# DELINEATING AQUIFER SYSTEM AND GROUNDWATER RESOURCES ASSESSMENT OF LOHAGARA MUNICIPALITY IN NARAIL DISTRICT, BANGLADESH

**Sajal Kumar Adhikary[1], Tanmay Chaki[2*], Mizanur Rahman[3] and Ashim Das Gupta[4]**

[1]*Assistant Professor, Department of Civil Engineering, Khulna University of Engineering &Technology, Khulna-9203, Bangladesh, e-mail: sajaladhikary@yahoo.com*
[2]*Junior Specialist, Water Resources Planning Division, Institute of Water Modelling (IWM), Dhaka, Bangladesh, e-mail: tanmayiwm@gmail.com*
[3] *Senior Groundwater Specialist, Water Resources Planning Division, Institute of Water Modelling (IWM), Dhaka, Bangladesh, e-mail: mrm@iwmbd.org*
[4]*Professor Emeritus, Water Engineering and Management, School of Engineering and Technology, Asian Institute of Technology (AIT), Bangkok, Thailand, e-mail: ashim.dasgupta@gmail.com*

## ABSTRACT

*The present study is an attempt to investigate existing hydrogeological framework for delineating the underlying aquifer system of Lohagara Municipality under Narail district of Bangladesht for existing groundwater resource assessment. For this purpose, hydrogeological, lithological, hydrological, meteorological and other relevant data have been collected. The IWM customized software "depth-storage" model has been used for producing hydrostratigraphic columner sections, which represent the nature and extent of aquifer system and determining specific yield of sediment formation. From striplogs distribution, it reveals that a productive aquifer exits below the alteration of fine sand aquifer, aquitard and aquiclude layers. The analysis also shows that two major (upper and lower) aquifers exist within the depth from 61m to 95m and from 198m to 216m or beneath throughout the study area. In addition, specific yield of the aquifers varies from 0.07 to 0.20 indicating that the aquifer consists of fine to medium sand. Moreover, a thick aquifer having thickness approximately 30m exists at Isangati and Kamthana Lohagara. However, there is an evidence of prominent aquifer at 200m to 235m throughout the study area containing varying thickness of more or less 36m below the aquiclude. The analysis of storage coefficient and hydrostratigraphic sections shows that the upper aquifer is semi-confined and lower aquifer is confined in nature. The study estimates that groundwater resources for shallow aquifer in Lohagara Pourashava at May 01, 2003 for 6m and 7m depths are 7.48 Mm³ and 10.00 Mm³, respectively, whereas at November 01, 2003, it is estimated as 11.29 Mm³ and 13.81 Mm³ for 6m and 7m depths, respectively. According to water balance studies, it can be concluded that the groundwater recharge is about 390mm for the deeper aquifer in 2003 and the corresponding annual aquifer storage volume is estimated as 7.25 Mm³, which mostly comes from the horizontal flow.*

**Keywords:** *Aquifer sustainability, Groundwater modelling, Groundwater resource, Hydrogeological framework, Lohagara Municipality, Narail district*

## 1. INTRODUCTION

Groundwater (GW) is usually considered as a source of potable water supply in the developing world because it is readily available in nature and naturally protected from the contamination. It is commonly used for irrigation and supplying water for meeting industrial and domestic requirements all over the world (Hoque et al., 2007). Like many other natural resources, GW resource is being exploited at an increasing rate all over the world and thus, GW exploitation is an important issue in the field of modern hydrogeology (Hoque et al., 2007; Balek, 1989). It is evident that the sustainability of existing GW supply structure and supplementary use of surface water depends on the reliable assessment of available GW resources for the area under consideration. For this purpose, an integrated distributed geohydrological model is often required. The model serves as a tool to simulate the recharge, flow and potential head of GW within the defined hydrogeological boundary (Kumar, 2011; Anderson and Woessner, 1992). The numerical model helps in estimating the present available resources and subsequently helps in predicting the potential effect on GW changes under different options of water allocation scenarios. Aquifers are generally very convenient sources of water because they are naturally occurring underground reservoirs, which usually have an enormous storage capacity. Since many aquifers contain high quality waters, their application for drinking water production and human consumption is obvious and they are used as a source of potable water source all over the world. As their storage capacity is quite large,

they can provide a continuous supply of water, even in dry seasonal periods when rainfall is very less and/or nearly absent and surface water is fast depleted.

GW is the principal source of drinking and irrigation water supplies in Bangladesh. Until recently, 97% of the population used to rely on GW for drinking purposes while more than 70% of the total irrigated area is served with GW sources (Hasan et al., 2007; BGS and DPHE, 2001). In Bangladesh, GW occurs in the extensive alluvial aquifers at shallow depths and meets most of the water demands for drinking and agricultural uses. More than 10 million shallow hand pumped wells, locally known as hand tube wells (HTWs), are used to provide drinking water to the almost entire rural areas and in urban areas of the country, where there is no piped water supply (Hasan et al., 2007). Development of the GW resource for irrigation and other uses is a vital component of the government's agricultural strategy to achieve food self sufficiency in Bangladesh (Wahid et al., 2007), which is also highlighted in the national water management plan of the country (WARPO, 2001). Thus, there is an urgent need to formulate a strategic plan for appropriate assessment and development of its groundwater resources (GWR) for an aquifer system under consideration. Balek (1989) and Karanth (1987) reported that the component of groundwater study generally contains two major sub-components such as hydrogeological studies and groundwater modelling and assessment. Hydrogeological study has been carried out to understand the regional and local hydrogeological setting, hydrostratigraphical framework, delineation of the underlying aquifer system, status of groundwater level (GWL) fluctuations and groundwater quality (GWQ). The GW model is developed for understanding GW flow dynamics and assessment of existing GWR at the present as well as future development scenarios. In the present study, the hydrogeological setting and available GWR in Lohagara Municipality under Narail district of Bangladesh have been studied. Although Lohagara Municipality is largely dependent on GWR for domestic and irrigation purposes, currently there is no management plan in place and large scale uncontrolled GW exploitation is taking place (IWM, 2011). Lack of appropriate understanding of the GW system in terms of resource utilization, is one of the major limitations to the effective management of this resource. Therefore, the present study has been undertaken to investigate the existing hydrogeological framework and underlying aquifer characteristics of Lohagara Municipality and to quantify the available GWR in relation to natural recharge and extraction options in Lohagara Municipality under Narail district of Bangladesh.

## 2. MATERIALS AND METHODS

### 2.1 The Study Area

The study area for the present study, Lohagara Municipality, is situated in Lohagara upazilla (sub-district) under Narail district of Bangladesh (Figure 1). The area is about 16.16 sq. km for the present case study. It is bounded by the Ganges River on the North, by the River Padma on the East and by Western border upazillas on the west. The southern boundary of the study area is defined as the boundaries of the upazillas of Sharsha, Jhikargacha, Jessore Sadar, Narail Sadar, Lohagara, Kashiani and Muksudpur.

