# LONG-TERM TREND OF GROUNDWATER LEVELS IN NORTH-WEST REGION OF BANGLADESH

**MS THESIS**

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**BANGLADESH AGRICULTURAL UNIVERSITY**
**MYMENSINGH**

**JUNE 2018**

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**BY**

**MD. FERDOUS PARVEZ**

**Examination Roll No.: 16 IWM JD 07 M**
**Registration No.: 39159**
**Session: 2011—2012**

Submitted to the Department of Irrigation and Water Management
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**JUNE 2018**

# DEDICATED TO

MY BELOVED PARENTS

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***The Author***

**LONG-TERM TREND OF GROUNDWATER LEVELS IN NORTH-WEST REGION OF BANGLADESH**

## ABSTRACT

Groundwater is a renewable and dynamic natural resource in Bangladesh. The fluctuation of groundwater level/water table over the prevailing hydrologic cycle (one year) controls the dynamic nature of groundwater resources. The long-term trend of the annual highest and lowest depths of groundwater levels reflects sustainability issues of the resource in a region. To ensure sustainable use of groundwater, it is important to know the long-term trend of groundwater levels. So, this study determined and evaluated the long-term trend of groundwater levels in the north-west hydrological region of Bangladesh. The trends of the yearly highest and lowest depths of groundwater levels for 350 monitoring wells over the past 32 years (1985–2016) were determined by using MAKESENS trend analysis model. The dry season (March – April) lowest groundwater levels in 65.71% of the monitoring wells and the wet season (August – September) highest groundwater levels in 69.71% of the monitoring wells show significantly ($p<0.05$) decreasing/lowering trend over the study years. Majority (59.72%) of the wells had their dry season water levels below 6 m from the ground surface for 3 to 6 months in each year, keeping suction-mode pumps out of operation; 6 m is considered as the effective suction lift after subtracting 2 m dynamic drawdown during pumping from the actual suction lift of 8 m. The locations of a large number (15.14%) of monitoring wells, stationed in Bogra, Rajshahi, Naogaon, Joypurhat and Chapai Nawabgonj, reveal having severe water scarcity, especially for domestic supply, for whole year over the study period; the water levels in these wells remained below 6 m throughout the year. Therefore, extraction of groundwater for various usages needs to be kept in check, especially for sustainable domestic and irrigation water supply. Water saving technologies and judicious water usages need to be in practice to achieve water supply sustainability.

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# CHAPTER 1

# INTRODUCTION

# Chapter 1

# INTRODUCTION

## 1.1 Importance of groundwater

An excerpt from Razzaq (1980) – the character of Bangladesh and its people is dominated today, as it has always been dominated, by the river system and the water it carries or helps to carry – properly describes the importance of water in Bangladesh. Of course, the contribution of groundwater is to be added with it, as it supplies 79% of the water demand for irrigation, livestock, household and industrial usages (FAO, 2010). Bangladesh is in the downstream of Ganges-Brahmaputra-Meghna (GBM) catchment/basin. These rivers, accompanied by a monsoon, bring enough water for five months (June – October) of the year and act as an abundant source of surface water in the country for this period. But, many of the rivers flowing into Bangladesh from upstream countries carry less water in dry season (November – May). Consequently, in the dry season, surface water is inadequate in most parts of the country, especially in the drier north-west region, where there is very limited storage of surface water. The scarcity of surface water makes groundwater the inevitable source to supplement dry season water demand, as the country is underlain by a good aquifer system, including both deep and shallow groundwater resources (Alam *et al.*, 2003; Michael and Voss, 2009).

## 1.2 Dynamic and renewable nature of groundwater

The quantity of groundwater stored in an aquifer of a given size depends on recharge into and abstraction from the aquifers. Prior to widespread groundwater abstraction from the mid-1980s and onwards, water tables (upper level of the zone of saturation) in the largely unconfined aquifers in Bangladesh were generally shallow with a weak seasonal fluctuating trend. After the monsoon period, water tables were near or, in some places, at the surface. At the end of the dry season (April–May), the water tables would have receded, mainly, due to evapotranspiration and inter-basin flow out of the aquifer. Much of the potential recharge from rainfall and flooding in the monsoon period was rejected due to limited storage capacity of the aquifers. But, with increasing utilization of groundwater, water tables fall during the dry season, when pumping for various usages and discharge to the rivers (which are at low levels in the dry season) depletes the aquifers. The deepest groundwater conditions are found from April to mid-May, whereas the shallowest water tables are found in November (CSIRO, WARPO, BWDB, IWM, BIDS & CEGIS, 2014).Thus, pumping of groundwater from the aquifers in dry season increases the storage space available to accommodate recharge during monsoon (Shamsudduha *et al.*, 2011). More than 90% of the annual recharge to the unconfined aquifers occurs during the monsoon, between May and September (MPO, 1987; WARPO, 2000). During this season, water table rises across Bangladesh since high rainfall and an associated inundation recharge the aquifers. Thus, groundwater in Bangladeshis a renewable and dynamic natural resource.

## 1.3 Present state of groundwater level in north-west Bangladesh

The use of shallow aquifers for irrigation in Barind area of north-west Bangladesh is unsustainable (Shamsudduha *et al.*, 2009; Shahid and Hazarika, 2010; Dey *et al.,* 2013; Kirby *et al.*, 2013). The area is now facing water scarcity problems in both agriculture and secured livelihood (Alice, 2010). The topography and climatic condition of the north-west Bangladesh is accountable for this situation. Groundwater recharge in Bangladesh is mainly occurred by monsoon rainfall and flooding in addition to the contribution from irrigated crop fields. Due to high elevation of the north-west Bangladesh, most part of it is in flood-free zone. So, the main source of groundwater recharge in this area is rainfall, which is also the lowest in this part of the country. Consequently, the area has become considerably drought prone. Moreover, a thick sticky clay surface (6.10–21.34 m) of Barind Tract acts as aquitard and hinders groundwater recharge by increasing surface runoff. As a result, groundwater level in the north-west Bangladesh is successively falling over the years with increasing withdrawal of water for irrigation (Rahman and Mahbub, 2012). Changes in a spatial-time series (1990–2010) of pre-monsoon and post-monsoon groundwater depths in the north-west region suggest that if the current level of groundwater use continues, resulting groundwater level will decline continuously and may pose a long-term threat to the sustainability of irrigated agriculture (Ahmad *et al.,* 2014).

## 1.4 Importance of trend of historical groundwater level

Trend is a general direction in which something is developing or changing, and analysis of trend reveals the pattern of change. According to Kivikunnas (1998), trends have meaning to experts and its field of application is in process monitoring, diagnosis and control. Trend of groundwater level over considerable time reveals the condition of groundwater resources in terms of sustainability. Trend analysis of both meteorological and hydrological data is often needed to explain the dynamic behavior of the groundwater level (Hasanuzzaman *et al.,* 2017). These investigators employed both parametric (linear regression) and non-parametric approaches to find the state of groundwater resource in Bogra district of north-west Bangladesh. In determining the trend of time-series data, MAKESENS statistics is a well-recognized and adopted method. This statistics is based on non-parametric Mann-Kendall test for identifying the trend and non-parametric Sen's method for quantifying the trend. Among the advantages of this trend statistics, the most prominent one is that, it is applicable for both monotonic and non-monotonic trends.

## 1.5 Critical depth (suction limit) of groundwater

Groundwater is extracted in Bangladesh, mostly, by shallow tubewell (STW) and deep tubewell (DTW). The number of shallow tubewells (STW) is much more than deep tubewell (DTW); there are 1.77 million irrigation pumps in Bangladesh of which STW numbers 1.56 million (SPIS, 2015; BADC, 2016). In addition to irrigation, most STWs also supply water for domestic usage. As STW uses atmospheric pressure to lift water, the depth from where this tubewell can abstract water is limited. STWs cannot extract water from below 8.0 m, but practically they cannot extract water from below 6.0 m when drawdown ($\approx$ 2.0 m) created during pumping is taken into account. This depth is known as suction limit (we call this as critical depth in relation to STW operation). However, other low-capacity suction-mode pumps, such as Hand Tube Well (HTW), do not create considerable drawdown during pumping and they can operate up to 8.0 m suction. If groundwater level resides below the suction limit, it makes the suction-mode pumps inoperative, thus leading to water supply scarcity, especially for domestic water supply.

## 1.6 Objectives of the study

The goal of the study is to know the long-term trend of the yearly maximum (highest) and minimum (lowest) groundwater levels of north-west region of Bangladesh over the past 32 years (1985–2016). The specific objectives of the study are:

(a) to identify and quantify the trends of groundwater levels over the years 1985 to 2016,

(b) to classify the trends of groundwater levels into groups based on direction of change, and

(c) to identify locations where groundwater level drops below critical suction limit of suction-mode pumps.

# CHAPTER 2

# REVIEW OF LITERTURE

# Chapter 2

# REVIEW OF LITERATURE

Groundwater abstraction has remarkably increased since the 1980s for various usages, including irrigation and drinking water supply in Bangladesh. Due to the increasing use of water with time and the limitations of the other water sources like lack of availability, adequate quantity and desired quality, the consumption of groundwater is increasing day by day. Thus, the abstraction of groundwater has also increased with a consequent possibility of mining of groundwater level. This reality compels researchers doing research on the topic related to sustainable groundwater use. Several researchers have done research on this topic and their findings pertinent to the present study are presented in this chapter.

## 2.1 Importance of groundwater

The importance of water in general and groundwater in particular can be easily realized by the water consumption data put together in this section. Between the two major sources of water, surface water is mainly used for irrigation. The estimated yearly surface water use is 6.2 $km^3$ in the north-west region, while the north central, north-east and south-east regions each consumes a little over 1 $km^3$, and the south-west region consumes about 2.5 $km^3$ (CSIRO, WARPO, BWDB, IWM, BIDS & CEGIS, 2014). Groundwater is used intensively in Bangladesh to meet urban, industrial and irrigation requirements; the largest use of groundwater is for irrigation. In recent decades, the development of agriculture in the dry season has relied, particularly, on the use of groundwater from shallow tube wells. In the north-west region, about 95% of irrigation water comes from groundwater, extracted mainly with STWs, and the proportion from groundwater has increased greatly in the recent years.

Groundwater use for dry season irrigation is one of the major factors in achieving rice grain food self-sufficiency. The north-west region has the most intensive use of groundwater; over 97% of the irrigated area (during 2009-2010) was covered by groundwater followed by the central (84%), south-west (76%), north-east (45%) and south-east (45%) regions. The volumes of groundwater use for irrigation was estimated from the regional water balances to be about 11.0, 2.5, 0.6, 3.6 and 1.0 $km^3$ in the north-west, north-central, north-east, south-west and south-east regions, respectively (CSIRO, WARPO, BWDB, IWM, BIDS & CEGIS, 2014; Kirby *et al*., 2014), or about 25 $km^3$ in total. Mainuddin *et al*. (2014) estimated the total irrigation water demand of Bangladesh as 33 $km^3$. The regional water balances give estimates of average (average from 1986 to 2010; eastern hills excluded) irrigation water use of 25 $km^3$, of which 19 $km^3$ (80%) is supplied by groundwater and 6 $km^3$ (20%) by surface water. The proportion supplied by groundwater varies from nearly 100% in the north-west region to about 40% in the south-west region (CSIRO, WARPO, BWDB, IWM, BIDS & CEGIS, 2014; Kirby *et al*., 2013). The Food and Agriculture Organization (FAO) of the United Nations estimated that the total water withdrawal in Bangladesh in 2008 was 36 $km^3$, of which 31.5 $km^3$ was for irrigation, 3.6 $km^3$ for domestic water use and 0.8 $km^3$ for industry; 79% was sourced from groundwater and 21% from surface water (FAO, 2010).

## 2.2 Recharge-depletion characteristics of aquifers

Groundwater aquifer maintains its dynamism by recharging in wet season and emptying itself in dry season. Abstraction by pumping with tubewell is the major component of groundwater discharge from the aquifers. If there is no pumping from the aquifer, only a part of water loss occurs through evapotranspiration, inter-basin movement and affluent-contributing river flow in dry season. Then, a part of the potential recharge from rainfall and flooding in the monsoon period would be rejected due to aquifer's limited storage capacity. In reality, groundwater abstraction in dry season increases the storage capacity available to accommodate recharge during the monsoon period; this is an induced recharge. Shamsudduha *et al*. (2011) used an example of monitoring well GT1918006 located in Burichang upazila of Comilla district in eastern Bangladesh to demonstrate induced recharge from groundwater pumping. In that region, 82% cultivable lands are under groundwater-fed irrigation schemes. As illustrated in Fig.2.1, prior to large-scale abstraction, much of the potential recharge was rejected due to 'aquifer full' condition. However, groundwater abstraction has augmented the storage capacity, leading to a longer recharge opportunity period to the aquifer and increased recharge volumes.

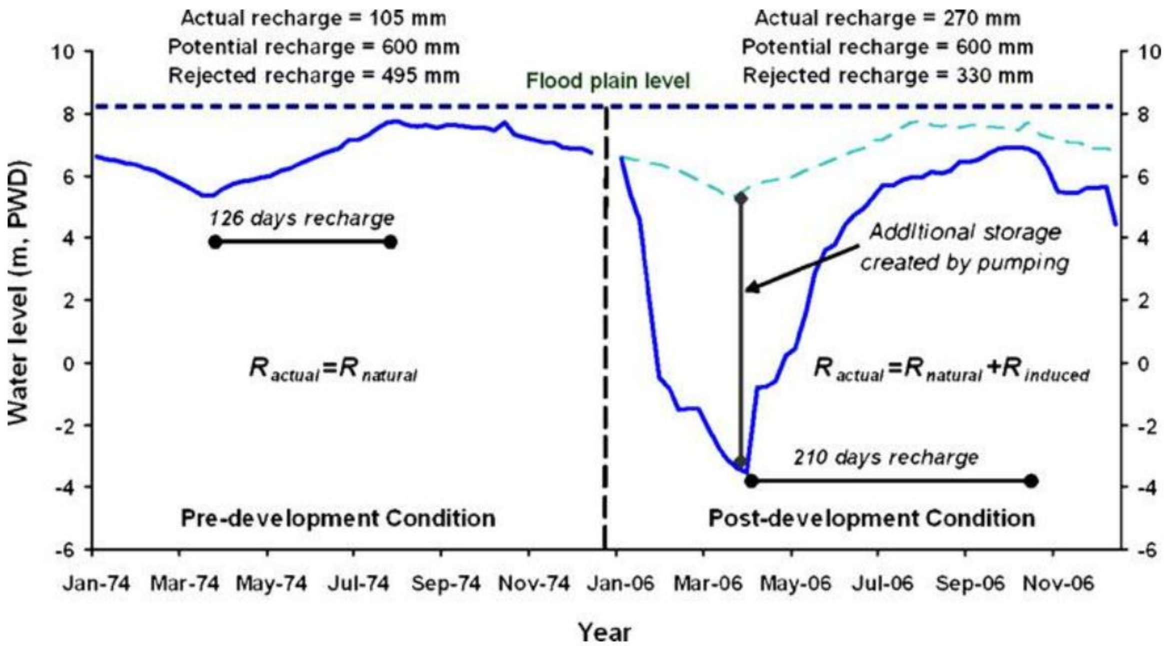



Figure 2.1: Groundwater levels during pre-development (1974) and post-development conditions in monitoring well GT1918006 (previous ID CM004) located in Burichang upazila of Comilla district (PWD: Public Works Datum) (after Shamsudduha *et al*., 2011)

## 2.3 Present state of groundwater in the study area

Dey *et al*. (2013), by analyzing groundwater level data of 30 years (1981–2011) in five districts (Rajshahi, Pabna, Bogra, Dinajpur and Rangpur) of north-west region, found a declining trend of groundwater table. They identified Rajshahi, Pabna, Bogra, Dinajpur and Rangpur as severely depleted areas, with depletion of groundwater table between 2.3 m and 11.5 m. Shahid and Hazarika (2010) worked on groundwater drought in north-west region by analyzing groundwater hydrographs and rainfall time-series. They concluded that ever-increasing groundwater extraction for irrigation in the dry season and recurrent droughts are the causes of declining groundwater level in the region. Hodgson *et al*. (2014) studied water table trends of 709 monitoring wells out of 1256 all around Bangladesh that monitored weekly groundwater level over the period 1985–2010. Based on both the maximum and minimum water-level trends, they categorized the wells into four types as:

- **Type 1 wells**: both the minimum and maximum groundwater levels are declining with little recovery,
- **Type 2 wells**: both the minimum and maximum water levels are declining with some recovery,
- **Type 3 wells**: dry season maximum water level is declining but monsoon minimum water level remains steady, and
- **Type 4 wells**: both the dry season maximum and monsoon minimum water levels are steady.

Hodgson *et al*. (2014) reported most prevalent groundwater irrigation in the north-west hydrographic region. There are two distinct sub-regions where trends of groundwater level are regionally characteristic. In the northern sub-region, which is north of Joypurhat and Bogra, water tables remain relatively stable with large number of type 3 and type 4 wells; there are only a few type 2 wells and no type 1 well in this sub-region. In the southern sub-region, trend types 1 and 2 dominate most wells. The hydrogeological setting of the sub-regions appears to play some role in the differences in water-level trend types. The northern sub-region is more elevated and dominated by alluvial fan deposits with thin upper silt and clay layers. In contrast, the southern sub-region includes the Barind Tract and areas of thicker clay layers associated with type 1 and type 2 water-level trends. There is some spatial correlation between thickness of the upper silt and clay layers and declining water tables. Wells in the northern sub-region are relatively stable in comparison to those in the southern sub-region. Water tables are generally closer to the surface in the north, with few wells exceeding the 8-m critical depth for suction mode pumps. In the south, the declining water table reflects the topographic and hydrogeological setting with the Barind Tract having generally deeper groundwater levels, leading to many more wells exceeding 8 m depth of their water levels. Naogaon, Joypurhat, Nawabganj and Rajshahi districts have a high proportion of monitoring wells with strongly declining trends of water level, indicating that groundwater resources in this region are at risk if abstraction continues to grow further and preventive measures are not implemented. Shahid and Hazarika (2010) investigated groundwater scarcity and drought in the Barind area by using monthly groundwater level fluctuation data of 85 sites. Their study reveals that groundwater scarcity in 42% area is an every-year phenomenon in that region.

## 2.4 Methods of trend analysis

Trend analysis of time-series of groundwater table data reveals the pattern of change of groundwater table over the time period; it reveals both direction and magnitude of the changes. Several methods are available for trend analysis, of which the commonly used ones are highlighted below.

i. **Regression-analysis-based methods:** Linear regression, when applied to time-series data, fits the data to a model of form $y = mx + c$, where $m$ represents the rate of change and $c$ represents the $y$-intercept of the line.
ii. **Triangular episodic presentation and qualitative scaling:** Cheung (1992) developed a formal framework for extraction and representation of process trends. They formulated a language called 'triangular episodic representation' for the extraction of trend.

iii. **Dynamic time-warping:** Dynamic time-warping uses dynamic programming to align a time-series under study and a given template so that some measure of total distance is minimized (Rainer and Juang, 1993).

iv. **Wavelets:** Recently, wavelet-based signal processing methods have gained popularity, for example in de-noising, data compression and feature extraction. Wavelet analysis preserves both the time-domain and frequency-domain information of the signal.

v. **Qualitative temporal shape analysis:** Konstantinov and Yoshida (1992) have proposed a generic methodology for qualitative analysis of temporal shapes of process variables. Their procedure consists of three phases: analytical approximation of the process variable, its transformation into symbolic form based on signs of the first and second derivatives of an analytical approximation function, and calculation of degree of certainty.

vi. **Mann-Kendall-Sens (MAKESENS) analysis:** MAKESENS statistics is based on non-parametric Mann-Kendall test for determining the trend and non-parametric Sen's method for determining the magnitude of the trend (Salmi *et al*., 2002).

## 2.5 Critical water level depth for suction-mode pumps

All suction-mode pumps, including shallow tubewell, STW, utilize atmospheric pressure to lift water. Standard atmospheric pressure is 1.03 $kg/cm^2$, which is equivalent to 8 m of water column/head. This implies that the maximum limit for suction-mode tubewells for abstraction of groundwater is 8 m. This is the theoretical critical depth or suction limit. But, due to friction losses in the piping system, the limit is less than 8 m. In addition to the friction loss, a drawdown of 1–2 m occurs depending on the aquifer properties while pumping. Thus, practically 6 m is taken as the standard critical depth (maximum suction lift) for pumping groundwater by STW and other suction-mode pumps.

## 2.6 Justification of the study

In addition to the falling groundwater levels, there are evidences that the recharge to the aquifers in many areas is less than the volume of groundwater withdrawn for irrigation. Several studies show evidence of over-extraction of groundwater, thus revealing the threat to groundwater sustainability. For example, Adham *et al*. (2010) showed that the recharge potential of a small area within Barindarea is quite low, and actual recharge (roughly equivalent to 100 mm per year) is insufficient to replenish the water withdrawn for irrigation. Rahman and Roehrig (2006) showed that recharge is insufficient in some parts of the area, but were just sufficient in other parts prior to 2006, generally in the range of 350–500 mm per year. Shamsudduha *et al*. (2009) and Kirby *et al*. (2013) concluded that the use of shallow aquifers for irrigation in the Barind area is unsustainable. The groundwater use in the Barind area exceeds recharge, the water tables are falling, and the use is unsustainable (Rahman *et al*., 2013; Hossain and Bahauddin, 2013). But, the situation is less clear elsewhere. Groundwater use may be sustainable in some parts of the country in the sense of not leading to a continuing and ultimately catastrophic decrease. However, even where use is sustainable in that sense, there may be problems with shallow drinking water wells or shallow tubewells providing irrigation running dry in late dry season when the groundwater table is at its greatest depth (Shahid and Hazarika, 2010). Many monitoring wells show water levels that fall below 8 m during March, April and May (Hodgson*et al*., 2014), thus hindering sustainability, especially in domestic water supply (CSIRO, WARPO, BWDB, IWM, BIDS & CEGIS, 2014). To ensure sustainability, the pre-requisite is to know the condition of the groundwater resources. This brings the necessity of trend analysis, which provides good pictures of the condition of the resources. The water scarcity identification based on critical depth can identify the places with water scarcity for irrigation and domestic needs. This can reveal the actual problems created by groundwater scarcity that local people face. Also, this can guide for necessary social studies.

