Groundwater Resources Development in Bangladesh: Contribution to Irrigation for Food Security and Constraints to Sustainability

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Abstract

Bangladesh occupies the major part of the delta of the Ganges-Brahmaputra-Meghna (GBM) river system and lies mostly within the Bengal Basin. The unconsolidated near surface Pleistocene to Recent fluvial and estuarine sediments underlie most of Bangladesh, generally form prolific aquifers, and groundwater is drawn predominantly from these quaternary strata. Since the 1960's, groundwater has been used extensively as the main source of drinking and irrigation water supply. About 75 percent of cultivated land is irrigated by groundwater and the remaining 25 percent by surface water. Of the abstracted groundwater about 70-90 percent is used for agricultural purposes and the rest for drinking and other water supplies. The country started emphasizing groundwater irrigation in mid-seventies with deep tube wells (DTW), but soon shifted its priority to shallow tube wells (STW).

The groundwater resource is one of the key factors in making the country self sufficient in food production. Groundwater-irrigated agriculture plays an important role in poverty alleviation and has greatly increased food production. The need for conjunctive use of surface and groundwater is highlighted in the National Water Policy (NWPo, 1999). This policy has established a linkage between water resources and the rural livelihood and ultimately the link to poverty alleviation. The country's GDP is highly dependent on the development of water resources in general. Trends indicate that farmers are becoming increasingly productive as a result of enhanced access to irrigation through groundwater (BMDA, 2000). For groundwater irrigation, the prime source of power energy for lifting water is fossil fuel (diesel or petrol) and electricity. Hence the linkage between the energy for lifting groundwater and irrigation economics is also very important.

Until now, availability of groundwater has not been a constraint to agricultural development. But this resource is increasingly facing various problems including quality hazards in many areas where the exposure to pollution from agriculture, urbanized areas and industrial sites as well as arsenic contamination in shallower groundwater aquifers makes the water unfit for human consumption and in some cases even for irrigation purposes. High rates of pumping for irrigation and other uses from the shallow aquifers in coastal areas may result in widespread saltwater intrusion, downward leakage of arsenic concentrations and the general degradation of water resources. Besides, use of agrochemicals *may cause contamination of shallow groundwater and sediments. Continuous decline of groundwater tables due to over-withdrawal has also been reported from some areas. Thus the overall situation calls for urgent groundwater management for sustainable development. Groundwater management must adopt an integrated approach taking into account a wide range of ecological, socio-economic and scientific factors and needs.*

Introduction

The Ganges-Brahmaputra-Meghna river system has the largest total sediment load in the world, eroded from the Himalayas and generating fluvio-deltaic sediment layers, which form productive fresh water aquifers in most parts of Bangladesh. The country has gained a significant success in the development of groundwater for its irrigated agriculture and rural water supply. The country started emphasizing groundwater irrigation in the mid-seventies with deep tube wells (DTW), but soon shifted its priority to shallow tube wells (STW). The growth of minor irrigation flourished just after the independence of 1971. Until 1950's farmers used only traditional means of irrigation, the swing basket and '*doan*'. These traditional technologies are capable of lifting water up to about 1 to 1.5m. The first major irrigation project started in the early sixties in the Thakurgaon area, northwest of Bangladesh under Bangladesh Water Development Board (BWDB) sinking 380 DTWs. Increasing demand due to the growth of population made it necessary to increase food production. DTW and STW irrigation was extended rapidly during the late 1970's and the 1980's. As a result the target for self-sufficiency in food has almost been achieved. Minor irrigation using groundwater has, in fact, been the single most important driving force behind the steady expansion of agricultural output in recent years. Besides STW and DTW, the minor irrigation also involves pumping technologies like deep set/ very deep set shallow tube wells (DSSTW/ VDSSTW), force mode tube wells (FMTW) and low lift pumps (LLP), etc. DTWs are cased wells where pump is set within the well below the water level. A diesel engine or an electric motor is mounted above the well and is connected to the pump by shaft. STWs are irrigation wells fitted with a suction mode centrifugal pump and a small diameter well to depths of 4 to 6 m. Diesel engines or electrical motors coupled with centrifugal pumps are placed at the wellhead and the casing itself acts as a suction line. DSSTWs and VDSSTWs are set into a pit of about 2m where water table decline below suction capacity of 7-8m. LLPs are significant for surface water irrigation mounted on a floating platform. The pumping capacities of STW, DTW and LLP are around 12,000; 50,000 and 12,000-50,000 m^3/day, respectively. However, the majority of the technologies are STW and LLP. STW has increased in numbers throughout the country from 133,800 in 1985 to 925,200 in 2004 (Table 1). There were 24,700 DTWs in operation in 2004. In the minor irrigation sector, based on both groundwater as well as surface water, groundwater is likely to continue to be the main source of irrigation expansion and a key contributor to future agricultural growth.

STWs are driven by surface mounted centrifugal pumps, which can draw water from up to 7.5m depths. These are relatively inexpensive, easy to install, easy to maintain and are shared between small groups of farmers. With the continuous abstraction, the water table in many areas started declining and the STWs were no

Table 1. Groundwater development by STW[1] and DTW[2] (BADC, 2005)

Year	No. of STW	No. of DTW	Year	No. of STW	No. of DTW
1985	133,800	15,300	1993	348,900	25,700
1988	186,400	23,500	1995	488,900	26,700
1989	217,900	23,300	1996	556,400	27,200
1991	270,300	21,500	1998	664,700	25,400
1992	309,300	25,500	2001	707,600	23,500
			2004	925,152	24,718

[1] STW = Shallow Tubewell, [2]DTW = Deep Tubewell

more capable of pumping under suction mode during the peak irrigation period.

The development of groundwater for irrigation has had a major positive impact on food grain production in Bangladesh. Hence, groundwater irrigated agriculture plays an important role in poverty alleviation. However, excessive groundwater abstraction for irrigation has posed a great challenge to the rural drinking water supply using hand-operated tube wells. The presence of arsenic has further worsened the situation. In urban and peri-urban areas, groundwater abstraction has lowered water levels beyond the potential of natural recharge. Thus the overall situation calls for an urgent groundwater management and sustainable development. Statistics reveal that about 75 percent of total cultivated land is irrigated by groundwater and 25 percent by surface water (Table 2).

Table 2. Status of irrigation in Bangladesh, 1995-1996 (WARPO, 2001)

Mode of irrigation	Type of equipment	No. of equipment in operation	Area irrigated ha	%
Groundwater	STW	556,400	1,937,700	57
	DSSTW[1]	19,300	64,600	2
	DTW	27,200	537,900	16
Surface Water	LLP[2]	60,700	577,200	17
	TRAD[3]	673,000	226,400	7
Others		161,800	50,100	1
Total			3,394,900	100

[1]DSSTW = Deep set shallow tubewell, LLP = Low lift pump TRAD = Treadle pump.

