APPLICATION OF GIS TO IDENTIFY SPATIAL AND TEMPORAL EXTENT OF CRITICAL CONDITION FOR RURAL DRINKING WATER SUPPLY DURING DRY SEASON

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ABSTRACT

Huge drawdown of the groundwater table is one of the environmental hazards due to large scale groundwater withdrawal during dry period. Hand tube wells (HTWs) and shallow tube wells (STWs) operated under gravitational force, are the main supplier of drinking water in rural areas may be dry out due to excessive drawdown. This study was conducted to identify the unit areas (upazillas) within Dinajpur district of Bangladesh where groundwater goes under critical level (6m) using bservation wells data during 1995-2003. Three interpolation methods available in GIS tools namely, inverse distance weighted (IDW), Thin-plate Spline and Kriging have been tested to construct groundwater level surface from the observation well data and Kriging with ordinary linear semi-variance model has given the most accurate result. The maximum duration of critical period for drinking water supply in the study area has been found as 120 days in 1999. The maximum critical areas were 49.7% of the study area which causes severe drought in 1995.

Keywords: *ArcView, Hand tube well, Shallow tube well, Spatial Analyst, Upazila.*

1. INTRODUCTION

A basic safe and reliable water supply to rural communities around the world has been a key target of development strategies for several decades. The Millennium Development Goals present targets for halving the proportion of people without sustainable access to safe drinking water by year 2015. In Bangladesh, groundwater is the major source of dry period irrigation water as well as drinking water. About 78% irrigation water and more than 90% of total potable water are supplied from groundwater source (NMIDP, 1998). Groundwater development concept to protect crops from natural droughts was first initiated in north-west region of Bangladesh in early ‘60s since there is limited scope for surface water development in the area. A number of groundwater irrigation projects have been implemented in north-west part of Bangladesh since 1962. During 1962-64, a total of 381 Deep Tubewells (DTWs) were installed in this area by Bangladesh Water Development Board (BWDB) to meet the water demands for wheat and local variety rice known as *Aman*. Seeing the benefit of the project, Bangladesh Agricultural Development Corporation (BADC) installed about 3,000 DTWs in northwest Bangladesh. The largest groundwater irrigation project of Bangladesh is situated in the greater Dinajpur district. Later, 960 DTWs were installed, including rehabilitation of abandoned old DTWs during 1985-89 by BWDB. Local people with their own initiative have installed a large number of Shallow Tubewell (STW) to irrigate their land although these are not cost effective.

However, hundreds of shallow and hand tube wells become inoperative due to over exploitation of groundwater, lack of adequate groundwater recharge during wet season and low specific yield of upper aquifers. Environmental impacts, due to abstraction of groundwater for irrigation on drinking water supply by hand tubewells, ponds, khals and beels are yet to be ascertained. This situation can be exacerbated by 2030 when water demand will be doubled due to expected increase in dry season agriculture (Hossain, 2000). Huge drawdown of the groundwater table is one of the environmental hazards due to large scale groundwater withdrawal. For this HTWs and STWs that are the main supplier of drinking water in rural areas, may be dry out. Therefore, identify critical areas and duration of scarcity of safe and potable water supply during dry season in Dinajpur district needs to be studied. The present study has been conducted to identify the areas where groundwater goes under a certain level of safe yield from which water cannot be withdrawn with hand tube wells under gravitational force. The study would be useful to identify the areas where shallow and hand tube wells under gravitational force become inoperative during dry season. It will also help to develop sets of guideline for possible solutions to mitigate the rural drinking water supply problem during the dry seasons.

