JOURNAL OF
ENVIRONMENTAL HYDROLOGY

The Electronic Journal of the International Association for Environmental Hydrology
On the World Wide Web at http://www.hydroweb.com

VOLUME 14 2006

# SALINITY INTRUSION AND ITS MANAGEMENT ASPECTS IN BANGLADESH

**Md. Mizanur Rahman**[1]
**Amartya Kumar Bhattacharya**[2]

[1]Bangladesh Water Development Board
Dhaka, Bangladesh
[2]Bengal Engineering and Science University
Shibpur, Howrah, India

*Fresh water flows counterbalance salinity intrusion in the coastal zone of Bangladesh. To quantify the required fresh water, requires a detailed understanding of physical phenomena including tidal motion, wind mixing, groundwater discharge, and river flow. The coastal zone comprises part of the flat Ganges Delta, which is crisscrossed by large tidal rivers discharging into the Bay of Bengal. The estuaries and tidal river systems of the coastal zone have been formed by long period deltaic accretion which was dominated by the historical morphological changes of the Ganges and Brahmaputra rivers. The major estuarial rivers of the south-central region are interlinked and fed by numerous smaller channels. The approximate population in the coastal area is 40 million. They are very vulnerable to natural disasters along a 720 km coastline. Saline water intrusion is the main problem in the southwestern zone. About 60 and 15 percent of arable land (total 1.0 mha of croplands) of southwestern and southeastern Bangladesh respectively are affected by salinity during dry periods. The salinity is caused by cyclone and storm surges, high spring tide inundation and capillary actions. Its effect on the soil surface and root zones is to decrease crop production about 0.13 metric tons every year. The increase of salinity intrusion and decrease of arability will prevail due to climate change effects and the reduction of flood plain areas, and it may propagate throughout the country. Management of salinity intrusion is a vital issue for Bangladesh. Saline water proofing by structural management like coastal embankment projects, dams, sluices, and coastal area zoning, as well as non-structural management strategies that change the land use and other activities, can be a vision of a sustainable livelihood and environment for Bangladesh.*

## INTRODUCTION

The movement of saline water into a freshwater aquifer or surface reservoir is known as saltwater intrusion, and if the source of this saline water is sea water, then this process is known as seawater intrusion. Aquifers in hydraulic connection with saline or sea water may contain saltwater in adjacent portions while other portions of the aquifer contain fresh water. Freshwater is slightly less dense (lighter) than saltwater, and it tends to float on top of the saltwater when both fluids are present in an aquifer. The relationship based on the density difference between saltwater and freshwater is used to estimate the depth to saltwater based on the thickness of the freshwater zone above sea level. The relationship is known as the Ghyben-Herzberg relation (Figure 1). In the coastal area of Bangladesh, hydrogeological conditions vary considerably even within short distances. Groundwater, with a gradient of about 1:20000, flows from north to south having localized outflow into rivers and ponds in the dry season and inflow into the aquifer from surface water sources in the rainy season. Transmissivities of the main aquifer in the coastal area range from 250 $m^2$/day to 10000 $m^2$/day with an average value of 1000 $m^2$/day. The storage capacity of the aquifer generally increases with depth with the increase in the grain size of aquifer materials. The entire area is underlain by thick water bearing formations of varying depths and the regional hydrogeology is very complex (Ahmed, 1996). Shamsuddin (1986) observed that the salinity distributions in Khulna, Barisal and Patuakhali regions were not in agreement with the Ghyben-Herzberg theory.

An example sketch is given in Figure 2 showing aquifers and aquitards which vary spatially in both thickness and elevation. There may be several aquifers present, and each aquifer will have different hydraulic characteristics (recharge, pressure, capacity, etc.) and susceptibility to seawater intrusion. The hydraulic characteristics can vary significantly from one location to another, even within a single aquifer. This variability and complexity of our groundwater system introduces uncertainty in solving adverse situations. As a result, water resource planning and management efforts have primarily relied on review of water use proposals on an individual site specific basis.

