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ENVIRONMENTAL ASPECTS OF GROUNDWATER DEVELOPMENT IN BANGLADESH: AN OVERVIEW

L R Khan

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1. ABSTRACT

Groundwater is an important source of water for irrigation and public supplies in Bangladesh. It is the major dry season source of water in many parts of the country. In recent years the increased demand for water for agricultural and domestic uses has been met by abstracting more groundwater. Heavy abstraction of groundwater has had environmental consequences in many areas of the country. This paper describes some environmental impacts of groundwater abstraction from heavily exploited zones in Bangladesh.

2. INTRODUCTION

Groundwater is an important source of water for irrigation, domestic and industrial uses throughout Bangladesh. Although average annual rainfall is very high (232 cm as per report of MPO, 1987) irrigation is of critical importance during half of the year ie October to May. During these months irrigation from surface source is not practically available in many areas as water in the rivers is scarce. Therefore, the use of groundwater has become increasingly important source of irrigation during the dry season. In addition, over 90% of the population of Bangladesh relies upon groundwater for drinking water. Based upon a recent study of MPO (1987) the national estimate of net groundwater abstraction for irrigation is 5227 Mm^3/year. Potable water supplies and industrial consumption is estimated to be about 908 Mm^3. Groundwater use is not evenly distributed over the country. Groundwater development has been made in the regions where good aquifers ie, water bearing geologic formations are located and where a demand for agricultural and industrial supplies exists. Unfortunately, the development of groundwater resource in this country during the last decade did not proceed according to rules or procedures to ensure optimum use. Different methodologies and engineering concepts for the development of groundwater through various pumping technologies such as deep tubewells (DTWs), shallow tubewells (STW), hand tubewell (HTW) and manually operated shallow tubewell for irrigation (MOSTI) have been practised without detailed investigation of the resource and its management policy. Little attention has been given to the after effects of heavy groundwater withdrawal for both agricultural and domestic uses. In many cases effects of groundwater development such as decline in water levels, reduction in river flows, quality problems, and subsidence were not anticipated. As a result, many environmental consequences e.g. preservation of amenity and public health, fisheries, navigation, salinity, etc. have been encountered and maximum benefit by development of groundwater resource could not be harnessed.

The aim of this paper is to describe the possible environmental problems which are encountered as a result of the abstraction of groundwater from major regional aquifers of Bangladesh. The conceptual or theoretical background of these problems under prevailing conditions have also been outlined here.

3. GROUNDWATER AVAILABILITY

Bangladesh is a vast alluvial plain which covers an area of 143,998 km^2 of which about 65% is a composite of ancient deltaic plains, 10% is the alluvial plain of the modern Ganges-Brahmaputra river system and 25% is hilly terrain (Jones Inc, 1987). Beneath the alluvial plain there are thick deposits of sediment infilling the Bengal basin. This huge territory-quaternary sedimentary infill is a complex mix of deltaic deposits from a vast continuous aquifer with local clayey sediments. There is a regionally extensive mostly unconsolidated, aquifer system throughout the country. This aquifer system is divided into two parts: an upper aquifer composed primarily of quaternary to recent sediments which may exceed 300 metres in thickness; and a lower aquifer sequence possibly extending to 1600 metres depth. Based on MPO's study (1987) the upper aquifer system has a three-fold sequence: an upper silty clay (2 to 100m thick) overlaying a fine sand and silt aquifer, known as the composite aquifer (3 to 60m thick); and the main aquifer composed of moderate to well sorted medium to coarse sands (30 to more than 100m thick). This aquifer extends from a depth of about 150m to more than 300m and has excellent water transmission properties.

The aquifers underneath the major parts of the country are fed annually from natural recharge. In Bangladesh, recharge occurs primarily through direct infiltration and percolation from relatively large amounts of rainfall and flood water. Annual flood peaks of the major rivers recharge laterally into the adjacent groundwater reservoir where they effectively become bank storage. During the dry season (October to January) a certain amount of groundwater discharges horizontally into streams and contributes to the baseflow while part of recharge is lost vertically through evapotranspiration. Therefore, the potential recharge ie, the amount of water which initially percolates (both vertically and laterally) to the groundwater reservoir, does not contribute fully to aquifer storage. Essentially all annual replenishment of the aquifer occurs during the monsoon season beginning in June and ending in October.

