan during the lowest strand of sea level during the Late Pleistocene-Early Holocene. During this time the sea level decreased to ~ 135 m at approximately 18000 years BP (after that there was a sea level rise up to 12 ka and again declined up to 10 ka.). At that time (18 ka) the shoreline was at the outer margin of the continental shelf and Pleistocene and Tertiary sediments were subjected to aerial erosion (Acharrya, et al. 2000). The basal gravel and sand was not uniformly developed as it was developed in the valleys/fan. The depth of gravel bed varies from place to place. (Generally it is within 18m to 100m). A regression of the sea occurred between 12,000 and 10,000 years BP. The Upper part (lower member of Umitsu) is composed of coarse sand with scattered gravels. The coarser sediments are more in the upper reaches. The top of the upper part is weathered and oxidized up to a depth of 15 meters which implies that the sea level was at least 10 meter lower during this time (10-12 ka).

The basal gravel bed mark the bottom surface of the Late Pleistocene-Early Holocene and the upper surface is formed of the oxidized sediment layer.

3.4.4.5 Middle Holocene (**10-6 ka**): The period beginning with 10,000 years marked an important change in the sedimentation in the Ganges Delta. Rapid sea level rise marked the initiation and growth of deltaic sedimentation. After that there was a transgression (rise in sea level occurred from 10,000 –6000 ka). Early-Mid Holocene transgressions led to back flooding and over-topping of the entrenched alluvial channels that were formed during low-stand setting. High sediment load from the rapidly eroding Himalayas and intense precipitation competed with rapid sea-level rise to continue sluggish deltaic sedimentation over entrenched valley fills and adjacent floodplains, marshes, lagoons and estuaries. The Middle Holocene sediments are characterized by lenticular sand bodies with clay, silt and peat layers that were developed in a transgressive phase of the sea level. Carbon^{14} dating show that much of the peat layers were most probably deposited during a high stand of sea level (about 2 meters above the present level) at around 6 ka. The Middle Holocene sediments can be correlated with the Upper and Middle Unit of Umitsu (1993). It may be possible to map the boundary between the Middle and Upper Holocene by widespread peat layers (6000 years BP) developed at that time. The oxidized zone at the bottom and large-scale development of peat at the top may be used to map this unit.

3.4.4.6 The Upper Holocene started from the 6 ka and continues till the present time. The Upper Holocene sediments are recognized by the interlayered/interfingered silt, clay and fine sand which forms the upper most part of the sedimentary column of the delta and the recent flood plains of the GBM Delta Complex. Upper Holocene sediments are not found in the slightly uplifted parts of the delta such as the Chandina Formaion (Tippera Surface and equivalent). The sea level started to fall from ~6000 years BP and is continuing to fall.

3.4.4.7 Developing standardized composite sections of the above divisions of the Late Pleistocene-Holocene sediments is a great challenge for the geologists working in the GBM delta complex. In Europe also they faced similar challenges regarding the Pleistocene-Holocene glacial sediments during the early twentieth century, and it took them about fifty years to solve these problems. But with the development of modern dating techniques (C^{14} and other isotopic) available, we expect that this work can be done in less than a decade. Sooner the work is initiated earlier it will be solved.

CHAPTER IV

Aquifer Systems of Bangladesh

4.1 Introduction

4.1.1 In Bangladesh thick semi-consolidated to unconsolidated fluvio-deltaic sediments of Miocene to the present have many aquifers. But except the Dupi Tila Sandstone Formation of the Plio-Pleistocene age, others are too deep to consider for ground water extraction except in the Hilly Region of the country (18% of Bangladesh). Most of the ground water withdrawn for domestic or agricultural purposes in the Barind and Madhupur Uplands areas are from the Dupi Tila Sandstone. Parts of the Tista Fan area in Northern Bangladesh (Himalyan Foredeep and the Rangpur Platform) in Fig. 2.2 and the Piedmont area along a narrow strip of the hills of the greater Mymensingh and Sylhet districts also withdraw all water from sediments older than Late Pleistocene. Water withdrawn from these formations are not yet contaminated by arsenic.

4.1.2 The floodplains of the major rivers and the active/inactive delta plain of the GBM Delta Complex occupy 82% of the country. In these regions major aquifer systems belongs to the Late Pleistocene to Holocene sediments. The sedimentation history of this period has been discussed in Chapter 3. From the present available subsurface geological information it appears that most of the good aquifers of the country occur between 30 to 130 m depth. As discussed before, these sediments are cyclic deposits of mostly medium to fine sand, silt and clay. The individual layers cannot be traced for long distances both horizontally or vertically. All the sand or silt layers can be considered as aquifers of limited extent. In such cases, instead of individual layers a zone with identifiable characteristics are generally taken for classification of sediments as well as aquifers.

4.1.3 In all the groundwater studies undertaken in Bangladesh, the aquifer systems have not been divided stratigraphically. Conceptual models of hydro-geological conditions, based on simple lithology and depth rather than stratigraphic units, have been used to assess the engineering and hydraulic properties of aquifers and deep tube well designs to depths of 150 m. The reason being that very little work has been done on the sedimentation history of Late Pleistocene-Holocene in Bangladesh.

4.1.4 UNDP (1982) study classified the aquifers into three zones. These are the 1) Upper Shallower or the Composite Aquifer, 2) Main Aquifer, and 3) Deep Aquifer. Greater part of the country except Dhaka and the coastal area generally was divided into these three zones from a study of the lithologic section up to a depth of 137 m from the existing tube well logs : Upper clay and silt; Silty to fine sand; and Medium to coarse grained sand and gravel. This study also divided the country into 15 hydrogeological zones on the basis of the geological factors, aquifer characteristics and development constrains. These 15 zones have different potentialities for the development of groundwater (Fig. 4.1). Summary of the aquifer characteristics in these zones are given in Annex-II (Table A4.1). The extensive geological analysis presented in Technical Report 4, MPO (1987) classified the main aquifer into 36 units (Fig. 4.2). These are described briefly in Annex-II (Table 4.2). A more flexible two-tier classification was presented by EPC/MMP (1991). Aggarwal et al. (2000) (Fig. 4.3) on the basis of isotopic studies classified the water at different depths in four types and made a three-tier division of the aquifers. BGS-BWDB (1999) and BGS-DPHE (2001) (Fig. 4.4), with slight adjustments of the UNDP (1982) study also made a three-tier classification of the aquifers zones. A comparative picture showing these divisions are presented in the table below: -

UNDP, 1982		DFID, 2001		Aggarwal & Others, 2001	
i)	Upper aquifer (composite aquifers)	i)	Upper Shallow	i)	1st aquifer (Type 1 & 2)
ii)	Main aquifer	ii)	Lower Shallow	ii)	2nd aquifer (Type 3)
iii)	Deep aquifer	iii)	Deep Aquifer	iii)	3rd aquifer (Type 4)

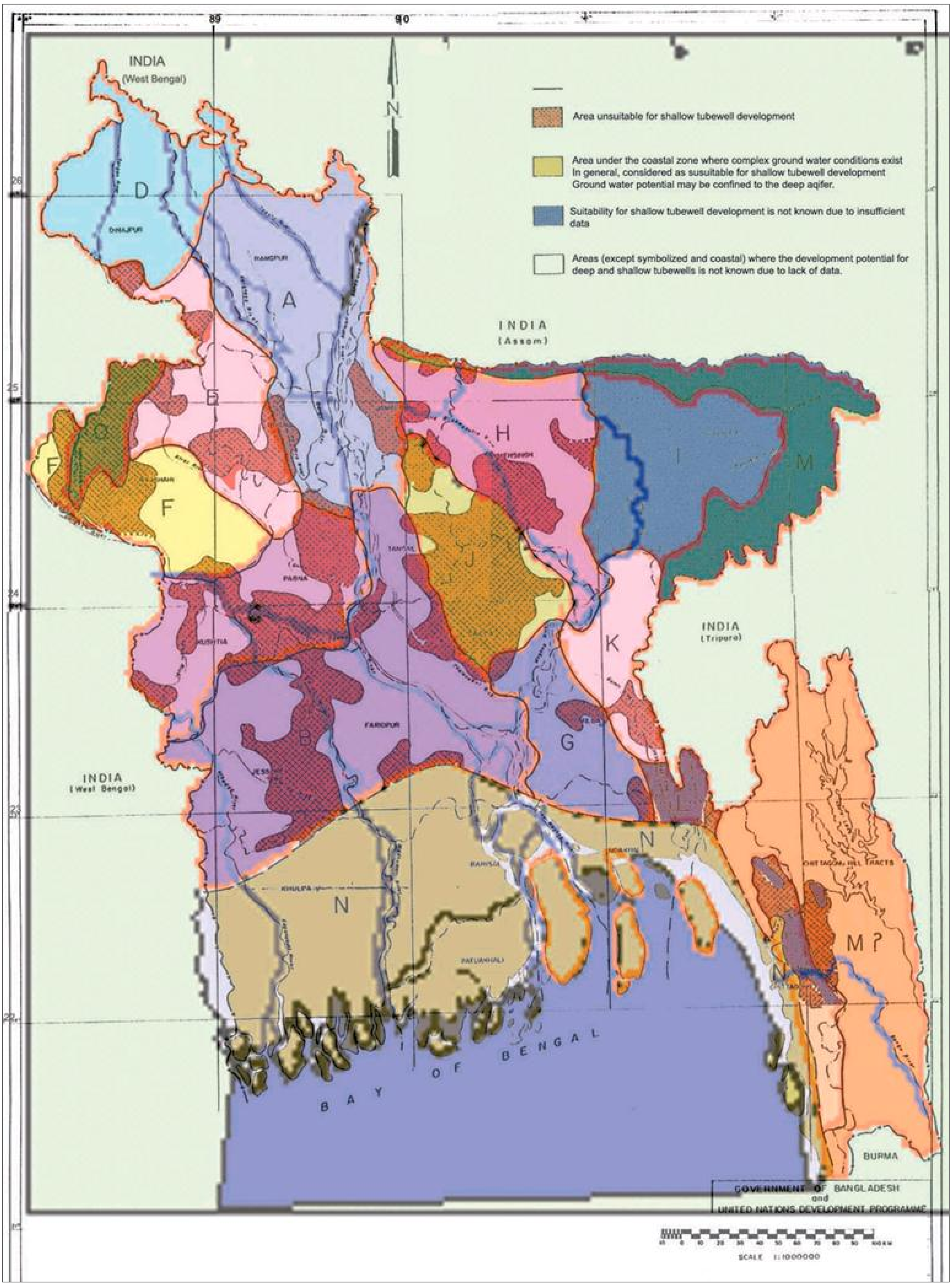

Fig. 4.1 Groundwater Development Zones (UNDP, 1982)

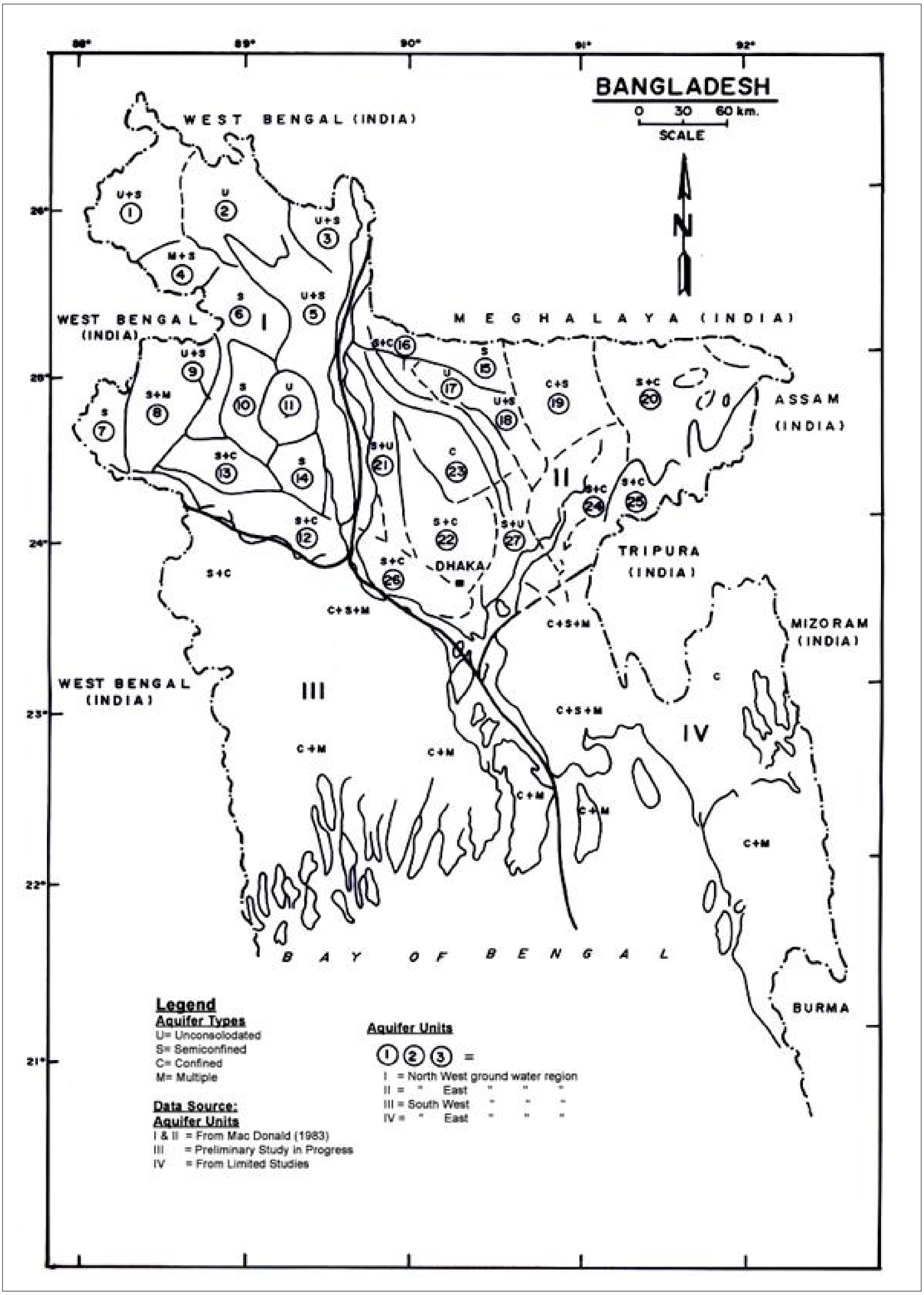

Fig. 4.2 Regional Aquifer Types (MPO, 1987)

