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Hydrogeological Condition and Assessment of Groundwater Resource Using Visual Modflow Modeling, Rajshahi City Aquifer, Bangladesh

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Abstract: The Rajshahi city is the fourth largest metropolitan city in Bangladesh on the bank of the River Padma (Ganges). Here an upper semi-impervious layer overlies aquifer – the source for large-scale groundwater development. The groundwater resource study using Visual MODFLOW modeling shows that recharge occurs mainly due to infiltration of rainfall and urban return flow at low rate, and water level fluctuates seasonally in response to recharge and discharge. Hydraulic connection between river and aquifer which indicates inflow from high river water levels beyond its boundaries. The total groundwater abstraction in 2004 (15000 million liters) is lower than total input to aquifer reveals an ample potentiality for groundwater development with increasing demand. But groundwater shortage (1000 million liter/year) especially in the vicinity of the River Padma in dry season happens due to its increasing use and fall of river water level resulting in reduced inflows and hence decline in groundwater level. The conjunctive use of surface water-groundwater and its economic use will help for sustainable groundwater supply to avoid adverse impact.

Keywords: Hydrogeology, Groundwater resource assessment, Aquifer, Rajshahi, Bangladesh.

INTRODUCTION

The study area is the Rajshahi City Corporation (RCC) with a total area of 98 km^2 and a population of 0.7 million (RDA, 2002) (Fig.1). At present RCC provides only 57 million liters of water per day or 38% out of daily demand of 103 million liters, which is extracted from 52 deep tubewells (DTWs) along with 4,750 hand tubewells (HTWs) and 250 Tara pumps. Groundwater is suitable for drinking and public health purposes (Ahmed et al. 1999, 2002). The demand will be 165 million liter per day by 2020. At present only 70% of the population has access to piped water supply and 30% through HTWs and others. Some parts of the City face water crisis largely due to fall of groundwater level especially during dry period. The projected population and water demand up to 2020 are shown in Fig.2.

To develop groundwater resources in a sound manner, knowledge of the groundwater flow systems, monitoring techniques and quantification methods of groundwater resources are essential. The aim of the study is to assess hydrogeological conditions and to apply the modeling technique for reliable assessment of the groundwater resource for future development in RCC area.

GEOGRAPHY AND GEOLOGY

Rajshahi enjoys sub-tropical climate with a mean annual rainfall of 1625 mm, which is much lower than the national average of 2550 mm. During summer (March-May) temperature rises above 40°C, but falls below 5°C in mid-winter (January). The mean relative humidity is low (60%) in early summer (March) and high (88%) in late monsoon (August-September).

The study area is a small part of the Ganges River basin – a flat alluvial basin. The surface geology consists mainly of sedimentary formations, mostly riverine in origin. The area has a general slope from south (Padma river bank) to north with ground elevation of 17.0-18.0 m Public Works Datum (PWD) (MacDonald and Partner, 1981; Goodbred,

Table 1. Stratigraphic Succession of RCC Area

Age	Rock Unit	Lithology	Thickness (m)
Recent-Late Holocene	Alluvium	Very fine sand, silt and clay	0-25
Early Holocene	Sandy Unit	Very fine to medium sand associated with coarse sand and gravel	25-85