2. DATA AND METHODOLOGY

Dinajpur district of Bangladesh consists of thirteen upazilas. But due to data unavailability seven upazilas has been selected for the study area. The study area includes seven upazilas of Dinajpur district namely Biral, Birganj, Bochaganj, Chirirbandar, Dinajpur Sadar, Kaharole and Khansama. The area is bounded by Tangon river in the west, Thakurgaon district in the north, Nilphamari district in the east and Indian border in the south. The area lies between 25°28’16.6” N to 26°3’46.7” N latitudes and 88°22’58.5” E to 88°52’33.3” E longitudes. The study area is about 64 km long from north to south and 48 km wide from east to west. Study area map has been presented in Figure 1(a). The topography of the study area is gently low from the north to the south. The land level varies from 25.5 m PWD to 55.5 m PWD. The digital elevation model (DEM) of the study area has been presented in the Figure 1(b).

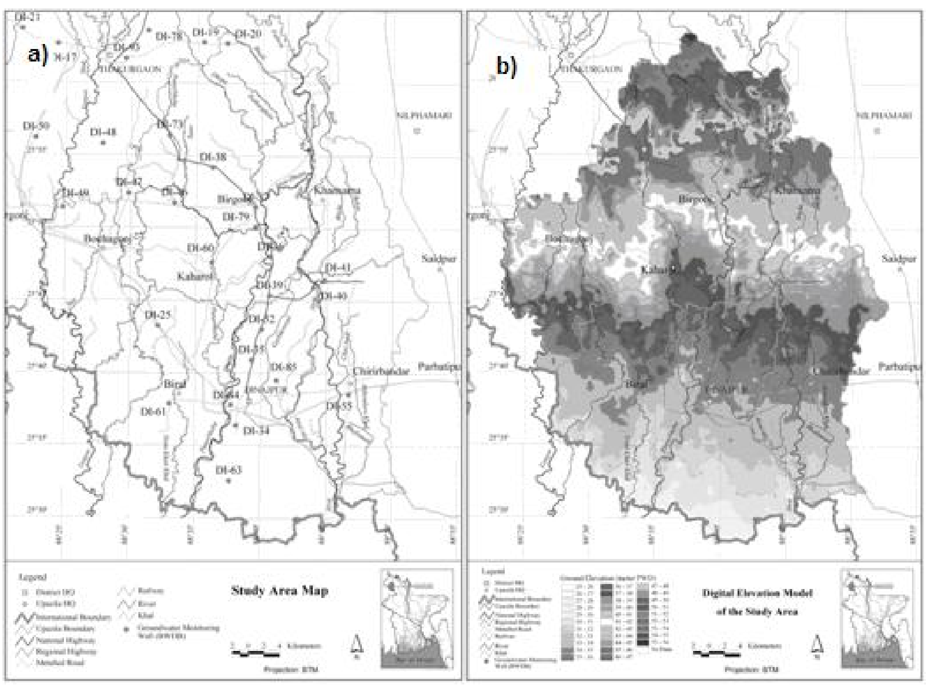

Figure 1: (a) Study Area Map and (b) Digital Elevation Model (DEM)

The existing groundwater table of the study area during dry season has been analysed for the last available nine years' data (1995-2003). The analysis has been done from groundwater observation well data, reports, and maps of existing deep tube well project of greater Dinajpur district. These data have been collected from Bangladesh Water Development Board (BWDB) and Institute of Water Modelling (IWM), Dhaka. The collected groundwater (GW) observation well data have been processed with Microsoft Excel spreadsheet and analysed using ArcViewGIS 3.2 software (ESRI, 1999). A maximum of 6 meter depth to groundwater table from ground surface has been considered as safe yield limit to ensure the drinking water supply in the study area through HTWs and STWs respectively with full operational efficiency.

Using this GIS software at first the method of interpolation has been selected on the basis of finding out interpolation and extrapolation errors. A number of available interpolation techniques available in GIS have been considered which are briefly introduced below:

a. The inverse distance weighted (IDW) interpolation method is a local method that assumes that the unknown value of a point is influenced more by nearby control points than those further away;

b. Thin plate Splines creates a surface that passes through control points and has the least possible change in slope at all points (Franke, 1982). In other words, thin-plate splines fit the control points with a minimum-curvature surface;

