Spatiotemporal depletion of groundwater level in a drought-prone Rangpur district, northern region of Bangladesh

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Abstract

Water insufficiency during the pre-monsoon season and rapidly falling underground freshwater levels is a common scenario in the towns and cities of Bangladesh. The objective of the study is to investigate the spatiotemporal depletion of groundwater levels (GWL) in a drought-prone Rangpur district, northern region of Bangladesh. Groundwater observation well data from 1980 to 2019 was used for this purpose. Rainfall, temperature, irrigation, and land use/land cover datasets are used to assess the factors influencing groundwater level depletion. Linear regression, and the least square regression model were used to identify the trend of GWL depletion. Results show that GWL in drought-prone regions is declining rapidly because of the excessive withdrawal of groundwater and land-based reservoirs for irrigation and household needs. The declining GWL is alarming during the pre-monsoon and post-monsoon seasons due to some disproportional mismanagement in the study area. Among the rates of decline, the trend in maximum depth has a comparatively higher rate than the others. Findings from the study show that severe withdrawal of groundwater in agriculture, a decreasing amount of annual rainfall, and degradation of climatic factors in the area are all attributed to a lowering trend in groundwater level.

1. Introduction

Groundwater is a fundamental regular asset of our mother earth that establishes around 95% of the freshwater on our planet, making it key to human existence and the financial turn of events. For our environment, groundwater plays a vital part in keeping the water level and stream in waterways, lakes, and wetlands. Over the past fifty years, groundwater has been widely used for household and technical purposes, irrigation, and other different purposes, which has created a huge pressure on the adequacy of groundwater (UNCSD, 2012). More than two billion people worldwide rely on it for drinking water, and about half of the world's food production is based on irrigated agriculture, which is heavily reliant on underground water (Morris et al., 2003). Because of the absence of surface water resources, groundwater is the most fundamental essential for expanding crop production as well as for the manageable agrarian turn of events. Yearly, 982 km3 of groundwater is removed internationally for different purposes (NGWA, 2016). The large volume of groundwater used in irrigation has approximately 70% of world freshwater demands and almost 90% of daily household consumption supplied by groundwater (Siebert et al., 2010). The water system is important to food security in many parts of the world, and groundwater use has grown to become a major source of irrigation water, especially in China and South Asia (Huang et al., 2014).

Though Bangladesh is blessed with a large number of inland water resources, it is also rich in groundwater resources, though not limitless. An enormous amount of groundwater is being siphoned every year, predominantly for irrigation and homegrown and mechanical utilization, through various water-lifting gadgets. Groundwater availability has contributed to increased agricultural productivity in Bangladesh. In Bangladesh, 90% of irrigation activities depend on groundwater and the rest of the irrigation depends on other inland freshwater sources (Zahid and Ahmed, 2006). Bangladesh needs much higher food production for its densely populated population and poor people who live mostly in poverty in rural areas. The yearly normal precipitation nearby during the period 1971–2011 differs from 1326 to 1650 mm with a normal of 1505 mm, which is about 39%, not exactly the public normal of Bangladesh (2456 mm). There is a lack of rainfall after the monsoon. Every type of crop production demands irrigation at this time. especially for Boro rice production, if fully dependent on groundwater irrigation, because at this time, surface water bodies lose their properties. As a result, topsoil loses its moisture after the monsoon. As a result, soil loses its production capability, so it depends on irrigation for crop production (Kirby et al., 2014). In Bangladesh, about 4.2 million ha of land is inundated by groundwater (both shallow and profound cylinder wells), though just 1.03 million ha is flooded by surface water utilizing low-lift siphons (BADC, 2013). During the dry season, too much groundwater is taken out for the water system, machinery, and home gardens. This has caused the groundwater level to drop, so that it doesn't fully refill during the rainy season in some places.

Sensational growth in the populace has prompted the misuse of both surface and groundwater assets, including the consumption of 21 of the world's 37 significant aquifers (Richey et al., 2015). In recent years, Bangladesh has faced declining natural groundwater, which suggests groundwater withdrawal in urban and rural areas for different purposes such as household, irrigation, and industries, which is unsustainable (Serajul, Farzeen & Islam, 2017). From the last 20 years' data of groundwater level fluctuation, it is evident that the groundwater level of Dhaka City is continuously declining. Groundwater level fluctuation patterns have abruptly changed and steeply declined after 1990 (Ahmed, 2019). A lowering trend in groundwater level and the rates of groundwater level change varied from 0.1 to 1.3 (m/decade) during the period 1981–2017 in the northern part of Bangladesh. The predicted results show that groundwater levels will be lowered from 2018 to 2025, which is alarming for future groundwater utilization (Salam et al., 2019). In Rangpur, there is a large fluctuation in groundwater tables during the monsoon and pre-monsoon seasons.

We should understand that the depletion of the water table is a major problem because it will be a requirement for the next era also. And if it were depleted today, then life would not be possible on earth. And the main cause of the depletion of the water table is the population, because an increase in the population also increases all other requirements that consume large amounts of groundwater. But the level of the water table in the villages is still above the level of the water table in the cities. Groundwater consumption may be the reason for the over-extraction of groundwater for irrigation and the lethargic pace of infiltration through the upper dirt to the silty mud layer. The increment or reduction of precipitation can enormously influence the groundwater level as it is the essential hotspot for the groundwater to re-energize (Hasanuzzaman et al., 2017; Park et al., 2011). The fundamental explanations for groundwater decay are overexploitation of water, population increment, urbanization, precipitation change, and so on (Serajul, Farzeen & Islam, 2017). The tapping of groundwater ought to be controlled. We can undoubtedly use significantly more groundwater than we should if we do not have a better understanding of our groundwater supply. Though rice is the staple food in the country, it is necessary to reduce this crop's cultivation to protect against the rapid depletion of groundwater resources. Moreover, water-saving irrigation techniques such as alternate drying and wetting and raised bed techniques need to be promoted for farming (Rahman, Hosono, & Jahan, 2018). Presently, there can be numerous elements answerable for the consumption of the water table. In this way, the most important things are probably the growing population, the lack of energy-saving technology, agricultural activities, and the growth of industries.

Most of the examinations revealed that groundwater level utilization changes happen because of superfluous extraction for irrigational purposes, yet these assessments have not adequately explained the justification for changes in groundwater fatigue. The data opening is particularly genuine in agrarian countries like Bangladesh. Regardless, numerous assessments on groundwater levels in Bangladesh, including the examination area, have been conducted, and there are a couple of gaps and deficiencies in the momentum composition. For instance, Kaya et al. (2018) expected groundwater level in the Reyhanl area in Turkey through Artificial Neural Network (ANN), M 5 tree (M5T) approaches, but they didn't reveal whether there is an association between groundwater level and climatic limits. Rahman & Mahbub (2012) simply focus on groundwater depletion with the expansion of irrigation in the Barind Tract. Sumaiya & Khatun (2016) examine groundwater variability as it relates to precipitation variability. Kutub (2015) focused on groundwater weariness circumstances, but didn't concentrate on controlling factors. As such, more investigations are required for a more significant appreciation of groundwater levels and different controlling components. In this manner, more exploration is needed for a more profound understanding of groundwater levels and diverse controlling elements. The key objectives of the present study are: (1) to quantify the spatial and temporal trends of groundwater level in the drought-prone regions on both annual, monthly, and seasonal scales for the period 1980–2019; (2) to analyze the periodicity of groundwater level on the annual, monthly, and seasonal scales; and (3) to detect the controlling parameters that are most influencing the groundwater level in the northern region on annual, monthly, and seasonal scales. The result of this examination can help with the taking of suitable measures and various alternatives by policymakers to guarantee reasonable groundwater for the executives and financial advancement in comparable areas around the world.