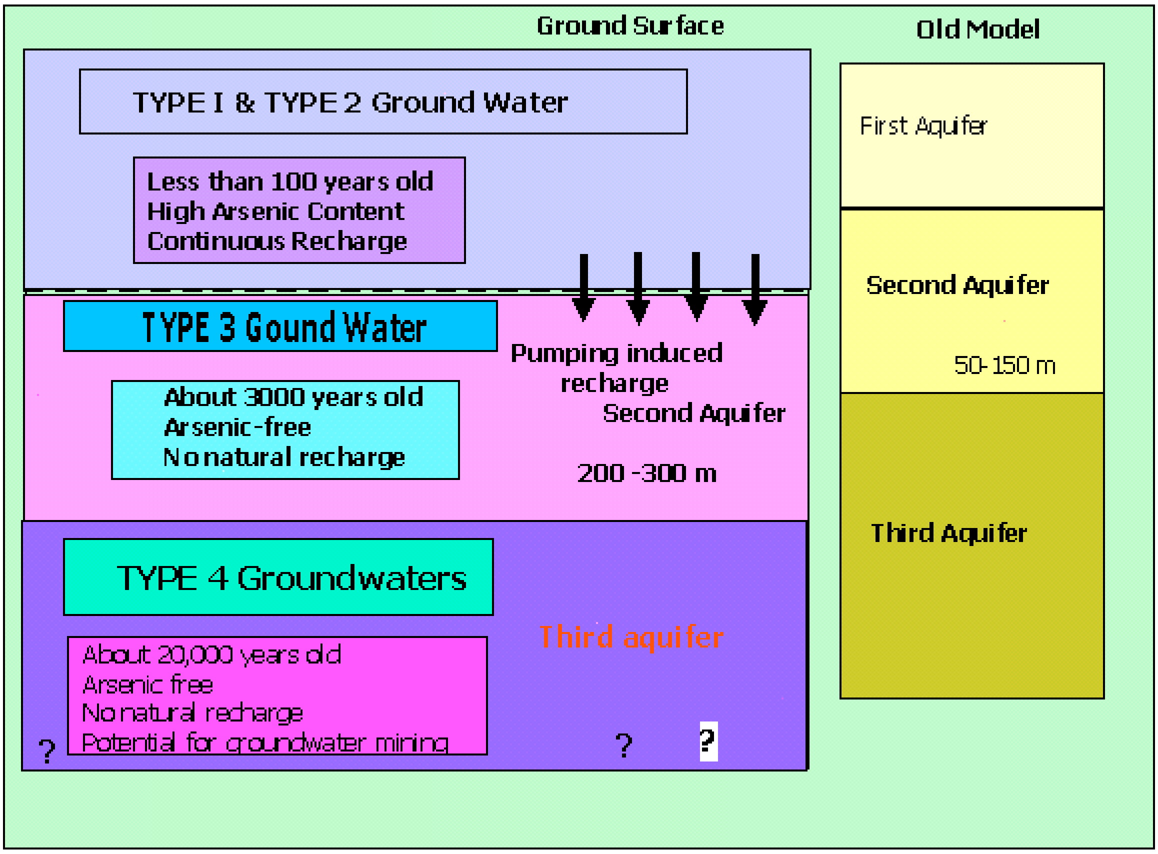

Fig. 4.3 Revised Hydro-geological Model Based on Isotopic and Hydro-chemical Data (Aggarwal, 2000)

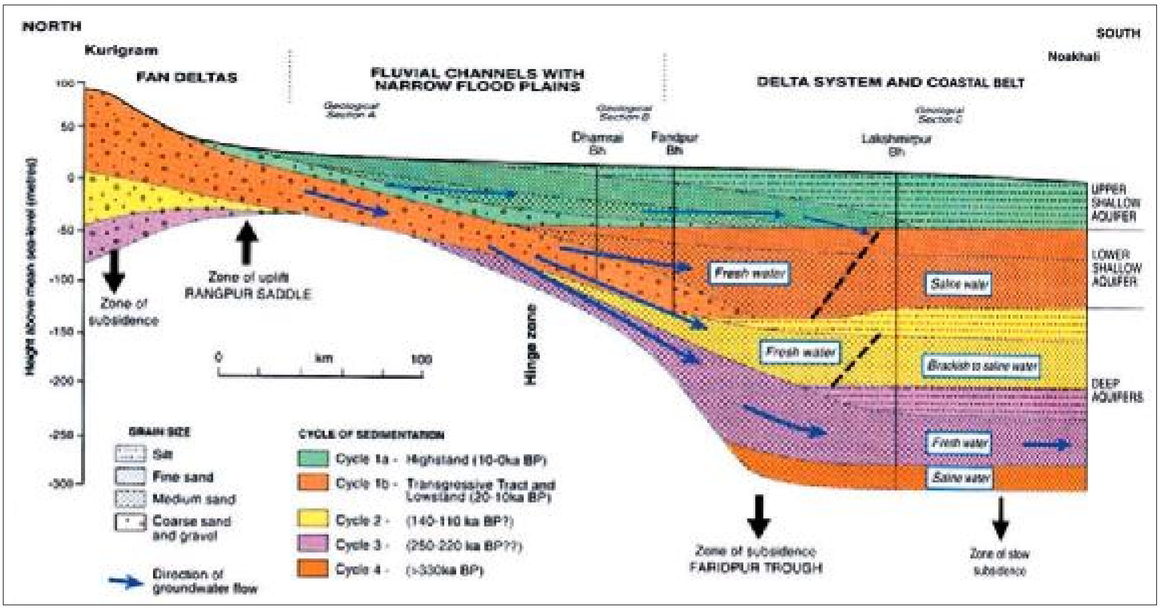

Fig. 4.4 Hydro-geological Cross-section From North to South Across Bangladesh. Particularly Shown are the Geological Structures and Groundwater Flow Patterns Within Mid-Upper Quaternary Sediments (BGS-DPHE, 2001).

4.2 The upper (shallower) or the composite aquifer

4.2.1 Below the upper clay and silt unit of depth ranging from less than a meters to several hundred meters, very fine to fine sand, in places inter bedded or mixed with medium sand of very thin layers are commonly encountered. Discontinuous thin clay layers often separate these sand layers. The thickness of this zone ranges from a few meters in the northwest to a maximum of 60 m in the south. Over most of the country it represents the uppermost water bearing zone. In the coastal region water in this aquifer zone is saline with occasional fresh water pockets.

4.3 The main aquifer

4.3.1 This is the main water bearing zone and occurs at depths ranging from less than 5 m in the north-west to more than 75 m in the south and most of the country. It is either semi-confined and leaky or consists of stratified interconnected, unconfined water bearing zones. This aquifer is comprised of medium and coarse grained sediments, in places inter bedded with gravel. These sediments occur to depths of about 140 m below ground surface. Presently, groundwater is drawn predominantly from this aquifer zone.

4.4 The deeper aquifer

4.4.1 The deeper unit is separated from the overlying main aquifer by one or more clay layers of varied thickness and extent. Deep aquifers are generally based on depth and in some areas include those aquifers whose waters have no access vertically upward and downward but flow very slowly along the dips and slopes of the aquifers. This water bearing zone comprises of medium to coarse sand, in places inter-bedded with fine sand, silt and clay. At present water bearing formation deeper than 150-200 m are being exploited on limited quantity in the coastal zone to cater the need of municipal water supply and in the rural areas for drinking purpose. Large scale extraction has not been encouraged in the coastal areas due to possibility of sea-water intrusion or leakage from the upper aquifer.

4.4.2 Unfortunately all the above classifications do not take into account the sedimentological parameters or the depositional history of the aquifer sediments. Till now the aquifers of the delta plain and the flood plains of the GBM Delta Complex have been divided on the basis of depth. But it is a well established fact that the sedimentation rate and subsidence in the whole of the Bengal Basin were not uniform throughout the

Quaternary. Due to neo-tectonic activity the delta was segmented into several blocks that subsided or uplifted at different rates in relation to one another. As such, sediments of very different nature or of different geological age can be found at similar depths. The JICA (2002) study states that, "the definition of shallow aquifer and deep aquifer is not clear due to the difference of hydrogeological conditions by place to place. It is said that the shallow aquifer and deep aquifer is bounded by an aquitard at a depth of 150m in central Bangladesh, but the boundary is located more deep portion in the southern coastal districts". Considering the above facts, an attempt has been made to divide the aquifer systems in the GBM Delta Complex from a geological point of view i.e. in line with the proposed divisions of the Late Pleistocene-Holocene sediments (Fig. 4.5). This seems to be comparatively more logical than the conventional divisions based only on depth. The major divisions in this classification will be:

1) Plio-Pleistocene Aquifers
2) Late Pleistocene-Holocene Aquifers
    a) Late Pleistocene-Early Holocene Aquifers
    b) Middle Holocene Aquifers
    c) Upper Holocene Aquifers

4.4.3 These divisions are matched with the sedimentary units of the Quaternary in the GBM Delta Complex as discussed in Chapter III (Table 3.3)

4.5 The Plio-Pleistocne Aquifers

4.5.1 The Plio-Pleistocene Aquifers of the Dupi Tila Formation lies beneath the Pleistocene Madhupur Clay Formation. This aquifer is composed of light gray to yellowish brown, medium to coarse sand with pebble beds. All of the water for Dhaka City is withdrawn from this aquifer but the water is as yet arsenic safe. This aquifer is confined to semi-confined.

4.6 The Late Pleistocene-Early Holocene Aquifers

4.6.1 The Late Pleistocene-Early Holocene Aquifers are not continuous all over the country. This to some extent corresponds to the Deep Aquifer of UNDP study (1982), lower part of the Deep Aquifer of the BGS-DPHE study (2001) and the Third Aquifer of Aggarwal et. al. (2000). Aggarwal et al. has dated water from this aquifer as about 20,000 years old. The sediments of this aquifer to some extent correspond to the Late

Pleistocene-Early Holocene Unit of the sediment section. Water within this aquifer is found to be arsenic safe but heavy withdrawal from this aquifer needs further study.

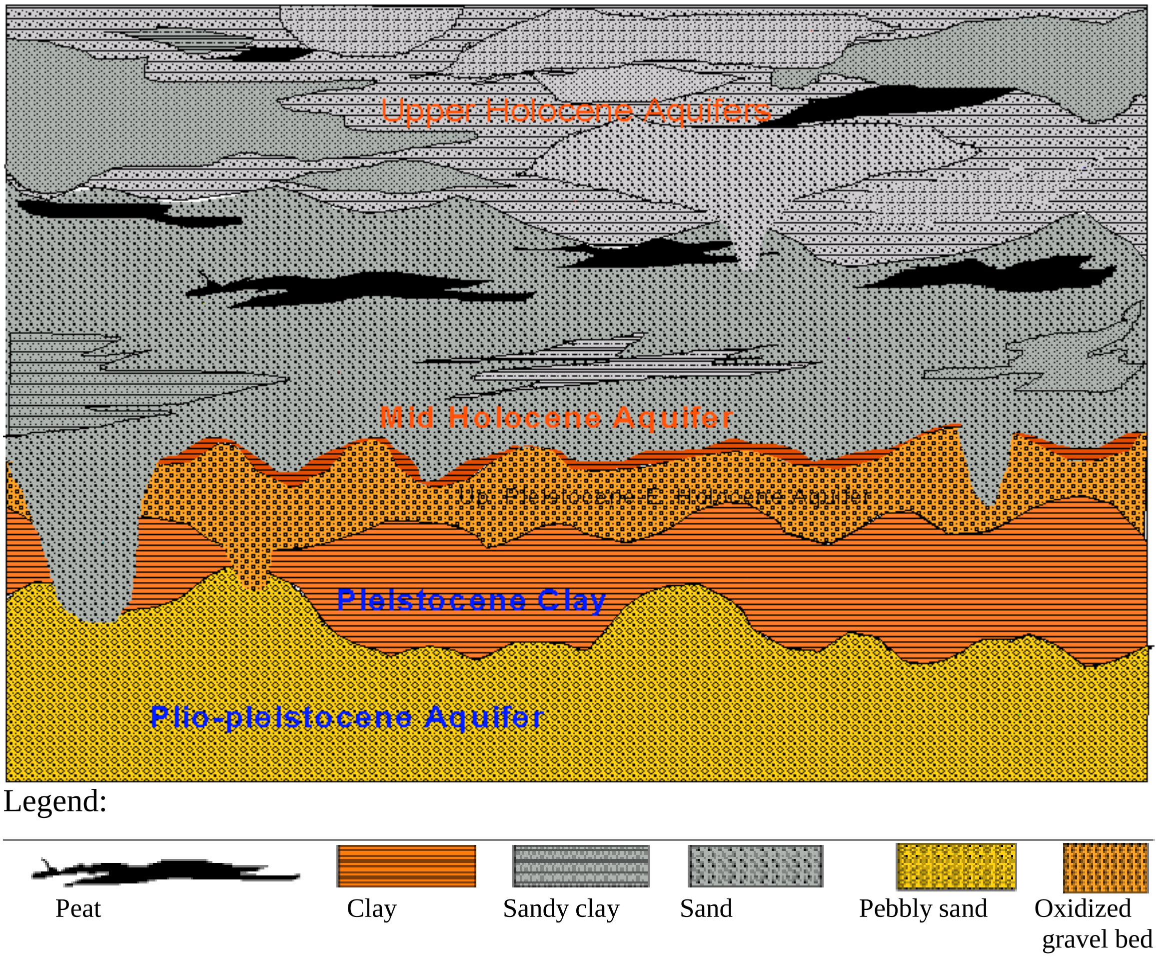

Fig. 4.5 Schematic Diagram of The Aquifers on Geological Point of View. (Islam And Uddin, 2002)

4.7 Middle Holocene Aquifers

4.7.1 Above the Late Pleistocene-Early Holocene Aquifer lies the fine sand which becomes coarser in the upper part. This sandy sequence varies greatly both vertically and horizontally. The upper part also contains silt and peaty organic matters. These Mid-Holocene Aquifers may be considered as in a similar position in the geological section as the Main Aquifer (UNDP, 1982), the Second Aquifer (Aggarwal et. al., 2000) or the Lower Shallow Aquifer (BGS-DPHE, 2001) in the floodplain and deltaic areas of Bangladesh. Aggarwal et al. (2000) dated water from this aquifer as about 3000 years old. Most of the ground water in Bangladesh is withdrawn from this aquifer and the water is severely affected by arsenic contamination.

4.7.2 The sediment from the surface samples in the Chandina Formation areas (Tippera Surface) dates around 6,000 ka. In this area the Middle Holocene aquifer will be encountered nearest to the surface, but in most of the river basin and the delta plain areas this will be at different depths.

