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Investigation of Ground water Potential using Mathematical Model: A Case Study in Part of Northwest Region of Bangladesh

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ABSTRACT: *Groundwater is the most essential and valuable resources for agriculture, domestic and industrial purposes. Unplanned withdrawal of groundwater is risky for the system due to limited replenishment and increasing water demand with continuously growing population, especially for the arid and semi-arid catchments. Scarcity of rainfall in time and reducing of upstream flow in the internal rivers have increased dependency on groundwater irrigation. Estimation of groundwater potential for a region is essential not only for sustainability of irrigation project but also for a sustainable water resources management at the regional level, which means in general at the basin scale. Due to the competition of all water users of a river basin, especially in water scarce regions, a comprehensive approach is needed regarding agricultural, domestic, industrial, and ecological aspects. In this paper, a case study was carried out for Pabna, Sirajgonj, Bogra, Gaibandha, Rangpur, Kurigram, Nilphamari and Lalamonirhat Districts which is situated in the north-west part of Bangladesh using physically distributed hydrological modelling. To bring about 3,000 km^2 potential land under irrigation through sustainable water resources management, an integrated Groundwater-Surface Water model was developed using mathematical modelling tools which was calibrated for the period 2006-2010 and validated for the period 2011-2013. Using model result, groundwater water resources, requirement for present and future demand for various purposes and possible expansion of irrigation coverage for the study area were assessed. As a result irrigation coverage as well as agricultural production would be increased considerably if the project is implemented following the study findings and suggestions. So the study output has positive impact and for sustainable water resources management it is essential to use the state-of -the art technology.*

Keywords: *Mathematical Modelling, Irrigation, Groundwater, Surface water, Zoning. Potential resources, Sustainable water resources management.*

I. INTRODUCTION

Currently, one-third of the world's population is living in countries and regions of water resources limitation (Bates, et al., 2008). Because of limited water availability imposing strong restrictions on natural and human systems, the management of water resources has become an increasingly pressing issue in semiarid and arid regions. Generally, when the demand of water has reached the limits that the natural system can provide, water shortage can become a major obstacle to social and economic development for one region (Bronster et al., 2000; Li et al., 2006). Therefore, these issues have forced planners to contemplate and propose ever more comprehensive, complex, and ambitious plans for water resources systems in the semiarid and arid regions (Li et al.,2008).

Different studies have documented that groundwater level declined substantially during the last decade causing threat to the sustainability of water use for irrigation in this region and impacting upon other sectors too (Jahan et al. 2010). Due to lack of proper knowledge, indiscriminate installation of pumps and non-availability of modern technologies, farmers inappropriately lift water without caring ground sources. These impacts upon interlinked sources of water table which is declining alarmingly in many areas of Bangladesh. Although the groundwater dominates the total irrigated area, its sustainability is at risk in terms of quantity in the northwest region (Simonovic 1997; Shahid 2011). Frequent shortage of water in the region has had impacts that can be ranged as economical, social and environmental (Takara and Ikebuchi, 1997; Sajjan et al. 2002; Dey et al. 2011).

A recent study shows that groundwater level in some areas falls between 5-10 m in dry season and most of the tubewells fail to lift sufficient water (Dey and Ali 2010). Researchers and policymakers are advocating sustainable development as the best approach to today's and future water problems (Loucks2000; Cai X et al. 2001). With groundwater development, fluctuations will amplify; but as long as rainfall is managed to recharge aquifers, and proactive water saving strategies are put in place, a steady and sustainable state can be achieved (IWMI 2010). In mainstream irrigation thinking, groundwater recharge is considered as a by-product of flow irrigation, but in today's world, groundwater recharge needs to be understood on its first emergency for making groundwater sustainable integrating all possible options (IWMI 2010).

Hydrologic model was a useful tool for water resources management (Sahoo et al., 2006). Previously, many lumped hydrologic models were developed to investigate watershed hydrology. With a low data requirement, these lumped catchment models could reflect runoff dynamics and water balance in water resource management systems. However, the lumped models assumed the study watershed as a spatially homogeneous region, and the spatial heterogeneity of the climate variable and land surface was not considered (Bronster et al., 2000).