#### 2.1.1 Climate

The study area experiences a typical tropical monsoon climate, with hot wet summers from May to September and cool dry winters. The rainy season occurs approximately from May to October and almost 90% of the total annual rainfall occurs during this period. Both temperature and relative humidity remain high in this season. Mean daily temperature is fairly constant between months of April and September and show little variation across the region, being of the order of $28^0$C. From October, temperature begins to decline, and mean daily temperature reaches to a minimum of about 19 to $19.5^0$C in January. In April, maximum daily temperature in the region can often exceed $35^0$C, while in January minimum daily values can be below $10^0$C. The rainfall distribution in the study area is not uniform. The lowest mean annual rainfall is about 1800mm, which is observed in northwest stretched strip and increases towards eastward and reaches about 2100mm and 2400mm in Narail and Bhanga, respectively.

#### 2.1.2 Topography and Soil Characteristics

The study area has an almost flat topography and characterised by a fairly plane land except the water bodies such as rivers, ponds, depressions and beels etc. Peat occurs extensively in the Gopalganj-Khulna Beels and locally in some Haors of the Sylhet basin. The soils contain organic matter at the surface or buried under a mineral soil layer below at a depth of up to 40cm. The organic material that forms the Histic horizon varies from dark brown, fibrous peat to semi-liquid black muck. They have been included as Histosols. Soils of this area are result of deposition of Ganges alluvium. Ganges alluvium is calcareous when deposited, but most basin clays and some older ridge soils have been decalcified and acidified in their upper layers; lime is found only in the

subsoil or substratum of such soils. Clay soils predominate in basins and on the middle parts of most ridges, with loamy soils (and occasionally sands) occurring mainly on ridge crests. The cut-off parts of the Meghna floodplain have a smooth relief and predominantly silty soils, which are deeply flooded by rainwater in the monsoon season. The unit covers most of the districts of Rajshahi, Natore, Pabna, all districts of Khulna division, and parts of Manikganj, Narayanganj, Munshiganj, Shariatpur, Madaripur, Barisal, Gopalganj. This physiographic unit is almost triangular in shape and bounded by the Ganges tidal floodplain on the south. On its southern end it traps the Gopalganj-Khulna Beels. pH of soil ranges from 7.0 to 8.5.
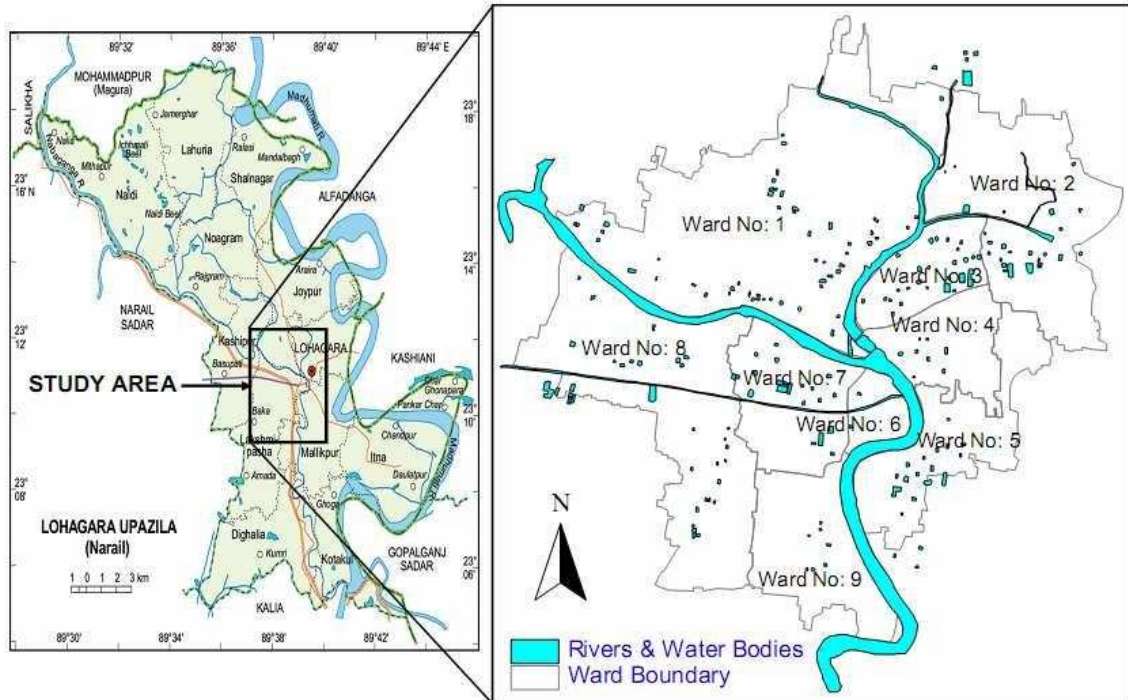


Figure 1: The study area (Lohagara Municipality) in Lohagara Upazilla of Narail district.

### 2.1.3 Geomorphological and Hydrogeological Setting

Geomorphologically, Lohagara upazilla belongs to Ganges River floodplain which comprises the active floodplain of the Ganges and the adjoining meander floodplain. The latter mainly comprises a smooth landscape of ridges, basins and old channels. The relief is locally irregular alongside the present and former river courses, especially in the west, comprising a rapidly alternating series of linear low ridges and depressions. The Ganges channel is constantly shifting within its active floodplain, eroding and depositing large areas of new char land each flood season, but it is less braided than that of the Brahmaputra-Jamuna. Seasonal flooding is mainly shallow in the west and north, with the highest ridge crests remaining above normal flood levels, but flood depths increase towards the east and the south. Flooding is mainly by accumulated rainwater and the rising GW table except on the active Ganges floodplain and close to distributary channels which cross the meander floodplain. Hydrogeological investigations had been undertaken to assess aquifer information of sedimentary formation. Past studies (BWDB, 1993) give an idea about the depth and thickness of the aquifer layers in the study area. Hydrogeological parameters of this area are governed by the litho-stratigraphic and prevailing tectonic activities, which is part of regional hydrogeological setting and tectonic features. The Quaternary sequence provides good aquifers, which have been extensively exploited in Bangladesh. The aquifers are generally thick multilayered with high transmissivity and storage coefficient. In addition, the aquifer systems can broadly be distinguished in the study area is recent sand forming both confined and semi-confined aquifer.