Dey *et al.* (2013) did trend analysis of groundwater level as a part of their study to check sustainability of groundwater in Barind area and selected only five districts (Rajshahi, Dinajpur, Pabna, Rangpur and Bogra) out of sixteen in north-west region for this. Hodgson *et al.* (2014) did trend analysis of groundwater levels of 709 wells all around Bangladesh, but that study did not evaluate the significance level of the observed trends. Also, trend analysis needs to be done and kept up-to-date by using the latest data sets. Again, trends are so far determined by using empirical formulae/methods. So, determining trend of the same data set by using different methods opens ways for verification of those methods and observed trends. Therefore, the present study is intended to determine the trend of groundwater level over 1985–2016 of the entire north-west part of Bangladesh.

# CHAPTER 3

# METHODOLOGY

## Chapter 3

# METHODOLOGY

### 3.1 Study area

Bangladesh has eight hydrological regions. These regions, as shown in Fig.3.1, are: North West (NW), North Central (NC), North East (NE), South East (SE), South Central (SC), South West (SW), Eastern Hills (EH), and the active floodplains and charlands of the main rivers and estuaries (WARPO, 2000). The study area was the NW hydrological region.

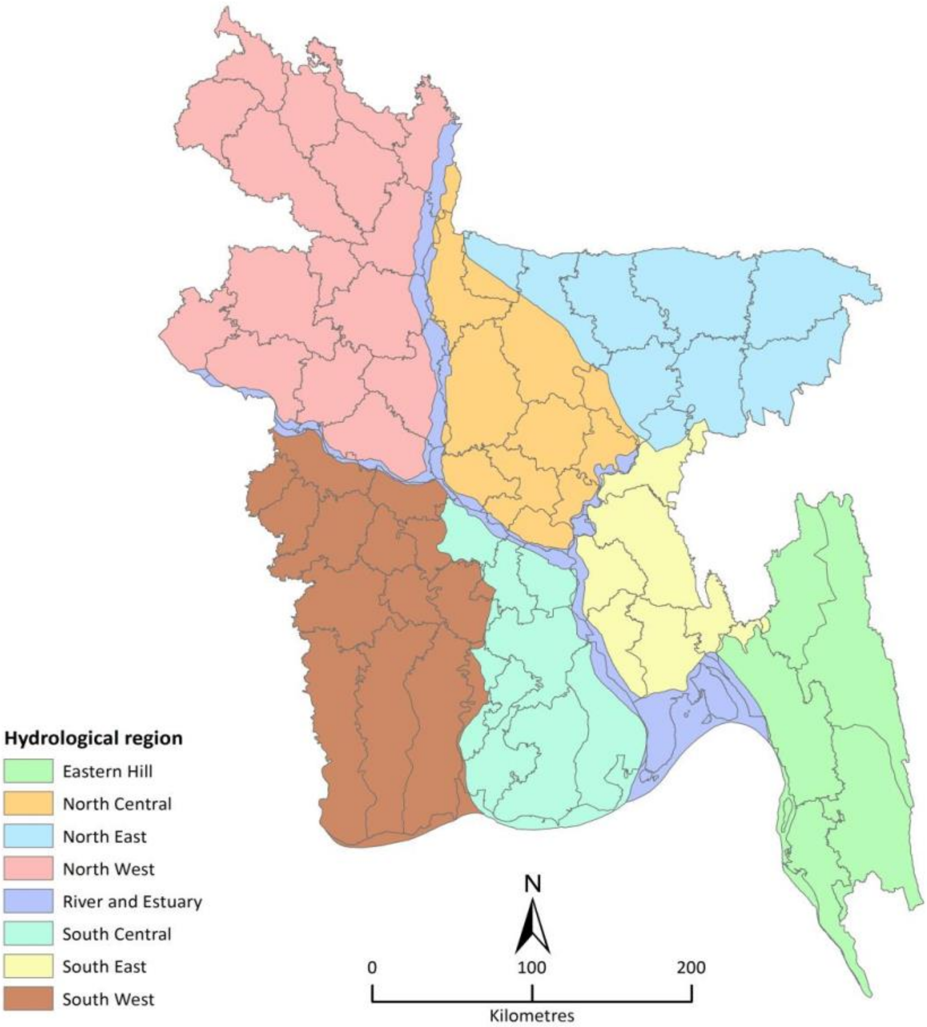



Figure 3.1: Hydrological regions of Bangladesh

The study area covers two administrative divisions: Rajshahi and Rangpur. Rajshahi division (Fig.3.2) has an area of 18,174.4 square kilometers (7,017.2 sq. mile) (Wikipedia) and a population of 18,484,858 (Population Census, 2011). It consists of 8 districts, which comprise 70 upazillas (the next lower administrative tier) and 1,092 Unions (the lowest administrative tier). Rangpur division (Fig.3.3) also consists of 8 districts. There are 58 upazillas under these districts. Rangpur is the northern-most division of Bangladesh and has a population of 15,665,000 (Population Census, 2011).


Figure 3.2: Map of Rajshahi division showing its 8 districts

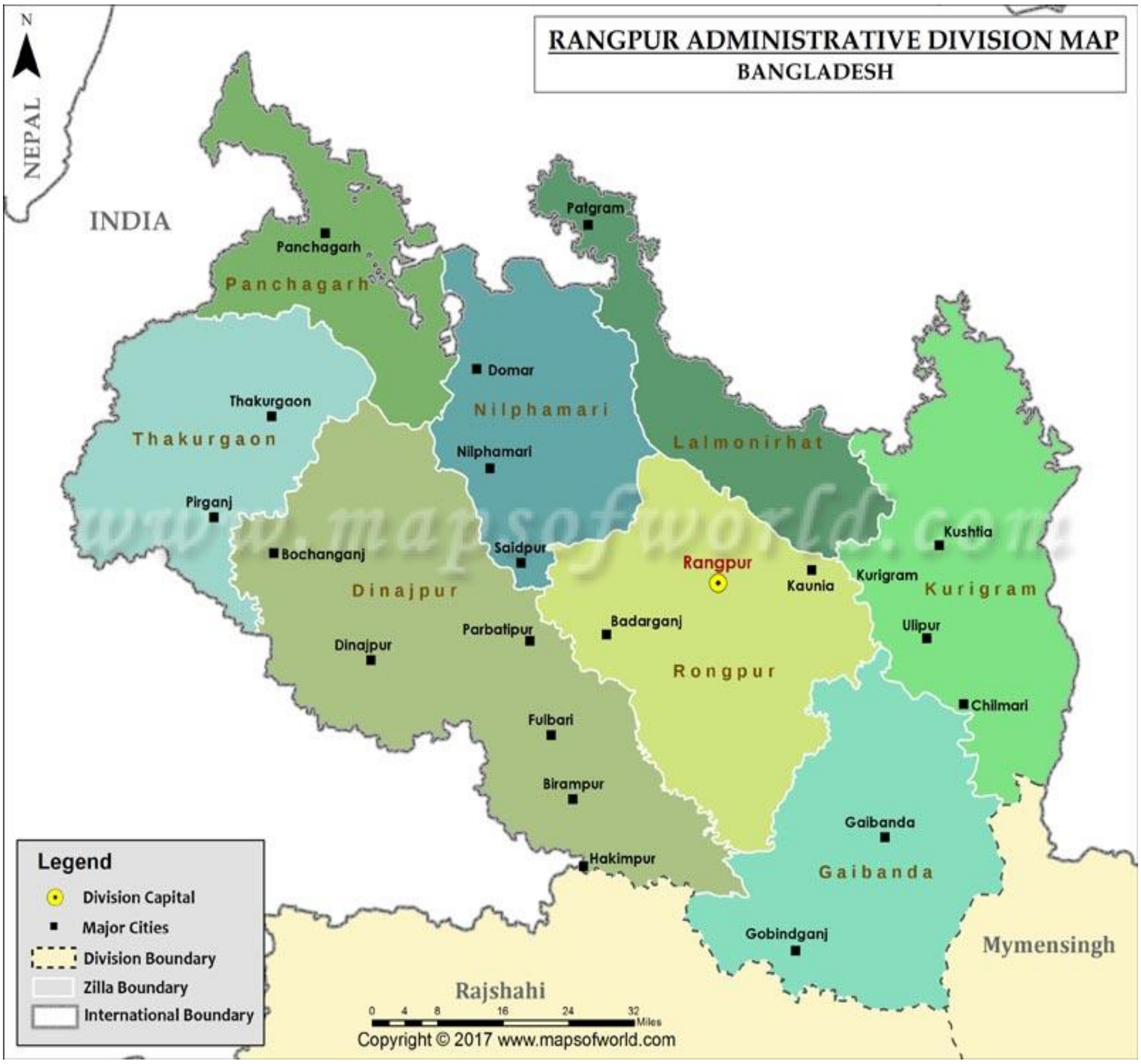



Figure 3.3: Map of Rangpur division showing its 8 districts

The study area includes the northern zone of north region, north-western zone and western zone of the seven climatic sub-regions of Bangladesh (Fig.3.4). These three zones are identical in climatic parameters except the humidity. The north-western zone is drier and western zone is the driest. The region has maximum temperature above 32$^{o}$C in summer and mean minimum below 10$^{o}$C in winter. The annual average rainfall is 1927 mm in the NW hydrological region and potential evapotranspiration is 1309 mm (CSIRO, WARPO, BWDB, IWM, BIDS & CEGIS, 2014).

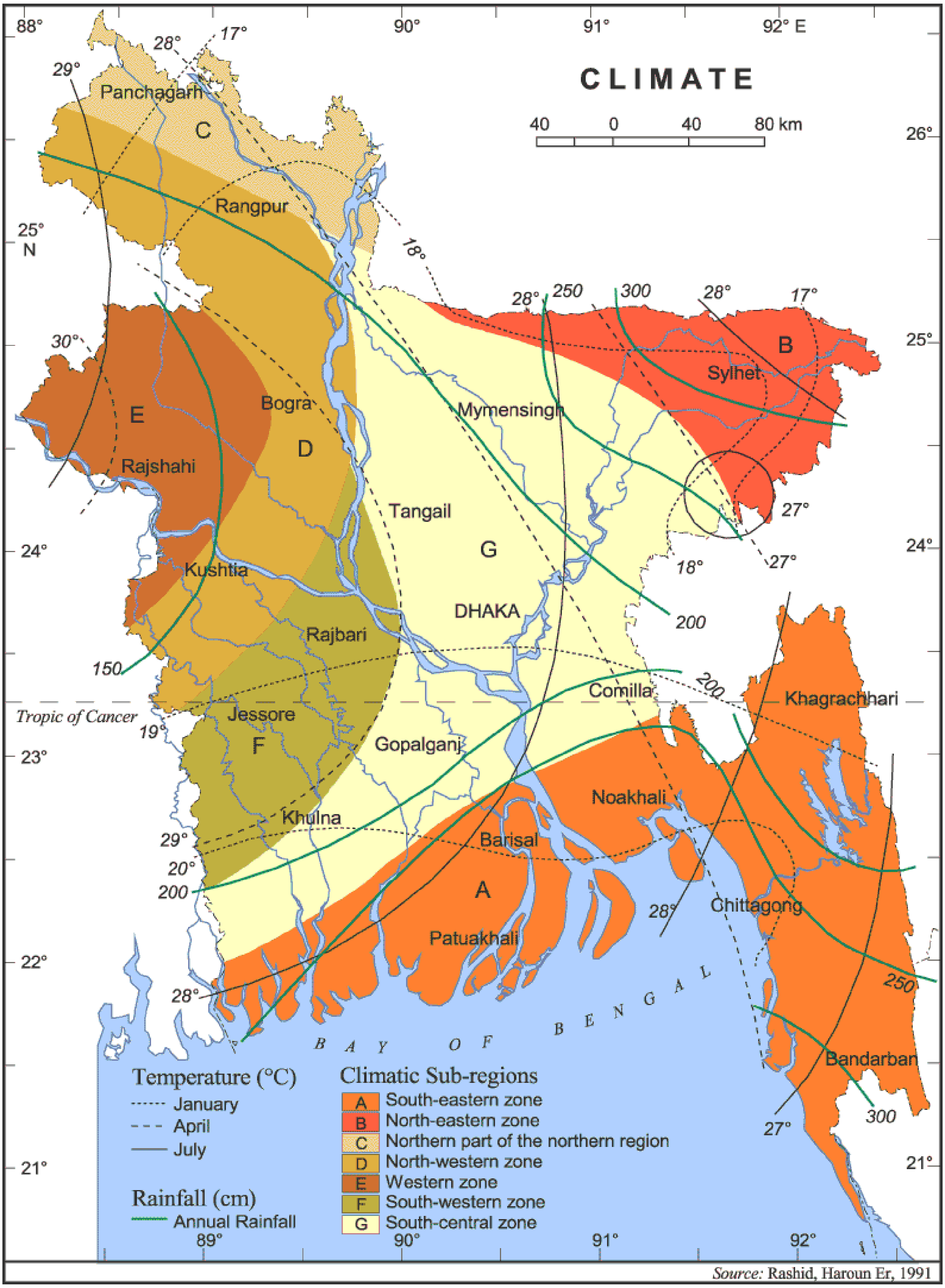



Figure 3.4: Seven climatic sub-regions of Bangladesh (Source: http://www.agrislide.com/climatic-sub-regions-of-bangladesh/)

## 3.2 Data collection

Bangladesh Water Development Board (BWDB) maintains an extensive groundwater monitoring database, which contains time series of water table depth recordings of about 1200 monitoring wells across the country (Fig.3.5) (Hodgson *et al.*, 2014). Many wells have water level data from the mid-1960s onwards. However, most wells have weekly data from 1985. The study area (NW hydrological region) has total 437 monitoring wells, the water level data of which from year 1985 to 2016 were utilized in this study.

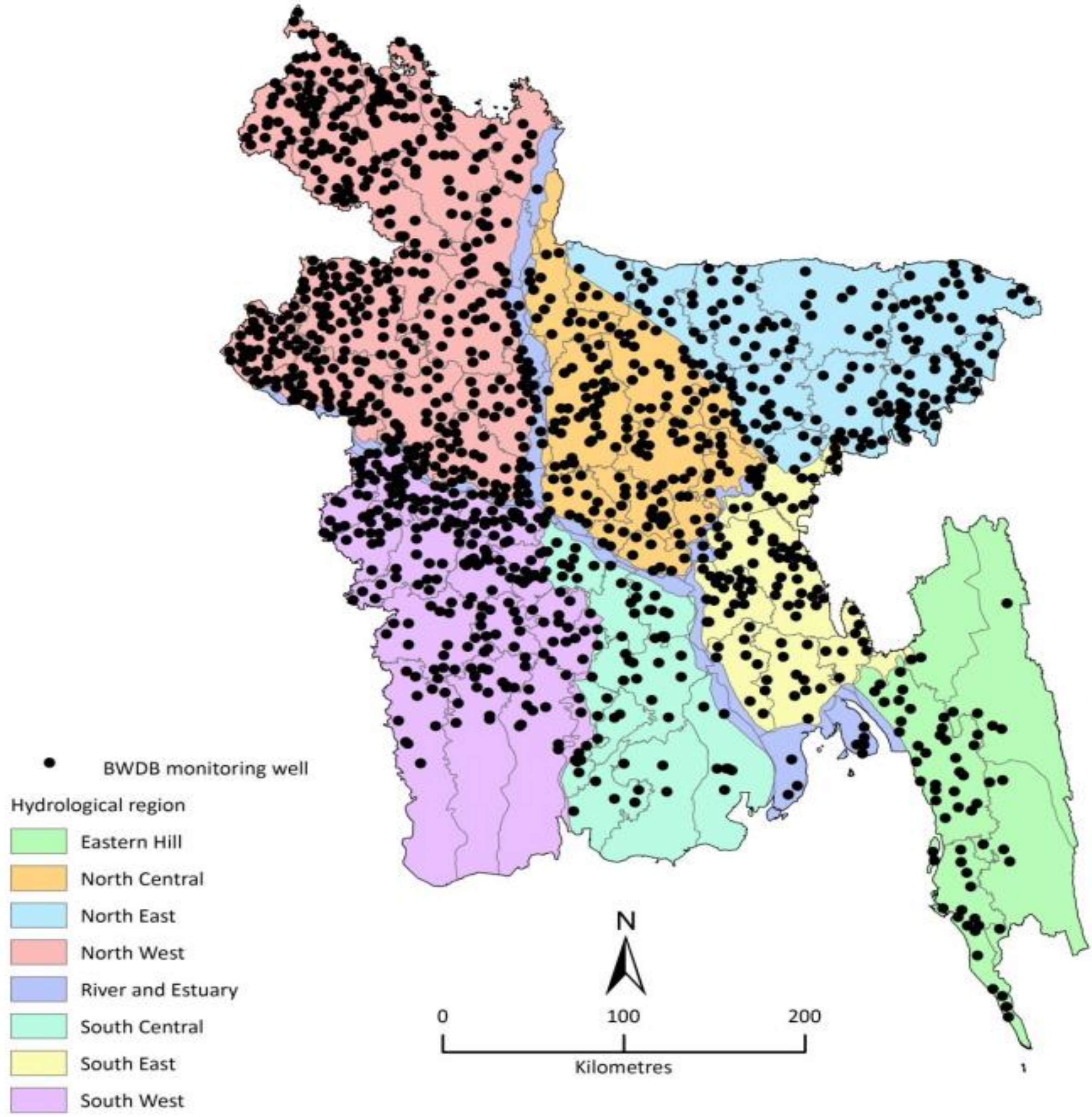



Figure 3.5: Hydrological regions of Bangladesh and distribution of groundwater level monitoring wells

## 3.3 Data preparation

The first step in analyzing a time series is to plot the observed data against time. This shows up important features of the data such as trend, seasonality, discontinuities and outliers (Chatfield, 1980). The data of groundwater level were first arranged and sorted according to the wells. The wells were divided into four categories. The first category consists of wells having data of typical distribution like, for example, Well ID GT6915004 (Fig.3.6).

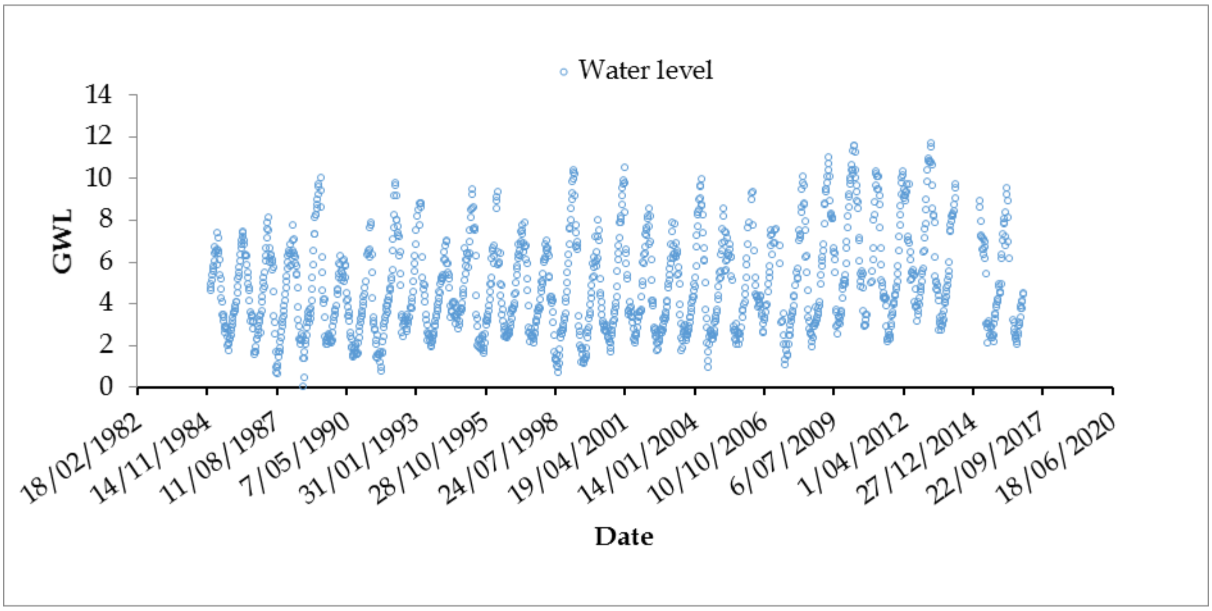



Figure 3.6: A typical variation of groundwater level of monitoring Well ID GT6915004 (first category) over time

The second category wells have missing data of 5 to 7 years or more. An example for this category wells is Well ID GT7088502, which does not have water level record from 2009 to 2015. This well shows a discontinuous distribution of water level (Fig.3.7). The third category wells include those providing irrational/absurd distribution of water level over time. Well ID GT6475035 is an example of this category (Fig.3.8). In this well, after 29 February 1988, the water level distribution pattern abruptly changed and the whole cycle lifted itself up and then continues. Also, the water levels on 11 July 2011, 19 September 2011 and 23 December 2013 are found out of water cycle.