Consequently, several distributed and semidistributed hydrological models were developed in response to the aforementioned challenges (Apul et al., 2005). For example, Refsgaard (1997) integrated MIKE SHE, MIKE 11, MIKE 21, and DAISY to study the environmental assessment in connection with the Gabcikovo hydropower scheme. Sahoo et al. (2006) used the physically distributed hydrological modeling system (MIKE SHE) to study the watershed response to storm events within the Manoa-Palolo stream system on the island of Oahu, Hawaii. IWM (2005, 2006, 2009 and 2014) used the physically distributed hydrological modeling system (MIKE SHE & MIKE 11) for the assessment of potential groundwater and surface water resources. The primary advantage of the distributed hydrological models was enabled to reflect the spatial variations for characteristics of watershed (e.g., rainfall, topography, soil type, and land use) (Refsgaard, 1997). However, higher data requirement became a main obstacle on extensively applying these models to practical problems.

Both the Poverty Reduction Strategy (PRS) and Millennium Development Goal (MDG) of the Government of Bangladesh attached priority to increase agricultural production. In this backdrop, Barind Multipurpose Development Authority (BMDA) undertook a programme entitled "Groundwater Resource Study and Interaction Information System (IIS) Development of Pabna, Sirajgonj, Bogra, Gaibandha, Rangpur, Kurigram, Nilphamari and Lalmonirhat Districts through Mathematical Model Study" having gross area of 17,455 km2 and cultivable area of 12,765 km^2. The study was carried out by IWM (2014) to bring about additional 3,084 km^2 cultivable land under irrigation for maximizing crop production

The study area is shown in Fig. 1 where yearly rainfall varies from 1800 mm to 2600 mm, relative humidity is from 46% to 83% and land leve varies from 4 to 68 mPWD. The objective of this paper is to review the state of art for investigation of potential groundwater resources for irrigation and ultimately growing food production by bringing more area under irrigation coverage without allowing environmental degradation.

II. APPROACH AND METHODOLOGY

Estimation of groundwater potential for a region is essential not only for sustainability of irrigation project but also for a sustainable water resources management at the regional level, which means in general at the basin scale. Due to the competition of all water users of a river basin, especially in water scarce regions, a comprehensive approach is needed regarding agricultural, domestic, industrial, and ecological aspects.In order to achieve the study objectives, IWM (2014) developed an integrated GW-SW model for the study area. The models developed under this study based on MIKE-11 (DHI, 1999) and MIKE-SHE (DHI, 1999). All the major river systems and updated topographic features were included in surface water (sw) model setup while hydro-geological setting, aquifer properties, DEM, land use pattern, abstractions were incorporated in groundwater (gw) model. Both the models were coupled through MIKE SHE. The coupled model was calibrated for the period of 2006 to 2010 and validated for the period of 2011-2013. The validated model was used to simulate various options and to assess the resources.Groundwater resources were assessed considering yield criteria of 7m depth from ground surface, so that STW & HTW remain active and potential recharge was assessed upto the depth which recharge fully during monsoon due to rain. Usable recharge was considered as 75% of the potential recharge (IWM, 2006) to account for various uncertainties inherent in different assumptions and natural loss. Irrigation zones were demarcated on the basis of water availability, groundwater level fluctuation, functionality of suction mode pumps, safe yield, extent of irrigation coverage, extent of drainage congestion etc. Environmental impacts, social acceptance and economic viability of the project were also assessed. The approach of the study is shown in a schematic plan illustrated in Fig. 2.