4.8 Upper Holocene Aquifers

4.8.1 The Upper Holocene Aquifers are developed all over the deltaic and flood plain areas. This does not occur in the Chandina Formation areas (Tippera Surface). The lower part is composed of silt and clay at the bottom, and fine sand at the top. The upper part is composed of silt and clay, and is commonly found to be inter-bedded or mixed with medium sand. In UNDP (1982) classification this aquifer is mentioned as Upper Composite Aquifer, in BGS-DPHE (2001) report it is considered as Upper Shallow Aquifers and Aggarwal et al. mentions it as the First Aquifer. Aggarwal et al. dated water from this aquifer as about 100 years old. Water of this Upper Aquifer is also affected by arsenic contamination.

4.8.2 Each of the Holocene aquifers contains a number of sand layers/lenses that are stacked and interconnected, which makes them of leaky type from which the contamination spread vertically from one place to another (Fig. 4.5).

4.8.3 Government of Bangladesh is giving top priority to the issue of arsenic contamination of the groundwater. Detailed mapping of the aquifer systems from the geological point of view can help in the planning for systematic withdrawal of arsenic free groundwater. This new approach need coordinated integrated works of detailed lithofacies and palynofacies analyses and, age dating of the sediments and water along with shallow geophysical surveys in the different geological districts of Bangladesh.

4.9 Aquifer Characteristics

4.9.1 BGS-DPHE study (2001) has compiled most of the data on the aquifer systems and their characteristics available till 1999 in detail. This report does not like to repeat them. The locations of the main aquifers in Bangladesh is indicated by the distribution of average transmissivities (Fig. 4.6). The characteristics of the different aquifer systems collected from different sources are given in tabular form in Annex - II (Tables A.4.1 to A 4.18). But the work done so far is not sufficient for most areas of Bangladesh. Detailed work as done by JICA (2002) in three upazilas of Chuadanga, Jenaidah, and Jessore districts should be undertaken in each district of Bangladesh for any plan for withdrawal of ground water in future.

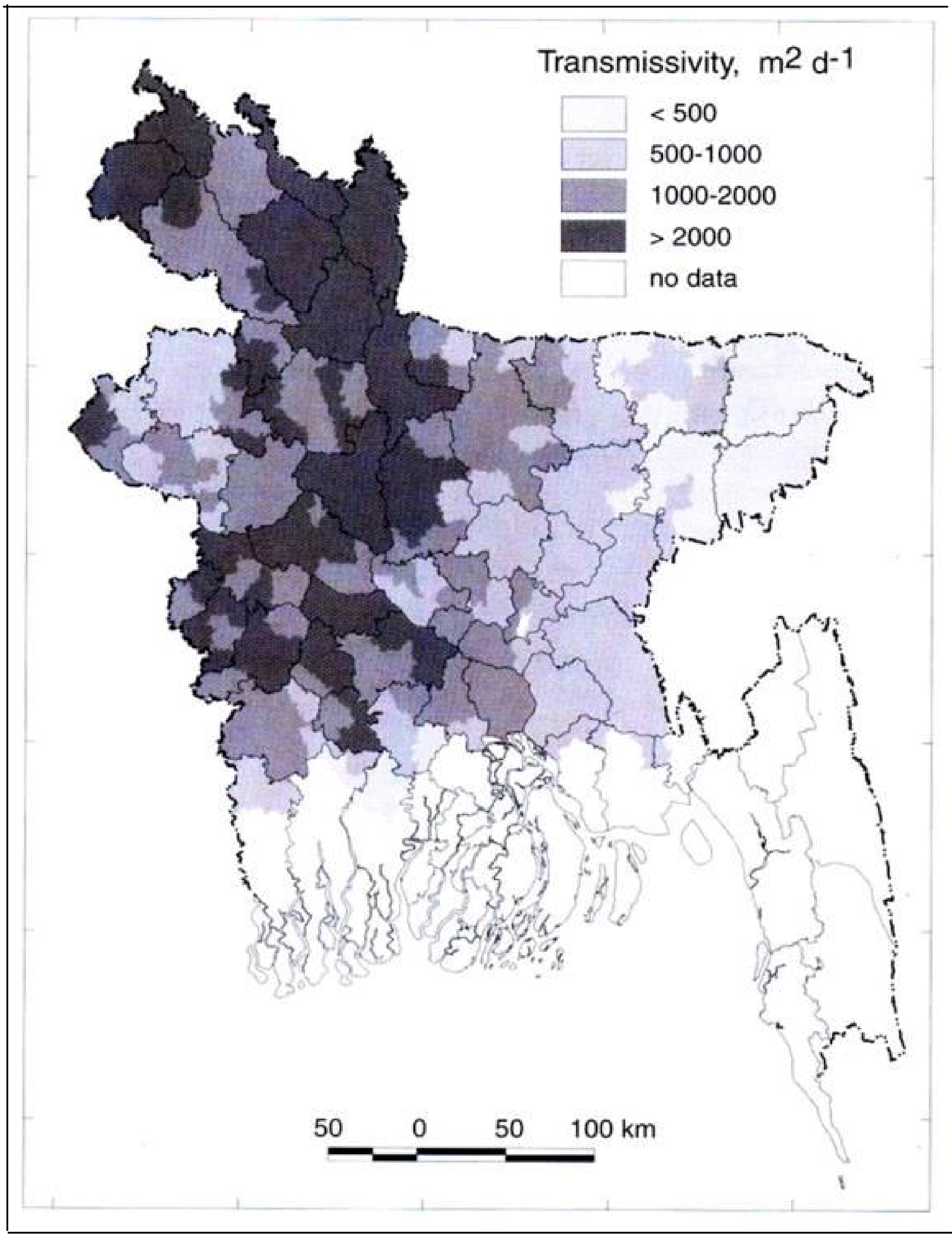

Fig. 4.6 Map of the Variation in Aquifer Trnsmissivity Across Bangladesh (BGS-DPHE, 2000)

4.10 Recharge of the aquifers

4.10.1 In Bangladesh the principal sources of groundwater recharge includes the following: a) rainwater that infiltrate and percolate through the unsaturated zone. The long term mean monthly rainfall and potential evapo-transpiration for four cities in Bangladesh are shown in Annex-II (Table 4.14). Flood water which overflow the river and stream banks infiltrated into the groundwater. The flooding situation from 1954 to 1988 is shown in Annex-II (Table 4.15). Water from the permanent water bodies (river, canals, haors, beels, jheels, ponds, irrigated fields etc.) that lie above the water table also percolate to the groundwater.

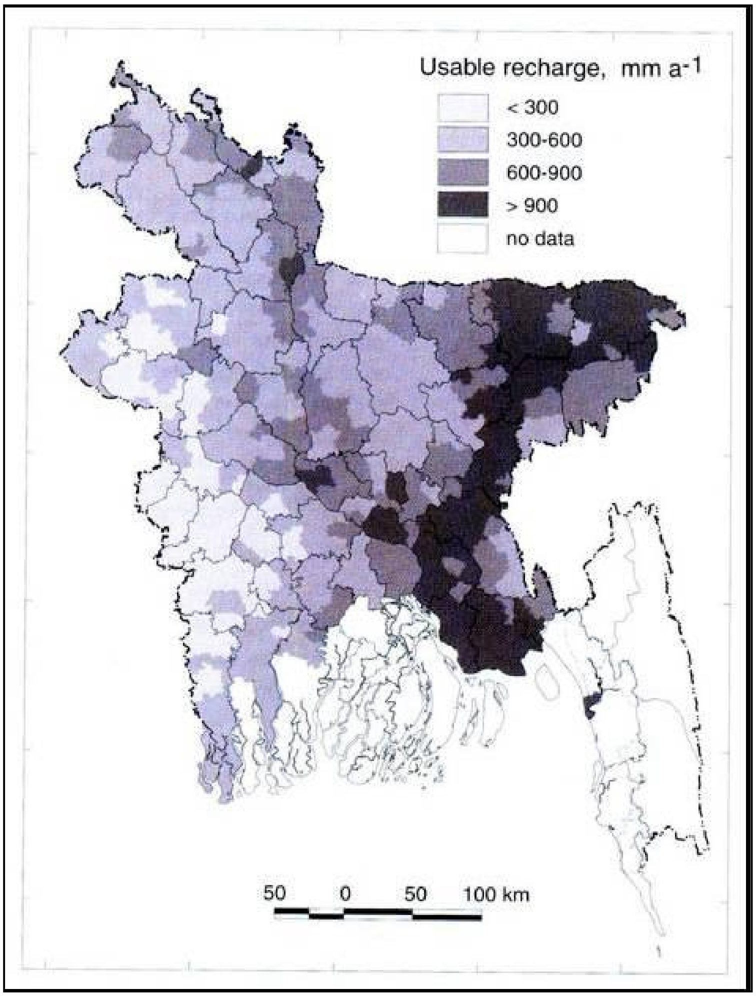

Fig. 4.7 Actual Recharge Across Bangladesh (BGS- DPHE, 2002

4.10.2 In the Pleistocene terraces the recharge occurs through the incised antecedent drainage channels that cut through near surface clays into the underlying sandstone. The greatest scope of recharge is within the coarse grained sediments and the least is within the fine grained sediments like clay. In Bangladesh the maximum recharge is in the eastern belt (except hilly areas) and the minimum is in the western belt. The actual recharge in different areas of the country is shown in Fig. 4.7 which shows its relationship with mean annual rain fall in different parts of the country.

4.10.3 The nature of recharge of groundwater in deep aquifer in Khulna region because of unmanaged development is shown in Fig. 4.8.

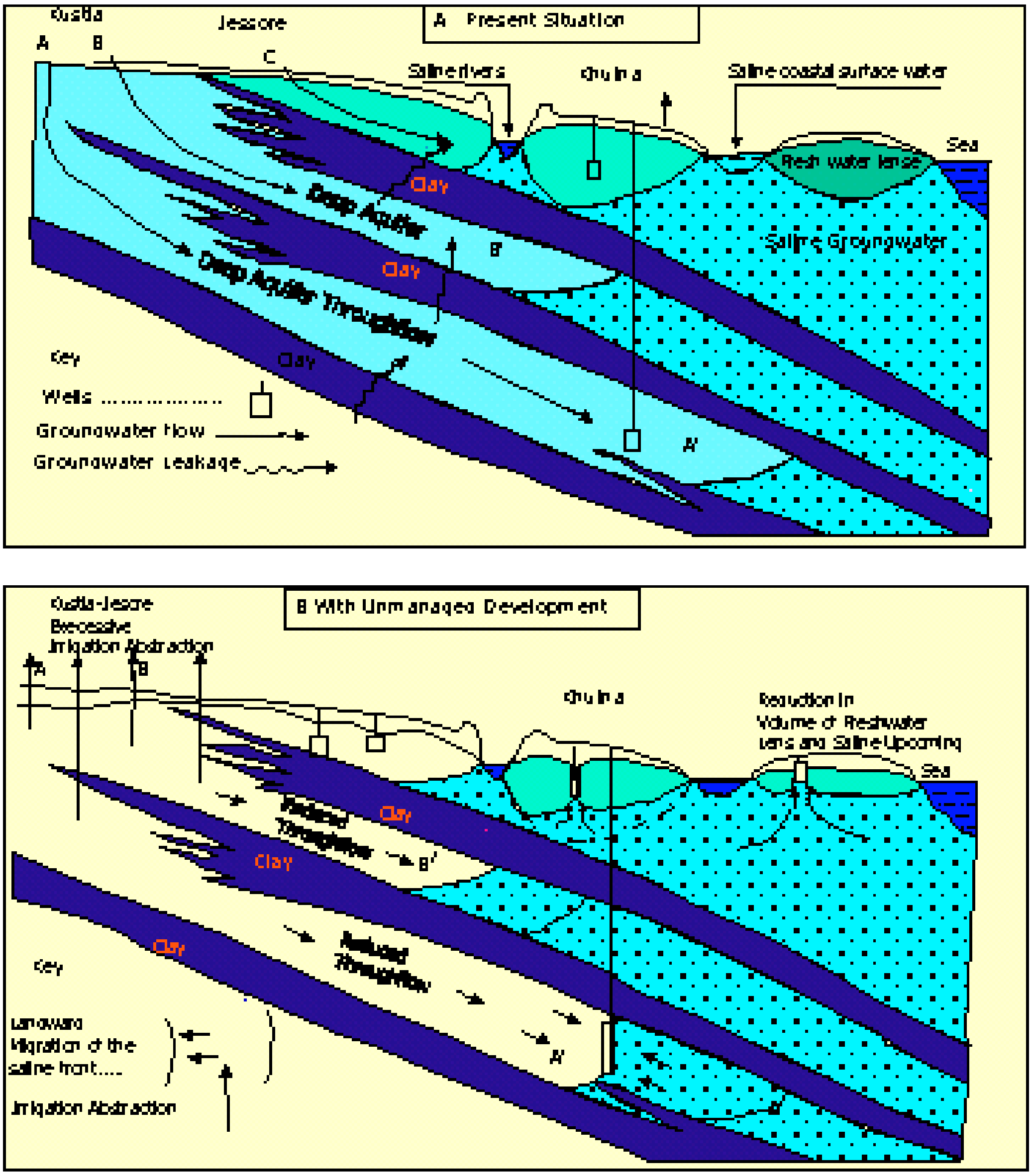

Fig. 4.8 Possible Relationship of Fresh and Saline Groundwater in SW Bangladesh. The Effect of Unmanaged Development (Source MPO/Harza, 1986)

4.10.4 Storage of groundwater is depleted by its abstraction and is replenished by recharge. In Bangladesh large volume of groundwater abstraction occurs by the large number of hand, shallow and deep tube wells for irrigation, public water supply and domestic uses.