2. Materials And Methods

2.1 Description of the study area

The research will take place in Bangladesh's Rangpur District, a minor administrative entity in the country's north. It lies between 25°18'N and 25°56'N, as well as 88°58'N and 89°30'E. Its boundaries are formed by Kurigram District, the northeasternmost district; Nilphamari District, the northwesterly most district; the east-most district; and Dinajpur District, the westernmost district (Fig. 1). The appraisal region centers around Rangpur, which has a space of around 2401 square kilometers and shows an extremely fast pace of extension. Over the most recent couple of decades, land use designs in Rangpur changed throughout the investigation period (Islam, 2017). Also, the different effective climatic factors changed their character. The Rangpur investigation was directed to survey the consumption rate of groundwater level and the possibility of that. There are a few large cities in Bangladesh. Rangpur is one of them, situated in the Rangpur Division. On December 16, 1769, Rangpur was made a municipality. This is one of the oldest districts in the country. Rangpur Sadar has four municipalities, to be specific: Rangpur Sadar, Badarganj, Pirganj, and Haragach, and eight upazilas, specifically: Badarganj, Mithapukur, Gangachara, Kaunia, Rangpur Sadar, Pirgacha, Pirganj, and Taraganj. The Ghagot river passes beside Rangpur city. The area of Rangpur town is around 43 square kilometers and became a municipality in 1869. Figure 1, showing the location of Rangpur in the country, also presents the Upazila boundary. Rangpur is home to four major rivers: Tista, Ghagot, Karotoye, and Jamuneshori. The Cikli, Akhira, and Shamasundori rivers flow over Rangpur. The Tista River basin covers the majority of the Rangpur district, accounting for 80 percent of alluvial soils, while the rest is covered by barind terraces, which represent barind soil. The groundwater level in the dry season lies between 4.5 mbgl (meters below ground level) and 6.5 mbgl, while in the wet season it stays between 2.5 and 3.5 mbgl. Rangpur is faced with a monsoon climate with the dry and wet seasons, though these two seasons are subdivided into six seasons. The annual rainfall is 2192 mm. There is no or negligible rainfall in the first and last few months of a year. More than 350 mm of rainfall occurred in Rangpur in May and June. The average temperature in Rangpur is 24.9°C.

2.2 Description of data sources and quality control

Table 1shows the sorts of information that were utilized in this exploration. Climatic data presents the correlation of groundwater and climatic parameters.

Table 1
Depiction of indicators utilized for groundwater exhaustion model structure

Predictors	Unit	Worldly range	Source	Description	Date of collection
Groundwater level	m	1980–2019	Bangladesh Water Development Board (BWDB)	Weekly average Groundwater level	18.10.2020 and 27.12.2020
Rainfall	mm/y	1980–2019	Bangladesh Meteorological Department (BMD)	Monthly average rainfall	15.10.2020
Temperature	ºc	1980–2019	Bangladesh Agriculture Research Council (BARC)	Weekly maximum and minimum temperature	22.10.2020
Irrigated area	Acre	1980–2019	Bangladesh Bureau of Statistics (BBS)	Yearly total irrigated area	04.11.2020

To assess the depletion of groundwater level in the study area, we have collected the data from the "Bangladesh Water Development Board (BWDB)", and the meteorological data from the "Bangladesh Meteorological Department (BMD)". The quality control of the datasets was checked by and BWDB and BMD staffs.

2.3 Analytical procedure

80 observing wells in the study area were investigated for this study. The research investigates groundwater level fluctuations during wet and dry seasons in 2020. Groundwater level data from 1 August, 2020 and 1 May, 2020 were utilized for the wet and dry seasons, respectively. The GIS base IDW interpolation method was used to visualize the spatial variation of groundwater level for different seasons in the study area. For investigating the historical groundwater level during the wet and dry seasons, the study used groundwater level data from 1980 to 2019. Historical trends and yearly changes in groundwater level were identified using the historical data. The study also identified the impacts of different climatic factors (i.e., rainfall, temperature, and irrigation) on groundwater level in the study area through a time series plot of historical data. A correlation analysis was conducted for groundwater level with precipitation, evapotranspiration, and soil type. Finally, the study predicts the future value (i.e., 40 years from now) of groundwater level using historical data and the Least Square Method. The method of estimating predicted groundwater level with the Least Square Method is shown in the following.

Hence, we shift the arithmetic mean of the two middle years, we define

$$t=\frac{x-\frac{1}{2(x1+x2)}}{\frac{1}{2(intervals)}} \quad (1)$$

Where t values are in units of six months (half-year).

Let the straight-line trend equation between U_t and t be,

$$U_t=a + bt \quad (2)$$

Since, $\sum t = 0$, the normal equation for estimating a and b give

$$a=\frac{\sum U_t}{n} \quad (3)$$

$$b=\frac{\sum U_t.t}{\sum t^2} \quad (4)$$

We calculate x_n using existing formulas. x_n represents the year for which we want to predict the groundwater level. Eq. (1) is calculated as x = 40 because our observation period is 40 years. Then we calculate the values of a and b from equations (3) and (4). Then we can predict an annual groundwater level from the Eq. (2).

3. Results

3.1 Groundwater level fluctuation during wet and dry seasons

In Bangladesh, May represents the driest condition, a prelude to a wet climate. The winter season also represents dry weather, but May represents the most depleted condition of groundwater level because it is far enough from the rainy season. August represents dry weather because it is covered by the rainy season.

According to groundwater level data as of August 1, 2020, 57.5% of wells represent a water level of 2.5–3.5 mbgl, followed by 17.5%, 12.5%, and 12.5% of wells represent a water level of fewer than 2.5 mbgl, 3.5–4.5 mbgl, and above 4.5 mbgl, respectively. As found by Fig. 2 (a), all wells in Pirgacha Upazila represent less than 2.5 mbgl. Mithapukur, Pirganj, Rangpur Sadar, and Kaunia Upazila show a water level depth of 2.5–3.5 mbgl. In Taraganj Upazila and Badarganj Upazila, water level depths are 3.5–4.5 mbgl and more than 4.5 mbgl, respectively. The maximum profundity to the water level of 5.36 mbgl is seen in Badarganj Upazila, whereas the minimum is 2.12 mbgl in Pirganj Upazila.

According to groundwater level data as of May 1, 2020, 42.5% of wells represent the groundwater table in the depth range of 4.5–5.5 mbgl, followed by 7.5%, 12.5%, 12.5%, and 12.5% of wells represent the groundwater level of 3.5–4.5 mbgl, 2.5–3.5 mbgl, 5.5–6.5 mbgl, and above 6.5 mbgl, respectively. According to Fig. 2(b), all wells in Pirgacha Upazila show 2.5–3.5 mbgl. At Mithapukur, Pirganj, Rangpur Sadar, and Kaunia Upazila, the depth is 3.5–4.5 mbgl. On the other hand, the water level in Gangachara is 4.5–5.5 mbgl and in Taraganj, Kaunia Upazila, it shows a range of 5.5–6.5 mbgl. In Badarganj Upazila, the water level is more than 6.5 mbgl. The maximum groundwater depth (i.e., 6.78 mbgl) is found in Badarganj Upazila, while the minimum groundwater depth (i.e., 2.60 mbgl) is found in Pirganj Upazila.

According to water level impatience of August 2020 compared to May 2020, groundwater level of 93.75% (i.e., 75) wells show a rise and 6.25% (i.e., 5) are trying not to show any adjustment in water level. About 31% of wells represent an ascent in the groundwater table in the scope of under 1 mbgl. Figure 3 shows about 39% of wells represent an improvement in the groundwater table in the 1–2 mbgl range and 20% of wells represent an improvement in the groundwater table more than 2 mbgl range. Most of the wells represent rise/decay falls between the scopes of 0–2 mbgl.

According to Figs. 3, fourteen monitoring wells show groundwater levels below 2.5 m from the surface in the wet season, but none in the dry season. Respectively, the groundwater level of 46 monitoring wells stays between 2.5 and 3.5 m in the wet season, while only 10 m during the dry season in this range. Water levels of between 3.5 and 4.5 mbgl were shown by 10 wells in the wet season and 6 wells in the dry season. Another outcome was discovered when we searched for the water level to reach between 4.5 and 5.5 mbgl. At this reach, 10 wells in the storm season and 33 in the pre-rainstorm season. In this range of water level, there are no wells for the wet season but 10 for the 5.5 to 6.5 mbgl range and 10 wells above 6.5 mbgl during the dry season.

3.2 Historical groundwater level during the wet and dry season

Figure 4 shows the historical groundwater level in the wet season for the study area. Mithapukur and Pirganj Upazilas show the most depleted state of groundwater, among others. The comparatively stable groundwater levels are shown in Gangachara and Kaunia Upazilas. For several years, there has been a very fluctuating depletion of groundwater tables in Taraganj and Badarganj Upazilas. Rangpur has suitable conditions for groundwater level, so there is very little fluctuation in groundwater level. Mithapukur, Pirganj, Badarganj, and Pirgacha Upazilas have lower levels of groundwater than the others. In 1995, 2000, 2010, and 2011, several Upazilas had lower groundwater levels.