### 2.1.4 Existing Agricultural Practices

The major part of the study area is agricultural land. It has homestead, pond and beels also. The crop calendar reveals that T. Aman, HYV-Aman, HYV-Boro, and Potato are the main crops in the study area. Land use and vegetation are used in the model to calculate actual evapo-transpiration depending on the actual crops grown in the project area. Under the present study, spatial distribution of crops has been determined from a comprehensive field campaign. However, for the model input, these cropping types and cropping pattern have

further been simplified considering the major crops that require irrigation water. A crop database for each crop, which defines leaf area index, root depth and other properties of each crop are developed based on FAO publications (FAO, 1979) and used in the model. Paddy is grown almost everywhere through the year in each of the Karif-I (March-June), Karif-II (July-October) and Rabi (November-February). Pulse, oilseeds, vegetables, jute, wheat, sugar cane, potato, Mango, etc, are major non-paddy crops. With all availability of irrigation water, growers of the study area shifted towards growing more productive Boro-Fallow-HYV T. Aman.
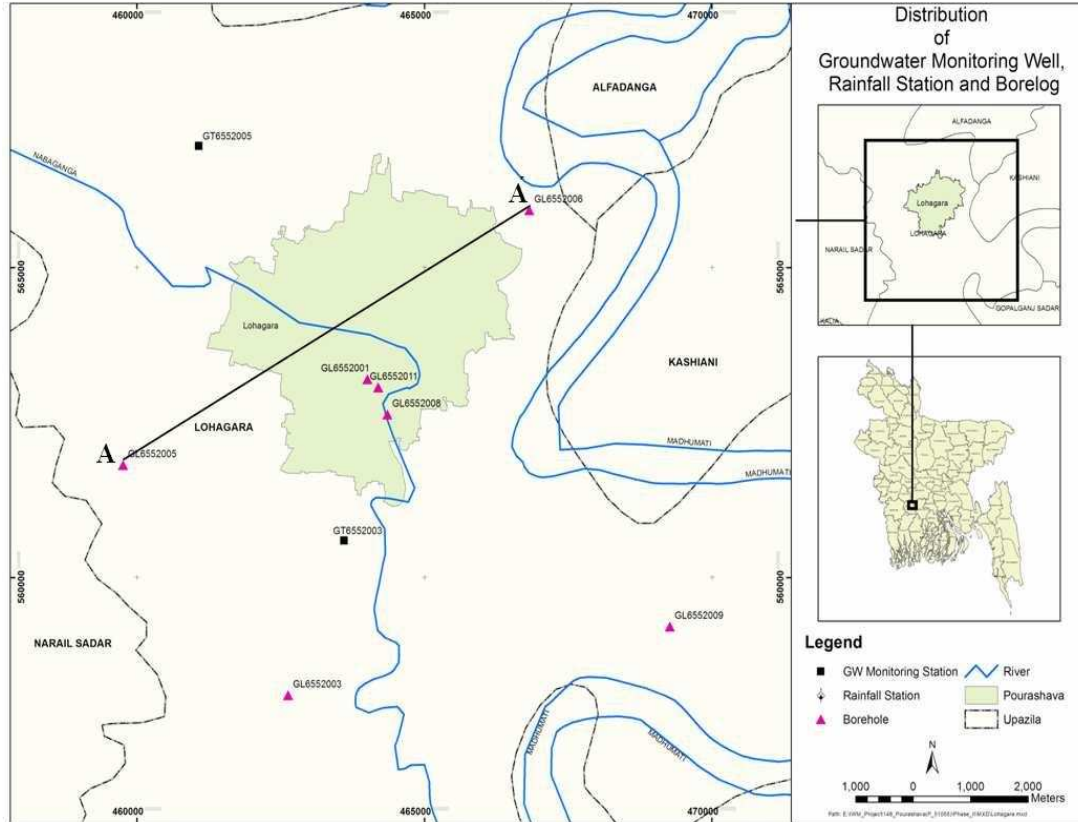


Figure 2: Borelog location and hydrostratigraphic section alignment A-A of Lohagara Pourashava area

## 2.2  Establishment of Hydrogeological Setting

### 2.2.1  Topography

A well-prepared Digital Elevation Model (DEM) is essential for visualizing the floodplain topography and for accurate modelling. A DEM of 300m resolution has been developed to define the topography of the study area and used in the model development. Topographic data for the study area has been extracted from the topographic database developed by FAP-19 based on irrigation planning maps available at IWM and also from the topographic survey conducted for Lohagara Municipality by IWM. Roads alignment and homestead coverage also have been collected from Roads and Highway Department (RHD) and LGED. Utilizing these data, a DEM of 300m resolution has been developed to define the topography of the study area. DEM shows that elevation of the area varies from 0.60 to 9.00 m PWD (meters above Public Works Datum of Bangladesh).
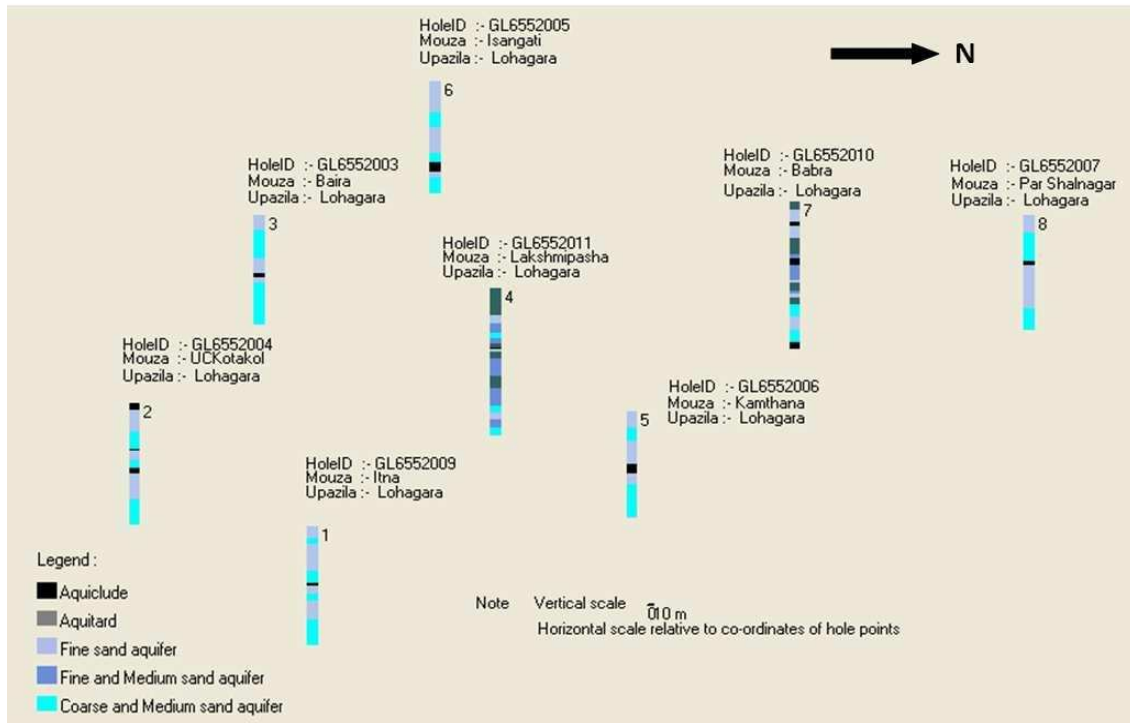
Figure 3: Striplogs and distribution of borelog location in and around Lohagara Municipality

