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Estimation of Potential recharge and groundwater resources assessment- A case study in low Barind area, Bangladesh

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Absract

The study area consists of eight upazilas of north-west region of Bangladesh. This is one of the driest parts of Bangladesh, normally less rain from November to April. The study area has been irrigated using about 2100 Deep Tubewells. It covers only about 80% of the total cultivable area. The remaining 20% area has been planned to cover by installation of additional Deep Tubewell under Bangladesh Multipurpose Development Authority (BMDA). To ensure the long term sustainability, the consequences of the groundwater development in the region need to be analyzed. This study tried to explore the appropriate modelling technique to increase agricultural production through sustainable utilisation of available water resources using Visual MODFLOW. From the study it can be seen that groundwater resources are inadequate in Raninagar, Durgapur and Puthia upazilas of the study area. Present withdrawals of groundwater to fulfil the requirement of Boro in excess of actual recharges and available resources have created the tendency of continuous lowering of groundwater level in these 3 upazilas. The deficit indicates a non-sustainable situation with increasing draw down. 80% coverage of Boro for all cultivable land of upazilas will incur an additional draw down, for which, quite a large number of shallow tubewells need to be replaced by Deep Tubewell. Monitoring of groundwater level in these upazilas need to be carefully continued for future action. Vertical percolation of rainwater is the main source of groundwater; increasing duration of percolation time and area by construction of water control structures on the rivers and Kharies will increase groundwater recharge. There is a possibility of increase of groundwater recharge by conservation of surface water in rivers and kharies in the post monsoon by retention structures. Conjunctive use of surface water —groundwater irrigation should be promoted and a conjunctive water allocation plan must be established.

1 Background

Agriculture has great importance on the economy of Bangladesh. Population growth poses pressures on agriculture and sustainable development and demands at the same time for more food production. For increasing the agricultural production and to reduce environmental impacts from agriculture, it is also necessary to investigate the interrelationship between rainfall, surface water and groundwater on one side and demand for irrigation water and crop production on the other side. The sustainable use and management of groundwater is now a great challenge for the national water agencies of Bangladesh. Nowadays Bangladesh government is conscious about the development and sustainable use of groundwater. The national water policy encourages future groundwater development for irrigation by both the public and private sectors (NWPo §4.7.b; MoWR, 1999). In the policy matrices of Water Resources Development and Management of the Poverty Reduction Strategy Paper put emphasis on groundwater utilization in Bangladesh

2 Present Problem and Aim of the Study

The study area has limited scope of surface water development and potential for groundwater development. Groundwater development takes place in the regions of intensive irrigation since 1968 (MPO, 1986). During the recent past years, the number of Deep Tube wells (DTW) has been significantly increased. At present, about 2100 Deep Tube Wells, 45,000 Shallow Tube Wells (STW) and other mode of irrigation wells are being used in the study area for irrigation (IWM, 2005). In total it covers 88% of the total irrigable area in the study area. The remaining irrigable area has been planned to cover by installation of additional DTWs under a specific project. The expansion of the irrigation system is not easy in the study area due to the following problems: (1) rain scarcity from November to April, though about 1000 to 2000 m rainfall during the monsoon (2) limited scope(s) of water conservation during the wet season for further use in the dry season (3) lack of knowledge of existing recharge patterns and potentials.

The main objective of the proposed study is to apply water resources modelling techniques with the view to increase agricultural production through sustainable utilization of available water resources. The study focuses specially on irrigation adoption based on groundwater availability in order to propose an effective planning and an efficient management of the water resources. The specific objectives for the present study are four: 1) Development of mathematical models for the study area using existing hydro-geological and meteorological data including calibration and validation of the model. 2) Assessment of groundwater resources and aquifer recharge, including the assessment of surface water contribution to aquifer. 3) Application of models for various scenarios development. 4) Assessment of groundwater availability as well as potential use for the future.

