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TREND ANALYSIS OF THE HYDROLOGICAL COMPONENTS IN A WATERSHED: A CASE STUDY FOR BOGURA DISTRICT IN BANGLADESH

Muhammad Abdullah[1]
Mahmid Saminur Rahman[1]
Md. Atiqur Rahman[2]
S.M. Sahabuddin[2]

[1]Water Resources Planning Division, Institute of Water Modelling, Dhaka, Bangladesh
[2]Irrigation Management Division, Institute of Water Modelling, Dhaka, Bangladesh

Use of groundwater for domestic and irrigation purpose is common phenomenon in north-western districts of Bangladesh. Due to over-abstraction in recent years, the control of groundwater level lowering has become a challenge to the north-western districts of Bangladesh. Bogura is one of the north-western districts located in the active Brahmaputra-Jamuna flood plain and is considered susceptible to substantial strain due to groundwater depletion. The aim of this study is to analyse the trend and extent of the groundwater table in Bogura district up to the year 2030 because of the expanding status and possible variability of the water demand. MIKE SHE, an integrated hydrological model has been used to simulate the fluctuating water table to assess the groundwater resources and future scenario analyses. Normal rainfall for the period of years 1985 to 2011 has been found 1672 mm. The same normal rainfall has been considered for the projection years 2012 to 2030. The temporal rainfall fluctuations were taken directly from a different study. Projections of the relevant hydrological components were anticipated in relation to the suitable projection models. The simulated result from the year 2006 to 2030 shows the depletion rate of the study area varies from 0.00 to 2.92 cm/year for mean depth of phreatic surface. In case of maximum depth of phreatic surface, the depletion rate varies from 1.20 cm/year to 14.45 cm/year. After a drought of rainfall events, a lower phreatic surface has been observed; this is however regained in subsequent heavy rainfall events.

INTRODUCTION

Water is a renewable resource and the availability of water is complicated because of its uneven distribution over the localities. Evaporation and precipitation are two key parameters responsible for replenishing the fresh water supply constantly and quickly (Altaner, 2012). Groundwater is the largest source of usable, fresh water in the world. In many parts of the world, domestic, agricultural and industrial water needs is being met using groundwater; where surface water supplies are not available (Siebert and D¨oll, 2010). In Bangladesh from 1985 to 2008, the contribution of groundwater has increased from 38% to 79% and surface water has declined from 62% to 21% (Shaw et. al., 2011). The ratio of groundwater to surface water use is much higher in north-western districts of Bangladesh compared to other parts of the country (Shahid and Behrawan, 2008). More than 90% of the population in Bangladesh relies on groundwater; about 97% of rural people are using over 10 million hand tube wells to fulfil their drinking water needs (Amin, 2009). According to the Bangladesh Bureau of Statistics, the population of Bangladesh has increased from 28.93 million in 1901 to 149.77 million in 2011 (BBS, 2011). Rice yield has increased from 1.0 MT/ha in 1971-1972 to 2.8 MT/ha in 2008-2009 due to the increase of high yield variety Boro cultivation area from 10% in 1971-1972 to 44% in 2006-2007 (BBS, 2008a). The northwest region of Bangladesh covered broadlyby 16 districts (together called the Rajshahi Division), reported the highest percentage (27.22%) of households with Hybrid Boro cultivation (BBS, 2008b). Brahmaputra and Ganges basin have the largest irrigated area of the world (Bjorklund et. al., 2009; Vrba and Van der Gun, 2004). Bangladesh whereas, having the largest quantity of groundwater abstractions, eventually is known as one of the highest groundwater declination countries in the world (Tiwari et. al., 2009).

Due to expanding irrigation in the north-west region of Bangladesh led to huge groundwater withdrawn with their dry climate and comparatively high temperature. Between the periods of 1984-85 to 2010-2011, tubewell intensity has increased from 6.9 to 36 per square kilometer of land area. Whereas deep tubewells have become almost doubled, shallow tubewell has increased more than 5 times and irrigated land has increased about 1.6 times (Dey et.al., 2013). Lowering of groundwater table during dry months is a serious threat to the operation of shallow tubewell, hand tubewell and dug wells (NWMP, 2001). In the greater Rajshahi area, extraction exceeds the recharge and groundwater table which declined 3 meters between 2004 and 2010 (Luby, 2013). Due to over-abstraction in recent years, the groundwater of Bogura district, a part of the north-western region of Bangladesh has been lowering at 46.65 cm/year (Abdullah, 2017).

Climate change is led to intensify the global hydrologic cycle (IPCC, 2014; Pervez and Henebry, 2014; Huntingon, 2006). A part of freshwater resources in dry most tropical regions is projected to decrease due to climate change over the 21st century (IPCC, 2014). A number of studies have been carried out to understand the impact of climate change on irrigation water demand and all of them predicted the increase of crop-water demand due to climate change (Yano et al., 2007). In the north-western region of Bangladesh, climate change will increase the daily irrigation demand by 0.8 mm per day during the end of this century (Shahid, 2011). Another study predicted the yield reduction of 20% and 50% of Boro rice for the years of 2050 and 2070 respectively due to climate change (Basak. et.al., 2010).

Bogura is one of the north western districts in the Rajshahi Division of Bangladesh, which is located in the active Brahmaputra-Jamuna flood plain. The area has been under considerable strain due to groundwater depletion with the increasing trend of water use (Abdullah, 2014). This study has taken an attempt to understand the trend and extent of the groundwater table of Bogura district due to climate change both at spatial and temporal scale. MIKE SHE model has been used for predicting the groundwater table by analysing the existing hydrologic parameters of Bogura district. The objective of the study will also cover the determination of the groundwater resources of the underlying aquifer system of the Bogura district for the projected years up to 2030.