Many reports have been published on the availability of groundwater reserve throughout the country. It has become cumbersome on the part of the Water Development Authorities to rely on these information in order to extend groundwater development programme with full confidence. According to the study of BWDB and UNDP (1982) available groundwater is 19640 Mm^3. On the basis of the report of Groundwater Circle of BWDB (Karim, 1984), the available recharge varies from 30 mm to 300 mm per unit area throughout the country based on soil strata and physiographic conditions. The total available recharge is about 14800 Mm^3 over an area of about 93000 km^2. In the Hand Tubewell-II Project Report which has been prepared jointly by FAO and UNDP, the total amount of available groundwater is estimated at 36565 Mm^3 or 29.64 M acre-ft (Mirza, 1986). In the draft final report of MPO (1985) it was mentioned that the total usable groundwater recharge within this country is 42543 Mm^3. The usable groundwater is considered to be 75 per cent of mean annual potential recharge leaving 25 per cent for some uncertain factors as calibration error, future land use and flood control development. But in the recent

MPO report (1987) it is mentioned that the available recharge is 24,414 Mm^3. This was estimated by reducing usable recharge for geographic and physical limitations on groundwater use; eliminating areas where water needs are already met by surface water development; and deducting outflow to rivers (baseflow, seepage) and evapotranspiration losses. There is wide variation in the above mentioned data of groundwater available within the country. The relative reliability of these data has become a matter of concern. Estimates of groundwater availability by various organisations as mentioned above rely on different methodologies and concepts. Some are based on general topographic and hydrologic conditions and many make simple assumptions about aquifer behaviour. However, recently MPO (1987) carried out a detailed groundwater study based on sophisticated mathematical models considering regional variations in soils, geology, land use and local hydrological conditions. Regional estimates of groundwater availability by MPO are summarized below.

Table 1. Regional Summary of Groundwater Availability in Bangladesh.

Region	Potential and Usable GW. Mm^3			Available GW, Mm^3	
	Area (Km^2)	Potential (Mm^3)	Usable (Mm^3)	Area (Km^2)	Volume, Mm^3
North-West	30161	17834	13391	29191	9480
North-East	34755	23748	17811	22133	9615
South-East	30068	11956	8967	3644	1538
South-Central	14264	4814	3611	5031	1801
South-West	25616	5250	3958	11813	1980
Regional total	134864	63622	47718	71812	24414

* Source: MPO Technical Report No 51, 1987.

4. EXTENT OF GROUNDWATER UTILISATION

In Bangladesh groundwater has been being used for irrigation and public supplies for about two decades. Until 1980 the major element of irrigation growth in this country have been the low-lift pumps (LLPs). The development of groundwater utilization through deep, shallow and hand tubewells started after 1972. During 1979-80, about 76% ie, 1.071 M hectare of total irrigated area was covered by surface water irrigation and the remaining 24% ie, 0.34 M hectares were irrigated with groundwater. Due to acute shortages in surface water during the major cropping season and also in response to the availability of the groundwater resources throughout the major parts of the country, the national water utilization plan has been changed. In recent years, increased irrigation facilities have tremendously increased groundwater utilization. During the Second Five Year Plan (Planning Commission, 1985), the area irrigated by groundwater increased to 1.23 Mha. During 1985 19,815 DTWs, 156,249 STWs and 285, 367 MOSTIs (MPO, 1987) extracted groundwater throughout the country. The area irrigated by groundwater by this time was nearly half of the total irrigated land, ie, about 2.5 Mha.