2 Study Area Description

The study area is situated in the Northwestern part of Bangladesh (Figure 1). The geographic boundary of the study area is 354971E, 691490N for the South Western corner and 415953E, 755620N for the North eastern corner and covers approximately 210800 ha where the cultivated area is about 160952 ha. Bagmara, Puthia, Durgapur, Mohanpur upazilas of Rajshahi district, Raninagar, Manda, Atrai, and Naogaon Sadar upazilas of Naogaon district have been analyzed for the study. The topography of the area varies from 22 meters Public Work datum (mPWD) in Mohadevpur in the northern part to 9 mPWD in Naogaon in southern part with a mean of 15.5 m. The study area is relatively flat, sloping towards northeast and southeast and experiences flood during monsoon.

The study area experiences a tropical humid monsoon climate. Annual temperature varies from 10^0C to 35^0C (MacDonald, 1983). The rainy season is quite wet with a range of

1200 mm to 2100 mm rainfall. Almost 80% of the rainfall occurs during June to October. The relative humidity in the study area varies from 46% to 83% (IWM, 2005).

The study area is drained mainly by three major rivers: Atrai, Sib-Barnai, and LNagar, a number of small rivers, which criss-cross the region. However, there are some low lying areas and small beels in the region. These low lying areas and beels get dried up during dry season.

In the study area, different fruit trees grow the year round. The main winter vegetables are Rabi (November to March) crops, while Kharif-I (April to June) crops are HYV Aus, B. Aus, Jute, Kaon, Til and summer vegetables. During the Kharif-II (July to October) grows HYV Aman, local variety Aman and rainy season vegetables.

Figure 1: Study Area Map

The main dependence for irrigation is on groundwater, being extracted mainly by deep and shallow tubewells (IWM, 2005). Every year new DTW and STW are installed and some tubewells go out of operation. Flooding irrigation is practiced for both DTW and STW. The percentage of currently irrigation coverage is in the range of 72% to 97% of the net cultivable area.

3 Data Analysis

According to the modelling requirements, a significant amount of data has been collected. All the data are secondary and have been obtained from the Institute of Water Modelling (IWM), Bangladesh Agricultural Development Corporation (BADC), Bangladesh Multipurpose Development Authority (BMDA) and Bangladesh Water Development Board (BWDB) etc. In addition to the data quality checking, data analysis also has been carried out for estimation of different model parameters.

The subsurface lithological characterization of the study area and the configuration of the hydro-stratigraphic units for groundwater flow model have been prepared. A total 1233 irrigation well logs from BWDB, BMDA and Local government Engineering Department (LGED) distributed all over the study area have been reviewed. According to the analysis the average about 21 m thick aquitard at the top is followed by a comparatively thin top aquifer. Actually, the second aquifer is the main aquifer which sometimes meets with the first aquifer. For model purposes the minimum thickness 0.1 m was considered. On the basis of subsurface lithological information, a regional (Manda, Raninagar, Naogaon, Bagmara and Mohanpur) hydrostratigraphic model and cross-sections have been prepared using rockworks software 2004. The Hydrostratigraphic model and fence diagram show the presence of two major aquifer systems in the study area, which is separated by a thin aquitard layer. The aquifer layer is composed of medium sand to fine sand, medium sand to coarse sand and occasionally coarse sand. The aquitard layer is composed of clay, silty clay and very fine sand. The analyses show that the thickness of the upper aquitard is not uniform in the study area. Cross sections prepared for the study area also show that the aquitard 2 and aquitard 3 are not continuous in some places and the both aquifer constitute a big aquifer in those places. From the collected aquifer tests data and development tests data the Hydraulic conductivity, specific yield and specific storage were calculated and used in the model.

The irrigation water was calculated on the basis of crop water requirements (CWR) for the whole model area by using CropWat 5.7 (FAO, 1992). The recharge was calculated by adding the irrigation water plus the monthly rainfall minus the actual monthly evapotranspiration. Losses were also considered.