The groundwater level in Badarganj Upazila stays lower than in other Upazilas of Rangpur district. From 1980 to 2005, there was an almost stable condition of groundwater levels. In the wet season after 2005, there was an unstable condition in groundwater levels. From 2005 to 2011, groundwater levels decreased in Badarganj Upazila; from 2012 to 2014, the average groundwater level was rising. Then, between 2016 and 2018, there was another depletion of groundwater. In Gangachara Upazila, there is an almost similar depth of groundwater level over the study period from 1980 to 2019. After 2000, groundwater levels in Kaunia Upazila decreased rapidly. In Mithapukur Upazila, lower groundwater levels between 1982 and 1989 and then in 1990 to 1992 raised the level of groundwater. From 1992 to 1997, the groundwater level in Mithapukur Upazila decreased. Another rise occurred in 1998, and another depletion occurred in 2001. After 2002, there was a falling trend in those levels, and after 2010, there was a rising trend in the groundwater level during the monsoon in Mithapukur Upazila. Since the start of this investigation period, the degree of groundwater has fallen in Pirgacha Upazila. Several uplifting events occurred in 1990, 1998, 1999, 2001, 2003, and some others. After 2013, there was a regular increase in groundwater levels. More fluctuations occurred, among others, in Pirganj Upazila. In 1983, 1987, 1989, 1996, 2000, 2001, 2007, and 2010, there was a fall in the groundwater level in Pirganj Upazila. After 2001, the average groundwater level in Pirganj Upazila rose. Stable conditions are observed for Rangpur Sadar and Taraganj Upazila over this period.

Except for Rangpur Sadar, every upazila has depleted characteristics of the groundwater table. During the wet season, the groundwater level in Rangpur Sadar has increased.Water demand is lower in areas with fewer agricultural activities, semi-urban areas, and less developed areas of Rangpur city. So, there are almost no bad effects on groundwater levels. The depletion rate by year is: Pirganj Upazila: 0.05062 m; Mithapukur Upazila: 0.019251 m; Badarganj Upazila: 0.015592 m; Gangachara Upazila: 0.007713 m; Kaunia Upazila: 0.052993 m; Taraganj Upazila: 0.003514 m. In Rangpur Sadar, groundwater levels uplifted 0.00539 m per year during the wet season.

Figure 5 shows the level of groundwater in the dry season. This represents the most depleted state of groundwater. Groundwater in Badarganj Upazila shows the most depleted state of groundwater, among others. In Fig. 5, comparatively stable groundwater levels are shown in Pirganj, Mithapukur, Gangachara, and Kaunia Upazilas during these periods. For several years, there has been a very fluctuating depletion of groundwater tables in Taraganj and Badarganj Upazilas. Rangpur has suitable conditions for groundwater level, so there is very little fluctuation in groundwater level. Badarganj and Taraganj Upazilas experienced more severe conditions in several years, including 1982, 1994, 1997, 2000, 2005–2007, and 2019. In Kaunia Upazila, the water level is almost stable, depleted only in 2012–2014. At the beginning of this period, the unstable groundwater level in Mithapukur Upazila during the dry season. From 1995 to 2005, it was stable. After 2005, this level fell, and the very nearest condition was in 2017.

The depletion rate by year for: Pirganj Upazila: 0.008312 m, Taraganj Upazila: 0.008575 m, Pirgacha Upazila: 0.018343 m, Kaunia Upazila: 0.027028 m, and Gangachara Upazila: 0.018239 m. Three upazilas have positive year-to-year changes in groundwater level: Rangpur Sadar (0.000013 m), Mithapukur Upazila (0.01649 m), and Badarganj Upazila (0.00036 m).Badarganj has had a comparatively bad situation for groundwater levels since 1980, but with time, its most depleted level is improving (Fig. 5). Mithapukur has a lot of inland water reservoirs, so there is a suitable groundwater level throughout the year. Rangpur Sadar has less demand for water for irrigation and there is not much demand for industrial uses of water.

3.3 Influence of climatic and irrigation factors on groundwater level

The groundwater system is a dynamic system that changes seasonally and over an extended period and has a water-powered inclination corresponding to the surface shapes. This unique framework proposes that groundwater be removed. No, it doesn't stay static and be devastated and unsaturated, but it does arrive at its base immersion during the dry seasons. The depletion of groundwater forces the best use of groundwater during the Khariff and Rabbi seasons by irrigation. In this extreme circumstance, the fundamental methodology for groundwater extraction is to abuse groundwater capacity in the spring until it is exhausted and then get ready for resupply during the monsoon season. If groundwater is not extracted and used, it ends up in inland waters. In a characteristic framework, groundwater re-energize is generally reliant upon precipitation since it contributes straightforwardly to the re-energize of the basic aquifers. Sumaia & Khatun, (2010); Jahan et al., (2010) have referenced precipitation on a superficial level as the fundamental wellspring of groundwater re-energized in Bangladesh, and it is clear that without rainfall, groundwater recharge also ceases gradually. Excessive rainfall in the upper countries causes flooding in Bangladesh, causing a floodwater flow responsible for the recharge of groundwater. Adham et al. (2010) tracked that diminishing precipitation has constrained developing likely evapotranspiration, crop evapotranspiration, and net irrigation has become more dependent on groundwater, leading to a tendency to deplete groundwater levels.

Effect of Rainfall

Standard re-energize and precipitation time arrangements show an unmistakable connection between precipitations and re-energize (Fig. 6). At the point when yearly precipitation is higher (or lower) than normal precipitation, yearly groundwater recharge is likewise higher (or lower) than normal (Petit et al., 2021). This propensity is affirmed by the noticeable connection between the yearly groundwater stockpiling equilibrium and yearly precipitation. By and by, changes in groundwater capacity are profoundly connected with precipitation.

At the point when yearly precipitation is below the mean value, the yearly stockpiling balance is negative (groundwater capacity decays), though the yearly storage balance is positive (rises in groundwater capacity) when the mean value is lower than the yearly precipitation. Rainfall constitutes the main source of groundwater. Rainfall affects the rate of infiltration into an aquifer, so any change in rainfall and storm patterns may affect the amount of recharge.

The groundwater level and rainfall pattern bend gradually downwards. In the dry season, rainfall decreases and groundwater levels are depleted. While rainfall occurs in the wet season, after 10 to 40 days, there is the best level of groundwater. Observation wells show that water levels dropped after the monsoon because it rained less. This happened because the recharge decreased, which meant that less rainfell.

On account of ordinary precipitation or less precipitation, there can be a circumstance where pre-rainstorm levels are exhausted. Excess rainfall in the monsoon represents groundwater levels near the surface. This amount could be allocated to the variety in the rainfall design. In some cases, substantial power precipitation causes more spillover and less invasion, resulting in a decrease in the re-energized amount and consumption levels. Broad precipitation for quite a while gives more penetration during the rainy season. This has been studied in various observation data sets. A programmed water level recorder assists with understanding the impact of precipitation on groundwater re-energize (LLC, 2021). The effect of rainfall is on soil moisture. High soil moisture requires more evapotranspiration, resulting from more rainfall that indirectly helps with more groundwater recharge. Soil moisture during the day and night decreases the soil temperature, which provides a protective plant root system and helps with more water infiltration into an aquifer. To account for plant environment adjustment at higher dampness content, plant development rate and yield increased (Al-kayssi & A.W., 2004).

Effect of Temperature

More temperature suggests low soil moisture; low moisture represents the low content of water in the soil. When there is a lower amount of water in the dirt, there is less infiltration and less permeation. There is less percolation effect on the recharge of the aquifer. That recommends the consumption of groundwater level and good and bad times for groundwater level (Hasan et al., 2018).

Since the dynamic energy of a molecule is comparative with its temperature, disappearance proceeds even more quickly at higher temperatures. The higher temperature influences higher vanishing from the surface and higher happening from plants, which are likewise affected by climate and weather, which incorporate sun-based radiation, temperature, relative stickiness, and wind (and other meteorological variables). When higher temperature powers evaporate water from the surface, the measure of energy fundamental to dissipation decreases. Evaporating water from the surface in a short time means less infiltration of water. When the weather is sunny, water is lost from the surface more quickly than when it is cloudy or cool. On the other hand, during the monsoon season, there are high temperatures that are responsible for more rainfall over the year. More rainfall occurs at a high rate of groundwater recharge. So, temperature is responsible for more evaporation in the pre-monsoon, which suggests groundwater level depletion, and more rainfall in the monsoon suggests groundwater improvement.