For groundwater irrigation, the prime source of power energy for lifting water is fossil fuel (diesel or petrol) and electricity. Both sources of power/energy are costly for the rural people. However, irrigation has direct impact on food and livelihood security. Hence, in the context of energy sector instruments (reform/ restructuring of energy sector, pricing of power, reliability of supply) the linkage between the energy and irrigation economics is very important.

National Water Policy and Groundwater

The purpose of all water resources-based policies and those associated with water resources such as agriculture, fisheries and environment is to allocate resources and allow the development in such a way as to maximise the benefits to the population and enhancing the resources itself for a sustainable development. The need of conjunctive use of surface and groundwater is highlighted in the GoB's National Water Policy (NWPo) formulated in 1999. The NWPo has provided broad principles of development of water resources and their rational utilization under different constraints. It is the policy to ensure that all necessary means and measures will be taken to manage the water resources of the country in a comprehensive, integrated and equitable manner. This policy has established a linkage between the water resources and the rural livelihood and ultimately to poverty alleviation.

To address issues related to harnessing and development of groundwater and the general management of water resources in an efficient and equitable manner the following objectives are highlighted in the NWPo,

- Develop a state of knowledge and capability that will enable the country to design future water resources management plans by itself addressing economic efficiency, gender equity, social justice and environmental awareness to facilitate achievement of the water management objectives through broad public participation.
- Improve efficiency of resource utilization through conjunctive use of all forms of surface water and groundwater for irrigation and water supply. Develop and disseminate appropriate technologies for conjunctive use of rainwater, groundwater and surface water.
- Strengthen appropriate monitoring organizations for tracking groundwater recharge, surface and groundwater use and changes in surface and groundwater quality. Preserve natural depressions and water bodies in major urban areas for recharge of underground aquifers. Take steps to protect the water quality and ensure efficiency of its use.
- Encourage future groundwater development for irrigation through both the public and private sectors, subject to regulations that may be prescribed by government from time to time.

The NWPo also emphasizes collaboration with co-riparian countries to establish a system for exchange of information and data on relevant aspects of hydrology, morphology, water pollution, ecology, changing watershed characteristics, cyclones, droughts, flood warning etc. and to help each other understand the current and emerging problems in the management of the shared water resources as well as to seek international and regional cooperation for education, training, and research in water management.

The government reserves the right to allocate water to ensure equitable distribution, efficient development and use and to address poverty. The policy is to continue with irrigation expansion with tube wells and hand-operated tube wells will be gradually replaced by force mode '*Tara*' pumps with increased lift. Fresh drinking water is pumped from deeper layers in the salinity-prone southern part using force mode deep wells. Cities and urban areas are facing the problem of receding water table due to heavy groundwater extraction for piped water supply. Dhaka city experiences a declining water level at the rate of 1 to more than 1.5 m each year. In the wake of abstraction beyond natural recharge potential, the policy is to gradually shift emphasis from groundwater-based water supply towards surface water based water supply around the city area.

Groundwater Aquifers in Bangladesh

Generally, four major physiographic units exist at the surface of Bangladesh (Figure 1). These are, (a) Tertiary sediments in the northern and eastern hills; (b) Pleistocene Terraces in the Madhupur and Barind Tracts; (c) Recent (Holocene) floodplains of the Ganges, the Brahmaputra and the Meghna rivers and (d) the Delta covering the rest of the country. Most of the present land surface of the country covered by the Holocene flood plains deposited by the GBM river systems. About 6000 year ago sea level was much lower and the major rivers dissected deep channels adjacent to the Madhupur and Barind Tract areas. Deltaic floodplains with some Pleistocene terraces constitute the major part of the Basin. Basinal sediments consist primarily of unconsolidated alluvial and deltaic deposits except the complex geology area of pre-quaternary sediments that cover the northeastern and southeastern hilly areas of the country. Together with the tertiary sedimentary sequences the maximum thickness of the deposit is more than 20km.

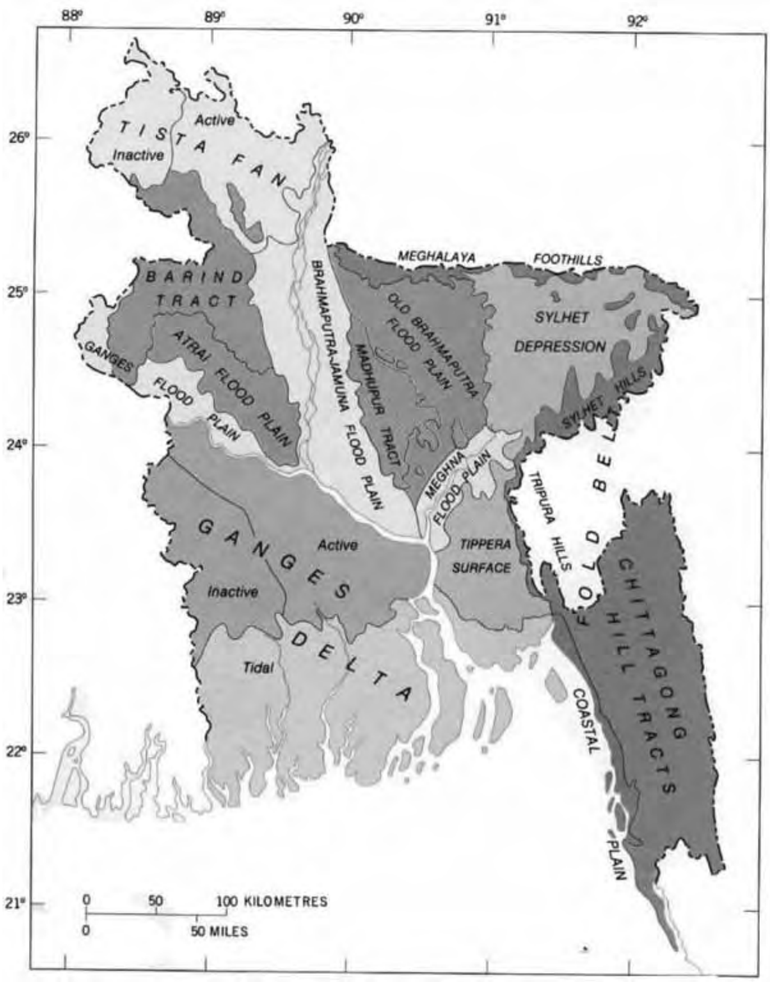

Figure 1. Phygiographic map of Bangladesh (Alam et al, 1991)

The tropical monsoon climate together with favorable geological and hydrogeologic conditions indicates high potential storage of groundwater in the country. The unconsolidated near surface Pleistocene to Recent fluvial and estuarine sediments underlying most of Bangladesh generally form prolific aquifers. Thick semi-consolidated to unconsolidated fluvio-deltaic sediments of Miocene age to the recent form many aquifers. But except the Dupi Tila sandstone formation of the Plio-Pleistocene age, others are too deep to consider for groundwater extraction except in the hilly region (18 percent of Bangladesh). Most of the groundwater withdrawn for domestic or agricultural purposes in the Barind and Madhupur uplands areas is from the Dupi Tila aquifers. The floodplains of the major rivers and the active/inactive delta plain of the GBM Delta Complex occupy 82 percent of the country. From the available subsurface geological information it appears that most of the good aquifers occur between 30 to 130 m depth. These sediments are cyclic deposits of mostly medium to fine sand, silt and clay. The individual layers cannot be traced for long distances, horizontally or vertically.