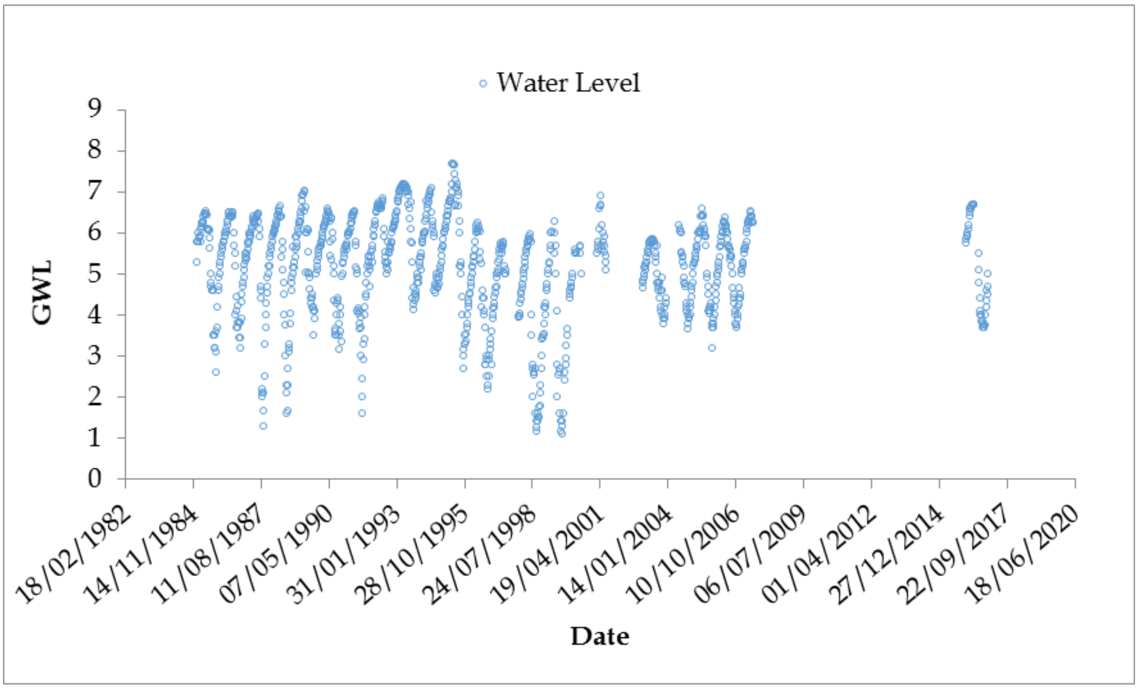



Figure 3.7: A discontinuous groundwater level of monitoring Well ID GT7088502 (second category) over time

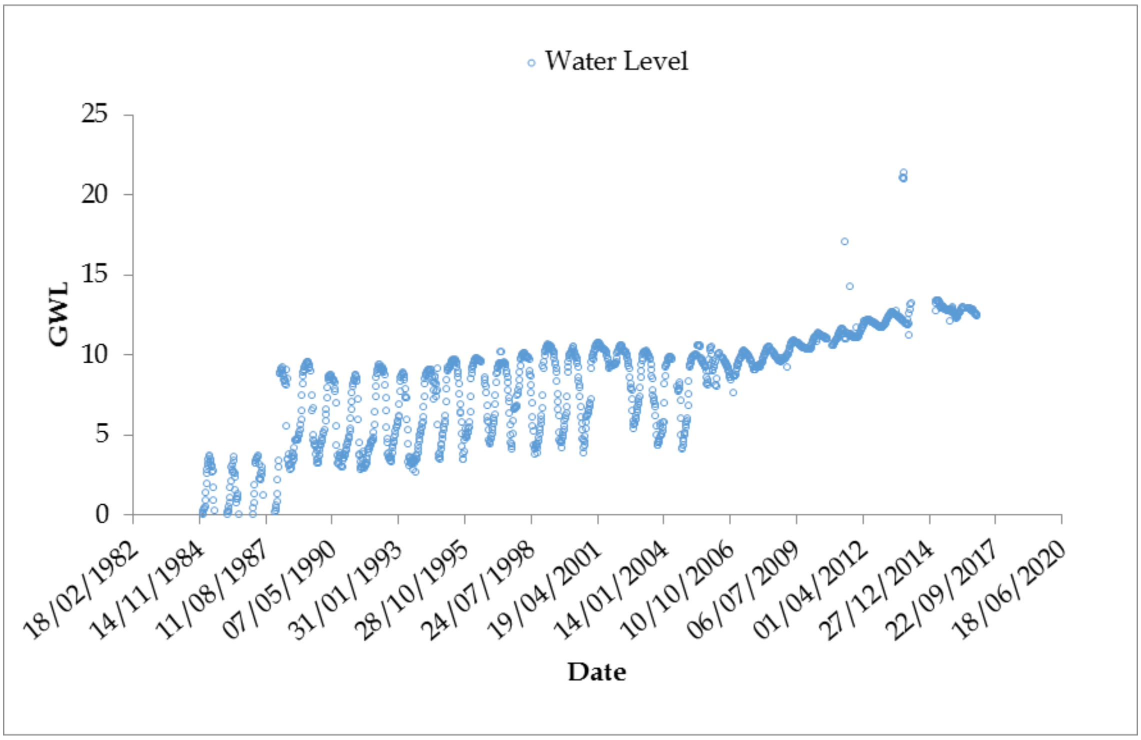



Figure 3.8: An irrational/absurd variation of groundwater level of monitoring Well ID GT6475035 (third category) over time

The fourth category wells have identification limitations. These well could not be located precisely. A total number of seven wells are within this category.

After categorizing, the wells showing discontinuous and irrational distribution of water levels were discarded. Also the wells having identification limitations were rejected. Among the 437 wells of the study area, 350 wells with good data set were selected for trend analysis in this study. A list of these wells along with their locations is given in Appendix-1. The annual maximum and minimum depths of water levels of the wells with typical water level distributions and with known locations were identified and listed separately for each well.

### 3.4 Trend analysis

The trends of the annual maximum and minimum depths of water levels were determined by using MAKESENS trend statistics. MAKESENS utilizes Gilbert's (1987) S-statistics and Z-statistics. For time series with less than 10 data points, S-statistics is used. For time series with ≥10 data points, Z-statistics is used. If $x_1$, $x_2$, $x_3 \ldots x_j$ represent $n$ data points where $x_j$ represents the data point at time $j$ then Mann-Kendall statistics "S" is given by

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \text{sigh}(x_j - x_k) \quad (1)$$

where

$\text{sigh}(x_j - x_k) = 1$, if $x_j - x_k > 0$

$\text{sigh}(x_j - x_k) = 0$, if $x_j - x_k = 0$

$\text{sigh}(x_j - x_k) = -1$, if $x_j - x_k < 0$

The normalized Z-statistics is given by,

$$Z = \frac{S-1}{[\text{VAR}(S)]^{\frac{1}{2}}} \quad \text{if } S > 0 \quad (2)$$

$$Z = \frac{S+1}{[\text{VAR}(S)]^{\frac{1}{2}}} \quad \text{if } S < 0$$

$Z = 0 \qquad\qquad \text{if } S = 0$

## 3.5 Water scarcity identification

Based on the suction limit of STW and other suction-mode pumps, the critical depth was set to be 6 meters considering the suction limitation and dynamic drawdown during pumping. The monitoring wells were categorized into three groups based on their water level positions:

i. wells having water levels below critical depth during whole year over the study period (1985–2016 ),

ii. wells having water levels below critical depth for certain months in the year over the study period, and

iii. wells having water level above critical during whole year over the study period.

After categorizing the wells, their locations (up to village level) were identified to reveal the condition of groundwater availability of the places, especially for domestic water supply.

# CHAPTER 4

# RESULTS AND DISCUSSION

## Chapter 4

# RESULTS AND DISCUSSION

This study determined and evaluated the trends of historical groundwater tables/levels of the north-west Bangladesh to reveal the long-term dynamic nature of groundwater resource in the region. The findings of the study are presented in this chapter in compliance to the objectives of the study.

Data on both the annual maximum and minimum depth of groundwater levels, measured in 350 monitoring wells, were analyzed. Three possible features of groundwater-level trend (increasing, decreasing and constant/unchanged trends) reveal the present sustainability conditions of the groundwater resource. In this chapter, the first two sections present the condition of water level dynamics in all the monitoring wells. The third section categorizes the wells along with their locations based on critical depth of groundwater level. The fourth section focuses on areas exposed to domestic water scarcity.

## 4.1 Long-term trend of groundwater level

The MAKESENS model provides trends of groundwater levels in terms of Z-statistics (Eq.2), slope, intercept and statistical significance (Appendix-2 and Appendix-3). The Z-statistics is a deterministic index of the trend. The slope of the trend lines reveals if the trend is increasing or decreasing. Also, the slope determines the magnitude of the trend, that is, the amount of change per year. The intercept and slope together provide the trend line. Based on data type, especially the sensitivity of change, statistical significance of the trend is determined and presented by the model for significant levels $p= 0.1$, $0.05$, $0.01$ or $\leq 0.1$. For this study, $p= 0.05$ was taken as base for determining statistical significance of the water-level trends, i.e. trends having p ≥ 0.05 are considered significant; otherwise they are insignificant.

### 4.1.1 Trend of annual maximum groundwater level

#### 4.1.1.1 Direction of groundwater-level trend

Among the 350 monitoring wells under study, 300 wells show increasing trend of the annual maximum depth of groundwater level. Forty-eight (48) wells show decreasing trend of the water levels. The remaining 2 wells show constant/unchanged trend of the water level. Table 4.1 provides distribution of the three trend types of the annual maximum depth of groundwater levels of 350 wells over sixteen districts of the north-west region. This table has been arranged focusing on the number of monitoring wells in every district with the possible three trends of the groundwater level.

Table 4.1: Number of monitoring wells in different districts with different trends of the annual maximum depth of water level

| District | No. of wells with increasing water-level trend | No. of wells with decreasing water-level trend | No. of wells with constant water-level trend | Total number of wells |
|---|---|---|---|---|
| Rajshahi | 35 | 1 | 0 | 36 |
| Bogra | 20 | 7 | 0 | 27 |
| Dinajpur | 38 | 0 | 0 | 38 |
| Gaibandha | 12 | 5 | 0 | 17 |
| Joypurhat | 8 | 0 | 0 | 8 |
| Kurigram | 6 | 1 | 0 | 7 |
| Lalmonirhat | 13 | 1 | 0 | 14 |
| Naogaon | 32 | 1 | 0 | 33 |
| Natore | 9 | 4 | 0 | 13 |
| Chapai Nawabganj | 18 | 1 | 2 | 21 |
| Nilphamari | 16 | 8 | 0 | 24 |
| Pabna | 21 | 6 | 0 | 27 |
| Panchagarh | 18 | 4 | 0 | 22 |
| Rangpur | 8 | 4 | 0 | 12 |
| Shirajganj | 22 | 2 | 0 | 24 |
| Thakurgaon | 24 | 3 | 0 | 27 |
| Total number of wells | | | | 350 |

The majority of the monitoring wells (Table 4.1) shows increasing trend of the annual maximum depth of groundwater level, implying that the depletion of groundwater level has been increasing in dry seasons over the years (1985 – 2016). The decreasing trend of annual groundwater level, on the other hand, indicates complete replenishment of the aquifer after abstraction for various usages. The constant trend suggests no permanent change of water level over the years. This trend also implies that the aquifers are completely replenished during monsoon after depletion in dry season, with a possibility of recharge rejection when the aquifer is replenished before the end of rainy season. Dinajpur and Joypurhat districts have the highest proportion (100%) of monitoring wells showing increasing trends of the annual maximum depth of groundwater level. Nilphamari has the highest number (8 out of 24) of wells showing decreasing trend of the water level. Only Chapai Nawabganj has 2 wells showing constant trend of groundwater level. The increasing, decreasing and constant trends of groundwater levels in three monitoring wells are shown, for example, in Figs.4.1, 4.2 and 4.3, respectively.

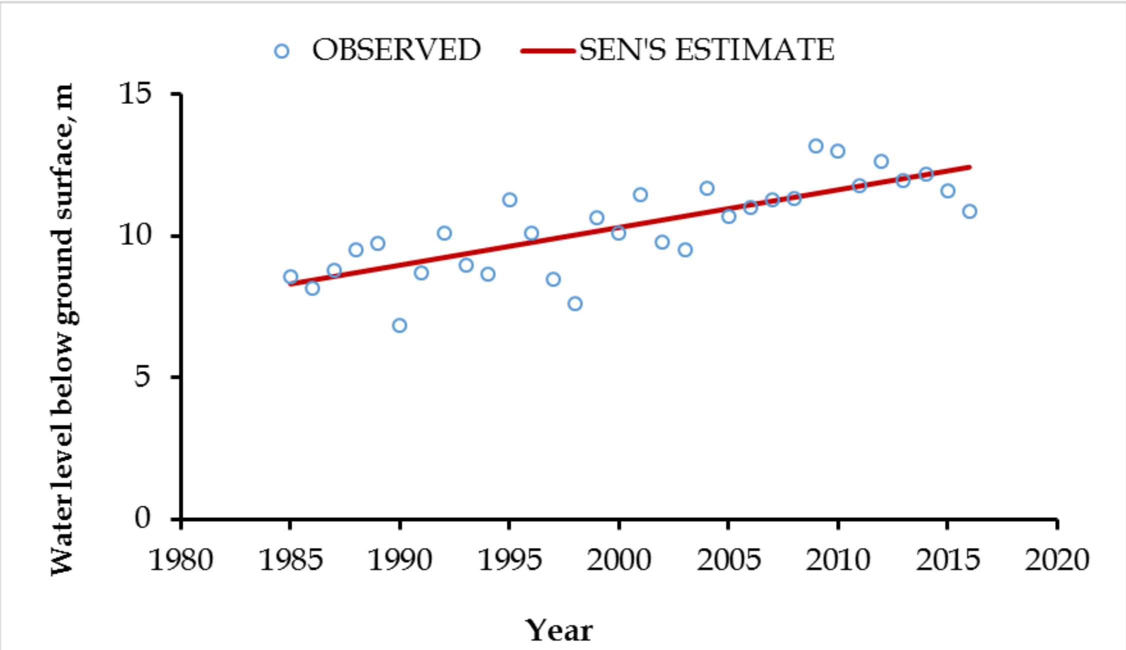



Figure 4.1: Increasing trend of the annual maximum groundwater level in monitoring Well ID GT7605003 (Z = 4.72 and slope = 0.133)

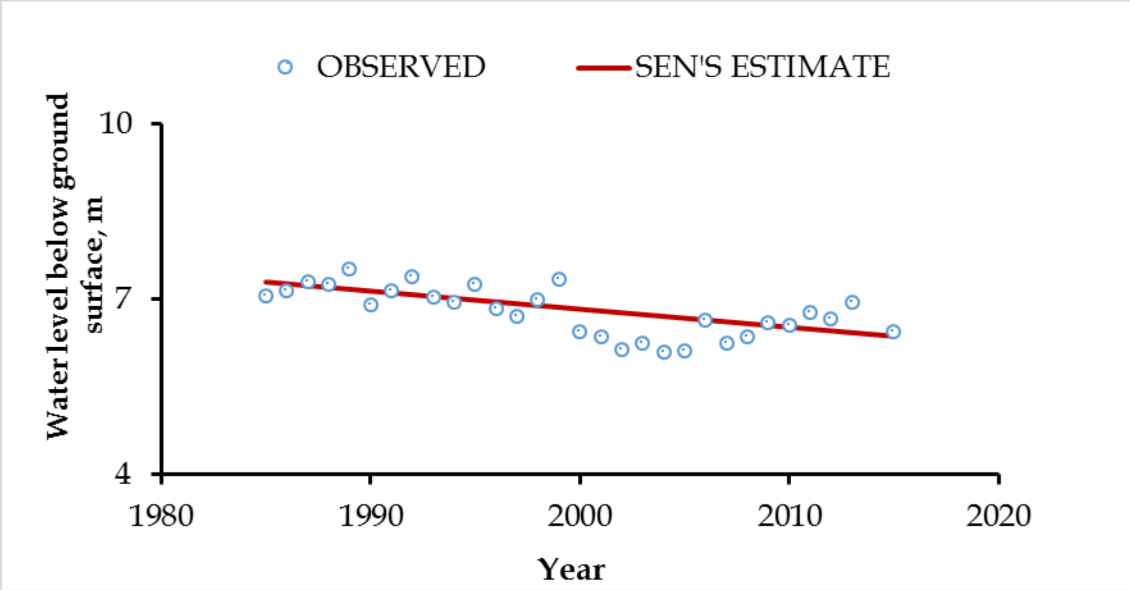



Figure 4.2: Decreasing trend of the annual maximum groundwater level in monitoring Well ID GT7616012 (Z = -3.39 and slope = -0.031)

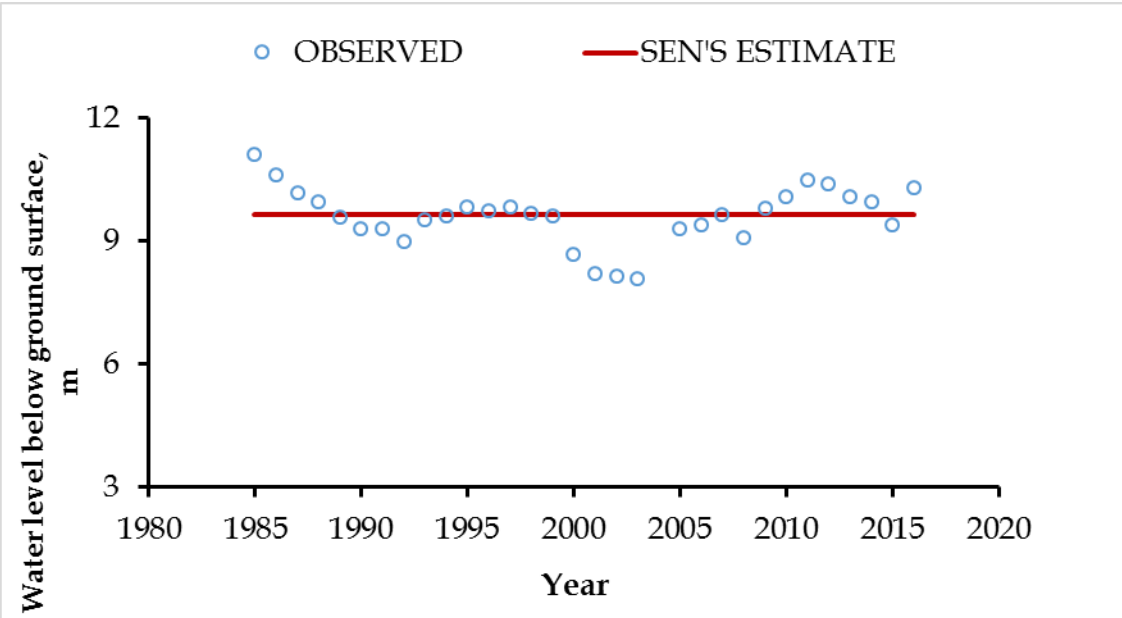



Figure 4.3: Constant annual maximum groundwater level in monitoring Well ID GT7066014 (Z = 0.0 and slope = 0.0)

The increasing water-level trend outnumbers the other two trend categories (decreasing and constant trends) for maximum depths of groundwater levels

(Table 4.1). The situation presented by trend analysis implies unsustainable use of groundwater in the north-west region; the groundwater level is declining in the dry season with successive years for most of the wells. This is mostly due to increased cultivation of irrigated crops and unwise use of water for other purposes. According to Shamsudduha *et al.* (2009), these areas are of intensive Boro cultivation. Given the necessity of increasing crop production, increased water requirement in irrigated agriculture is inevitable. However, introducing water saving techniques and increasing irrigation efficiency in the areas can ensure sustainability of groundwater use. Also, municipal use of water needs to be kept in check. Extravagant use of water for domestic purpose is also responsible for ever-declining groundwater level.

### 4.1.1.2 Magnitude of groundwater-level trend

Among the 300 monitoring wells (Table 4.1) with increasing trend of the maximum depths of annual groundwater level, the trends of water levels in 244 wells are significant (p = 0.05) and that of the remaining 56 wells are insignificant. Of the 48 wells with decreasing trends of groundwater level, 17 wells show significant trend and 31 wells show insignificant trend in groundwater levels. The monitoring wells are listed in Table 4.2 based on the significance level of their water-level trends. For comparison, four monitoring wells with different categories of water-level trend are shown, for example, in Fig.4.4.

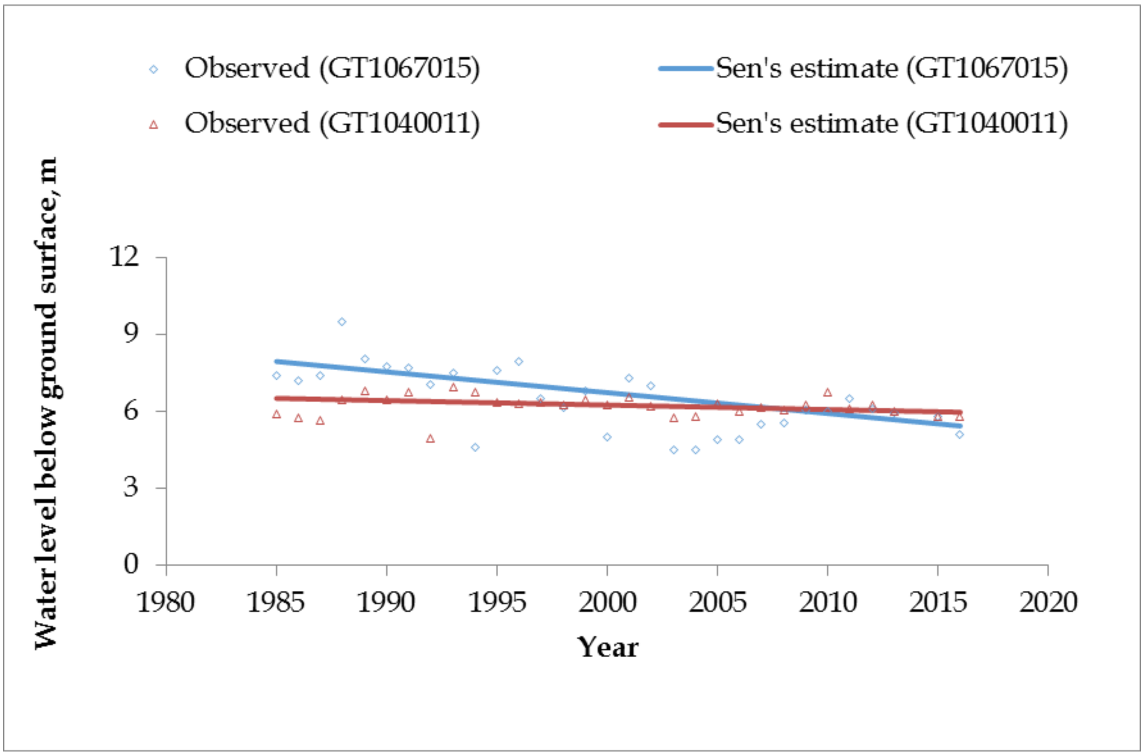
Table 4.2 reveals that 81.33% monitoring wells with increasing trend and 35.42% monitoring wells with decreasing trend of the annual maximum depths of groundwater levels are significant (p = 0.05). Statistical significance indicates the importance of the trend for planned management of the groundwater resources. If the trend is not significant then the estimated change is not worth worrying. As the increasing trend for maximum depths of groundwater levels covers majority portion of the monitoring wells considering significance level, it suggests that, the declining groundwater level in the dry season is statistically true, on which basis, it can be said emphatically that water use policy in those areas need to be revised to ensure sustainability of groundwater use.