4 Model Setup

Visual Modflow is a complete and easy-to-use modeling environment for practical applications in three-dimensional groundwater flow and contaminant transport simulations. It is a finite difference model, which solves a system of equations describing the major flow and related processes in the hydrological system (Visual Modflow user's guide, 2002). To asses the groundwater resources and surface water- groundwater interaction Visual Modflow 3.0 has been used.

The model setup involves a geometrical description and specification of physical characteristics of the hydrological system. The major components of the model setup include recharge, saturated zone, river system and abstraction. The study area has been discretized into a grid of 500 by 500 m square cells. The model has around 12,668 active cells, which are the basic units to provide all the spatial and temporal data as input and to get the corresponding output data. A 300 m resolution DEM has been obtained from IWM and has been used for the model development. The main rivers Atrai, Sib-Barnai, Lajmuna, Lnagar, Fakirni and Musakhan have been included to the model. Some of them form the external and some the internal model boundary. Aquifer properties such as hydraulic and vertical conductivity, specific yield, and storage coefficient have been defined for each layer from the analyses of aquifer and well development tests data. Potential heads of the monitoring wells were used to generate initial condition contour map and it is taken applicable for all the geological layers same, as all layers are leaky in nature and thus interconnected. A total of 17 monitoring wells are available along the west, north-west and south west boundary line. No monitoring well is available along the south-east boundary lines of the study area. Water level data from IWM for Lnagor, Sib-barnai and Musakhan River have been used along south-east boundary line. All layers are leaky in nature and thus interconnected. Therefore the same boundary condition is applied in all the layers. For model calibration and verification, the water requirement and abstraction data for the period of 1997 to 2005 were needed, requiring information about cropping pattern and crop coverage. Since abstraction data were not available, water extraction for the period of 1997 to 2005 has been estimated. After estimating the total upazilawise irrigation water requirement, the water is uniformly distributed to each cell according to crop coverage. After lumping the aquifer and soil properties, five layers have been finalized for the description of geology and incorporated into the model. The same default time step and computational parameters for the model have been used for the entire simulation period.

5 Model Calibration and Validation

The goal of this calibration procedure is to minimize differences between the observed data and simulated values. Usually, the model is considered calibrated when it reproduces historical data within some acceptable level of accuracy (Delleur, 1999). The model has been calibrated for the period 1997 to 2003. The calibration has been done against groundwater levels. During calibration the input hydraulic conductivity, specific yield, storage coefficient and river leakage coefficient have been adjusted. Calibration has been done against the observed data of 16 monitoring groundwater level stations. In general, the overall calibration of the Barind model is acceptable, but there is scope for further improvements. To check whether the calibrated model is an adequate representation of the physical system or not, validation has been carried out for the calibrated model. The model was validated for the period of January 2004 to December 2005. Validation results show similar trend of groundwater fluctuation and good matching of groundwater levels between observed and simulated values for both of the validation periods. From the results of the model validation, it could be concluded that the parameters used in the calibrated model are acceptable.

6 Results and Discussions

The aquifer characteristics as well as recharge patterns and the groundwater abstraction rate vary spatially within the whole study area. The water budget for each upazila for the period of January 1997 to December 2005 has been estimated by using Visual MODFLOW Zone Budget option. These results can be useful for groundwater management and decisions on water allocation in individual upazila according to groundwater availability. Figure 2 shows the water budget in the upazila Manda for the years 1997 to 2005.

