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Evaluation of Groundwater Using Single Cell Thana Model: Study on Pirgachha Upazila, Rangpur District, North-Western Part of Bangladesh

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Abstract

The nation occupies a special location at the meeting point of the Ganges, Brahmaputra, and Meghna (GBM), three significant rivers. The three rivers' waters empty into the Bay of Bengal. For the following reasons, the catchment area of the three rivers is considered to be part of one basin: Ganges-Brahmaputra-Meghna Basin. In the basin where the Teesta River flows northwest near Pirgachha Upazila. This upazila's upper aquifer has a direct connection to the river, which is important for aquifer recharge. The Single Cell Thana Model, employed in this work, was created to simulate the potential of groundwater resources on a Thana basis. In Bangladesh, irrigation is the predominant use of water, especially in large urban canters where consolidation has grown significantly over the previous 25 to 30 years. This has resulted in a significant increase in food production and widespread use of irrigated agriculture during the Rabi season (15 October-15 March). It is well known that Bangladesh has water scarcity during the dry season and water plenty during the wet season, which severely disrupts the nation's socioeconomic operations and agricultural practices. Nowadays the northwest of the country, particularly in the study area, is in a touch-and-go position. Cooperation between the countries in the co-basin is necessary to handle the issues brought on by this water shortage, as well as the effective use, conservation, and development of water resources. It is also urgently necessary to recognize the actual situation of the groundwater.

Subject Areas

Goundwater Resources on a Thana Basis

Keywords

Individual Cell Thana Model, Groundwater, Surface Water, Rainfall, Irrigation

1. Introduction

Bangladesh constitutes the major portion of the Bengal Basin which is considered as the southeastern part of the Indian sub-continent and is commonly known as Himalayan Foredeep (Reimann, 1993) [1]. The research area in Pirgachha upazila is located at Rangpur Saddle, the part of Indian Platform. The aquifer is directly adjacent to the Teesta River system and groundwater from the Dupi Tila sands is very high quality and productive as well. The Dupi Tila sands form an aquifer system divided into an upper and lower aquifer which is 300 m and 1600 m thick accordingly by discontinuous clay (WARPO, 2001) [2]. An upper silty clay aquifer (2 to 100 m deep) sits on top of a fine sand and silt aquifer (3 to 60 m deep), known as the composite aquifer, and the primary aquifer, which is made up of moderate to well-sorted medium to coarse sands, is arranged in a threefold succession. (MPO, 1974/75) [3] [4].

The population of the study area is 31.33 million/313,319 (BBS, 2011) [5] and the abstraction of groundwater is about 9399.57 m^3/day (WARPO, 2016) [6]. The lithostratigraphy and prevailing tectonic activities are the main hydro-geological parameters of this area. The geology can be attributed to the Quaternary alluvial sequence, which is a part of the Teesta River floodplain. The region's layered hydro-stratigraphy is primarily uniform and composed of sands, silts, and clays. Based on the likelihood of a bore log and lithological classification, different hydro-stratigraphic units' subsurface sediment formation has been categorized. Borehole has been installed in the study area 25.3 m in depth and the aquifer permeability is 91.4 m^2/day and hydraulic conductivity is 4000 m/day. According to SCTM, the gross area of Pirgachha region is 26,681 ha or 266.81 km^2, Net Cultivable area is 19,893 ha or 198.93 km^2 (WARPO, 2016) [6].

However, the main goals of this study are to develop the simulation of water resources in the ground potential using Single Cell Thana Model and to know how the aquifer system responds to resource improvement using third monthly time increments.

2. Methodology

2.1. Study Area

Pirgachha is the upazila of Rangpur district in the division of Rangpur. It is located in the southeast of Rangpur city at 25.71˚N 89.39˚E (**Figure 1**). Additionally,

Figure 1. Location map of study area (Source: Banglapaedia).

it has a 12-kilometer east west and a 6-kilometer north-south perimeter. The Single Cell Thana Model was utilized for the research, and NWMP2001 contains the majority of the data files required for the model. For a period variant data has been changed and relates in particular to rainfall data (third monthly rainfall data for the period from 1965-2012) (WARPO, 2016) [6], reference crop evapotranspiration data (daily average for third monthly period), land type distribution and soil types within land type areas, crop distribution over various land uses, flood extent and depth for different flood phases, factors used in calculated gross irrigation volume demand, edge water retention capacity for different land types allowing for surface retention outside flooding periods, soil physical characteristics including infiltration and deep percolation capacity, number and thickness of model layers (up to 4 layers), local relief characteristics (related to flood phases), hydro-geological parameters for individual layers and storage characteristics which are depth dependent for the upper 22 m (NWRD, 2001) [7]. After preparing the data file the model has been run and then needs to be calibrated. ArcGIS and some local software are used to illustrate the hydro-geological parameters.

2.2. Water Regulation

Groundwater resources are widely accessible and of high quality in many regions of the world. In such locations, creating access to these resources is relatively cheap and easy, and frequently does not require significant government coordination or support. Groundwater is a preferred supplier at the grass-roots level due to its inherent hydrological advantages, which also result in various scale-neutral socioeconomic benefits. Since a few decades ago, groundwater has been the primary source of irrigation and one of the major contributors to the capacity of Bangladesh to produce all of its own food. At the beginning of the 1970s, Bangladesh's primary sources of drinking and residential water supplies were surface water (such as ponds and rivers), precipitation, and deep wells. Groundwater was added in the late 1970s and early 1980s to prevent pathogenic microorganisms from contaminating surface water. In Bangladesh's rural areas, tens of thousands of manually operated tube wells were put in place to deliver pathogen free groundwater for drinking purposes. Although the precise number of hand tube wells is unknown, the nation is thought to have 10 million tube wells overall. The vast majority of these tube wells are private and reach depths of 10 to 60 mg (meters below ground level) in the shallow portions of alluvial aquifers (DPHE-BGS 2001) [8].

The National Water Policy (NWP 1999) [9] of Bangladesh emphasizes the increased use of surface water whenever and wherever it is available. Both sustainable development and climate change adaptation depend heavily on water storage. Not just during the dry months, but also during the monsoon, a sizable portion of Bangladesh struggles with a lack of water for irrigating its agricultural lands. There is a lot of room for rainwater collecting before there are significant losses because of evaporation, transpiration, runoff, and drainage. BWDB has built a number of embankments, barrages, and canals to reduce the damaging effects of floods and utilize the extra water for irrigation. BWDB has already begun work on projects to irrigate around 1.7 Mha of land with surface water (Zahind A., 2015) [10]. Over the time there was no regulatory control on Groundwater abstraction (BUET, 2020) [11].

Therefore, Groundwater withdrawal rate increased dramatically and the use of surface water was almost steady. The People's Republic of Bangladesh's government approved Bangladesh Water Act, 2013 where it is clearly mentioned in the section 19: "Fixing the lowest safe yield level in aquifer and restrictions on abstracting groundwater". According to section 45 of BWA, 2013 (Act No. 14 of 2013) [12], The Government of the People Republic of Bangladesh approved Bangladesh water Rules 2018 where in the Rules 28 of section 10 (Groundwater Protection, Conservation and Management) "Fixing the lowest safe yield level in aquifer". Before going to approved BWA, 2013 [12] and BWR, 2018 [13] there are few historical development of water legislation and institution in Bangladesh like. The canal Act, 1864, The Irrigation Act, 1876, The Bangladesh Agricultural Development Corporation Ordinance, 1961, The Bangladesh Irrigation Water rate Ordinance, 1983, The Groundwater management Ordinance, 1985 (By the approval of Groundwater Management Act, 2018 the Groundwater management Ordinance, 1985 has been abolished). To ensure the water resources development and its equal uses, the Water Resources Planning Act, 1992 [14] has been approved. Another milestone has been approved by the Government National Water Policy 1999 for human survival, socio-economic development of the country and preservation of its natural environment. However, the control on Groundwater is still insignificant. Previous studies on groundwater in Bangladesh (BWDB-UNDP 1982 [15]; MPO 1987 [3] [4], 1991 [16]; WARPO 2000 [17]) estimated that increasing groundwater-fed irrigation will increase net recharge in regions where surface geology and soil qualities are porous and, as a result, favour recharging (Figure 2). According to these investigations, the annual potential