Table 4.2: Distribution of the monitoring wells based on statistical significance of their annual maximum water-level trends in different districts

| District | No. of wells with increasing trend | | No. of wells with decreasing trend | | No. of wells with constant trend | | Total |
|---|---|---|---|---|---|---|---|
| | Sig. | Insig. | Sig. | Insig. | Sig. | Insig. | |
| Rajshahi | 33 | 2 | 0 | 1 | 0 | 0 | 36 |
| Bogra | 16 | 4 | 4 | 3 | 0 | 0 | 27 |
| Dinajpur | 38 | 0 | 0 | 0 | 0 | 0 | 38 |
| Gaibandha | 10 | 2 | 2 | 3 | 0 | 0 | 17 |
| Joypurhat | 8 | 0 | 0 | 0 | 0 | 0 | 8 |
| Kurigram | 3 | 3 | 0 | 1 | 0 | 0 | 7 |
| Lalmonirhat | 9 | 4 | 0 | 1 | 0 | 0 | 14 |
| Naogaon | 30 | 2 | 0 | 1 | 0 | 0 | 33 |
| Natore | 6 | 3 | 0 | 4 | 0 | 0 | 13 |
| Chapai Nawabganj | 15 | 3 | 0 | 1 | 0 | 2 | 21 |
| Nilphamari | 14 | 2 | 7 | 1 | 0 | 0 | 24 |
| Pabna | 14 | 7 | 1 | 5 | 0 | 0 | 27 |
| Panchagarh | 9 | 9 | 1 | 3 | 0 | 0 | 22 |
| Rangpur | 5 | 3 | 0 | 4 | 0 | 0 | 12 |
| Shirajganj | 13 | 9 | 2 | 0 | 0 | 0 | 24 |
| Thakurgaon | 21 | 3 | 0 | 3 | 0 | 0 | 27 |
| Total wells | | | | | | | 350 |


GT8172035: Z = 6.04, slope = 0.30; significantly increasing

GT1020005: Z = 0.5, slope = 0.006; insignificantly increasing




GT1067015: Z=-3.45, slope= -0.081; significantly decreasing

GT1040011 Z = -1.85, slope = -0.0175; insignificantly decreasing

Figure 4.4: An example of significant and insignificant trend types of the annual maximum groundwater level in four monitoring wells

### 4.1.2 Trend of annual minimum groundwater level

#### 4.1.2.1 Direction of groundwater-level trend

Among the 350 monitoring wells under study, 315 wells show increasing trend of the annual minimum depths of groundwater levels. Thirty-one (31) of them show decreasing trend of the water levels. The remaining 4 wells show constant/unchanged trend of the water level. Table 4.3 provides a list of different trend types of the annual minimum groundwater levels of 350 wells. This table has been arranged focusing on the number of monitoring wells in every district with the possible three trend-types of the groundwater levels.

Table 4.3: Number of monitoring wells in different districts with different trends of the annual minimum groundwater level

| District | No. of wells with increasing trend | No. of wells with decreasing trend | No. of wells with constant trend | Total |
|---|---|---|---|---|
| Rajshahi | 36 | 0 | 0 | 36 |
| Bogra | 27 | 0 | 0 | 27 |
| Dinajpur | 37 | 1 | 0 | 38 |
| Gaibandha | 13 | 2 | 2 | 17 |
| Joypurhat | 8 | 0 | 0 | 8 |
| Kurigram | 6 | 1 | 0 | 7 |
| Lalmonirhat | 10 | 4 | 0 | 14 |
| Naogaon | 33 | 0 | 0 | 33 |
| Natore | 13 | 0 | 0 | 13 |
| Chapai Nawabganj | 20 | 1 | 0 | 21 |
| Nilphamari | 15 | 9 | 0 | 24 |
| Pabna | 25 | 1 | 1 | 27 |
| Panchagarh | 20 | 2 | 0 | 22 |
| Rangpur | 9 | 3 | 0 | 12 |
| Shirajganj | 22 | 2 | 0 | 24 |
| Thakurgaon | 21 | 5 | 1 | 27 |
| Total wells | | | | 350 |

The majority of the monitoring wells (Table 4.3) show an increasing trend of the annual minimum depths of groundwater levels, implying that the depletion of groundwater level has been increasing in the wet seasons over the years (1985–2016). The decreasing trend of the annual minimum groundwater level indicates proper replenishment of the aquifers. Rajshahi district has the highest proportion (100%) of the monitoring wells with increasing trends of groundwater levels. Nilphamari has the highest number (9 out of 15) of the monitoring wells with decreasing trends of groundwater levels. Four of the wells show constant trend of the groundwater levels, indicating no change of groundwater levels over time. Gaibandha had the highest number (2) of wells with constant trends of groundwater levels. The increasing, decreasing and constant trends of groundwater levels in three monitoring wells are shown, for example, in Figs. 4.5, 4.6 and 4.7, respectively.

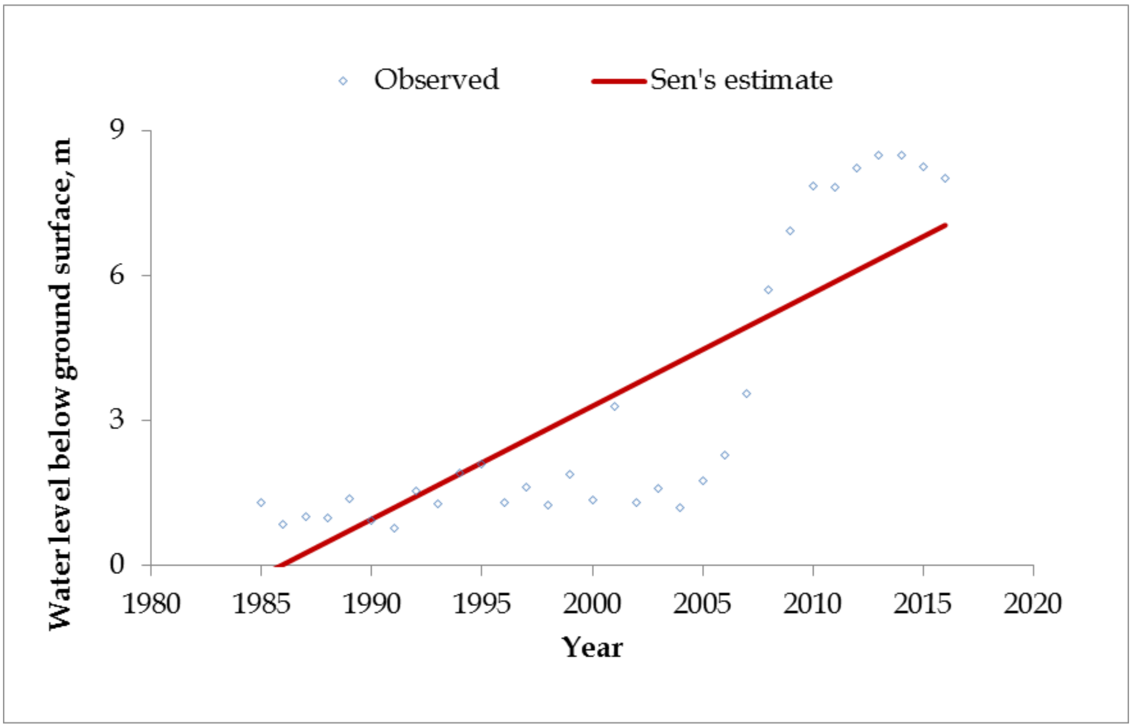



Figure 4.5: Increasing trend of the annual minimum depth of groundwater level in monitoring Well ID GT1054014 (Z = 5.4 and slope = 0.234)

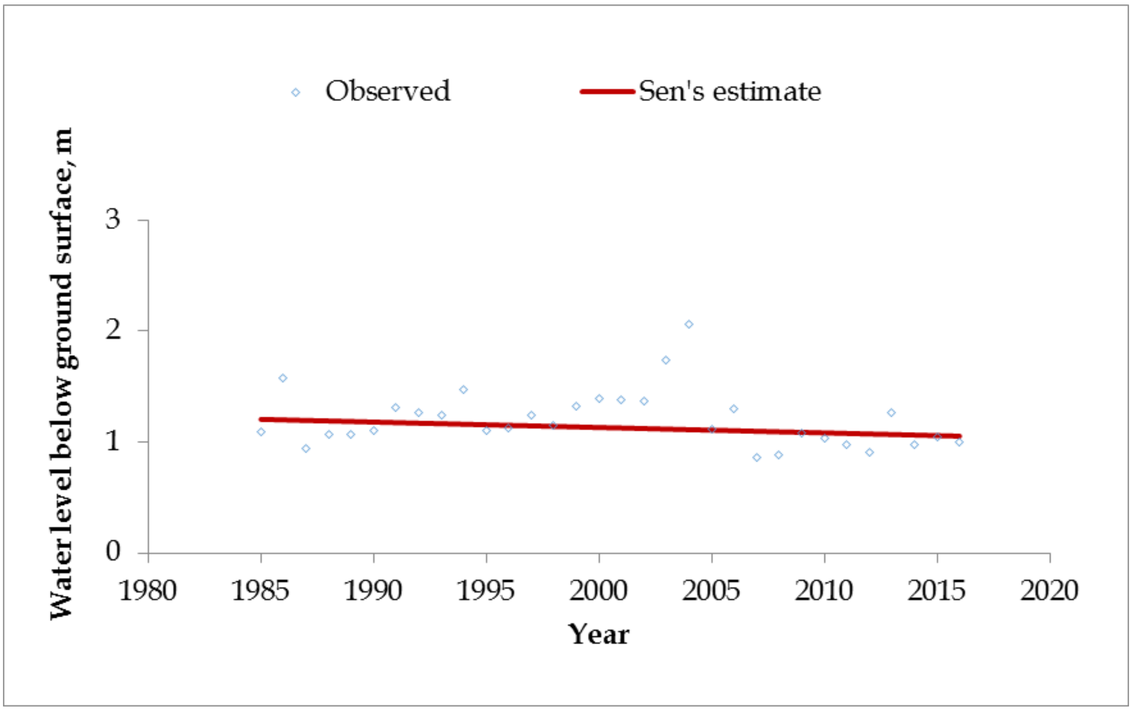



Figure 4.6: Decreasing trend of the annual minimum depth of groundwater level in monitoring Well ID GT5233001(Z = -1.22 and slope = -0.005)

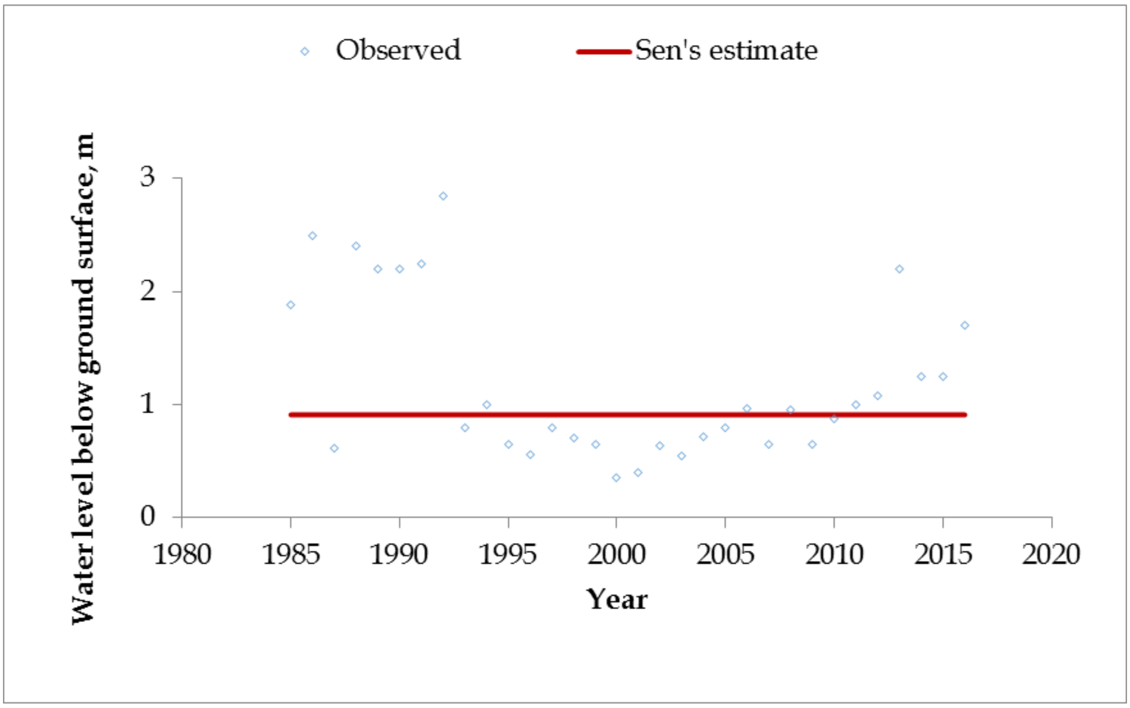



Figure 4.7: Constant annual minimum depth of groundwater level in monitoring Well ID GT9494016 (Z = -0.18 and slope = 0.0)

The increasing water-level trend outnumbers the decreasing and constant water-level trends for the minimum annual depths of groundwater levels (Table 4.3). This fact implies the lack of adequate recharge to the aquifers in wet season. The north-west region of Bangladesh has the lowest amount of annual rainfall, and the region has a layer of thick (6.10–21.34 m) aquitard (Rahman and Mahbub, 2012). Both these factors hinder adequate recharge to the aquifers and, consequently, cause declining water-level trend in the wet season. Also, the monsoon rainfall as well as annual rainfall in the northern part of Bangladesh has a decreasing trend for most of the districts (Bari *et al.*, 2016), making the available water for recharge limiting. Therefore, recharge to the aquifers needs to be augmented to ensure groundwater availability in the dry season. Also, if groundwater is not replenished properly, the possibility of mining increases, which opens up the path of land subsidence. To make sure that the aquifers are replenished properly, artificial recharge can be introduced into those areas. Rainwater harvesting in the existing ponds can also contribute to groundwater recharge.

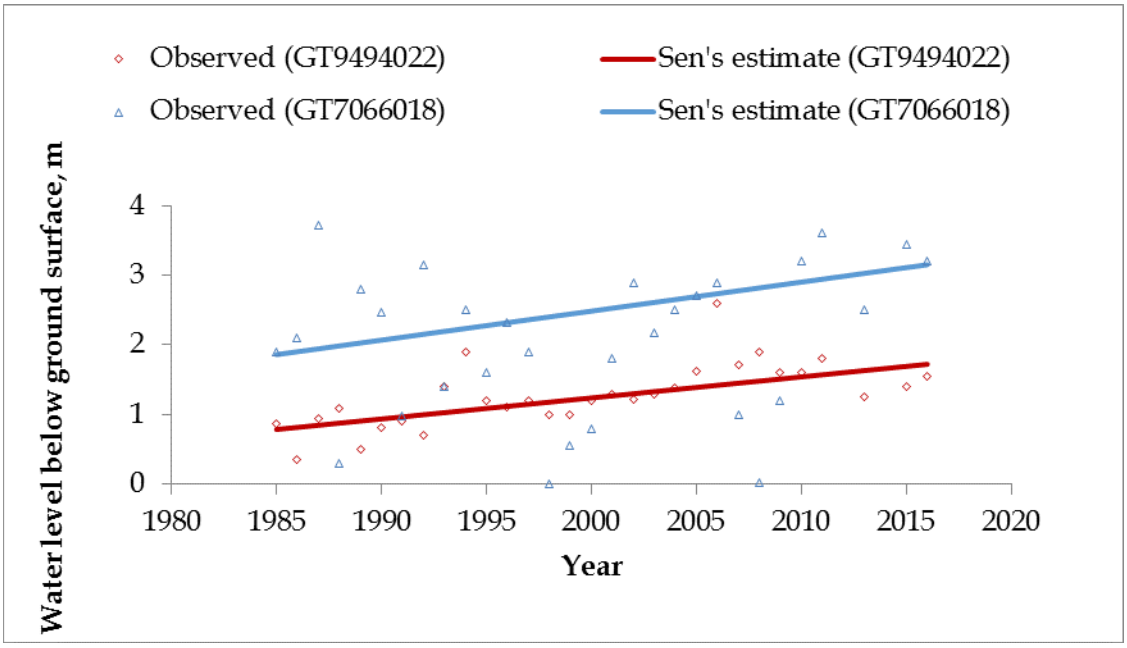
### 4.1.2.2 Magnitude of groundwater-level trend

Among the 315 monitoring wells (Table 4.3) with increasing trend of the minimum annual groundwater level, the trends of water levels in 230 wells are significant ($p=0.05$) and that of the remaining 85 wells are insignificant. Of the 31 wells with decreasing trends in groundwater levels, 6 wells show significant trend and 25 wells show insignificant trend in their water levels. Only four wells show constant trend in their water levels. The monitoring wells are distributed in Table 4.4 based on the significance level of their water-level trends. For comparison, four monitoring wells with different categories of water-level trends are shown, for example, in Fig.4.4.

In Table 4.4, the trends of the majority of increasing annual minimum groundwater levels are significant, implying that the declining groundwater level in the wet season is remarkable and needs attention. On the other hand, majority of the decreasing trend is insignificant, implying that the increment in the groundwater level in the wet season is statistically worthless to be taken into consideration. These findings emphasize the necessity of taking corrective decision on the declining groundwater levels in wet season and suggest implementing techniques to augment groundwater recharge.

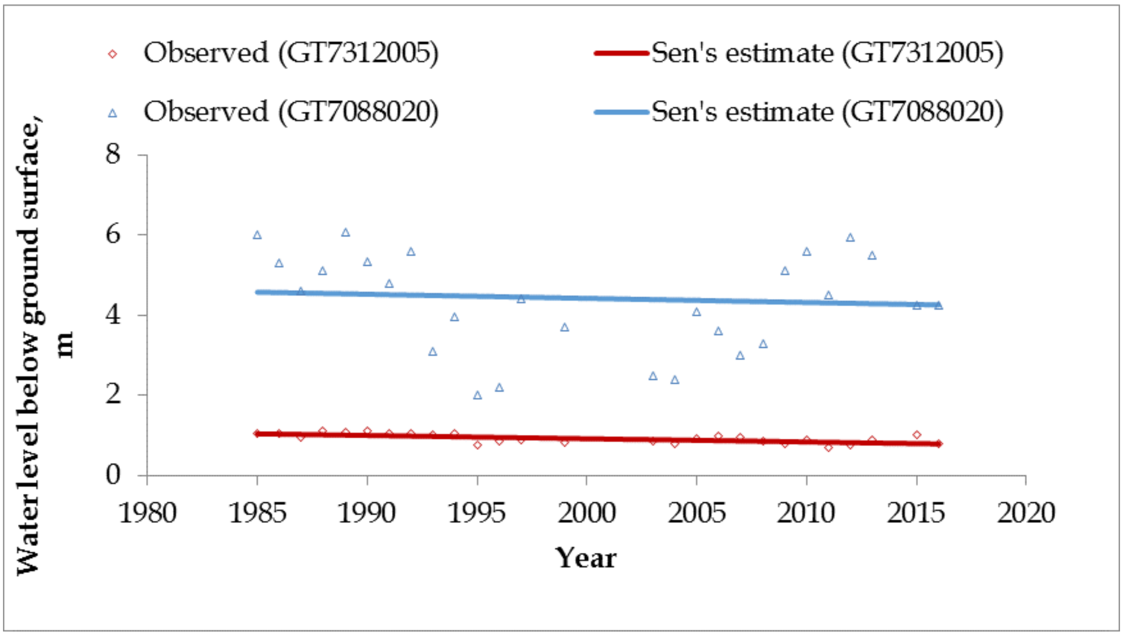
Table 4.4: Distribution of the monitoring wells based on statistical significance of their annual minimum water-level trends in different districts

| District | No. of wells with increasing trend | | No. of wells with decreasing trend | | No. of wells with constant trend | | Total |
|---|---|---|---|---|---|---|---|
| | Sig. | Insig. | Sig. | Insig. | Sig. | Insig. | |
| Rajshahi | 35 | 1 | 0 | 0 | 0 | 0 | 36 |
| Bogra | 24 | 3 | 0 | 0 | 0 | 0 | 27 |
| Dinajpur | 22 | 15 | 0 | 1 | 0 | 0 | 38 |
| Gaibandha | 7 | 6 | 1 | 1 | 0 | 2 | 17 |
| Joypurhat | 7 | 1 | 0 | 0 | 0 | 0 | 8 |
| Kurigram | 2 | 4 | 0 | 1 | 0 | 0 | 7 |
| Lalmonirhat | 4 | 6 | 0 | 4 | 0 | 0 | 14 |
| Naogaon | 31 | 2 | 0 | 0 | 0 | 0 | 33 |
| Natore | 11 | 2 | 0 | 0 | 0 | 0 | 13 |
| Chapai Nawabganj | 17 | 3 | 0 | 1 | 0 | 0 | 21 |
| Nilphamari | 6 | 9 | 3 | 6 | 0 | 0 | 24 |
| Pabna | 20 | 5 | 0 | 1 | 0 | 1 | 27 |
| Panchagarh | 11 | 9 | 0 | 2 | 0 | 0 | 22 |
| Rangpur | 4 | 5 | 0 | 3 | 0 | 0 | 12 |
| Shirajganj | 10 | 12 | 0 | 2 | 0 | 0 | 24 |
| Thakurgaon | 19 | 2 | 2 | 3 | 0 | 1 | 27 |
| Total wells | | | | | | | 350 |




GT7066018: Z = 1.74, slope = 0.042; insignificantly increasing

GT9494022: Z = 4.35, slope = 0.03; significantly increasing




GT7088020: Z = -0.28, slope = -0.01; insignificantly decreasing

GT7312007: Z = -3.45, slope = -0.081; significantly decreasing

Figure 4.8: An example of significant and insignificant trend-types of the annual minimum groundwater level in four monitoring wells

## 4.2 Locations with critical depth of groundwater level

The annual groundwater levels (minimum and maximum) in some monitoring wells never dropped below 6 meters (critical depth for suction-mode pumps) during the year 1985–2016, while the water levels in some monitoring wells were always below 6 meters. But, some wells had water levels below 6 m during 3–6 months in most of the years during 1985–2016. Based on the critical depth of groundwater level (6 m), the monitoring wells, regardless of their water-level trend categories, were divided into three groups (Appendix-4). The list of monitoring wells, focusing on the numbers in each districts, having their water levels always greater than critical depth, those maintain critical depth in 3–6 months in most of the years, and those having water levels always above the critical depth are given in Table 4.5.

