

Scope for Groundwater Development in North West Region of Bangladesh

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Abstract: Due to decreasing trend of river flow and increasing demand of water for irrigation, domestic and other purposes, it is an urgent need to investigate the scope of ground water (GW) development within safe yield criteria. Surface water (SW) and groundwater is a part and parcel of the hydrological cycle. So it is essential to consider both the ground and surface water in an integrated approach and this can be done using physically distributed mathematical modeling tools. In this paper, a case study was carried out for Panchagarh, Thakurgaon, Dinajpur and Joypurhat Districts which is situated in the north-west region of Bangladesh using physically distributed hydrological modelling. With the existing irrigation facilities, it was possible to bring only about 40% of the total cultivable land under irrigation. To bring more potential land under irrigation through sustainable water resources management, an integrated GW-SW model was developed using mathematical modelling software MIKE-11 and MIKE-SHE which was calibrated for the period 2003-2007 and validated for the period 2008-2009. Using model result, groundwater and surface water resources, possible expansion of irrigation coverage and a zoning map suitable for different mode irrigation equipment for the study area was assessed along with requirement of additional number of Deep Tube Well (DTW). Considering the scarcity of SW and safe yield criteria the potential GW was identified and additional 4803 DTWs of 2 cusec capacity for 28 Upazilas to cover the future demand. 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. Some area were also been identified which is potential for surface water irrigation. The economic analysis shows minimum EIRR value of 29.85% when all costs increase by 30%. So the study output has positive impact and for sustainable water resources management it is very 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 (Loucks 2000; 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 and 2009) 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 "Deep Tube Well Installation Programme, Unit-2, Thakurgaon". The is a draught prone area covering 28 Upazilas of Dinajpur, Thakurgaon, Panchagarh and Joypurhat districts having gross area of 7,63,100 ha and cultivable area of 5,75,152 ha. The yearly rainfall varies from 1800 mm to 2600 mm, relative humidity varies from 46% to 83% and topography varies from 94 mPWD to 15 mPWD. With the existing irrigation facilities, it was possible to bring only about 40% of the total cultivable area under irrigation. Under this project, IWM (2009) carried out the study to investigate the groundwater development using mathematical modeling techniques.

The objective of this paper is to review the state of art to investigate the scope of GW development for irrigation and ultimately growing food production by bringing more area under irrigation coverage without allowing environmental degradation.

II. Approach and Methodology

The investigation for the scope of groundwater development should be done by sustainable approach considering both surface and sub-surface water in an integrated way. Due to the competition of all water users of a river basin, especially in water scarce regions, a comprehensive approach is needed regarding not only agricultural purposes but also domestic, industrial, and ecological aspects.

The MIKE SHE model is a physical distributed hydrological modeling system covering the entire land phase of the hydrological