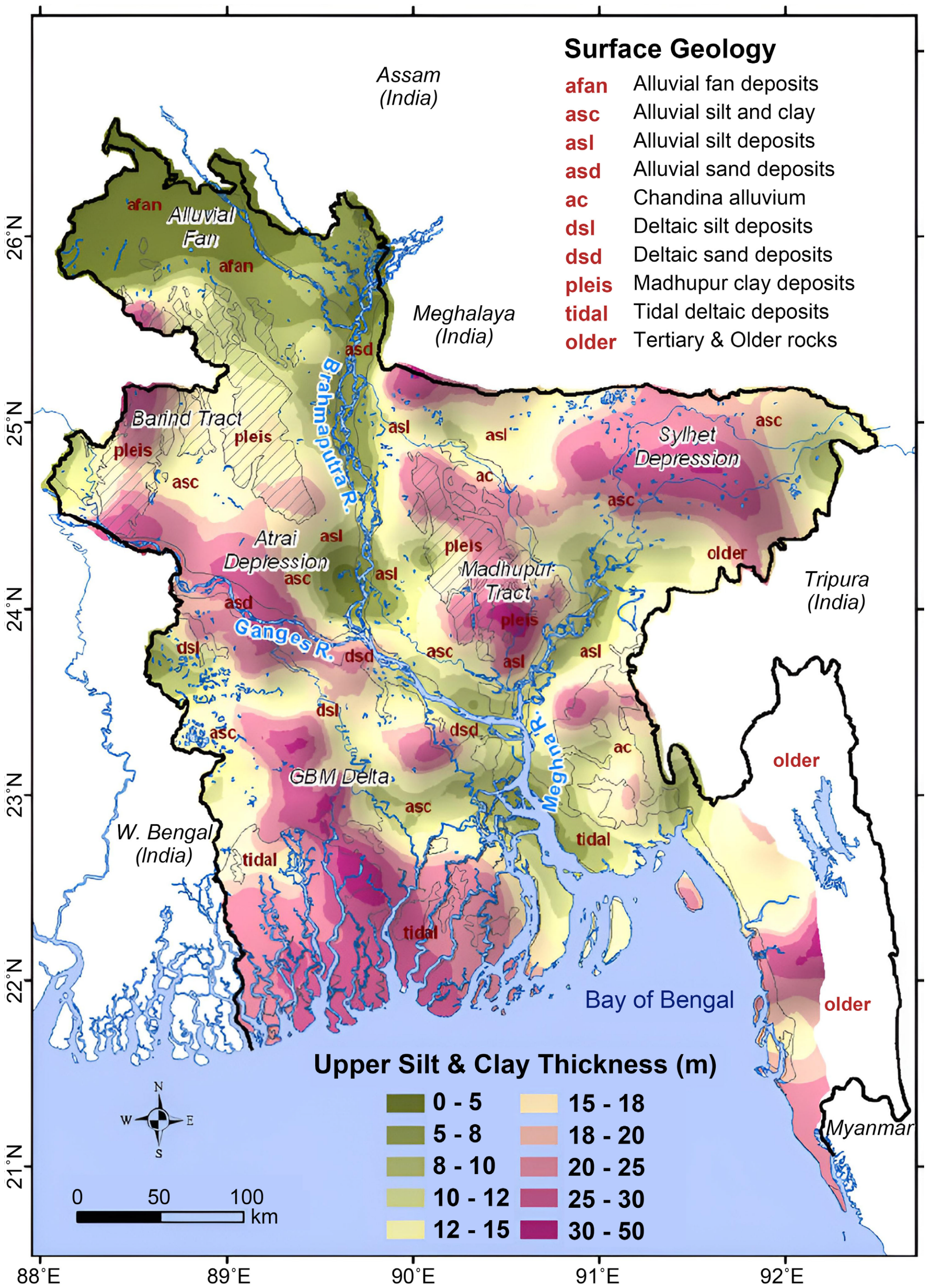


Figure 2. Diagram showing the thickness of the upper silt and clay (Shamsudduha *et al.* 2011) [16].

and usable recharge for each location was between 135 and 1910 mm and 183 and 1287 mm, respectively (**Figure 3**). The BWDB-UNDP study used a hydrological balance to assess potential recharge, with runoff being predicted to be 20% - 40% of the annual precipitation.

According to a study by Shamsudduha *et al.* (2011) [18], groundwater recharge was estimated for the long-term mean recharge period (1985-2007), the post-development groundwater-fed irrigation period (2002-2007), and the pre-development groundwater-fed irrigation period (1975-1980) (**Figure 4**). The findings indicate that, with the exception of Comilla district, Bangladesh's actual (net) recharge is higher in the northwest (Dinajpur district) and western (Rajshahi district) regions than in the south (Khulna district) and east. Where potential recharge was previously believed to be 500 - 700 mm along the Rivers Brahmaputra and Ganges, net recharge is high (300 - 600 mm) (MPO 1987 [3] [4]; MPO 1991 [16]). Similar to potential recharge, net recharge in the northwest of the GBM Delta ranges from 250 to 600 mm. The net yearly recharge is much lower (150 mm) in the southeast GBM Delta and Sylhet regions while the estimated potential recharge is large (400 - 2000 mm; BWDB-UNDP 1982 [15]; MPO 1987 [3] [4], 1991 [16]). Greater net recharge increases are seen in northwest areas and along the Brahmaputra and Ganges rivers; changes in recharge are minimal elsewhere in the nation. The significant discrepancy between actual

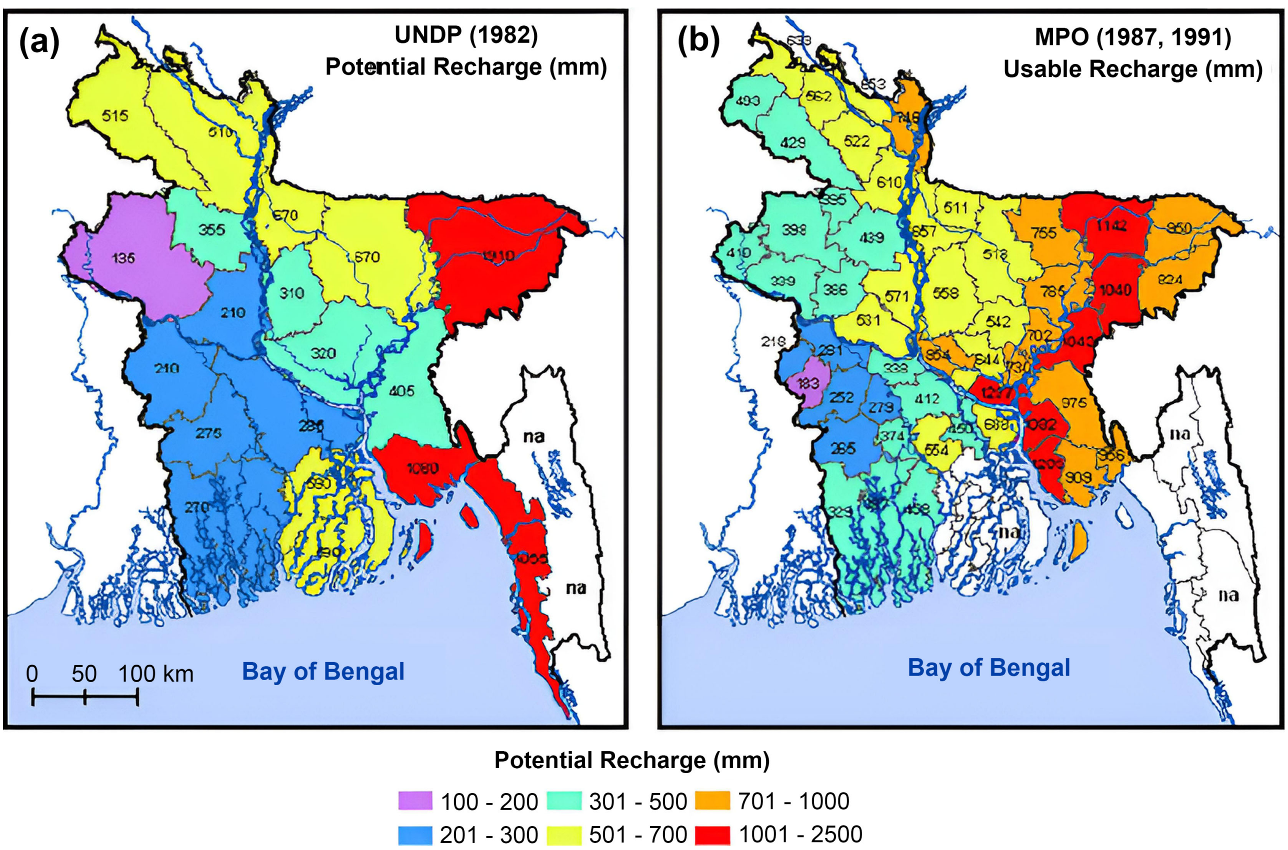


Figure 3. Various research estimates of area-wise potential and usable recharge (Shamsudduha *et al.* 2011) [18].