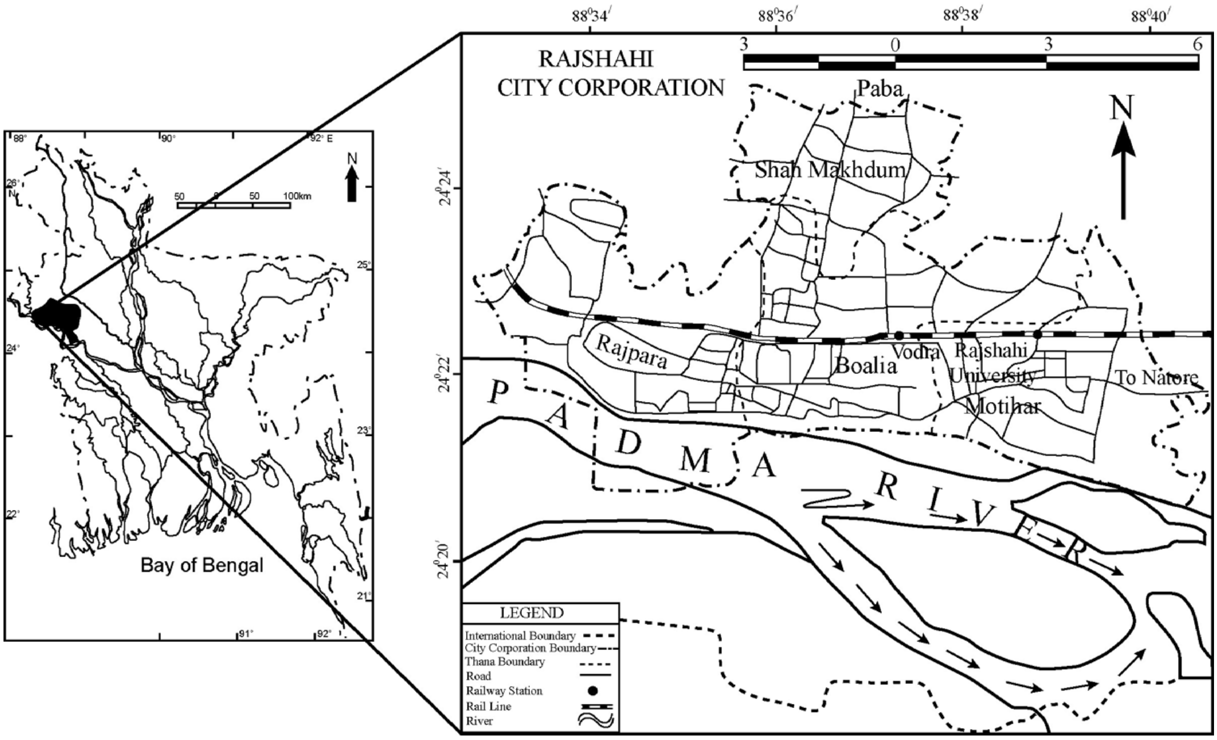

Fig.1. Location Map of Rajshahi City Corporation Area

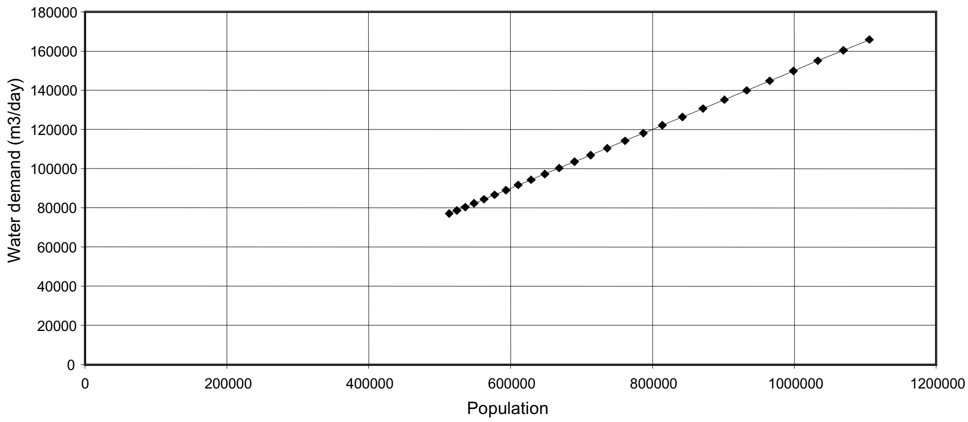

Fig.2. Projected Population and Water Demand up to 2020.

et al. 2000; Allison et al. 2002). The stratigraphic succession on the basis of exploratory bore-log data of Department of Public Health Engineering (DPHE) is given in Table 1.

HYDROGEOLOGICAL CONDITION

Evaluation of Aquifer System

In the present study, evaluation includes: (a) geometry by using available bore-log data of DPHE, and (b) hydraulic characteristics like transmissivity (T) and storage co-efficient (S) computed by aquifer performance tests of 31 wells conducted by DPHE. The locations of boreholes along with hydrogeological cross-sections are shown in Figs. 3 and 4.