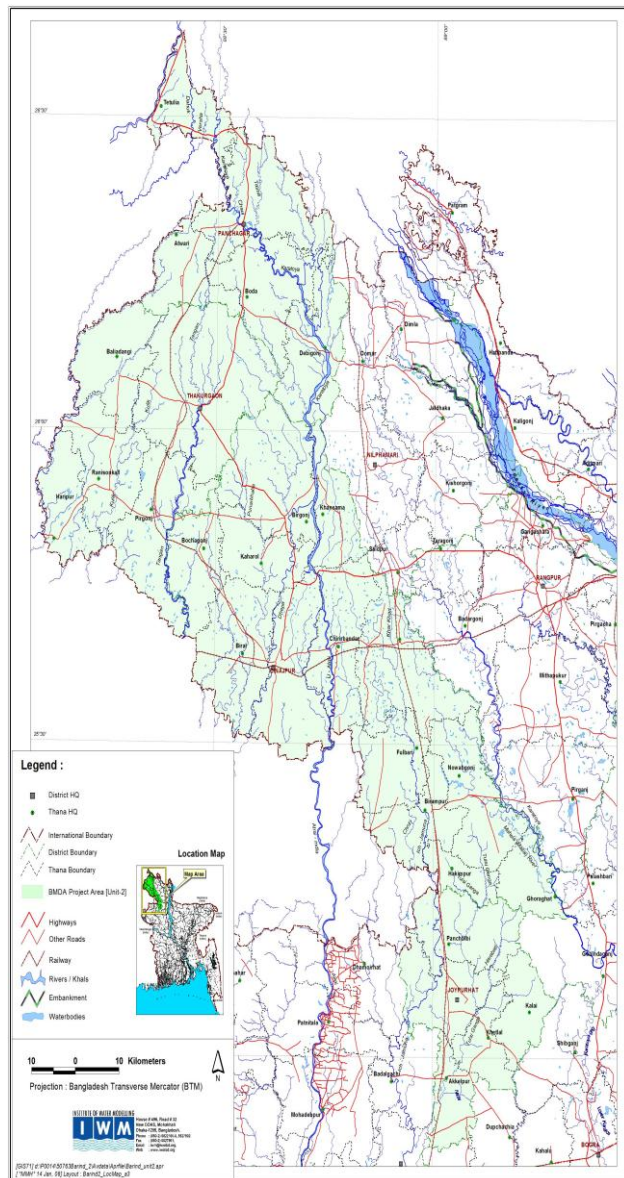


Figure 1: Location Map of the Study Area

cycle (Abbott et al., 1986). The model consists of five modules: overland flow, evapotranspiration, unsaturated flow, saturated flow and channel flow modules (DHI, 1999). The saturated flow that is allowed for a fully three-dimensional (3D) way is described by the Darcy equation and solved by the iterative implicit finite difference technique. 3D finite difference method is used to simulate the 3D saturated flow in saturated porous media.

$$\frac{\partial}{\partial x} \left(K_{xx} \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left(K_{yy} \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left(K_{zz} \frac{\partial h}{\partial z} \right) - Q = S \frac{\partial h}{\partial t}$$

where K_{xx} , K_{yy} , and K_{zz} are the hydraulic conductivity along the x, y, and z directions. The h is the hydraulic head, Q represents the source=sink terms, and S is the specific storage coefficient. The channel flow is calculated by the one-dimensional simulation using the full dynamic Saint Venant equations. The coupling between MIKE SHE and MIKE 11 is made via river links.

In order to achieve the study objectives, IWM (2009) developed an integrated gw-sw model for the study area. The models developed under this study are based on MIKE-11 (DHI, 1999) for the simulation of flows in rivers, irrigation systems, channels and other water bodies and MIKE-SHE (DHI, 1999) for groundwater model. 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, irrigation abstractions were incorporated in groundwater (gw) model. Both the models were coupled through MIKE SHE. The coupled model was calibrated for period of 2003 to 2007 and validated for the period of 2008-2009. The validated model was used to simulate various options and to assess the resources.

Surface water resources at some key locations were assessed based on average year dry period minimum flow. However, for sustainability of a river, it is not feasible to utilize all available resources. As such, useable resource has been considered as 70% of the available resources and 30% as “in-stream flow requirement” in the river (IWM, 2006). 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. Useable 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.

III. Results and Discussions

The model was simulated for the following three scenarios:

Option 0: Base Condition i.e. Existing Situation with 50% dependable rainfall

- Hydrological condition for the design year 2002 (avg. condition).
- Existing all features i.e. existing crop coverage, irrigation demands etc.

Option 1: Future Option with design year

- Hydrological condition for the year 2002 (avg. condition).
- Crop coverage for future condition; Upazila-wise 80% crop coverage of Boro for the cultivable area except few upazila e.g. Panchagarh, Tentulia.

Option 2: Future Option with extreme dry year

- Hydrological condition for the year 1994 (extreme dry condition).
- Crop coverage for future condition; Upazila-wise 80% crop coverage of Boro for the cultivable area except few upazila e.g. Panchagarh, Tentulia.