On a regional basis, three aquifers have been identified and named by BWDB-UNDP (1982) (Figure 2). These are,

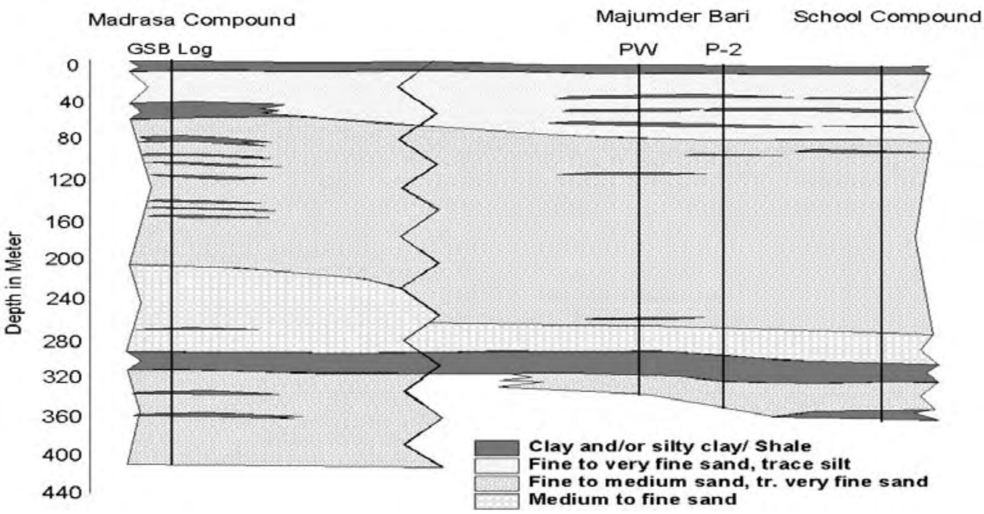

Figure 2. Aquifer system in lower delta floodplain, Sreerampur, Chandpur (BWDB, 2004)

The Upper (Shallow) or the Composite Aquifer

Below the surface clay and silt unit, less than few to several hundred meters thick very fine to fine sand, in places inter bedded or mixed with medium sand of very thin layers are commonly encountered. The thickness of this zone ranges from a few meters in the northwest to maximum of 60m in the south. Over most of the country it represents the upper water-bearing zone.

The Main Aquifer

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

The Deeper Aquifer

The deeper water-bearing unit is separated from the overlying main aquifer by one or more clay layers of varied thickness. Deep aquifers generally include those aquifers whose waters have no access vertically upward and downward but flow very slowly along the dips and slopes of the aquifers. The depths of the deep aquifers in Bangladesh containing usable water range from 190 to 960 m on the Dinajpur platform and 250 to 1500 m in the basin and mainly include the sediments of the Gondwana, Jaintia, Surma and Tipam groups and parts of the Dupi Tila Sandstone Formation (Khan, 1991). This water bearing-zone comprises medium to coarse sand in places inter-bedded with fine sand, silt and clay. At present the water-bearing formation deeper than 150-200 m are being exploited on limited basis in the coastal zone to cater to the need of municipal water supply and in the rural areas for drinking purpose. Large scale extraction has not been encouraged due to possibility of seawater intrusion or leakage of saline or arsenic contaminated water from the upper aquifer.

Considering age, except the hilly regions, aquifers can be divided into following two categories for floodplains, delta and terrace areas.

The Pleistocene Aquifers

The major terrace areas considered being of Pleistocene age of highly oxidized sediments including the Madhupur Tract in greater Dhaka, Tangail and Mymensingh districts and the Barind Tract in greater Rajshahi and Bogra districts. The Plio-Pleistocene aquifers of the Dupi Tila Formation lie beneath the Pleistocene Madhupur Clay Formation (Figure 3). This aquifer is composed of light grey to yellowish brown, medium to coarse sand with pebble beds and dated as about or more than

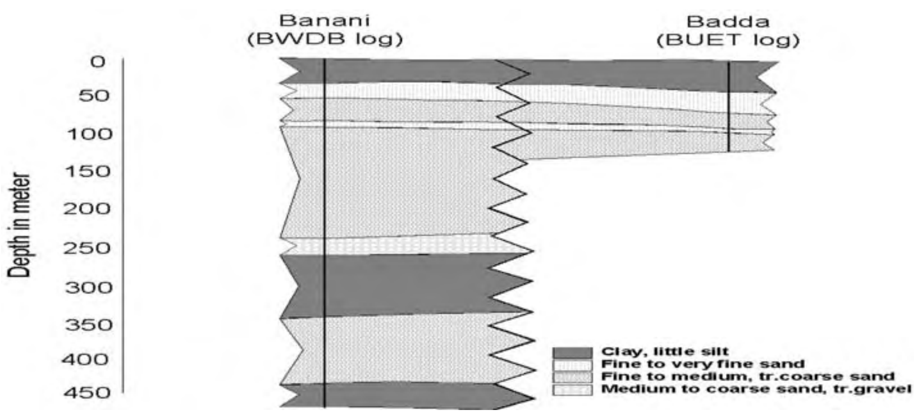

Figure 3. Pleistocene Dupi Tila aquifer of Dhaka city (Zahid et al, 2004)

20,000 years old (Aggarwal et al., 2000). All of the water for Dhaka city is withdrawn from this aquifer and the water is as yet arsenic safe.

This aquifer is confined to semi-confined in nature. The reddish-brown mottled deposits underlain by lower Pleistocene Dupi Tila Formation are more compacted and weathered and generally have a higher content of clay and silt than the recent Holocene alluvial deposits. The Dupi Tila forms the main aquifer beneath the terrace areas. Madhupur clay has been buried by younger sediments only on the margins where it lies beneath floodplain deposits (BWDB-UNDP, 1982).

With the existing deep tube well records in and around Manikganj district, two alluvial aquifer systems named Madhupur aquifer (Figure 4) and Jamuna aquifer are classified (Davies, 1994). The older Madhupur aquifer occurs within Dupi Tila Formation sediments that underlie the Madhupur Pleistocene terraces. The younger Jamuna aquifer system occurs within grey non-indurated alluvial sediments of the Dhamrai Formation that infill the Jamuna, Brahmaputra and Ganges river valleys. The Jamuna aquifer system occurs within non-indurated grey alluvial sands and gravels at the Late Quaternary Dhamrai Formation. The Lower Dhamrai Formation is fining upward succession of coarse sand and gravels deposited by strongly flowing braided rivers and were deposited between 20,000 and 48,000 year BP. The upper Dhamrai Formation with coarse to medium sands of maximum 7000year BP age were also deposited as a series of upward fining units, from smaller braided and meandering rivers.