The aquifer system is classified as:

a Upper silty-clay layer (Zone-I): The area is covered with grey to brown clay and silty clay layer of semi-impervious nature, which exhibits the typical characteristics of an aquitard of thickness 10-25 m. An isopach map of top silty clay layer is shown in Fig. 5.

b *Aquifer (Zone-II):* Extends throughout the area below the upper silty-clay layer of thickness 25-85$^+$ m and is divided into composite aquifer - upper one comprising grey and light brown coloured very fine to fine grained

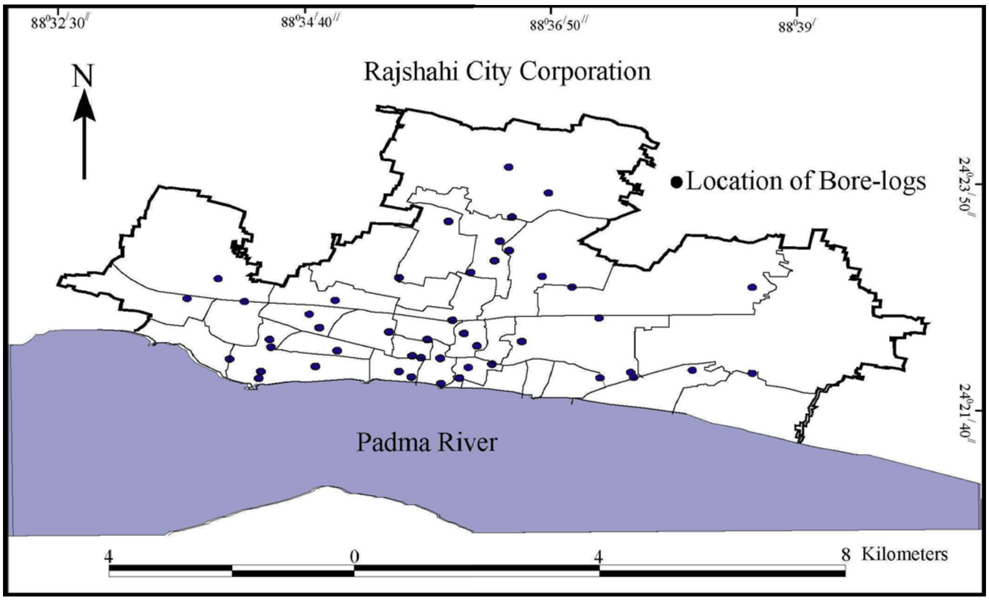

Fig. 3. Borehole Locations along with Profiles of A-A' and B-B'.