Hydrographs of simulated groundwater tables from different options were compared at some pre-selected locations. Sample comparison plots of hydrographs are shown in Figure 2. It reveals that, in option 1, groundwater drops about 1 m and option 2, groundwater level further drops down upto 1m from option 1 in some places. However in some places the water level in option 1 and 2 is same due to the same groundwater level. This situation may occur, where the effect of drought is insignificant. However, during monsoon, the groundwater level regain its original position which further investigated by comparing groundwater depth map.

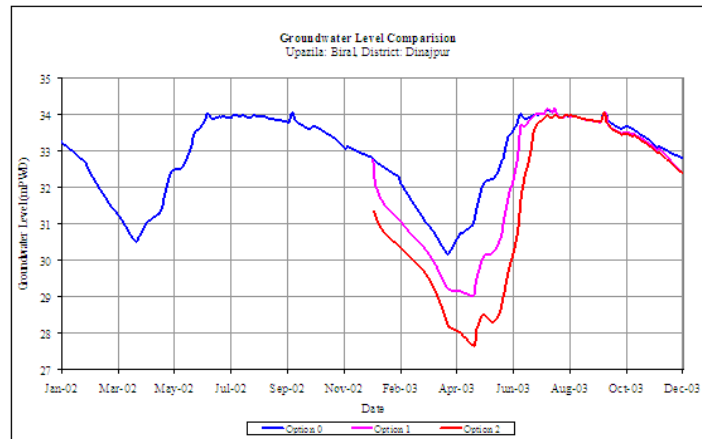


Figure 2: GWL Comparison for Different Options

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, evapotranspiration, boundary inflow and outflow. All the factors were considered during estimation of potential recharge through water balance for each Upazila. The water balance for Akkelpur Upazila (MIKE SHE output) is shown in Figure 3; Potential Recharge = 601 mm (for SZ-Storage change) – 20 mm (for UZ-Storage change) = 581 mm. Upazilawise potential resources and usable resources is given in Table 1.

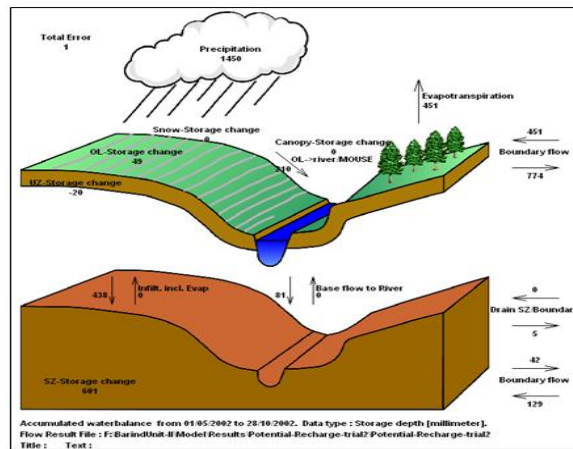


Figure 3: Water Balance Components of Akkelpur Upazila: May-October

Estimation of Tubewell Requirement

From the analysis of different options, it was revealed that, there is scope for irrigation expansion in some Upazilas under average hydrological condition. The number of DTWs and STWs required to satisfy the water demand for proposed irrigation expansion was estimated for Shallow and deep. From the point of Farmers’ preference on DTW because of lower irrigation cost than STW, DTWs are proposed in Shallow zone area. Upazilawise required no. of additional DTW is given in Table 1.

Table 1: Upazilawise Potential GW and Required DTW

| District | Upazila | Resources (mm) | | DTW_Re q | Existing No of | | Proposed DTW |
|------------|------------|----------------|--------|----------|----------------|-----|--------------|
| | | Potential | Usable | | STW | DTW | |
| Panchagarh | Atwari | 709 | 532 | 209 | 1872 | 69 | 140 |
| | Boda | 958 | 713 | 332 | 2726 | 105 | 227 |
| | Debiganj | 1193 | 894 | 278 | 2255 | 56 | 222 |
| | Panchagarh | 825 | 619 | 180 | 3718 | 20 | 160 |
| | Tentulia | 994 | 746 | 177 | 1028 | 13 | 164 |
| Dinajpur | Biral | 715 | 536 | 286 | 10533 | 138 | 148 |
| | Birampur | 672 | 504 | 483 | 1883 | 298 | 185 |