MATERIALS AND METHODS

Study Area

Bogura district is considered as the study area and it comprises of 12 Upazilas which is illustrated in Figure 1. The study area is bounded on the north by Gaibandha and Joypurhat zila, on the east by Jamalpur and Sirajganj zila, on the south by Sirajganj and Natore zila, and on the west by Naogaon and Joypurhat zila.

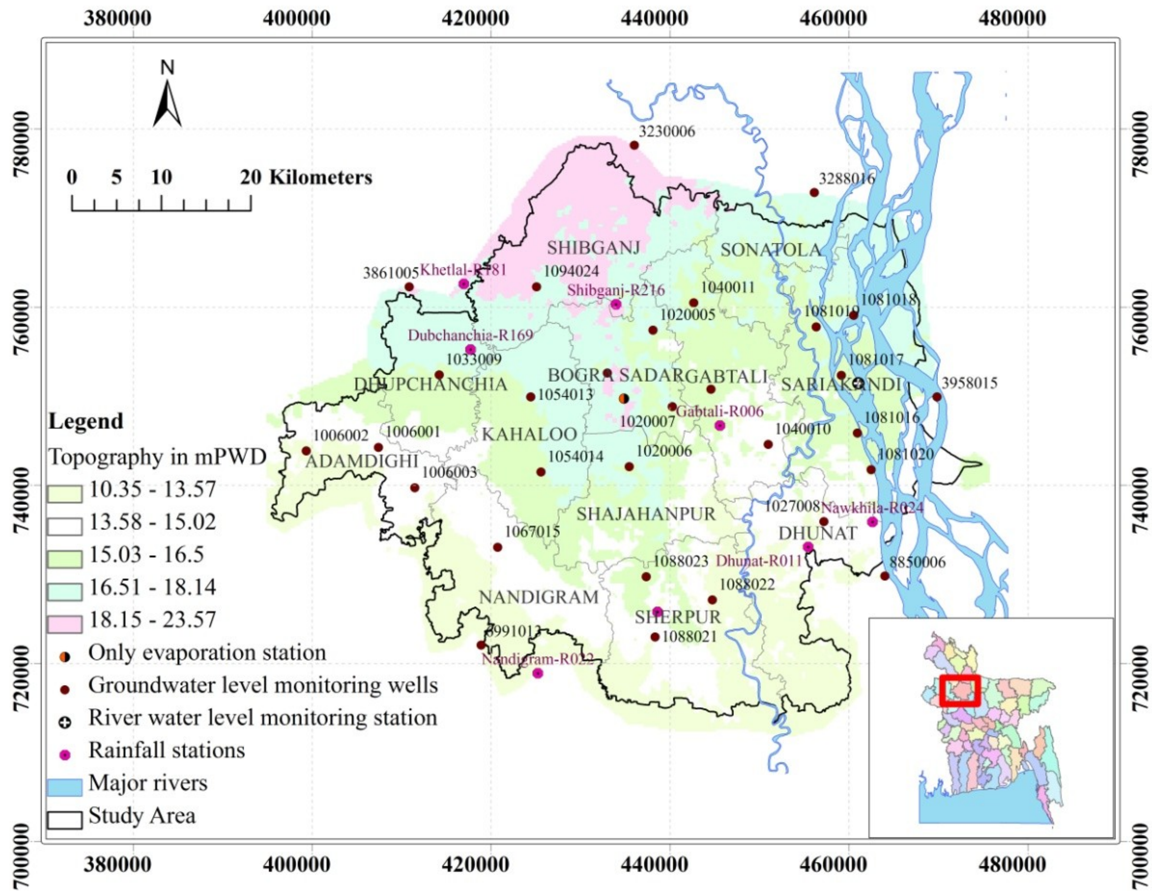

Figure 1. Map of the study area (Bogura district)

Data Collection and Projection upto the Year 2030 for MIKESHE Hydrological model

For the model development of MIKE SHE hydrological model, the following data (Table 1) are used. However, topography, lithology, land use and cropping pattern are used directly from the mentioned IWM project (IWM, 2014). The locations of the hydrological data monitoring wells used in this study are shown in Figure 1**.** Trend detection of hydrological components using Mann-Kendall test, Sen's slope method, and linear regression has been analyzed (Abdullah, 2017) and the corresponding data has been projected upto the year 2030 for MIKE SHE hydrological model.

Table 1: List of hydrological data used for this study

Data Type	Main Source	Collected from	Data Range	Background Details of the Used Data	Use in this study
Groundwater level	BWDB	IWM	2005-2012	Study area boundary wells: GT323006, GT328806, GT3958015, GT8850006, GT6991013 and GT3861005.	GWL at Model Boundary
				Wells inside Study area: all calibrated wells.	Calibration and Validation
Rainfall	BWDB	IWM	1985-2011	Rainfall stations: R006, R011, R022, R024, R033, R169, R181 and R216.	Spatial distribution of rainfall data
	BBS	BUET	1985-2011	Declared rainfall for Bogura district.	Assessment of normal rainfall
Evapotranspiration	BWDB	IWM	1985-2012	Evaporation station: CL6.	Model evapotranspiration
Surface water level	BWDB	IWM	2005-2012	River Jamuna at Mathurpara Station. Other levels from the calibrated model under IWM, 2014	Model river water level

Hydrometeorology of the study area

Precipitation, evapo-transpiration and surface water level data are the main hydro-meteorological inputs use for the groundwater model.