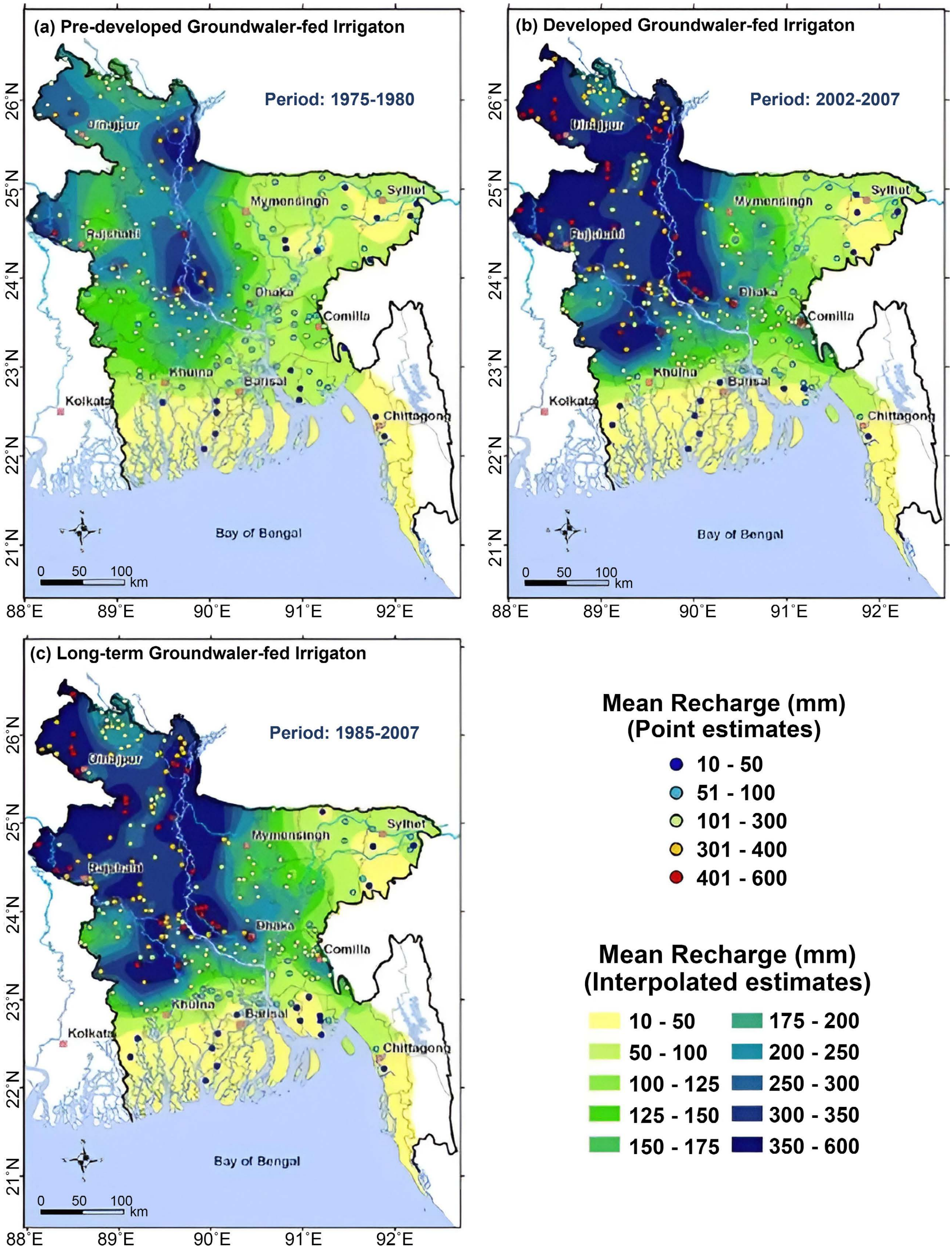


Figure 4. Showing groundwater recharge maps for the pre-development groundwater-fed irrigation period (1975-1980), the post-development groundwater–fed irrigation period (2002-2007), and the long-term mean recharge period (1985-2007) (Shamsudduha *et al.* 2011) [18].

and potential recharge in these places shows that a significant portion of the available recharge is lost through evapotranspiration and surface runoff.

2.2.1. Sectoral Impact

Groundwater is a part of the natural water cycle. Some part of the precipitation that lands on the ground surface infiltrates into the subsurface. The part that continues down through the soil until it reaches rock material that is saturated is groundwater recharge. Some sectors directly impact these valuable resources. These are:

1) Agricultural Sector

The rapid development of groundwater use for irrigation in the country has resulted in significant agricultural growth, but in many regions, such development has become unsustainable because of aquifer overexploitation or water and soil salinization. The northwestern part of the country is facing a severe problem exploiting groundwater for agricultural purposes. Groundwater abstraction for irrigated agriculture is becoming more and more common due to the growing competition for fresh water. The necessity for groundwater irrigation has progressively increased over the past few decades for a variety of reasons, including the old major canal systems' unreliability and farmers' increasing need to control their irrigation applications. Additionally, some farmers, particularly in semi-arid regions, have been obliged to use groundwater as a drought remedy due to climate uncertainty. Water resource planners and managers need to be concerned about the growing overexploitation of significant aquifers around the world as well as groundwater contamination (Chandra A. Madramootoo C.A., 2012) [19].

2) Residential Sector

Groundwater is the main source for household purposes. In the urban area where the water level is gradually declining. For example, the water table in Dhaka city is rapidly decreasing. Therefore, the groundwater from the nearby cities started to move toward Dhaka city. It is a very alarming event for the nation. On the other hand, since the discovery of significant arsenic (As) pollution of groundwater in shallow aquifers in Bangladesh in the early 1990s, the main focus of attention has been on drinking water (BGS-DPHE 2001) [8]. So, besides its usefulness, there are some furious risks for the humankind.

3) Environmental Sector

Water is an essential resource for socio-economic development, human life sustenance, and ecosystem preservation. Groundwater is our major source of water. The extreme use of groundwater resources can have serious concerns, such as uplifting and seismic activities, ecological environment deterioration, land subsidence, vegetation degradation, livelihoods for rural poor, and food security implications. Livestock production systems in particular have expanded through the utilization of groundwater in areas devoid of perennial surface water sources. Environmental changes are most marked in vegetation systems that were utilized ephemerally and opportunistically in years of good rains prior to the all-year-round exploitation facilitated by groundwater. The nature of vegetation changes is taken into consideration, including whether such changes reflect environmental degradation and whether they are permanent. Particularly noteworthy are the decline in biodiversity and altered relationships between annual and perennial grasses and brush cover (Thomas D.S.G., 2003) [20].

4) Industrial Sector

Many industries like textile, dyeing, bleaching, pharmaceutical, food processing, and metallurgical are well established in the Savar, Gazipur, Narayanganj, and Dhaka Industrial areas. They use groundwater to satisfy their demand for water. The main causes of this overexploitation of aquifers are the abstraction for irrigation, drinking water, industrial and mining uses (UN Environment, 2019) [21]. The relative importance of each of these uses varies significantly by country, depending on climate and the degree of economic development. The Water Resources Planning Organization (WARPO) under the Ministry of Water Resources recently worked on "Industrial Water Use in Bangladesh 2020". The Ministry of Water Resources already approved the English version of that policy. Therefore, it is a great achievement for Bangladesh for using water utilization in the Industrial sector.

2.2.2. Issues of Groundwater

1) Climate Change

Climate change becomes of ever greater concern and although this issue is currently getting a great deal of attention, its effect on groundwater is still underexposed. The situation is exacerbated by rising temperatures, increasing heatwaves, and high evaporation rates. A rise in temperature in a climate that is changing results in an increase in evaporation, which in turn causes a decrease in runoff and recharge (*i.e.*, a decrease in surface flow and the amount of water available for aquifer replenishment). Longer periods of drought and flooding may result from increased precipitation variability and more severe weather events brought on by climate change, which has an immediate impact on groundwater availability and dependence. Aquifer depletion is more likely during prolonged droughts, especially when it comes to tiny, shallow aquifers. Due to groundwater's function as a buffer, those who live in water-scarce areas will depend on it more and more. The demand for groundwater is also increased by the indirect effects of climate change, such as the escalation of human activity and modifications to land use. In a changing climate, strategic groundwater usage is becoming more crucial for ensuring global food and water security. This is just another justification for the increased prominence of groundwater in discussions about climate change (Ref. IGRAC) [22]. Water in the ground provides a critical freshwater supply, particularly in dry regions where surface water availability is limited. Climate change impacts on GWS (groundwater storage) could affect the sustainability of freshwater resources (Wu, WY, Lo, MH, Wada, Y. *et al.*, 2020) [23]. Saline Water Groundwater quality, as well as quantity both, suffer from the effects of climate change. Sea level rise may cause coastal aquifers to become contaminated with salt water, compromising the quality of the groundwater. It is challenging to prevent the intrusion of salt water into a freshwater system once it has started. Small island developing states and already-low-lying coastal areas are particularly vulnerable. On the other hand, salty or brackish groundwater basins offer chances for both economic activity and ecosystem development. In order to implement successful management strategies in the face of climate change, it is important to understand these systems (Ref. IGRAC) [22].

2) Economic Growth

According to the historical development of the cities, infrastructures, and economy, Groundwater plays a vital role. Without the groundwater, the land or cities will be barren land. So, it is true that the most plentiful source of freshwater on earth, groundwater, is essential to life. It is a resource that has been trapped underground due to sedimentation, volcanic activity, or percolation from the earth's surface (Fetter 2001 [24]; Fitts 2012 [25]). Half of the world's population relies on groundwater as their main supply of drinking water, and it also supports ecosystems by giving them access to water, nutrients, and a mostly constant temperature (Kløve *et al.* 2011) [26]. Such groundwater-related ecosystems may be crucial to human health, food, and energy production, as well as recreation (Machard de Gramont *et al.* 2011) [27].

Moreover, Millions of people rely on groundwater for their livelihoods and food security, particularly in Asia's developing agricultural economy. Groundwater currently provides around 50% of the world's supply of potable water, 40% of the industrial water demand, and 20% of the water used for agriculture (UNESCO 2003 [28]; Molden 2007 [29]). 32% of people in Asia and the Pacific use groundwater as their main source of drinking water, according to Morris *et al.* (2003) [30]. However, there are other places where the amount of groundwater used for drinking is significantly higher. For instance, 60% of rural Cambodians (ADB 2007 [31]; ADB 2007 [32]) and 76% of Bangladeshis without access to piped systems (ADB 2007 [33]; ADB 2007 [31]; ADB 2007 [32]) rely on tube wells.