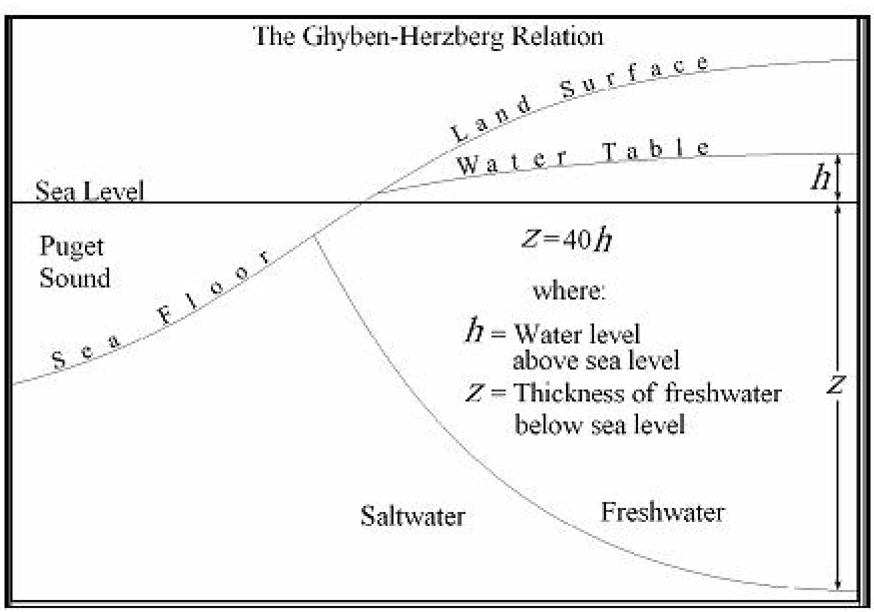


Figure 1. The Ghyben-Herzberg relation.

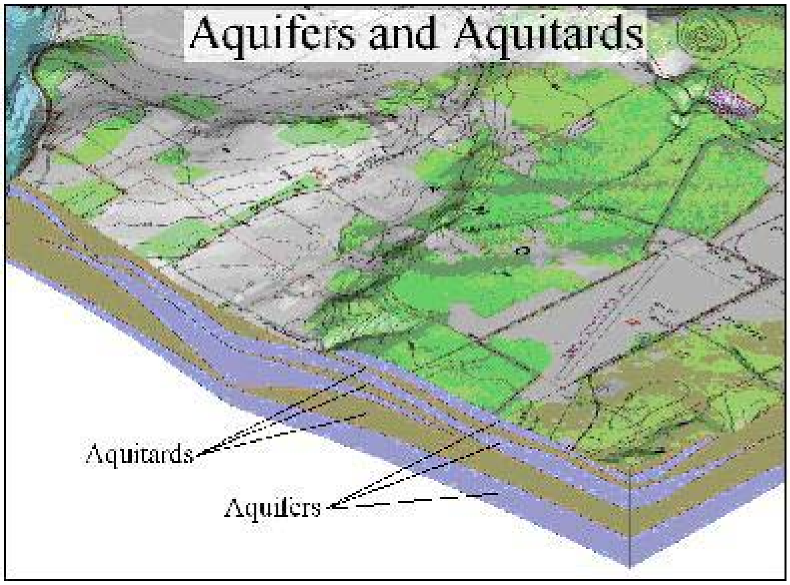


Figure 2. Example of spatial variation of aquitards and aquifers.