Based on the reports of the Third Five Year Plan of the Government of Bangladesh (Planning Commission, 1985) total irrigable area is estimated to be about 4.45 M hectare. Area irrigated by the end of 1984-85 was estimated to 2.50 M hectare which is about 56% of the potential area. The remaining 1.97 M hectare are yet to be brought under irrigation. It is planned to expand irrigated area to about 88% of potentially irrigable area by 1990 (Planning Commission, 1985). Demand for urban and rural water supplies throughout the country has increased so that allocation for public water supplies have been updated in the Third Five Year Plan. This recognises the need for more groundwater due to irrigated agriculture and public water supplies incorporating additional deep, shallow and hand tubewells throughout the country.

5. ENVIRONMENTAL ASPECTS OF GROUNDWATER ABSTRACTION

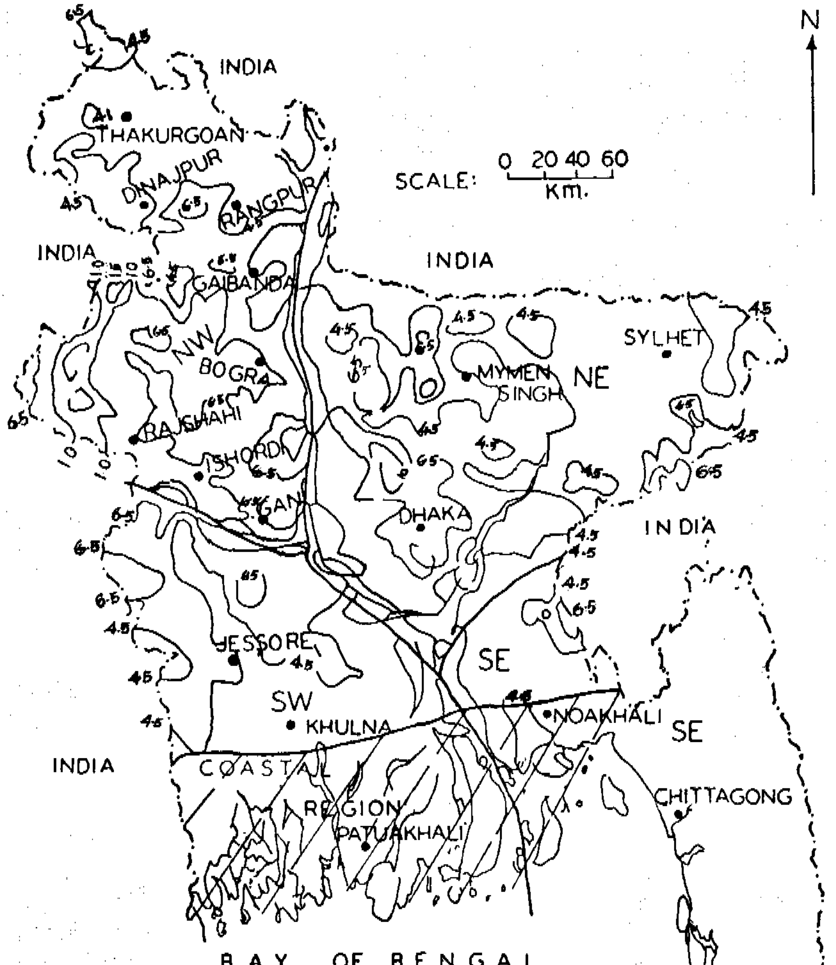
Groundwater is generally regarded as a renewable natural resource. It is extracted from the aquifer like other minerals such as oil, gas or coal. The Development of water supplies from a groundwater system begins typically with a few production wells. Over time more tubewells are drilled and the rate of abstraction increases. As numbers of tubewells increase the aquifer system starts to exceed its natural recharge capability and a mining or overdraft condition occurs. Extensive abstraction of groundwater may entail a number of undesirable results such as decline in groundwater level, salinity or water quality problems, reduction of flow in the connected rivers, land subsidence, and interference with prior water right of others. Thus groundwater abstraction can cause many environmental problems.

Although groundwater has been developed in Bangladesh for irrigation and public supplies over the last decade, little attention has so far been given to after-effects of groundwater withdrawal. In many areas the development of groundwater has led to alarming environmental crisis situations. Awareness of the important role that groundwater can play when developed as a major resource is now increasing as a result. The possible environmental consequences of groundwater abstraction in this country are discussed in the next section of the paper.