c. Kriging (after the South African mining engineer, D.G. Krige) is a geo-statistical method for spatial interpolation. The technique of kriging assumes that the spatial variation of an attribute such as changes in grade within an ore body is neither totally random nor deterministic (Davis, 1986; Isaaks and Srivastava, 1989; Webster and Oliver, 1990; Cressie, 1991; Bailey and Gatrell, 1995). Kriging is classified as ordinary and universal based on the presence and absence of drift or structure which representing a trend. Assuming the absence of a drift, ordinary kriging focuses on the spatially correlated component. The measure of the degree of spatial dependence among the sampled known points is the semivariance that can be fitted with a mathematical function or a model such as spherical, circular, exponential, linear, and Gaussian.

Once the interpolation method is selected, critical areas have been delineated in each year from 1995 to 2003 taking the highest groundwater drawdown data in a particular date of each year. To delineate critical areas for drinking water supply an interpolated surface of groundwater level (GWL) has been made from the collected GW observation well data. The GWL surface has been deducted from the surface of digital elevation model (DEM) to calculate the depth of GW table (GWD) from the earth surface. Then the GWD has been reclassified in two types of areas i) GW depth is less than 6 meters, and ii) GW depth is above 6 meters i.e. the critical areas. Finally, customized tools have been developed using Avenue scripts (built in object-oriented programming language in ArcView GIS) in ESRI's ArcView GIS 3.2 software with Spatial Analyst 2.0 extension to make the delineation of water scarce area for different time on the basis of available data.

3. ANALYSIS USING GIS TOOLS

Because of the availability of good aquifer and limited scope of surface water development, groundwater in the study area is being used to meet the irrigation as well as domestic and industrial demands. DTWs and STWs are being used for abstracting irrigation water; HTWs are being used for drinking water supply in the rural areas; and DTWs are being used to meet the drinking and industrial water demands in the municipal areas. As HTWs and STWs operate under suction mode, these become completely inoperable condition when depth to groundwater table goes below suction limit, i.e., 7m from ground surface. Wetlands, ponds and small streams also dry out when groundwater table goes below 7m. On the other hand HTWs and STWs can operate with full efficiency when groundwater table remains within 6m from ground surface. If water table remains within 6 to 7 m depth, HTWs and STWs still can abstract water but efficiency will be less and more energy will be required. Considering these facts, 6m depth to groundwater table from ground surface has been considered as safe yield limit to ensure the drinking water supply in the study area through HTWs and STWs respectively with full operational efficiency. The critical areas are those where the groundwater table goes below the safe yield limits. These are critical for drinking water supply during the dry period.

Two ways of selecting interpolation method of groundwater level measurement have been implemented, one is for Interpolation (finding internal unknown values) and the other is for Extrapolation (finding external unknown value). The methodology was finding out as an unknown value implementing with different interpolation methods excluding the known value. Then the errors were calculated. Here the groundwater observation well DI-61 located in Biral has been excluded from the interpolations that are shown in Table 1.

Table 1: Comparison of Interpolation Errors

Well No.	**Interpolation Method**			**Value in meter**	**Actual value**	**Error (%)**
Groundwater Observation Well - DI-61 (Biral)	IDW			29.13	27.5	5.93
	Spline			27.83	27.5	1.20
	Kriging	Ordinary	Spherical	28.18	27.5	2.47
			Circular	28.14	27.5	2.33
			Exponential	28.24	27.5	2.69
			Gaussian	20.29	27.5	-26.22
			Linear with sill	28.09	27.5	2.15
		Universal	Linear Drift	27.43	27.5	-0.25
			Quadratic Drift	28.37	27.5	3.16
Groundwater Observation Well - DI-55 (Chirirbandar)	IDW			30.68	29.01	5.76
	Spline			31.39	29.01	8.20
	Kriging	Ordinary	Spherical	29.27	29.01	0.90
			Circular	29.23	29.01	0.76
			Exponential	29.35	29.01	1.17
			Gaussian	-52.98	29.01	-282.63
			Linear with sill	29.19	29.01	0.62
		Universal	Linear Drift	28.42	29.01	-2.03
			Quadratic Drift	26.33	29.01	-9.24