<u>Precipitation</u>

The normal rainfalls of surrounding stations are found within 10 to 12% of that concerned station (Subramanya, 1994). Quality checking of rainfall data has been made using double mass curves. From the frequency analysis and the thresholds selected by FAO (FAO, n.d; Tekwa and Bwade), rainfall events in wet, normal and dry years were obtained using the 20, 50 and 80% standard probabilities of exceedance (Chow et. al., 1988; Subramanya, 1994). The normal rainfall of Bogura district from the year 1985 to 2011 was found 1672mm (source: BBS; Abdullah, 2014).

The same normal rainfall of 1672mm is considered for projecting model from the year 1985 to 2030 (Figure 2). The monthly and yearly fluctuations of rainfall have been taken directly from Rajib et. Al., 2010. According to Rajib et. al., 2010, the year 2012, 2014, 2016, 2019, 2021, 2022, 2025 and 2028 are found as the dry (rainfall) years having 10 to 28% less rainfall and year 2013, 2015, 2020, 2023, 2027 and 2029 are found as the wet years having 18 to 41% higher rainfall from the normal rainfall event. From projected annual rainfall of Bogura district, the year 2021 and 2022 can be regarded as consecutive drought years for minimum rainfall events having about 28% and 23% less rainfall from average annual rainfall. On 1st May 2023, the groundwater level is assumed to be the most critical due to consecutive droughts years. The effects of the phreatic surface after consecutive drought years will be discussed in the year 2023.

<u>Evapotranspiration</u>

Evapotranspiration rate varies with climatic variables such as wind speed (Zhao et. al., 2014), net radiation (Xu et. al., 2006), temperature (Zhao et. al., 2014), short wave (Zhao et. al., 2014), sunshine hour (IPCC, 2014) etc. Considering available climatic factors, annual evaporation value in the study area has been found about 1462mm (or about 4 mm/day). The value is almost constant throughout the last couple of years. The same value, 4 mm/day has been considered for the projection years up to 2030.

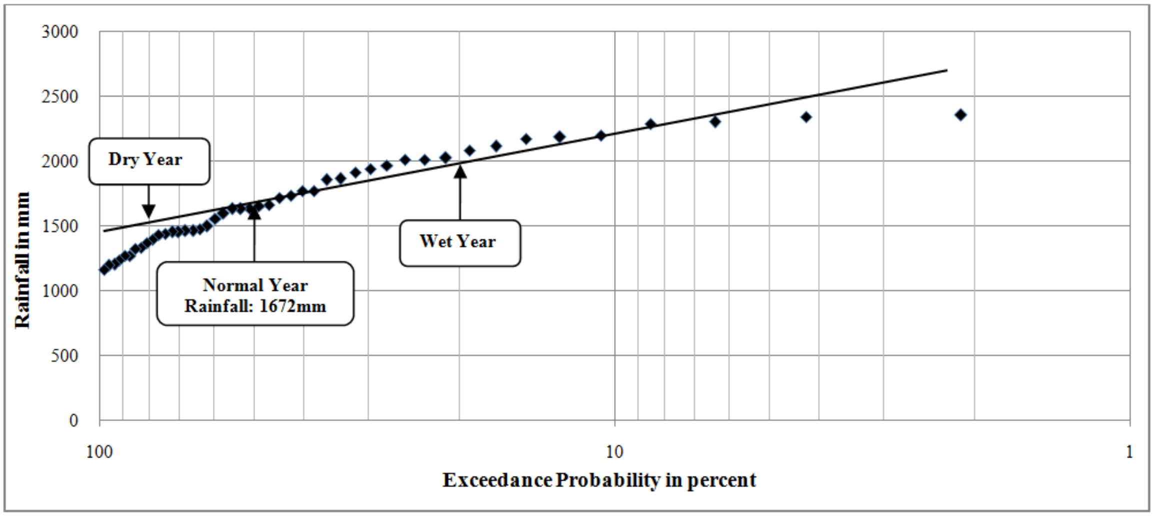

Figure 2. Normal Rainfall of Bogura district (year: 1985-2011)

<u>River water level</u>

Some major rivers and a list of beels are the main surface water sources in the study area. Major rivers passing through the study area are Jamuna, Karatoya, Nagar, Bangali, and Ichamati. Among all rivers, Jamuna is contributing major role and dominating surface water resources (Abdullah, 2014; IWM, 2014). For model build-up, calibrated river water level data has been used from the mentioned IWM project (IWM, 2014). For river Jamuna, 5.11 cm/year depletion rate has been found from trend detection test (Abdullah, 2017). This trend has been considered for the projection model on baseline (2012) time series plot. In case of other river water level, the same time series plot for the year 2012 has been used up to 2030.

Hydrogeology of the study area

Groundwater wells at study area boundary wells are used as boundary condition. Whereas, the abstraction data were also assessed on the basis of internal groundwater wells.

<u>Groundwater Level</u>

Groundwater observation level data is an important parameter for the groundwater model as it is used for calibration, boundary condition and the initial condition of the model. There are 30 groundwater observation wells of Bangladesh Water Development Board (BWDB) within the study area (Figure 1). Among them, 6 observation wells are at the study area boundary, those are used as boundary condition of the model. 24 observation wells are inside the study area those have been used for calibration purpose. The measured groundwater levels are expressed in terms of national datum, mPWD.

For the projected groundwater level of the model boundary wells, two (2) boundary conditions were considered. The first one has taken zero depletion rate over the years up to 2030. The second one assumed the same groundwater level depletion rate which will be continued over the years up to 2030.

<u>Abstraction due to Water Use</u>

In the study area, direct abstraction data is not available. To overcome this limitation, water abstraction data for 2005 to 2012 is estimated. The main assumption behind this estimation is that the irrigation and domestic water requirement is directly proportional to the rate of abstraction. Abstraction rate has been obtained from the information of cropping pattern and crop coverage throughout the study area for different crops. Domestic water demand for the domestic population (BBS, 2011) has also been included.