5.1 Decline of Groundwater Levels

Except in the Chittagong Hill Tracts, Rajshahi high Barind Tract and the Madhupur Tract, groundwater exists at shallow depths in Bangladesh. Except in these areas groundwater levels are at or near surface level from August to October. The lowest groundwater levels usually occur between April and May. These range from 3m below land surface to more than 8m in areas of extensive groundwater abstraction (MPO, 1985). Fig 1 shows the depth to groundwater throughout the country during the period of lowest level.

In several areas of Bangladesh such as Rajshahi, Bogra, Pabna, Comilla, Mymensingh and Dhaka, groundwater abstractions are causing a large decline in groundwater levels during the dry season. Typical examples are shown in Fig 2. Other than in the Dhaka and Comilla areas, groundwater levels re-obtain their normal static water level if sufficient recharge occurs during the wet season. Temporary overdraft conditions which are evident in some areas, particularly in Rajshahi, Rangpur, Bogra and Jessore districts are due to hydrological droughts and the extensive utilization of groundwater. It has been observed recently (Mirza, 1986; Bhoumik, 1986) that in the northern districts of Rajshahi and Bogra, groundwater levels have been depleted to a level of 9-13 metres below the static water table. As a result of this decline in



LEGEND

DEPTH TO GROUNDWATER LEVEL IN METRES BELOW GROUND SURFACE ······ 4.5

FIG. 1 DEPTH TO GROUNDWATER LEVEL THROUGHOUT BANGLADESH IN THE MONTH OF APRIL, 1983.
SOURCE: MPO, 1985.