4.10.5 The regional hydraulic gradient is low that reflects the low topographic gradient of the country. Approximate wet season regional groundwater gradients are shown in Annex II (Table 16)

4.10.6 The hydrographs of some selected areas indicate that the annual amplitude of seasonal water table change is effected by annual recharge and increased abstraction (Fig 4.9). The maximum depth of groundwater in different regions of the country is shown in Fig. 4.10

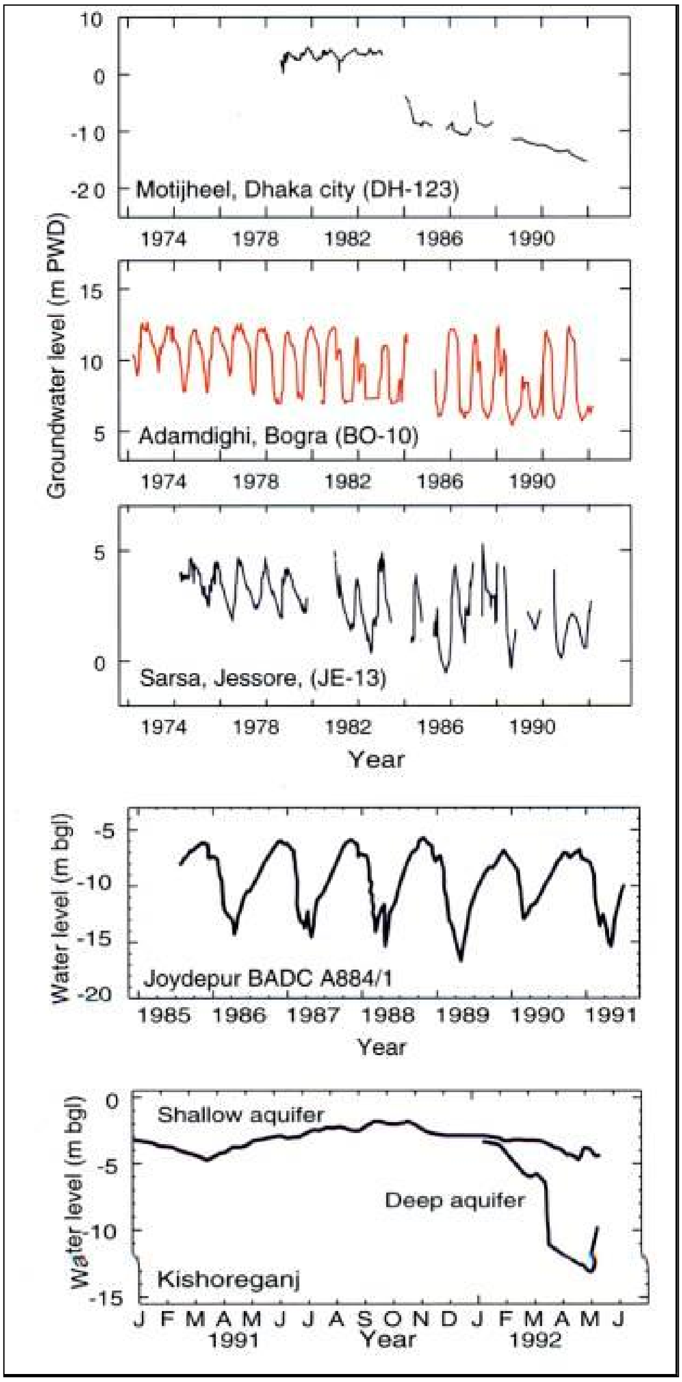

Fig. 4.9 Examples of Hydrographs From Selected Sites in Main Aquifers of Bangladesh (BGS-DPHE, 2002)

4.10.7 The groundwater flows generally from north to south. In the coastal belt the freshwater in the deeper part are probably fed along the stacked channel deposits (Fig. 3.5 BGS-DPHE) from the river systems. Most of the flow probably takes place through the in-filled incised channels under the major rivers. BGS-DPHE (2001) show a geological section from Faridpur to Dhamrai with a four layer aquifer structure across the Brahmaputra river just before its confluence with the Ganges (Fig. 4.11) and has calculated that it will take 44 ka to flush the layer 3 with a flow rate of 8400 m^3d-1, whereas in layer 2 it will take 71 ka with a flow rate of 4770 m^3d-1. This difference is due to the differences of porosity of the aquifers. Similar section from Faridpur areas is shown in Fig. 4.12.

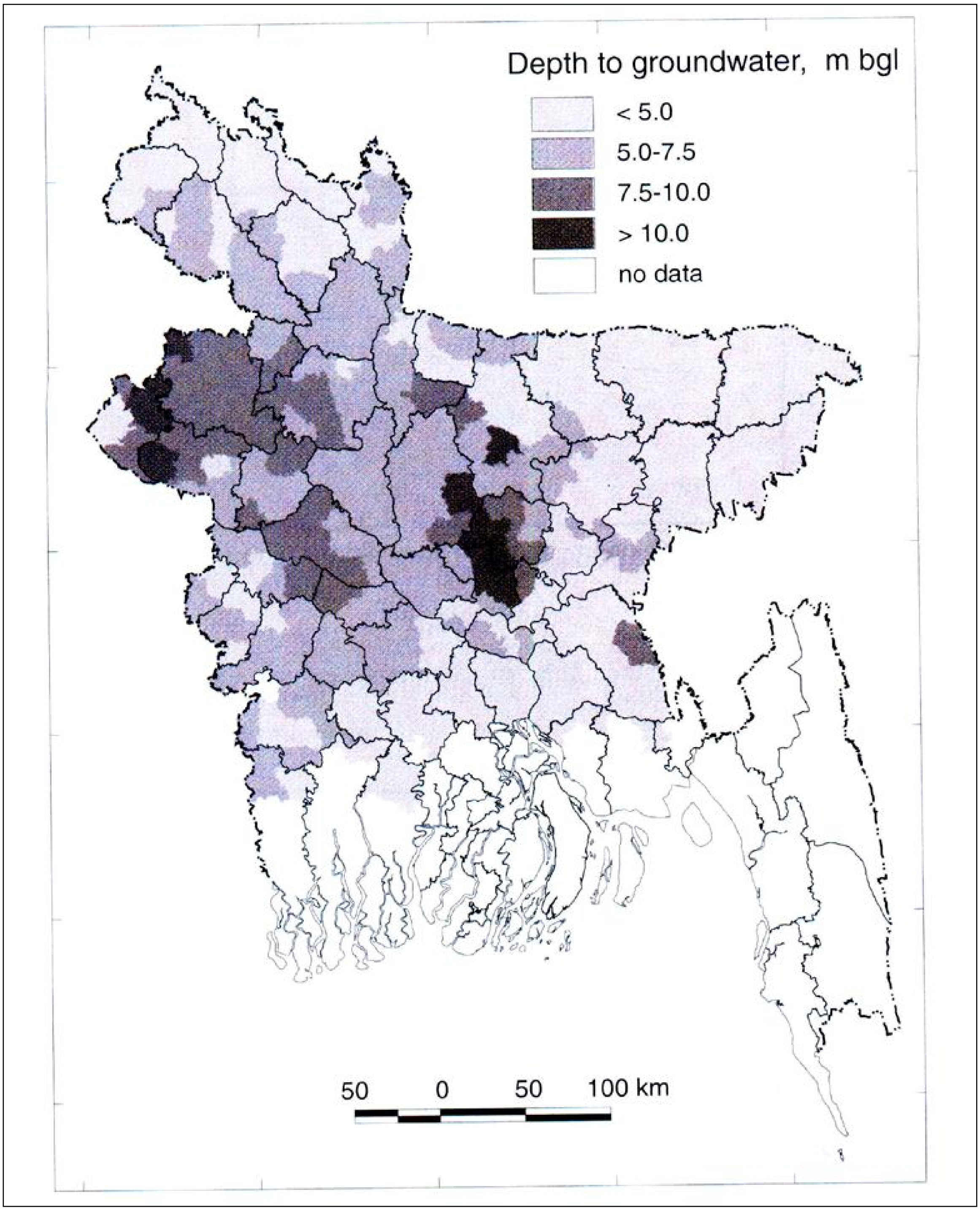

Fig. 4.10 Map Indicating the Maximum Depth to Groundwater. (Sources Water Level Data for 1964-1993 from BWDB, BADC, DPHE and DWASA; Analysed by EPC/MMP (1994).

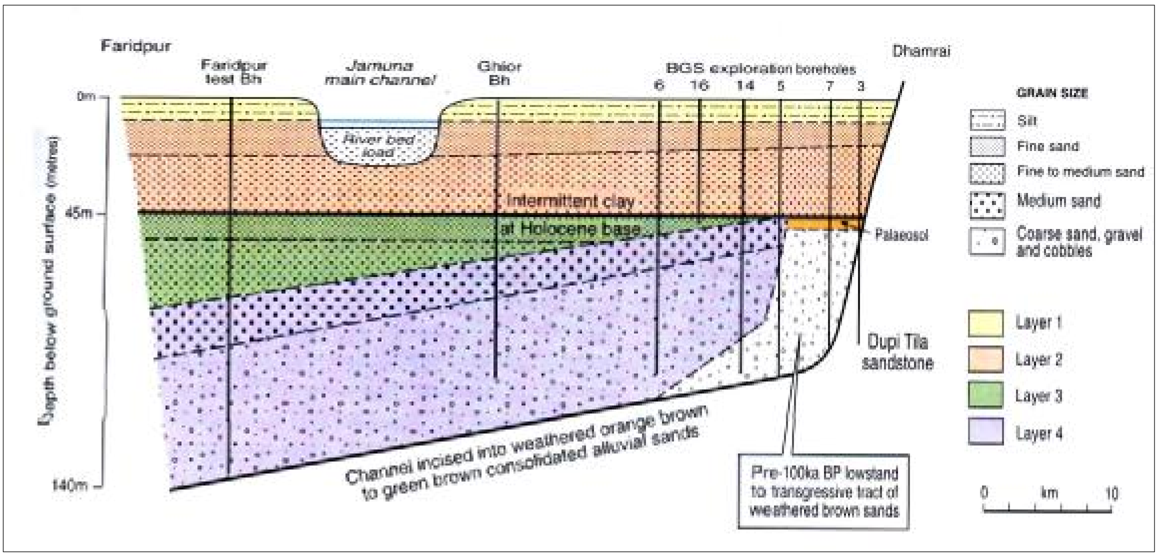

Fig. 4.11 Geological Cross Section Through the Jamuna Channel Alluvium Deposits Showing the Four Layer Aquifer Structure (BGS-DPHE, 2000)

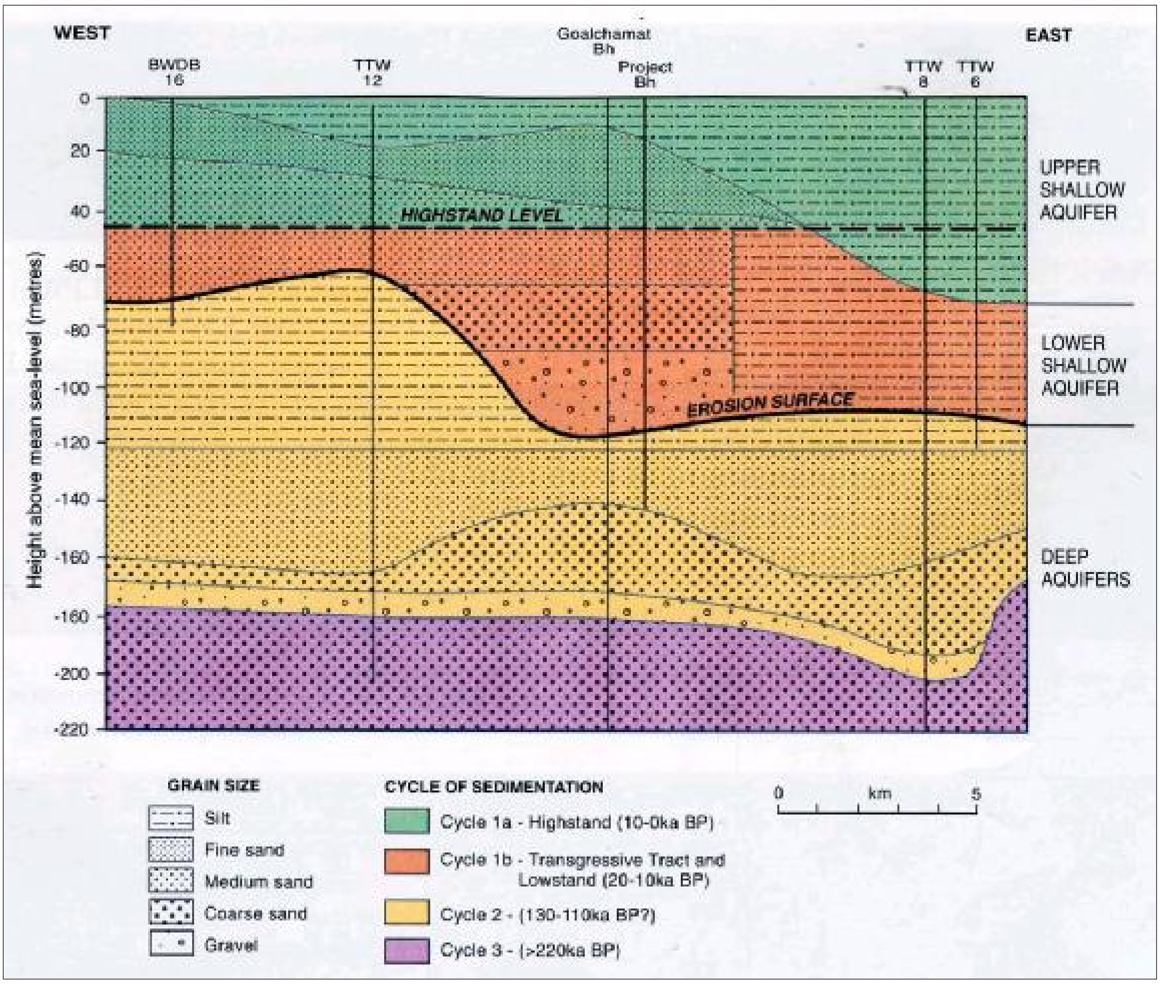

Fig. 4.12 Geological Cross Section Through the Faridpur Special Study Area (BGS-DPHE, 2001)

CHAPTER V

Arsenic in Ground Water in Bangladesh

5.1 Introduction

5.1.1 After independence, the Government of Bangladesh undertook a massive program to provide bacteriologicaly safe drinking water for the people of the country. This resulted in installation of millions of shallow tube wells (hand pumps) to extract safe drinking water. In 1997, Bangladesh was claming to have provided safe drinking water to about 97% of the population (National Plan of Action for Children, 1997). Exact numbers of these hand tube wells used for withdrawing water for household purpose are not known but the number may be anywhere from 6 - 11 millions. Except in some limited areas these shallow manually operated tube wells are extracting water from depths of less than 50 m.