Spatial and temporal variation of water demand has been assured according to the land use map (Figure 3) and cropping pattern (Table 2) through the study area. Water demand for wheat, vegetables, and mustard are almost the same compared with boro (IWM, 2014). Wheat is considered as a sample crop with representative demand of all other dry crops except boro. Jute and sugarcane are considered as null demand similar to fallow land.

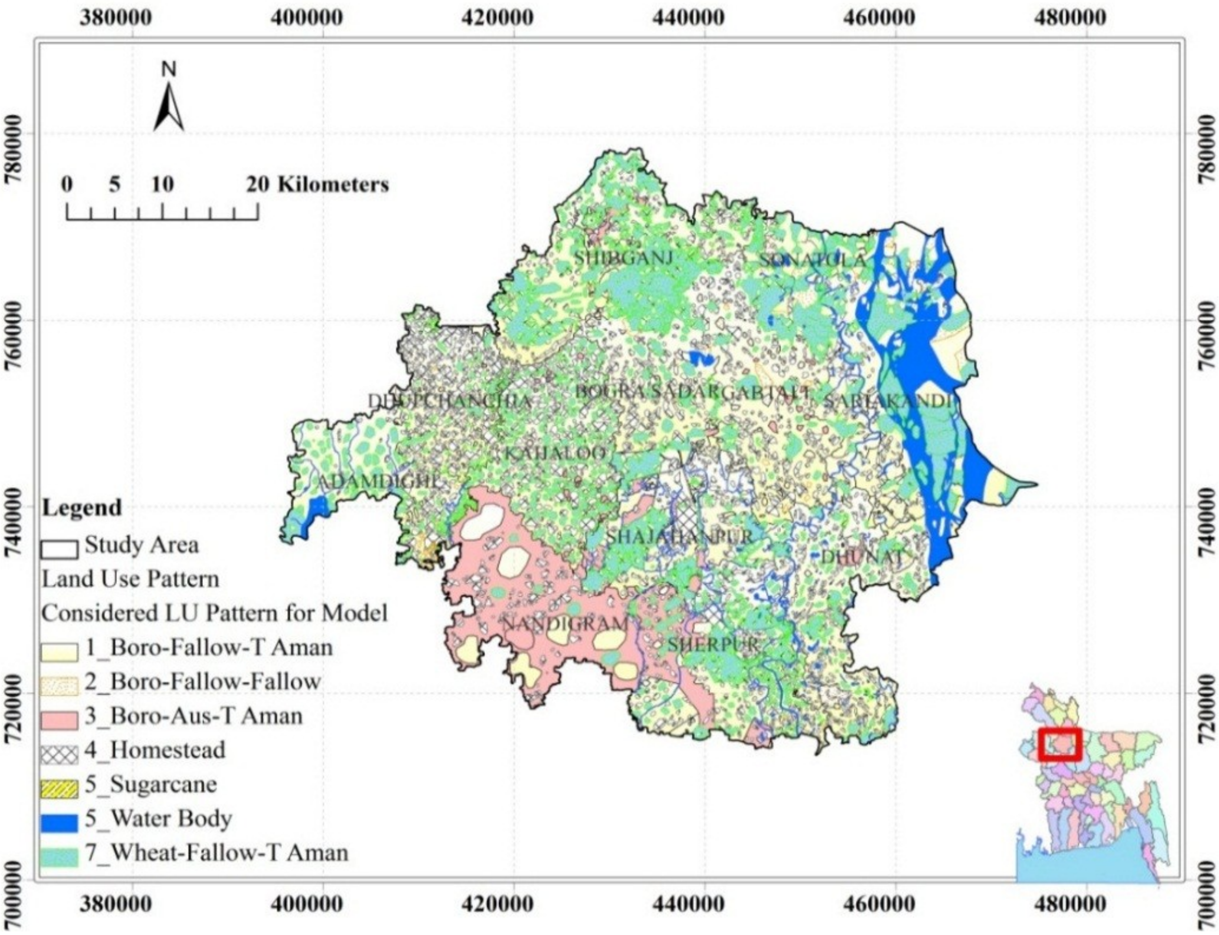

Figure 3. Adopted land use pattern for the MIKE SHE hydrological model

Abstraction from groundwater depends mainly on irrigation and domestic water requirement round the year. Irrigation water is the dominating percentage compared with domestic needs. The average capacity of DTW and STW under Bogura district is considered as 56 l/s and 14 l/s respectively (IWM, 2014). According to the Bureau of Statistics, from 1991 to 2011, the population growth rate of an urban and rural area in Bogura district was 4.68% and 0.7% respectively (BBS, 2011). Domestic water demand in Bogura district has increased from about 151.53 MLD in 1991 to 210.57 MLD in 2011 and the last 20 years domestic demand has increased about 59 MLD. In last decade, according to Census (BBS, 2011), this rate is higher about 1.91% from 174.31 MLD in 2001 to 210.57 MLD in 2011 compared with last 20 years rate which is about 1.66%.