2.2.3. Groundwater Budget/Volume

A basic equation can be used to represent the balance of water inflows and outflows or water budget (**Figure 5**), for a groundwater system: $I - O = \Delta S$ where I stand for the entire system inflows, O for the total system outflows, and S for storage change. The difference between deposits (inflows) and withdrawals (outflows) is equal to the change in the account balance (storage) in the water balance equation, similar to how it is in a bank statement. Changes in elastic storage as a result of aquifer depressurization (in confined aquifers) or a drop in the water table (in unconfined aquifers) cause changes in the potentiometric surface in groundwater systems. The inflows and outflows are exactly balanced at a steady state, or equilibrium condition, where S is 0 and $I = O$ in the budget equation above. The potentiometric surface is stable, in other words. Calculations of the groundwater budget are typically used by groundwater management agencies to

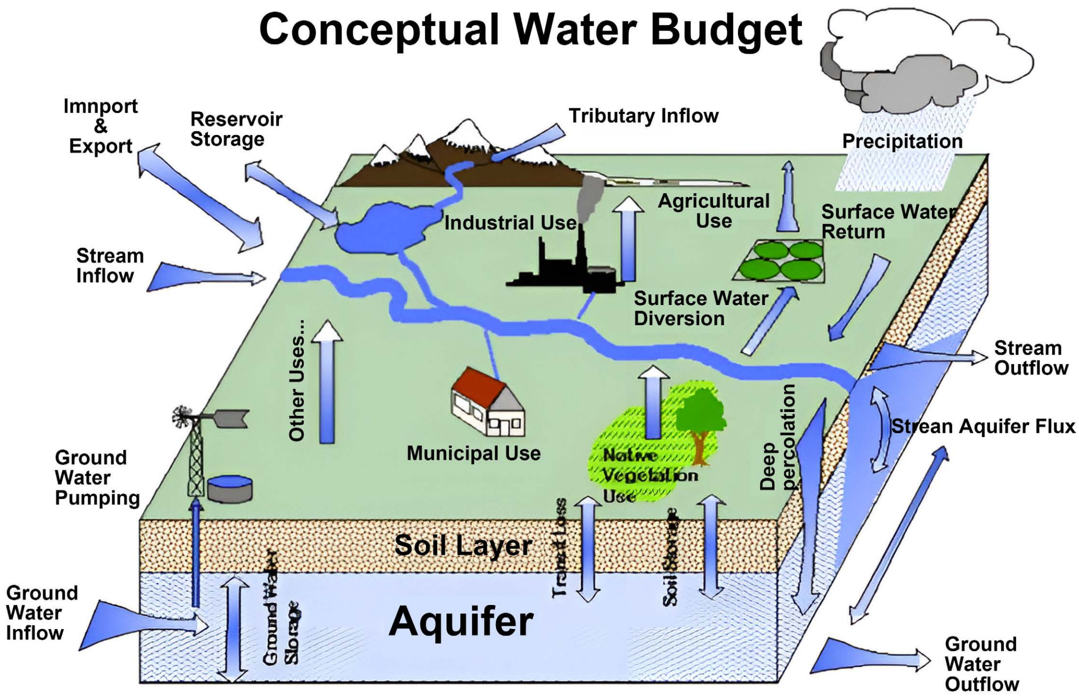


Figure 5. Diagrammatic representation of examples of inflows and outflows from a surface water system and an aquifer (identified in blue): Colorado State Division of Water Resources.

assess the sustainability of withdrawals for various reasons. When there are hydraulic connections between nearby aquifers, the groundwater budget estimate frequently has to be complemented by additional aquifer monitoring (S. Viaroli *et al.*, 2017) [34].

2.2.4. Groundwater and Surface Water Interaction

Low river flows are commonly controlled by river-aquifer exchange, the magnitude of which is governed by hydraulic properties of both aquifer and aquitard materials beneath the river. Low flows are often important ecologically (Jan H. Fleckenstein, Richard G. Niswonger, and Graham E. Fogg, 2006) [35]. Alluvial sediments commonly display a high degree of heterogeneity with values of hydraulic conductivity (K) spanning several orders of magnitude (Miall, 1996) [36]. Interaction between an alluvial aquifer system and a river will be influenced by the spatial arrangement of hydrofoils at the interface between the river and the underlying aquifer (Woessner, 2000) [37]. Consequently, subsurface heterogeneity may have a profound influence on how a river responds to changes in groundwater levels (**Figure 6**).

2.2.5. Groundwater Pollution/Injection

Groundwater pollution (also called groundwater contamination) occurs when pollutants are released into the ground and make their way down into groundwater. This type of water pollution can also occur naturally due to the presence of a minor and unwanted constituent, contaminant, or impurity in the groundwater, in which case it is more likely referred to as contamination rather than

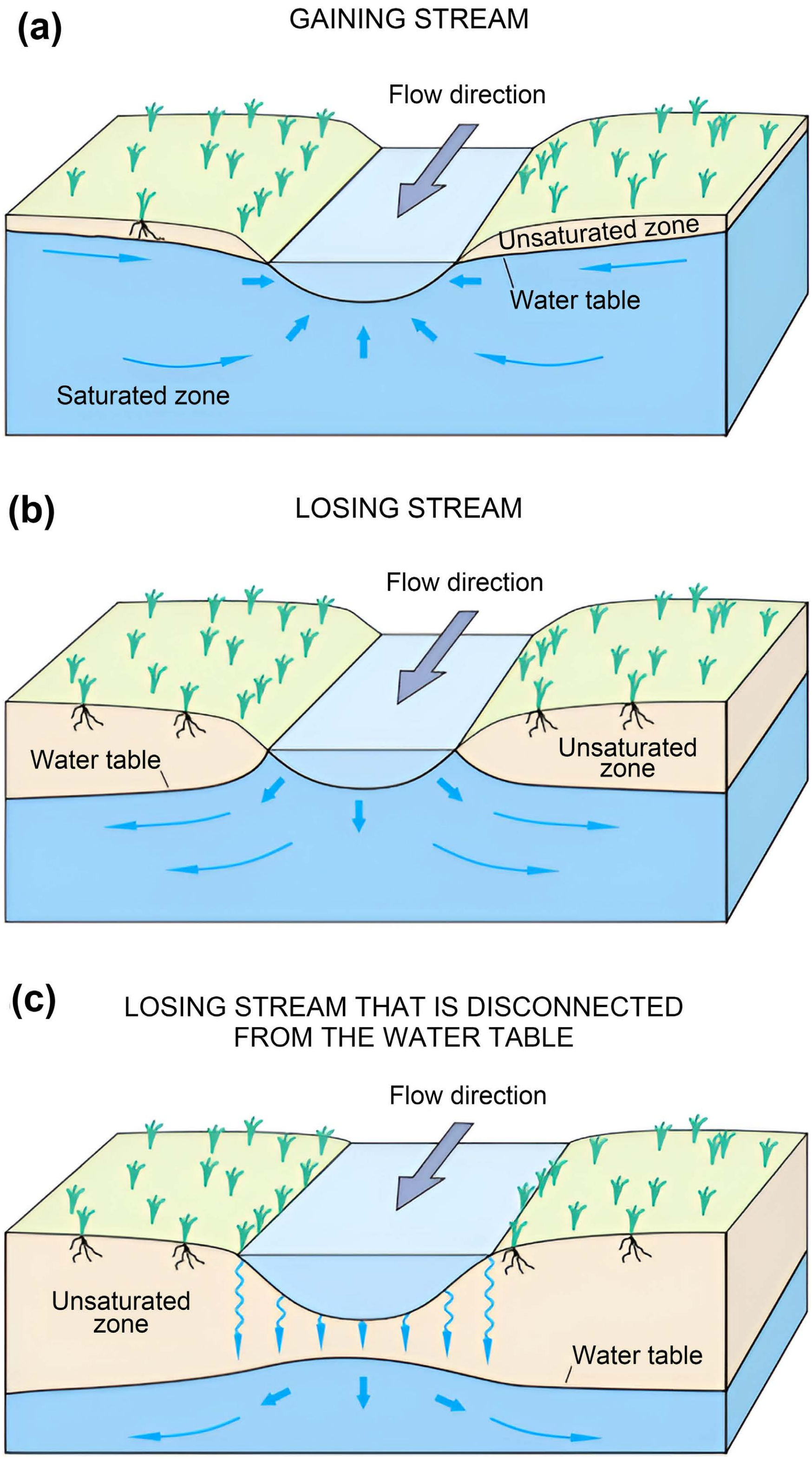


Figure 6. Diagrams showing the relationship between surface water and groundwater, including (a) a gaining stream, (b) a losing stream where surface water percolates downward and laterally to the water table, and (c) a losing stream that is "disconnected" or "detached" from the underlying aquifer; this scenario typically only occurs in arid environments. Reference: USGS Circular 1186.

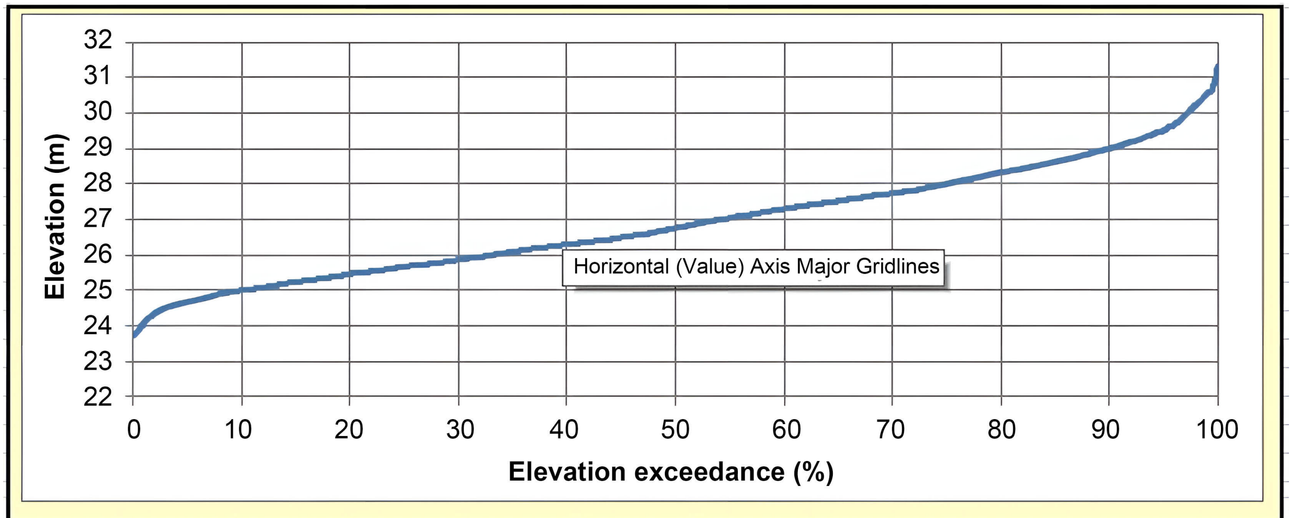
pollution (Ref. Wikipedia) [38]. There are five major ways groundwater can be contaminated by chemicals, bacteria, or saltwater: Surface Contamination, Subsurface Contamination, landfill and Waste Disposal, Atmospheric Contamination, and Saltwater Contamination. The majority of drinking-quality groundwater is found close to the surface of the earth and is quickly contaminated. The nationwide hundreds of thousands of subterranean wastewater disposal injection wells have the potential to contaminate underground sources of drinking water, which is a big concern. The nation's fluid waste is disposed of in waste disposal wells in around 11% of the total. Injection wells may be extremely helpful or detrimental. These wells are used for a wide range of purposes, ranging from helpful ones like recharging aquifers and producing oil, gas, and minerals to improper ones like the incorrect dumping of poisonous and hazardous wastes (Ref. EPA) [39].