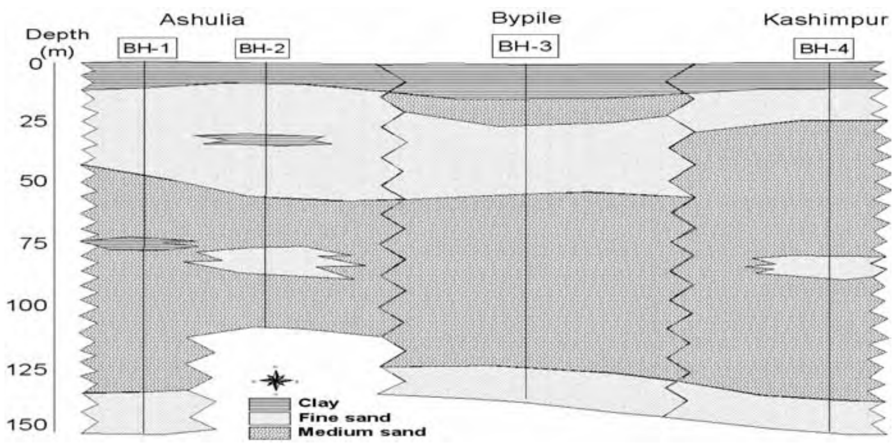

Figure 4. Madhupur Dupi Tila aquifer adjacent to Jamuna aquifer in Savar-Gazipur area ([a]Zahid et al, 2004)

Monsur (1990) dated the Dupi Tila Formation as being more than 900,000yrs old. The Dupi Tila sandstone forms the saturated zone on the Dinajpur shield and platform (Figure 5). This Dupi Tila Sandstone Formation extends all over Bangladesh probably excepting the western two third of the delta. The total thickness of the aquifers measures more than 300 m.

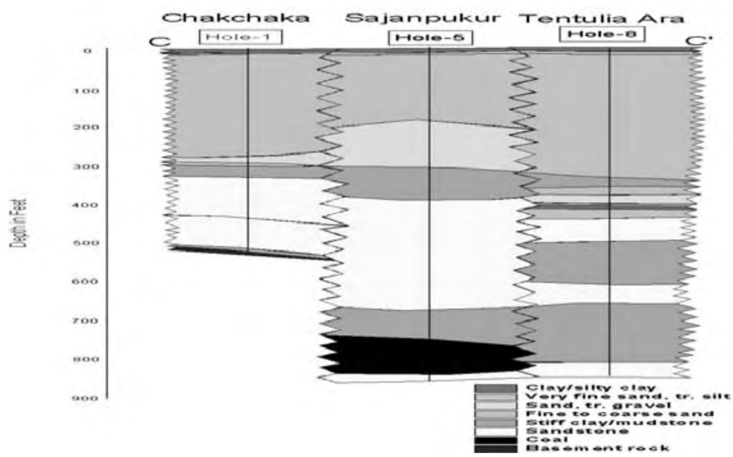

Figure 5. Sandstones reserve water in Platform area

The Holocene Aquifers

Other than the terrace areas, the remaining part of the Bengal Basin consists predominantly of Holocene alluvial and deltaic sediments. The age of Holocene aquifers range from 100 to more than 3,000 years (Aggarwal et al., 2000). In the land above tidal inundation, these deposits are composed primarily of silt and sand of appreciable thickness extending to depth of more than hundred meters. In the lower delta, they are principally silt, clay and peat. These sediments contain high water content and are generally loosely compacted and usually grey in color. Holocene and Pleistocene alluvium form the principal aquifers in the country.

The Recent alluvium deposits are of varying characteristics classified from piedmont deposits near the foot of the mountains to inter-stream alluvium including deposits in the interior, merging with swamp and deltaic deposits approaching the southern shoreline. Stratified deposits of sand, silt and clay constitute the subsurface formations. The character of the deposits varies remarkably vertically. Coarse and medium sand with gravel are found mainly in the northern border areas of greater Rangpur and Dinajpur districts. The sediments of coastal areas and northwestern part of Rajshahi district are predominantly silt, clay and fine sand with occasional coarse sand. The deeper aquifer consisting of fine to medium sand vertically extends 180 to more than 250 m depths from the surface and is separated by 10 to 50 m thick clay layer from the overlying aquifer (Figure 6) and is promising for groundwater exploration in Chittagong coastal plain aquifer (Zahid et al., 2004).

Rainwater is the principal source of groundwater recharge in Bangladesh. Floodwater, which overflows the river and stream banks, also infiltrates into the groundwater. Water from permanent water bodies (rivers, canals, wetlands, ponds, irrigated fields etc.) that lie above the water table also percolates to the groundwater. In the Pleistocene terraces, the recharge occurs through the incised antecedent drainage channels that cut through near-surface clays into the underlying sands. The greatest scope of recharge is within the coarse grained sediments and the least is within the fine-grained sediments like clay. The regional hydraulic gradient is low, reflecting the low topographic gradient. The groundwater flows generally

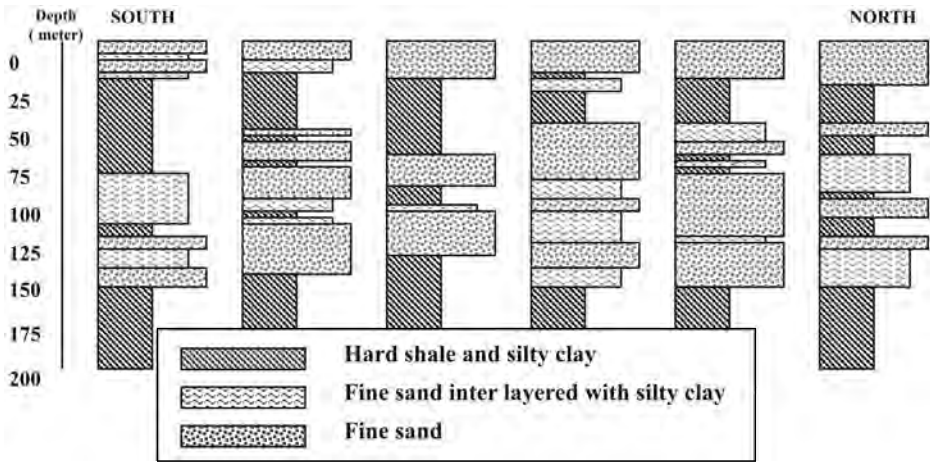

Figure 6. Rangadia coastal plain aquifer, Chittagong (Zahid et al., 2004)

from north to south. Most of the flow probably takes place through the in-filled incised channels under the major rivers.