Table 4.5: Distribution of the monitoring wells over different districts based on critical depth (suction limit) of groundwater level

| District | No. of wells having GWL always below suction limit | No. of wells having GWL below suction limit maintaining a cycle | No. of wells having GWL always above suction limit | Total |
|---|---|---|---|---|
| Rajshahi | 11 | 25 | 0 | 36 |
| Bogra | 6 | 20 | 1 | 27 |
| Dinajpur | 0 | 27 | 11 | 38 |
| Gaibandha | 12 | 5 | 0 | 17 |
| Joypurhat | 2 | 6 | 0 | 8 |
| Kurigram | 0 | 4 | 3 | 7 |
| Lalmonirhat | 0 | 0 | 14 | 14 |
| Naogaon | 16 | 17 | 0 | 33 |
| Natore | 0 | 13 | 0 | 13 |
| ChapaiNawabganj | 6 | 15 | 0 | 21 |
| Nilphamari | 0 | 2 | 22 | 24 |
| Pabna | 0 | 27 | 0 | 27 |
| Panchagarh | 0 | 5 | 17 | 22 |
| Rangpur | 0 | 5 | 7 | 12 |
| Shirajganj | 0 | 24 | 0 | 24 |

| | | | | |
|---|---|---|---|---|
| Thakurgaon | 0 | 14 | 13 | 27 |
| Total wells | | | | 350 |

The large proportions (209 out of 350) of the monitoring wells have their water levels below suction limit for several months of the year. These types of wells maintain a water-level cycle throughout the year, with the water level staying below critical depth (6 m) in the dry season. The groundwater levels in 88 monitoring wells stay above suction limit/critical depth, making shallow tubewell (STW), and other suction-mode pumps operational throughout the whole year. Fifty-three (53) wells always have their water levels below critical depth.This information raise questions about technical feasibility of the STWs in the region. The STWs, which dominate over other tube wells, lead to water scarcity when fail to operate because of suction lift limitation. A total of 74.86% monitoring wells (both category 1 and 2) become unworkable in the dry season. Currently, installation of DTWs in the Barind area is prohibited by the government due to groundwater sustainability issue, adequate replenishment of aquifer, proper operation of the existing DTWs, and efficient distribution and utilization of water in the dry season is suggested as solutions for water scarcity.

## 4.3 Domestic water scarcity

In the north-west region of Bangladesh, household water supply is mostly covered by groundwater, the abstraction of which is done by both STWs and DTWs. The shortcoming of STW, due to limited suction lift (practically 6 m, including dynamic drawdown during pumping), restricts water supply. Figure 4.9 illustrates the regional distribution of the monitoring wells based on critical depth of their water levels. The yellow dots in the figure denote the wells having water levels below suction limit in the dry season (3–6 months). The red dots show the wells having water levels always below suction limit, and the green ones give the wells having water levels always above suction limit. It is revealed that Bogra, Rajshahi, Naogaon, Joypurhat and Chapai Nowabgonj, forming the Barind track, have all the red-colored wells, showing severity of water scarcity due to failure of STWs. As Barind track has low rainfall and high runoff due to a thick aquitard starting from the ground surface, the reason of this distribution is easily comprehensible. The green wells (groundwater levels reside above suction limit) amass in the northern part (Rangpur, Gaibandha, Kurigram, Dinajpur, Nilphamari, Panchagor and Thakurgaon) of the study area, showing good condition of the groundwater resource for some areas. The wells having water levels below suction limit are found distributed all around the north-west region, indicating areas of dry season water scarcity.

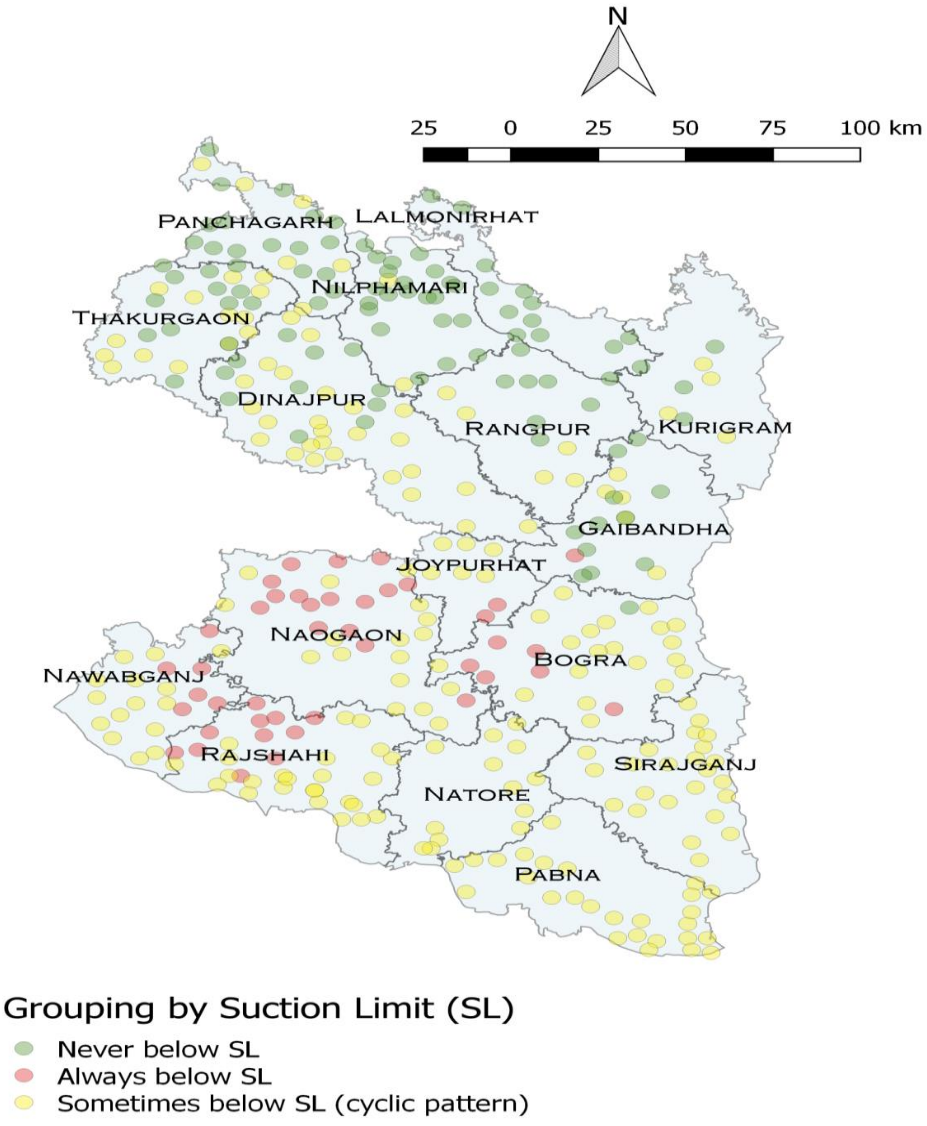



Figure 4.9: Distribution of the monitoring well-types based on suction limit in different districts in the north-west region of Bangladesh

# CHAPTER 5

# CONCLUSIONS AND RECOMMENDATIONS

# Chapter 5

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

From the trend analysis of the annual maximum and minimum depths of groundwater levels in 350 monitoring wells over the period 1985–2016, the following conclusions were drawn:

i. For the annual maximum/highest depths of groundwater levels:
   a. 85.71% of the monitoring wells show increasing/upward trend of their groundwater levels; 81.33% of these wells show significantly ($p = 0.05$) increasing trends of their groundwater levels.
   b. 13.72% of the monitoring wells have decreasing trend of their water levels; the trends of 35.42% of these wells are significant.
   c. 0.57% of the monitoring wells show unchanged groundwater levels.

ii. For the annual minimum/lowest depths of groundwater levels:
   a. 90% of the monitoring wells show increasing trend of their water levels; the trends of 73.02% of this category wells are significant ($p = 0.05$).
   b. 8.86% of the monitoring wells show decreasing trend of their water levels; the trends of 19.35% of this category wells are significant.
   c. only 1.14% of the monitoring wells show unchanged groundwater levels.

iii. For grouping of the monitoring wells based on suction limit:
   a. 15.14% of the monitoring wells have their water levels always below suction limit (6 m) of suction-mode pumps.
   b. 59.72% of the monitoring wells maintain a cycle of water level below suction limit in 3–6 months during dry season throughout the study period.

c. the water levels of 25.14% monitoring wells never fall below critical depth/suction limit.

iv. For domestic water scarcity

a. In some parts of Bogra, Rajshahi, Naogaon, Joypurhat and Chapai Nowabgonj districts that form the Barind track, have severe water scarcity, especially for domestic supply, due to failure of shallow tubewells.

b. In most parts of the north-west region, there remains water scarcity during 3–6 months in the dry season of the years.

## 5.2 Recommendations

In light of the findings of this study, the following recommendations were made:

i. Based on the findings of this study, groundwater development policy of the north-west region of Bangladesh needs to be adjusted.

ii. Special attention needs to be given in areas where groundwater levels drop below critical suction limit of suction-mode pumps. Alternate technology for pumping groundwater needs be made available to provide household water.

iii. Different trend-analysis methods may yield different results. So, for reliable results, more than one trend-analysis method needs to be used to reliably determine trends/trend of the groundwater levels.

iv. In this study, identification of well locations with water scarcity based on suction limitation was done, but the social impact of water scarcity was not investigated in detail. Further study needs be done to find the clear image of those wells and social impacts of water scarcity in the concerned locations.

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# APPENDICES

# APPENDICES

**Appendix-1. Distribution of 350 monitoring wells selected for the study**

| WELL ID | DISTRICT | UPAZILA | VILLAGE | WELL ID | DISTRICT | UPAZILA | VILLAGE |
|---|---|---|---|---|---|---|---|
| GT8112001 | Rajshahi | Baghmara | Tahirpur | GT8172033 | Rajshahi | Paba | Bagdhanihat |
| GT8112002 | Rajshahi | Baghmara | Bhabaniganj | GT8172035 | Rajshahi | Paba | Hatgodagari |
| GT8112003 | Rajshahi | Baghmara | Birkutsha | GT8172036 | Rajshahi | Paba | Paba |
| GT8122005 | Rajshahi | Boalia | Master para | GT8172037 | Rajshahi | Paba | Namobhadra |
| GT8125006 | Rajshahi | Charghat | Mullikbagha | GT8172038 | Rajshahi | Paba | Bhodra |
| GT8125008 | Rajshahi | Charghat | Holidagachi | GT8172039 | Rajshahi | Paba | Talaimari |
| GT8125009 | Rajshahi | Charghat | Moktarpur | GT8172040 | Rajshahi | Paba | Haripur |
| GT8125010 | Rajshahi | Charghat | Gorshohurpur | GT8182041 | Rajshahi | Puthia | Puthia |
| GT8125011 | Rajshahi | Charghat | Yousufpur | GT8182042 | Rajshahi | Puthia | Jhokrakul |
| GT8125012 | Rajshahi | Charghat | Moshidpur | GT8194046 | Rajshahi | Tanore | Shamashpur |
| GT8131015 | Rajshahi | Durgapur | Alipur | GT8194048 | Rajshahi | Tanore | Gollapara |
| GT8134016 | Rajshahi | Godagari | Kazipara | GT8194049 | Rajshahi | Tanore | Tanore |
| GT8134017 | Rajshahi | Godagari | Godagari | GT8194047 | Rajshahi | Tanore | Mundumalahat |
| GT8134018 | Rajshahi | Godagari | Rajapurhat | GT1006001 | Bogra | Adamdighi | Talshoes |
| GT8134019 | Rajshahi | Godagari | Poshunda | GT1006002 | Bogra | Adamdighi | Sontehar |
| GT8134020 | Rajshahi | Godagari | Gorermath | GT1006003 | Bogra | Adamdighi | Sontehar |
| GT8134021 | Rajshahi | Godagari | Madarpur | GT1020004 | Bogra | Bogra sadar | Sutrapur |
| GT8134022 | Rajshahi | Godagari | Dumuria | GT1020005 | Bogra | Bogra sadar | Gukul |
| GT8134027 | Rajshahi | Godagari | Bhogobontapur | GT1020006 | Bogra | Bogra sadar | Sonaidighi |
| GT8134028 | Rajshahi | Godagari | Sreemontapur | GT1020007 | Bogra | Bogra sadar | Malotinagar |
| GT8153030 | Rajshahi | Mohanpur | Lalich | GT1027008 | Bogra | Dhunat | Dhunut |
| GT8153031 | Rajshahi | Mohanpur | Mohanpur | GT1033009 | Bogra | Dhupsanchia | Barogram |
| GT8172032 | Rajshahi | Paba | Damkurahat | GT1040010 | Bogra | Gabtali | Baladighi |

**Appendix-1. Distribution of 350 monitoring wells selected for the study (continued)**

| WELL ID | DISTRICT | UPAZILA | VILLAGE | WELL ID | DISTRICT | UPAZILA | VILLAGE |
|---|---|---|---|---|---|---|---|
| GT1040011 | Bogra | Gabtali | Gabtali | GT2721011 | Dinajpur | Bochaganj | Jinore |
| GT1040012 | Bogra | Gabtali | Saudabari | GT2721502 | Dinajpur | Bochaganj | Bajnia |
| GT1054013 | Bogra | Kahaloo | Kazipur | GT2721503 | Dinajpur | Bochaganj | Bairkuri |
| GT1054014 | Bogra | Kahaloo | Mohespur | GT2730012 | Dinajpur | Chirirbandar | Bhushirbandar |
| GT1067015 | Bogra | Nandigram | Nandigram | GT2730013 | Dinajpur | Chirirbandar | Ranirbandar |
| GT1081016 | Bogra | Sariakandi | Ramnagar | GT2730014 | Dinajpur | Chirirbandar | Kishmotfaizan |
| GT1081017 | Bogra | Sariakandi | Gossaibari | GT2730015 | Dinajpur | Chirirbandar | Saskandar |
| GT1081018 | Bogra | Sariakandi | Ramsandrapur | GT2730016 | Dinajpur | Chirirbandar | Chirirbandar |
| GT1081019 | Bogra | Sariakandi | Fulbari | GT2738017 | Dinajpur | Fulbari | Phulbari |
| GT1081020 | Bogra | Sariakandi | Boraikandi | GT2738018 | Dinajpur | Fulbari | Rangamati |
| GT1088021 | Bogra | Sherpur | Sherpurshospa | GT2743019 | Dinajpur | Ghoraghat | Lalbag |
| GT1088022 | Bogra | Sherpur | Laximkone | GT2747021 | Dinajpur | Hakimpur | Hakimpur |
| GT1088023 | Bogra | Sherpur | Kalshimati | GT2756023 | Dinajpur | Kaharole | Mukundapur |
| GT1094024 | Bogra | Shibganj | Shibgonj | GT2756024 | Dinajpur | Kaharole | Purbasadipur |
| GT1094025 | Bogra | Shibganj | Alladipur | GT2756026 | Dinajpur | Kaharole | Kashipur |
| GT1095026 | Bogra | Sonatola | Sukkanpukur | GT2760029 | Dinajpur | Khansama | Jahangirpur |
| GT1095027 | Bogra | Sonatola | Sonatala | GT2764030 | Dinajpur | Sadar | Dinajpur town |
| GT2710001 | Dinajpur | Birampur | East jaganathp | GT2764031 | Dinajpur | Sadar | Uttar gobindap |
| GT2712002 | Dinajpur | Birganj | Bishnupur | GT2764033 | Dinajpur | Sadar | Nasipur |
| GT2712003 | Dinajpur | Birganj | Birganj | GT2764034 | Dinajpur | Sadar | Goaldhihi |
| GT2712004 | Dinajpur | Birganj | Kabirajhat | GT2764035 | Dinajpur | Sadar | Tajpur |
| GT2712005 | Dinajpur | Birganj | Dolua | GT2764036 | Dinajpur | Sadar | Mohanpur |
| GT2712006 | Dinajpur | Birganj | Daulatpur | GT2764037 | Dinajpur | Sadar | Panchbari |
| GT2717008 | Dinajpur | Biral | Mangalpur | GT2764038 | Dinajpur | Sadar | Nimnagar |
| GT2717009 | Dinajpur | Biral | Biral | GT2764039 | Dinajpur | Sadar | Madhabpur |
| GT2717501 | Dinajpur | Biral | Kazipara | GT2769040 | Dinajpur | Nawabganj | Tapanghat |
| GT2721010 | Dinajpur | Bochaganj | Setabganj | GT2777042 | Dinajpur | Parbatipur | Madhya para |

**Appendix-1. Distribution of 350 monitoring wells selected for the study (continued)**

| WELL ID | DISTRICT | UPAZILA | VILLAGE | WELL ID | DISTRICT | UPAZILA | VILLAGE |
|---|---|---|---|---|---|---|---|
| GT2777043 | Dinajpur | Parbatipur | Parbatipur | GT4952003 | Kurigram | sadar | Kurigram |
| GT3224001 | Gaibandha | Sadar | Station road | GT4952004 | Kurigram | sadar | Sora |
| GT3224002 | Gaibandha | Sadar | Mohimagonj | GT4952005 | Kurigram | sadar | Pateshani |
| GT3224003 | Gaibandha | Sadar | Tulshighat | GT4961007 | Kurigram | Nageshwari | Sreepur |
| GT3230005 | Gaibandha | Gobindaganj | Sinjani | GT4994008 | Kurigram | Ulipur | Ulipur |
| GT3230006 | Gaibandha | Gobindaganj | Pargayra | GT4994009 | Kurigram | Ulipur | Durgapur |
| GT3267008 | Gaibandha | Palashbari | Nuniagari | GT5233001 | Lalmonirh.[1] | Hatibandha | Barakhata |
| GT3267009 | Gaibandha | Palashbari | Jhalingi | GT5233002 | Lalmonirh. | Hatibandha | Hatibanda |
| GT3282010 | Gaibandha | Sadullapur | Dhaperhat | GT5233004 | Lalmonirh. | Hatibandha | Daikhawa |
| GT3282011 | Gaibandha | Sadullapur | Sadullapur | GT5239005 | Lalmonirh. | Kaliganj | Ttarmusratmo |
| GT3288014 | Gaibandha | Saghatta | Ullah(gazaria) | GT5239006 | Lalmonirh. | Kaliganj | Aditmari |
| GT3288015 | Gaibandha | Saghatta | Bonarpara | GT5239007 | Lalmonirh. | Kaliganj | Bairati |
| GT3291017 | Gaibandha | Sundarganj | Bamandanga | GT5239008 | Lalmonirh. | Kaliganj | Baninagar |
| GT3291018 | Gaibandha | Sundarganj | Chachiamirja | GT5255009 | Lalmonirh. | Sadar | Lalmonirhat |
| GT3282012 | Gaibandha | Sadullapur | Hasanpara | GT5255010 | Lalmonirh. | Sadar | Tiestakutubkh |
| GT3230004 | Gaibandha | Gobindaganj | Gobindagonj | GT5255011 | Lalmonirh. | Sadar | Gokunda |
| GT3230007 | Gaibandha | Gobindaganj | Gobindagonj | GT5255012 | Lalmonirh. | Sadar | Khodrasaptana |
| GT3282013 | Gaibandha | Sadullapur | Hasanpara | GT5270013 | Lalmonirh. | Patgram | Ufarmara |
| GT3847001 | Joypurhat | Sadar | Joypurhat w.d. | GT5270015 | Lalmonirh. | Patgram | Islam nagar |
| GT3847002 | Joypurhat | Sadar | Chakbarket | GT5233003 | Lalmonirh. | Hatibandha | Archimbichad |
| GT3847003 | Joypurhat | Sadar | Parbatipur | GT6403001 | Naogaon | Atrai | Singsara |
| GT3861004 | Joypurhat | Khetlal | Nischintapur | GT6403002 | Naogaon | Atrai | Palsha |
| GT3861005 | Joypurhat | Khetlal | Khetlal | GT6403003 | Naogaon | Atrai | Bhaproboalia |
| GT3874006 | Joypurhat | Panchbibi | Panchabibi | GT6406004 | Naogaon | Badalgachhi | Badalgachhi |
| GT3874007 | Joypurhat | Panchbibi | Dowypur | GT6406005 | Naogaon | Badalgachhi | Gopalpur |
| GT3874008 | Joypurhat | Panchbibi | | GT6406006 | Naogaon | Badalgachhi | Jagadishpur |
| GT4909002 | Kurigram | Chilmari | Ramna | GT6428007 | Naogaon | Dhamoirhat | Kashipur |

**Appendix-1. Distribution of 350 monitoring wells selected for the study (continued)**

| WELL ID | DISTRICT | UPAZILA | VILLAGE | WELL ID | DISTRICT | UPAZILA | VILLAGE |
|---|---|---|---|---|---|---|---|
| GT6428008 | Naogaon | Dhamoirhat | Kharampur | GT6915004 | Natore | Baraigram | Jalsuka |
| GT6428009 | Naogaon | Dhamoirhat | Jotsrirampur | GT6941001 | Natore | Gurudaspur | Patharia |
| GT6428010 | Naogaon | Dhamoirhat | Fatepur | GT6941005 | Natore | Gurudaspur | Gurudaspur |
| GT6428011 | Naogaon | Dhamoirhat | Debipur | GT6944006 | Natore | Lalpur | Lalpur |
| GT6447021 | Naogaon | Manda | Baddapur | GT6944007 | Natore | Lalpur | Bilmaria |
| GT6450015 | Naogaon | Mahadebpur | Kumrail | GT6944009 | Natore | Lalpur | Lalpur |
| GT6450016 | Naogaon | Mahadebpur | Enayetpur | GT6944010 | Natore | Lalpur | Lalpur |
| GT6450017 | Naogaon | Mahadebpur | Khajur | GT6963012 | Natore | Natore sadar | Gobindapur |
| GT6450018 | Naogaon | Mahadebpur | Joanpur | GT6991013 | Natore | Singra | Karacmaria |
| GT6450019 | Naogaon | Mahadebpur | Binodpur | GT6991014 | Natore | Singra | Pakuria |
| GT6460025 | Naogaon | Sadar | Dubulhati | GT6991015 | Natore | Singra | Singra |
| GT6460026 | Naogaon | Sadar | Kirtipur | GT6991016 | Natore | Singra | Parsinaga |
| GT6460027 | Naogaon | Sadar | Par naogaon | GT7037001 | Nawabg.[2] | Gomastapur | Parbatipur |
| GT6475036 | Naogaon | Patnitala | Madhyanagar | GT7037003 | Nawabg. | Gomastapur | Khorkadanga |
| GT6475037 | Naogaon | Patnitala | Gaganpur | GT7037004 | Nawabg. | Gomastapur | Sahebgram |
| GT6475038 | Naogaon | Patnitala | Shibpurhat | GT7037005 | Nawabg. | Gomastapur | Rahanpur |
| GT6475039 | Naogaon | Patnitala | Jamalpur | GT7056006 | Nawabg. | Nachole | Nizampur |
| GT6475040 | Naogaon | Patnitala | Nazirpur | GT7056007 | Nawabg. | Nachole | Nachole |
| GT6475041 | Naogaon | Patnitala | Nadhuni | GT7056009 | Nawabg. | Nachole | Fazilpur |
| GT6479044 | Naogaon | Porsha | Nithpur | GT7056010 | Nawabg. | Nachole | Molliqepur |
| GT6479046 | Naogaon | Porsha | Khairpur | GT7066012 | Nawabg. | Sadar | Amnura |
| GT6485047 | Naogaon | Raninagar | Abedpur | GT7066013 | Nawabg. | Sadar | Chapai polsha |
| GT6485048 | Naogaon | Raninagar | Raninagar | GT7066014 | Nawabg. | Sadar | Nawabgonj |
| GT6486049 | Naogaon | Sapahar | Jabai | GT7066015 | Nawabg. | Sadar | Debinagar |
| GT6486051 | Naogaon | Sapahar | Nischintapur | GT7066016 | Nawabg. | Sadar | Chunakhali |
| GT6486052 | Naogaon | Sapahar | Ramrampur | GT7066018 | Nawabg. | Sadar | Ramjibonpur |
| GT6915002 | Natore | Baraigram | Garmati | GT7088020 | Nawabg. | Shibganj | Baliadighi |