3. Result and Discussion

In the study area, rainfall is the main source of recharge, where water is used for agricultural purposes as well as domestic or household activities finally evaluates the trend of groundwater either inclining or declining. Flooding in the study area depends on the supply of water from the upstream country and it is rarely indicated in the rainfall data of the study causes flooding. In Bangladesh, three major geomorphological zones are recognized whereas the study area is in the floodplain zone, and physiographically Bengal Basin is recognized as twenty physiographic units whereas the study area is situated in the Teesta Fan (active) area. The area consists of Barind Tract measures about 265.32 km2 actually this area is located at the level Barind area in the Rangpur district (WARPO, 2001 [2], 2002 [40]). The average elevation of the study area is 29.60 m with respect to mean sea level (**Figure 7**) and the basement is shallow in comparison with the SE, NE, or other parts of the country. The storage and recharge actually depend on how much rainfall is precipitate or how much water is carried out by the channel. In the rainy season when enough rainfall occurs then recharge is sufficient but due to climate change and severe drought in the study area, the winter season faces a shortage of water. Moreover, the north-western part of the country is also a major part of the agricultural sector. The land types are classified for modelling purposes into 10 categories and soil types are classified into 08 categories. A variety of soil types exist for each land type but in this model only three (03) most dominant soil types within the land type area are taken into consideration. This upazila's dominant land types are medium-high land permeability (64.96%), highland permeable (22.76%), and basin clay (100%) while the less important soil type is fine sandy loam, which is responsible for only 9% of the medium highland permeable land. Through the permeable dominant terrain type, significant amounts of direct recharge from rainfall can be preserved.

3.1. Rainfall

Rainfall can significantly affect the behavior of groundwater levels both directly



HO	H	MH	ML	L	B	OW	land types
5.8	22.76	68.64	0.73	0	0	2.07	flood phase as % of gross area
		0	0	0	0	0	relief difference from old re_GHijk.dat (m)
30.05	28.52	26.21	24.44	24.08	24.08	24.08	weighted average elevations (m)
		2.32	**4.44**	**4.44**	**4.44**	**4.44**	relief difference from area-elevation curve analysis (m)
						26.90	average elevation (m)

Figure 7. Elevation curve of Pirgachha upazila, Rangpur district.

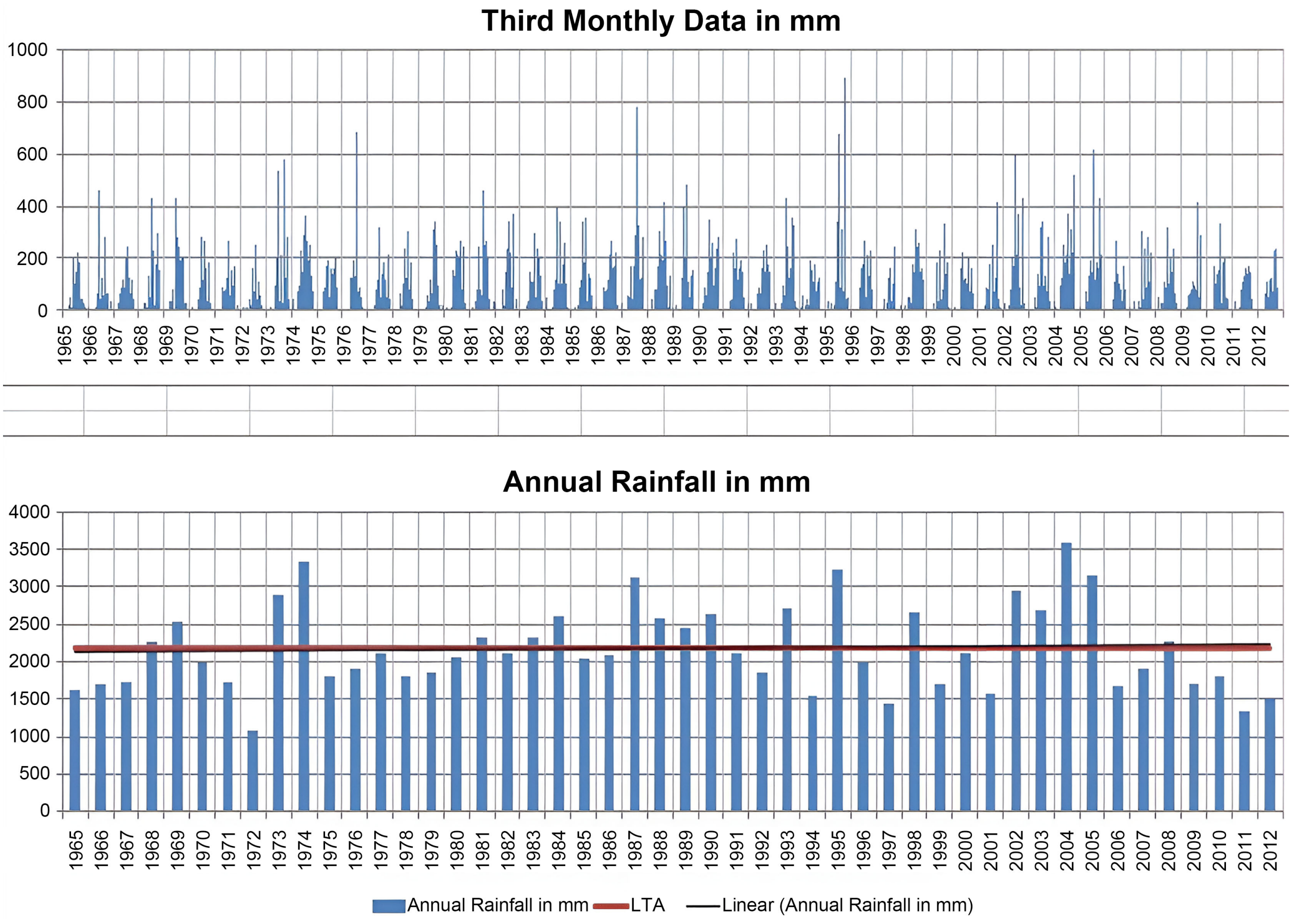
(by direct recharging) and indirectly (by contributing to flooding in low-lying areas). Figure 8(a) displays the third monthly and yearly rainfall as well as cumulative departures from the long-term average for various time periods. The annual rainfall has a range between 1050 to 3500 mm, with a long-term average (LTA) of 2250 mm. There are fluctuations noticed in the annual rainfall, but a significant downward trend shows after 2008. Moreover, the long-term trend rainfall of the said area shows 500 mm which is highest in June 2010 and then 300 mm in August 2011 (Figure 8(b)). Additionally, cumulative deficits for both the T Aman period (August to October) and the main irrigation period (January to early May) are made public. Similar declining tendencies were seen for the years 2005 to 2012 as well (Figure 8(c)). This may be a cause for the prospective increase in groundwater requirements during a given irrigation crop period. Bangladesh experienced droughts of major magnitude in 1973 (Adnan, 1993 [41]; Hossain 1990, 33 [42]) that was also observed in the annual rainfall graph in 1972 which occurred in the minimum range. Then 1985, 1989, 1992 and 1994 had limited rainfall and that was below the average. But it was quite memorable that in the last 7 years, the rainfall quantity was remarkably low.