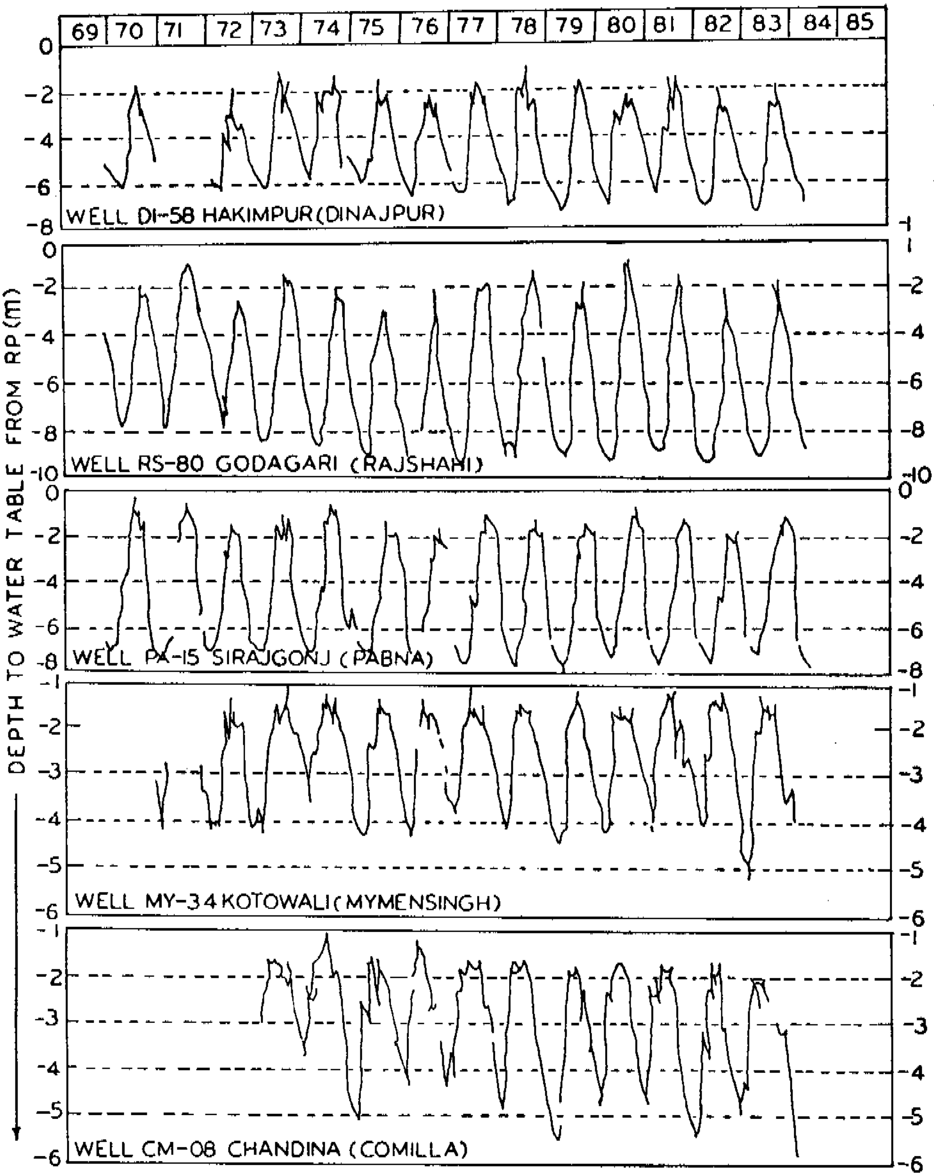


FIG. 2 WELL HYDROGRAPHS SHOWING GROUNDWATER LEVEL FLUCTUATIONS (SOURCE MPO, 1985)

groundwater levels most of the shallow and hand tubewells which have been installed for irrigation and drinking purposes in these areas, have failed. This occurs because the pumping head has gone beyond the maximum suction lift limit (maximum theoretical suction lift limit is about 10 metres) of centrifugal pumps, installed for running shallow tubewells. Furthermore, about 50,000 ponds, tanks and ditches in the Barind areas within the northern districts have almost dried up (Bhoumik, 1986). The draft decline in water levels in these local water bodies is due to the pumping of groundwater from the adjacent shallow aquifers and to evaporation losses. Therefore, this particular region is facing an acute shortage of water for surface irrigation, drinking and fish culture which ultimately has emerged as a threat to the environment.

Usually the rainfall in the northern part is less than in other regions of the country. During the last few years rainfall was much lower than ever recorded before. Agricultural production did not reach expected levels due to limited availability of irrigation water under drought conditions. Heavy pumping of underground water using shallow tubewells has exhausted soil moisture within the upper shallow aquifer. In addition to agricultural crops, many fruit and deep rooted trees within this northern region of the country have been affected due to decline in groundwater levels. The most important issue in this region is the reduced amount of soil moisture available to vegetation, particularly to crops and trees. This has focussed attention on the possibility that groundwater development projects upset the natural ecological balance.

5.2 Groundwater quality issues

In order to assess groundwater development potential, its quality in relation to various uses is as important as its quantity. In general, groundwater quality in most areas of Bangladesh is suitable for agricultural, domestic, municipal and industrial uses. However, in the coastal regions e.g. south-western parts and also in Patuakhali and Barisal districts of the south, this quality criterion is a severe constraint of groundwater development. In Khulna, Jessore and Satkhira districts of the south-west region, northward movement of salinity has increased in the recent past due to a reduction in dry season flows (low-flow) in the river Ganges. This is attributed to the Farrakka barrage located immediately upstream of Bangladesh. Since concurrently, heavy pumping of groundwater from the aquifer is also undertaken in this region, the salt water interface is also moving inwards and the aquifers (reservoirs) are contaminated with saline water. Saline water is of limited use for irrigation, domestic and industrial uses and ultimately causes many environmental hazards. When the horizontal movement of water in the aquifers is fully encroached with salt-water from the Bay of Bengal many of the production wells in the South-west of Bangladesh will have to be abandoned. Salinity is also becoming a constraint in many parts of South-east region of Bangladesh such as in Brahmanbaria, Chandpur and Noakhali districts. Increased use of groundwater for irrigation may degrade soil properties and ultimately hamper the growth and yield of crops. Khan et al (1977) and Khan & Basak (1986) found that an excess amount of iron content was present in the groundwater in some places of Dinajpur district in the north end at Madhupur, Mymensingh Sadar and Trishal Upazilas of the central region of Bangladesh. The precipitation of iron cemented together a continuous layer of soil which formed a hard, water-impermeable reddish-brown layer known as hardpan. This hardpan restricts usual penetration by plant roots. Plant growth and yield are also depressed because of decreased soil aeration, permeability and drainage. The effects of excess amounts of harmful minerals due to ground water extraction have already been encountered in Bogra, Dinajpur, Satkhira and other northern areas of Bangladesh. Once agricultural soils are being affected by harmful mineral components in the groundwater, further groundwater utilization can make the agricultural lands non-productive and create the need for complex soil and water management practices.