Effect of Irrigation

In Rangpur, minor irrigation plays a vital role to expand the irrigated area, increase food production, and thereby helping to make sure the food security of the country. For the formulation of economic policy and plan for agricultural development, adequate and reliable statistical data about the number & types of irrigation equipment (both diesel and electric) irrigated area benefited farmers are very much essential.

Rice production is the biggest client of water system water, representing around 77.6% of the total rice production dependent on irrigation (BBS 2014). About two-thirds of irrigation water is driven by underground water (Bari & Anwar 2000). Customarily, Bangladesh is designated as a river country, and it's anything but an advanced history of utilizing river and canal water for different purposes. Sumiya and Khatun (2016) found evidence that water from a stream or a trench was a good way to water crops in the past. Just as with the presentation of high-return assortments, particularly after the 1980s, the reliance on groundwater for irrigation has expanded fundamentally the nation over. Rasheed (2016) asserted in his examination that during the 1970s, 90% of all-out rural land relied upon surface water hotspots for irrigation in the dry season. Since 1986–87, an extraordinary extension of groundwater utilized for irrigation has been seen (Rasheed, 2016). In a few kinds of examination, Boro rice has been viewed as the most serious of rice assortments. In this investigation, utilizing groundwater for irrigation of rice production was considered as one of the components that influenced the decay of groundwater levels. Investigated information shows that among the three varieties of rice production, Boro rice is the most water system concentrated, though Aus and Aman's rice require less water system. The irrigated region under Boro rice production is multiple times higher than the Australian rice production area and multiple times that of the Aman rice production area (Sumaia & Khatun, 2016).

In Rangpur, irrigated areas are increasing very fast (Fig. 8). That's the most effective cause of groundwater depletion. During the dry season, when irrigation takes place, the groundwater level in Pirganj, Pirgacha, Gongachara, Taraganj, and Kaunia Upazilas goes down below its natural level.

Correlations of groundwater level with precipitation, evapotranspiration, and soil type

The impact of precipitation on groundwater levels is assessed through month-to-month groundwater levels and month-to-month precipitation information to determine the actual cycles that overwhelm the progressions in spring stockpiling. The correlation between groundwater and rainfall and groundwater and potential evapotranspiration (PET) is shown in Fig. 9. There is no negative correlation observed in any of the monitoring wells, implying that the depth of groundwater decreases as precipitation increases. Every monitoring well showed a positive correlation with rainfall. Normalized re-energize and rainfall time series exhibit an unmistakable connection between rainfall and re-energize at all stations. At the significant level, at the 99% level, a weak positive correlation was found among all the monitoring wells, with a coefficient correlation in the range of 0.25 to 0.5. On the other hand, 50% of the monitoring wells show a comparatively strong correlation between rainfall and groundwater level at a significant level of 99% in this region, with a coefficient correlation in the range of 0.4 to 0.5 (Fig. 9). The absence of a decent connection between precipitation and groundwater levels reinforces the likelihood that precipitation-affected varieties in groundwater levels decline as groundwater levels become affected by anthropogenic mediations (Gardner & Heilweil, 2009). Comparatively, developed upazillas like Badargonj, Mithapukur, and Rangpur Sadar monitoring wells represent less correlation between rainfall and groundwater level. The groundwater levels in these areas are affected by human activities and the infiltration rate of rainwater.

This region is covered in silt and clay soil particles. Silt and clay are made of minuscule particles with a lot of pore space between them. Soils with higher porosity have more pore space and a higher infiltration rate than those with lower porosity. Silt and clay have less porosity, and they reduce groundwater permeability. Since this region consists of almost the same permeable soil, groundwater storage is slightly affected by soil permeability among these monitoring wells. The effect of continued groundwater reflection and less water penetration brings about a bringing down of groundwater levels in the dry season and eventually high occasional changes in groundwater levels and a solid rainfall groundwater connection. The great rainfall-groundwater level relationships that we see suggest that the shallow groundwater level quickly impacts the nearby rainfall designs (Gardner & Heilweil, 2009). A shift to higher rainfall may allow for an advance rather than a constrained re-energizing of groundwater (Doll & Florke, 2005). Monitoring wells showed a strong correlation between PET and groundwater level, with a correlation coefficient in the range of 0.5 to 1.0.

3.4 Future prospect of average groundwater level

The yearly normal profundities of the groundwater level revealed falling patterns in five upazilas and rising patterns in two upazilas; no pattern is just a single above and beyond the years being scrutinized (1980–2019) (Fig. 10). As per these pattern esteems, we anticipate the possibility of a normal groundwater level, as well as the yearly greatest profundity and the base profundity of groundwater level in our investigation region. Every wet season, groundwater in shallow aquifers is replenished. After the monsoon, the depth of the maximum water level also decreases, which makes the distance of the water level from the surface during the dry season even greater than it is during the wet season.

After 20 years, the annual average groundwater table fell for Taraganj Upazila at 0.071 m, for Pirganj Upazila at 0.569 m, for Pirgacha Upazila at 0.515 m, for Kaunia Upazila at 0.708 m, and Gangachara Upazila at 0.176 m. The other three upazilas will show annual groundwater levels rising at Badarganj Upazila of 0.037 m, Rangpur Sadar of 0.172 m, and Mithapukur Upazila of 00.011 m.

After 40 years, the annual average groundwater table fell for Taraganj Upazila by 0.146 m, for Pirganj Upazila by 1.168 m, for Pirgacha Upazila by 1.058 m, for Kaunia Upazila by 1.454 m, and Gangachara Upazila by 0.36 m. At Badarganj Upazila, Rangpur Sadar, and Mithapukur Upazila, annual groundwater levels will rise by 0.076 m, 0.26 m, and 0.022 m, respectively.

There are very few depletions and rising rates, but these rates are not negligible. In recent years, climatic factors have rapidly changed, which directly affects the condition of the average level of groundwater. The underground water in the closest aquifers is renewed every year, and after that, the water levels and how they change are a very important part of groundwater surveying.

4. Discussion

This study aimed to investigate the spatiotemporal depletion of groundwater levels in a drought-prone northern region of Bangladesh. The spatiotemporal trends of groundwater level on annual, monthly, and seasonal scales for the period 1980–2019 were quantified. Compared with the wet season, in the dry season the water level goes down from the ground level. The groundwater scenario from the last wet and dry season shows the closest and farthest water level from the surface. In Badarganj, Kaunia, and some parts of Taraganj, more groundwater was exposed in the dry season compared with others. In Rangpur, the maximum depth of groundwater is 6.78 mbgl and the maximum depth is 2.42 mbgl. Maximum depth ranges from 3.98 mbgl to 6.78 mbgl, with a minimum of 2.42 mbgl to 5.36 mbgl. From the time series of the most depleted levels of groundwater, Badarganj and Taraganj faced more depth compared with others. The maximum depth of groundwater level fluctuated the most in the years 1994–1995, 2005–06, and 2013–14. The time series of minimum depth reflects that Rangpur Sadar, Gangachara, and Kaunia have good conditions for groundwater level in the wet season. In Rangpur, Badarganj has more depth, and Mithapukur has less depth, on average groundwater level. Analysis of the groundwater tables from 1980 to 2019 with trendline shows five Upazilas have a downward movement in average groundwater level. The other three upazilas show the positive movement of groundwater levels, which is a very good sign for any region. Badarganj, Mithapukur, and Rangpur Sadar improved their groundwater levels. In 2005, different upazilas had similar maximum depths. According to future trends, twenty years of annual groundwater table declines have left Taraganj Upazila with an average annual decrease of 0.07 m, Pirganj Upazila with an average annual decrease of 0.56 m, Pirgacha Upazila with an average annual decrease of 0.512 m, and Gangachar Upazila with an annual decrease of 0.176 m. The annual groundwater levels in the other three upazilas will rise by 0.037 m in Badarganj Upazila, 0.172 m in Rangpur Sadar, and 0.011 m in Mithapukur Upazila. Annual average groundwater levels in Taraganj, Pirganj, Pirgacha, Kaunia, and Gangechara upazilas all decreased by more than one meter over the course of 40 years. In Badarganj Upazila, the groundwater level will rise by 0.076 meters, in Rangpur Sadar by 0.26 meters, and in Mithapukur Upazila by 0.022 meters.