### 2.2.2 Stratigraphic Analysis and Aquifer Delineation

Hydrogeological investigation for the Lohagara Municipality has been carried out to define the hydrostratigraphic layers. Eight lithological borelogs were collected from DPHE and BWDB for lithological characterization of the sub-surface sedimentary formation, producing hydrostratigraphic cross-sections and for preparing input data of GW model. Among the borelogs of the area, maximum depth of the available borelog is 305m. Sub-surface lithological characterization of the study area and configuration of the hydrostratigraphic units has been prepared by analyzing the individual lithological units and depth of different aquifers. IWM customized software "depth-storage" model has been used for producing the columnar sections and determining the specific yield of sediment formations. Spatial distributions of eight striplogs and their locations are projected all over the study area (Figure 2 and 3). Hydrostratigraphic columnar sections represent the nature and extent of aquifer in and around the municipality area. From striplogs distribution (Figure 3), it reveals that a productive aquifer exits below the alteration of fine sand aquifer, aquitard and aquiclude layers.
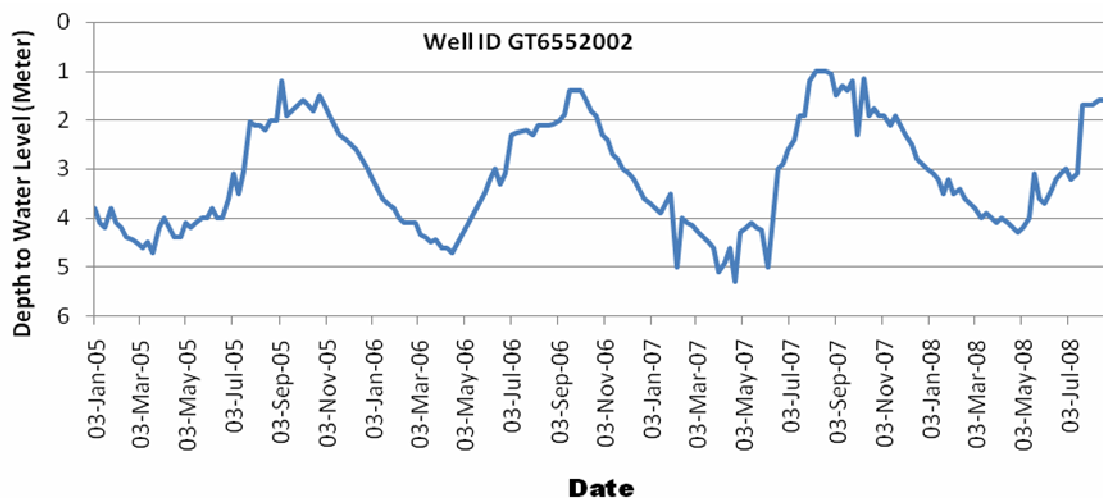


Figure 4: Hydrograph of Lohagara Municipality and its surrounding area

### 2.2.3 Groundwater Table Fluctuations

Groundwater level (GWL) variation over the period is the primary indicator, which reveals the aquifer response on recharge, abstraction, and aquifer discharge as gravity release. GW hydrograph has been developed from the analysis of the collected data for assessing annual GWL fluctuation. GWL data were collected from the Bangladesh Water Development Board (BWDB) and long term GWL hydrograph (Figure 4) is constructed. It reveals that GWL fluctuates between 2.5 m and 5 m with annual recharge–discharge conditions. From the hydrograph, it is also observed that there are fluctuations in the water level of the study area but having no declining trend.

## 2.3 Groundwater Modelling and Assessment

For hydrogeological study and GWR assessment, specific emphasis has been given for the municipality area and its vicinity at least the area of Lohagara upazilla. For the GW modelling, a larger study area is generally considered to avoid the boundary influences in model computations (Kumar, 2011; Anderson and Woessner, 1992). Based on these criteria, the developed GW model domain covers an area of about 9,582 sq. km. in this study, which includes Meherpur, Kushtia, Chuadanaga, Jhenaidah, Magura, Rajbari, Faridpur and Part of Gopalganj, Narail & Jessore districts of Bangladesh.

### 2.3.1 Data Acquisition and Analysis

For the purpose of groundwater source identification and resource assessment, large numbers of hydrogeological and meteorological data have been collected from BWDB, DPHE, BMD. From these secondary data and also from IWM's own data-bank, relevant data to the study area have been used in hydrogeological and GW modelling studies. For hydrogeological study of the Lohagara Municipality and its surrounding area, secondary data has been collected for analysis. Collected secondary data first assessed through necessary quality control procedure and subsequently used for further analysis. There is no aquifer test data is available from secondary source (BWDB, 1997) for the target location of the study area. As such, aquifer properties could not be determined for the Lohagara Municipality and its surrounding area. The model has been developed based on the secondary data collected from the field and also with the data available in IWM. To quantify the resources precisely, the primary data such as geophysical investigation to identify the geological formation and also pump test data to determine the aquifer properties is needed. The model has been calibrated based on secondary data which needs to be validated with the primary data collected in the field.

### 2.3.2 Model Setup and Simulation Specification

GW model setup involves a geometrical description and specification of physical characteristics of the hydrological system of the study area. In this study, the model has been developed using MIKE-SHE mathematical modelling software tool, developed by DHI Water and Environment Pty Ltd. (DHI, 1999). MIKE-SHE is a comprehensive mathematical modelling system that covers the entire land-based hydrological cycle, simulating surface flow, infiltration, flow through the unsaturated zone (UZ), evapotranspiration and GW flow; it is designed to address dynamic exchange of the water between these components. Major components of the model setup include evapotranspiration, unsaturated zone, saturated zone, overland flow and river systems. The default time step control and computational control parameters for overland flow (OL), UZ and saturated zone (SZ) have been used for entire simulation period. However, simulation periods of the calibration, validation and prediction models were different and user specified. The study area has been discretized into 1 km square grids in the horizontal plan. The model has 9,998 grid cells, where 420 grids are the boundary cells and the rest are computational cells. The grid cells are the basic units to provide all the spatial and temporal data as input and to obtain corresponding data as output. The coupling of surface water (SW) and GW model involves a number of specifications. The river reaches where the coupling will take place have been defined in the river model. In the present study, all the major rivers and khals within the study area have been coupled with GW system. Type of river-aquifer exchanges and the flooding conditions have also been defined. The flow exchange between the SZ component and the river component is mainly dependent on head difference between river and aquifer and properties of riverbed material such as leakage coefficient (Nobi and Das Gupta, 1997). For river-aquifer exchange, leakage coefficients along with the hydraulic conductivity of the SZ are taken into account for most of the river reaches.