Figure 1: Location Map of the Study Area

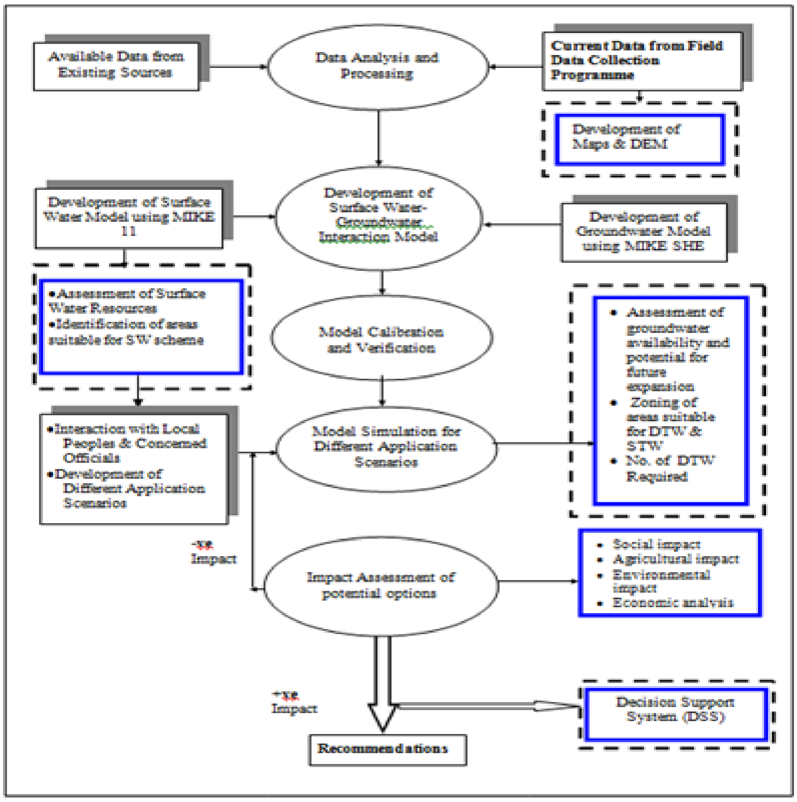

Figure 2: Schematic Diagrams of the Study

III. RESULTS AND DISCUSSIONS

1.1 Assessment of Groundwater Resources

Upazila-wise groundwater resource for average hydrological year was assessed based on recharge characteristics, potential recharge and safe yield criteria. The end of April is the end of irrigation period when the lowest water table generally occurs, after that water table starts rising due to recharge from rainfall. Recharge is the net storage in saturated and unsaturated zone. The components that influence the groundwater storage after April are mainly rainfall, runoff, overland flow, overland storage, drain to river, evapo-transpiration, boundary inflow and outflow. All the factors were considered during estimation of potential recharge through water balance for each Upazila. The water balance (MIKE SHE output) for Rangpur Sadar is shown in Fig. 3; Potential Recharge = 1795mm (precipitation) – 3mm (overland flow) – 715mm (Evapo-transpiration) – 56mm (outflow) + 216mm (inflow) – 15mm (overland storage) – 201mm (drain SZ/Boundary) = 1021mm. The total yearly demand for irrigation, drinking and industrial purposes were also estimated. Upazilawise potential resources and total yearly demand in the study area are given in Table 1.