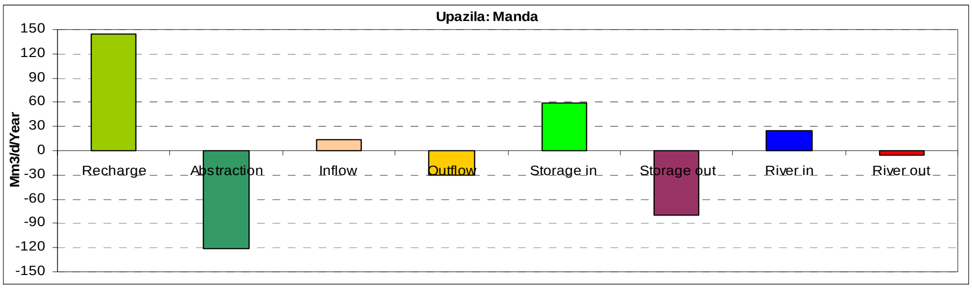

Figure 2: Water Budget for the Upazila Manda for Simulation Period 1997-2005

In the study area, the aquifer recharge to groundwater begins with the rainfalls from May and continues up to October, while recharge from irrigated crop fields occurs from December to the end of March. The aquifers become full in the months of August / September but excess rains are available to recharge till October, if there is room for recharge. The groundwater storage is reduced due to withdrawal for irrigation and domestic uses 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 ~ outflow) from the net input recharge. Table 1 shows the actual recharges of each upazila, which has been estimated from the model output data.

Table 1: Upazilawise Actual Recharge

Sl.No	Upazila	Recharge (mm)	Inflow (mm)	Outflow (mm)	River In (mm)	River Out (mm)	Actual Recharge (mm)
1	Atrai	484	47	63	90	27	531
2	Bagmara	348	63	31	58	19	418
3	Durgapur	344	52	38	10	03	365
4	Manda	407	39	99	84	16	414
5	Mohanpur	378	56	157	98	24	351
6	Naogaon	433	106	80	65	23	500
7	Puthia	403	30	80	33	10	377
8	Raninagar	513	70	92	29	33	486

The depth of net irrigation requirement for the irrigated area has been distributed over the entire upazila and the equivalent depth of the net irrigation requirement has been estimated for each Upazila. These equivalent depths of net dry period irrigation requirements for the year 2005 have been compared with actual recharge estimated in this study (Table 1). Information on water use for supplementary irrigation also has been collected from BADC .The water use for supplementary irrigation also has been compared with actual recharge. The main purpose of this effort is to find out the over-exploited upazila(s) and to see the scope for further expansion. Comparison of actual recharge and net irrigation water requirement for the year 2005 are given in Table 2. Table 2 reveals that total actual recharge is higher than net irrigation requirement for Boro cultivation in the study area. However, upazilawise comparison shows resource constraints for only Boro cultivation in Durgapur, Puthia and Raninagar upazilas.

Table 2: Comparison of Actual Recharge and Net irrigation Requirement for the Year 2005

Upazila	Area (Sq km)	Actual Recharge (mm)	Irrigation Req: for Boro (mm) Year 2005	Remaining Water (mm)	Supl. Irrigation (mm)	Remaining Water (mm)
Atrai	284	531	399	132	0	132
Bagmara	363	456	422	34	19	15
Durgapur	**195**	**365**	**414**	**-- (-49)**	**26**	**--(-75)**
Manda	376	414	251	163	16	147
Mohanpur	163	385	345	40	11	29
Naogaon	276	500	455	45	19	26
Puthia	**193**	**377**	**380**	**-- (-3)**	**20**	**--(-23)**
Raninagar	**258**	**486**	**521**	**-- (-35)**	**0**	**--(-35)**
Average	=∑(Area*value)/ ∑Area	**447**	**394**	**53**	**14**	**39**

The actual recharge also has been compared with the actual abstracted water calculated from numbers of DTW and STW considering 75% efficiency of DTW and 50% efficiency of STW. The information on DTW and STW has been obtained from BMDA. Comparisons of actual recharge and actual extracted water for the year 2005 are given in Table 3.