Groundwater Irrigation and Poverty Alleviation

GDP in Bangladesh is highly dependent on the development of water resources in general. Trends indicate that smallholder farmers are becoming increasingly productive as a result of enhanced access to irrigation through groundwater. In terms of poverty alleviation, the small and marginal landholders are the primary target group for the National Water Management Plan (NWMP) when it comes to improving access to irrigation, enhancing their productivity, cropping intensities and the volume of agricultural products. For various social and economic reasons, these small and marginal farmers have been unable to increase production sufficiently, and consequently have been targeted as the focal points for development assistance.

To improve the quality of life of the people in the Barind area as well as to support and sustain agricultural growth, and improving the environmental situation the Barind Integrated Area Development Project (BIADP) (BMDA, 2000) has been under taken since 1986 covering 767,900 ha gross area of three Barind districts-Rajshahi, Nawabganj and Noagaon (40 percent of total). It is estimated that 62 percent of total cultivable area are irrigable utilizing groundwater. Before the project, Barind Tract was an unfavorable agricultural section of the country. With the increased and assured availability of irrigation water, the agricultural scenario has fundamentally changed. Most irrigation development in the project area has taken place through the use of DTWs and STWs. In all the Barind districts, the increase in number of DTWs has been manifested in the overall agricultural growth. The increase in yield of *Boro* rice is 43 to 120 per cent in the districts within the project area. A contributing factor to the spread in cultivation of modern rice varieties is the increased availability of irrigation water. According to the farmers, they would not have achieved in two decades what they have achieved in the last few years due to BMDA interventions. Cropping intensity in the project area increased from 141 percent in 1991 to 200 percent in 1998-99. At the beginning of the project, the three Barind districts were marginally surplus food producers, however, with the introduction of DTWs, their surplus over the project period increased substantially. Income level increased because of increasing agricultural production, increased demand for labor and increased wage rates.

Besides implementing a comprehensive package of agricultural development activities/ interventions, BIADP also introduced various associated programs like afforestation, re-excavation of ponds, construction of cross-dams, installation and electrification of DTWs etc. All these components played a positive role in improving the livelihood of the people with positive and highly satisfactory economic returns. The total cost recovery of the project was worked out to be Tk. 1,067 million of which the recovery from the beneficiaries of irrigation interventions was Tk. 1,013 million (Table 3). The financial and economic annual total incremental benefits of the project for the year 1999-2000 were estimated at Tk. 2,917 million and Tk. 2,603 million, respectively. All this indicates that the investment of the project has been economically and socially profitable that has had direct impact on poverty alleviation.

Table 3. Statement of cost recovery and financial sustainability of BIADP in million Taka (BMDA, 2000)

Year	Total cost	No. of DTWs in operation	Cost of irrigation components	O and M cost of irrigation	O and M cost of others	Total cost recovery	Irrigation cost recovery
1986-90	965	529	667	106	22	104	80
1990-91	712	871	712	-	-	-	-
1991-92	170	2,193	162	31	1	22	22
1992-93	441	3,173	415	49	2	53	49
1993-94	641	3,650	547	45	5	66	61
1994-95	881	5,066	802	70	3	139	135
1995-96	720	5,516	655	44	3	151	146
1996-97	633	5,611	607	34	1	130	128
1997-98	397	6,044	353	54	6	130	126
1998-99	294	6,247	247	81	12	174	170
1999-00	111	6,185	97	45	6	99	96
Total	5,967		5,264	558	62	1,067	1,013

Present value of 1 million Taka = 16,000 USD (Approx.).

Benefit-Cost Analysis of Various Pump Technologies to Groundwater Irrigation

Detailed cost analysis made by the NWMP on tube well technologies operating in the agricultural sector shows that energy cost is about 70-80 percent and capital costs is only 22-26 percent of total annual cost for STWs. In Bangladesh, diesel (fuel) is taxed while electricity is subsidised. The operating costs of FMTWs are similar to that of STWs but can draw water from greater depths. The present trend in using STW is good enough as it meets the present need. It is envisaged that groundwater abstraction can be kept profitable with FMTW even with the receding water table if supplies of electricity are made available at affordable prices in the future. Supply of energy in terms of electricity and diesel fuel plays an important role in the steady expansion of irrigated agriculture.

To grow more food grains in dry *Rabi*-season under minor irrigation different types of irrigation technologies are used in Bangladesh. An NWMP study (Hossain et al., 2002) reveals that LLPs are the cheapest form of minor irrigation, with their generally low pumping lifts and technical simplicity (Table 4). Total annual costs of LLP diesel pumping are only Tk. 0.30/m^3 and Tk. 0.23m^3 at financial and economic prices, or Tk. 3300/ha and Tk. 2500/ha,respectively. STWs are the next cheapest mode. Typical diesel-powered STW operating under static water level of 5 m from the ground surface has average costs of Tk. 0.69/m^3 and Tk. 0.53/m^3 at financial and economic prices, or Tk. 7600/ha and Tk. 5800/ha, respectively. This is more than double the LLP costs. Tube well pumping costs increase rapidly as groundwater levels decline. For an average 7 m depth, diesel-powered STWs set into a pit of 2 m (DSSTWs) costs about Tk. 0.90/m^3 and Tk. 0.69/m^3, or Tk. 9900/ ha and Tk. 7600/ha,respectively at financial and economic prices. However electricity-powered STWs with a lift of 7m costs around Tk. 0.40/m^3. FMTWs also suffer from high capital costs relative to the suction mode pumps. Although the annual financial cost of an electric FMTW (Tk. 0.87/m^3) is lower than a diesel DSSTW (Tk. 0.90/m^3), the capital investment is much higher. DTW irrigation has

Table 4. Annual minor irrigation costs (1998-99)

Technology	LLP	STW	STW	DSSTW	VDSSTW	VDSSTW	FMTW	DTW
Static water level (m)	4m	4m	5m	7m	9m	11m[(1)]	13m	13m
Average command area (Base Case) (ha)								
Diesel pumping	8	3.2	3.2	3.2	3.2	3.2	-	16
Electric pumping	16	4.4	4.4	4.4	4.4	4.4	4.6	22
Total annual costs with "average" pumpage								
Diesel: Financial	26,366	19,918	24,314	31,807	36,005	40,468	-	176,928
Diesel: Economic	20,207	15,307	18,635	24,385	27,903	31,341	-	134,554
Electric: Financial	21,322	13,597	15,332	19,340	24,477	28,024	41,027	149,230
Electric: Economic	22,879	13,449	15,480	19,726	25,025	29,152	39,891	139,176
Annual costs per ha with "average" pumpage								
Diesel: Financial	3,296	6,224	7,598	9,940	11,252	12,646	-	11,058
Diesel: Economic	2,526	4,783	5,824	7,620	8,720	9,794	-	8,410
Electric: Financial	1,333	3,090	3,485	4,395	5,563	6,369	8,919	6,783
Electric: Economic	1,430	3,057	3,518	4,483	5,687	6,625	8,672	6,326
Annual cost per m^3 water with "average" pumpage								
Diesel: Financial	0.30	0.57	0.69	0.90	1.02	1.15	-	1.01
Diesel: Economic	0.23	0.43	0.53	0.69	0.79	0.89	-	0.76
Electric: Financial	0.12	0.28	0.32	0.40	0.51	0.58	0.81	0.62
Electric: Economic	0.13	0.28	0.32	0.41	0.52	0.60	0.79	0.58

Source: NWMPP Note: [(1)] Use of VDSSTWs to pump from this depth is not common at present.

the highest capital costs of the four basic models. Electric DTWs are cheaper than diesel DTWs. Cost of electric DTWs is more then three times that of a diesel DSSTW.