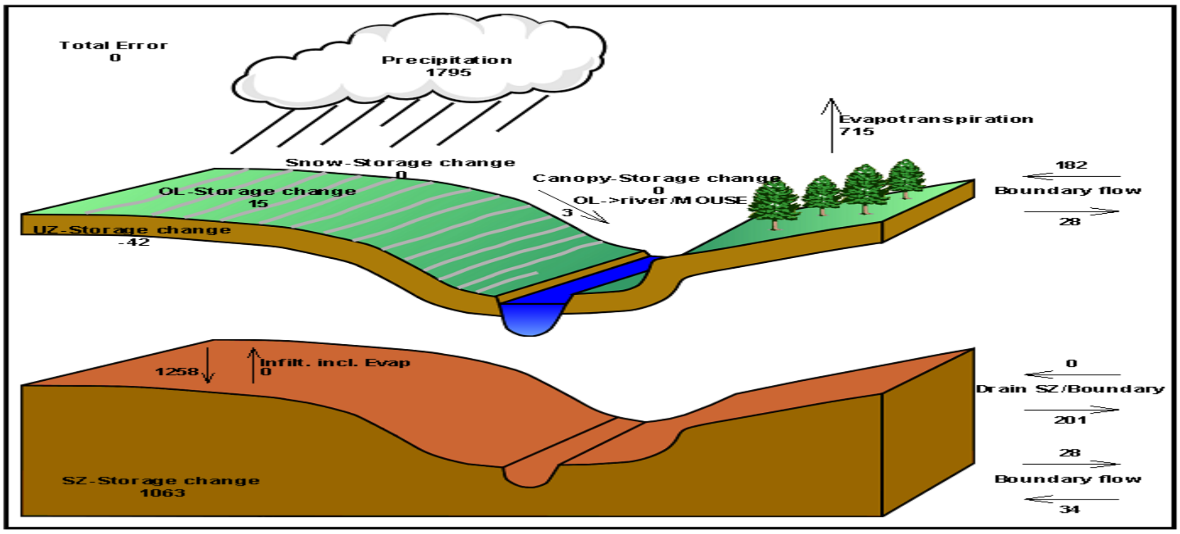

Figure 3: Water Balance Components of Rangpur Sadar

District	Upazila	Potential Recharge (mm)	Total Demand (mm)	Upazila	Potential Recharge (mm)	Total Demand (mm)
Pabna	Atgharia	585	365	Ishwardi	495	245
	Bera	526	289	P. Sadar	852	318
	Bhangura	754	414	Santhia	513	262
	Chatmohar	629	318	Sujanagar	671	283
	Faridpur	669	397			
Sirajganj	Belkuchi	878	353	Shahjadpur	680	400
	Chauhali	686	159	S. Sadar	869	319
	Kamarkhanda	875	314	Tarash	734	475
	Kazipur	1168	334	Ullahpara	990	447
	Royganj	1095	427			

District	Upazila	Potential Recharge (mm)	Total Demand (mm)	Upazila	Potential Recharge (mm)	Total Demand (mm)
Bogra	Adamdighi	935	498	Nandigram	916	614
	B. Sadar	972	595	Sariakandi	1054	345
	Dhunat	813	506	Shajahanpur	982	524
	Dhupchanchia	901	406	Sherpur	855	530
	Gabtali	916	544	Shibganj	823	490
	Kahaloo	969	497	Sonatola	896	572
Gaibandha	Fulchhari	987	339	Sadullapur	797	436
	G.Sadar	961	447	Saghatta	720	519
	Gobindaganj	781	570	Sundarganj	1026	404
	Palashbari	737	491			
Rangpur	Badarganj	842	492	Pirgachha	1023	341
	Gangachara	904	508	Pirganj	1026	399
	Kaunia	1083	423	R.Sadar	1021	474
	Mitha Pukur	946	417	Taraganj	874	519
Kurigram	Bhurungamari	1318	396	Phulbari	961	384
	Char Rajibpur	895	182	Rajarhat	1059	374
	Chilmari	1172	241	Raumari	977	372
	K. Sadar	1132	340	Ulipur	974	360
	Nageshwari	1076	383			
Nilphamari	Dimla	1054	353	Kishoreganj	900	378
	Domar	1010	448	N. Sadar	759	432
	Jaldhaka	1080	463	Saidpur	847	487
Lalmonirhat	Aditmari	894	418	L.Sadar	923	431
	Hatibandha	934	370	Patgram	751	341
	Kaliganj	962	415			

1.2 Development of Future Scenarios:

The developed model was simulated for a number of future scenarios, out of those three are described here;

Option 0: Base Condition i.e. Existing Situation with 80% dependable rainfall

- Hydrological condition for the design year 2008 (80% dependable).

- All existing features i.e. existing crop coverage, irrigation demands etc.

Option 1: Future Option with design year

- Hydrological condition for the design year 2008 (80% dependable).
- Crop coverage for future condition

Option 2: Future Option with extreme dry year

- Hydrological condition for the year 1994 (extreme dry condition).
- Crop coverage for future condition

From the analysis of different options, it was revealed that, there is scope for irrigation expansion in some Upazilas under average hydrological condition.

Spatial distribution maps of maximum and minimum depth to groundwater tables were prepared (Fig. 4) to see the effect of pumping during irrigation season and also to see whether groundwater table regains to its original positions or not. It was observed that maximum depth to groundwater table remains within 2.0 m to 8.0 m in most of the areas on 1st May. The groundwater table goes beyond the suction limit of shallow tube well (STW) or hand tube well (HTW) in some part of the area but groundwater table regains to its original position during monsoon due to recharge from rainfall and remains below 2 m in most of the areas.

The model was also simulated for base and future condition to see the impact on groundwater for expansion of irrigation in future where command area has been increased upto 80% of cultivable area and also for extreme dry year condition. The comparison of the groundwater level hydrograph is shown in Fig. 5. It is observed that groundwater level goes further below due to additional abstraction but it regains to its original level due to recharge from rainfall. It is also observed that in dry year condition, having less rainfall, further depletion of groundwater table occurs than that in option 1.