5.1.2 Simultaneously, for self-sufficiency in food, the cultivation of high yielding variety of rice spread all over the country and large number of deep and shallow tube wells for irrigation were sunk. In 1997 hybrid varieties of rice was introduced in the country with consequent higher demand for ground water. It must be mentioned that history of irrigation in Bangladesh is not very old. This started mainly with the introduction of the high yielding variety of rice in the early sixties and the major development took place from early seventies. BGS-DPHE (2001) mentions that the total area under irrigation coverage has risen from 1.52 million hectares (Mha) in 1982-83 to 3.79 Mha by 1996-97 and the proportion of irrigation water drawn from groundwater has also changed significantly. In 1982-83 groundwater represented 40% of total irrigation consumption that rose to 70% in 1996-97. Latest compilation by Bangladesh Agricultural Development Corporation (BADC, 2001) show that out of a total of 3,56 Mha of land under irrigation, about 75.07% or 2,65 Mha are irrigated by groundwater. BADC (April 2001) reports that there are 23,536 deep tube wells (DTW) and 7,07,574 shallow tube wells (STW) which are mechanically operated and 67,878 manually operated shallow irrigation tube wells. Unfortunately these divisions between deep and shallow are not based on depth from the surface but on technology of extraction of water that in many cases may be extracting water from the same aquifer. The term shallow tube well is a misnomer as STW may be installed to depths similar to DTW. In Bangladesh the term "shallow" only indicates an irrigation well, normally fitted with a suction mode (centrifugal) pump. BADC defines the deep and shallow tube wells in the following manner. The deep tube wells are cased wells into which turbine / force mode pumps are immersed. The pump is set within the well below the pumping water level. Shallow tube wells (SWT) are small irrigation tube wells having discharge capacities of about 14 l/s, one fourth of a DTW. BGS-MMI (1999) and the BGS-DPHE (2001) studies considered tube wells less than 150 m as shallow tube wells and tube wells greater than or equal to 150 m as deep tube wells.

5.1.3 Groundwater has become the main source of drinking and irrigation water supply in Bangladesh. Though the exact figures are not available it is assumed that of the abstracted groundwater 95% to 98% is used for agricultural purpose and the rest for drinking water supply.

5.1.4 In recent years, the presence of arsenic in groundwater has disrupted the whole scenario of its use. Since the identification of the arsenic contamination in groundwater of Bangladesh, the scientists and several agencies have engaged themselves to detect the problem. Though some work have been done, yet no consensus has been reached about the mechanism of how the arsenic is being released and its mobility in the groundwater.

5.2 Source and cause of arsenic contamination of the groundwater

5.2.1 Scientists agree that in Bangladesh the cause of the arsenic is natural (geological) and that it is not introduced by human activity such as mining operations. However, opinions differ over how the arsenic ended up dissolved in the water supply. There are three main theories:

5.2.2 1) The *pyrite oxidation hypothesis* assumes that a lowering of groundwater table draws in oxygen, which oxidizes sulfides and thus releases arsenic, implying that dams/barrages built across rivers upstream deplete the lowlands of water, thus lowering the groundwater table, etc.

5.2.3 2) The *agro-chemical hypothesis* shifts the blame to the use of phosphate fertilizer by local farmers with the supposed effect of contaminating the soil with arsenic.

5.2.4 3) The *oxyhydroxide reduction process* takes place in shallow (<150m) younger deltaic sediments with large organic components (high oxygen demand). Recently concluded work by the British Geological Survey and their associates after an extensive survey of tube wells throughout Bangladesh strongly favours this hypothesis.

5.2.5 Among the causes the JICA team (2002) suggests that the disassociation of ferric oxyhydrooxide and release of iron and arsenic ion into the groundwater occur under reduction condition. The dissolved arsenic migrates along with the movement of groundwater. The work done by the GSB-USGS (GSB interim report, 2002) suggests that high concentration of arsenic in the Holocene sediments could be attributed to the dissolution of residual iron oxides. The low dissolved iron content is inconsistent with reductive dissolution. The arsenic enrichment of altered micas supports the association with phyllosilicates in reduced sediments. The lack of co-variation with other compositional parameters in the water suggests multiple processes may affect the arsenic concentration (GSB interim report, 2002). So, the exact process of contamination is yet to be resolved.

5.3 Bangladesh national standard of arsenic content in drinking water

5.3.1 The Department of Environment in 1997, determined the acceptable limit of arsenic in drinking water of Bangladesh as 0.05 mg/l in place of WHO recommend level of 0.01 mg/l (1993). In other words, the Bangladesh standard is 0.05 mg/l (milligram per litre) or 50 μg/l (microgram per litre), which is same as 0.05 ppm (parts per million) or 50 ppb (parts per billion) respectively).

5.4 History of detection and the analyses of ground water for arsenic in Bangladesh

5.4.1 DPHE detected the presence of arsenic in tube well water in 1993, first at Chapai Nawabganj, a northwestern district of Bangladesh (BGS-MMI, 1999). Presence of arsenic was confirmed in numerous shallow and deep wells in different parts of the country by 1995. BWDB also detected arsenic contamination in groundwater of the western border belt of the country in 1996. Subsequently, 7000 patients were identified as suffering from different types of arsenicosis (NIPSOM, DCH and DPHE) and it was presumed that water of millions of tube well may contain arsenic with different level of concentration.

5.4.2 From 1993 different organizations have carried out local, regional or national surveys to detect the arsenic concentration in groundwater. In early 1997 the issue of arsenic as a problem has featured nationally through mass awareness campaigns by the government, and a number of NGOs and research organizations.

5.4.3 It has been reported that out of 64 districts, drinking water in 61 districts are contaminated by arsenic (Table-5.1) though the percentages of the tube wells contaminated vary from above 90% to less than 5% (Fig. 5.1).

5.4.4 Available laboratory analytical results compiled under the project 'Groundwater Studies for Arsenic Contamination in Bangladesh` conducted by BGS-MML (1999) (Annex IIIA, Table.5.2) show that out of 9271 analyses, arsenic concentration in 3242 samples exceeded the limit of 0.05 mg./l. which is 35% of all samples examined. Summary of pre-existing laboratory data by district are given in Annex IIIA, (Table.5.3) (BGS-MML ,1999).

Table 5.1 Arsenic Contamination Statistics at a Glance in Bangladesh

Divi-sion	District	Upazila	Total Tube Well (TW) Tested	No of well Depth <150 (meter)	Arsenic Conc. <0.05 (mg/L)	Arsenic Conc. >0.05 (mg/L)	No of Well Depth >150 (meter)	Arsenic Conc. <0.05 (mg/L)	Arsenic Conc. >0.05 (mg/L)
6	61 out of 64	433 out of 496	3534	3207	2327	880	327*	324*	3*
***Deep Tube Well**									

(Source BGS-DPHE, 2001)

5.4.5 The intensity of arsenic contamination and the necessity to provide feedback to a large population, use of field testing kits has been popularized. All these kits provide semi-quantitative results while others determine compliance with the 0.05 mg/l standard only. Using field test kit, a nationwide survey was carried out by DPHE with the assistance of UNICEF (1997) and a database of some 23,000 tests has been recorded.

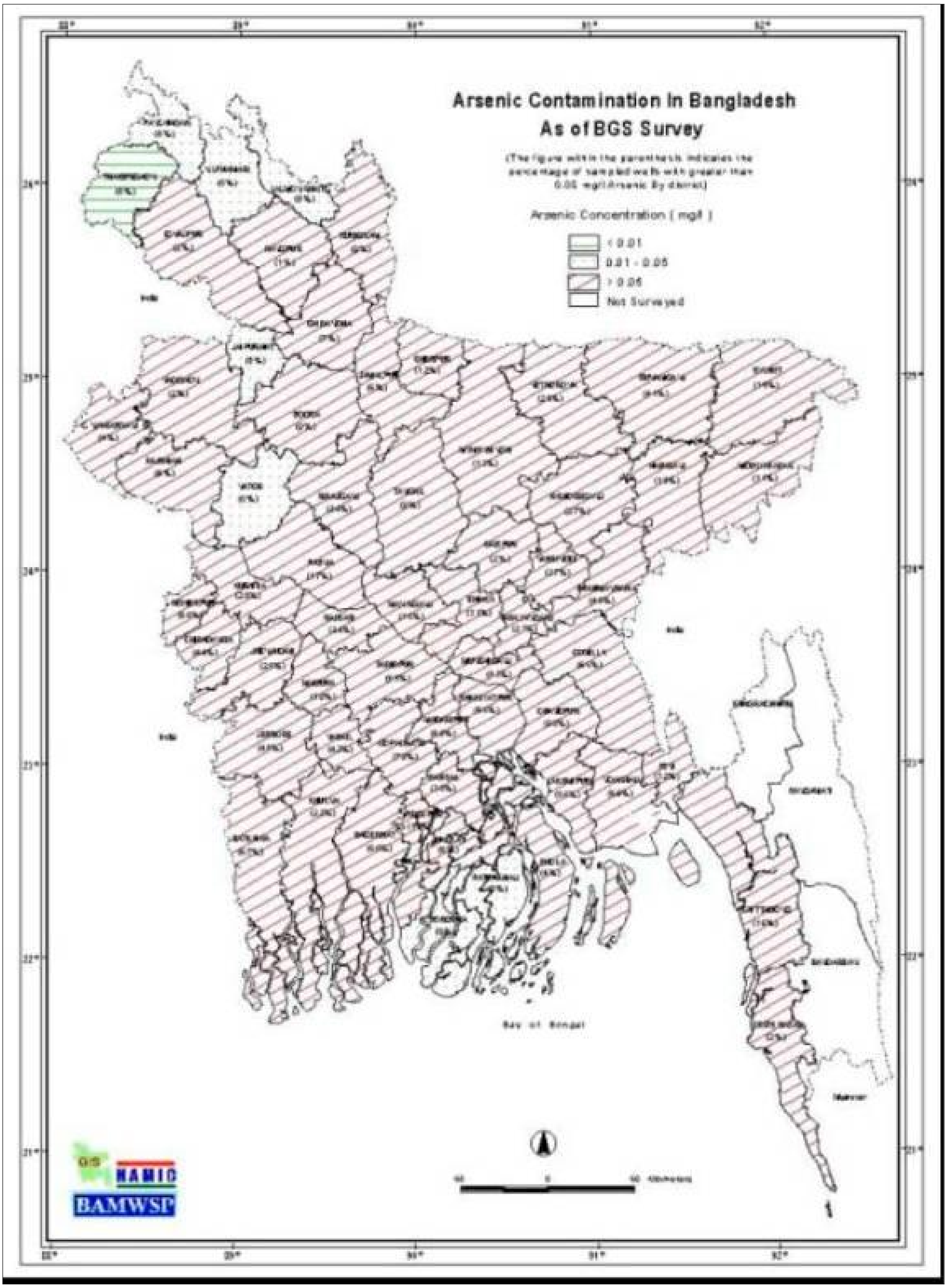

Fig. 5.1 Arsenic Affected Districts of Bangladesh with Percent of Tube Wells Contaminant Shown in Parenthesis.

5.4.6 NGO Forum and Grameen Bank have carried out extensive surveys, while BRAC (Jakariya, 1997) tested all 12,000 wells in Hajiganj upazila of Chandpur district where 93% of drinking water wells are contaminated by arsenic. A summary of field test results by districts is given in Annex - IIIA (Table 5.4), where 21% of all samples are found to be contaminated. The field test surveys show that the southwest region and the southeast region are most extensively contaminated. From the survey, significant arsenic contamination of groundwater in Sylhet is also identified.

5.4.7 Random surveys were conducted by a number of other agencies to assess the extent of arsenic contamination in Bangladesh. In December 1996, Asia Arsenic Network (Japan based NGO) carried out a detailed survey in Samta village of Jessore and reported that 90% of the tube wells are arsenic contaminated (BGS-MMI, 1999).

5.4.8 In early 1997 BUET made a random survey in northeast part of Bangladesh under North East Minor Irrigation Project (NEMIP) and tested 1210 water samples of which 61% of the samples were above 0.01mg/l and 33% were above 0.05 mg/l of arsenic. A further 751 samples were analyzed by BCSIR of which 42% contain above 0.05mg/l of arsenic (BGS-MMI, 1999).

5.4.9 By personal contacts it was learned that DPHE, GSB and BAEC carried out repeat quality control tests of at least 5% of all the filed test analyses results. Such information could not be confirmed from any other organizations carrying out analyses of ground water by field test kits in Bangladesh.

5.5 Geographic distribution of arsenic in the ground water in Bangladesh

5.5.1 Arsenic contamination is not uniform in all areas of Bangladesh. It is seen that the broad surface geological divisions have a good correlation with the arsenic distribution in the country (Fig. 5.1). An interim report showing the areas of the country that is free from any amount of arsenic in the ground water in Bangladesh was submitted to the Secretary, Ministry of Local Government, Rural Development and Cooperatives, Local Government Division was submitted in November 1, 2001. (Annex-I).

5.5.2 The geological units of the geological map of Bangladesh can be broadly divided into 11 basic geological districts (Fig. 5.2). Distribution of arsenic in two selected upazilas of the different geo-districts are presented in Annex IIIA (Tables 5.5 to 5.15.) The spatial distribution of arsenic shows that some of the geo-districts (Alluvial Fan geo-districts, Residual geo-districts, Bedrock geo-districts) ground water is safe from arsenic contamination.