5.3 Pollution and health hazard

Much of the drinking water (about 90%) and nearly half the irrigation water in Bangladesh is obtained from groundwater. Therefore, the influence of groundwater and its quality on the environment cannot be ignored. The water in streams, lakes, oceans and soils naturally contains a variety of dissolved substances. In Bangladesh where land is relatively flat, the saturated zone is often by less than a metre below the soil surface. During the wet season, rainfall flushes the soluble substances from soils and may transport them to groundwater. Crop production in low rainfall areas is supplemented by irrigation from rivers, local water bodies (haors, beels) and groundwater. The dissolved substances from these sources are thus added to the soils. If the content of dissolved salts in the irrigation water is high, repetition of this process over a period of few years may make the soil too saline to support plants. On the other hand, if enough irrigation water is added to flush the excess salts out of the soil, the salinity of groundwater in the shallow aquifers may be increased. Excessive salinity of groundwater is undesirable for agriculture as well as for drinking purposes.

Application of fertilizers, especially of nitrogen to agricultural lands can add nitrate to the groundwater through leaching or direct percolation. When nitrate-polluted groundwater is utilized it may cause health problems. When nitrate is ingested in excess, the resulting nitrate causes meta-haemoglobinemia - a fatal disease, and several other human health problems such as birth defects, cancer and nervous system impairment (CAST, 1985). Although nitrate pollution problems as a result of groundwater utilization have not yet been identified in Bangladesh, the possibility of their occurrence cannot be ignored. Bacterial contamination of groundwater in rural as well as in urban areas from organic residues, including crop residues, homestead wastes, animal manures and sewage sludges may also cause health problems. If groundwater is polluted with chemical pesticides it can degrade drinking water. Extensive use of groundwater for irrigation can encourage the growth of mosquitoes in wet paddy fields, which may cause the spread of malarial diseases.

5.4 Reduction in river flows

Generally a groundwater system is hydraulically connected with a river system. Bangladesh is a riverine country. Therefore, most of the shallow aquifers have hydraulic continuity with the neighbouring rivers. Where a stream channel is in direct contact with an unconfined aquifer, the stream may recharge groundwater or receive discharge as base flow from the aquifer storage, depending on the relative water level gradient.

The sources of streamflow in the major rivers within the northern region of the country during the dry period are inflows from the upstream catchment area (India), the groundwater run-off from the aquifer storage, and also rainfall if there is any. During recent years, streamflows in dry seasons in the major rivers e.g. the Ganges and the Brahmaputra have declined drastically due to withdrawal of water in the upstream regions. It has been reported that the streamflows in the Ganges have reduced to nearly 736 cumec between 1983-1984 (Alam, 1985). Therefore, during dry periods the observed streamflows in the rivers are mostly contributed by the aquifer storage as baseflow. Groundwater abstraction from tubewells, particularly shallow tubewells near the river is directly at the expense of river flow. Due to excess pumping of groundwater in the dry season, water levels in many rivers fall below normal dry weather flow. Due to reductions in dry season streamflows and also to heavy groundwater abstractions, a new hydrologic equilibrium has been attained in the northern region and the groundwater levels have declined up to 9-13 metre from the static water level in many places of this region.