For domestic water demand calculation, Bogura district is subdivided into zila town, Upazila town, and rural areas; where Bogura Sadar Upazila has been considered as zila town. Population in rest of the

Table 2. Crop Calendar for the study area

Month	Land ID				All crops in the corresponding land	
	1	2	3	7	Crops	Land ID
July	Fallow	Fallow	Aus	Fallow	Aus	3
August	Fallow	Fallow	Aus	Fallow	Aus	3
	T-Aman	Fallow	T-Aman	T-Aman	T-Aman	1+3+7
September	T-Aman	Fallow	T-Aman	T-Aman	T-Aman	1+3+7
October	T-Aman	Fallow	T-Aman	T-Aman	T-Aman	1+3+7
November	T-Aman	Fallow	T-Aman	T-Aman	T-Aman	1+3+7
December	T-Aman	Fallow	T-Aman	T-Aman	T-Aman	1+3+7
	T-Aman	Fallow	T-Aman	Wheat	T-Aman+Wheat	1+3+7
January	T-Aman	Fallow	T-Aman	Wheat	T-Aman+Wheat	1+3+7
	HYV-Boro	HYV-Boro	HYV-Boro	Wheat	HYV-Boro+Wheat	1+2+3+7
February	HYV-Boro	HYV-Boro	HYV-Boro	Wheat	HYV-Boro+Wheat	1+2+3+7
March	HYV-Boro	HYV-Boro	HYV-Boro	Wheat	HYV-Boro+Wheat	1+2+3+7
April	HYV-Boro	HYV-Boro	HYV-Boro	Fallow	HYV-Boro+Wheat	1+2+3+7
May	HYV-Boro	HYV-Boro	HYV-Boro	Fallow	HYV-Boro+Wheat	1+2+3+7
	Fallow	Fallow	Aus	Fallow	Aus	3
June	Fallow	Fallow	Aus	Fallow	Aus	3

11 Upazilas have been considered as Upazila town and all the rural swater demand is assumed as 120 l/c/d for zila town, 100 l/c/d for Upazila town and 50 l/c/d for rural population respectively. Another consideration has been taken that per capita demand will be constant from 2011 to 2030. After the analysis it has been found for the year 2012 that, the domestic demand of Bogura district is about 5% of irrigation water demand.

Based on BBS (BBS, 2011) population data and UN, 2011 estimation population projection up to the year 2030 has been made. For urban and rural areas of Bogura district, the growth rate for the projected year from 2015 to 2030 has been considered high and low rate respectively (UN, 2011). Also, estimated density has been compared with the United Nations estimation that is approximately equal. Projection of domestic water demand is considered as straight line increment between every 5 years interval.

MIKE SHE model set up

The groundwater model up to a depth of 80m, covering the entire study area with grids size of 1000m×1000m was developed using MIKE SHE hydrological modeling tools. The model area spreads over 12 Upazilas of Bogura district having an area about 3479 sq km.

Simulation Specification

The default time step control and computational control parameters for overland flow (OL), unsaturated zone (UZ) and Saturated Zone (SZ) have been used for entire simulation period (3rd May 2005 to 31st December 2030). However, simulation periods of the calibration, validation, and prediction models were different and user specified.

Model Domain and Grid Size

The study area has been discretized into 1000m x 1000m square grids and the number of cells in x and y directions are 90 and 70 respectively. The model has 3721 grid cells, where 802 grids are within the boundary cells and the rest 2919 grids are computational cells. A geographical limit of the study area starts from 390000 to extends 480000 in easting and from 710000 to extends 780000 in northing respectively.

Topography

From updated topography of the study area, level variation throughout the study area is about 13m; from 10.35 mPWD in Dhunat to 23.57 mPWD in Shibganj Upazila (Abdullah, 2014; IWM, 2014). The northern part of the study area has a higher elevation than the southern part. A well-prepared digital elevation model (DEM) of 300 m resolution is used to define the topography of the study area.

Lithology

A general purpose subsurface lithology of the study area has been prepared by IWM through analyzing the sedimentary structure, its grain size, hydraulic properties, its thickness and depth (IWM, 2014). Same litho-logical layers have been taken for this study to prepare MIKE SHE hydrological model. Considering litho-logical variation and groundwater flow capacity, 3 hydro-stratigraphic units of the study area have been defined as topsoil, aquitard, and aquifer (Figure 4).

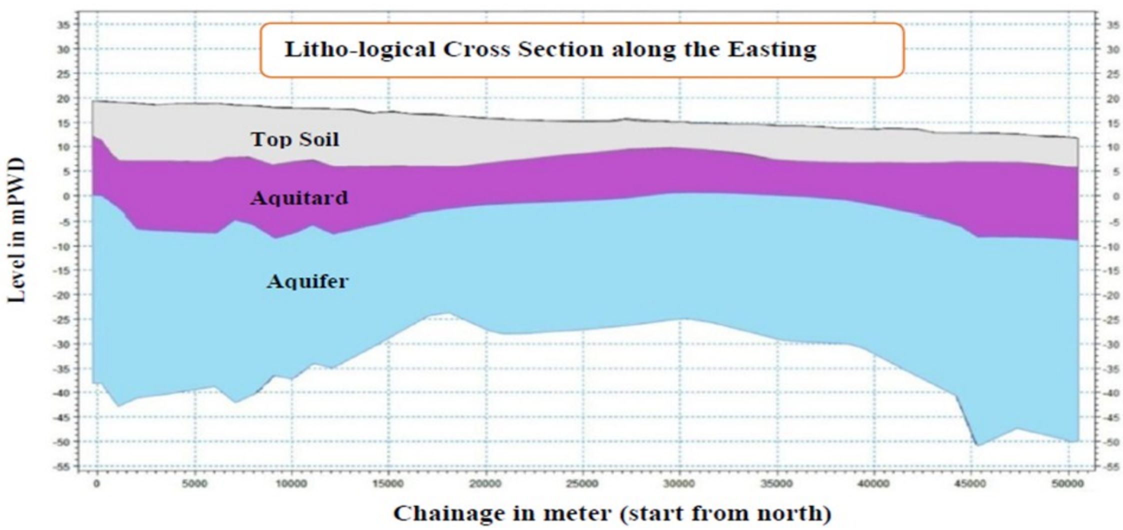

Figure 4. Lithological cross-section along easting 440000

Aquifer Properties

Aquifer tests have been performed in accordance with IWM developed database to understand the aquifer geometry and aquifer characteristics which include vertical and horizontal hydraulic conductivity and specific yield. Calibrated model data having the same aquifer hydraulic properties of the mentioned project (IWM, 2014) has been used in this study. It is found that in the Bogura district area, horizontal hydraulic conductivity mostly varies from 33 m/day to 75 m/day. High hydraulic conductivity indicates that the aquifer is highly permeable.