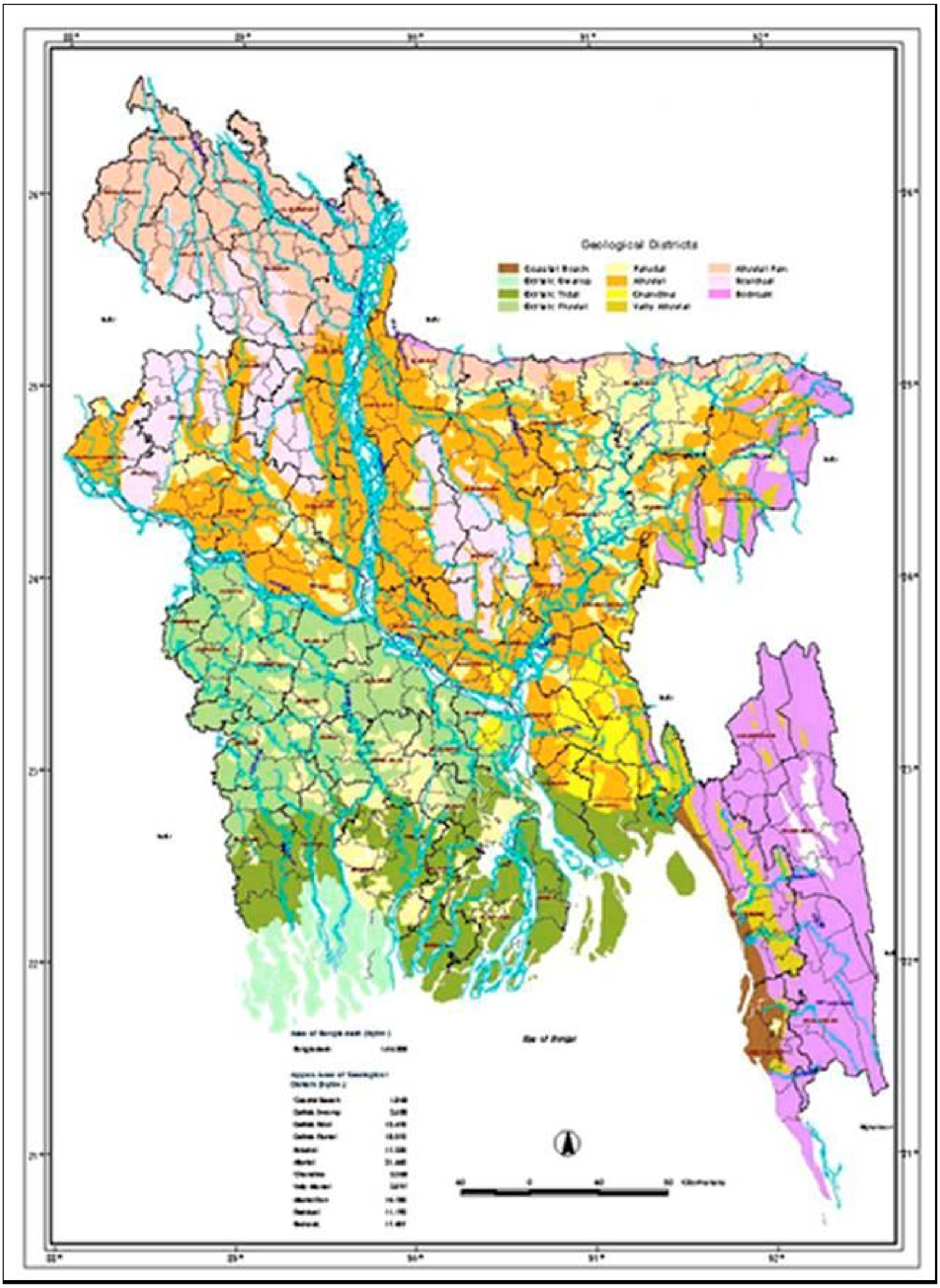

Fig. 5.2 Geological Districts with Administrative Boundaries (Source: GSB)

These areas are as follows.

1. The Eastern and Northern Frontier Hilly Regions and including Chittagong and Hill Tract districts hill ranges of north – eastern Sylhet district and hills along the narrow frontier strip of Sylhet and Mymensingh districts.
2. The Pleistocene terrace on the Pleistocene Uplands including the Barind and the Madhupur Tracts and the Lalmai Hill ranges covering widespread areas of greater Rajshahi, Bogra, Dhaka, Mymensingh and Tangail districts.
3. The piedmont areas of greater Dinajpur and Rangpur districts

5.5.3 The floodplain and deltaic areas are severely affected. The most contaminated district was found to be Chandpur where 90% of the tube well water exceeds the Bangladesh allowable limit (0.05 mg/l) of arsenic concentration (BGS-DPHE, 2001). In BGS-DPHE report only one district , Takurgaon in the extreme north-west of Bangladesh (near the Himalyayan foot hills) is reported to have no tube well having higher than the Bangladesh standard of arsenic limit. A broad north-south band of low arsenic tube wells are found in the SW Bangladesh (Gorai-Bhairab valleys).

5.5.4 Based on the intensity of arsenic concentration of Bangladesh standard the whole country can be divided into 3 categories in concentration of arsenic in the ground water (BGS-DPHE, 2001) (Fig.5.1).

5.5.5 1. Least Affected Districts (Upto 10% of the tested wells are contaminated): Thakurgaon, Barguna, Jaipirhat, Lalmonirhat, Natore, Nilphamari, Panchagarh, Patuakhali (all 0%), Rangpur (1%), Dinajpur, Naogaon, Gazipur, Cox's Bazar (all 2%), Bhola, Nawabganj (both 4%), Jhalkathi, Rajshahi (both 6%), Gaibandha (7%), Tangail, Kurigram, Bogra (all 9%).

5.5.6 2.Remarkably Affected Districts (11-50% of the tested wells are contaminated): Habiganj (10%), Moulavibazar (11%), Sherpur (12%), Mymensingh (13%), Manikganj (15%), Chittagong (16%), Pirojpur, Pabna (both 17%), Sylhet (18%), Magura (19%), Khulna (22%), Narayanganj (23%), Rajbari, Sirajganj (both 24%), Jhenaidah (26%), Narshingdi, Kishoreganj (both 27%), Kushtia, Netrokona (both 28%), Barishal (30%), Dhaka (31%), Feni (32%), Brahmanbaria (40%), Sunamganj (41%), Narail (42%), Chuadanga (44%) and Jessore (48%).

5.5.7 3. Worst Affected Districts (>51% of the tested wells are contaminated):
Chandpur (90%), Munshiganj (83%), Gopalganj (79%), Madaripur, Noakhali (both 69%), Satkhira (67%), Comilla, Faridpur, Shariatpur (all 65%), Meherpur, Bagerhat (both 60%) and Lakshmipur (56%).

5.5.8 Arsenic statistics for the twelve most contaminated and twelve least contaminated districts (BGS-DPHE, 2001) are given in Annex-IIIA, Table 5.16 and 5.17 respectively. The statistics of 268 upazilas are given in Annex-IIIA (Table 5.18)

5.5.9 In 2000, GSB has conducted, "Arsenic Pollution Investigation" in twelve upazilas. Summary of the result is enclosed in Annex-IIIB (GSB, Interim Report 2002).

5.6. Vertical and Stratigraphic Distribution of Arsenic in the Groundwater

5.6.1 Vertical distribution of arsenic in the different aquifers is important to quantify the magnitude of the problem. Such distribution is related to the lithology and other parameters of the aquifers. Arsenic bearing aquifers has no uniformity with depth and thickness. The contamination of aquifers is generally found within 7 to 159 m depths.

5.6.2 It has been established by now that aquifers belonging to the Dupi Tila formation of Plio-Pleistocene age or older rock formations are not contaminated by arsenic. Arsenic contamination has not been reported from the Hill areas or the Pleistocene Uplands areas of the country. Also there is no reported arsenic contamination from the Himalayan Foredeep (Fig. 4.1) areas of the country. It is not that less water is withdrawn from the aquifers of those areas. Dhaka City can be cited as an example where 238 tube wells withdraw about 2.4 billion litres of water per day but no arsenic contamination has been reported as yet. The upazilas or parts thereof of the upazilas where all the aquifers are safe are listed in Table 5.19 and listed in more details in the Annex I.

5.6.3 BGS-DPHE (2001) shows that water from only about 1% of the tube wells below a depth of 150 m have arsenic contamination of higher than the Bangladesh standard of 0.05 mg/l from across the country (Table 5.1).

5.6.4 Out of 327 deep well samples (307 wells are deeper the 150 m. and 20 wells are deeper then 200 m) only 3 (1%) exceeded 50 µg/l limit. Existing data shows that out of 909 sampled wells deeper the 200 m, 34 (4%) are contaminated. Ground water within 10 m from the surface generally contains low arsenic but within 50-100 m depth range in most cases arsenic concentration is very high. The regional survey identified that 58% of total samples collected from 10-30 m depth contain arsenic content of more than 50 µg/l whereas, below 200 m this is only 0.7%. Depth wise occurrences of arsenic from regional survey of 3534 wells are given in Tables 5.20 and 5.21

Table 5.19 Fresh Groundwater Depth Zone of The Aquifers of Studied Areas

Location	**Source**	**Arsenic safe depth range (M.)**	**Remarks**
1	**2**	**3**	**4**
North-South striking hilly areas of Chittagong, Cox's Bazar, Rangamati, Bandarban, Khagrachari and greater Sylhet districts, along the frontier of greater Mymensingh districts. The Barind and the Madhupur Pleistocene Uplands areas, completely 14 Upazilas and partially 32 Upazilas. Includes Dhaka City.		All the aquifers	More or less arsenic safe areas excepting few cases in the channel fill association of meandering deposit.
Araihazar, Narayanganj.	BWDB	60-91	
In and Around Manikganj Town.	BWDB	Below 180	
Kachua, Comilla	BWDB	Below 243	
Faridpur Sadar.	BWDB	Below 122	
Ekhlashpur Pourashava, Noakhali.	DANIDA	180->272	With variable thickness.
Raipur Town, Laxmipur.	DANIDA	310-350	
TAMTA, Ramganj, Laxmipur.	DANIDA	230-340	In places intercalated with thin clay lenses.
Tulabaria, Feni.	DANIDA	155-250	In places intercalated with thin clay lenses.
Patuakhali Pourashava.	DANIDA	305-380	With variable thickness and in places intercalated with thin clay lenses.
Kalapara Pourashava, Patuakhali.	DANIDA	305->354	Intercalated with thin clay lenses.
Galachipa Pourashava, Patuakhali.	DANIDA	300-360	
Amtoli Pourashava, Barguna.	DANIDA	320-372	With variable thickness and in places intercalated with thin clay lenses.
Pathoghata, Barguna.	DANIDA	240->300	With variable thickness.
Khulna City.	DPHE/BWDB	>260	
Satkhira.		>225	Occasionally fresh water trapped lenses encountered within 137m. depth.

Table. 5.20 Average Concentration of Arsenic in Wells as a Function of Well Depth

Depth interval (m)	Number of wells	% of wells	Average As concentration (μg L^{-1})	% of wells with >50 μg L^{-1}
<15	287	8	58	25
15-30	1180	33	76	31
30-60	1258	36	56	26
60-90	317	9	33	21
90-150	165	5	45	35
150-200	32	1	7	1
>200	295	8	3	1
All	3534	100	55	25

Table 5.21 Two-Way Classification of Tube wells According to Their Arsenic Concentration and Depth

Depth range (m)	% of wells in a given depth range that are in a given arsenic copncentration range As concentration range (μg L^{-1})							
	<10	10-50	50-100	100-150	150-200	200-300	>300	Total %
<25	53	17	9	5	3	4	8	100
25-50	57	16	9	4	3	5	6	100
50-100	55	22	10	5	3	3	2	100
100-150	26	37	27	5	2	3	0	100
150-200	78	19	3	0	0	0	0	100
>200	97	2	0	0	0	0	0	100

5.6.5 BGS-DPHE (2201) mentions that "there is a distinct trend for the older wells to be more contaminated than the younger wells. It is tempting to deduce from this that the shallow wells become more contaminated with time … Though there could be other correlated variables that may account for the trend." But the history of sinking of both shallow hand tube wells and irrigation wells from 60s onward seems to lead to conclude that there is a time relation to the concentration of arsenic of the wells. Data from the water supply schemes of the North 24-Pargana district from West Bengal, India also seem to lead to such a conclusion.

5.6.6 BAEC in association with BWDB and other agencies has undertaken isotope studies in different arsenic affected areas. Salient observations of the isotope study indicate that the shallower and deeper aquifers of the country also have different isotopic signatures. The shallower groundwater (< 100 m depth) having high arsenic contents are modern and continually replenished with a residence time of 30-40yrs. Deeper aquifers (>100 m. depth) are generally arsenic free and are recharged on a large time scale of over 100 years. The possibility of interconnection between arsenic affected shallower aquifer and arsenic free deeper aquifer at few locations may be due to improper design and development fault of DTW. Deeper groundwater is old waters (3000-20,000yrs) and apparently it appears that there is no interconnection between the shallower and deeper aquifers.

5.6.7 Study report of GSB (interim report of GSB, 2002) indicates that there is a an impervious clay layer in between 30 to 70 m in an around Comilla and Brahmanbaria area (Brahmanpara, Debidwar, Daudkandi, B.baria, Akhaura, Sarail, Kasba) below which water is not contaminated. This clay layer is not horizontal rather it is very much undulated. Below this clay layer lies the Dupi Tila sandstone of Plio-Pleistocene age. In some cases tube wells below 70 m are found arsenic contaminated, in these cases the tube wells were probably located in fossil river channels that cut through the clay bed. Few tube wells below 100 m at sandbars in Daudkandi are reported to be arsenic contaminated which may be easily explained by the river shifting processes. Similarly few tube wells within 10-15 m depth are found arsenic free. In the coastal belt tube wells more than 100 m depth are found less arsenic affected though salinity is a big problem there.

5.6.8 The boundary between the shallow and deep aquifers at Chuadanga is about 160 m and at Jhenidah it is about 190 m and there are thick clay layers between them. In Jessore area the deep aquifer is at depths of nearly 300 m. In these areas water withdrawn from the deep aquifers are not arsenic contaminated (JICA, 2002), whereas the upper aquifers are contaminated by various ranges.

5.6.9 All the workers in Bangladesh have reported that, except in very rare cases the aquifers in the Late Pleistocene-Holocene sediments deposited during the transgrssive phase of the 21-18 ka to 12-10 ka and composed mainly of coarse sand with pebbles or gravel are safe from arsenic contamination.

5.7 Information from the western part of the GBM delta Complex

5.7.1 Though the latest reports from neighboring 24 Pargonas district of West Bengal show that about 14% of the deep tube wells reaching these deposits have become contaminated with arsenic in less then a decade as shown in Table 5.22 (Personal Communication, Dipankar Chakrabarty, IES, Jadavpur Univ., also Abstract Vol. Int. Seminar 2002, DCH)

Table 5.22a Arsenic Status in Deep Tube well of Deganga Block, North 24-Parganas, West Bengal (Survey report from 15.01.2000 to 18.11.2000)

Total No. of Gram Pahchayet (G.P.)	13
No. of surveyed Gram Panchayet (G.P.)	13
Total No. of Villages	181
No. of surveyed villages	99 (deep tube wells are not available in all villages)
Tube wells with maximum depth found in 99 villages	196.96 m
Total no. of tub well analyzed	374 (≥100 m)

(Each sample analyzed twice, we have identified for each tube well)

Table 5.22b Arsenic Concentration Distribution at a Glance (For 374 Tube wells ≥100 m)

No. of samples <5 µg/l	No. of samples ≥ 5 µg/l	No. of samples ≥ 10 µg/l	No. of samples ≥ 50 µg/l
216 (57.75%)	158 (42.25%)	130 (34.76%)	52 (13.9%)

6-9 µg/l	10-49 µg/l	50-99 µg/l	100-149 µg/l	150-200 µg/l
19 (5.08%)	78 (20.85%)	38 (10.16%)	9 (2.4%)	5 (1.33%)

Maximum depth where arsenic found		
≥ 5 µg/l	≥ 10 µg/l	≥ 50 µg/l
196.96 m	181.81 m	181.81 m

Table 5.22c Distribution of Concentration of Arsenic With Depth at a Glance

As concentration in µg/l	Depth in meter				
	≥ 510 (total)	≥100 -<125	≥ 25 - <150	≥150 - <175	≥175 - 197
<5	216 (57.75%)	11 (2.94%)	101 (27.05%)	99 (26.4%)	5 (1.33%)
≥ 5	158 (42.25%)	10 (2.67%)	51 (13.6%)	90 (24.06%)	7 (1.87%)
6-9	19 (5.08%)	2 (0.53%)	5 (1.33%)	12 (3.20%)	0
10-49	78 (20.85%)	4 (1.06%)	24 (6.4%)	45 (12.03%)	5 (1.33%)
50-99	38 (10.16%)	1 (0.26%)	17 (4.5%)	20 (5.34%)	0
100 - 149	9 (2.40%)	1 (0.26%)	2 (0.53%)	5 (1.33%)	1 (0.26%) (depth181.81)
150 - 200	5 (1.33%)	1 (0.26%)	0	3 (0.80%)	1 (0.26%) (depth = 181.81)

5.7.2 Some test results of ground samples of deep aquifers from the Public Health Engineering Department, West Bengal. A summary of the results of the analyses is shown in Table 5.23.