### 2.3.3 Calibration and Validation

The purpose of model calibration is to achieve a satisfactory agreement with the measured data by adjusting the input parameters within acceptable range (Anderson and Woessner, 1992). As a coupled SW-GW model contains huge numbers of input data, the parameters to adjust during the calibration could be numerous. During the calibration, it is therefore important to adjust the parameters within the acceptable range determined from field measurements, and also to minimize the number of adjusted parameters. In this study, the initial input

parameters have been obtained from field measurements and other secondary sources. The model has been calibrated for the period of 1997 to 2003. During calibration overland leakage coefficient, vertical hydraulic conductivity, storage coefficient and river leakage coefficient have been adjusted. In the present model, calibration was done against observed GWL and a total of 62 observation wells were used for the calibration and validation purposes. It is customary that the calibrated model should be verified outside the calibration period (Anderson and Woessner, 1992). In order to increase the reliability of the model, it should be validated using another set of data. The period of validation was taken as 2004 to 2007.

### *2.3.4 Groundwater Resources Assessment*

The data analysis suggests that only two geological layers exist within 7m depth. Saturated thicknesses of these two layers have been calculated based on the following considerations:

- Case (a): if thickness of first layer exceeds 6m or 7m depth, entire saturated thickness lies only in first layer.
- Case (b): if thickness of first layer remains above GWL, entire saturated thickness lies only in second layer.
- Case (c): if case (a) & case (b) do not occur, then saturated thickness lies in both first and second layers. To find out the thickness of first layer within the saturated thickness, simply depth of water table is subtracted from the thickness of first layer. Then, part of first layer within the saturated thickness is subtracted from the entire saturated thickness to find out the thickness of second layer within the saturated thickness.

The availability of GWR within the 6m and 7m depths are estimated based on the available saturated thickness up to 6m and 7m depths multiplied by the specific yield ($S_Y$) of the area under consideration. The volume of the available GWR is calculated using the equation as = area x $\Delta h$ x $S_Y$, where $\Delta h$ is the saturated thickness within 6m and 7m depths. By using this procedure, model grid wise GW availability on 2003 has been estimated. Saturated thickness of first and second layers are multiplied by the corresponding specific yield ($S_Y$) values and summed up to get the depth of water availability of a grid. Availability in volumes is calculated by multiplying the depth of water availability by the area of the grid. Finally, the available GWR is estimated based on the number of grids that lie within the study area.

## 3. RESULTS AND DISCUSSIONS

### 3.1 Delineating Aquifer System

The developed columnar section and estimated specific yield of three borelogs are presented in Figure 5, which indicates that fine sand dominated all over the study area from the top most layers varying in depth from place to place. Two prominent aquifers (e.g. upper and lower) are present within the depth from 63m to 90m and from 198m to 216m or more throughout the study area. Specific yield of the aquifers varies from 0.07 to 0.20, which describes that the aquifer consists of fine to medium sand. Hydrostratigraphic section along A-A´ (Figure 2) represents the hydrostratigraphic layers distribution of the Lohagara Municipality and its surrounding area and is presented in Figure 6. It reveals that top most layer is aquitard. Below the aquitard layer, alteration of fine sand dominated and medium sand dominated aquifer is evidenced within different depths and separated from the lower productive aquifer by the clay layer. A thick aquifer having thickness approximately 30m exists at Isangati and Kamthana Lohagara. However, a prominent aquifer is evidenced at 200m to 235m throughout the study area at varying thickness having thickness more or less 36m below the aquiclude. From the analysis of storage coefficient and hydrostratigraphic section, it appears that the upper aquifer is semi-confined and lower aquifer is confined in nature. By analyzing the stratigraphy of the study area, major hydrostratigraphic units are delineated and average thickness of hydrostratigraphic unit are summarized in the Table 1.

Table 1: Summary of hydrostratigraphic units and their extents

| Hydrostratigraphic Unit | Depth (m) | | Average Thickness (m) |
|---|---|---|---|
| | from | to | |
| 1st Aquitard | 0 | 30 | 30 |
| 1st Fine Sand Aquifer | 31 | 60 | 30 |
| 1st Aquifer | 61 | 95 | 36 |
| 2nd Fine Sand Aquifer | 96 | 150 | 55 |
| 1st Aquiclude | 170 | 190 | 21 |
| 2nd Aquifer | 200 | 235 | 36 |

**Section of Borehole**
BorelogID : GL6552011
Village : Lakshmipasha
Mouza : Lakshmipasha
Upazila : Lohagara
District : Narail

| Fromdepth(m) | Todepth(m) | Specific Yield |
|---|---|---|
| 000.00 | 054.86 | 0.07 |
| 054.86 | 073.15 | 0.10 |
| 073.15 | 091.44 | 0.13 |
| 091.44 | 103.63 | 0.15 |
| 103.63 | 115.82 | 0.13 |
| 115.82 | 121.91 | 0.07 |
| 121.91 | 124.96 | 0.03 |
| 124.96 | 131.06 | 0.10 |
| 131.06 | 146.30 | 0.07 |
| 146.30 | 182.87 | 0.13 |
| 182.87 | 207.25 | 0.07 |
| 207.25 | 243.83 | 0.13 |
| 243.83 | 259.07 | 0.15 |
| 259.07 | 271.26 | 0.10 |
| 271.26 | 289.55 | 0.13 |
| 289.55 | 304.79 | 0.15 |

**Section of Borehole**
BorelogID : GL6552005
Village : Isangati
Mouza : Isangati
Upazila : Lohagara
District : Narail

| Fromdepth(m) | Todepth(m) | Specific Yield |
|---|---|---|
| 000.00 | 067.00 | 0.10 |
| 067.00 | 097.00 | 0.20 |
| 097.00 | 150.00 | 0.10 |
| 150.00 | 170.00 | 0.15 |
| 170.00 | 190.00 | 0.03 |
| 190.00 | 200.00 | 0.10 |
| 200.00 | 210.00 | 0.15 |
| 210.00 | 230.00 | 0.20 |
| 230.00 | 232.00 | 0.15 |