The minimum error has been recorded as -0.25% for Kriging Method (Type-Universal with Linear Drift). To calculate Extrapolation influence error, groundwater observation well DI-55 located near Chirirbandar has been excluded from the interpolations. The minimum error has been recorded as 0.62% for Kriging Method (Type-Ordinary, Linear will sill). Moreover, visualising the spatial representation of groundwater depth grids creating with all interpolation methods, it can be concluded that Kriging Method (Type-Ordinary, Linear) fulfils the objectives of the present study. Therefore, all the spatial analyses of delineating critical areas for drinking water supply in the study area on the basis of groundwater depth have been conducted using Kriging Method (Type-Ordinary, Linear).

4. RESULT AND DISCUSSION

The critical areas for drinking water supply in the study area during dry period have been delineated for different years. The data have been selected as the date of the maximum drawdown value for each year for all the spatially distributed groundwater observation wells. The delineated critical areas have been presented in Table 2. The maximum critical areas were in 1995 (49.7%) which causes severe drought in study area.

Table 2: Critical area in different years for drinking water

Year	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Critical Area (ha)	101,382	79,275	61,867	43,571	56,917	86,902	96,359	41,263	54,334
% of Total Area	49.7	38.8	30.3	21.3	27.9	42.6	47.2	20.2	26.6

The total critical areas in 1995, 1996, 2000 and 2001 are above the average (33.8%) critical area as shown in Figure 2. In 1998 and 1999, the critical areas were fewer than in other years due to major floods occurred in 1997 and 1998 which recharged groundwater tables. The interpolation maps of critical areas above the average value (33.8%) area shown in Figure 3. The most critical areas lie in Biral, Dinajpur Sadar, Kaharole and Khansama upazilas of Dinajpur district where annual groundwater level fluctuation is in the range of 4.0m to 11.0m. Bochagonj, Birganj and Chirirbandar upazilas of Dinajpur district have been found as negligible critical areas where annual groundwater level fluctuation varies from 1.5m to 6.5m.

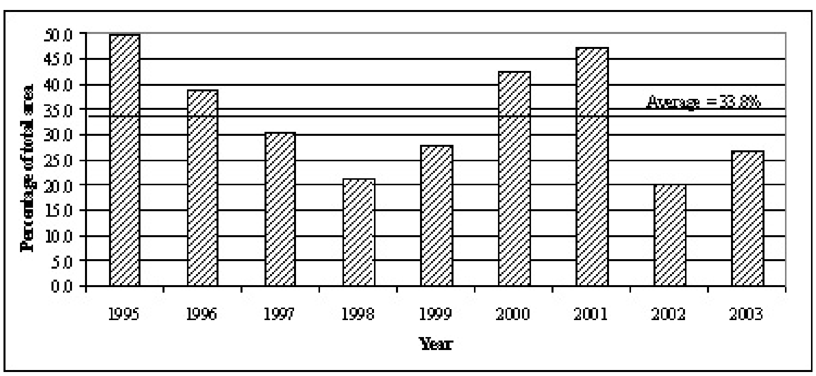

Figure 2: Percentage of Drinking water scarcity during dry period of different years

Temporal analysis of drinking water scarcity during different years has been presented in Figure 4. It is observed that frequently occurred critical situation of drinking water supply is in Biral, Dinajpur sadar, Kaharole and Khansama upazilas. The maximum duration of critical period for drinking water supply in Dinajpur Sadar upazila has been found in 1999 as 120 days. The time frame of scarcity of drinking water lies between March to June in each year. Bochaganj, Birganj and Chirirbandar upazila has been found as of negligible duration of scarcity of drinking water. The duration varies in different upazilas during different years due to the spatial variation of groundwater was withdrawn.