Badarganj Upazila suffers from more groundwater vulnerability. Soil permeability is responsible for water infiltration. More permeable soil is ready for more infiltration, which creates more groundwater recharge. When topsoil loses its permeability, it indicates more runoff and less infiltration. The majority of Badarganj, as well as parts of Mithapukur and Pirganj, were built on Barind tract soil, making groundwater vulnerable in that area. Irrigation during the dry season is most responsible for groundwater fluctuation between the monsoon and pre-monsoon seasons. Rice production is the largest irrigation water user. About two-thirds of the irrigation water comes from groundwater. It is dependent upon the season. While in the summer season, the groundwater tends to get low because of dryness and evaporation, it gets rich during the blustery season or at the colder time of year. There is no monitoring well taking measures below 2.5 m of groundwater, which represents the depletion of the groundwater table over the whole area. Rapidly pumping water from the aquifer that is replenished over a long-term period causes groundwater depletion problems. The volume of groundwater is diminishing in numerous spaces in Rangpur in light of siphoning in the drier months for groundwater extraction, mainly for irrigation. Normal groundwater siphoning is the essential driver of groundwater exhaustion.

Four controlling factors of groundwater depletion were identified in the study area. Groundwater recharge increases or decreases as a result of greater or lower annual precipitation, respectively (Petit et al., 2021). On the other hand, the high temperatures seen during the monsoon season are responsible for the greater annual rainfall. Groundwater recharge increases the amount of rain that falls. Temperature causes higher evaporation in the pre-monsoon, which indicates a decrease in groundwater levels, whereas more rain in the monsoon indicates an increase in groundwater levels. According to Bari and Anwar (2000), irrigation is used in nearly 77.6 percent of all rice cultivation, making rice farming a major user of system water. two-thirds of the irrigation water. The area of irrigated land in the city of Rangpur is rapidly expanding. Depletion of groundwater occurs mostly as a result of this practice.

The groundwater system is dynamic, and the level of groundwater is affected by different climatic factors (Salam et al., 2020). The rainfall and groundwater level trendlines are slowly moving downward. In the dry season, rainfall decreases and groundwater levels are depleted. While rainfall occurs in the wet season, after 10 to 40 days, there is the best level of groundwater. Solar radiation, rainfall, and groundwater levels all have a positive relationship. Irrigated areas, domestic and livestock water use, temperature, and groundwater levels continue to have negative relationships. In Rangpur, there is almost no relationship between humidity and groundwater level, which is similar to the results of Elbeltagi et al., (2022).

From the significant interpretation of the level of groundwater in the observation period and prospect, we have found some recommendations against this incident. The displaying of water interest and use from farming, industry, and homegrown areas should be better with revealing insights. It can also be improved by utilizing advanced social methodologies based on expert-based displaying. The extraction from the more profound restricted aquifers prompts the survey as to the reason for the change in shallow aquifers. Once groundwater has been separated from more profound aquifers, water in a confined aquifer depends on unconfined aquifer replenishment. It should be limited to the extraction of groundwater from bound springs. Groundwater use can be cut down in areas where groundwater is the only source of water by making water systems more efficient and switching from flood systems to sprinkler and trickle systems (Pham et al., 2022).

In the dry season, there are fleeting separations between water-organic markets. At that time, the request can be handled through the durable utilization of surface water and groundwater that fills the water deficiency in the spring. The siphoning of groundwater ought to be managed. If we don't know a lot about where our groundwater comes from, we can definitely use a lot more than we should.

5. Conclusion

This paper assesses the groundwater conditions in Rangpur from 1980 to 2019. Groundwater abuse was found to be the significant driving variable for groundwater exhaustion. Also, human activities and climatic components contribute to changing groundwater. The major components affecting groundwater levels are precipitation, temperature, moistness, and groundwater misuse. Groundwater in the nearby springs is refreshed every year, and after that, the situation with groundwater tables and how they change is a very important part of judging groundwater.

Trend analysis and the least square method were investigated to improve the methods to estimate the groundwater level. The outcomes show a diminishing pattern of groundwater level in both dry and wet seasons, with the yearly normal groundwater level aside from a couple of inconsistencies in Rangpur. Rangpur's chances of showing falling minimum, maximum, and average groundwater levels are likely.

The extent of this examination was affected by the restricted information accessible on environmental change and human exercise. Restricted data can't separate their particular effects on groundwater. Then, at that point, further investigation of the effect of human activities on environmental change concerning groundwater will be significant later on. We should, of course, need more money to study our groundwater supply instead of just taking it, so that we can draw specific lines and use it better.

Declarations

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Code availability

Code will be available upon reasonable request on corresponding authors

Data availability

Data will be available upon reasonable request on corresponding authors

Author contribution

Monir, M.M., designed, conceptualized, drafted the original manuscript; Sarker, S.C., Sarkar S.K, planned the documents; Ahmed. M, and Mallick J., involved in the literature review, software, mapping, statistical analysis, interpretation of the analysis and discussion; Pal, S.C., and Monir, M.M., contributed to instrumental setup, data analysis, validation; Rahman M.S., contributed to data collection and extraction; Islam, A.R.M.T., Mallick, J., and Sarkar S.K., had done the internal review and proofreading during the manuscript drafting stage.

