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DETERMINATION OF SUSTAINABLE ZONES FOR GROUNDWATER ABSTRACTION FROM THE MULTI-LAYERED AQUIFER SYSTEM IN THE BENGAL BASIN, BANGLADESH

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INTRODUCTION

- Model formation and study of major controls on regional flow in the entire Bengal Basin aquifer system are described by Michael and Voss (in press) to allow study of the largest scale of groundwater flow that might occur in the Bengal Basin.
- A three-dimensional model was used for this study to simulate groundwater flow in southeastern portion of the Bengal Basin.
- The model was used to study the impacts of geologic formations and different development stresses on groundwater flowpaths and travel time mainly from the sources (recharge areas) to different aquifer units under steady-state conditions.
- The modeled area is characterized by heavy withdrawal of groundwater. Increasing demand of water due to increasing populations has initiated the need for and effective management of available groundwater resources.
- In the study region, multi-layered aquifer conditions exist, with arsenic contamination at shallow depth (5-50m) and high iron and brackish groundwater occurring mainly in the deeper layers (upto about 300m) that forms a constraint to groundwater development in the area (Zahid et al., 2008; DPHE-BGS, 2001).
- Alluvial deposits carried by the Ganges-Brahmaputra-Meghna (GBM) river systems have gradually built up the Delta and Meghna estuary while tidal deposits are dominant in the southern coastal plain.
- The GBM river system has the largest total sediment load in the world; this is derived from the Himalayan and Indo-Burman range (Uddin and Lundberg, 1998, Coleman, 1969) and deposited in the basin with fluvio-deltaic sediments of considerable thickness.
- The Holocene and Plio-Pleistocene Dupi Tila Formation are considered for sustainable groundwater development; other units are too deep to explore by traditional low cost methods.

STUDY AREA

- The study area is bounded by the Meghna River in the west, the Tripura hills in the east, the Titas River and the Bay of Bengal at its north and south respectively (Figure).
- The Meghna estuarine floodplain, Tippera surface (Morgan and McIntire, 1959) and the lower delta in the coastal land-form of Bengal basin are the dominant physiographic units in the study area.

- Tippera surface has rectangular drainage pattern in contrast to the braided and meandering pattern of the floodplain.

Figure: Study area and model area in southeastern Bangladesh.

METHODOLOGY

MODEL DESCRIPTION

- Conceptual models are important for understanding flow-system behavior under possible aquifer-aquitard system conditions and also able to depict the relative importance of vertical leakage and advective solute transport under natural and developed conditions.
- A mathematical model of a groundwater system comprised of a differential equation that describes flow within the system, defines an expression of the mass balance and a set of boundary conditions that affect how water enters and leaves the system.

Model Unit	Geology	Depth Range (m)	Maximum Thickness (m)	No. of Vertical Cells
Unit1	Aquitard	0-1	1	1
Unit2	Aquitard	1-16	15	2
Unit3	1 st Aquifer (Upper)	16-46	30	3
Unit4	1 st Aquifer (Lower)	46-76	30	3
Unit5	Aquitard	76-101	25	3
Unit6	2 nd Aquifer (Upper)	101-176	75	8
Unit7	2 nd Aquifer (Lower)	176-286	110	11
Unit8	Aquitard	286-300	14	2
Unit9	3 rd Aquifer (Upper)	300-400	100	10
Unit10	3 rd Aquifer (Lower)	>400	2596	10

Model geologic units and vertical discretization.

Hydrogeology

- Hydraulic conductivity (horizontal) for the mid-western part of the model area was measured between 2.5x10-5 and 7.0x10-5 m/sec for lower part (180-230 m depth) of the 2nd aquifer and between 3.43-05 and 2.3-04 m/sec for the 3rd aquifer, whereas vertical hydraulic conductivity is 10-100 times lower than horizontal hydraulic conductivity (230-330 m depth).
- Deep aquitard vertical hydraulic conductivity was measured as about 4.0x10-6 m/sec.
- Total calculated irrigation abstraction for 2004 was 2669 Mm3 that was 810 Mm3 in 1995-96 (BMDA, 2004).
- For household purpose, 9 m3/person/year is considered which is in total 115 Mm3.

Figure: Model Heads of Different Aquifer Units of south-east Bangladesh in 2004 Development Stages under Different Geologic Conditions.

Boundary Conditions

- The static water table i.e. groundwater level in the monsoon is very close to the land surface in the model area and actual recharge is considerably less than potential recharge (BWDB-UNDP, 1982).
- The eastern boundary of the model area is the Tripura hills of older formation formed by massive sandstone and hard shale, the flow from this boundary into the system is negligible and hence this is fixed as no-flow boundary.
- The northern and western side of the model area is bounded by the rivers Titas and Meghna respectively, regional groundwater flow is southward along the river Meghna and are closed to east-west movement irrespective of development stresses—thus northern and western boundary conditions are taken as closed and constant head boundaries.