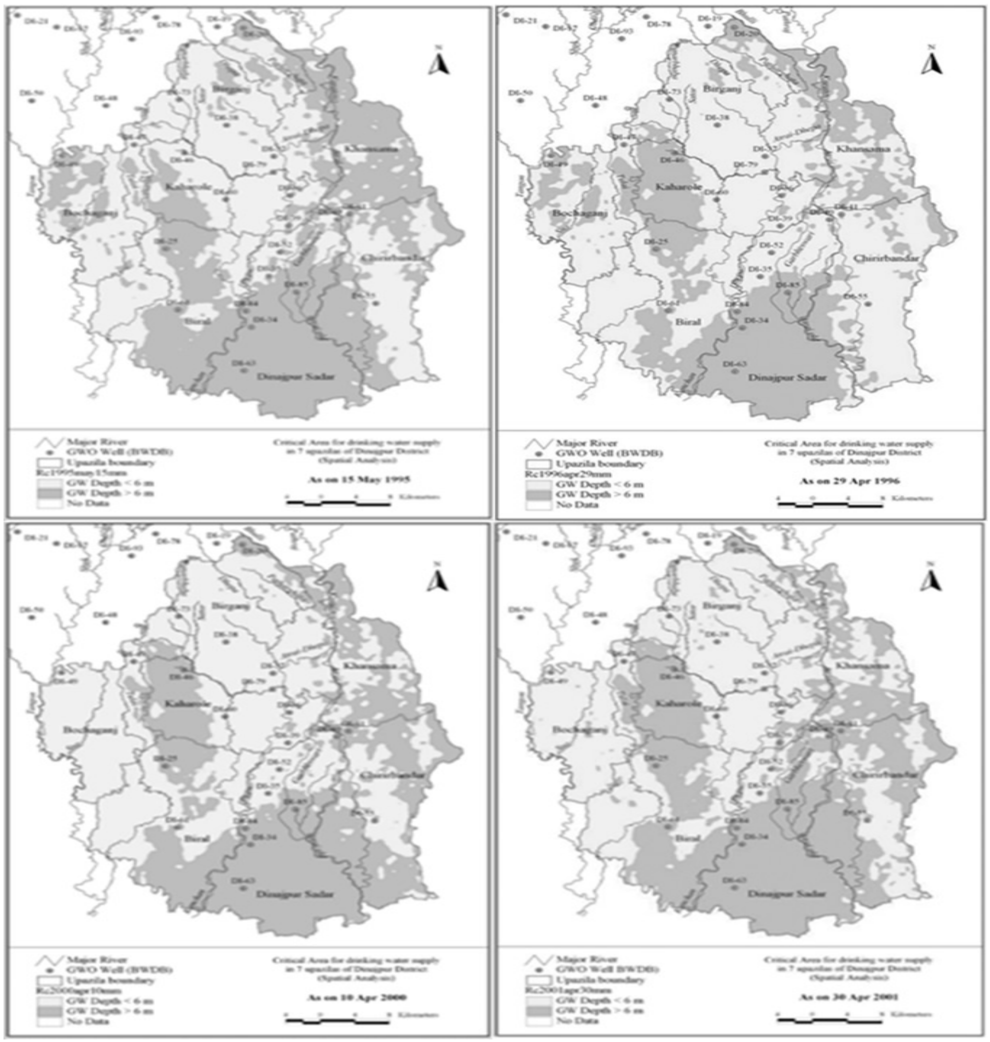

Figure 3: Critical Areas during dry season of 1995, 1996, 2000 and 2001

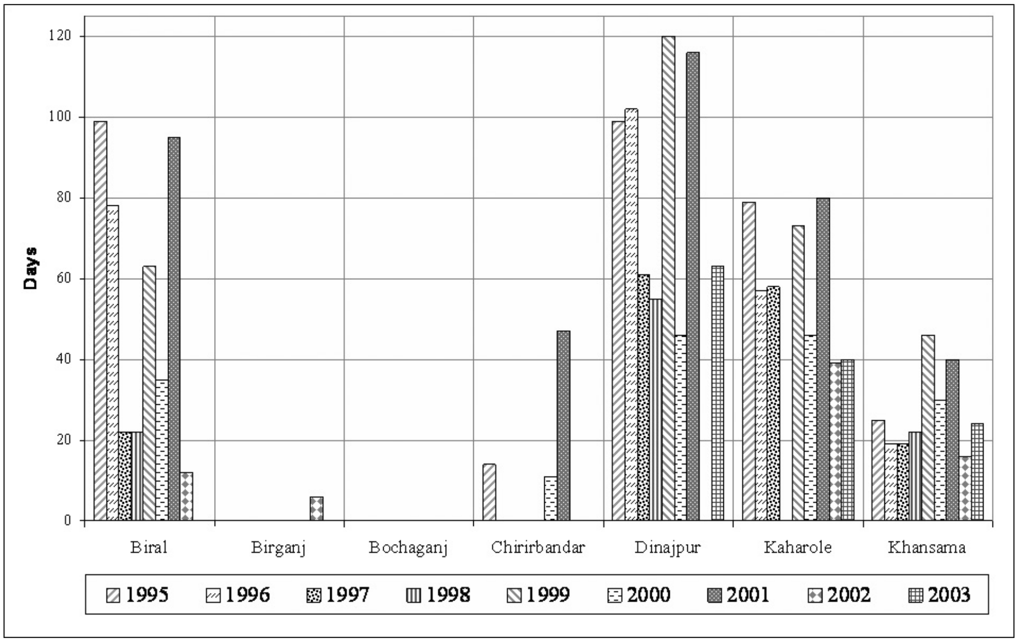

Figure 4: Upazila-wise duration of drinking water scarcity during different years

5. CONCLUSIONS

Based on the study findings, major conclusions and recommendations have been summarized below.

a. The groundwater table and quality monitoring should be done regularly following the guidelines for assessment of annual safe yield and groundwater budgeting. Large scale groundwater withdrawal by DTWs should be limited during dry period up to safe yield limits (6m below ground elevation).
b. In severe drought areas where groundwater table goes below the suction limits, the HTWs should be replaced by Tara pumps (extended piston HTWs). The suction limit of a tara pump is about 12 meters below ground elevation.
c. An alternative to Tara pump, DTWs can be installed for rural drinking water supply in the severe drought areas. If DTWs are installed, water supply would be piped. So cost will be higher.
d. Existing dry period irrigation practice in the study area is mostly from groundwater source, a major portion of which is being abstracted through STWs. At present, high yield variety (HYV) crops covers nearly 47% of all cultivable land. HYV require more water for irrigation in the dry period than the local crops. It has been suggested to plant local crops which required less amount of irrigation to make the water resources sustainable for the future.