## GEOLOGY AND HYDROGEOLOGY OF BANGLADESH
(from Ravenscroft and McArthur, 2004)

Alluvial and deltaic sediments of the Ganges, Brahmaputra and Meghna rivers build the Bengal Basin, the eastern part of which is Bangladesh (Morgan and McIntire, 1959). The north–south section in Figure 3 provides a generalized description of the aquifers in the coastal zone of Bangladesh (Figure 4). The basin was dissected and infilled many times by the major rivers during Pleistocene times leading up to the last glacial maximum (LGM) at 18 ka BP (ka BP = thousands years before present) when sea level stood some 130 m lower than present (Umitsu, 1993; Kudrass et al., 1999; Goodbred and Kuehl, 2000). The flooded coastal plain and incised channels of Bangladesh were rapidly filled by estuarine, deltaic and alluvial sediments in the latest Pleistocene/ Holocene transgression. The sediments that fill the accommodation space created by these incised channels have distinctly different hydraulic and geochemical properties from those inter-fluvial sediments (e.g., the Barind and Madhupur Tracts) that predate them (BADC, 1992; Ravenscroft, 2003). Inter-fluvial sediments increasingly contain Cl-rich brackish water towards the coast (Hoque et al., 2003). The post-LGM valley-fill sediments are uncemented dark grey sands containing groundwater that is reducing and sometimes methanogenic (Ahmed et al., 1998), high in Fe and As (DPHE, 1999; Nickson et al., 1998, 2000; McArthur et al., 2001). The interfluvial and underlying sediments that predate the LGM are formed by oxidized, often brown-colored, sands of lower average permeability (MPO, 1987; BADC, 1992). The aquifer sands are fine-to-medium grained with typical hydraulic conductivities of 10–50 m/d which contain water that is less reducing, low in Fe and As, and is generally less mineralized (Ravenscroft, 2003). Aquitards are more prominent southwards and normally contain brackish groundwater. The brackish water is connate, and has locally leaked into underlying sands (Hoque et al., 2003). As the aquifers become more strongly confined, the waters tend to become more reducing and higher in Fe (Rus, 1985).

Pliocene to Holocene sediments are extensively tapped to supply drinking water and the majority of irrigation and industrial supplies (MPO, 1987). The deep coastal aquifers are not used for irrigation because of high cost of wells >200 m deep. Aquifers below about 150 m have been intensively pumped for municipal supply over a period of 20–30 yrs at towns such as Khulna,