Top Soil

Soils of the study area are classified into five (5) groups: 1) Barind Track Soils, 2) Grey Terrace Soils, 3) Shallowly Flooded Silty Clays, 4) Tista Flood Plain Soils, and 5) Unstable Alluvium Charlands (IWM, 2014). All of the soil types are suitable for growing rice paddy and vegetables throughout the years. Topsoil in the south-western part of Bogura district is clay dominated than the north-eastern part.

Precipitation

Eight (8) rainfall stations having eight spatial distribution of rainfall has demarcated by Thiessen Polygon.

Overland Flow

Overland flows are governed by the roughness of topography. A lower value of roughness has been considered in the model since the area is mainly of agricultural land. A Manning number (M) 10 has been specified describing the surface roughness. Since the area is dominantly agricultural, a constant value has been considered for the entire area. Exchange of overland flow and groundwater flow occurs when soil becomes completely saturated and at the same time, there is pond water on the ground surface. Like river-aquifer exchange, leakage coefficient along with hydraulic conductivity is taken for overland-groundwater exchange (Akram, 2008).

The initial condition of groundwater level

Potential heads of the monitoring wells are used to generate initial condition contour map and it is taken applicable for all the layers alike.

Spatial and Vertical Discretization

The study area is discretized into 3721 cells having 1000m grid squares in its horizontal plane. The three computational layers define the vertical discretization of the 3-D groundwater model. Special consideration is given to the unsaturated zone, where the vertical resolution is as fine as 0.1m, 0.5m, 1m and 5m towards the increasing depths.

Model Calibration Parameters

Horizontal Hydraulic Conductivity,Vertical Hydraulic Conductivity, Specific Yield, and StorageCo-efficient are the main model calibration parameters.These parameters are applied on the 3 defined layers as topsoil, aquitard, and aquifer. Specific yield and storage coefficient is taken directly from the referenced project (IWM, 2014); that is not discussed in the present study. Mainly vertical hydraulic conductivity is calibrated with the range of one-fourth (1/4) to one-twentieth (1/20) of the horizontal hydraulic conductivity.

Model calibration and model validation

The purpose of model calibration is to achieve an acceptable agreement with measured data by adjusting the input parameters within an acceptable range. The model has been calibrated for the period from 2005 to 2009. Calibration and validation results for the wells of Bogura Sadar Upazila are shown in Figure 5.

Reasons for Deviation between Simulated and Observed Groundwater Level

There is no field observation data for crop water requirement and irrigation water demand. Irrigation water demand data collected from the mentioned project (IWM, 2014). The project estimated crop water requirement for adopted land use pattern according to the field survey conducted in 2012. Similarly, per capita domestic consumption has been taken as a general value that was assessed from Ahmed and Rahman, 2003 for the whole of Bangladesh. Industrial water demand has been taken as a percent of domestic demand. Almost even distribution of irrigation water extraction has given an overestimation of drawdown in low dense irrigation area and vice versa. So, exact consumption has not been incorporated into the model as abstraction data.

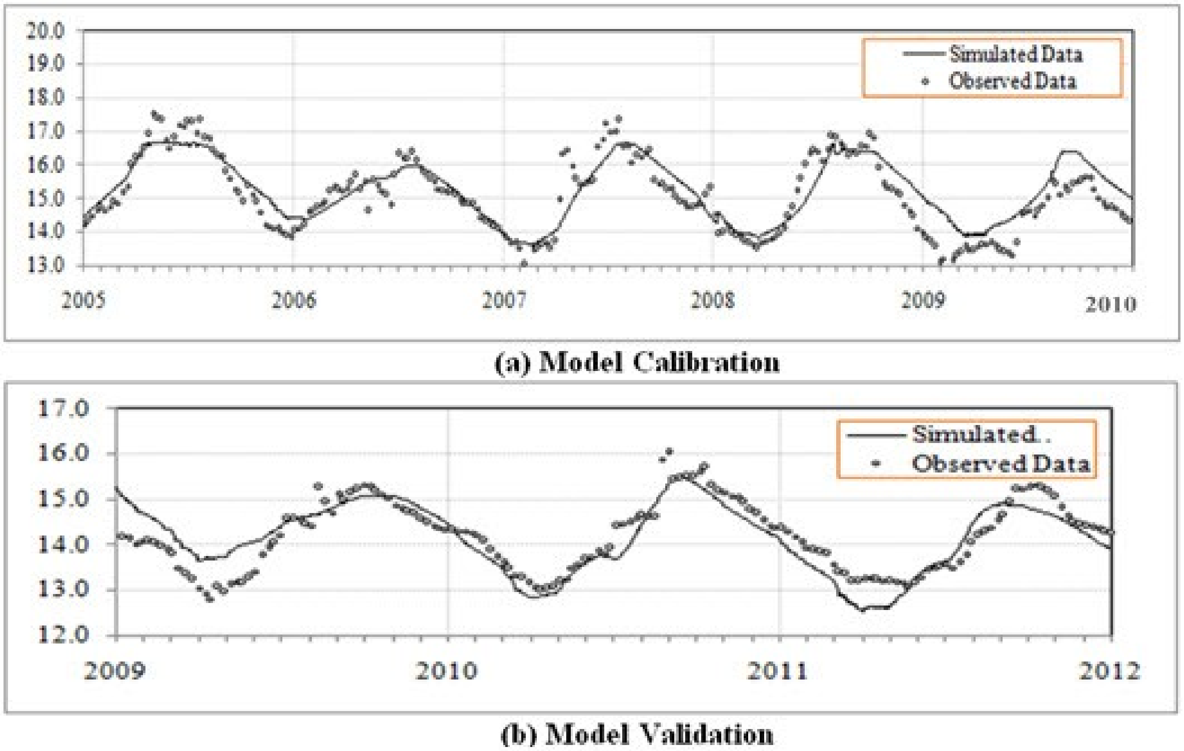

Figure 5. Calibration and Validation of the model for groundwater level at the well: GT1020005 of Bogura Sadar Upazila