REFERENCES

Baily, T.C. and Gatrell, A.C. (1995). *Interactive Spatial Data Analysis*. Harlow, England: Longman Scientific & Technical.

Cressie, N. (1991). Statistics for Spatial Data, Chichester, New York: John Wiley & Sons.

Davis, J.C. (1986). Statistics and Data Analysis in Geology, 2nd edition, New York: John Wiley & Sons.

Environmental Systems Research Institute Inc. (ESRI) (1999). ArcView GIS the Geographic Information System for Everyone, Redlands, California, USA

Franke, R. (1982). Smooth Interpolation of Scattered Data by Local Thin Plate Splines. Computers and Mathematics with Applications 8: 273-281.

Hossain, A. (2000). Groundwater Monitoring and Management, Pakistan Water Partenership, Islamabad, Pakistan.

Issaks, E.H., and Srivastava, R.M. (1989). An Introduction to Applied Geostatistics, Oxford: Oxford University Press.

NMIDP. (1998). National Minor Irrigation Development Project, National Minor Irrigation Census 1996/97. Sir Willium Halcrow & Partners Ltd. And DHV Consultants BV, Dhaka, Bangladesh, 120.

Webster, R., and Oliver, M.A. (1990). Statistical Methods in Soil and Land Resource Survey. Oxford: Oxford University Press.