Table 3: Comparison of Actual Recharge and Water Extraction for the year 2005

Upazila	Area(sq km)	Actual Recharge (mm)	Abstraction: Year 2005 (mm)	Remaining Water (mm)
Atrai	284	531	295	236
Bagmara	363	456	255	201
Durgapur	**195**	**365**	**384**	**-- (-19)**
Manda	376	414	235	179
Mohanpur	163	385	186	199
Naogaon	276	500	247	253
Puthia	**193**	**377**	**399**	**-- (-22)**
Raninagar	258	486	322	164
Average	=∑(Area*value)/∑Area	**447**	**284**	**163**

Table 3 reveals that actual abstraction is higher than the actual recharge in Durgapur and Puthia upazila. These two upazilas have no scope for further groundwater development based on estimated actual recharge. Furthermore, estimation of usable recharge needs to be considered for better management decision.

Surface Water –Groundwater Interaction

The flow exchange between the aquifer and river at different locations has been investigated. The interactions depend mainly on the difference of the water level in the river and in the underground reservoir, as well as aquifer materials in the river-banks and in the bed of the rivers. The flow rate to and from the river and aquifers was estimated in 13 different locations of the rivers of the study area.

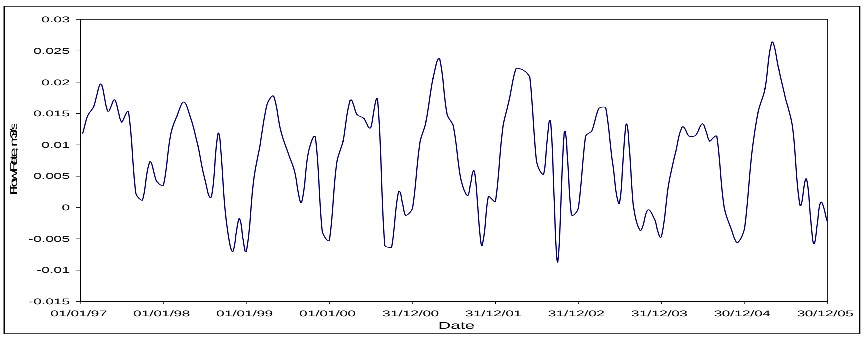

Figure 3: Surface Water- Groundwater interaction in Atrai river

The flow exchange between aquifer and river along the river Atrai has been presented in figure 3. The aquifer has an average inflow rate of 0.009 m^3 /sec and the average outflow rate is 0.0007 m^3 /sec. The aquifer fed the river during dry seasons which starts in November. This is mainly due to the dryness of the river. During wet seasons the river water level is generally high compared to the groundwater level and acts as the source of flow to the aquifer. Due to the hydraulic gradient between the river water level and the groundwater level, the water flows from the river to the aquifer.

Scenario Analysis

The observed annual rainfall of 10 stations falls in and around the study area, for a period of 33 years (1971-2004) has been considered for statistical analysis. According to the recommendation of Flood Action Plan (FAP)-25 study, data has been fitted to 3-parameter Log Normal distribution to find out the average and extreme dry year. The statistical software HYMOS 4.0 has been used for this purpose. 2001 (1:2 years) and 1994 (1:10 years) has been selected as design year (average year) and extreme drought year respectively.

The base condition includes design year, 2001 hydrological situation and other existing situations (year 2005) that prevail in the field. Hydrographs of simulated groundwater have been obtained at some pre-selected locations, which show that the maximum and minimum depth to groundwater table occurs at May and end of October respectively. It can be seen from the analysis that the maximum depth to groundwater table remains in the range between 2.0 and 12.0 m in most of the areas. Suction mode tube wells will not operate in the areas where groundwater table remains below 7.0 m. This situation is probably due to high extraction. It is also observed from the analysis that during the peak time, groundwater table almost regains to its original position.