3.2. Flooding

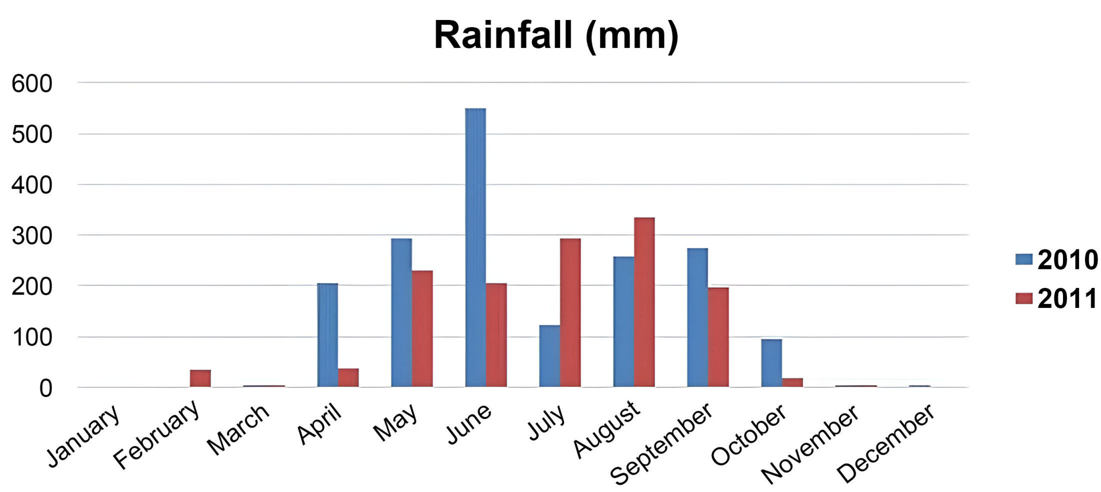
The north-western part of Bangladesh is a foothill of the Himalayan Mountain and a downstream part of the south-eastern Indian sub-continent. Therefore, no major impact of the flood on the study area except for some flash floods through the Teesta River is the main drainage channel for flowing flood water and our neighboring country India releases huge amounts of water due to excessive water or excessive rainfall there. Moreover, the average elevation (26.90 m) of this area is much higher in respect to other flooded areas.

3.3. Irrigation Development

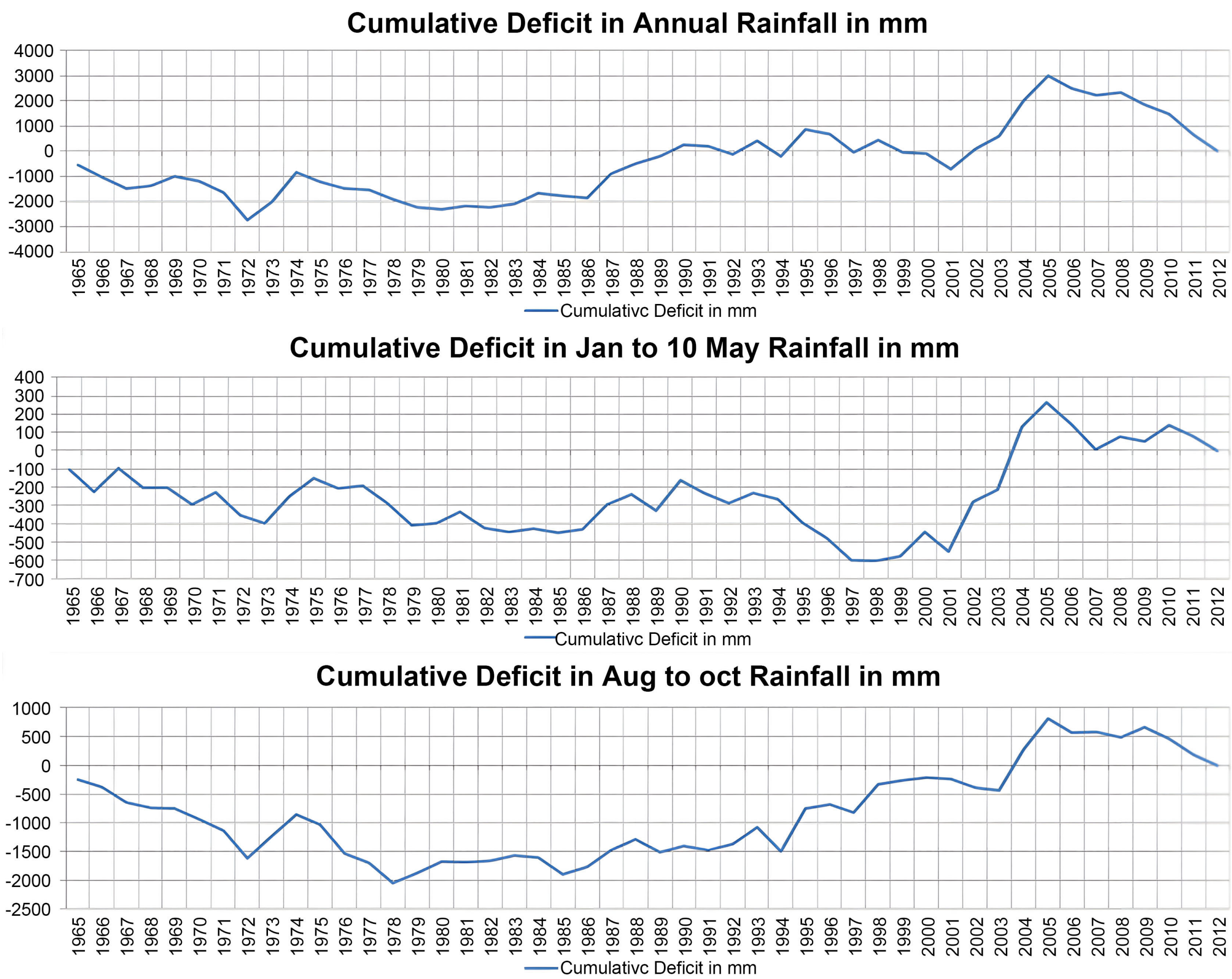
The SCTM incorporates 16 major crops or crop groups (BBS, 1974/75) [3] [4]



(a)



(b)



(c)

Figure 8. (a) Long term rainfall trends (b) Annual rainfall (c) Rainfall deficit hydrograph.

where the number of irrigated crops is 12 and non-irrigated crops is 4. This is compensated by an increase in surface water use, thus keeping the total irrigated area at some 50% of NCA. The reason for the decline in groundwater use is not known, but could relate to the changes in land use, such as irrigation and due to climate change, and the construction of an embankment at the upstream part of Teesta River at the Indian side. According to the irrigation development analyses, it is clearly observed that the use of groundwater and surface water is quite resembled. Over the time period surface water use is increasing more than groundwater.

3.4. Hydrograph Analysis and Interpretation

BWDB groundwater monitoring station namely GT8573011 is considered for long-term hydrograph analysis. Water level data of the piezometric well is used to draw hydrographs and incorporated with their nearest bore log to see the lithology where the fluctuations observe (**Figure 9**). From the analysis of the

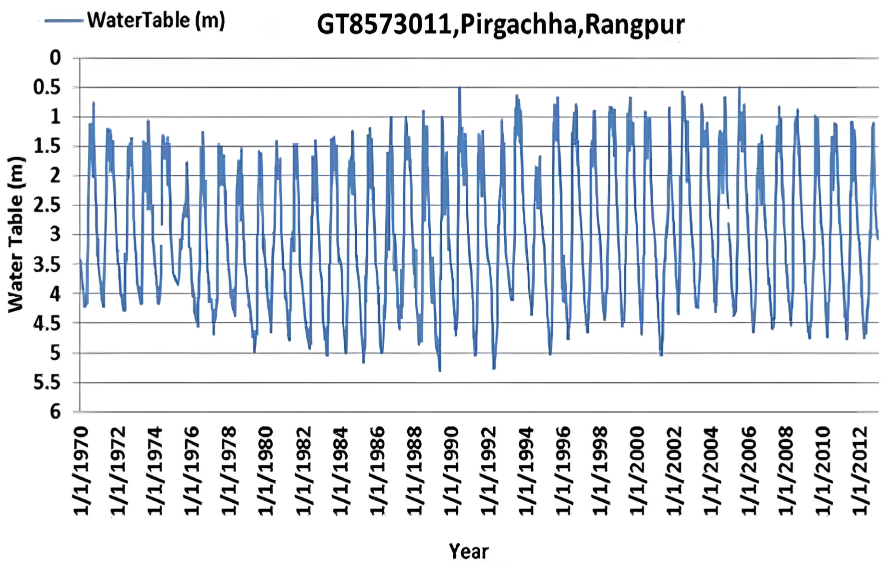


Figure 9. Long term hydrograph of station GT8573011 and section of bore log.

hydrograph, reveals the behaviors of groundwater and the aquifer where the piezometric well is installed. The variations of hydrographs are checked with the data of available parameters that influence the groundwater levels and it shows a decreasing pattern from 1970-2012. The hydrograph indicates a 4.2 m water level in 1970, 4.7 m shows in 2012, and though 1990-1992 it decreased to a maximum of 5.4 m. The decreasing pattern of water level also indicates the shortage of rainfall as well as low recharge and withdrawal of more groundwater because the daily necessity of growing people is increasing day by day. It should be noted that the aquifer is unconfined. Data errors are common practice in Bangladesh. The proper assessment of long-term hydrograph describes the potential documents of groundwater study and justified the validity of all the groundwater level-related information. The piezometric well data is widely used not only for hydrograph analysis but also in different fields of groundwater study.