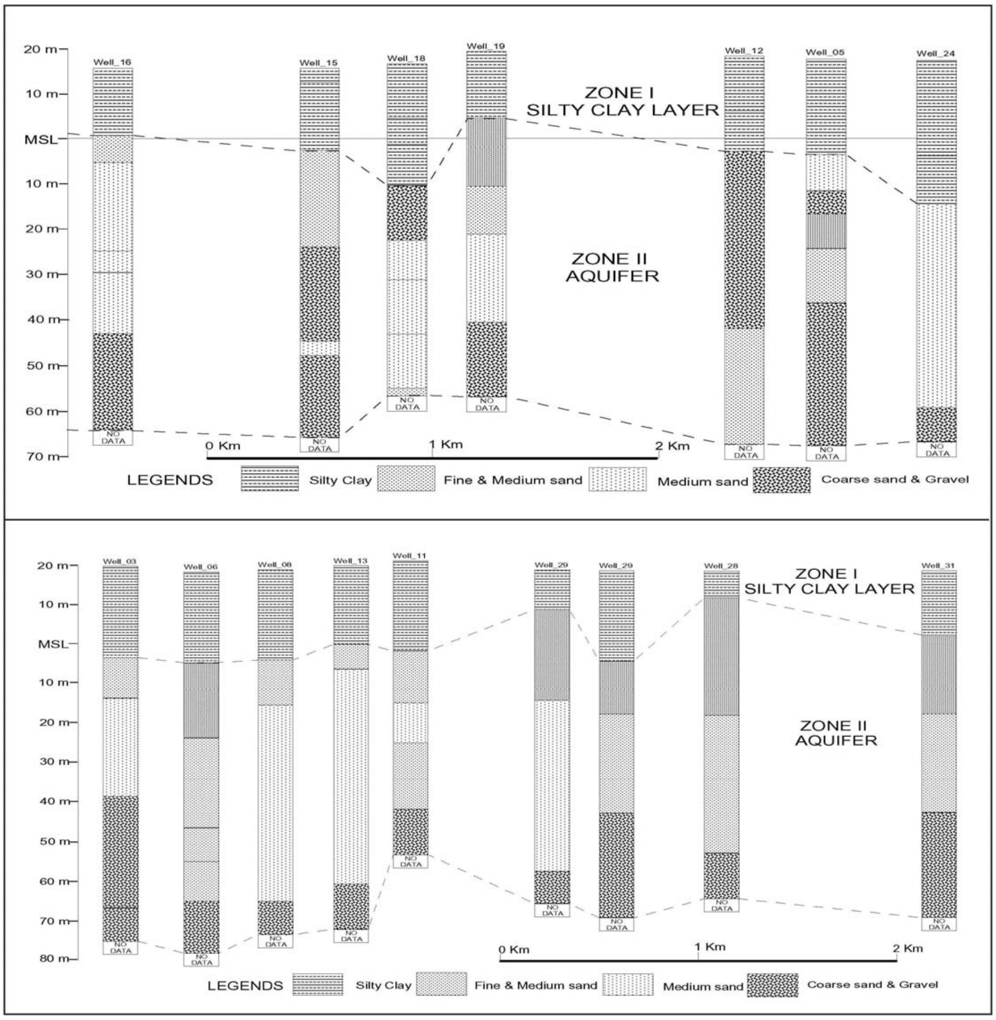

Fig. 4. Hydrogeological cross-sections **(a)** A-A' and **(b)** B-B'.

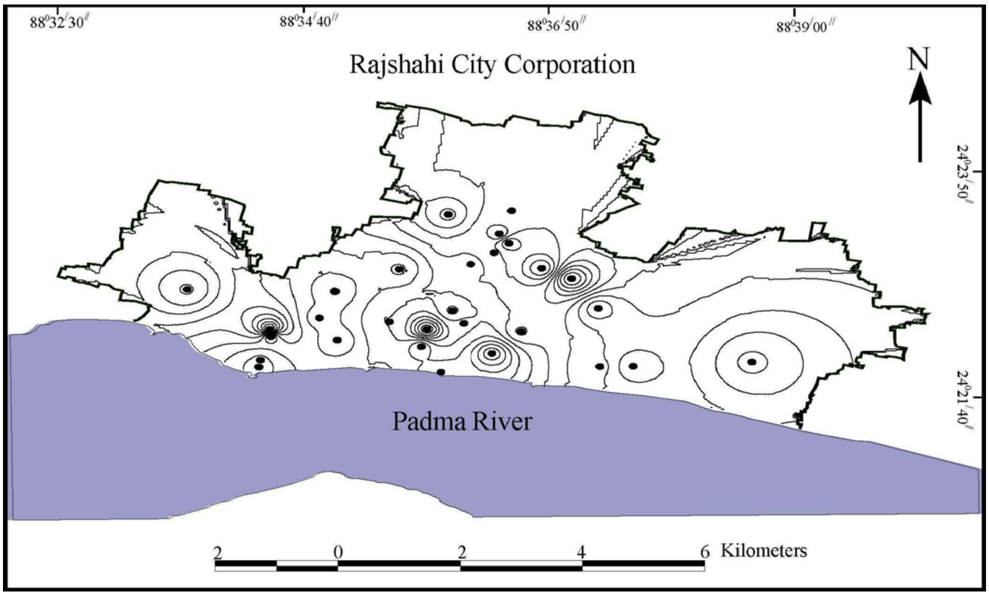

Fig. 5. Isopach map of upper silty-clay layer..

sand inter-bedded with clay and silt; and - lower one main aquifer composed of fine to coarse-grained sand with gravel and is considered as principal source of groundwater. The lower boundary of this zone could not be delineated due to non-availability bore-log data.