**Section of Borehole**
BorelogID : GL6552006
Village : Kamthana
Mouza : Kamthana
Upazila : Lohagara
District : Narail

| Fromdepth(m) | Todepth(m) | Specific Yield |
|---|---|---|
| 000.00 | 034.00 | 0.10 |
| 034.00 | 060.00 | 0.15 |
| 060.00 | 088.00 | 0.10 |
| 088.00 | 110.00 | 0.10 |
| 110.00 | 130.00 | 0.03 |
| 130.00 | 152.00 | 0.10 |
| 152.00 | 173.00 | 0.15 |
| 173.00 | 215.00 | 0.20 |
| 215.00 | 218.00 | 0.20 |
| 218.00 | 219.51 | 0.10 |

**Legend**

- Clay ,Concretion ,Decomposed material, etc
- Silt ,Very fine sand , Mica , etc
- Fine sand
- Medium sand , Coarse sand , Gravel , Pebble , etc

Figure 5: Three columnar sections and specific yield of borelog in and around the Lohagara Municipality

**Legend :**
- Aquiclude
- Aquitard
- Fine sand aquifer
- Fine and Medium sand aquifer
- Coarse and Medium sand aquifer

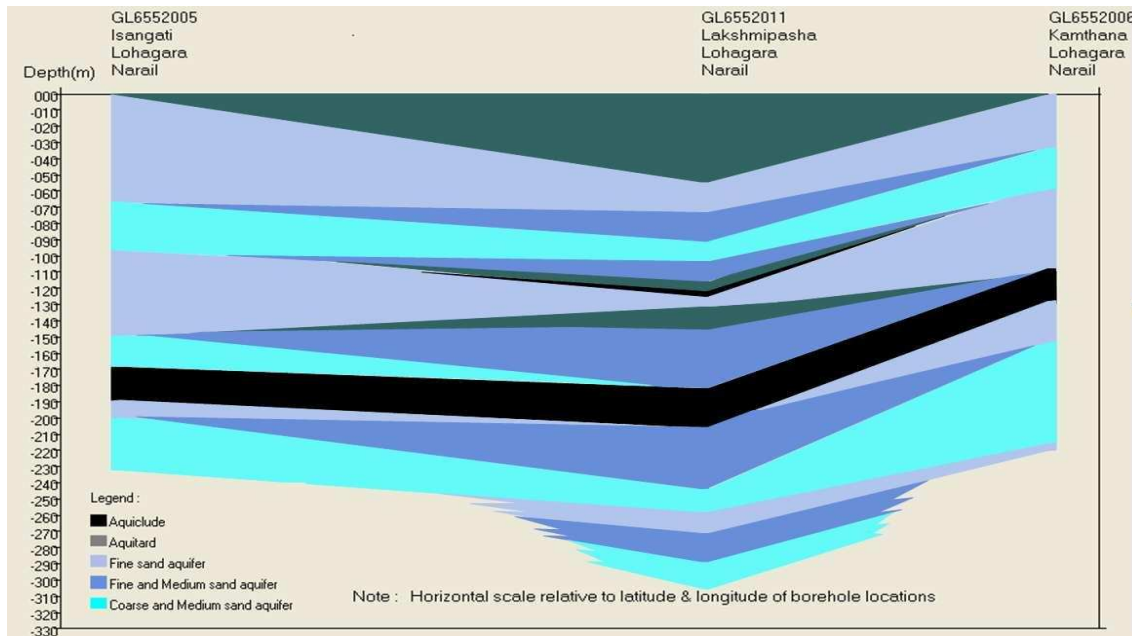Note : Horizontal scale relative to latitude & longitude of borehole locations

Figure 6: Hydrostratigraphic section along A-A′ of Lohagara Municipality

## 3.2 Calibration and Validation of GW Model

The developed GW model is calibrated and validated against the observed GWL from a total of 62 monitoring wells in and around the study area. The sample calibration and validation plots in the representative monitoring wells are presented in Figure 7 and Figure 8, respectively. Overall, validation results show similar trend of GWL fluctuations and good matching of GWL 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. Thus, the model can be used for prediction purpose. Hydrographs of simulated groundwater tables (GWT) were obtained at some pre-selected locations, which show that the maximum and minimum depth to GWT occurs at the end of April and end of October respectively. Hydrographs of observed GWT also supports the above findings. Based on these findings, spatial distribution maps of depth to phreatic

surface on May 01, 2003 and November 01, 2003 within Lohagara Municipality area (Figure 9). It is observed that during the peak time, GWT almost regains to its original positions.
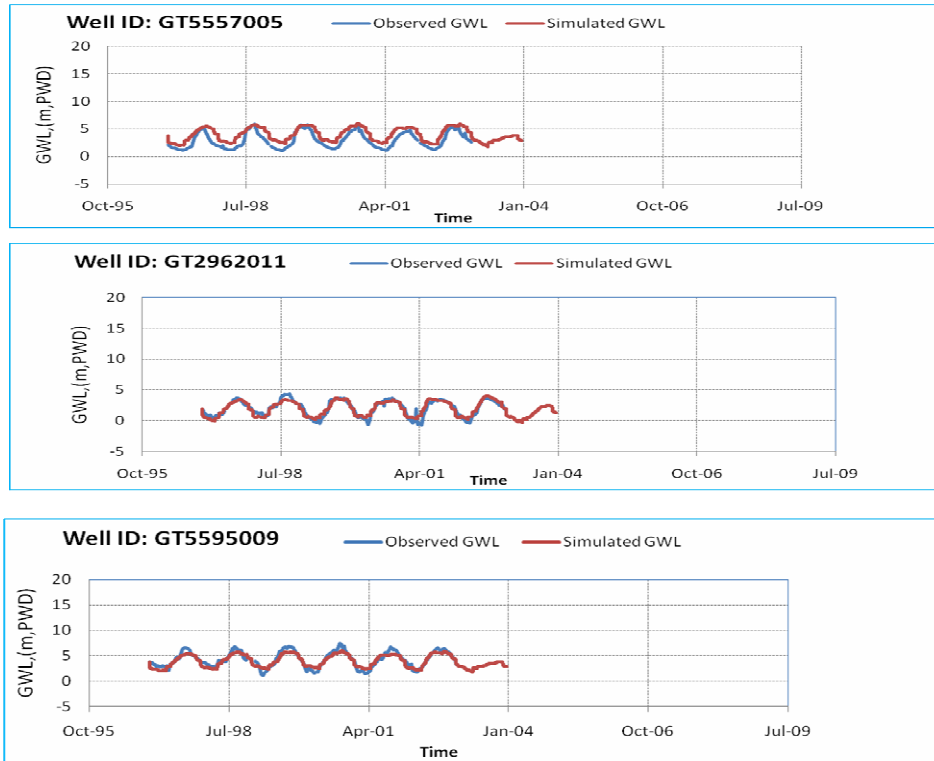