Benefit-cost ratio determined from the NMWP study is shown in Table 5. The study shows that irrigation by LLP and STW, the most widespread forms of minor irrigation, are highly profitable in both financial and economic terms. For the two widely applicable models, LLPs, and STWs with an average static water level of 5m, both with diesel pump sets; the estimated average financial returns after deducting the full cost of irrigation are about Tk. 11,600/ha and Tk. 7300/ha, respectively. The benefit-cost ratios are 4.5:1 and 2.0:1. Even a DSSTW with a static water table of 7m yields a financial profit of Tk. 5000/ha and a benefit-cost ratio of 1.5:1.

Table 5. Benefit-cost ratios from minor irrigation (Hossain et al., 2002)

Irrigation technology	LLP	STW	STW	DSSTW	VDSSTW	VDSSTW	FMTW	DTW
Static water level (m)	4m	4m	5m	7m	9m	11m	13m	13m
Average command area (Base Case) ha								
Diesel Pumping	8	3.2	3.2	3.2	3.2	3.2	-	16
Electric Pumping	16	4.4	4.4	4.4	4.4	4.4	4.6	22
Annual irrigation benefits per ha (based on boro cropping) (Tk)								
Financial	14,900							
Economic	14,000							
Benefit-cost ratios at 12%								
Diesel: Financial	4.52 : 1	2.39 : 1	1.96 : 1	1.50 : 1	1.32 : 1	1.18 : 1	-	1.35 : 1
Diesel: Economic	5.54 : 1	2.93 : 1	2.40 : 1	1.84 : 1	1.61 : 1	1.43 : 1	-	1.66 : 1
Electric: Financial	11.18 : 1	4.82 : 1	4.28 : 1	3.39 : 1	2.68 : 1	2.34 : 1	1.67 : 1	2.20 : 1
Electric: Economic	9.79 : 1	4.58 : 1	3.98 : 1	3.12 : 1	2.46 : 1	2.11 : 1	1.61 : 1	2.21 : 1

Source: NWMPP estimates.

So, better operation and maintenance of DTWs, improving the management efficiency, increasing electrification of DTW, sinking new DTWs in the potential areas may increase crop production that can play important role in poverty alleviation.

Major Problems in Groundwater Development

The water resources of Bangladesh are facing different problems including quality hazards in many areas where the exposure to pollution from agriculture, urban areas and industrial sites as well as arsenic contamination in shallower groundwater aquifers makes the water unfit for human consumption and in some cases even for irrigation purposes. It has been estimated that the population of 61 districts has been suffering from arsenic contamination (DPHE, 2001).

To protect the population from water-borne diseases, primarily from the consumption of polluted and dirty surface water, effort has been made throughout the country during the past two decades to replace drinking water supplies from surface water with groundwater and millions of shallow tube wells (<100m deep) have been installed in the shallower part of the unconfined/leaky aquifers. Since the early 1990's, after the discovery of arsenic contamination in shallow groundwater, deeper tube wells have been installed (100- 250m depth) in an attempt to find safe groundwater for drinking water supplies. Most of these tube wells have little or no arsenic, but the wells often contain high concentrations of iron and high salinity. Below this level good quality groundwater can be found if confining clay bed separates the upper aquifer from deeper aquifer like many areas of lower delta (Figure 7).

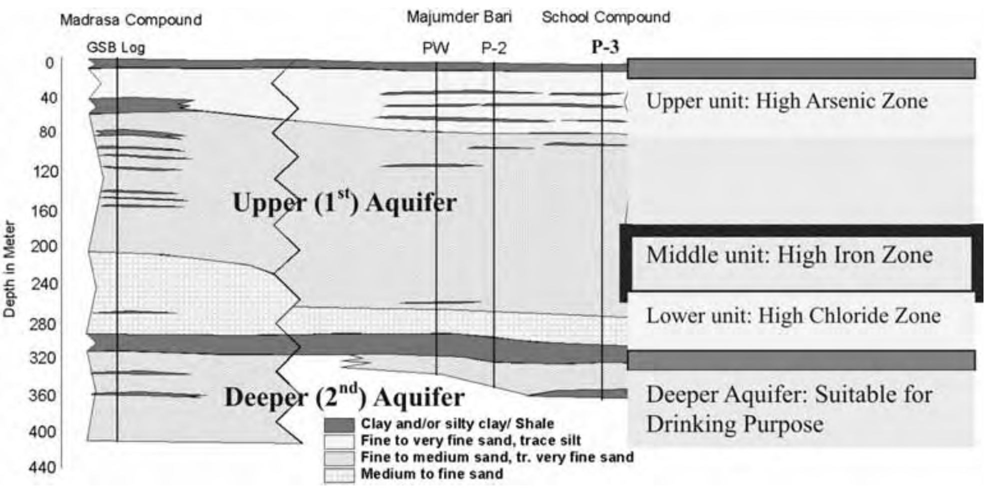

Figure 7. Generalized distribution of water quality hazard in lower deltaic plain aquifer, Sreerampur, Chandpur (BWDB, 2004)

Impact of Irrigation Pumping on Groundwater Drawdown

In rural areas, lowering of the groundwater table due to groundwater abstraction disturb seasonally shallow hand tube wells used for drinking water supply. Besides, the cost of irrigation pumping increases with the lowering of the water table. The over-withdrawal of groundwater for agriculture mainly causes drawdown in the dry season. However, the groundwater table regains its static water level in most of the country with sufficient recharge of rainwater (Figure 8-A).

In the highly populated urban areas, most noticeable in Dhaka city, recharge to the aquifers is much less than abstraction of groundwater. The lowering trend of groundwater level during the last 32 years is 20 to 30m with an average decline of more than 1.0 m/year. Continuous decline in water level with little or even no fluctuation has been observed (Figure 8-B). This lowering of the water level leads to increased pumping cost, abandonment of wells, and land subsidence.