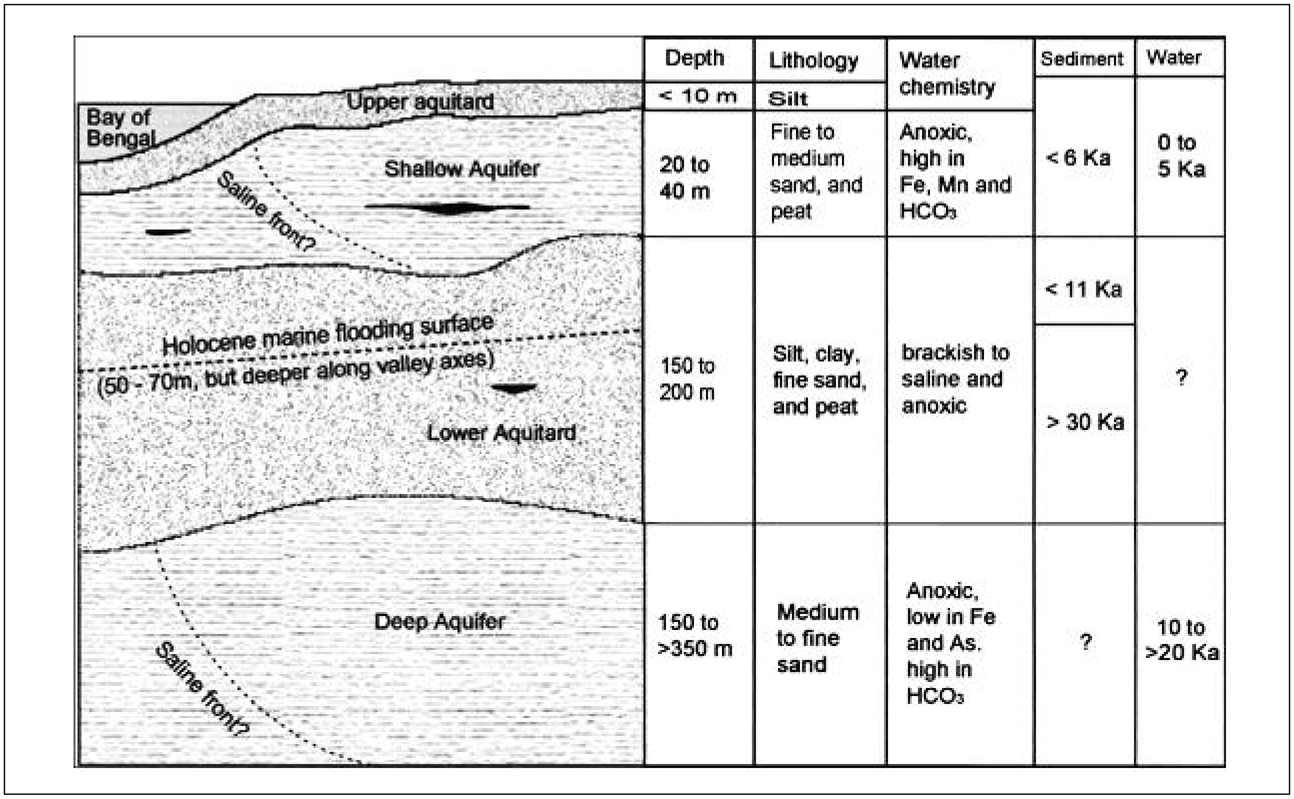


Figure 3. Schematic of aquifer stratigraphy in the coastal zone of Bangladesh (Ravenscroft and McArthur, 2004).

Barisal and Noakhali, and as yet have not been significantly affected by salinization (LGED, 1994), despite claims to the contrary (Hassan et al., 1998; Rahman et al., 2000).

## Salinity Processes in Bangladesh

For the deposition of silt and clay, the spatial distribution and concentrations of salinity in the estuary are important in the formation of the delta. The intrusion of saline water inland determines the suitability of estuary water for drinking, irrigation and other purposes. During the wet season, the vertical variation of salinity may play a role in the seasonal storage of sediment at the outside of the estuary.

Because of its shallow depth, the Meghna Estuary is generally a well-mixed estuary where the salinity is constant in a vertical water column (BWDB et al., 1998). During the monsoon, the Land Reclamation Project (LRP) and Meghna Estuary Survey (MES) measured an approximately 100 km long zone (Kutubdia-Sandwip) that develops in the southeastern part of the estuary where vertical variation occurs when a layer of brackish water moves in with the tide in the form of a salt wedge. The general concept is that during the dry season, part of the sediment is brought back into the estuary through a so-called tidal pumping process, and deposited there (BWDB et al., 1998).

In the coastal area of Bangladesh salinity increases during minimum river discharges but never exceeds seawater salinity (34 ppt). Intrusion of saline water during the dry season is up to Char Gazaria where salinities are less than 1 ppt. Salinity intrusion can increase either due to a decrease of fresh water flow in the Lower Meghna River during the dry season, or due to further penetration of tide into the river system. Intrusion may be aggravated by upstream withdrawal of water and the reducing size of floodplains, or by climate change impacts like a decrease in dry season rainfall