**Appendix-1. Distribution of 350 monitoring wells selected for the study (continued)**

| WELL ID | DISTRICT | UPAZILA | VILLAGE | WELL ID | DISTRICT | UPAZILA | VILLAGE |
|---|---|---|---|---|---|---|---|
| GT7088021 | Nawabg. | Shibganj | Shibgonj bazar | GT7385026 | Nilphama. | Saidpur | Nizbari |
| GT7088022 | Nawabg. | Shibganj | Parkrishnapur | GT7385027 | Nilphama. | Saidpur | Bangalipur |
| GT7088023 | Nawabg. | Shibganj | Monkhasa | GT7605001 | Pabna | Atgharia | Atghoria |
| GT7088024 | Nawabg. | Shibganj | Roshia | GT7605002 | Pabna | Atgharia | Atghoria |
| GT7088025 | Nawabg. | Shibganj | Dubra | GT7605003 | Pabna | Atgharia | Durgapur |
| GT7088029 | Nawabg. | Shibganj | Dhaninagar | GT7616004 | Pabna | Bera | Nutanpara |
| GT7312001 | Nilphama.[3] | Dimla | Thakurgaon | GT7616005 | Pabna | Bera | Natiabari |
| GT7312002 | Nilphama. | Dimla | Khogakharibari | GT7616006 | Pabna | Bera | Talimnagar |
| GT7312003 | Nilphama. | Dimla | Ramdanga | GT7616007 | Pabna | Bera | Horidebpur |
| GT7312004 | Nilphama. | Dimla | Khalishachapa | GT7616008 | Pabna | Bera | Natunmirpur |
| GT7312005 | Nilphama. | Dimla | North jhunagac | GT7616009 | Pabna | Bera | Bijoygonj |
| GT7312006 | Nilphama. | Dimla | Uttar goyabari | GT7616010 | Pabna | Bera | Bijoygonj |
| GT7315007 | Nilphama. | Domar | Chilahati | GT7616011 | Pabna | Bera | Bijoygonj |
| GT7315008 | Nilphama. | Domar | Gomnati | GT7616012 | Pabna | Bera | Nolbhanga |
| GT7315009 | Nilphama. | Domar | Mirzagonj | GT7622013 | Pabna | Chatmohar | Chatmohor |
| GT7315010 | Nilphama. | Domar | Domar | GT7639017 | Pabna | Ishwardi | F.mohamadp |
| GT7315011 | Nilphama. | Domar | Baragacha | GT7639018 | Pabna | Ishwardi | Pearpur |
| GT7315012 | Nilphama. | Domar | Kumarbamnia | GT7639019 | Pabna | Ishwardi | Sarajhaudia |
| GT7315013 | Nilphama. | Domar | Harinchara | GT7639020 | Pabna | Ishwardi | Sarajhaudia |
| GT7315014 | Nilphama. | Domar | Domar | GT7655022 | Pabna | Sadar | Atuadakhnpar |
| GT7336016 | Nilphama. | Jaldhaka | Balagram | GT7655025 | Pabna | Sadar | Daponia |
| GT7336017 | Nilphama. | Jaldhaka | Jaldhaka | GT7655026 | Pabna | Sadar | Hemayetpur |
| GT7336018 | Nilphama. | Jaldhaka | Kherkatibazer | GT7655027 | Pabna | Sadar | Hemayetpur |
| GT7336019 | Nilphama. | Jaldhaka | Kaligonj(golna | GT7683030 | Pabna | Sujanagar | Shujanagar |
| GT7336020 | Nilphama. | Jaldhaka | Shalongram | GT7683031 | Pabna | Sujanagar | Dulai |
| GT7345022 | Nilphama. | Kishoreganj | Magura | GT7683032 | Pabna | Sujanagar | Nayagram |
| GT7345023 | Nilphama. | Kishoreganj | Baravita | GT7683033 | Pabna | Sujanagar | Satbaria |

**Appendix-1. Distribution of 350 monitoring wells selected for the study (continued)**

| WELL ID | DISTRICT | UPAZILA | VILLAGE | WELL ID | DISTRICT | UPAZILA | VILLAGE |
|---|---|---|---|---|---|---|---|
| GT7364025 | Nilphama. | Sadar | Nilphamari rly | GT8549006 | Rangpur | Sadar | Gangachara |
| GT7683034 | Pabna | Sujanagar | Satbaria | GT8549007 | Rangpur | Sadar | Jafarganj |
| GT7683035 | Pabna | Sujanagar | Satbaria | GT8558008 | Rangpur | Mithapukur | Mithapukur |
| GT7704001 | Panchag.[4] | Atwari | Puratonatwari | GT8558009 | Rangpur | Mithapukur | Chuhat |
| GT7704002 | Panchag. | Atwari | Tarai | GT8558010 | Rangpur | Mithapukur | Shantipurbaza |
| GT7704003 | Panchag. | Atwari | Alokhawa | GT8573011 | Rangpur | Pirgachha | Pirgacha |
| GT7704501 | Panchag. | Atwari | Toreya | GT8576012 | Rangpur | Pirganj | Pirganj |
| GT7704502 | Panchag. | Atwari | Jugikata | GT8576013 | Rangpur | Pirganj | Baradarga |
| GT7725004 | Panchag. | Boda | Tasherpara | GT8592014 | Rangpur | Taraganj | Fazilpur |
| GT7725005 | Panchag. | Boda | Boda bazar | GT8811001 | Sirajganj | Belkuchi | Shrenagar |
| GT7725006 | Panchag. | Boda | Sakowa | GT8811002 | Sirajganj | Belkuchi | Chala |
| GT7725008 | Panchag. | Boda | Maraya colony | GT8827003 | Sirajganj | Chauhali | Betil-hatkhola |
| GT7734009 | Panchag. | Debiganj | Kalupir | GT8844005 | Sirajganj | Kamrkhanda | Kamarkhanda |
| GT7734010 | Panchag. | Debiganj | Lakshmirhat | GT8850006 | Sirajganj | Kazipur | Roibari |
| GT7734011 | Panchag. | Debiganj | Sonahar | GT8850008 | Sirajganj | Kazipur | Ratankandi |
| GT7734012 | Panchag. | Debiganj | Debiganj | GT8861009 | Sirajganj | Royganj | Raygonj |
| GT7734013 | Panchag. | Debiganj | Tokrabasha | GT8861010 | Sirajganj | Royganj | Solonga |
| GT7773014 | Panchag. | Sadar | Jagdal | GT8861011 | Sirajganj | Royganj | Chandikona |
| GT7773015 | Panchag. | Sadar | Bodinajot | GT8867012 | Sirajganj | Shahjadpur | Dariapur |
| GT7773016 | Panchag. | Sadar | Panchagarh | GT8867013 | Sirajganj | Shahjadpur | Kashipur |
| GT7773018 | Panchag. | Sadar | Dafadarpara | GT8878014 | Sirajganj | Sadar | Sirajganj |
| GT7790020 | Panchag. | Tentulia | Burabarihat | GT8878015 | Sirajganj | Sadar | Harina |
| GT7790021 | Panchag. | Tentulia | Bangla bandh | GT8878016 | Sirajganj | Sadar | New bogara |
| GT7790022 | Panchag. | Tentulia | Shalbahan | GT8878017 | Sirajganj | Sadar | Daulatpur |
| GT7790023 | Panchag. | Tentulia | Tentulia | GT8878018 | Sirajganj | Sadar | Ditpuralal |
| GT8503001 | Rangpur | Badarganj | Badarganj | GT8878019 | Sirajganj | Sadar | Sialkoal |
| GT8527003 | Rangpur | Gangachara | Lalchandpur | GT8878020 | Sirajganj | Sadar | Ponsosuratia |

**Appendix-1. Distribution of 350 monitoring wells selected for the study (continued)**

| WELL ID | DISTRICT | UPAZILA | VILLAGE | WELL ID | DISTRICT | UPAZILA | VILLAGE |
|---|---|---|---|---|---|---|---|
| GT8549005 | Rangpur | Sadar | Nababganj | GT9482503 | Thakurg. | Pirganj | Tanshia |
| GT8889022 | Sirajganj | Tarash | Nimgachi | GT9486011 | Thakurg. | Ranisankail | Chandnchaha |
| GT8889023 | Sirajganj | Tarash | Gunta | GT9486012 | Thakurg. | Ranisankail | Ranisankail |
| GT8894024 | Sirajganj | Ullah para | Ullapara | GT9486014 | Thakurg. | Ranisankail | Ranisankail |
| GT8894025 | Sirajganj | Ullah para | Charmohanpur | GT9494015 | Thakurg. | Sadar | Ruhea |
| GT8894026 | Sirajganj | Ullah para | Binayekpur | GT9494016 | Thakurg. | Sadar | Farabari |
| GT8894027 | Sirajganj | Ullah para | Hatkamrul | GT9494017 | Thakurg. | Sadar | Hariharpur |
| GT9408001 | Thakurg.[5] | Baliadangi | Lahiri | GT9494019 | Thakurg. | Sadar | Goryagoplpu |
| GT9408002 | Thakurg. | Baliadangi | Baliadangi | GT9494020 | Thakurg. | Sadar | Bhelajan |
| GT9408003 | Thakurg. | Baliadangi | Lalapur | GT9494021 | Thakurg. | Sadar | Madhabpur |
| GT9408501 | Thakurg. | Baliadangi | Barabari | GT9494022 | Thakurg. | Sadar | Singia |
| GT9451004 | Thakurg. | Haripur | Haripur | GT9494023 | Thakurg. | Sadar | Saltahari |
| GT9451005 | Thakurg. | Haripur | Monnatali | GT9494025 | Thakurg. | Sadar | Doulatpur |
| GT9451502 | Thakurg. | Haripur | Pahargaon | GT9494027 | Thakurg. | Sadar | Khalishakuri |
| GT9482006 | Thakurg. | Pirganj | Saidpur | GT9494028 | Thakurg. | Sadar | Singpara |
| GT9482008 | Thakurg. | Pirganj | Chandpur | GT9494029 | Thakurg. | Sadar | Thakurgaon |
| GT9482010 | Thakurg. | Pirganj | Pirganj | GT9494030 | Thakurg. | Sadar | Kalibari |

[1]Lalmonirhat; [2]Chapai Nawabganj; [3]Nilphamari; [4]Panchagar; [5]Thakurgaon

**Appendix-2. MAKESENS trend analysis results for annual maximum groundwater levels**

| Well ID | Test Z | Slope | Remarks | Signif.[1] | Well ID | Test Z | Slope | Remarks | Signif. |
|---|---|---|---|---|---|---|---|---|---|
| GT8112001 | 3.42 | 0.16 | Increasing | S[2] | GT8172038 | 5.79 | 0.198 | Increasing | S |
| GT8112002 | 4.38 | 0.229 | Increasing | S | GT8172039 | 2.35 | 0.057 | Increasing | S |
| GT8112003 | 1.44 | 0.061 | Increasing | N[3] | GT8172040 | 6.18 | 0.240 | Increasing | S |
| GT8122005 | 5.64 | 0.189 | Increasing | S | GT8182041 | 5.16 | 0.127 | Increasing | S |
| GT8125006 | 4.71 | 0.063 | Increasing | S | GT8182042 | 5.60 | 0.263 | Increasing | S |
| GT8125008 | 5.21 | 0.101 | Increasing | S | GT8194046 | 6.99 | 0.236 | Increasing | S |
| GT8125009 | 4.36 | 0.173 | Increasing | S | GT8194048 | 6.91 | 0.369 | Increasing | S |
| GT8125010 | 1.25 | 0.013 | Increasing | N | GT8194049 | 7.25 | 0.256 | Increasing | S |
| GT8125011 | 4.64 | 0.166 | Increasing | S | GT8194047 | 3.10 | 0.257 | Increasing | S |
| GT8125012 | -1.82 | -0.020 | Decreasing | N | GT1006001 | 5.68 | 0.086 | Increasing | S |
| GT8131015 | 5.40 | 0.364 | Increasing | S | GT1006002 | 3.65 | 0.033 | Increasing | S |
| GT8134016 | 5.89 | 0.245 | Increasing | S | GT1006003 | 5.87 | 0.066 | Increasing | S |
| GT8134017 | 6.07 | 0.114 | Increasing | S | GT1020004 | -2.86 | -0.043 | Decreasing | S |
| GT8134018 | 3.73 | 0.150 | Increasing | S | GT1020005 | 0.50 | 0.006 | Increasing | N |
| GT8134019 | 6.42 | 0.447 | Increasing | S | GT1020006 | 5.13 | 0.057 | Increasing | S |
| GT8134020 | 5.92 | 0.165 | Increasing | S | GT1020007 | 3.16 | 0.027 | Increasing | S |
| GT8134021 | 4.38 | 0.079 | Increasing | S | GT1027008 | -0.08 | -0.001 | Decreasing | N |
| GT8134022 | 5.37 | 0.127 | Increasing | S | GT1033009 | 4.23 | 0.110 | Increasing | S |
| GT8134027 | 3.24 | 0.053 | Increasing | S | GT1040010 | -0.08 | 0.000 | Decreasing | N |
| GT8134028 | 4.57 | 0.084 | Increasing | S | GT1040011 | -1.85 | -0.017 | Decreasing | N |
| GT8153030 | 6.42 | 0.250 | Increasing | S | GT1040012 | 3.99 | 0.042 | Increasing | S |
| GT8153031 | 6.97 | 0.479 | Increasing | S | GT1054013 | 2.21 | 0.045 | Increasing | S |
| GT8172032 | 5.30 | 0.381 | Increasing | S | GT1054014 | 5.79 | 0.070 | Increasing | S |
| GT8172033 | 6.78 | 0.333 | Increasing | S | GT1067015 | -3.45 | -0.081 | Decreasing | S |
| GT8172035 | 6.04 | 0.300 | Increasing | S | GT1081016 | -5.01 | -0.115 | Decreasing | S |
| GT8172036 | 4.47 | 0.157 | Increasing | S | GT1081017 | 3.30 | 0.046 | Increasing | S |
| GT8172037 | 4.91 | 0.120 | Increasing | S | GT1081018 | 2.70 | 0.072 | Increasing | S |

**Appendix-2. MAKESENS trend analysis results for annual maximum groundwater levels (continued)**

| Well ID | Test Z | Slope | Remarks | Signif. | Well ID | Test Z | Slope | Remarks | Signif. |
|---|---|---|---|---|---|---|---|---|---|
| GT1081019 | -3.07 | -0.030 | Decreasing | S | GT2738017 | 5.95 | 0.190 | Increasing | S |
| GT1081020 | 1.10 | 0.018 | Increasing | N | GT2738018 | 5.32 | 0.102 | Increasing | S |
| GT1088021 | 1.15 | 0.014 | Increasing | N | GT2743019 | 3.59 | 0.041 | Increasing | S |
| GT1088022 | 3.30 | 0.029 | Increasing | S | GT2747021 | 4.88 | 0.064 | Increasing | S |
| GT1088023 | 5.02 | 0.108 | Increasing | S | GT2756023 | 3.30 | 0.023 | Increasing | S |
| GT1094024 | 5.02 | 0.108 | Increasing | S | GT2756024 | 2.98 | 0.032 | Increasing | S |
| GT1094025 | 5.39 | 0.071 | Increasing | S | GT2756026 | 2.95 | 0.075 | Increasing | S |
| GT1095026 | 1.62 | 0.012 | Increasing | N | GT2760029 | 3.51 | 0.031 | Increasing | S |
| GT1095027 | 5.58 | 0.108 | Increasing | S | GT2764030 | 3.80 | 0.031 | Increasing | S |
| GT2710001 | 2.51 | 0.040 | Increasing | S | GT2764031 | 2.86 | 0.025 | Increasing | S |
| GT2712002 | 4.59 | 0.180 | Increasing | S | GT2764033 | 3.46 | 0.032 | Increasing | S |
| GT2712003 | 2.06 | 0.017 | Increasing | S | GT2764034 | 3.45 | 0.103 | Increasing | S |
| GT2712004 | 3.62 | 0.054 | Increasing | S | GT2764035 | 5.88 | 0.182 | Increasing | S |
| GT2712005 | 2.70 | 0.028 | Increasing | S | GT2764036 | 4.27 | 0.061 | Increasing | S |
| GT2712006 | 2.07 | 0.024 | Increasing | S | GT2764037 | 5.38 | 0.158 | Increasing | S |
| GT2717008 | 4.59 | 0.098 | Increasing | S | GT2764038 | 5.45 | 0.085 | Increasing | S |
| GT2717009 | 4.59 | 0.098 | Increasing | S | GT2764039 | 4.36 | 0.169 | Increasing | S |
| GT2717501 | 5.77 | 0.050 | Increasing | S | GT2769040 | 4.10 | 0.044 | Increasing | S |
| GT2721010 | 4.67 | 0.053 | Increasing | S | GT2777042 | 6.21 | 0.125 | Increasing | S |
| GT2721011 | 4.17 | 0.043 | Increasing | S | GT2777043 | 5.86 | 0.093 | Increasing | S |
| GT2721502 | 5.40 | 0.103 | Increasing | S | GT3224001 | 3.18 | 0.029 | Increasing | S |
| GT2721503 | 4.51 | 0.049 | Increasing | S | GT3224002 | -3.37 | -0.044 | Decreasing | S |
| GT2730012 | 4.15 | 0.100 | Increasing | S | GT3224003 | 2.67 | 0.031 | Increasing | S |
| GT2730013 | 3.66 | 0.033 | Increasing | S | GT3230005 | -1.19 | -0.007 | Decreasing | N |
| GT2730014 | 2.64 | 0.033 | Increasing | S | GT3230006 | 2.95 | 0.016 | Increasing | S |
| GT2730015 | 3.40 | 0.034 | Increasing | S | GT3267008 | -1.88 | -0.025 | Decreasing | N |
| GT2730016 | 5.40 | 0.074 | Increasing | S | GT3267009 | -1.65 | -0.016 | Decreasing | N |

**Appendix-2. MAKESENS trend analysis results for annual maximum groundwater levels (continued)**

| Well ID | Test Z | Slope | Remarks | Signif. | Well ID | Test Z | Slope | Remarks | Signif. |
|---|---|---|---|---|---|---|---|---|---|
| GT3282010 | 2.96 | 0.043 | Increasing | S | GT5233004 | 2.11 | 0.019 | Increasing | S |
| GT3282011 | 2.78 | 0.023 | Increasing | S | GT5239005 | -1.40 | -0.024 | Decreasing | N |
| GT3288014 | 2.32 | 0.020 | Increasing | S | GT5239006 | 3.73 | 0.023 | Increasing | S |
| GT3288015 | 2.06 | 0.017 | Increasing | S | GT5239007 | 4.82 | 0.042 | Increasing | S |
| GT3291017 | 0.39 | 0.002 | Increasing | N | GT5239008 | 5.03 | 0.041 | Increasing | S |
| GT3291018 | 1.02 | 0.017 | Increasing | N | GT5255009 | 3.91 | 0.045 | Increasing | S |
| GT3282012 | 4.81 | 0.058 | Increasing | S | GT5255010 | 3.54 | 0.020 | Increasing | S |
| GT3230004 | 3.08 | 0.025 | Increasing | S | GT5255011 | 4.45 | 0.039 | Increasing | S |
| GT3230007 | 6.28 | 0.097 | Increasing | S | GT5255012 | 4.58 | 0.067 | Increasing | S |
| GT3282013 | -2.22 | -0.050 | Decreasing | S | GT5270013 | 1.20 | 0.008 | Increasing | N |
| GT3847001 | 4.48 | 0.041 | Increasing | S | GT5270015 | 0.37 | 0.004 | Increasing | N |
| GT3847002 | 3.09 | 0.190 | Increasing | S | GT5233003 | 1.70 | 0.027 | Increasing | N |
| GT3847003 | 5.56 | 0.170 | Increasing | S | GT6403001 | 4.69 | 0.149 | Increasing | S |
| GT3861004 | 6.12 | 0.137 | Increasing | S | GT6403002 | 5.03 | 0.056 | Increasing | S |
| GT3861005 | 5.66 | 0.085 | Increasing | S | GT6403003 | 0.73 | 0.028 | Increasing | N |
| GT3874006 | 5.64 | 0.105 | Increasing | S | GT6406004 | 3.50 | 0.064 | Increasing | S |
| GT3874007 | 3.10 | 0.062 | Increasing | S | GT6406005 | 5.27 | 0.120 | Increasing | S |
| GT3874008 | 3.03 | 0.077 | Increasing | S | GT6406006 | 3.51 | 0.183 | Increasing | S |
| GT4909002 | 5.65 | 0.070 | Increasing | S | GT6428007 | 6.21 | 0.179 | Increasing | S |
| GT4952003 | 1.80 | 0.016 | Increasing | N | GT6428008 | 1.46 | 0.015 | Increasing | N |
| GT4952004 | -1.25 | -0.027 | Decreasing | N | GT6428009 | 4.19 | 0.050 | Increasing | S |
| GT4952005 | 1.19 | 0.006 | Increasing | N | GT6428010 | 3.87 | 0.060 | Increasing | S |
| GT4961007 | 1.72 | 0.012 | Increasing | N | GT6428011 | 5.21 | 0.155 | Increasing | S |
| GT4994008 | 2.26 | 0.018 | Increasing | S | GT6447021 | 5.80 | 0.094 | Increasing | S |
| GT4994009 | 4.35 | 0.055 | Increasing | S | GT6450015 | 5.27 | 0.074 | Increasing | S |
| GT5233001 | 0.42 | 0.002 | Increasing | N | GT6450016 | 4.69 | 0.082 | Increasing | S |
| GT5233002 | 3.81 | 0.026 | Increasing | S | GT6450017 | 7.35 | 0.163 | Increasing | S |