It is observed that the monitoring wells are located in the northern part of the upazila, where the least potential impacts of industrial and urban development except the river Teesta. The piezometric well GT8573011 is installed within the shallow aquifer at a depth of 25.3 m which is shown in Hydro-stratigraphic section A-A' (**Figure 10**). The hydrograph consists of piezometric well data of monitoring station GT8573011 represents the water table within the upper finer materials. The nature of the water table hydrograph indicates that the upper finer material is very thick and leakage occurs to the underlying aquifer almost over the year. Some common features are observed within the groundwater levels of monitoring station GT8573011. The hydrographs of the piezometric well with the upper clay thickness of the nearby borehole reflect at the time of full recharge the aquifer behaves as unconfined in nature. The hydrograph of the piezometric well (1970-2012) indicates that the groundwater development, sources of recharge, and rechargeable area are more or less uniform, and full recovery

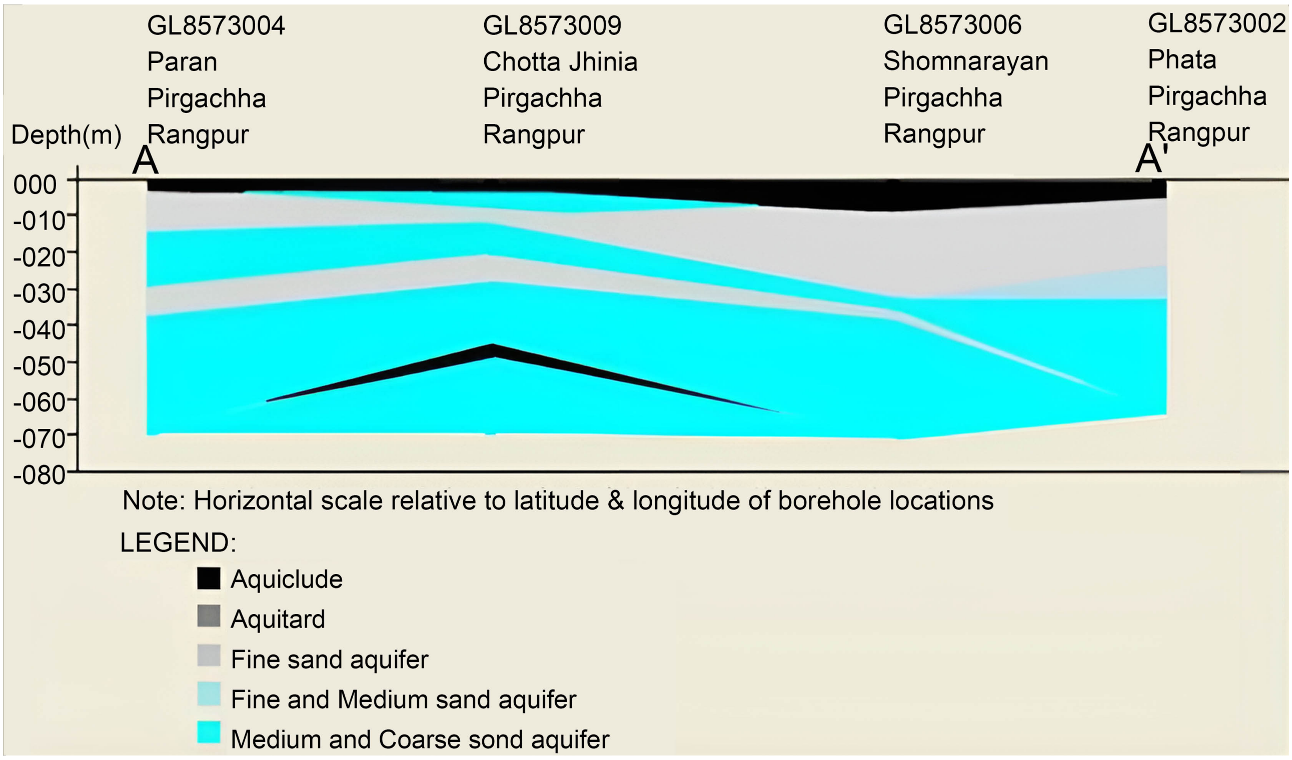


Figure 10. Hydro-stratigraphic section A-A' of the study area.

occurs during the subsequent rainy season. Seasonal variation of recharge is also evident within this segment.

3.5. Determination of Storage Co-Efficient and Vertical Permeability

The values of the storage coefficient of the fluctuation zone of the aquifer and vertical permeability of top clay are derived from the water balance of recession and recovery periods through hydrograph analysis. Δh (mm) is the difference between the maximum depth to water level and thickness of the upper clay. Hydraulic Conductivity (Kv) (mm/day) is the value of vertical permeability/hydraulic conductivity of the upper clay. Specific Yield (Sy) represents the value of the specific yield of the fluctuation zone of the aquifer where the piezometers are installed. The value of vertical hydraulic conductivity of top clay and specific yield of the fluctuation zone are essential not only to assess recharge of an area but widely used in different fields of groundwater study. The hydrographs of one monitoring station GT8573011 express the values of vertical hydraulic conductivity (Kv) of top clay and specific yield (Sy) of the fluctuation zones of the aquifer where the monitoring stations are installed. The derived values and the other necessary information are presented in Table 1. Due to minor irrigation data, the value of Qgross is assumed to be 900 (mm/unit gross area) for Barind Formation. The characteristics of the top clay of the study area are Barind clay. The values of Qgross of Pirgachha upazila are 900 mm. The recession period T1 ranges from 118 - 135 days where the average is 128 days. The recovery period

Table 1. Derived hydro-geological parameters from the hydrograph analyses.

St Id	Year	Clay Thickness (m)	T1 (day)	T2 (day)	T1 + T2 (day)	Δh (mm)	Qgross (mm)	Kv (mm/d)	Sy
GT8573011	1989	9.00	130	110	240	3500	900	3.75	0.28
GT8573011	1990	9.00	135	115	250	4000	900	3.60	0.28
GT8573011	1998	9.00	118	128	246	3500	900	3.65	0.28
Average			127. 6	117.6	245.3	3666. 6	900	3.67	0.28

T2 ranges from 110 - 128 days where the average is 118 days. A wide range of values of T2 shows decline trends perhaps due to early and late monsoons or variations of rainfall and flood water in the area. The value of Δh ranges 3500 - 4000 mm which is responsible for variations of recharge and groundwater development of the area.

The thickness of clay in the study area varies from 2 - 10 m. Hydro-stratigraphic section also reveals that this area mostly composed of fine, medium, and coarse sand aquifers is present from 30 - 60 m depth in the southern part and 5 - 70 m in the northern part. The nature of the aquifer geometrically is unconfined in nature.

3.6. Maximum Depth to Water Level

The average vertical hydraulic conductivity (Kv) of the upper clay of the area is 3.67 mm/day. The higher value of Kv justified the land types of the study area which mostly consists of small basin clay and scope of recharge is sufficient. The specific yield (Sy) of the shallow aquifer where the monitoring stations are installed is 0.28. The specific yield implies the upper aquifer consists of fine sand which is also agreed with the available lithology of the boreholes. For observation of maximum depth to water level, data on 26th April and 20th September 2010 is used.

3.7. Flow Net

The goal is to identify the subsurface flow directions inside and surrounding the study area. In order to avoid data from other aquifers, monitoring station data are chosen and installed in the first primary aquifer. The maximum depth of the water level contour map (**Figure 11**) was created using data from April 2010 and includes a 1 m contour interval. Additionally, two flow nets are created at a contour interval of 1 m, one for the lowest height (**Figure 12**) and the other for the highest elevation (**Figure 8**), using data from April and September for the year 2010 in the appropriate ways.

Both of the flow nets are steep cone-shaped depressions centering to the station GT8573011 and the Eastward groundwater flow direction of Pirgachha upazila indicates subsurface inflow occurs all over the year of the study area comparing the surroundings areas (**Figure 13**). The flow nets also reveal that no groundwater divide exists at the time of the end of irrigation and at the time of full recovery within the flow net area. The productive aquifer underlined by the

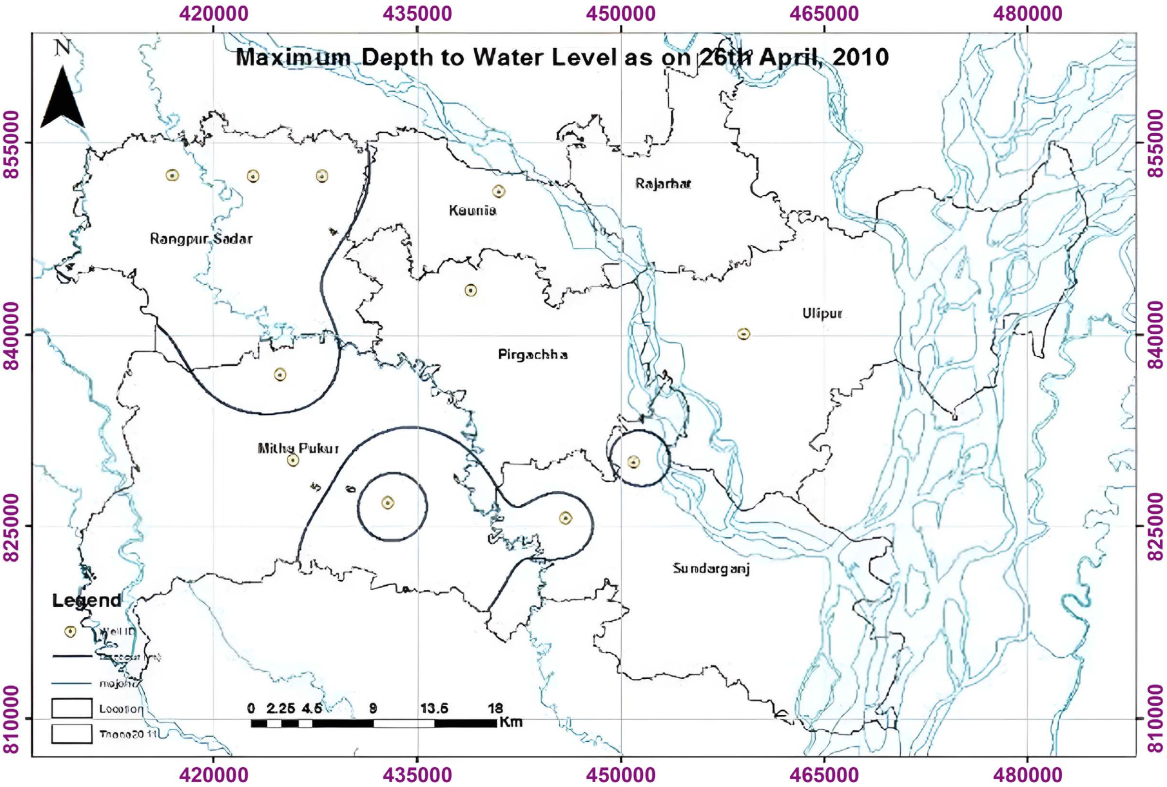


Figure 11. Maximum depth to water level on 26th April, 2010.