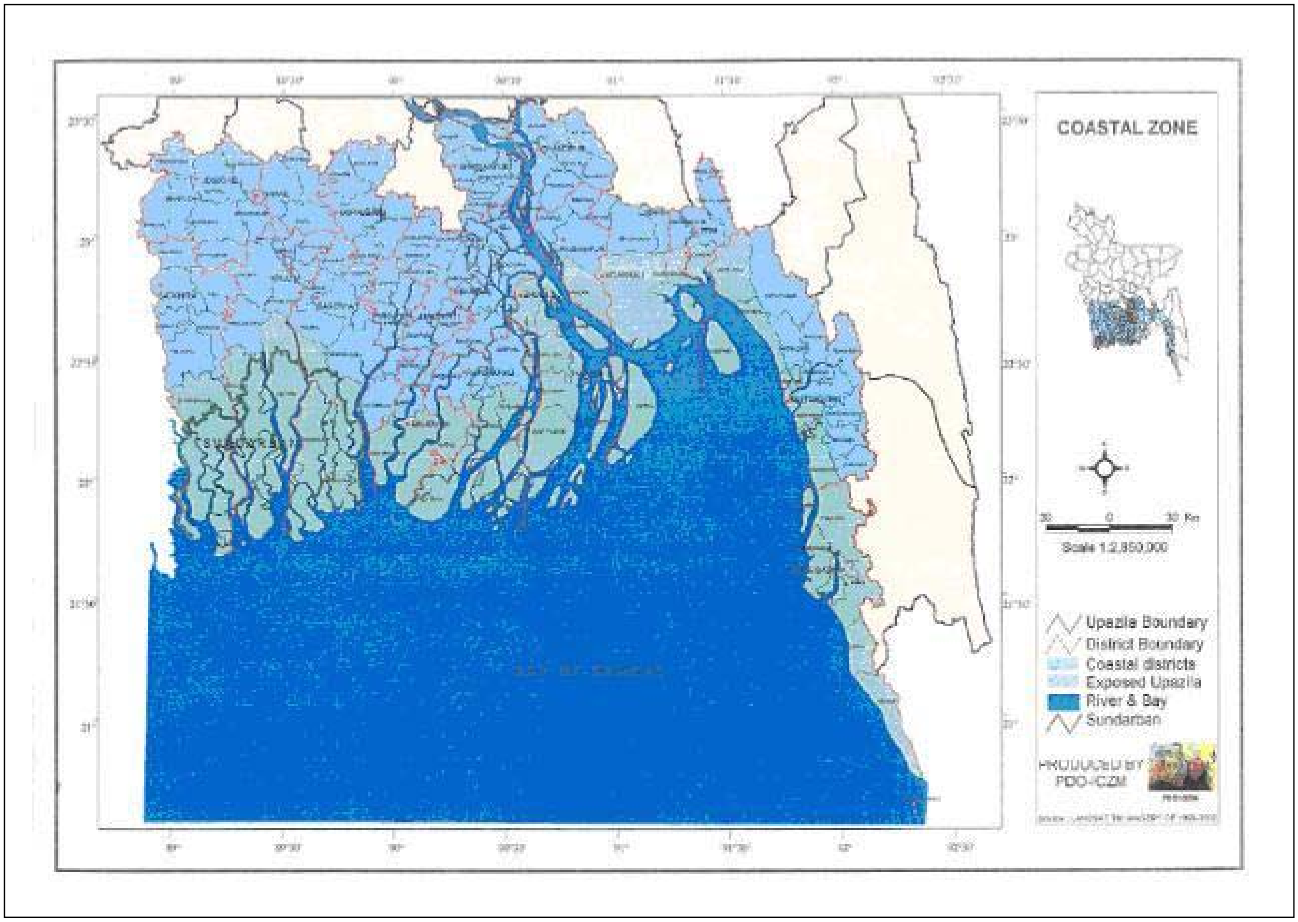


Figure 4. Coastal Zone of Bangladesh (PDO-ICZM, 2002).

and sea level rise.

The surface water and soil salinity of coastal districts is shown in Table 1. In Khulna district salinity creates problems to agricultural production and affects the supply of clean water for industrial use. The same problem also exists in Chittagong when there are no releases from Kaptai Lake. The augmentation of salt water in the surface waters increases the abstraction of groundwater which then becomes vulnerable to a risk that salt water will be drawn into the aquifer.

## Salinity Management Aspects in Bangladesh

Salinity impacts are not limited to economic activities, like agricultural crop production, fish and shrimp, and availability of water suitable for agriculture and industry. River water salinity also has important implications for the natural environment, such as the functioning of the Sundarban ecosystem, sedimentation rates in tidal rivers, and human health. Human health is especially influenced by the sole dependence on saline water for domestic purposes (BWDB et al., 1998). The coastal zone groundwater aquifer is contaminated with salt above permissible levels at various places. In Bangladesh, the official permissible threshold level of salt in groundwater is 600 mg/l chloride (ESCAP, 1987), which is higher than elsewhere. But for the coastal districts, due to the lack of good water, the permissible level is set at 1,000 mg/l.