RESULTS AND DISCUSSIONS

Predicted Phreatic Surface using MIKE SHE Hydrological model for Present Crop Pattern

The present (2012) crop pattern and corresponding water demand were extended up to the year 2030. The phreatic surface using MIKE SHE model has been simulated for present crop pattern. The mean depth of the phreatic surface has considered as the average depth of phreatic surface within a Upazila. Maximum depth of pheatic surface is the maximum depth of phreatic surface within the Upazila. As for example, Sherpur Upazila have 299 cells. Maximum and mean depth of phreatic surface will indicate the maximum and mean value of 299 cells respectively.

The hydrographs for simulated phreatic surface in input successive drought years (the year 2022 and 2023) show that the maximum depth of groundwater table occurs within the period of April to May (end of the dry period) and minimum depth of groundwater table occurs within the period of October to November (end of the wet period). To describe the most lowering level of groundwater in a year, 1st May has been taken as a maximum depth of phreatic surface.

The study output of MIKE SHE hydrological model shows that the average groundwater depletion rate is nearly negligible upto the year 2030. In the context of Upazila wise depletion, Sherpur Upazila is showing the highest probability of depletion at the rate of about 2.92cm/year, while Sariakandi Upazila is showing the depletion rate approaches to zero (Table 3). Depletion rate in the south-western part has shown comparatively higher for both mean and maximum phreatic surface than in the north-eastern part. In the eastern and north-eastern part, especially the river (Jamuna) surrounded region of the study area shows less depletion rate than the western or south-western part.

Table 3. Depletion rate of the phreatic surface for all Upazilas under Bogura district (period: 2006-2030)

Upazila under Bogura district	Depletion Rate in cm/year from MIKE SHE Hydrological model	
	Mean depth of Phreatic Surface of the Upazila	Maximum depth of Phreatic Surface of the Upazila
Adamdighi	2.26	2.59
Bogura Sadar	0.47	5.07
Dhunat	1.17	5.77
Dhupchanchia	0.32	4.89
Gabtali	0.14	3.21
Kahaloo	1.57	9.75
Nandigram	0.33	7.99
Sariakandi	0	1.20
Shahjahanpur	0.22	11.57
Sherpur	2.92	14.45
Shibganj	0.91	6.28
Sonatola	1.50	4.12

Predicted Phreatic Surface using MIKE SHE Hydrological model for Change in Crop Pattern

The reasons behind the consecutive drought years in 2021 and 2022, the 1st May in 2023 has been assumed as most affected period up to year 2030. For the analysis of different crop pattern, irrigation water demand has been predicted from the year 2012 to 2030. Three (3) types of Rabi crop pattern in the dry season have been considered as (i) present crop pattern (about 70% boro and 30% wheat), (ii) only boro in the whole crop area (100% Boro), and (iii) only wheat considered as a sample low demand crop in the whole crop area (100% Wheat). At the same time, three (3) types of crop water demand have been considered as (i) same crop water demand from year 2012 to 2030), (ii) annual demand increment rate is assumed at 1.25% to attain 1.25 times of present demand in 2030, and (iii) annual demand increment rate is assumed at 2.25% to attain 1.50 times of present demand in 2030. For present crop pattern has been analysed for 3 demand scenarios. In case of extrement scenarios either for 100% Boro or 100% Wheat (the sample low demand crop), 1.25% water demand scenario has been analysed. The depth of pheratic surface has been analysed for five (5) scenarios.

Predicted the mean depth of phreatic surface

In the this article, possible effects on groundwater table as mean depth of phreatic surface has been observed. Possible effects for choosing different Rabi crops specially for dry seasons with respect of time has been analysed. Table 4 shows the predaicted mean depth of phreatic surface for the year 2023 due to variable cropping pattern. In the south-western part, comparatively higher depth of phreatic surface has been observed than in the north-eastern part. In the eastern and north-eastern part, especially river (Jamuna) surrounding the region of the study area shows less depth of phreatic surface than the western or south-western part. Higher demand crop leads to a higher depth of the phreatic surface of the study area.

Depth of phreatic surface above the suction limit of hand tube well

The effect of present cropping trend with respect to the localities has been analysed in this section. Traditional hand tube wells are used in the major portion of the study area for drinking purpose. This analysis is attempted to show how many areas could be disturbed for higher demand crops in the dry period. Figure 6 shows the affected cells having the depth of phreatic surface is above 6m (suction limit

Table 4: Predicted mean depth of phreatic surface for change in crop pattern and crop water demands