Table 5.23 Public Health Engineering Department, West Bengal, India.Barasat Laboratory Division, 24-Parganas District

Sr. No.	**Block Name**	**Name Of Water Spply Scheme**	**Zone No.**	**T/W No.**	**Depth Of T/W**	**Date Of Collection**	**Date Of Testing**	**Test Results**		**Remarks**
								As mg/l	Fe Mg/l	
1	HABRA - 1	Gobradanga W/S Scheme	I	2	138.15 mtr.	11.12.2001	12.12.2001	0.120	4.50	Raw Water (Unsafe)
2	-DO-	-DO-	I	3	222.98 mtr.	11.12.2001	12.12.2001	0.087	1.50	-DO-
3	DO-	-DO-	I	3	222.98 mtr.	21.03.2002	22.03.2002	0.095	1.50	-DO-
4	-DO-	-DO-	II	2	88.83 mtr.	21.03.2002	22.03.2002	0.120	3.80	-DO-
5	-DO-	Maslandapur W/S Scheme	I	1	449 ft.	11.12.2001	13.12.2001	0.054	2.05	-DO-
6	-DO-	-DO-	I	1	449 ft.	05.04.2002	09.04.2002	0.047	0.76	Raw Water Marginally safe
7	-DO-	-DO-	I	1	449 ft.	15.05.2002	16.05.2002	0.068	2.15	Raw Water (Unsafe)
8	-DO-	-DO-	I	1	449 ft.	16.05.2002	17.05.2002	0.068	2.00	-DO-
9	DO-	-DO-	I	2	402 ft.	05.04.2002	09.04.2002	0.080	2.90	-DO-
10	-DO-	DO-	I	2	402 ft.	16.05.2002	17.05.2002	0.080	2.90	-DO-
11	DO-	-DO-	II	1	483 ft.	04.07.2001	05.07.2001	0.060	3.00	DO-
12	-DO-	DO-	II	1	483 ft.	07.07.2001	08.07.2001	0.060	3.00	-DO-
13	-DO-	-DO-	II	1	483 ft.	22.08.2001	23.08.2001	0.055	2.80	-DO-
14	DO-	-DO-	II	1	483 ft.	01.10.2001	03.10.2001	0.060	3.00	-DO-
15	-DO-	DO-	II	1	483 ft.	23.11.2001	26.11.2001	0.062	3.40	-DO-
16	DO-	-DO-	II	1	483 ft.	11.12.2001	13.12.2001	0.080	2.12	DO-
17	-DO-	DO-	II	1	483 ft.	04.04.2002	05.04.2002	0.080	4.75	-DO-
18	-DO-	-DO-	II	2	478 ft.	04.07.2001	05.07.2001	0.064	6.25	DO-
19	DO-	-DO-	II	2	478 ft.	07.07.2001	08.07.2001	0.065	6.25	-DO-
20	-DO-	DO-	II	2	478 ft.	22.08.2001	23.08.2001	0.042	5.00	-DO-
21	-DO-	-DO-	II	2	478 ft.	01.10.2001	03.10.2001	0.040	5.00	Raw Water Marginally safe
22	-DO-	DO-	II	2	478 ft.	23.11.2001	26.11.2001	0.050	5.30	Raw Water (Unsafe
23	-DO-	-DO-	II	2	478 ft.	11.12.2001	13.12.2001	0.082	2.00	DO-
24	DO-	DO-	II	2	478 ft.	04.04.2002	05.04.2002	0.095	2.30	-DO-

(Source: Data given to the visiting JICA-Asia Arsenic Network Team by the Public Engineering Dept., West Bengal, India and given to Mr. S.K.M Abdullah by Choudhury Mufad Ahmed, Sr. Asstt. Secretary, Local Govt. Division)

5.7.3 It may be mentioned that these deep tube wells were installed under a deep tube well project of the Government of West Bengal, India in 1993. At that time all the water sampled showed arsenic content of below 0.05 mg/l (Personal Communication, Dipankar Chakrabarty, IES, Jadavpur Univ. Jan. 2002). It is emphasized that the geological setting of the 24 Parganas Districts is very much similar to the adjoining delta plain geo-district of Bangladesh.

5.7.4 A news item published in, "The Statesman" dated July 5, 2001 a daily news paper of Calcutta, West Bengal, India give some insight of the problems of deep tube wells in Kolkata, West Bengal, India. The news is quoted below:

"The water in many city areas is arsenic contaminated, the state minister for water investigation and development, Mr Nandagopal Bhattacharya, said in the Assembly today.

The affected areas are Alipur, Bansdroni, Golf Gardens, Jyotish Roy Road in Behala, Shahpur, Naktala, Garia and Purbalak.

To stop unplanned sinking of deep tube wells, the government has framed the West Bengal Resources Conservation, Protection and Development (Management, Control and Regulation) Bill 2000. The bill imposes penalty and even imprisonment for those who will sink deep tube wells without permission from the State Water Investigation Directorate (SWID). The Bill had been sent to the President for his assent, Mr Bhattacharya said. An administrative order has made it mandatory to get a SWID clearance before installing a deep tube well."

CHAPTER VI

CONCLUSIONS

- Arsenic contamination of ground water in Bangladesh is from natural source and not from any man made sources.

- Arsenic in Bangladesh was first detected in 1993. By 1999 the magnitude of the arsenic contamination was understood, which was very alarming. Tube wells used for drinking and cooking water was contaminated from a few to up to 90% in 61 districts out of 64 districts. Later it was found that the problem was more acute in 268 upazilas, which were termed as hotspots.

- The exact number of hand tube wells used for drinking and cooking water is not known which varies from 6 million to 11 millions. BADC (April, 2001) in a recent survey estimated that there are about 23,536 deep tube wells (DTW) and 7,07,574 shallow tube wells (STW) which are mechanically operated and 67,878 manually operated shallow irrigation tube wells.

- It is emphasized that more than 90% of the groundwater withdrawn is used for irrigation purpose and less than 10% is used for drinking purpose.

- Division of the aquifer systems has been historically done on the basis of depth or technology of the pumps because very little geological work has been undertaken till now. But considering the geological information available now both in Bangladesh and adjoining state of West Bengal, India it seems that it is more logical that the aquifer systems be divided on the basis of geological age of the aquifer sediments. In this report a conceptual model is proposed for assigning geological age to the aquifer systems on the basis of the proposed classification of the sediments of the Late Pleistocene to the present. The classification of the sediments has been proposed on the basis of sea level fluctuations during the last 21 thousand years.

- The above conceptual model was placed in an international workshop held in January 2002, with about 45 experts in the field of hydrogeology and Quaternary geology, about half of those being from U.K., USA, Japan, Canada, ESCAP and India. Most of the experts accepted the above conceptual models but with suggestions to acquire more information and data, mainly from drilling with subsequent age dating of Holocene sediments.

- The distribution of arsenic both geographically and vertically is related to the geological age of the sediments. Geographically, the tube wells in the delta proper and the flood plain areas are mostly affected by arsenic contamination. The hilly areas and the areas of Pleistocene Uplands of Barind and Madhupur are not affected and ground water from those areas is arsenic safe. Vertically, water of the aquifer sediments older than the Late Pleistocene, that is approximately 18-21 thousand years old has been found to be arsenic safe till now. In most cases water from the aquifers of the Late Pleistocene-Early Holocene are still arsenic safe. Most of the arsenic contaminated tube wells are drawing water from the Middle and Upper Holocene sediments. The younger sediments cover all most the whole of the delta proper and the flood plains of the major rivers. The aquifers of the Dupi Tila sediments of Pliocene age under the Barind and Madhupur uplands and all the aquifers of the hilly areas of the country are arsenic safe. Barind and the Madhupur uplands cover about 10% of the country where the Red Clay sediments of the Madhupur and Barind Residuum are exposed in the surface. But it is assumed that the Dupi Tila sediments can be found within depths of 200 m in more than double of the exposed area if proper investigations are done around the Red Clay areas of the Barind and the Madhupur uplands. Few tube wells that are found to have been arsenic contaminated in the valleys of the hilly areas are drawing water from the Upper Holocene Valley fills.

- Release mechanism of arsenic from the sediments to the ground water is not yet fully understood. But most workers seem to be inclined to support the iron oxide reduction hypothesis.

- The BGS-DPHE study (2001) mentions that there is a distinct trend for the older wells to be more contaminated than the younger wells, though there could be other correlated variables that may account for the trend. But considering the rapid increase in withdrawal of ground water both for drinking and irrigation from 60's onward seem to lead to such a conclusion. Data from the water supply schemes of the North 24-Pargana district from West Bengal, India also seem to lead to such a conclusion.

- Large scale extraction of ground water in the coastal areas has not been encouraged due to possibility of sea-water intrusion or leakage from the upper aquifer.

- Though the water of the Late Pleistocene- Early Holocene aquifers is arsenic safe, data from West Bengal, India shows that once deep wells is sunk and withdrawal of water starts these may not remain safe for long. Draft Final report of JICA on the three upazilas in three southwestern districts of Bangladesh is very clear on this point.

The JICA report mentions that, "The deep ground water in the southern part of Jessore district is free from arsenic & safe at present. However, groundwater levels will be declined by small amount of pumpage because the specific capacity & trnasmissivity is smaller than that of the shallow & the middle aquifers. Accordingly, safety of the deep ground water is assured unless huge amount of ground water is extracted by the irrigation wells which may develop deep aquifer in the future." Arsenic contamination of the deep tube wells in the city of Calcutta should also be kept in mind.

CHAPTER VII

Recommendations

Most of the Recommendations follow the recommendation of the International Workshop organized by the Ministry of Local Government, Rural Development and Cooperatives, Local Government Division, in January 2002.

7.1. **Legal and Administrative Issues**

- Ground water should be considered as a natural resource and a suitable "Ground water Act" should be enacted to control all activities regarding sustainable ground water exploration, development and management.

- A national standard should be established for arsenic content of irrigation by ground water.

- Government should coordinate all stakeholder activities in the sector based upon their approved strategy. Arsenic contamination of ground water has become a major problem faced by the nation. This problem should get the necessary attention and an "Arsenic Policy Support Cell" may be created by reorganizing the existing staff of the Local Government Division of the Government to give the necessary support to the already created High Powered Secretaries Committee and the National Expert Committee. Instead of fully dependent on the foreign consultants who will be more inclined to pursue the objectives of the Donors, the structure and facilities given to the personnel of this cell may be similar to that of the Power Cell of the Ministry of Energy. Local Government Division may obtain the necessary information from the Ministry of Energy.

- There is no single organization in the country that deals with all activities concerned with ground water, although all our neighboring countries have organizations such as, "Ground Water Commission", "Ground Water Board" or "Ground Water Agency" etc. The government should create or identify an organization bringing all the personnel working on ground water under one umbrella. It must be remembered that more than 90% of development of ground water has been done by the private sector under individual or group initiatives. As such major function of such an agency may be limited to the implementation of the above mentioned "Ground Water Act" as well as inter agency coordination necessary for research needed regarding all aspects of ground water including occurrence, development and use.

- Local Government Institutions should be given sufficient resources in recognition of its key role in ensuring provision of arsenic safe and bacteria free water to the people.

7.2. **Screening of Tube wells**

- Government has given due priority of screening all tube wells. It is recommended that the process be accelerated and screening of all tube wells both hand tube wells and irrigation tube wells of all kinds be completed as soon as possible. Priority should be given to the highly arsenic contaminated areas in accordance with the guidelines of the Government's Policy for safe Water Supply and Sanitation 1998. This policy should be updated, as much more information is available by this time.

- Field testing by the Field Kits may remain the main method of screening. But the result obtained from the field should be crosschecked for at least one in twenty samples (5%) by testing in a recognized laboratory by "Atomic Absorption Spectrophotometer" for quality control. Different agencies including the NGOs are using different methodologies for testing by field kits that need standardization.

- Reliable testing facilities should be available to the people at reasonable cost. It needs to be remembered that more than 90% of the tube wells whether for drinking water or for irrigation purposes were sunk and are being maintained by the private individuals or private groups, as such private sector should be given whatever encouragement needed to develop testing facilities.

7.3. **Monitoring of screened tube wells**

- System needs to be developed to monitor the presently safe tube wells, at least once each year. This can be done if under the proposed Ground Water Act, it is made compulsory to renew the license to operate a tube well whether a hand tube wells or mechanically operated deep tube well. In the 1985 Act, that was never implemented, this responsibility was given to the Upazila Councils to renew the licenses. But it is suggested that hand tube wells be the responsibility of the Union Councils and the mechanically operated deep tube wells be the responsibility of the Upazila Councils.

7.4. **Aquifer mapping**

- Detail knowledge of the aquifers is essential for a better management and utilization of groundwater. It is known that the aquifer in the Dupi Tila sediments of the Plio-Pleistocene age below the exposed Red Clay beds in the Barind and Madhupur areas is arsenic safe. Dhaka City is withdrawing a large amount of water from this aquifer, probably highest amount per square kilometer in Bangladesh, but still the water is arsenic safe. Barind and Madhupur uplands cover only 10% of Bangladesh that are expected to increase substantially if we explore up to a depth of 200-250 meters around the exposed areas. With the help of TEM surveys and shallow seismic along with shallow drilling it is possible to identify the Dupi Tila sediments in much larger areas then known at present. For example, drilling for natural gas in Shahbazpur in Bhola district and Muladi in Barisal district has shown that the Dupi Tila sediments occur there at depths of 350-425 and 300-590 meters respectively.