T and S values are computed by Theis, Copper-Jacob and Neuman methods (Kruseman and de Ridder, 1994) by using computer program as Aquifer Test 3.5, and range from 1019 to 6000 m^2/day and $5.54x10^9$ to 0.673 respectively.

Groundwater Level and Aquifer Response

The routine groundwater levels monitoring data of Bangladesh Water Development Board (BWDB) and monthly rainfall data from the Bangladesh Meteorological Department for the period of 1994-2004 have been used to prepare long-term groundwater and rainfall hydrographs. Selected hydrographs (Figs. 6 and 7) reveal that the groundwater level rises during monsoon, generally reaches its peak in late monsoon (August-October) and falls to a minimum in late summer (April-May). The initial response to recharge of groundwater by rainfall is observed in later part of May and continues until August and October. So, marked seasonal response to recharge and discharge is observed and no long-term variation in groundwater level is evident. But groundwater level only fluctuates due to annual cyclic alteration of seasons.

MODEL DEVELOPMENT AND APPLICATION

The methodology includes collection, analysis and processing of huge amount of field data such as topographic elevation from Digital Elevation Model (DEM), land-use, population, meteorological, river water level for monthly average of 1994-2004, hydrological, aquifer characteristics, groundwater abstraction and demand after quality checking and model application with Visual MODFLOW 2000 (Waterloo Hydrogeologic Inc). The geographical locations of the field data are converted into coordinates with an application named Geowin. Here the River Padma forms the external boundary of the model along the southern part, and its water level provides time varying head boundary conditions.

Data required for the groundwater model can be grouped as time invariant and variant data. Recharge for groundwater model from rainfall and urban return flow are described as: (i) monthly rainfall data from 1994 to 2004, and (ii) urban return flow due to leakage from water distribution and sewerage system. The groundwater model covers an area of 151 km^2 with the model grid cell size of 100´100 m^2. At the time of discretization, every month is selected as a stress period. The cross-section of model geologic formation along East-West direction is shown in Fig. 8.

To measure the performance of the model, calibrated water levels were compared with the observed groundwater levels shows the similarity of the groundwater table fluctuations near the rivers with the seasonal river level fluctuations which diminishes rapidly away from the rivers. So the surrounding rivers are hydraulically connected to the aquifer system and the groundwater flow towards the city owes to the high water levels beyond the river boundaries. On the other hand, aquifer is recharged by infiltration of

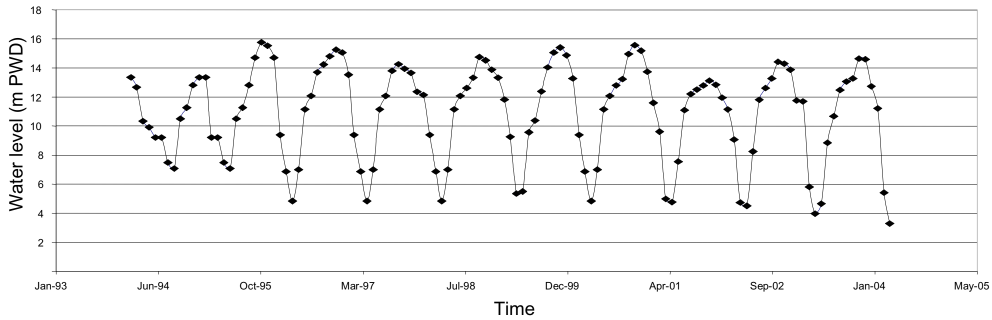

Fig.6. Hydrographs of observation wells.