Fig 3 illustrates schematically the hydraulic behaviour of an unconfined aquifer with a river system, which is very common in many areas of the country. Continuous abstraction of groundwater using tubewells under such circumstances (as shown in Fig 3) is limited to the difference between the dry weather flow and minimum acceptable flow. The maintenance of minimum acceptable river flows is necessary for fisheries development, inland transport and navigational purposes; and also to contain problems such as salinity and pollution by sewage effluents. Reduction in streamflows can have a negative effect on fish, population, growth rates and migratory patterns, resulting a complex impact upon the aquatic ecosystem.

5.5 Conflict among trade-offs

In this country, the development of groundwater resource through various technologies (DTWs and STWs) is usually undertaken in isolation. The STW programme has been the major groundwater development mode in this country. This programme has become much popular due to socio-economic conditions of people and the choice of private ownership. STWs are installed in the upper shallow aquifer, whereas DTWs are sunk in the main aquifer within the same area which is hydraulically connected with the overlying composite aquifer. Extensive withdrawal of ground water from

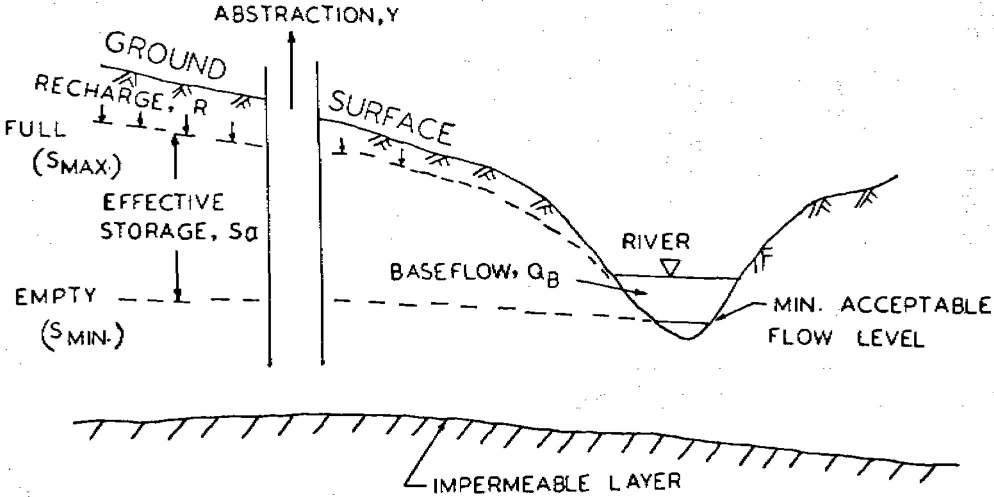
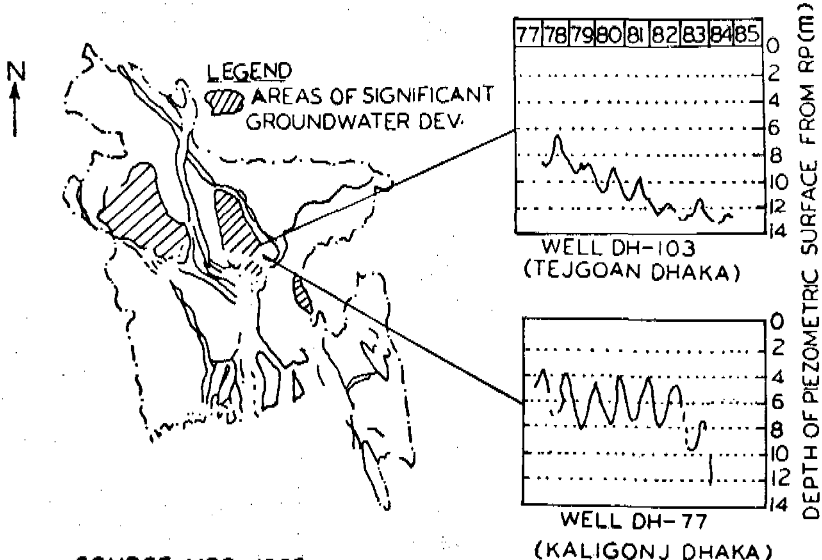


FIG. 3 SKETCH OF AN UNCONFINED AQUIFER CONNECTED WITH A RIVER SYSTEM.