Option 1 is the future development option, which mainly includes future cropping patterns and coverage and abstraction of water from groundwater to meet the irrigation demand of future crops. The purpose of this option is to assess the impact of future developments on the present state of water and environment with respect to the groundwater tables whether it will cross the safe yield of the aquifer. In this option, irrigated area for Manda ,Mohanpur, Niamatpur, Paba, Badalgachi, Charghat upazilas has been increased up to 80%. Hydrographs of simulated groundwater tables from this option have been compared with simulated groundwater tables from option 0 at some pre-selected locations. In some places, groundwater level drops down by about 0.5 to 1 m compared to the groundwater level of option 0 during irrigation period. This situation occurs due to the higher abstraction in the option 1 compared to option 0. However, groundwater level returns to its original position during the peak time of the monsoon in most areas. Groundwater tables under option 1 do not return to its original position during the peak time of the monsoon especially in Manda Upazila, near Niamatpur because of higher extraction in these places. This phenomenon reveals that aquifers from where increased abstraction is being carried out have not the potential to fulfill the crop water requirement of 80% crop coverage.

7 Conclusions and Recommendations

Conclusions

- The aquifer of the study area is semi-confined. The geology of the study area contains two aquifers which are interconnected in many places. The second aquifer is the main aquifer of the study area.
- The recharge due to rain and flooding starts in May and continues to the end of October. The groundwater model prepared in this study shows that the average recharge of the groundwater

is 398 mm per year (average of year 1997 to year 2005) in the study area, varying from 306 mm (in Puthia Upazila) to 439 mm (in Naogaon Upazila) in the same period.

- According to the assessment of aquifer recharge, irrigation requirements of year 2005 for Boro (a type of rice which requires highest amount of water for cultivation) and extracted water in 2005 depict that Durgapur, Raninagar and Puthia are over exploited areas.
- The total recharge for the period 1997 to 2005 (due to rainfall, irrigation and river leakage) is around 800 Mm^3/day/year, where as river leakage contributes with around 70 Mm^3/day/year, which is about 9% of the total recharge.
- According to the model study results, the river is in direct contact with the aquifer system, contributing to the aquifer recharge from March to November and receiving water from aquifers from December to February. The rivers have a positive influence on groundwater recharge.
- If the Boro rice production increases to 80% of the net irrigated cultivable area of the upazilas, the groundwater level would drop to about 1m in some places, even more than that in Manda upazila. In those places some shallow tubewells might be out of order.
- According to the selected scenarios, the groundwater level in dry season will be lowered by 0.2 m per year with the average recharge (year 2001) and current groundwater extraction condition (year 2005). Also in wet season the peak does not recover its original level, probably due to the high extraction if compared to the actual recharge.

Based on the findings of the study the following recommendations are proposed:

- The most effective and efficient way to reduce the pressure on groundwater extraction is the crop diversification which is of course difficult but possible to implement to some extent. Changing the cropping pattern from major Boro-crop, which requires more irrigation water, to mixed Boro, wheat and vegetables would reduce the groundwater extraction.
- The geographic location of the deep tube wells (DTW) should be determined. Groundwater table and quality monitoring should be done regularly.
- The adverse effect of over exploitation of groundwater may be overcome by aquifer recharge induced by surface water. This adverse effect should be assessed through more extensive modelling over 10-15 years time period.
- To develop a strategy to artificial recharge aquifers, during periods of high flows in the rivers, the shallow aquifers may maintain the groundwater level at depths of 2 m - 4 m. This could be extracted by farmers for irrigation during dry season.

8 Acknowledgement

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9 References

Delluer, Jaquas (1999): The Handbook of Groundwater Hydrology, Published by CRC press LLC.

IWM, (2005): Groundwater Model Study for Deep Tube Well Installation Project in Barind Area, Inception Report, Dhaka, Bangladesh

MoWR, 1999: National Water Policy of Bangladesh, Ministry of Water Resources, Dhaka, Bangladesh.

MPO (1986): Technical Report No. 5 on Groundwater Resources, Dhaka, Bangladesh

MacDonald (1983): Water Balance Studies Bangladesh, Final Report p30-p32

Visual Modflow User's Guide, 2002, Waterloo hydrology Inc.