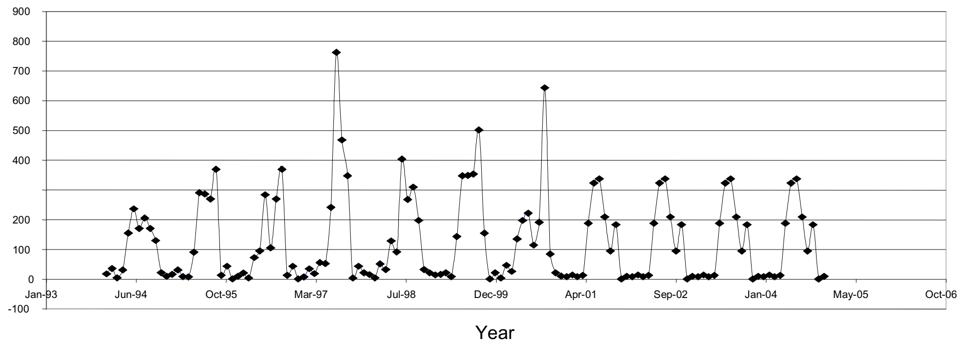

Fig.7. Rainfall hydrograph.

water from the precipitation, and from the return (urban) flows.

For calibration the model was run repeatedly following trial-and error method. The comparison between the observed and the simulated water levels after final calibration shows a satisfactory agreement. Contour maps of simulated groundwater levels in summer and monsoon seasons in the model area for 2004 are shown in Figs.9a and b. The calibration of residual histogram shows a normal distribution with the mean value of -1.034793. The validation using the secondary data has been carried out for the calibrated model to check for representation of the physical system and reveals that the parameters used in the calibrated model are acceptable. Thus the model can be used for prediction purposes.

Results of the simulations are analyzed and compared with the base condition such as groundwater level hydrographs and groundwater table contour maps to understand the present status of groundwater table, show that maximum and minimum depth of groundwater table occurs at the end of April and October respectively with a maximum depth ranges from 3.0 to 15.0 m PWD. The observed verses calculated hydrographs of observation well are shown in Fig.10, which is also supported by groundwater table hydrographs. The present status of water table after calibration shows good condition for both the periods.

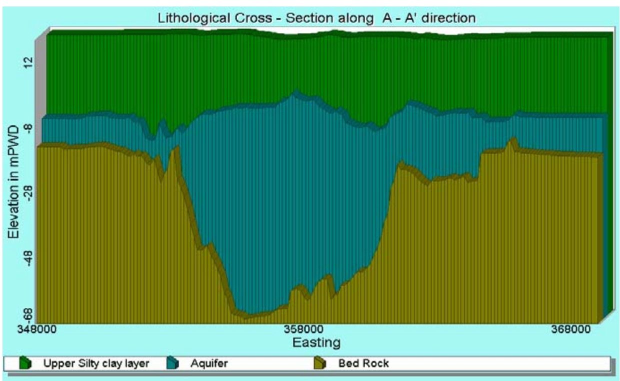

Fig.8. East-west cross-section of model geologic formations (A-A').

GROUNDWATER RESOURCE ASSESSMENT

The groundwater resource has been assessed based on recharge characteristics and available resources. The sources of groundwater replenishment are percolation of rainwater, urban return flow and horizontal flow of groundwater from the Padma River. Here the aquifer recharge occurs by rainfalls, while recharge from urban flow continues throughout the year. The groundwater storage is reduced due to withdrawal for domestic purposes and outflow to rivers, canals, ditches, ponds and other water bodies.

The actual recharge has been estimated by subtracting the components of drain to river and net outflow (inflow