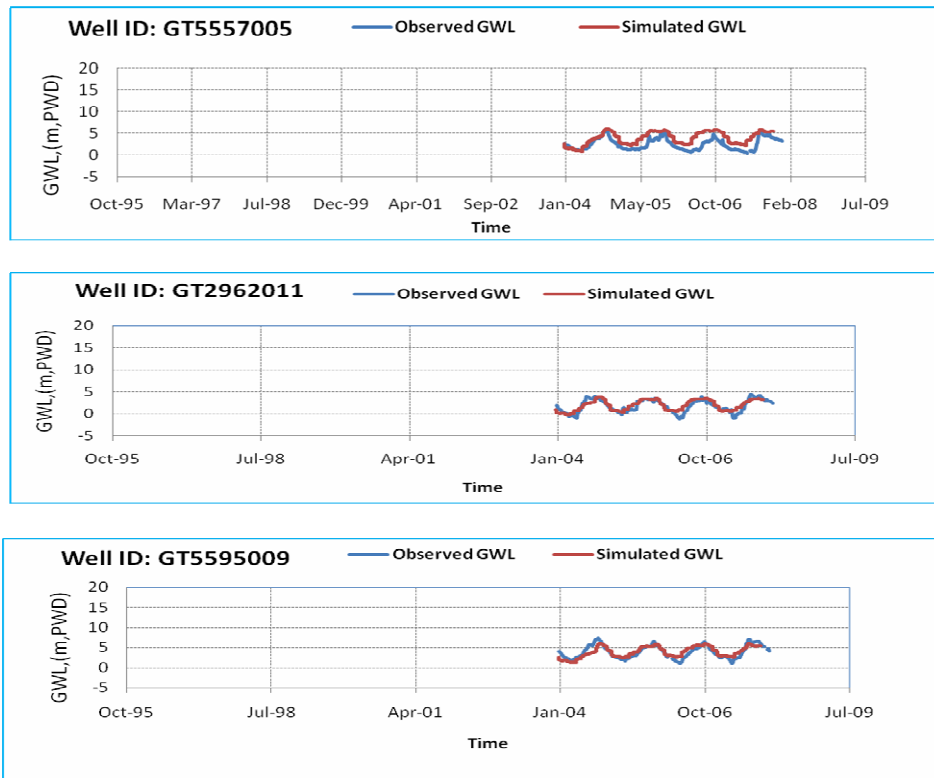Figure 7: Observed and simulated plots of GWL showing calibration of GW model



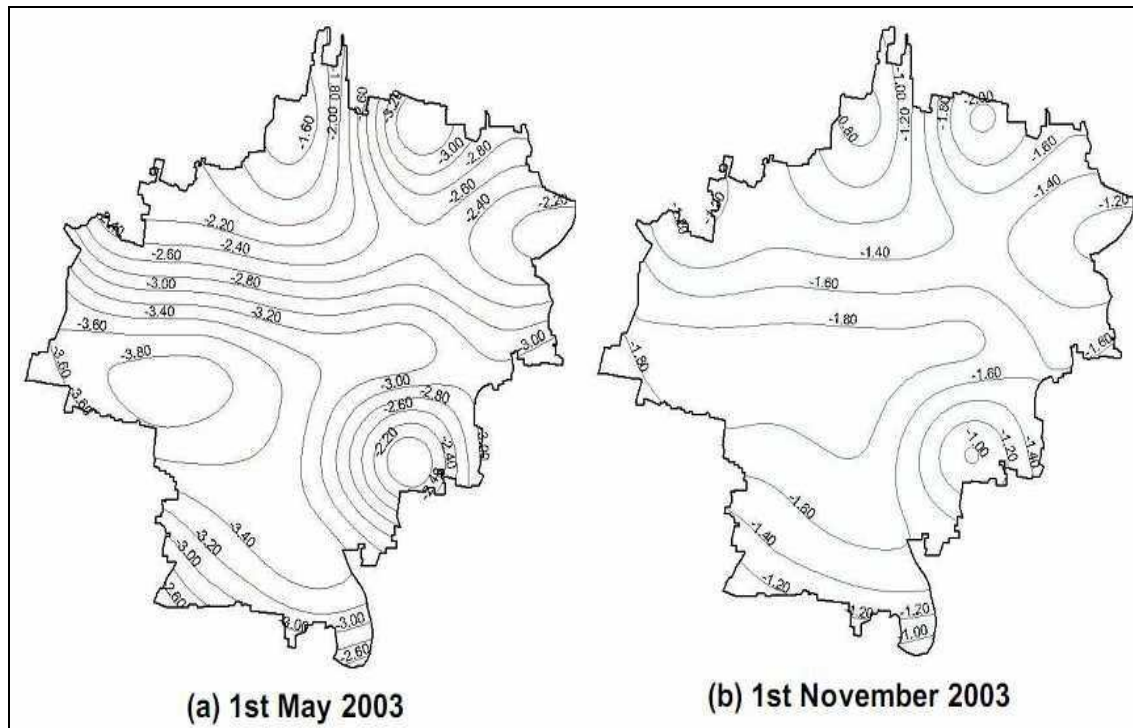Figure 8: Observed and simulated plots of GWL showing validation of GW model

Figure 9: Contour map of depth to phreatic surface for Lohagara Municipality for base condition

## 3.3  Assessment of Groundwater Resources

### 3.3.1 Groundwater Resources  in Shallow Aquifer

The base condition refers to the design year (year 2003 in this study) hydrological situations and other existing conditions that prevail in the practical field. The main purpose of simulating the base option is to understand the present state of the project under design year in terms of volume of water presently being used, whether it crosses the potential recharge of the aquifer, present state of GWT, crop coverage and scope for further irrigation expansions considering the water availability. Crop coverage under different crops at existing conditions has been considered in base option. Total amount of water required for irrigation is abstracted from the underlying aquifer of the study area. In the study area, GW is being used to meet the irrigation as well as domestic demands. Thus, reliable assessment of GWR is essential for effective water resources management and preservation of environment. Accordingly, GWR of the study area has been estimated based on the available resources before irrigation period.

The availability of GW in Lohagara Municipality of Narail district has been estimated on May 01, 2003 and November 01, 2003 for two different depths of 6m and 7m. It has been estimated that GWR in the shallow depth for Lohagara Municipality at the date of May 01, 2003 for 6m and 7m depths are 7.48 $Mm^3$ and 10.00 $Mm^3$, respectively. In addition, the GWR in the shallow aquifer at the date of November 01, 2003 are found as 11.29 $Mm^3$ for 6m depths and 13.81 $Mm^3$ for 7m depths.