Ethical approval

Not applicable

Consent to participate

Not applicable

Consent to publish

Not applicable

Conflict of interest

None

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Figures

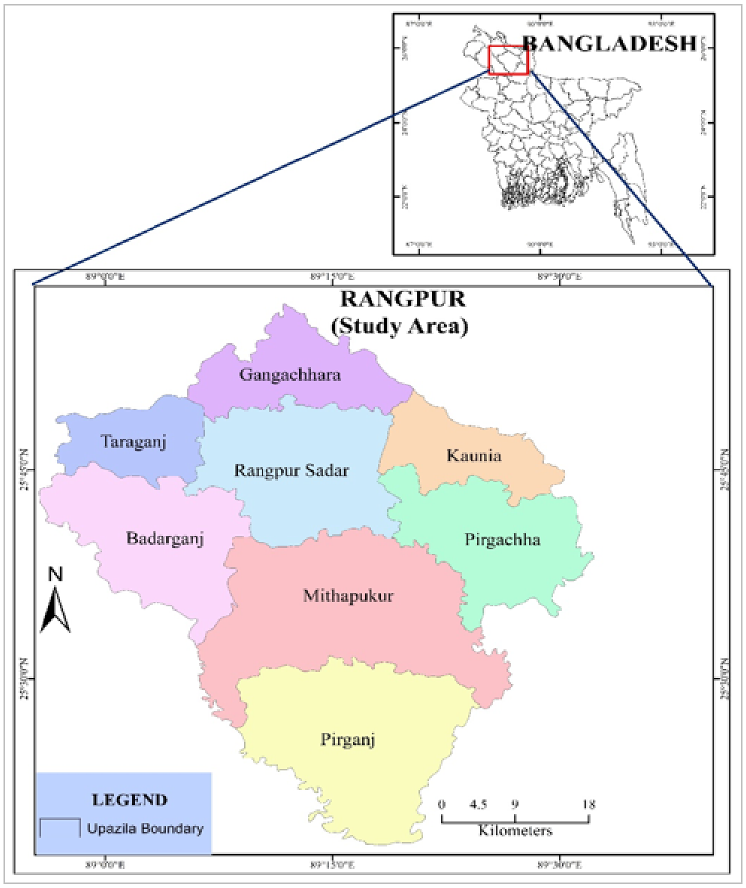

Figure 1

Location map showing the drought-prone region, Rangpur, Bangladesh

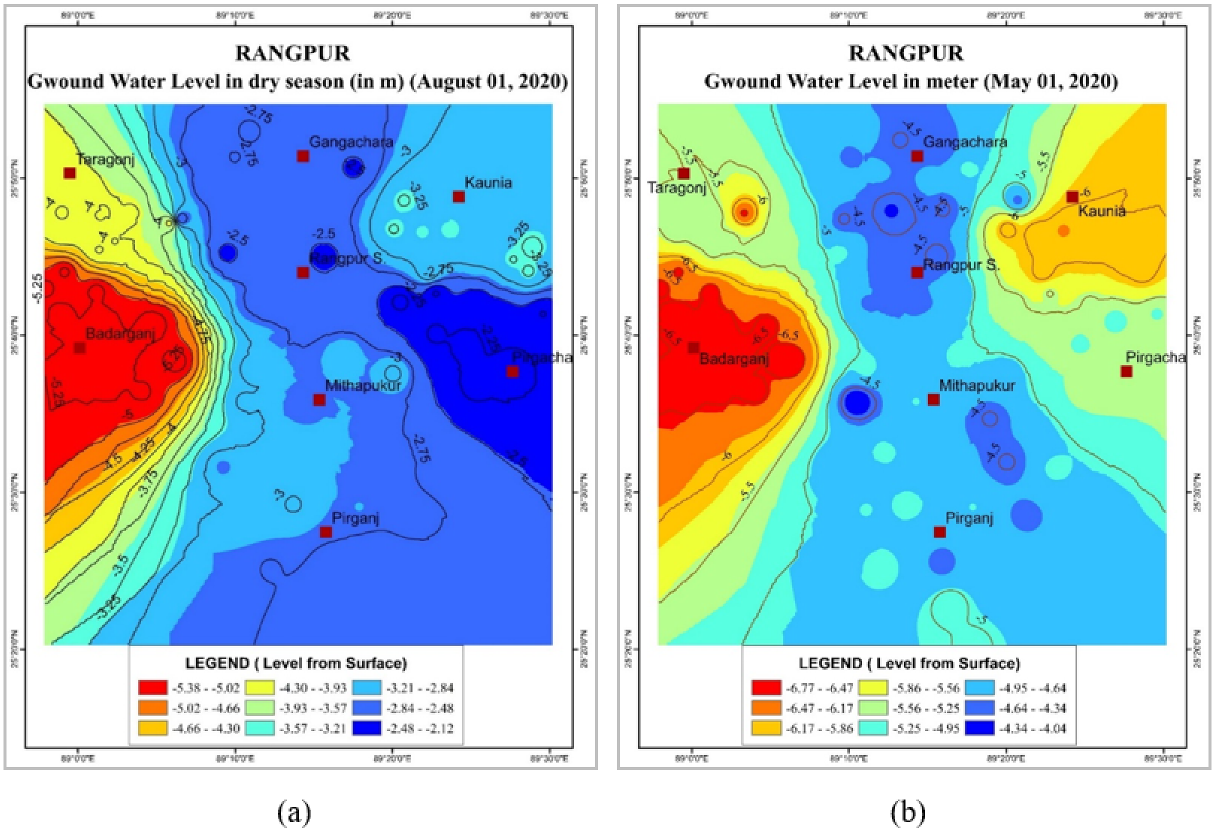

Figure 2

Present scenario of groundwater level of Rangpur in (a) dry season (1 August, 2020) and (b) wet season (1 May, 2020)

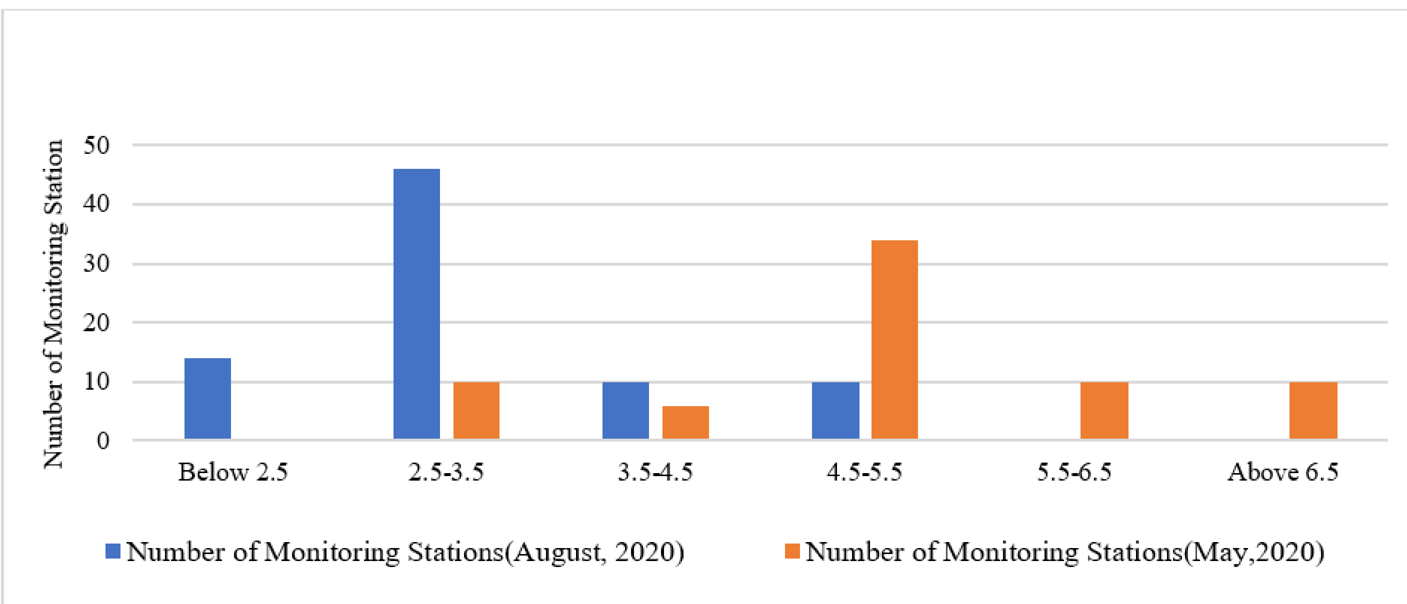

Figure 3

Groundwater level (in mbgl) Fluctuation (1 August 2020 Compared to 1 May 2020)

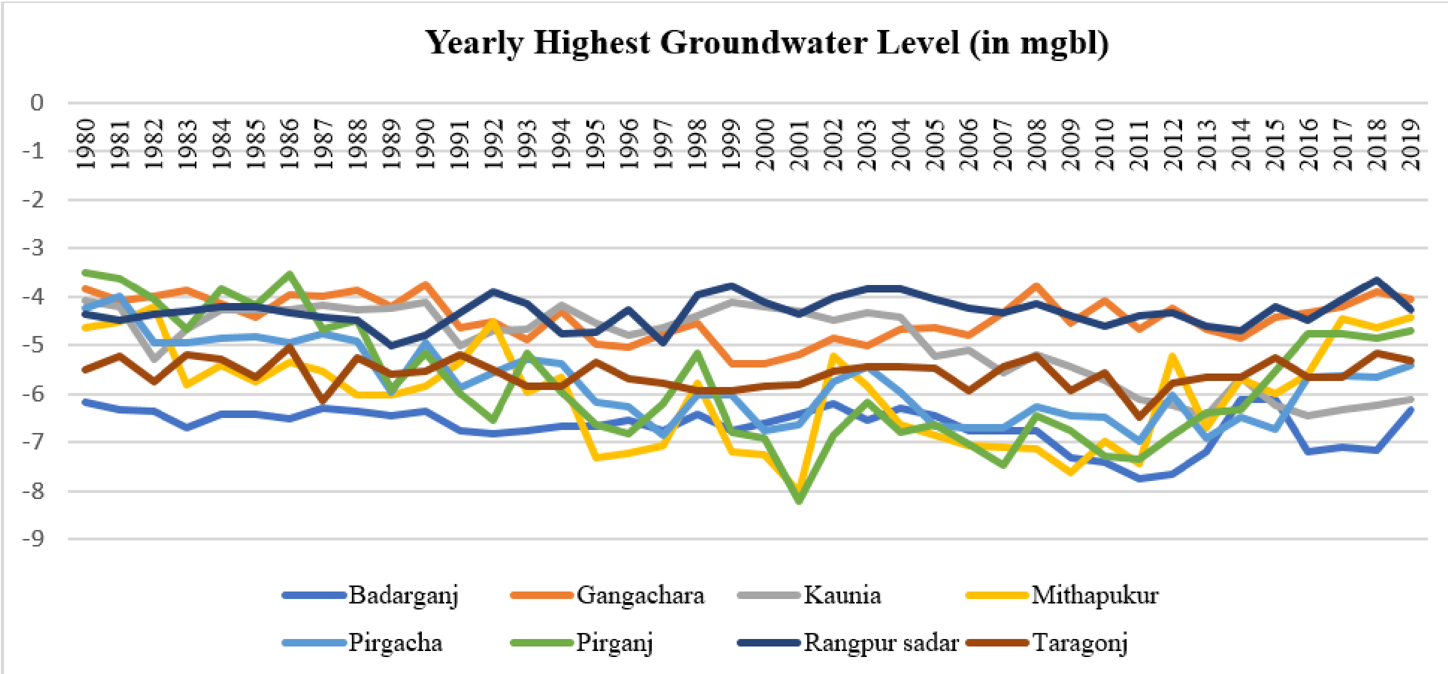

Figure 4

Groundwater level depletion in the wet season.