## Coastal Embankment Project

Coastal Embankments were implemented in the early 1960’s as structural measures to prevent salt-water intrusion only for agricultural production. In the 1980’s these were rehabilitated

Table 1. Salinity levels in ppm (SRDI, 2001).

| District | Surface water | Soil |
|---|---|---|
| Bagerhat | 5->10 | 4->15 |
| Barguna | 1-5 | 4->15 |
| Barisal | 0 | 0-4 |
| Bhola | 1-10 | 4->15 |
| Chandpur | <1 | 0 |
| Chittagong | 0-<1 | 0-8 |
| Cox's Bazar | <1 | >15 |
| Feni | 0-10 | 0-15 |
| Gopalganj | <1 | 0-15 |
| Jessore | <1 | 4-8 |
| Jhalokati | <1 | 4-8 |
| Khulna | 5->10 | 8->15 |
| Lakshmipur | <1 | 4-8 |
| Narail | 0 | <4-8 |
| Noakhali | <1-10 | 0->15 |
| Patuakhali | 1-10 | 8->15 |
| Pirojpur | 0-10 | 0-15 |
| Satkhira | 5-<10 | 4-<15 |
| Shariatpur | <1 | 0 |

providing facilities of salt water intrusion by facilitating shrimp farming and salt cultivation. In that time these polders were considered for mangrove afforestation which also need salt water to some extent.

The southwest of the Ganges Development Area of Bangladesh is saline. The southeast is relatively salt-free. The high salinity in the southwest allows production of salt water shrimps and is a key parameter that affects the species mix in the Sundarban. Salinity has also affected industrial use far inland. Some industries like Khulna Newsprint Mill are already being closed down. Figure 5 shows the time series of salt water increase in the southwest area of Bangladesh.

### Non-structural salinity management

Large scale change in land use from long term plant species to perennials can be the solution to the increasing trends of salinity. A number of studies have demonstrated that increasing the area of perennial plants will have substantial negative effects on stream flow. Reducing water for irrigation may increase the benefits of dryland salinity. The management of areas of high groundwater salinity and soils is important by maximizing recharge. Different scenarios may be developed for optimization of management of salinity. A sufficient understanding of catchment characteristics is important to ensure that the impact of salinity management is favorable for a range of natural resource conservation objectives.

## CONCLUSION

In Bangladesh salinity intrusion is a time varying event and with a minimum during the monsoon (June-October) when river discharge displaces the salinity front seaward in estuaries and floodplains. The salinity front moves inland from the month of November due to the reduction of fresh water flows and intrudes up to 150 km inland in the lower Meghna in the southeast and up to 290 km up the Passur River in the southwest of the country. Maximum salinity levels occur during March-April. The increase of salinity intrusion and decrease of arability will prevail due to climate change effects and reduction of flood plain areas due to sea level rise. Investigations indicate that one third