| | | | | | | | |
|--------------|--------------|-----|-----|-----|-------|-----|------|
| | Birganj | 998 | 740 | 474 | 3633 | 277 | 197 |
| | Bochaganj | 799 | 577 | 247 | 2126 | 96 | 151 |
| | Chirirbandar | 766 | 575 | 179 | 7400 | 155 | 22 |
| | Dinajpur | 729 | 547 | 232 | 12593 | 135 | 94 |
| | Fulbari | 776 | 582 | 556 | 5674 | 214 | 342 |
| | Ghoraghat | 695 | 521 | 375 | 1253 | 184 | 191 |
| | Hakimpur | 575 | 431 | 205 | 594 | 186 | 19 |
| | Kaharole | 603 | 450 | 252 | 1851 | 164 | 88 |
| | Khansama | 668 | 501 | 25 | 3664 | 78 | 5 |
| | Nawabganj | 511 | 383 | 536 | 3462 | 282 | 254 |
| Joypurhat | Parbatipur | 605 | 545 | 518 | 8844 | 271 | 247 |
| | Akkelpur | 581 | 436 | 482 | 894 | 216 | 266 |
| | Joypurhat | 453 | 340 | 298 | 3275 | 232 | 66 |
| | Kalai | 799 | 599 | 619 | 1345 | 340 | 279 |
| | Khetlal | 677 | 508 | 482 | 691 | 318 | 164 |
| Thakurgaon | Panchbibi | 635 | 476 | 625 | 3518 | 384 | 241 |
| | Baliadani | 773 | 527 | 350 | 1782 | 157 | 193 |
| | Hariapur | 718 | 537 | 236 | 1711 | 74 | 162 |
| | Pirganj | 775 | 566 | 407 | 3009 | 157 | 250 |
| | Ranishankail | 970 | 720 | 322 | 2763 | 174 | 148 |
| <i>Total</i> | | | | | | | 4802 |

Note 1: DTW Capacity 2 cusec, average running hour 12 hrs, command area 22-28 ha and STW Capacity 0.5 cusec, average running hour 5 hrs, command area 2.65 ha

Note 2: Existing no. of DTW is based on DAE report (2008), except for Nawabganj which is taken from IWM field survey and existing no. of STW is based on DAE report (2008).

Zoning Map

A simulated groundwater depth map has been prepared at the end of irrigation season that is at the end of April. It was observed that Groundwater level goes below 6m from the surface partly or fully in most of the Upazilas except Panchagarh, Tentulia and Khansama. The groundwater level drops down upto 19m in a small portion of the southern part of Dinajpur Sadar. This is due to the fact that, there may exist a geological belt of low specific yield for which water level drops suddenly with little change of abstraction. However, groundwater depth upto 6m is considered for suction limit of STW and HTW without constraint. A part in Upazilla Akkelpur beside Tulshiganga river has been identified for supplementary irrigation by surface water. Considering the suitability for different mode of irrigation equipment and opportunity for SW irrigation, the study area was demarcated as DTW zone, STW zone, SW scheme (existing), SW scheme (proposed) and a zoning map (Figure 4) was prepared accordingly for better management.

Economic Analysis

The economic analysis for the capital cost of the project is estimated to be Tk. 117,537.50 million and annual O&M cost is Tk. 8,569.59 million for consideration 100% of existing STW. It is estimated that annual paddy production will be increased to 1.80 million MT from existing. Due to the project, employment opportunities will be created for 17.1 million man-days during implementation and 38.6 million man-days of farm labour annually during operation. The risk analysis/sensitivity analysis shows minimum EIRR value of 29.85% when all costs increase by 30%.