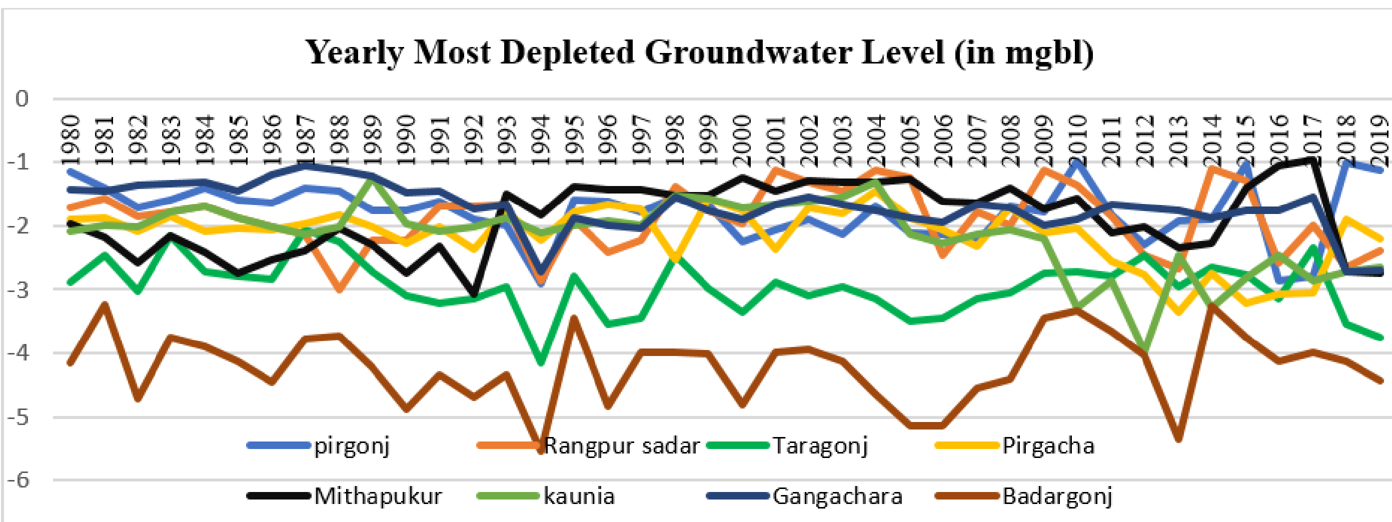

Figure 5

Groundwater level depletion in the dry season

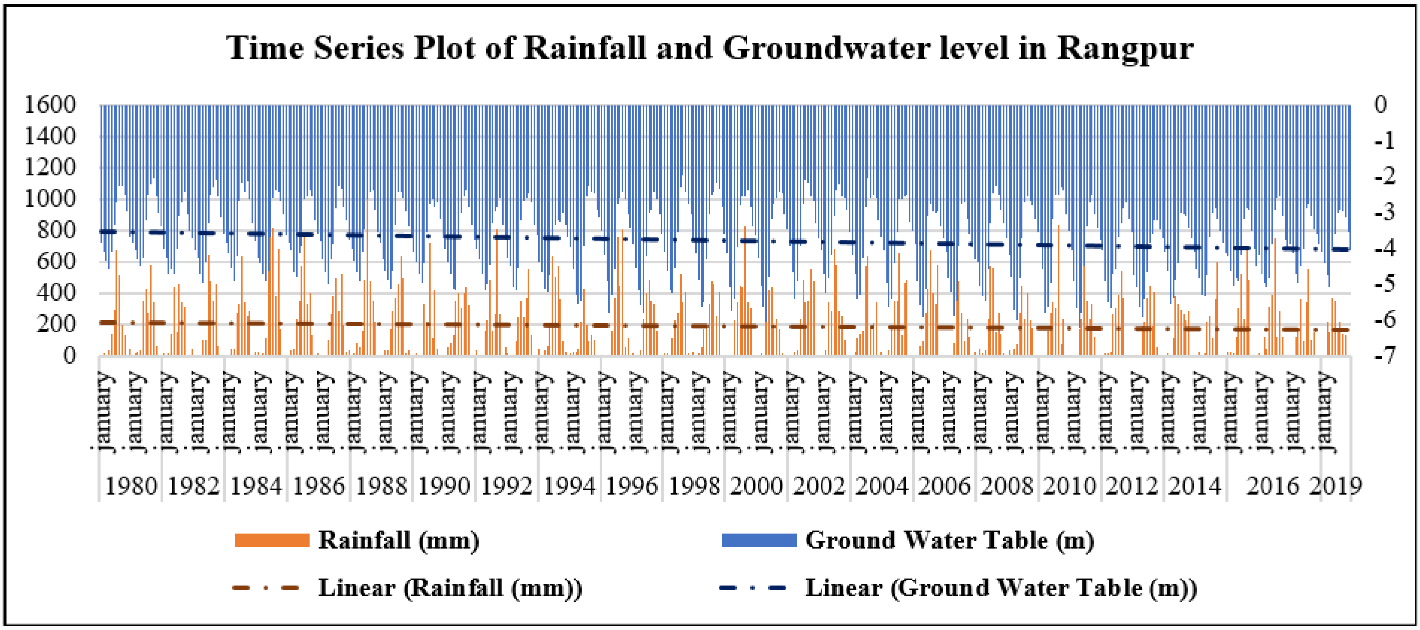

Figure 6

Groundwater levels with rainfall in Rangpur district

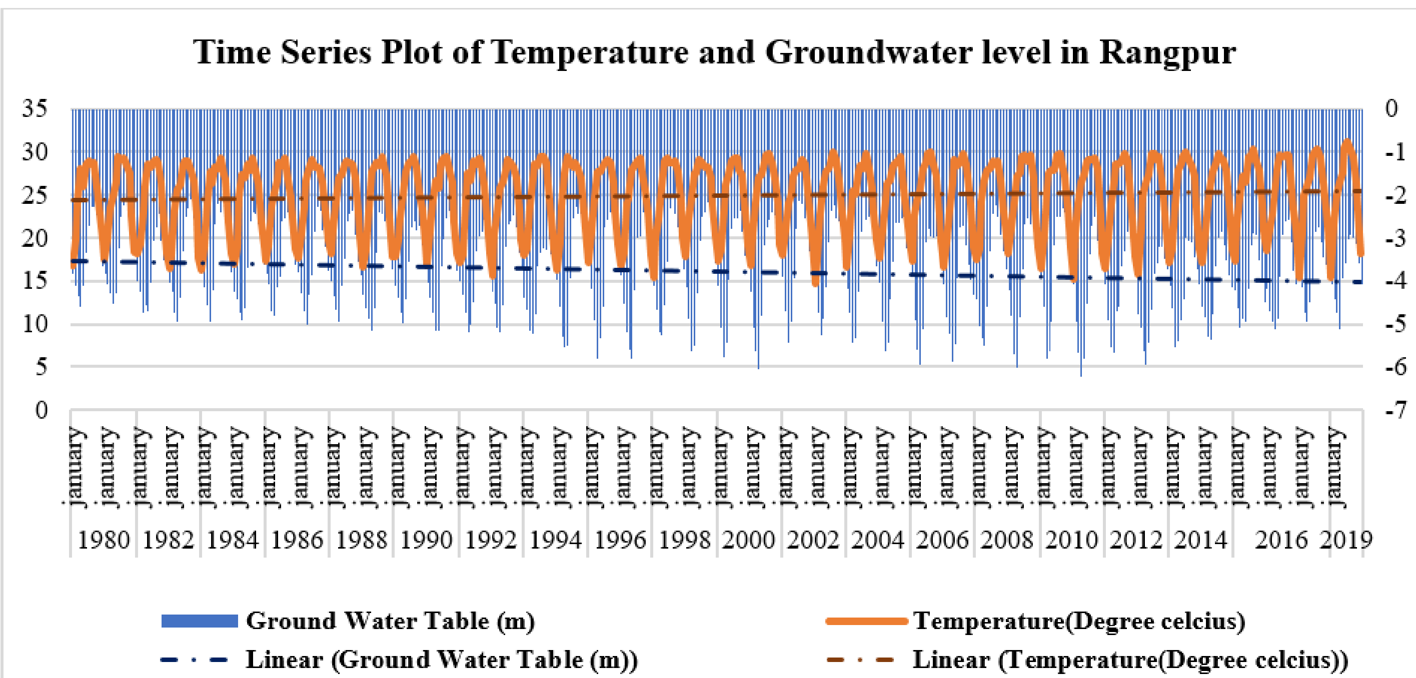

Figure 7

Temperature and Groundwater level in Rangpur

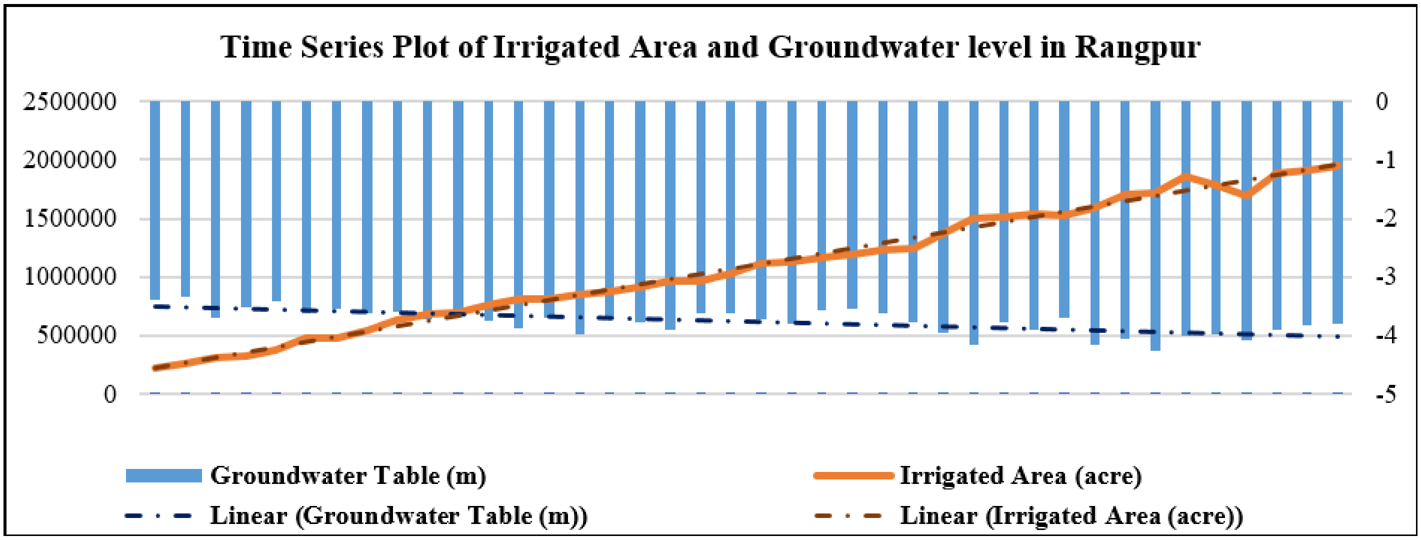