- Depth of the Dupi Tila sediments in the Tippera Surface areas is expected at lesser depths and this also needs to be explored.

- In major areas of the delta proper and the flood plain areas the aquifer sediments belong to the Late Pleistocene to Upper Holocene sediments. No definite criteria have yet been established to identify these sediments as the Late-Pleistocene-Early Holocene, Middle Holocene and Upper Holocene because mostly these are continuously alternative layers of sand, silt and clay. Age based standard composite sections of the sediments of the delta proper and the flood plain areas as well as methods of their field identification need to be established as soon as possible.

- Aquifer characteristics of these standard sections are to be established along with study of the aquifer sediments.

7.5. **Ground water management**

- In the areas where it is known that the ground water is withdrawn from the Dupi Tila sediments of the Plio-Pleistocene age, ground water must still play the major role in providing arsenic safe water to the people.

- In arsenic affected areas, no new tube wells be installed even in the presently arsenic safe aquifer to protect the presently safe water resources. This aquifer is frequently found at greater depths mostly in the Late Pleistocene-Early Holocene sediments. Tube wells should be considered as the last option. In case no other alternative water supply options like surface water treatments, dug wells, pond sand filter, rain water harvesting, solar distillation combined with rain water harvesting, aeration/passive sedimentation etc. are available or is prove to be ineffective than, in very limited areas deep tube wells may be considered. But if the wells are allowed for purpose of drinking water, it must be assured that no irrigation or industrial wells be installed in the above mentioned arsenic safe aquifers. The proposed "Ground Water Act" should be enacted as soon as possible where these conditions are included.

- Attempt should immediately be taken to develop community based pipe water supply system where ever arsenic safe water is available from the deep tube wells used for irrigation.

- For the last 100 years people were encouraged to use tube well water for obtaining bacterial free water. A large scale awareness campaign is needed should be launched to use other alternative water supply options suitable for the areas/ communities concerned, in places of arsenic contaminated water along with all the hazards of such water. Success stories of different alternative water supply options such as those developed by DPHE and Rural Development Academy, Bogra should get special focus in such awareness campaign.

- The government should form a technically qualified committee, under the proposed “Ground Water Act”, clearance from which will be made compulsory under the proposed act for sinking any deep tube well anywhere in the country. This will be similar to the "State Water Investigation Directorate (SWID)" in West Bengal, India.

- The abstraction rate of the safe aquifers needs to be determined to assess the potential for sustainable future water supplies from this resource.

- Determine uses that require arsenic safe water, such as drinking, cooking and agriculture etc.
- Develop enforceable standards for water well design and construction to prevent cross-contamination of aquifers.

7.6 Research

- Immediate and urgent research is needed to develop a cheap digital meter for analysis of arsenic content in water similar to digitized pH meter. This will make screening and monitoring of the tube wells much easier and more reliable.

- Investigate the release mechanism and mobilization as well as mobility of arsenic in the ground water on a priority basis.

- Detailed analyses and transport properties of aquifer sediments should be undertaken.

- Evaluate the effect on hydrological and geo-chemical systems to actual and future development of ground water resources.

- Identify the isotopic signature of the arsenic contaminated water and the arsenic safe water from the deep aquifer to study the interactions between shallow and deep aquifers.

- Soil arsenic analyses in the arsenic contaminated areas should be undertaken and research continued more seriously on the uptake of arsenic by different agricultural products and arsenic in the food chain.

- Investigate the seasonal changes in arsenic concentration and other information required for developing a reliable and cost effective monitoring program.

- Develop simple tools and methodologies to assist local drillers in site and depth selection.

CHAPTER VIII

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List of Abbreviations Used

As	Arsenic
BADC	Bangladesh Agricultural Development Corporation
BAEC	Bangladesh Atomic Energy Commission
BAMWSP	Bangladesh Arsenic Mitigation Water Supply Project
BAPEX	Bangladesh Petroleum Exploration Company
BCSIR	Bangladesh Council of Scientific and Industrial Research
BGS	British Geological Survey
BOGMC	Bangladesh Oil and Gas Development Corporation
BP	Before Present
BRAC	Bangladesh Rural Assistance Committee
BUET	Bangladesh University of Engineering and Technology
BWDB	Bangladesh Water Development
DANIDA	Danish Agency for Development Assistance
DCH	Dhaka Community Hospital
DG	Director General
DPHE	Department of Public Health Engineering
DTW	Deep Tube Well
DWASA	Dhaka Water Supply and Sewerage Authority
EPC	Eastern Progressive Consultants
ESCAPE	Economic and Social Commission for Asia and the Pacific
Fe	Iron
GBM	Ganges-Brahmaputra-Meghna
GCM	General Circulation Model
GSB	Geological Survey of Bangladesh
IAEA	International Atomic Energy Agency
IDA	International Development Association
IES	Institute of Environmental Sciences
JICA	Japan International Cooperation Agency
ka	Before Present
LGRD	Local Government and Rural Development
m	Meter
mg/l	Milligram per liter
Mha	Million Hectors
MMI	Mott MacDonald International
MML	Mott MacDonald Ltd.
MMP	Sir M MacDonald and Partners

MPO	Master Plan Organization
NAMIC	National Arsenic Mitigation Information Center
NGO	Non Government Organization
NIPSOM	National Institute for Preventive and Social Medicine
STW	Shallow Tube Well
SWID	State Water Investigation Directorate
TC	Technical Co-operation
TEM	Transient Electro-magnetic
TW	Tube Well
UK	United Kingdom
UNDP	United Nations Development Program
UNICEF	United Nations Children Emergency Fund
USA	United States of America
USGS	United States Geological Survey
WHO	World Health Organization
µg/l	Microgram per liter

EXECUTIVE SUMMARY

1. Ministry of Local Government, Rural Development & Co-operatives, Local Government Division vide their Notification No. LGD/WS-3/Arsenic/Option-1/2001/127 dated 06-08-2001 formed a "Task Force". The purpose of forming the Task Force was stated as, "It has been decided to form a Task Force to collect and collate relevant hydro-geological information available with various agencies and organizations in the country, develop future plan of action related to availability of arsenic free water and other related matter"

2. The Task Force met in several meetings and decided that it was not possible to undertake new work by its members. By this time BGS-DPHE 2001 report was available which compiled most of the work on the ground water and arsenic issues till 1999. Also the BWDB, DPHE, DPHE-DANIDA, BADC and BAMWSP had collected a large amount of data which was available to the Task Force.

3. From these information a few basic facts emerged, i) arsenic in the ground water is of natural origin, ii) the arsenic contamination of the ground water in Bangladesh both geographically as well as vertically is directly related to the different geological units of the country, iii) all the tube wells in the areas where ground water is withdrawn from the aquifers of the Plio-Pleistocene age or older is arsenic safe, even all most all of the tube wells withdrawing water from the aquifers of the Late Pleistocene-Early Holocene are also arsenic safe but may not remain so for appreciably long time, iv) most of the arsenic contaminated ground water belongs to the tube wells in the Ganges-Brahmaputra-Meghna (GBM) Delta Complex areas and the flood plains of the major rivers which comprises 82% of the country, v) in these areas up to 90% tube wells, mainly the shallow hand pumps in many upazilas are contaminated by higher than Bangladesh Standard of 0.05 mg/l of arsenic in water for drinking and cooking purposes, vi) exact number of the shallow hand tube wells supplying drinking water to most of the population in the country is not known that may vary from 6 to 11 millions, vii) the exact number of tube wells both mechanically or manually operated for irrigation are also not known, viii) approximately more than 90% of the ground water withdrawn is for irrigation purpose and less than 10% for drinking and cooking purpose.

4. In paucity of geological information mainly of the Late Pleistocene-Holocene age (that is the last 21,000 years or so), the earlier workers adopted a conventional classification of the aquifers as the 'shallow', 'middle or main' or ‘deep’ aquifer, which is not related to the geological age or formation from where the water is being withdrawn. It is quite often that sediments of the aquifers of the same geological age or formation may belong two different aquifer systems thus classified.

5. By this time amount of data available because of the work done by the organizations involve in ground water development and also from the oil and gas exploration companies gave some basis to attempt a classification of the sedimentary column of the monotonous fluvio-deltaic sediments of the Late Pleistocene-Holocene age. Already available geological map produced by the Geological Survey in 1999 also gave a clear idea of the geographic distribution of the sediments of different age. Also, some major work undertaken by the research workers in West Bengal, India became available. Taking into consideration of all these information an attempt was made to classify the sediments of the Late Pleistocene age and relate these divisions to the aquifer systems in Bangladesh.

6. The group working on the Task Force report was also given the responsibility to prepare the Country Paper of the Geo-hydrology section for the International Workshop held in January, 2002. This also gave the Task Force an immense opportunity to present the conceptual models of the Late Pleistocene-Holocene geology of Bangladesh and the concept to classify the aquifers on that basis to the most eminent experts from home and abroad.

7. It is important to note that most of the national as well as international experts agreed that future work on geo-hydro-chemical studies should keep in mind the conceptual models of the Late Pleistocene-Holocene geology as well as the classification of the aquifers based on that model.

8. By 1999 the magnitude of the arsenic contamination was understood, which was very alarming. Tube wells used for drinking and cooking water was contaminated from a few to up to 90% in 61 out of 64 districts. Later it was found that the problem was more acute in 268 upazilas, which were termed as hotspots.

9. The exact number of hand pumps used for drinking and cooking water is not known which varies from 6 million to 11 millions. BADC (April, 2001) in a recent survey estimated that there are about 23,536 deep tube wells (DTW) and 7,07,574 shallow tube wells (STW) which are mechanically operated and 67,878 manually operated shallow irrigation tube wells. It is emphasized that more than 90% of the groundwater withdrawn is used for irrigation purpose and less than 10% is used for drinking purpose.

10. Geographically, the tube wells in the delta proper and the flood plain areas are mostly affected by arsenic contamination. The hilly areas covering about 18% and the areas of Pleistocene Uplands of Barind and Madhupur covering about 10% areas of the country along with a small area in the northern most part comprising Panchagarh and a part of Takurgaon districts are not affected and ground water from those areas is arsenic safe. Vertically, water of the aquifer sediments older than the Late Pleistocene that is approximately 18-21 thousand years old has been found to be arsenic safe till now. In most cases water from the aquifers of the Late Pleistocene-Early Holocene are still arsenic safe. Most of the arsenic contaminated tube wells are drawing water from the Middle and Upper Holocene sediments. These younger sediments cover all most the whole of the delta proper and the flood plains of the major rivers.

11. Release mechanism of arsenic from the sediments to the ground water is not yet fully understood. But most workers seem to be inclined to believe in the iron oxide reduction hypothesis.

12. Though the water of the Late Pleistocene- Early Holocene aquifers is arsenic safe, data from West Bengal, India shows that once deep wells is sunk and withdrawal of water starts these may not remain safe for long. Draft Final report of JICA on the three southwestern districts of Bangladesh is very clear on this point. Accordingly, safety of the deep ground water can only be assured for a reasonable time, ground water extracted can be limited only to drinking water and not extended to the irrigation wells.

13. The recommendations presented in this report are in line with the recommendation of the International Workshop held in January 2002, organized by the Ministry of Local Government, Rural Development & Co-operatives, Local Government Division.

14. The major recommendations of this report are:

i) Ground water should be considered as a natural resource and a suitable "Ground water Act" should be enacted to control all activities regarding sustainable ground water exploration, development and management.

ii) A national standard should be established for arsenic content of irrigation by ground water.

iii) Arsenic issues to get the necessary attention, an "Arsenic Policy Support Cell" may be created by reorganizing the existing staff of the Local Government Division of the Government to give the necessary support to the already created High Powered Secretaries Committee and the National Expert Committee, instead of fully dependent on the foreign consultants who will be more inclined to pursue the objectives of the Donors, the structure and facilities given to the personnel of this cell may be similar to that of the Power Cell of the Ministry of Energy.

iv) There is no single organization in the country that deals with all activities concerned with ground water, such as, "Ground Water Commission", "Ground Water Board" or "Ground Water Agency" and it is necessary that the government should create or identify an organization bringing all the personnel working on ground water under one umbrella.

v) It must be remembered that more than 90% of development of ground water has been done by the private sector under individual or group initiatives, as such major function of this agency may be limited to the implementation of the above mentioned "Ground Water Act" as well as inter agency coordination necessary for research needed regarding all aspects of ground water including occurrence, development and use.

vi) Local Government Institutions should be given sufficient resources in recognition of its key role in ensuring provision of arsenic safe and bacteria free water to the people.

vii) System needs to be developed to monitor the presently safe tube wells, at least once each year and this can be done if under the proposed Ground Water Act, it is made compulsory to renew the license to operate a tube well whether a hand tube wells or mechanically operated deep tube well.

viii) It is known that the aquifers in the Dupi Tila sediments below the exposed Red Clay beds in the Barind and Madhupur areas are arsenic safe. Barind and Madhupur uplands cover about 10% of the country that are expected to increase substantially if we explored up to a depth of 200 – 300 m around the exposed areas and in these areas ground water can still play a major role in the supply of arsenic free drinking water.

ix) Detail knowledge of the aquifers is essential for a better management and utilization of ground water, as such detailed mapping of all the aquifers including all aquifer characteristics must get the highest priority of the immediate work program of any kind.

x) In major areas of the delta proper and the flood plain areas the aquifer sediments belong to the Late Pleistocene to Upper Holocene sediments but no definite criteria has yet been established to identify these sediments as the Late-Pleistocene-Early Holocene, Middle Holocene and Upper Holocene because mostly these are continuously alternative layers of sand, silt and clay which make it necessary that age based standard composite sections of the sediments of the delta proper and the flood plain areas as well as methods of their field identification need to be established as soon as possible.

xi) The government should form a technically qualified committee under the proposed "Ground Water Act", clearance from which will be made compulsory under the proposed act for sinking any deep tube well anywhere in the country.

xii) The abstraction rate of the safe aquifers needs to be determined to assess the potential for sustainable future water supplies from this resource.

xiii) Immediate and urgent research is needed to develop a cheap digital meter for analysis of arsenic content in water similar to digitized pH meter which will make screening and monitoring of the tube wells much easier and more reliable.

xiv) Identify the isotopic signature of the arsenic contaminated water and the arsenic safe water from the deep aquifer and to study the interactions between shallow and deep aquifers.

xv) Soil arsenic analyses in the arsenic contaminated areas should be undertaken and research continued more seriously on the uptake of arsenic by different agricultural products and arsenic in the food chain.