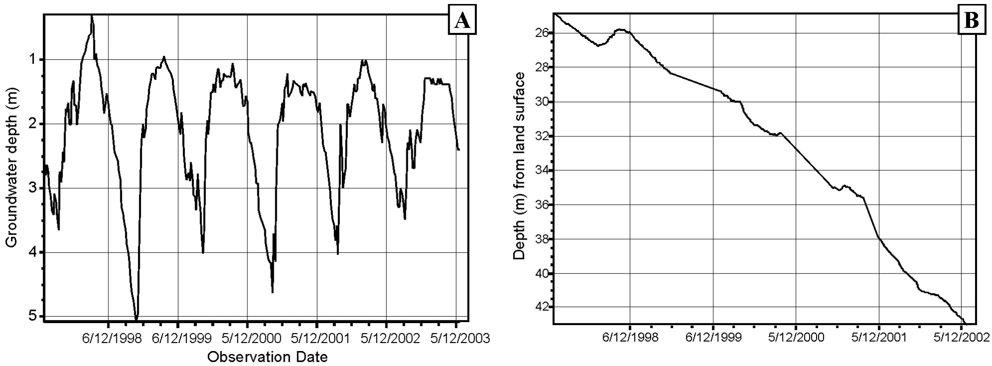

Figure 8. Groundwater table hydrograph from ground surface; A. Kachua, Chandpur; B. Banani, Dhaka City (BWDB, 2004)

Groundwater Pollution from Cities and Industries

Industrial activities are responsible for increased heavy metal levels in soils and sediments in many areas of the country. Sediment contamination by heavy metals is an important issue of increasing environmental concern. Increased unplanned urbanization and industrialization have already affected the environmental components; air, soil, sediment and water of the Dhaka city area. The tannery effluents discharged directly to the nature create environmental problems. Presence of higher accumulation of Cr, Al and Fe in topsoils (down to investigated 6m) with significant amount of Mn, Zn, Ni and Cu were observed (Figure 9), which has already influenced the quality of shallow groundwater.

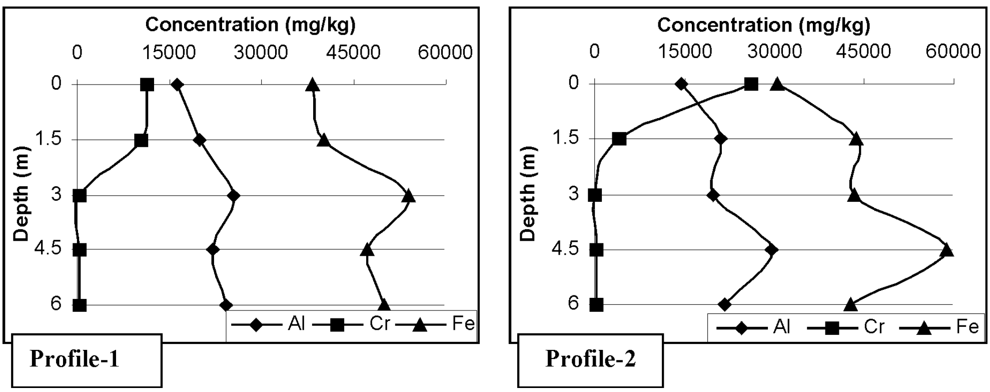

Figure 9. Alarming concentration level of Cr, Al and Fe in topsoil of Hazaribagh leather processing area, Dhaka city ([d]Zahid et al., 2004)

Groundwater Degradation from Agricultural Activities

Bangladesh has a very high population and aims for self-sufficiency in agricultural production. As a result, intensive farming with increased use of fertilizers and pesticides took place. Chemical fertilizers containing nitrogen, phosphorous and potassium are potential contamination sources. There is inadequate knowledge of the extent of this contamination and the impact on the groundwater resource. However, low levels of organochlorine pesticides (Heptachlor and DDT) have been detected at some locations. Higher ammonium and nitrate levels have also been found in shallow aquifers (Hossain, 1997).

Arsenic Contamination

In recent years, the presence of arsenic in shallow groundwater has disrupted the whole scenario of its use and since the last decade arsenic contamination in groundwater is considered an emergency health concern. It has been reported that out of 64 districts 61 are affected (GWTF, 2002). About 25 to 30 million or 25 to 30 percent rural population are at risk from arsenic contamination. In 1995, the presence of arsenic was confirmed in number of shallow and deep wells in different parts of the country. In 1996, Ground Water Hydrology Division of BWDB detected arsenic contamination in the western border belt of the country. Subsequently, patients have been identified as suffering from different types of arsenicosis and millions of tube wells contain arsenic in high levels of concentration. The arsenic-affected patients show arsenic skin lesions such as melanosis, leucomelanosis, keratosis, hyperkeratosis, dorsum, non-peting oedema, gangrene and skin cancer (Dhar et al., 1997).

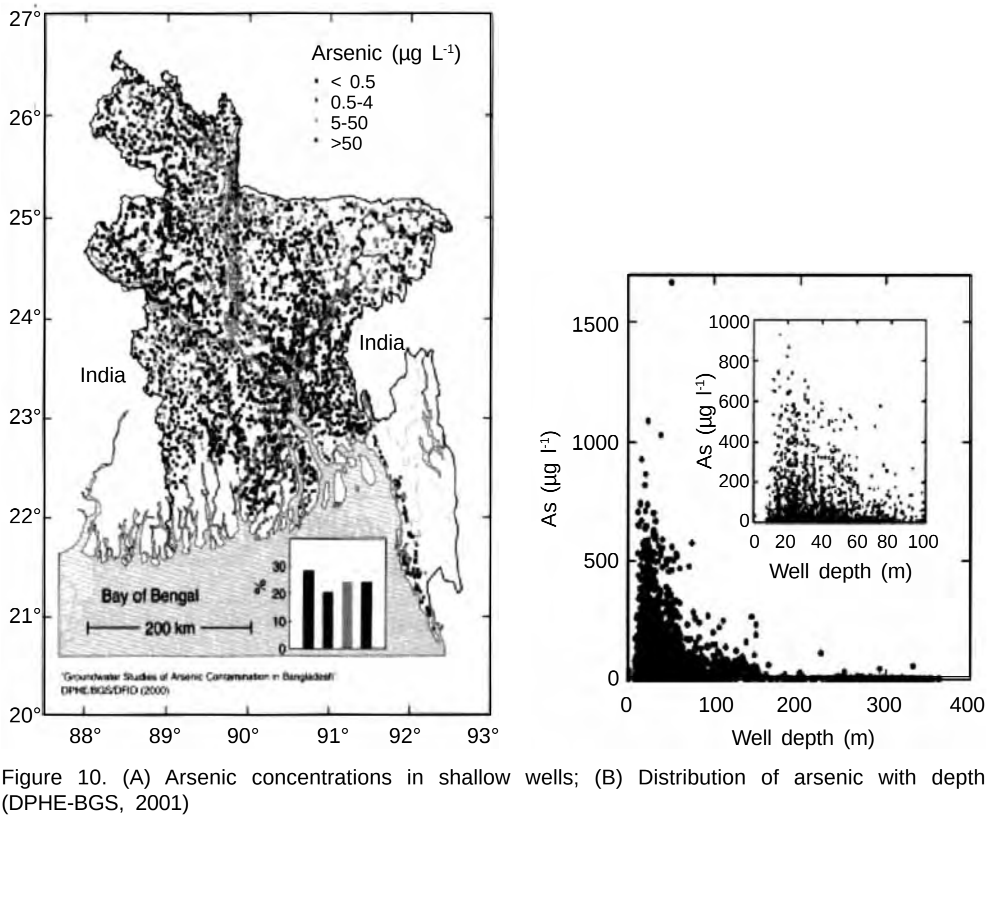

Figure 10. (A) Arsenic concentrations in shallow wells; (B) Distribution of arsenic with depth (DPHE-BGS, 2001)