Figure 8

Irrigated area and Groundwater level in Rangpur

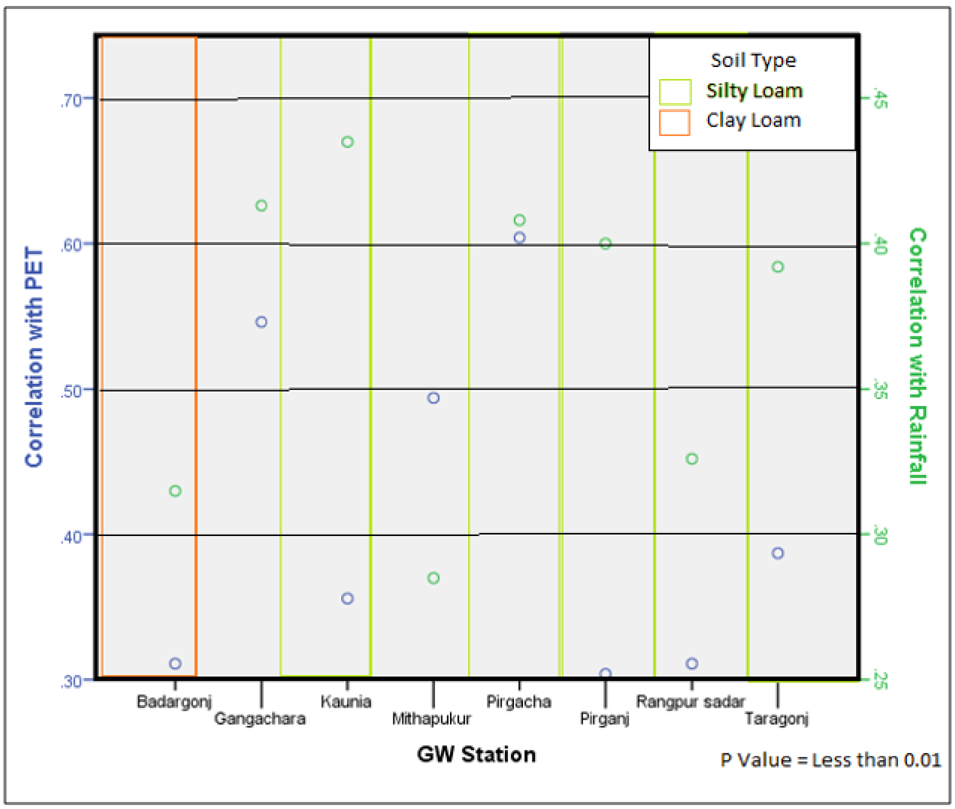

Figure 9

Correlations of groundwater level with precipitation, evapotranspiration, and soil type

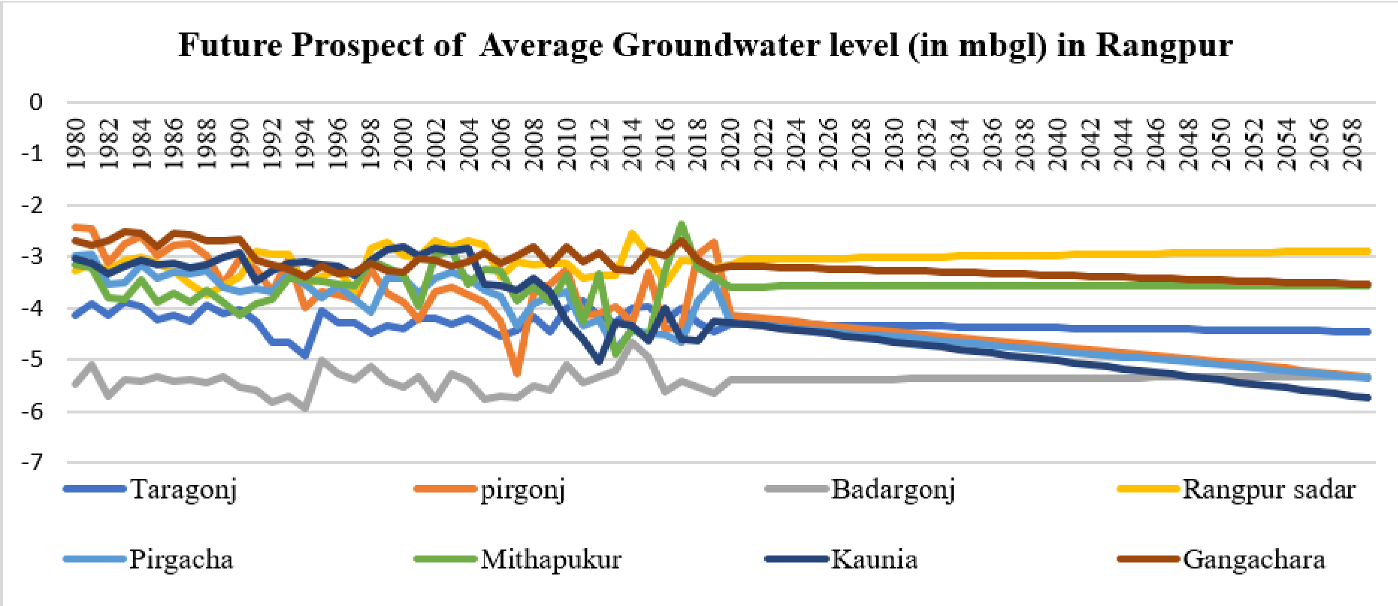

Figure 10

Future Prospect of Average Groundwater level (mbgl) in Rangpur