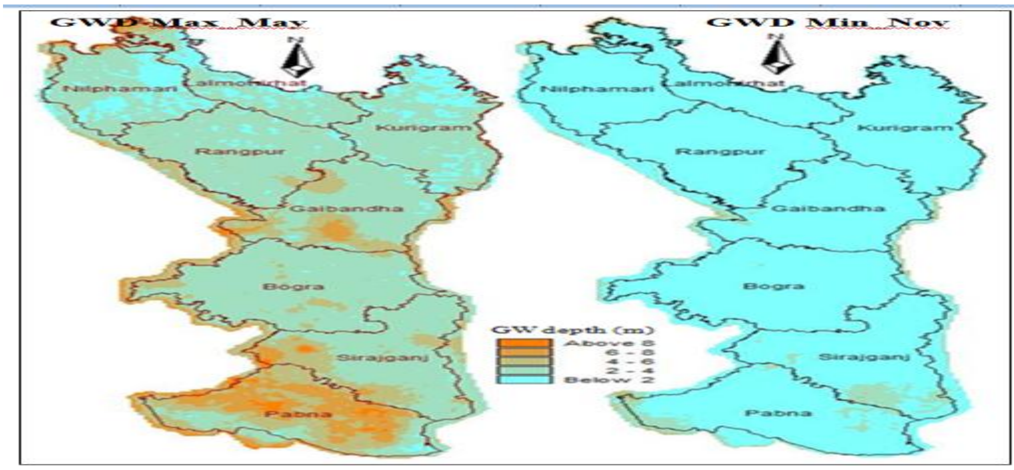

Figure 4: Depth to Groundwater Table for Base Condition

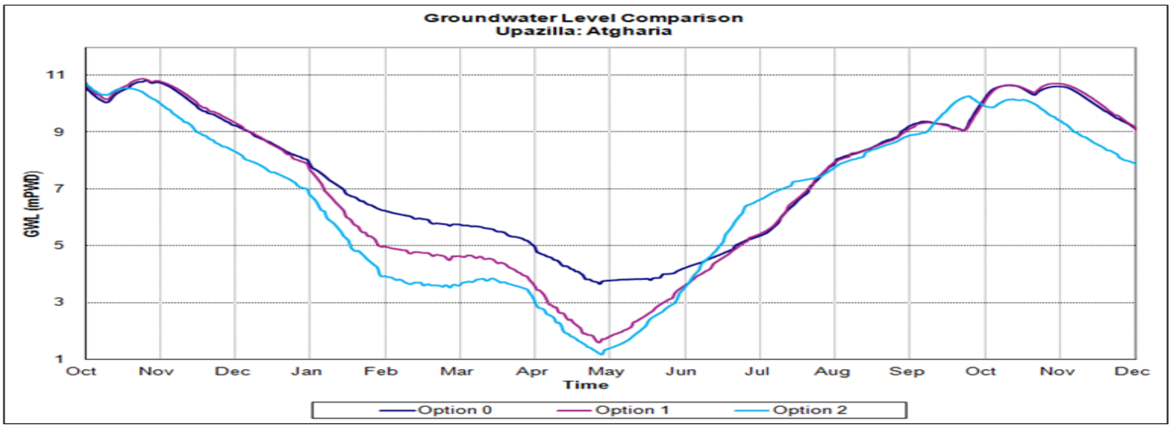

Figure 5: Comparison of Groundwater Level between Base and Future Condition

IV. CONCLUSIONS

The study was conducted to assess the potentiality of groundwater resources and to find out the scope for expansion of irrigation command area allowing no declining trend of groundwater table . The set of conclusions based on different components of the study are as follows:

- It reveals from the study that most of the area has high potentiality for groundwater development having higher rainfall & easily recharge of groundwater due to higher seepage & percolation rate in compare with Barind area and presence of water bodies and beels. There are no shortages of groundwater to meet the present demand. There is a sufficient surplus resource which may be used for further development bringing more potential area under irrigation in future.
- Model simulation reveals that for present condition during dry season, groundwater table goes below 10m to 12m from the ground surface in some part of Bogra and Pabna District but it regains to its original position during monsoon. Also at Iswardi, the groundwater level goes beyond suction limit (7m) of STW or HTW mainly due to low water level in Ganges during dry season though there is no considerable abstraction but groundwater table fully regains to its original level during monsoon.
- Having higher abstraction of groundwater for future condition, depletion of groundwater table may be about 1-2m during dry season but it is replenished in monsoon.
- Model simulation reveals that during dry year condition, depletion of groundwater level may occur in some upazilas of Bogra, so the monitoring is necessary.

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