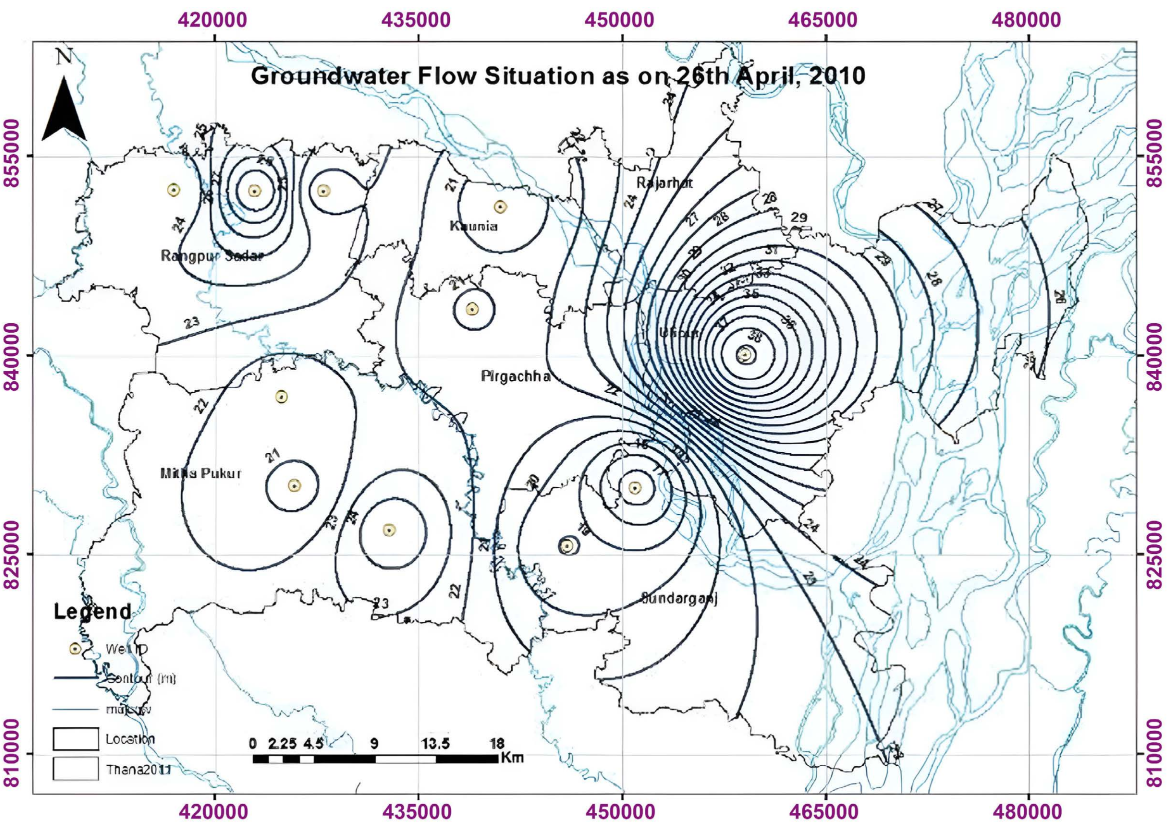


Figure 12. Subsurface flow direction (Minimum) of groundwater level on 26th April, 2010.

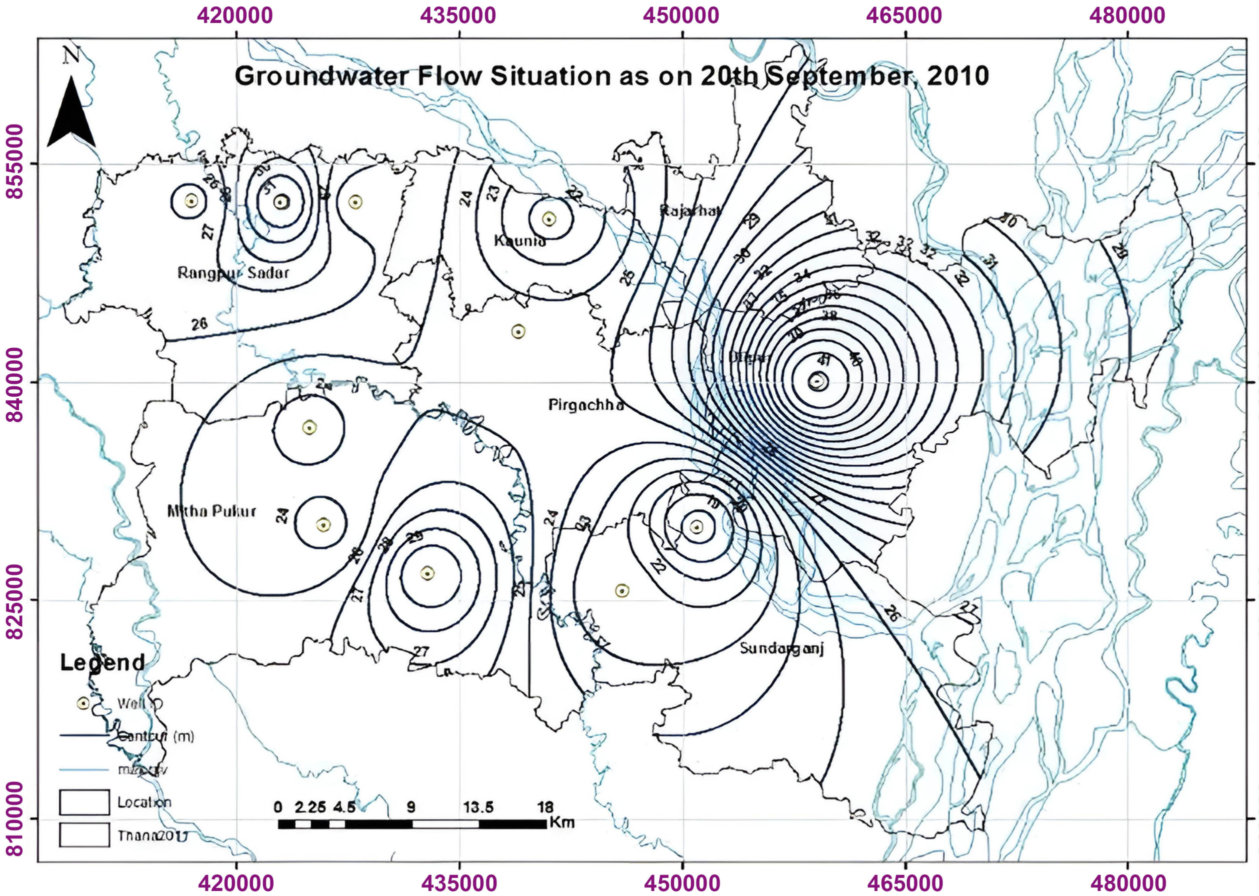


Figure 13. Subsurface flow direction (Maximum) of groundwater level on 20th September, 2010.

only 9 m clay which is very close to the river Teesta implies a very strong scope of hydraulic connection of the aquifer with the river Teesta.

4. Conclusions and Recommendation

There is a deficit in water resources in three of the seven dry season months. In this study, it has been considered that utilizable river flow can meet the crop demand for a maximum acreage of one kilometer strip on both banks of the river. Due to topographic constraints and practical limitations, it is unlikely that utilizable river flow could be fully used unless development projects are taken up. The lowest estimate of utilizable static water resources in the upazila has been considered to meet the crop demand exhaustively (after considering river resources). Usable groundwater resources are considered exhaustively to meet the remaining crop water demand as well as water supply requirements. The production aquifer of the study area is geometrically unconfined in nature. A shallow fine sand aquifer exists within the area the extension of which is not known due to insufficient bore log data. The Teesta River is nearby and the aquifer is overlain by 9 meters of clay, indicating a very strong hydraulic link between the two. According to the hydrograph study, the shallow aquifer's average specific yield, which is 0.28, indicates that medium to coarse sand predominates there. The average vertical hydraulic conductivity (Kv) of the upper clay is 3.67 mm/day and its thickness is very high in most of the areas, signifying the scope of recharge is noticed in the study area. The single monitoring station for the production aquifer, which also indicates the water level in the upazila's northern region, is groundwater monitoring station GT8573011. For greater interest in the study area, the number of monitoring stations for the production aquifer should be increased. The monitoring station GT8573011 is installed in the shallow medium to coarse sand aquifer. The rapidly increasing rate of urbanization and industrialization reduces the rechargeable area and invites greater demand for groundwater. Groundwater level declination occurs in both the upper and lower production aquifers. Even if the research area is not currently in a catastrophic position, public awareness should be raised so that people have a broad understanding of how to handle water resources because the study area is badly affected by drought throughout the dry season, especially during the Rabi season. As such without detailed study, a consequence of further development may become a threat to the aquifer environment.

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Conflicts of Interest

The authors declare no conflicts of interest.

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