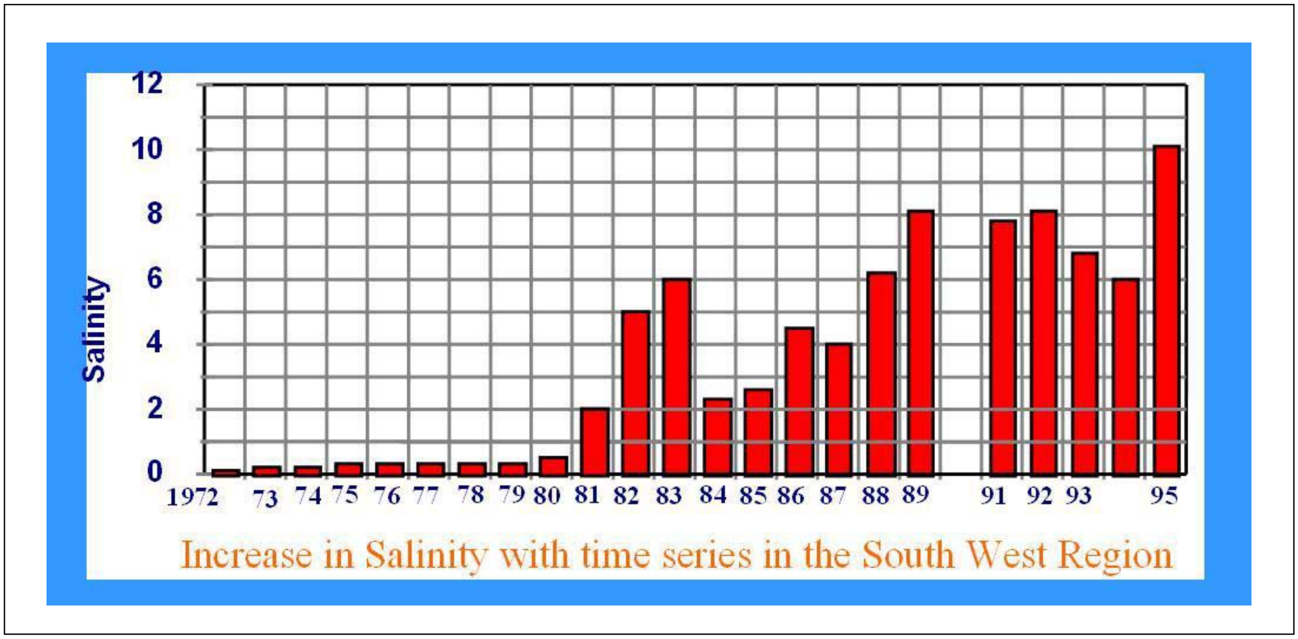


Figure 5: Increase in Salinity with respect to time in the southwest (http://www.sdnpbd.org/river_basin/bangladesh/bangladesh_salinity_intrusion.htm. Dated 19.02.2006)

of the country will be inundated as a result of the greenhouse effect, which may propagate saline water intrusion throughout the country. The total trans-boundary sources of potable water in groundwater aquifers will be affected because agriculture is the main livelihood of a highly dense population which requires huge groundwater abstractions for irrigation purposes. In this situation, management of salinity intrusion is a vital issue for Bangladesh. A vision of a sustainable livelihood and environment for Bangladesh includes saline water proofing by structural management like coastal embankment projects, dams, sluices, etc., as well as coastal area zoning as a non-structural management strategy to change land use. Further study to formulate the optimal model for proper management using different scenarios is a critical need.

## REFERENCES

Ahmed, F. 1996. Coastal water supply in Bangladesh, Reaching the Unchanged: Challenges For The 21st Century, 22nd WEDC Conference, New Delhi, India.

Ahmed, K.M., M. Hoque, K. Hasan, P. Ravenscroft, and L.R. Chowdhury. 1998. Occurrence and origin of water well methane gas in Bangladesh. J. Geol. Soc. India 51, 697–708.

BADC. 1992. Deep Tubewell II Project. Final Report. Mott MacDonald Ltd. and Hunting Technical Services. Report for Bangladesh Agricultural Development Corporation and Overseas Development Administration (UK).

BWDB, DHV International, DDC, SWMC. 1998. Draft Master Plan, Volume 2: Morphological Processes

DPHE. 1999. Groundwater Studies for Arsenic Contamination in Bangladesh. Final Report, Rapid Investigation Phase. Department of Public Health Engineering, Government of Bangladesh. Mott MacDonald and British Geological Survey.

Goodbred, S.L., and S.A. Kuehl. 2000. The significance of large sediment supply, active tectonics, and eustasy on margin sequence development: Late Quaternary stratigraphy and evolution of the Ganges–Brahmaputra delta. Sed. Geol. 133, 227–248.

Hassan, M.Q., M. Rahman, M.S. Islam, and S.Z.K.M. Shamsad. 1998. Effects of salinity on the hydrogeo-environment of Khulna city and Mongla Port area of Bangladesh. Dhaka Univ. J. Biol. Sci. 7, 113–127.