Figure: Vertical distribution of aquifer units and groundwater development zones.

Model Validation

- Regional groundwater flow from the eastern boundary of the model area is generally to the west and southwest.
- Assessment indicates, when the surface clay varies in thickness that is usual for the model area, the piezometric level in the 1st aquifer may locally drop below the base of the clay creating local unconfined conditions within the aquifer.
- Groundwater abstraction is partially balanced by leakage through the clay and partially by unconfined storage change in the aquifer.
- Water level in the shallow aquifer varies place to place due to local-scale lithologic variations too.

Figure: Groundwater contour maps for the 1st aquifer based on BWDB 2004 groundwater level data: (a) in monsoon (static water level); (b) in dry irrigation season.

Abstract

The use of deep groundwater (± 300 m deep) is becoming an important issue in the Bengal Basin, due to both water quality problems and an acute shortage of available water in upper aquifers. In southeastern Bangladesh, multi-layered aquifer conditions exist with arsenic contamination at shallow depths, and high iron and brackish groundwater occurring mainly in the deeper layers. Many previous studies have offered explanations for the high concentrations of dissolved arsenic in groundwater - most of which proposed that the arsenic is derived from geo-genic sources and its release in groundwater is through natural processes, not the result of anthropogenic practices. About three million tube-wells, installed at shallow depths (10 to 50m), discharged groundwater with arsenic concentrations more than the Bangladesh drinking water standard of 50 $\mu\text{g/l}$. Toxic levels of arsenic typically occur in the middle Holocene sediments deposited in low-lying delta and floodplain areas, which adversely affects the health of millions of people. Aquifers are recharged by vertical percolation as well as water from a long distance traveling from highly elevated eastern hilly terrain to deeper aquifers. Arsenic or chloride-rich groundwater in the upper aquifers is not likely to be drawn into the deep aquifer under conditions of moderate use from the deep aquifer water. Under the current trend of groundwater abstraction, the possibility of a mass transport of arsenic in the lower part of the first aquifer, just below the arsenic-contaminated zone, will increase in future (?).

DISCUSSION / CONCLUSION

Discussion

- Flowpaths and travel times for aquifer units at anisotropic condition under predevelopment, and 2004 and 2014 development stresses with aquitard horizontal and vertical hydraulic conductivities of 1.0x10-6 and 1.0x10-7 m/sec respectively are presented in Figure.
- Under predevelopment condition, Kachua aquifers are recharged by vertical percolation as well as water from long distance travel from highly elevated eastern hilly areas mainly to deeper aquifers.
- Under 2004 development condition, remarkable decrease in travel time i.e. vertical percolation of recharged water to shallow aquifer compare to predevelopment condition is due to huge irrigation and other pumping from the 1st and the upper part of the 2nd aquifer.
- The flow pattern is observed nearly similar like anisotropic condition with aquitards, vertical percolation of recharge water to deeper aquifers from surrounding floodplains increases.

Figure: Flowpaths and recharge zones for aquifer units at anisotropic condition under (a) predevelopment, (b) 2004, and (c) 2014 development stresses.

- Shorter flowpaths are observed for predevelopment and different development stresses compare to other geologic conditions.
- Compare to 2004 situation, travel time of vertical percolation of recharge water is decreased for the 1st aquifer with increased irrigation pumping in 2014 from lower part of the 1st aquifer.
- Considering different geologic conditions in 2004 development stress, average travel time i.e. age of recharged groundwater is found between 37 and 317, 832 and 3027 and 1065 and 3543 years respectively for the 1st, the 2nd and the 3rd aquifers.

Conclusion

- Flowpaths and travel time of groundwater are primarily controlled by hydrogeologic characteristics i.e. anisotropy and the pattern of pumping.
- The recharge zone for different aquifer units under different development stress is about same in different geologic conditions.
- Aquifers are recharged by vertical percolation as well as water from long distance travel from highly elevated eastern hilly areas mainly to deeper aquifers.
- Groundwater level in the shallow aquifer varies place to place mainly due to local-scale lithologic variations and pumping of groundwater.
- sea-water intrusion is a problem in coastal basins, possibility of sea-water encroachment would be accelerated with increased stress on groundwater and anticipated impact of climate change.

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Figure: Flowpaths and recharge zones for aquifer units at low anisotropic condition under (a) predevelopment, (b) 2004, and (c) 2014 development stresses.

Figure: Groundwater model predicts trends of future changes under different development stresses at certain geologic conditions (Zahid and Hassan, 2009).