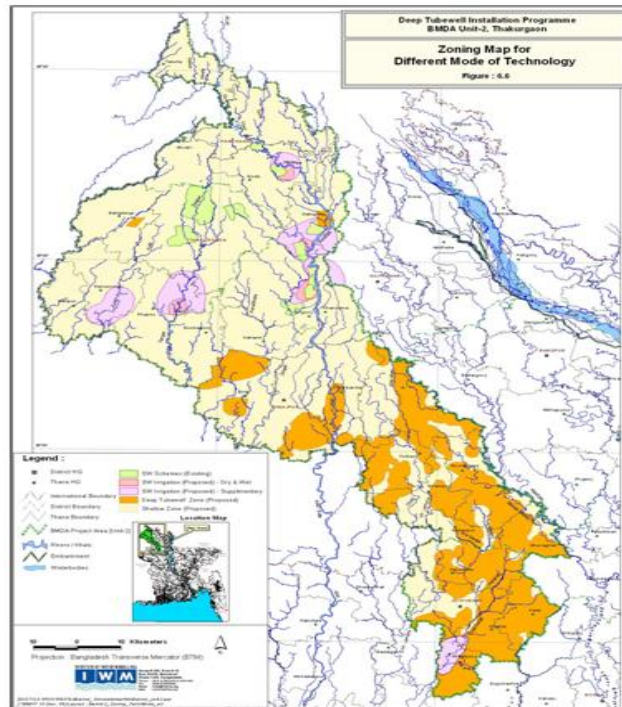


Figure 4: Zoning Map Suitable for Different mode of Irrigation

IV. Conclusions

The study was conducted to assess the availability of water resources and formulate strategy for its optimum utilisation as well as identification the required number of DTW to cover the additional cultivable land under irrigation. The set of conclusions based on different components of the study are as follows:

- Present dry period irrigation practice in the study area is mostly based on groundwater source because of limited availability of surface water. Groundwater abstraction comes through DTW and STW mode of technologies. A major portion of present irrigation coverage comes through STWs.
- Groundwater resources for the entire study area for the yield criteria of potential and usable are 2865 Mm³ and 2149 Mm³ respectively. Whereas the present irrigation requirement has been estimated as 1451 Mm³. So that in the study area as a whole there is no shortage of water to meet the present water demand rather there is surplus water
- The surplus water can be used for irrigation expansion in some Upazilas where boro coverage is less than 80%. However, when usable recharge is considered, little shortage of water is observed in Joypurhat Sadar, Khetlal and Panchbibi. This is due to the fact that Boro coverage is already more than 80% in those Upazilas which implies to higher water requirement and crop diversification of less water consuming should be inspired in those Upazilas.
- Model simulation reveals that groundwater level goes below 6m from the surface partly or fully in most of the Upazilas of the southern part of the study area which mostly covers Dinajpur and Joypurhat districts.
- Considering usable recharge and future irrigation requirement for Boro, there is shortage of water in some Upazilas like Nawabganj, Joypurhat Sadar, Khetlal and Panchbibi where present Boro coverage is already more than 80%. Hence Boro coverage in those Upazilas should not have further expansion and crop diversification as well as surface water irrigation should be promoted to reduce groundwater irrigation.
- Five rubber dams at Kaliganj, Laxminarayni and Kashimpur on Karatoya, Mohanpur on Atrai and Masnandapur on Tangon, have been proposed to store water for providing dry period irrigation in 4,924 ha and supplementary irrigation in 25,540 ha along the respective river reaches. Non-perennial rivers, Punarbhaba, Tulshiganga and Kulik have been proposed to utilise only for wet period supplementary irrigation to 21,198 ha by constructing water control structures at Gouripur on
- Punarbhaba, Sonamukhi on Tulshiganga and Rauthnagar on Kulik.
- The project is expected to be sustainable if it is implemented following the study finding and suggestions which has been done using the state-of-the art technology.

Acknowledgments

This study was done by Institute of Water Modelling (IWM) under Barind Multipurpose Development Authority (BMDA) supported by GoB Fund. The authors are grateful to the editors and the anonymous reviewers for their insightful comments and suggestions.

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