Hoque, M., M.K. Hasan, and P. Ravenscroft. 2003. Investigation of Groundwater Salinity and Gas Problems in Southeast Bangladesh. In: Rahman, A.A., Ravenscroft, P. (Eds.), Groundwater Resources and Development in Bangladesh. Bangladesh Centre for Advanced Studies, University Press Ltd, Dhaka.

Kudrass, H.R., V. Spiess, M. Michels, B. Kottke, and S.R. Khan. 1999. Transport processes, accumulation rates and a sediment budget for the submarine delta of the Ganges– Brahmaputra and the Swatch of No Ground, Bangladesh. International Seminar on the Quaternary Development and Coastal Hydrodynamics of the Ganges Delta in Bangladesh, Geological Survey of Bangladesh, Dhaka, September 20–21, 1999.

LGED. 1994. Municipal Services Project. Interim Report, vol. 5: Khulna Water Supply. Mott MacDonald Ltd in association with Louis Berger International, EPC Ltd and AQUA, Ltd. Report for Local Government Engineering Department and World Bank.

McArthur, J.M., P. Ravenscroft, S. Safiullah, and M.F. Thirlwall. 2001. Arsenic in groundwater: testing pollution mechanisms for aquifers in Bangladesh. Water Resour. Res. 37, 109–117. Mercado, A., 1985. The use of hydrogeochemical patterns in carbonate sand and sandstone aquifers to identify intrusion and flushing of saline water. Ground Water 23, 635–645.

Morgan, J.P., and W.G. McIntire. 1959. Quaternary geology of the Bengal Basin, East Pakistan and India. Geol. Soc. Am. Bull. 70, 319–342.

MPO. 1987. Groundwater Resources of Bangladesh. Technical Report Nr 5. Master Plan Organisation. Dhaka. Harza

Nickson, R., J. McArthur, W. Burgess, K.M. Ahmed, P. Ravenscroft, and M. Rahman. 1998. As poisoning of Bangladesh groundwater. Nature 395, 338.

Nickson, R.T., J.M. McArthur, P. Ravenscroft, W.S. Burgess, and K.M. Ahmed. 2000. Mechanism of arsenic poisoning of groundwater in Bangladesh and West Bengal. Appl. Geochem. 15, 403–413.

PDO-ICZM. 2002. Inventory of Projects & Initiatives in the Coastal Zone, Working Paper, WARPO, Ministry of Water Resources, Dhaka.

Rahman, M., M.Q. Hassan, M.S. Islam, and S.Z.K.M. Shamsad. 2000. Environmental impact assessment on water quality deterioration caused by the decreased Ganges outflow and saline water intrusion in south-western Bangladesh. Environ. Geol. 40, 31–40.

Ravenscroft, P. 2003. An Overview of the Hydrogeology of Bangladesh. In: Rahman, A.A., Ravenscroft, P. (Eds.), Groundwater Resources and Development in Bangladesh. Bangladesh Centre for Advanced Studies, University Press Ltd, Dhaka.

Rus, J.S. 1985. Geohydrological Investigations in Khulna. DPHE Water Supply and Sanitation Projects. DPHE. Netherlands–Bangladesh Development Co-operation Programme.

Shamsuddin, Sk. A.J. 1986. Water Supply in Coastal Region of Bangladesh, M.Sc. Thesis, Loughborough University of Technology, U.K.

SRDI. 2001. Soil and Water Salinity in the Coastal Area of Bangladesh. Soil Resource Development Institute, Ministry of Agriculture, Dhaka. 2001.

Umitsu, M. 1993. Late Quaternary sedimentary environments and landforms in the Ganges Delta. Sed. Geol. 83, 177–186.

www.sdnpbd.org/river_basin/bangladesh/bangladesh_salinity_intrusion.htm

ADDRESS FOR CORRESPONDENCE
Dr. Amartya Kumar Bhattacharya
Assistant Professor, Department of Applied Mechanics
Bengal Engineering and Science University
Shibpur, Howrah 711103
India

Email:amartya_67@rediffmail.com