Upazilas of Bogura district	The depth of Mean Phreatic Surface (meter) in 2012	Depth of Mean Phreatic Surface (meter) in 2023*				
		Present crop pattern; demand has been considered: 2012-2030			Boro for all crop areas; demand increment rate (annually): 1.25%	Wheat for all crop areas; demand increment rate (annually): 1.25%
		Same demand up to 2030	Annual increment rate: 1.25%	Annual increment rate: 2.25%		
Adamdighi	4.8	4.96	5.63	6.29	5.83	4.26
Bogura Sadar	4.1	4.17	3.91	4.05	3.92	3.10
Dhunat	3.64	3.70	3.82	3.93	4.13	3.23
Dhupchanchia	4.46	4.53	5.04	5.54	5.37	3.91
Gabtali	3.49	3.65	3.39	3.12	3.18	2.84
Kahaloo	3.65	3.76	4.65	5.54	5.31	3.68
Nandigram	4.17	4.29	4.64	4.99	4.76	3.31
Sariakandi	3.96	4.02	3.79	3.55	3.74	3.18
Shahjahanpur	4.54	4.69	4.45	4.39	4.80	3.14
Sherpur	4.21	4.23	4.42	4.61	4.52	3.23
Shibganj	4.53	4.64	4.47	4.29	4.49	3.70
Sonatola	4.21	4.33	3.99	3.65	3.95	3.31

* 2023 is selected as the most affected year up to 2030 after two consecutive drought event in 2021 and 2022.

of traditional hand tube well). For the higher demand crops, a significant number of cells to have a depth of phreatic surface above 6m. But, in some areas, this effect is insignificant than in other areas. Used hand tubewells in south-western Upazilas are more vulnerable than the north-eastern part. The high lifting mechanisms of groundwater withdrawn would be required in south-western Upazilas for the higher irrigation crops, specially in dry seasons.

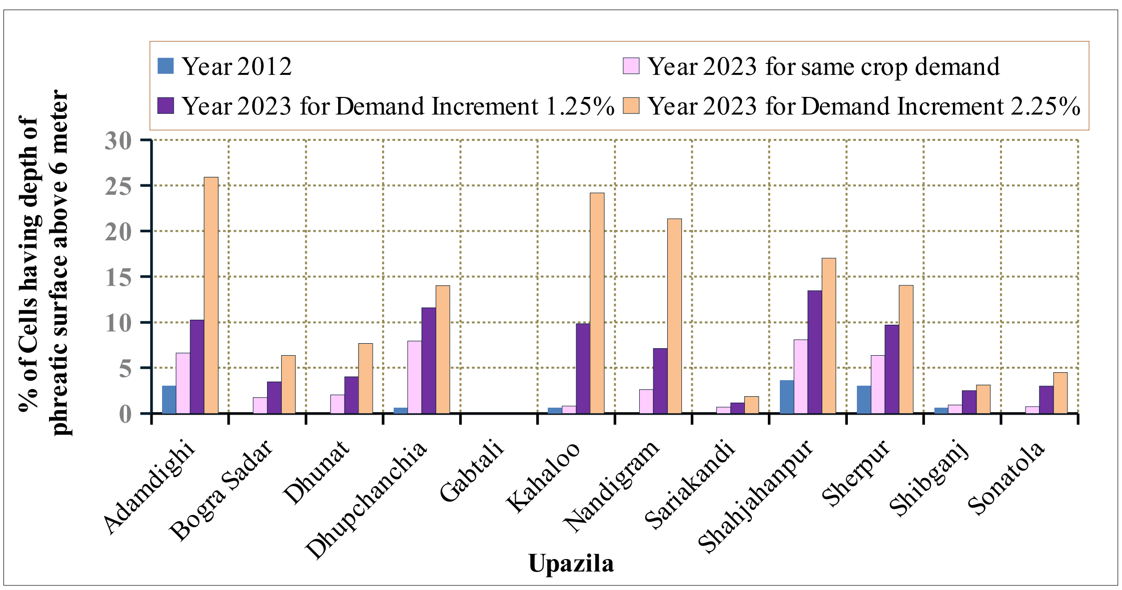

Figure 6. Percent of cells having the depth of phreatic surface is above 6m due to different crop pattern

CONCLUSIONS AND RECOMMENDATIONS

The main conclusions drawn from this study is found that uneven lowering trend of the phreatic surface has been found in different Upazilas of Bogura district. The depletion rates vary from 0.00 to 2.92 cm/year for the mean depth of phreatic surface. Depletion rate for maximum depth of phreatic surface varies from 1.20 cm/year to 14.45 cm/year. In the south-western Upazilas of Bogura district (Kahaloo, Nandigram, Shajahanpur and Sherpur) shows a higher rate of groundwater depletion. Rest of the Upazilas of Bogura district have a comparatively lower rate of groundwater depletion. Sariakandi Upazila shows no change in the phreatic surface over the simulated years.

The yearly fluctuation of the phreatic surface of Bogura district depends on annual rainfall pattern. The lower phreatic surface has found after drought rainfall years. In the south-western Upazilas of Bogura district, the mean phreatic surface may deplete up to 3m. However, in a few cells, it may extend up to 9m due to predicted hydrological parameters in the range of the year 2012 to 2030. For average rainfall year, depletion of the mean phreatic surface is not significant throughout the Bogura district. Maximum depletion of the mean phreatic surface has found only 0.53 meter from 2012 to 2030. Lowering of the phreatic surface in drought rainfall year is possible to recover by subsequent higher rainfall events. Contribution to groundwater recharge in Bogura district is mainly due to changing rainfall events over the simulated years.

The main recommendations for the future research are about the model setup that was prepared using average rainfall event (from 1995 to 2011). The rainfall data for the projected years has been taken from Rajib et. al., 2010. It is strongly recommended for future research that incorporation of rainfall events have to be supportive of recent climate change and other climate-logical effects. Upazila wise depth of phreatic surface should be discretized into micro-levels for better results. Other groundwater/hydrological modeling software similar to MIKE SHE can be used for the comparative result.

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ADDRESS FOR CORRESPONDENCE
Muhammad Abdullah
Associate Specialist
Water Resources Planning Division
Institute of Water Modelling
Dhaka, Bangladesh
E-mail: mkb@iwmbd.org; mabdullah03@gmail.com