**Appendix-2. MAKESENS trend analysis results for annual maximum groundwater levels (continued)**

| Well ID | Test Z | Slope | Remarks | Signif. | Well ID | Test Z | Slope | Remarks | Signif. |
|---|---|---|---|---|---|---|---|---|---|
| GT6450018 | 4.87 | 0.086 | Increasing | S | GT6991013 | 5.75 | 0.067 | Increasing | S |
| GT6450019 | -1.43 | -0.039 | Decreasing | N | GT6991014 | 1.66 | 0.017 | Increasing | N |
| GT6460025 | 5.08 | 0.140 | Increasing | S | GT6991015 | 2.84 | 0.069 | Increasing | S |
| GT6460026 | 4.21 | 0.073 | Increasing | S | GT6991016 | 1.30 | 0.046 | Increasing | N |
| GT6460027 | 4.20 | 0.081 | Increasing | S | GT7037001 | 3.70 | 0.050 | Increasing | S |
| GT6475036 | 7.07 | 0.178 | Increasing | S | GT7037003 | 6.41 | 0.812 | Increasing | S |
| GT6475037 | 5.52 | 0.126 | Increasing | S | GT7037004 | 1.12 | 0.020 | Increasing | N |
| GT6475038 | 4.56 | 0.117 | Increasing | S | GT7037005 | 3.52 | 0.140 | Increasing | S |
| GT6475039 | 5.82 | 0.197 | Increasing | S | GT7056006 | 5.95 | 0.509 | Increasing | S |
| GT6475040 | 3.29 | 0.057 | Increasing | S | GT7056007 | 7.05 | 0.448 | Increasing | S |
| GT6475041 | 4.54 | 0.068 | Increasing | S | GT7056009 | 4.30 | 0.459 | Increasing | S |
| GT6479044 | 2.27 | 0.132 | Increasing | S | GT7056010 | 4.97 | 0.068 | Increasing | S |
| GT6479046 | 7.10 | 0.166 | Increasing | S | GT7066012 | 6.31 | 0.509 | Increasing | S |
| GT6485047 | 5.90 | 0.085 | Increasing | S | GT7066013 | 0.68 | 0.021 | Increasing | N |
| GT6485048 | 5.02 | 0.066 | Increasing | S | GT7066014 | 0.00 | 0.000 | No trend | N |
| GT6486049 | 4.29 | 1.140 | Increasing | S | GT7066015 | 5.87 | 0.071 | Increasing | S |
| GT6486051 | 4.41 | 1.229 | Increasing | S | GT7066016 | 3.28 | 0.040 | Increasing | S |
| GT6486052 | 3.65 | 1.608 | Increasing | S | GT7066018 | 2.76 | 0.071 | Increasing | S |
| GT6915002 | 4.32 | 0.150 | Increasing | S | GT7088020 | 1.25 | 0.056 | Increasing | N |
| GT6915004 | 3.18 | 0.083 | Increasing | S | GT7088021 | -0.81 | -0.014 | Decreasing | N |
| GT6941001 | 3.57 | 0.200 | Increasing | S | GT7088022 | 0.00 | 0.000 | No trend | N |
| GT6941005 | 4.30 | 0.147 | Increasing | S | GT7088023 | 4.71 | 0.058 | Increasing | S |
| GT6944006 | -0.66 | -0.013 | Decreasing | N | GT7088024 | 4.08 | 0.036 | Increasing | S |
| GT6944007 | -1.44 | -0.042 | Decreasing | N | GT7088025 | 5.52 | 0.163 | Increasing | S |
| GT6944009 | -1.21 | -0.017 | Decreasing | N | GT7088029 | 4.66 | 0.050 | Increasing | S |
| GT6944010 | -0.88 | -0.013 | Decreasing | N | GT7312001 | -2.18 | -0.011 | Decreasing | S |
| GT6963012 | 1.65 | 0.054 | Increasing | N | GT7312002 | 3.76 | 0.027 | Increasing | S |

**Appendix-2. MAKESENS trend analysis results for annual maximum groundwater levels (continued)**

| Well ID | Test Z | Slope | Remarks | Signif. | Well ID | Test Z | Slope | Remarks | Signif. |
|---|---|---|---|---|---|---|---|---|---|
| GT7312003 | 3.44 | 0.028 | Increasing | S | GT7616006 | 1.22 | 0.034 | Increasing | N |
| GT7312004 | -3.00 | -0.033 | Decreasing | S | GT7616007 | 2.66 | 0.028 | Increasing | S |
| GT7312005 | -0.67 | -0.005 | Decreasing | N | GT7616008 | 3.32 | 0.035 | Increasing | S |
| GT7312006 | 4.35 | 0.058 | Increasing | S | GT7616009 | -0.71 | -0.015 | Decreasing | N |
| GT7315007 | 4.54 | 0.051 | Increasing | S | GT7616010 | 1.80 | 0.037 | Increasing | N |
| GT7315008 | 1.02 | 0.008 | Increasing | N | GT7616011 | 0.16 | 0.001 | Increasing | N |
| GT7315009 | 5.27 | 0.069 | Increasing | S | GT7616012 | -3.39 | -0.031 | Decreasing | S |
| GT7315010 | 3.54 | 0.037 | Increasing | S | GT7622013 | 4.45 | 0.147 | Increasing | S |
| GT7315011 | 5.53 | 0.077 | Increasing | S | GT7639017 | 3.23 | 0.061 | Increasing | S |
| GT7315012 | 6.48 | 0.166 | Increasing | S | GT7639018 | -0.23 | -0.003 | Decreasing | N |
| GT7315013 | 5.58 | 0.036 | Increasing | S | GT7639019 | 1.62 | 0.016 | Increasing | N |
| GT7315014 | 3.18 | 0.041 | Increasing | S | GT7639020 | 3.76 | 0.040 | Increasing | S |
| GT7336016 | -2.98 | -0.025 | Decreasing | S | GT7655022 | 3.73 | 0.067 | Increasing | S |
| GT7336017 | -4.43 | -0.051 | Decreasing | S | GT7655025 | 2.23 | 0.050 | Increasing | S |
| GT7336018 | 2.37 | 0.042 | Increasing | S | GT7655026 | 4.39 | 0.053 | Increasing | S |
| GT7336019 | 4.30 | 0.030 | Increasing | S | GT7655027 | 4.07 | 0.054 | Increasing | S |
| GT7336020 | -4.51 | -0.043 | Decreasing | S | GT7683030 | 1.66 | 0.021 | Increasing | N |
| GT7345022 | -2.53 | -0.022 | Decreasing | S | GT7683031 | 3.05 | 0.061 | Increasing | S |
| GT7345023 | -3.05 | -0.035 | Decreasing | S | GT7683032 | -1.58 | -0.061 | Decreasing | N |
| GT7364025 | 3.76 | 0.069 | Increasing | S | GT7683033 | 2.55 | 0.038 | Increasing | S |
| GT7385026 | 2.03 | 0.038 | Increasing | S | GT7683034 | 1.89 | 0.017 | Increasing | N |
| GT7385027 | 0.24 | 0.010 | Increasing | N | GT7683035 | 1.39 | 0.025 | Increasing | N |
| GT7605001 | 3.76 | 0.101 | Increasing | S | GT7704001 | 3.64 | 0.052 | Increasing | S |
| GT7605002 | 4.53 | 0.119 | Increasing | S | GT7704002 | 0.34 | 0.002 | Increasing | N |
| GT7605003 | 4.72 | 0.133 | Increasing | S | GT7704003 | -0.37 | -0.006 | Decreasing | N |
| GT7616004 | -1.38 | -0.011 | Decreasing | N | GT7704501 | 3.07 | 0.019 | Increasing | S |
| GT7616005 | -0.24 | -0.004 | Decreasing | N | GT7704502 | 1.83 | 0.018 | Increasing | N |

**Appendix-2. MAKESENS trend analysis results for annual maximum groundwater levels (continued)**

| Well ID | Test Z | Slope | Remarks | Signif. | Well ID | Test Z | Slope | Remarks | Signif. |
|---|---|---|---|---|---|---|---|---|---|
| GT7725004 | 1.14 | 0.021 | Increasing | N | GT8576013 | 1.48 | 0.044 | Increasing | N |
| GT7725005 | 1.29 | 0.022 | Increasing | N | GT8592014 | 2.43 | 0.026 | Increasing | S |
| GT7725006 | 1.49 | 0.029 | Increasing | N | GT8811001 | -2.42 | -0.028 | Decreasing | S |
| GT7725008 | 3.97 | 0.027 | Increasing | S | GT8811002 | 0.88 | 0.008 | Increasing | N |
| GT7734009 | 3.94 | 0.090 | Increasing | S | GT8827003 | 0.86 | 0.025 | Increasing | N |
| GT7734010 | 0.78 | 0.012 | Increasing | N | GT8844005 | 3.31 | 0.029 | Increasing | S |
| GT7734011 | 5.52 | 0.063 | Increasing | S | GT8850006 | 0.39 | 0.001 | Increasing | N |
| GT7734012 | 1.12 | 0.003 | Increasing | N | GT8850008 | 5.58 | 0.057 | Increasing | S |
| GT7734013 | 2.21 | 0.039 | Increasing | S | GT8861009 | 1.54 | 0.036 | Increasing | N |
| GT7773014 | 2.09 | 0.022 | Increasing | S | GT8861010 | 2.45 | 0.026 | Increasing | S |
| GT7773015 | -2.17 | -0.021 | Decreasing | S | GT8861011 | 4.43 | 0.102 | Increasing | S |
| GT7773016 | 0.29 | 0.003 | Increasing | N | GT8867012 | 4.15 | 0.052 | Increasing | S |
| GT7773018 | 5.29 | 0.065 | Increasing | S | GT8867013 | 2.77 | 0.063 | Increasing | S |
| GT7790020 | -0.62 | -0.006 | Decreasing | N | GT8878014 | 0.42 | 0.003 | Increasing | N |
| GT7790021 | -0.08 | -0.001 | Decreasing | N | GT8878015 | 3.49 | 0.035 | Increasing | S |
| GT7790022 | 1.60 | 0.012 | Increasing | N | GT8878016 | 3.64 | 0.023 | Increasing | S |
| GT7790023 | 5.18 | 0.039 | Increasing | S | GT8878017 | 4.72 | 0.062 | Increasing | S |
| GT8503001 | 2.56 | 0.026 | Increasing | S | GT8878018 | 0.55 | 0.003 | Increasing | N |
| GT8527003 | 2.25 | 0.024 | Increasing | S | GT8878019 | 1.80 | 0.015 | Increasing | N |
| GT8549005 | -0.88 | -0.010 | Decreasing | N | GT8878020 | 2.38 | 0.071 | Increasing | S |
| GT8549006 | -0.93 | -0.008 | Decreasing | N | GT8889022 | -2.18 | -0.065 | Decreasing | S |
| GT8549007 | 0.76 | 0.005 | Increasing | N | GT8889023 | 5.16 | 0.048 | Increasing | S |
| GT8558008 | -1.41 | -0.016 | Decreasing | N | GT8894024 | 1.02 | 0.013 | Increasing | N |
| GT8558009 | 1.66 | 0.012 | Increasing | N | GT8894025 | 4.78 | 0.061 | Increasing | S |
| GT8558010 | 2.74 | 0.053 | Increasing | S | GT8894026 | 1.84 | 0.026 | Increasing | N |
| GT8573011 | -1.69 | -0.012 | Decreasing | N | GT8894027 | 2.14 | 0.084 | Increasing | S |
| GT8576012 | 3.13 | 0.064 | Increasing | S | GT9408001 | 0.50 | 0.006 | Increasing | N |

**Appendix-2. MAKESENS trend analysis results for annual maximum groundwater levels (continued)**

| Well ID | Test Z | Slope | Remarks | Signif. | Well ID | Test Z | Slope | Remarks | Signif. |
|---|---|---|---|---|---|---|---|---|---|
| GT9408002 | 2.93 | 0.019 | Increasing | S | GT9494015 | 3.89 | 0.055 | Increasing | S |
| GT9408003 | -0.50 | -0.008 | Decreasing | N | GT9494016 | -0.29 | -0.006 | Decreasing | N |
| GT9408501 | 4.09 | 0.049 | Increasing | S | GT9494017 | 2.66 | 0.020 | Increasing | S |
| GT9451004 | 3.57 | 0.051 | Increasing | S | GT9494019 | 2.91 | 0.052 | Increasing | S |
| GT9451005 | 4.49 | 0.050 | Increasing | S | GT9494020 | 2.87 | 0.050 | Increasing | S |
| GT9451502 | 2.11 | 0.026 | Increasing | S | GT9494021 | 2.91 | 0.035 | Increasing | S |
| GT9482006 | 3.49 | 0.044 | Increasing | S | GT9494022 | 5.23 | 0.071 | Increasing | S |
| GT9482008 | 2.64 | 0.034 | Increasing | S | GT9494023 | 3.20 | 0.028 | Increasing | S |
| GT9482010 | 3.08 | 0.045 | Increasing | S | GT9494025 | 2.04 | 0.037 | Increasing | S |
| GT9482503 | 5.17 | 0.058 | Increasing | S | GT9494027 | 3.88 | 0.056 | Increasing | S |
| GT9486011 | 1.10 | 0.012 | Increasing | N | GT9494028 | -1.84 | -0.035 | Decreasing | N |
| GT9486012 | 3.42 | 0.026 | Increasing | S | GT9494029 | 6.31 | 0.070 | Increasing | S |
| GT9486014 | 4.59 | 0.036 | Increasing | S | GT9494030 | 1.76 | 0.020 | Increasing | N |

[1]Statistical Significance; [2]Significant (p=0.05); [3]Not significant (p=0.05)

**Appendix-3. MAKESENS trend analysis results for annual minimum groundwater levels**

| Well ID | Test Z | Slope | Remarks | Signif.[1] | Well ID | Test Z | Slope | Remarks | Signif. |
|---|---|---|---|---|---|---|---|---|---|
| GT8112001 | 2.58 | 0.055 | Increasing | S[2] | GT8172038 | 5.97 | 0.130 | Increasing | S |
| GT8112002 | 5.11 | 0.108 | Increasing | S | GT8172039 | 3.69 | 0.086 | Increasing | S |
| GT8112003 | 2.83 | 0.089 | Increasing | S | GT8172040 | 4.15 | 0.081 | Increasing | S |
| GT8122005 | 5.64 | 0.154 | Increasing | S | GT8182041 | 3.62 | 0.038 | Increasing | S |
| GT8125006 | 5.64 | 0.154 | Increasing | S | GT8182042 | 3.10 | 0.037 | Increasing | S |
| GT8125008 | 3.54 | 0.062 | Increasing | S | GT8194046 | 7.22 | 0.435 | Increasing | S |
| GT8125009 | 4.43 | 0.084 | Increasing | S | GT8194048 | 7.44 | 0.454 | Increasing | S |
| GT8125010 | 3.31 | 0.066 | Increasing | S | GT8194049 | 7.53 | 0.450 | Increasing | S |
| GT8125011 | 3.29 | 0.067 | Increasing | S | GT8194047 | 4.12 | 0.423 | Increasing | S |
| GT8125012 | 3.08 | 0.076 | Increasing | S | GT1006001 | 6.05 | 0.306 | Increasing | S |
| GT8131015 | 2.99 | 0.034 | Increasing | S | GT1006002 | 4.70 | 0.141 | Increasing | S |
| GT8134016 | 0.98 | 0.155 | Increasing | N[3] | GT1006003 | 5.85 | 0.300 | Increasing | S |
| GT8134017 | 5.11 | 0.178 | Increasing | S | GT1020004 | 3.58 | 0.108 | Increasing | S |
| GT8134018 | 2.66 | 0.202 | Increasing | S | GT1020005 | 3.33 | 0.082 | Increasing | S |
| GT8134019 | 6.89 | 0.644 | Increasing | S | GT1020006 | 4.33 | 0.153 | Increasing | S |
| GT8134020 | 6.50 | 0.285 | Increasing | S | GT1020007 | 4.80 | 0.142 | Increasing | S |
| GT8134021 | 5.09 | 0.156 | Increasing | S | GT1027008 | 3.28 | 0.088 | Increasing | S |
| GT8134022 | 3.75 | 0.066 | Increasing | S | GT1033009 | 4.61 | 0.160 | Increasing | S |
| GT8134027 | 3.68 | 0.083 | Increasing | S | GT1040010 | 2.60 | 0.050 | Increasing | S |
| GT8134028 | 4.22 | 0.096 | Increasing | S | GT1040011 | 1.64 | 0.023 | Increasing | N |
| GT8153030 | 6.08 | 0.219 | Increasing | S | GT1040012 | 3.97 | 0.068 | Increasing | S |
| GT8153031 | 6.02 | 0.197 | Increasing | S | GT1054013 | 4.56 | 0.201 | Increasing | S |
| GT8172032 | 2.94 | 0.081 | Increasing | S | GT1054014 | 5.40 | 0.234 | Increasing | S |
| GT8172033 | 6.39 | 0.304 | Increasing | S | GT1067015 | 5.32 | 0.137 | Increasing | S |
| GT8172035 | 3.52 | 0.058 | Increasing | S | GT1081016 | 0.86 | 0.003 | Increasing | N |
| GT8172036 | 5.23 | 0.057 | Increasing | S | GT1081017 | 2.43 | 0.042 | Increasing | S |
| GT8172037 | 5.27 | 0.105 | Increasing | S | GT1081018 | 2.30 | 0.046 | Increasing | S |

**Appendix-3. MAKESENS trend analysis results for annual minimum groundwater levels (continued)**

| Well ID | Test Z | Slope | Remarks | Signif. | Well ID | Test Z | Slope | Remarks | Signif. |
|---|---|---|---|---|---|---|---|---|---|
| GT1081019 | 1.17 | 0.020 | Increasing | N | GT2738017 | 4.78 | 0.139 | Increasing | S |
| GT1081020 | 2.19 | 0.027 | Increasing | S | GT2738018 | 5.27 | 0.086 | Increasing | S |
| GT1088021 | 3.23 | 0.082 | Increasing | S | GT2743019 | 1.04 | 0.020 | Increasing | N |
| GT1088022 | 3.70 | 0.163 | Increasing | S | GT2747021 | 4.20 | 0.072 | Increasing | S |
| GT1088023 | 4.09 | 0.063 | Increasing | S | GT2756023 | 0.61 | 0.005 | Increasing | N |
| GT1094024 | 4.09 | 0.063 | Increasing | S | GT2756024 | 5.33 | 0.088 | Increasing | S |
| GT1094025 | 4.57 | 0.100 | Increasing | S | GT2756026 | 4.05 | 0.041 | Increasing | S |
| GT1095026 | 3.16 | 0.043 | Increasing | S | GT2760029 | 0.88 | 0.006 | Increasing | N |
| GT1095027 | 4.37 | 0.096 | Increasing | S | GT2764030 | 1.05 | 0.013 | Increasing | N |
| GT2710001 | 3.13 | 0.108 | Increasing | S | GT2764031 | 0.20 | 0.005 | Increasing | N |
| GT2712002 | 4.80 | 0.055 | Increasing | S | GT2764033 | 0.41 | 0.005 | Increasing | N |
| GT2712003 | 3.24 | 0.066 | Increasing | S | GT2764034 | 1.84 | 0.010 | Increasing | N |
| GT2712004 | 1.35 | 0.012 | Increasing | N | GT2764035 | 5.42 | 0.083 | Increasing | S |
| GT2712005 | 1.26 | 0.008 | Increasing | N | GT2764036 | 2.84 | 0.049 | Increasing | S |
| GT2712006 | 1.36 | 0.017 | Increasing | N | GT2764037 | 2.97 | 0.037 | Increasing | S |
| GT2717008 | 2.88 | 0.028 | Increasing | S | GT2764038 | 4.33 | 0.119 | Increasing | S |
| GT2717009 | 2.88 | 0.028 | Increasing | S | GT2764039 | 3.23 | 0.027 | Increasing | S |
| GT2717501 | 4.72 | 0.095 | Increasing | S | GT2769040 | 4.56 | 0.099 | Increasing | S |
| GT2721010 | 2.06 | 0.021 | Increasing | S | GT2777042 | 3.55 | 0.022 | Increasing | S |
| GT2721011 | 1.84 | 0.004 | Increasing | N | GT2777043 | 5.69 | 0.132 | Increasing | S |
| GT2721502 | 3.67 | 0.016 | Increasing | S | GT3224001 | 5.69 | 0.132 | Increasing | S |
| GT2721503 | 0.37 | 0.001 | Increasing | N | GT3224002 | 0.60 | 0.013 | Increasing | N |
| GT2730012 | 3.63 | 0.047 | Increasing | S | GT3224003 | 1.76 | 0.010 | Increasing | N |
| GT2730013 | -1.31 | -0.012 | Decreasing | N | GT3230005 | 0.36 | 0.004 | Increasing | N |
| GT2730014 | 1.45 | 0.007 | Increasing | N | GT3230006 | 4.48 | 0.049 | Increasing | S |
| GT2730015 | 1.17 | 0.013 | Increasing | N | GT3267008 | 0.00 | 0.000 | No trend | N |
| GT2730016 | 1.29 | 0.014 | Increasing | N | GT3267009 | -0.28 | -0.004 | Decreasing | N |