SOURCE: MPO, 1985

FIG. 4 THE EFFECTS OF GROUNDWATER ABSTRACTION ON GROUNDWATER LEVELS.

the main aquifer will lower water level in the upper aquifer, thereby increasing the suction lift limit for the STWs, and also HTWs and MOSTIs in many places of the country. As a result, the STWs and HTWs run dry in many areas. The continued exploitation of groundwater resources for agricultural purposes will decrease water supply for private STWs and for HTWs for drinking water. The interaction of deep and shallow tubewell pumpings creates conflicts among groundwater usages. Conflicts between domestic water supply and irrigation demand will require new attention and action such as deepening the boreholes, construction of new ones, the lowering of pumps, command area development. Some policy choices on the direction of new investment also have to be made.

The use of groundwater for irrigation eventually diminishes the quantity of water available in the neighbouring ponds, beels, haors and other water bodies. Reduction of water levels in these water sources can have impact on spawning areas, feeding grounds, nursery habitats, etc. of aquatic species and result in decreased aquatic productivity.

5.6 Land subsidence

Changes in groundwater levels or subsurface moisture conditions may cause subsidence or settlement of the land surface. This can damage buildings, particularly in urban or metropolitan cities and can create special problems in the design and operation of structures for drainage, flood protection and water conveyance.

Land subsidence has been observed to accompany extensive lowering of the piezometric surface in regions of heavy pumping from aquifers, particularly confined ones. Many areas of subsidence due to groundwater pumping are known in the USA as well as in Japan, Mexico, Taipei, Italy and England. The most spectacular subsidence areas due to groundwater abstraction are the Southern Great Valley of California and Mexico city where maximum land settlement has exceeded about 4.57m (Walton, 1970). The Bangkok city area has also experienced a subsidence of about 1 metre due to groundwater abstraction (Brand, 1974). Todd (1980) reported that the average subsidence ratio at San Jose, California, equalled 1/13 indicating that the land surface subsided 1m for every 13m of lowering of the piezometric surface of the aquifer. Recently, Calcutta has experienced settlement due to groundwater pumping from the aquifer beneath the city.

The above mentioned examples indicate a possible settlement of Dhaka Metropolitan area as a result of heavy groundwater abstraction. The piezometric surface within the city area already declined to about 6m during last 6-7 years period (see Fig 4). The upper 20-30m beneath the city area is composed of a clay layer and the aquifer from where groundwater is withdrawn is more than 40m below the land surface (MPO, 1985). This decline of piezometric levels indicates pumping in excess of the safe yield of the aquifer. As has been shown, pumping under overdraft condition within the Metropolitan area can contribute to land subsidence. Although there is no physical evidence of this up to now and no investigation has yet been made, awareness of and attention to this potential effect on Dhaka city are needed.

6. CONCLUSION

The development of groundwater resources occurs at a time when world-wide interest in environmental matters has increased. There is concern about the possible consequences on the environment. In Bangladesh, groundwater has been developed extensively for irrigation and public supplies without consideration of the possible after-effects. The abstraction of groundwater for agricultural development and public supplies has already brought a degradation of the natural hydrological regime in many areas. As a result, environmental conditions have deteriorated in these areas, particularly the northern regions. In order to get the beneficial use of the important natural resource, groundwater, there is a need for overall management according to rules or procedures for its optimum use. Throughout the country groundwater management practices are either unknown or have become so difficult in terms of time and operation that they are ignored. Different concepts and methodologies for the development of groundwater resources through deep and shallow tubewells have been practised time and time again without detailed assessment of the resource, investigations of aquifer characteristics, economic viability or of operational and management difficulties. As a result, maximum benefits from groundwater use have not been obtained. In future, more careful consideration should be given to water management objectives based on investigations of the local environment and hydrology. The achievement of management objectives, of course, also depends upon geologic and hydrologic considerations, economic, legal, social, political and financial factors.

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