The DPHE study project initially covered 252 upazilas (sub-districts) in the country. During phase-I, the rapid investigation phase, 2023 samples from 41 districts were collected and analyzed and 51 percent of total samples exceeded the WHO guideline (10 µg/l) and 35 percent of total samples exceeded Bangladesh standard (50 µg/l) for arsenic concentration (DPHE-BGS-MML, 1999). The older aquifers beneath the Barind and Madhupur Tracts are free of arsenic but the adjacent floodplains may be badly affected.

Salinity Intrusion

The most characteristic type of water quality degradation occurring in the coastal plain aquifer of Bangladesh is seawater intrusion. Fresh groundwater generally occurs in deep aquifer layers, below a sequence of other aquifer layers containing saline or brackish groundwater (DPHE-DANIDA, 2001). In the southern regions of Bangladesh groundwater abstraction often takes place from the upper aquifer. In this area, intrusion of saline water into the pumping well is often a problem due to heavy pumping. High rates of pumping for irrigation and other uses from the shallow unconfined aquifers in coastal areas may result in widespread saltwater intrusion, downward leakage of arsenic concentrations and the general degradation of water resources. Khulna city aquifers are reported to have marine influence due to increased anthropogenic pressure. Saline waters have already intruded major groundwater sources of Khulna city, and the fresh groundwater resources are becoming limited. The saline water also infiltrates to the groundwater from the surface water component as the rivers in the dry season carries saline water in the region (Datta and Biswas, 2004). The hydro-chemical and hydrogeological understanding of the salinity intrusion to the groundwater is limited and comprehensive studies are needed.

Conclusion and Recommendations

Groundwater is one of the most valuable natural resources and plays a vital role in the development process of the country. Its sustainable development and proper management can be achieved with a clear understanding of the groundwater system, its geology, hydrogeology, the subsurface flow and the response of the system considering seasonal, tidal and pumping stresses. As such, investigation of the aquifer systems, understanding of formation behavior, regular monitoring of groundwater storage and quality are important for the development and integrated management of water resource.

Management

Matching long-term withdrawals of groundwater to recharge is the principal objective of sustainable groundwater resource planning. Maintaining the water balance of withdrawals and recharge is vital for managing human impact on water and ecological resources. Management of groundwater resources, projecting the future development possibilities and socio-economic as well as environment impact assessment, can be achieved covering following aspects;

- Because of increasing demand of water and to reduce dependency on limited fresh groundwater resources, utilization of available surface water and conjunctive use should be stressed as per NWPo and other guidelines of the government. This will minimize the seasonal fluctuation rate of water table and lessen stress on groundwater resource
- Excessive withdrawal of groundwater for irrigation, industrial and domestic use needs to be controlled. Groundwater resources that can safely be abstracted from both upper and deeper aquifers need to be assessed properly
- Regional modeling of the groundwater systems has to be developed for effective water resource management to plan agricultural, rural and urban water supplies and to forecast the groundwater situation in advance for dry seasons
- Assessment of maximum or most valuable utilization of groundwater resources by developing priorities for long-term use considering widespread droughts, shifting populations and agricultural expansion to minimize the increasing stress on groundwater supply in an area. Assess groundwater pollution and alternative measures of protecting the resource in the future and safeguarding the public health
- Better operation and maintenance of tube wells, operating the installed and installable DTWs under an appropriate system acceptable to farmers, improving the management efficiency, crop diversification, increase in electrification of DTW, sinking new DTWs in the potential areas may increase crop production.

Investigations

In present scenario, besides proper investigation of shallow aquifer formations, exploration on the deeper formation of aquifer systems (250-400 m deep)- probable potential safe source of drinking water in many areas, is very important. But its development needs detailed studies to avoid saltwater intrusion and other possible water quality and quantity degradation. As such, following studies might be emphasized:

- Investigations on aquifer system and understanding of aquifer behavior; identification of the subsurface lithologic units, lateral and vertical extent of the aquifers, delineate fresh and saline groundwater interface in the coastal areas and characterization of the properties of aquifer sediments.
- Assessment of groundwater resources; determination of the performance characteristics of wells and the hydraulic parameters of the aquifers; the impact on withdrawal; the chemical characteristics and potability of the aquifers and identification of arsenic, iron and chloride distribution patterns in the aquifers.
- Investigation of the recharge mechanism of water in the deeper confined aquifers; evaluation of the impact of hydrogeologic heterogeneity and temporal variability in the flow system on the practical use of the aquifer for water supply.
- The intensive farming takes place with increased use of fertilizers and pesticides. The consequences of such intensive farming practice need to be analyzed by assessing pollution of groundwater from fertilizers and pesticide in upper

aquifers, vertical and horizontal extent of pollution migration, leaching mechanism, time of migration and remedial measures etc.

Monitoring

- Extend existing network of groundwater monitoring wells spatially and vertically in different aquifers for calculating recharge, monitoring fluctuation of water table and movement of groundwater.
- Increase the numbers of groundwater sampling stations and water quality laboratories for monitoring water quality and any possibility of saline water encroachment or quality hazards.
- Prepare models to simulate the movement of groundwater flows and mass transport system in the region and finally an evaluation of hydrogeology of safe aquifer of the area.
- Zoning of groundwater aquifers, STW/DTW areas, saline encroachment areas, initiation and implementation of small-scale irrigation project, establishment of water resource information system, strengthen and upgrade the existing groundwater data centers.

Capacity Building

- To facilitate the actions for sustainable development and management of groundwater resources of Bangladesh, strengthening and capacity building of appropriate organizations is required.
- Creation or identification of an organization like 'Ground Water Board/ Agency/Commission' has been recommended by the Ground Water Task Force (GWTF), 2002 and other experts. As Bangladesh Water Development Board has the mandate of investigating and monitoring the status of groundwater all over the country and is working in this field since about 4 decades, field and laboratory facilities as well as appropriate man power of this organization should be strengthened for effective management plan of groundwater resources to agricultural, rural and urban water supplies.
- Formulation of 'Groundwater Act' or 'Groundwater Conservation Act' recommended by the GWTF and experts to control all sorts of activities need to be enacted soon to ensure sustainable long-term use of groundwater.

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