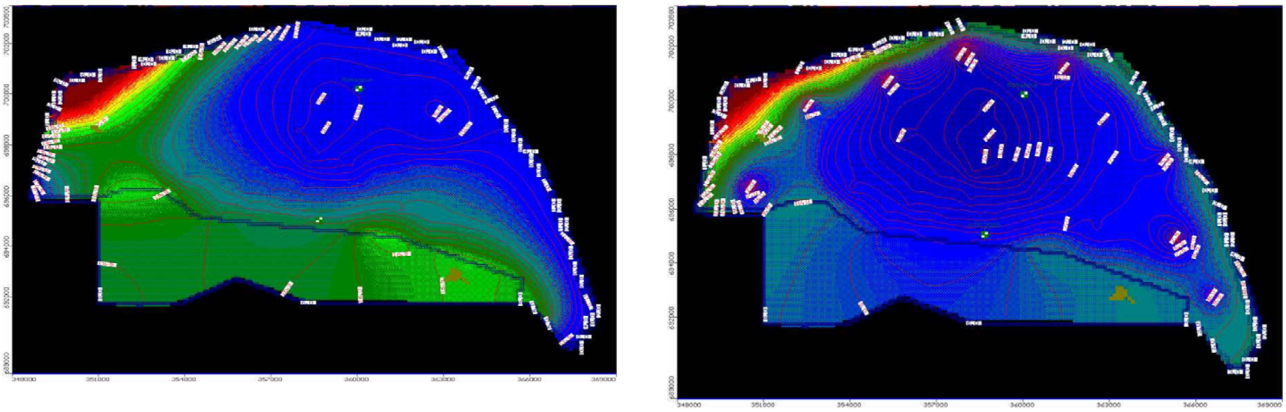

Fig. 9. Simulated groundwater levels (amsl) of study area **(a)** Summer. **(b)** Monsoon.

~ outflow) from the net input recharge, and also compared with the actual abstracted water from DTWs and HTWs with an efficiency of 75% and 50% respectively. The relationship between estimated actual recharge and groundwater abstraction for the year of 1994-2004 (Table 2) reveals that actual abstraction is lower than actual recharge having the scope for further groundwater development. But estimation of potential and usable recharge needs to be considered for better management decision.

The flow exchange between aquifer and river shows interactions depending mainly on river water level and groundwater table as well as aquifer lithology in river bank and bed and is shown in Fig.11. The aquifer has an average inflow rate of 6800 m^3/day (6.8 million liters) and the average outflow rate is 3040 m^3/day (3.0 million liters) for the year 2002. The aquifer feed the river from the month of November due to low river water flow. Beginning in July, the river water level rises and becomes higher than that of groundwater level and feeds the aquifer. But the groundwater level starts to decline in the vicinity of the river Padma due to feeding of river from aquifer because of falling of river water level and substantial use of groundwater. In water balance study storage changes (±?S) for the year 2004 is calculated as can -1.01 Mm^3 though it is gaining water both from the surrounding rivers and urban return.

After calibration of the model, the water balance for the year 2004 shows total abstraction of 15 Mm^3 or 15000 million liter per year is lower than the total contribution from rivers, precipitation and return flows. But the shortage of 1 Mm^3 or 1000 million litres/year of groundwater in dry season happens especially in the vicinity of river Padma due to substantial use of groundwater and lowering of river water level resulting declination of groundwater level. At the same time, abstraction of groundwater is increasing every year to meet the demand of water in need.

CONCLUSIONS

- Hydrogeologically, in RCC area, semi-impervious clay and silty-clay layer of Recent-Late Holocene age overlie sandy aquifer of Early Holocene – the principle source of groundwater for large-scale development.

Table 2. Actual recharges and groundwater abstraction for the year of 1994-2004

Year	Inflow (m^3/day)				Outflow (m^3/day)			
	Storage	River Leakage	Recharge	Boundary	Storage	Abstraction	River Leakage	Boundary
1994	11635	4758	1516	13996	21558	6535	3649	163
1995	4805	4512	1598	10683	11049	5938	4395	215
1996	5197	4154	1572	10001	9532	5938	5208	246
1997	110381	4515	1645	9886	117366	18073	4927	269
1998	116964	4891	1592	10922	86062	18128	4375	265
1999	111821	4973	1592	11752	95279	19822	3632	260
2000	138048	6337	2275	12594	117269	20231	3008	247
2001	116027	7137	1730	13257	96418	28594	2941	237
2002	116310	6420	1915	14455	84941	28960	1720	224
2003	124180	8810	1726	15801	117037	34147	1486	212
2004	109666	10206	1949	17082	112425	41318	1093	200