### 3.3.2 Groundwater Resources in Deep Aquifer

The GWR in the deeper aquifer is calculated based on the water balance study for the individual layers, since most of the water supply for domestic uses mainly depends on the availability of water resources at the deeper aquifer, A trial and error method is applied to find out the maximum abstraction without any negative changes of storage for the deeper aquifer. The net recharge for the deeper aquifer is estimated based on the final water balance study and presented in Figure 10. However, this assessment is based on the secondary data by assuming that the aquifer properties and boundary data for the deeper aquifer is similar to the upper aquifer. The main limitation of this assessment is that this obtained result need to be verified with the availability of field pump test data, which is not available at hand right now. The net recharge for the deeper aquifer is calculated as net recharge = 0 mm (from upper layer) – 23 mm (for outflow) + 413 mm (for inflow) = 390 mm. This amount of recharge mostly comes from the horizontal flow as presented in Figure 10. For this amount of GW recharge, the corresponding annual aquifer storage volume is estimated as 7.25 $Mm^3$.
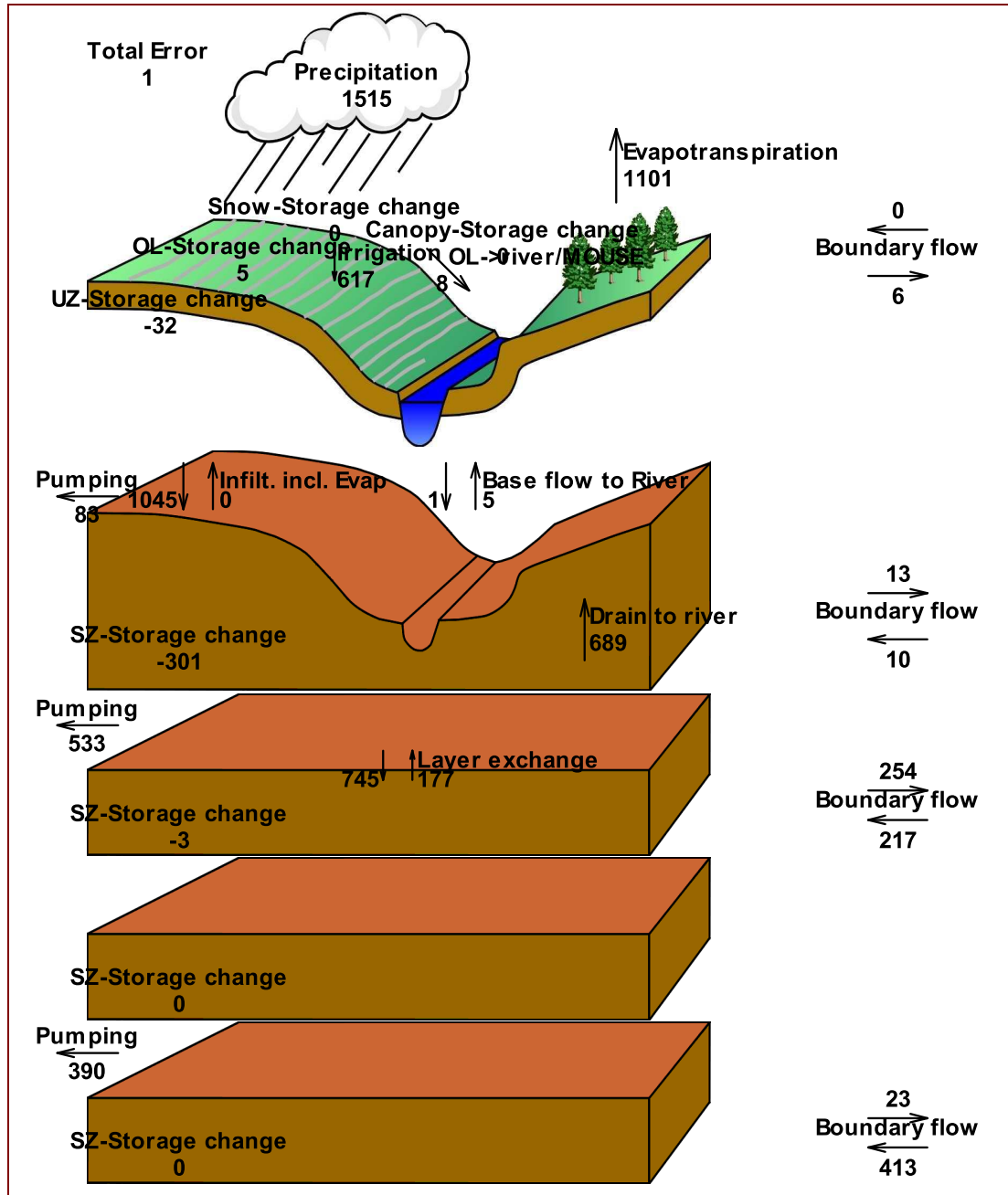
Figure 10: Water balance (in mm) for base condition on 2003 in Lohagara Municipality area

## 4. CONCLUSIONS AND RECOMMENDATIONS

From the developed hydrographs and water balance studies for different periods in the present study, the following conclusions can be drawn for the Lohagara Municipality of Narail district of Bangladesh:

- It can be concluded from the stratigraphic analysis that two major (upper and lower) aquifers are evidenced within the depth from 61m to 95m and from 198m to 216m or beneath throughout the study area. In addition, a thick aquifer having thickness approximately 30m exists at Isangati and Kamthana Lohagara. However, there exists a prominent aquifer at 200m to 235m throughout the study area containing varying thickness of more or less 36m below the aquiclude.
- The analysis of storage coefficient and hydrostratigraphic sections shows that the upper aquifer is semi-confined and lower aquifer is confined in nature. In addition, estimated specific yield of the aquifers indicates that the aquifer mainly consists of fine to medium sand.

- Maximum depth to GWT occurs at the end of April mainly due to irrigation abstraction and natural drainage which, however, recovers almost to its original position due to natural recharge at the end of September.
- The present study also estimates that GWR in the shallow aquifer for Lohagara Municipality at the date of May 01, 2003 for 6m and 7m depths are 7.48 $Mm^3$ and 10.00 $Mm^3$, respectively whereas the GWR at the date of November 01, 2003 found as 11.29 $Mm^3$ for 6m depths and 13.81 $Mm^3$ for 7m depths.
- From the water balance studies, it can be concluded that the GW recharge is about 390mm for the year 2003 for the deep aquifer, which comes mostly from the horizontal flow. For this amount of GW recharge, the corresponding aquifer storage volume is found to be 7.25 $Mm^3$ annually.

For the purpose of aquifer sustainability, following recommendations are suggested:
- Conjunctive use of SW and GW to meet the domestic, irrigation and industrial demand should be promoted and a conjunctive water allocation plan should be established.
- GWT and quality monitoring should be conducted regularly. The production well monitoring should also be done periodically to minimize the operation and maintenance cost of the project as well as to optimize the resource utilization.

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