**Appendix-3. MAKESENS trend analysis results for annual minimum groundwater levels (continued)**

| Well ID | Test Z | Slope | Remarks | Signif. | Well ID | Test Z | Slope | Remarks | Signif. |
|---|---|---|---|---|---|---|---|---|---|
| GT3282010 | 2.78 | 0.058 | Increasing | S | GT5233004 | 1.88 | 0.011 | Increasing | N |
| GT3282011 | 0.00 | 0.000 | No trend | N | GT5239005 | -1.69 | -0.015 | Decreasing | N |
| GT3288014 | -3.36 | -0.042 | Decreasing | S | GT5239006 | 0.53 | 0.005 | Increasing | N |
| GT3288015 | 1.56 | 0.023 | Increasing | N | GT5239007 | 1.40 | 0.009 | Increasing | N |
| GT3291017 | 1.36 | 0.021 | Increasing | N | GT5239008 | 2.32 | 0.012 | Increasing | S |
| GT3291018 | 1.95 | 0.025 | Increasing | N | GT5255009 | -0.26 | -0.001 | Decreasing | N |
| GT3282012 | 2.26 | 0.025 | Increasing | S | GT5255010 | -0.78 | -0.004 | Decreasing | N |
| GT3230004 | 3.20 | 0.040 | Increasing | S | GT5255011 | 0.50 | 0.003 | Increasing | N |
| GT3230007 | 6.44 | 0.257 | Increasing | S | GT5255012 | 3.58 | 0.044 | Increasing | S |
| GT3282013 | 2.66 | 0.047 | Increasing | S | GT5270013 | 3.11 | 0.023 | Increasing | S |
| GT3847001 | 5.31 | 0.170 | Increasing | S | GT5270015 | 1.48 | 0.013 | Increasing | N |
| GT3847002 | 2.96 | 0.106 | Increasing | S | GT5233003 | 4.43 | 0.049 | Increasing | S |
| GT3847003 | 4.91 | 0.117 | Increasing | S | GT6403001 | 1.02 | 0.020 | Increasing | N |
| GT3861004 | 6.51 | 0.244 | Increasing | S | GT6403002 | 3.91 | 0.051 | Increasing | S |
| GT3861005 | 4.90 | 0.209 | Increasing | S | GT6403003 | 2.04 | 0.047 | Increasing | S |
| GT3874006 | 5.71 | 0.109 | Increasing | S | GT6406004 | 3.28 | 0.103 | Increasing | S |
| GT3874007 | 4.32 | 0.156 | Increasing | S | GT6406005 | 3.20 | 0.073 | Increasing | S |
| GT3874008 | 1.49 | 0.023 | Increasing | N | GT6406006 | 4.86 | 0.153 | Increasing | S |
| GT4909002 | 0.73 | 0.007 | Increasing | N | GT6428007 | 6.63 | 0.384 | Increasing | S |
| GT4952003 | 4.70 | 0.056 | Increasing | S | GT6428008 | 2.06 | 0.053 | Increasing | S |
| GT4952004 | 1.12 | 0.014 | Increasing | N | GT6428009 | 5.50 | 0.160 | Increasing | S |
| GT4952005 | -0.36 | -0.004 | Decreasing | N | GT6428010 | 4.27 | 0.187 | Increasing | S |
| GT4961007 | 0.06 | 0.001 | Increasing | N | GT6428011 | 5.87 | 0.359 | Increasing | S |
| GT4994008 | 1.79 | 0.008 | Increasing | N | GT6447021 | 4.12 | 0.107 | Increasing | S |
| GT4994009 | 2.40 | 0.020 | Increasing | S | GT6450015 | 5.91 | 0.200 | Increasing | S |
| GT5233001 | -1.22 | -0.005 | Decreasing | N | GT6450016 | 4.36 | 0.121 | Increasing | S |
| GT5233002 | 1.63 | 0.012 | Increasing | N | GT6450017 | 7.14 | 0.304 | Increasing | S |

**Appendix-3. MAKESENS trend analysis results for annual minimum groundwater levels (continued)**

| Well ID | Test Z | Slope | Remarks | Signif. | Well ID | Test Z | Slope | Remarks | Signif. |
|---|---|---|---|---|---|---|---|---|---|
| GT6450018 | 5.42 | 0.285 | Increasing | S | GT6991013 | 3.83 | 0.151 | Increasing | S |
| GT6450019 | 5.71 | 0.118 | Increasing | S | GT6991014 | 2.84 | 0.056 | Increasing | S |
| GT6460025 | 4.10 | 0.076 | Increasing | S | GT6991015 | 2.24 | 0.035 | Increasing | S |
| GT6460026 | 4.55 | 0.110 | Increasing | S | GT6991016 | 1.82 | 0.037 | Increasing | N |
| GT6460027 | 4.27 | 0.157 | Increasing | S | GT7037001 | 3.23 | 0.157 | Increasing | S |
| GT6475036 | 5.42 | 0.383 | Increasing | S | GT7037003 | 5.61 | 0.268 | Increasing | S |
| GT6475037 | 6.12 | 0.336 | Increasing | S | GT7037004 | 1.77 | 0.061 | Increasing | N |
| GT6475038 | 5.44 | 0.311 | Increasing | S | GT7037005 | 4.50 | 0.338 | Increasing | S |
| GT6475039 | 6.70 | 0.399 | Increasing | S | GT7056006 | 3.82 | 0.550 | Increasing | S |
| GT6475040 | 5.61 | 0.141 | Increasing | S | GT7056007 | 3.91 | 0.677 | Increasing | S |
| GT6475041 | 5.34 | 0.257 | Increasing | S | GT7056009 | 3.09 | 0.401 | Increasing | S |
| GT6479044 | 3.75 | 0.300 | Increasing | S | GT7056010 | 3.86 | 0.142 | Increasing | S |
| GT6479046 | 6.96 | 0.360 | Increasing | S | GT7066012 | 4.22 | 0.390 | Increasing | S |
| GT6485047 | 6.37 | 0.310 | Increasing | S | GT7066013 | 2.21 | 0.041 | Increasing | S |
| GT6485048 | 4.39 | 0.159 | Increasing | S | GT7066014 | 2.35 | 0.071 | Increasing | S |
| GT6486049 | 3.96 | 0.444 | Increasing | S | GT7066015 | 2.64 | 0.103 | Increasing | S |
| GT6486051 | 3.67 | 0.419 | Increasing | S | GT7066016 | 3.49 | 0.117 | Increasing | S |
| GT6486052 | 1.53 | 0.101 | Increasing | N | GT7066018 | 1.74 | 0.042 | Increasing | N |
| GT6915002 | 1.27 | 0.017 | Increasing | N | GT7088020 | -0.28 | -0.010 | Decreasing | N |
| GT6915004 | 2.90 | 0.040 | Increasing | S | GT7088021 | 2.94 | 0.075 | Increasing | S |
| GT6941001 | 4.83 | 0.060 | Increasing | S | GT7088022 | 2.43 | 0.108 | Increasing | S |
| GT6941005 | 3.78 | 0.070 | Increasing | S | GT7088023 | 1.64 | 0.040 | Increasing | N |
| GT6944006 | 3.33 | 0.167 | Increasing | S | GT7088024 | 2.48 | 0.058 | Increasing | S |
| GT6944007 | 2.04 | 0.040 | Increasing | S | GT7088025 | 4.48 | 0.097 | Increasing | S |
| GT6944009 | 3.46 | 0.100 | Increasing | S | GT7088029 | 2.81 | 0.070 | Increasing | S |
| GT6944010 | 3.64 | 0.079 | Increasing | S | GT7312001 | -1.85 | -0.005 | Decreasing | N |
| GT6963012 | 2.98 | 0.080 | Increasing | S | GT7312002 | -1.47 | -0.002 | Decreasing | N |

**Appendix-3. MAKESENS trend analysis results for annual minimum groundwater levels (continued)**

| Well ID | Test Z | Slope | Remarks | Signif. | Well ID | Test Z | Slope | Remarks | Signif. |
|---|---|---|---|---|---|---|---|---|---|
| GT7312003 | 4.45 | 0.020 | Increasing | S | GT7616006 | -0.55 | -0.007 | Decreasing | N |
| GT7312004 | -0.59 | -0.001 | Decreasing | N | GT7616007 | 2.18 | 0.045 | Increasing | S |
| GT7312005 | -3.15 | -0.008 | Decreasing | S | GT7616008 | 3.62 | 0.050 | Increasing | S |
| GT7312006 | 4.38 | 0.019 | Increasing | S | GT7616009 | -0.18 | 0.000 | No trend | N |
| GT7315007 | 1.96 | 0.009 | Increasing | S | GT7616010 | 2.76 | 0.060 | Increasing | S |
| GT7315008 | 0.77 | 0.006 | Increasing | N | GT7616011 | 2.00 | 0.012 | Increasing | S |
| GT7315009 | 0.21 | 0.001 | Increasing | N | GT7616012 | 3.24 | 0.014 | Increasing | S |
| GT7315010 | 0.37 | 0.004 | Increasing | N | GT7622013 | 3.51 | 0.115 | Increasing | S |
| GT7315011 | -0.62 | -0.002 | Decreasing | N | GT7639017 | 3.47 | 0.067 | Increasing | S |
| GT7315012 | 1.87 | 0.010 | Increasing | N | GT7639018 | 1.03 | 0.020 | Increasing | N |
| GT7315013 | 4.15 | 0.046 | Increasing | S | GT7639019 | 2.58 | 0.047 | Increasing | S |
| GT7315014 | -1.32 | -0.007 | Decreasing | N | GT7639020 | 1.62 | 0.031 | Increasing | N |
| GT7336016 | -2.41 | -0.009 | Decreasing | S | GT7655022 | 3.88 | 0.099 | Increasing | S |
| GT7336017 | -3.77 | -0.017 | Decreasing | S | GT7655025 | 2.93 | 0.062 | Increasing | S |
| GT7336018 | 1.21 | 0.013 | Increasing | N | GT7655026 | 3.30 | 0.094 | Increasing | S |
| GT7336019 | 4.48 | 0.025 | Increasing | S | GT7655027 | 3.28 | 0.079 | Increasing | S |
| GT7336020 | 0.09 | 0.001 | Increasing | N | GT7683030 | 2.69 | 0.047 | Increasing | S |
| GT7345022 | 1.66 | 0.013 | Increasing | N | GT7683031 | 3.85 | 0.060 | Increasing | S |
| GT7345023 | -0.11 | -0.001 | Decreasing | N | GT7683032 | 0.36 | 0.005 | Increasing | N |
| GT7364025 | 0.44 | 0.002 | Increasing | N | GT7683033 | 2.23 | 0.029 | Increasing | S |
| GT7385026 | 2.16 | 0.035 | Increasing | S | GT7683034 | 2.12 | 0.020 | Increasing | S |
| GT7385027 | 0.42 | 0.002 | Increasing | N | GT7683035 | 3.05 | 0.044 | Increasing | S |
| GT7605001 | 3.50 | 0.087 | Increasing | S | GT7704001 | 1.92 | 0.009 | Increasing | N |
| GT7605002 | 3.90 | 0.092 | Increasing | S | GT7704002 | 1.72 | 0.005 | Increasing | N |
| GT7605003 | 4.24 | 0.090 | Increasing | S | GT7704003 | 1.12 | 0.003 | Increasing | N |
| GT7616004 | 1.53 | 0.017 | Increasing | N | GT7704501 | 2.34 | 0.016 | Increasing | S |
| GT7616005 | 0.60 | 0.005 | Increasing | N | GT7704502 | 3.37 | 0.015 | Increasing | S |

**Appendix-3. MAKESENS trend analysis results for annual minimum groundwater levels (continued)**

| Well ID | Test Z | Slope | Remarks | Signif. | Well ID | Test Z | Slope | Remarks | Signif. |
|---|---|---|---|---|---|---|---|---|---|
| GT7725004 | -0.24 | -0.002 | Decreasing | N | GT8576013 | 0.60 | 0.006 | Increasing | N |
| GT7725005 | 0.94 | 0.008 | Increasing | N | GT8592014 | 3.50 | 0.045 | Increasing | S |
| GT7725006 | 2.69 | 0.028 | Increasing | S | GT8811001 | 1.14 | 0.022 | Increasing | N |
| GT7725008 | 3.47 | 0.043 | Increasing | S | GT8811002 | 3.34 | 0.090 | Increasing | S |
| GT7734009 | 2.33 | 0.022 | Increasing | S | GT8827003 | 0.77 | 0.011 | Increasing | N |
| GT7734010 | 0.41 | 0.006 | Increasing | N | GT8844005 | 1.89 | 0.036 | Increasing | N |
| GT7734011 | 2.79 | 0.025 | Increasing | S | GT8850006 | 2.01 | 0.035 | Increasing | S |
| GT7734012 | 2.74 | 0.054 | Increasing | S | GT8850008 | 1.02 | 0.019 | Increasing | N |
| GT7734013 | 1.24 | 0.006 | Increasing | N | GT8861009 | 3.27 | 0.138 | Increasing | S |
| GT7773014 | 0.24 | 0.008 | Increasing | N | GT8861010 | 2.14 | 0.050 | Increasing | S |
| GT7773015 | 2.13 | 0.007 | Increasing | S | GT8861011 | 3.00 | 0.058 | Increasing | S |
| GT7773016 | 3.83 | 0.035 | Increasing | S | GT8867012 | 0.73 | 0.020 | Increasing | N |
| GT7773018 | 2.65 | 0.009 | Increasing | S | GT8867013 | 1.41 | 0.022 | Increasing | N |
| GT7790020 | -1.28 | -0.012 | Decreasing | N | GT8878014 | 0.88 | 0.019 | Increasing | N |
| GT7790021 | 6.73 | 0.045 | Increasing | S | GT8878015 | 2.14 | 0.048 | Increasing | S |
| GT7790022 | 1.57 | 0.013 | Increasing | N | GT8878016 | 2.28 | 0.035 | Increasing | S |
| GT7790023 | 0.00 | 0.000 | Increasing | N | GT8878017 | -0.06 | -0.002 | Decreasing | N |
| GT8503001 | -0.41 | -0.011 | Decreasing | N | GT8878018 | 1.04 | 0.022 | Increasing | N |
| GT8527003 | 3.77 | 0.024 | Increasing | S | GT8878019 | 1.72 | 0.042 | Increasing | N |
| GT8549005 | -1.80 | -0.037 | Decreasing | N | GT8878020 | 2.63 | 0.102 | Increasing | S |
| GT8549006 | 0.75 | 0.008 | Increasing | N | GT8889022 | -0.54 | -0.011 | Decreasing | N |
| GT8549007 | -1.30 | -0.011 | Decreasing | N | GT8889023 | 5.14 | 0.058 | Increasing | S |
| GT8558008 | 0.88 | 0.014 | Increasing | N | GT8894024 | 0.65 | 0.014 | Increasing | N |
| GT8558009 | 2.92 | 0.030 | Increasing | S | GT8894025 | 0.92 | 0.023 | Increasing | N |
| GT8558010 | 3.64 | 0.020 | Increasing | S | GT8894026 | 0.83 | 0.020 | Increasing | N |
| GT8573011 | 0.68 | 0.004 | Increasing | N | GT8894027 | 3.23 | 0.078 | Increasing | S |
| GT8576012 | 1.46 | 0.009 | Increasing | N | GT9408001 | 2.19 | 0.010 | Increasing | S |

**Appendix-3. MAKESENS trend analysis results for annual minimum groundwater levels (continued)**

| Well ID | Test Z | Slope | Remarks | Signif. | Well ID | Test Z | Slope | Remarks | Signif. |
|---|---|---|---|---|---|---|---|---|---|
| GT9408002 | 2.02 | 0.015 | Increasing | S | GT9494015 | 5.71 | 0.033 | Increasing | S |
| GT9408003 | -4.79 | -0.021 | Decreasing | S | GT9494016 | -0.18 | 0.000 | No trend | N |
| GT9408501 | 2.97 | 0.007 | Increasing | S | GT9494017 | -0.15 | -0.001 | Decreasing | N |
| GT9451004 | 4.37 | 0.054 | Increasing | S | GT9494019 | -0.97 | -0.004 | Decreasing | N |
| GT9451005 | 4.29 | 0.038 | Increasing | S | GT9494020 | -1.12 | -0.003 | Decreasing | N |
| GT9451502 | 1.80 | 0.034 | Increasing | N | GT9494021 | 4.06 | 0.026 | Increasing | S |
| GT9482006 | -2.84 | -0.012 | Decreasing | S | GT9494022 | 4.35 | 0.030 | Increasing | S |
| GT9482008 | 2.57 | 0.036 | Increasing | S | GT9494023 | 1.12 | 0.004 | Increasing | N |
| GT9482010 | 3.35 | 0.056 | Increasing | S | GT9494025 | 2.46 | 0.024 | Increasing | S |
| GT9482503 | 3.99 | 0.013 | Increasing | S | GT9494027 | 2.96 | 0.010 | Increasing | S |
| GT9486011 | 5.06 | 0.025 | Increasing | S | GT9494028 | 3.42 | 0.017 | Increasing | S |
| GT9486012 | 2.24 | 0.023 | Increasing | S | GT9494029 | 3.67 | 0.060 | Increasing | S |
| GT9486014 | 2.48 | 0.031 | Increasing | S | GT9494030 | 4.15 | 0.072 | Increasing | S |

[1]Statistical Significance; [2]Significant (p=0.05); [3]Not significant (p=0.05)

**Appendix-4. List of monitoring well-types based on suction limit (6 m)**

**Type 1: Wells having groundwater level always below suction limit**

| | | | | | | |
|---|---|---|---|---|---|---|
| GT8134016 | GT8172033 | GT1006003 | GT3861005 | GT6450017 | GT6475041 | GT7037003 |
| GT8134018 | GT8194046 | GT1033009 | GT6428007 | GT6450018 | GT6479046 | GT7037005 |
| GT8134019 | GT8194048 | GT1054013 | GT6428009 | GT6475036 | GT6485047 | GT7056006 |
| GT8134020 | GT8194049 | GT1054014 | GT6428010 | GT6475037 | GT6486051 | GT7056007 |
| GT8153030 | GT8194047 | GT1088022 | GT6428011 | GT6475038 | GT6486052 | GT7056009 |
| GT8153031 | GT1006001 | GT3861004 | GT6450015 | GT6475039 | GT3230007 | GT7066012 |

**Type 2: Wells having groundwater level always above suction limit**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| GT1095026 | GT3224003 | GT5233001 | GT5233003 | GT7315014 | GT7704501 | GT7790021 | GT9486011 |
| GT2712005 | GT3230005 | GT5233002 | GT7312001 | GT7336016 | GT7704502 | GT8527003 | GT9486012 |
| GT2712006 | GT3230006 | GT5233004 | GT7312002 | GT7336017 | GT7725004 | GT8549005 | GT9494016 |
| GT2721010 | GT3267008 | GT5239005 | GT7312003 | GT7336018 | GT7725005 | GT8549006 | GT9494017 |
| GT2721011 | GT3267009 | GT5239006 | GT7312004 | GT7336019 | GT7725008 | GT8549007 | GT9494021 |
| GT2721503 | GT3282011 | GT5239007 | GT7312005 | GT7336020 | GT7734010 | GT8558008 | GT9494023 |
| GT2730013 | GT3288015 | GT5239008 | GT7312006 | GT7345022 | GT7734011 | GT8558009 | GT9494028 |
| GT2730014 | GT3291017 | GT5255009 | GT7315007 | GT7345023 | GT7734012 | GT8573011 | GT9494030 |
| GT2730015 | GT3291018 | GT5255010 | GT7315008 | GT7364025 | GT7734013 | GT9408001 | |
| GT2756023 | GT3230004 | GT5255011 | GT7315009 | GT7385026 | GT7773015 | GT9408003 | |
| GT2760029 | GT4952004 | GT5255012 | GT7315010 | GT7704001 | GT7773016 | GT9408501 | |
| GT2764031 | GT4961007 | GT5270013 | GT7315011 | GT7704002 | GT7773018 | GT9482006 | |
| GT3224001 | GT4994008 | GT5270015 | GT7315013 | GT7704003 | GT7790020 | GT9482503 | |

**Type 3: Wells having groundwater level below suction limit maintaining an annual cycle**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| GT8112001 | GT1020005 | GT2730016 | GT3874007 | GT6944006 | GT7605002 | GT7734009 | GT8889022 |
| GT8112002 | GT1020006 | GT2738017 | GT3874008 | GT6944007 | GT7605003 | GT7773014 | GT8889023 |
| GT8112003 | GT1020007 | GT2738018 | GT4909002 | GT6944009 | GT7616004 | GT7790022 | GT8894024 |
| GT8122005 | GT1027008 | GT2743019 | GT4952003 | GT6944010 | GT7616005 | GT7790023 | GT8894025 |
| GT8125006 | GT1040010 | GT2747021 | GT4952005 | GT6963012 | GT7616006 | GT8503001 | GT8894026 |
| GT8125008 | GT1040011 | GT2756024 | GT4994009 | GT6991013 | GT7616007 | GT8558010 | GT8894027 |
| GT8125009 | GT1040012 | GT2756026 | GT6403001 | GT6991014 | GT7616008 | GT8576012 | GT9408002 |
| GT8125010 | GT1067015 | GT2764030 | GT6403002 | GT6991015 | GT7616009 | GT8576013 | GT9451004 |
| GT8125011 | GT1081016 | GT2764033 | GT6403003 | GT6991016 | GT7616010 | GT8592014 | GT9451005 |
| GT8125012 | GT1081017 | GT2764034 | GT6406004 | GT7037001 | GT7616011 | GT8811001 | GT9451502 |
| GT8131015 | GT1081018 | GT2764035 | GT6406005 | GT7037004 | GT7616012 | GT8811002 | GT9482008 |
| GT8134017 | GT1081019 | GT2764036 | GT6406006 | GT7056010 | GT7622013 | GT8827003 | GT9482010 |
| GT8134021 | GT1081020 | GT2764037 | GT6428008 | GT7066013 | GT7639017 | GT8844005 | GT9486014 |
| GT8134022 | GT1088021 | GT2764038 | GT6447021 | GT7066014 | GT7639018 | GT8850006 | GT9494015 |
| GT8134027 | GT1088023 | GT2764039 | GT6450016 | GT7066015 | GT7639019 | GT8850008 | GT9494019 |
| GT8134028 | GT1094024 | GT2769040 | GT6450019 | GT7066016 | GT7639020 | GT8861009 | GT9494020 |
| GT8172032 | GT1094025 | GT2777042 | GT6460025 | GT7066018 | GT7655022 | GT8861010 | GT9494022 |
| GT8172035 | GT1095027 | GT2777043 | GT6460026 | GT7088020 | GT7655025 | GT8861011 | GT9494025 |
| GT8172036 | GT2710001 | GT3224002 | GT6460027 | GT7088021 | GT7655026 | GT8867012 | GT9494027 |
| GT8172037 | GT2712002 | GT3282010 | GT6475040 | GT7088022 | GT7655027 | GT8867013 | GT9494029 |
| GT8172038 | GT2712003 | GT3288014 | GT6479044 | GT7088023 | GT7683030 | GT8878014 | |
| GT8172039 | GT2712004 | GT3282012 | GT6485048 | GT7088024 | GT7683031 | GT8878015 | |
| GT8172040 | GT2717008 | GT3282013 | GT6486049 | GT7088025 | GT7683032 | GT8878016 | |
| GT8182041 | GT2717009 | GT3847001 | GT6915002 | GT7088029 | GT7683033 | GT8878017 | |
| GT8182042 | GT2717501 | GT3847002 | GT6915004 | GT7315012 | GT7683034 | GT8878018 | |
| GT1006002 | GT2721502 | GT3847003 | GT6941001 | GT7385027 | GT7683035 | GT8878019 | |
| GT1020004 | GT2730012 | GT3874006 | GT6941005 | GT7605001 | GT7725006 | GT8878020 | |