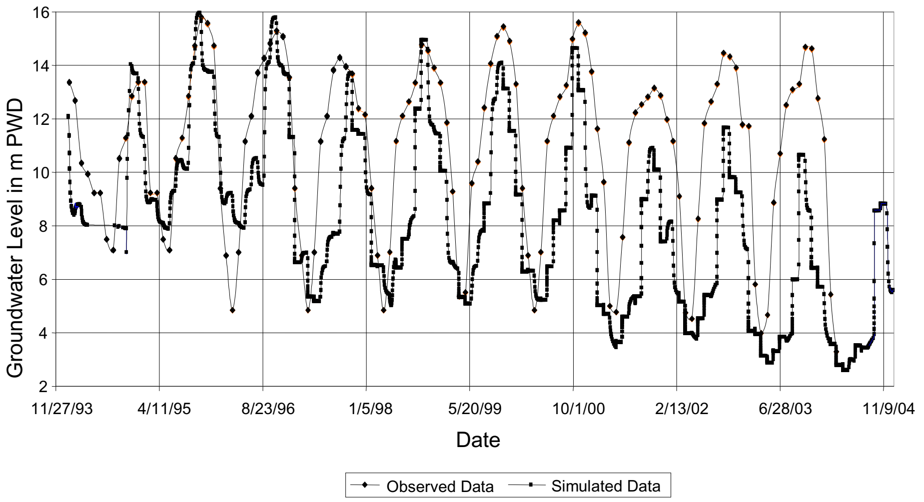

Fig.10. Observed vs. calculated hydrograph at observation well.

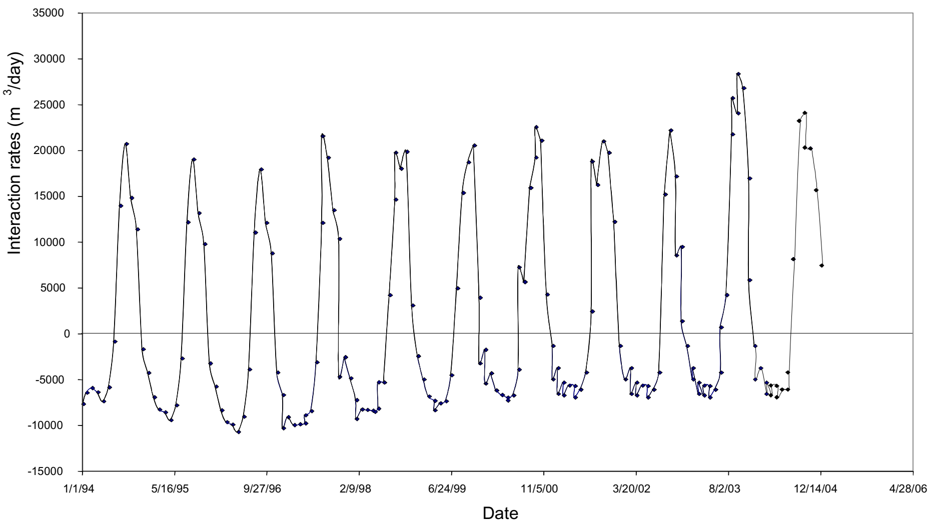

Fig.11. Exchange of flows between Ganges River and aquifer.

- The aquifer is hydraulically connected with River Padma and is feeding from high water level beyond the river boundaries. The groundwater recharge occurs from rainwater percolation and return flow (urban) with no long-term variation in groundwater level, but it only fluctuates with annual cyclic alteration of seasons.
- The model scenarios shows the declining trend of groundwater level in dry season in the vicinity of Padma happen due to lowering of peak river water level and substantial use of groundwater.
- Total abstraction of groundwater (15000 million litres/year) is lower than total recharge of aquifer. But shortage of groundwater only in vicinity of River Padma (1000 million litre/year) in dry season results from lowering of water level.

As groundwater abstraction is increasing every year to meet the demand, so suitable measures are necessary to preserve aquifer potentiality. Therefore, a comprehensive Water Law should be formulated for proper conservation and maintaining sustainable use of groundwater resource in RCC area. In this context, conjunctive use of Padma River water should be promoted.

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