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Climatic variability on groundwater recharge of Mymensingh district in Bangladesh

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Abstract

A study was carried out in Mymensingh sadar upazila of Bangladesh in order to evaluate the effects of climatic variability on groundwater (GW) recharge and evapotranspiration (ET) over the period of 2006 - 2015. The annual GW recharge was computed by using soil moisture balance method, while CROPWAT-8.0 model was used to determine potential evapotranspiration (PET) and Grindley method was also used to estimate actual evapotranspiration (AET). In the case study area, the average temperature and rainfall showed no trend (almost constant), whereas humidity showed a declining trend over the study period. Analysis of rainfall trend revealed that there was considerable increase in annual rainfall with a mean of 2125 mm found over the study period. Groundwater recharge showed an increasing trend over the whole period, and the maximum recharge of 247.86 mm found in 2013, while maximum GW depletion of 136.8 mm found in 2014. In case of annual PET, the maximum of 1403.76 mm found in 2006, whereas the minimum of 1115.76 mm found in 2013. The AET showed a slightly declining trend over the 10 years of study, and the highest average AET of 1014.24 mm observed in 2007, whereas the lowest of 772.92 mm was in 2013. There was no significant relationship among groundwater recharge and annual variability of average temperature, and average rainfall found while only the annual variability of average humidity was found to be inversely related with groundwater recharge.

Key words: Climatic parameters, climatic variability, groundwater recharge, evapotranspiration

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Introduction

Groundwater (GW), valuable and the largest source of fresh water in the world, is the water in the saturation zone held between soil particles and cracks in the soil. Total water resources of the world are estimated at about 1.37×10^8 Mha-m among which about 97.2 % is salt water and only 2.8 % is available as fresh water. Out of this 2.8 % fresh water, about 2.2 % is surface water (SW) and 0.6 % is GW, where only about 0.3 % can be economically extracted from the aquifer (Raghunath, 1987). Numerous global aquifers are depleting and the extraction is exceeding the recharge rate which is threatening the availability of global freshwater supply. The over extraction of groundwater causes drought and ultimately affects the crop yield (Thomas & Famiglietti, 2019 and Kroes *et al.*, 2019).

In Bangladesh, GW is the main source of irrigation and drinking water, and about 75% of irrigation water and 90% of drinking water come from the GW sources (Shahid *et al.,* 2006; Shariot-Ullah, 2018). Though a number of rivers crossed over Bangladesh, the sources of SW are not sufficient to fulfill the total requirement.

Total GW extraction for agricultural, industrial and domestic purposes was estimated to be about 10,600 Mm^3 throughout the country till 1991 (MPO, 1991).

Bangladesh is an agricultural country, where agriculture largely depends on the irrigation process during the dry season (mid-October to mid-June) since rainfall is minimal. GW is the most vital input for enhancing crop production as well as for sustainable agricultural development. Due to the development of irrigation in the country, the amount of GW extraction has increased significantly. Domestic and industrial uses have also increased dramatically. So, the extraction of GW has been increased up to 18,135 Mm^3 which is about 86 % of the 24,064 Mm^3 available recharge (Rahman, 1997). GW supplies 78.2 % of water in dry season irrigation and almost all municipal water supplies. Thus, the GW is the major source of water that is used for municipal water supply and irrigation purposes (Rasel *et al.,* 2013).

GW recharge is a hydrologic process in which water moves laterally from SW to GW, and this process normally occurs in the vadose zone below plant roots which is maintained by precipitation. The precipitated water can be lost by interception, ET, surface runoff and the remaining water percolates below the water table in the saturated zone as GW recharge. In hydrology and irrigation practice, it is observed that evaporation and transpiration processes can be considered advantageously less than one head as ET. The PET no longer critically depends on soil and plant factors but depends essentially on climatic factors. The real ET occurring in a specific situation is called AET (Subramanya, 1994).

Water resources are subjected to change due to meteorological and climatological impact all the year-long. Many climatic parameters such as precipitation, temperature, humidity, etc. affect GW recharge. In addition to these climatic parameters, GW recharge is also affected by human activities. Climatic variability highly influences GW resources by modifying recharge rates (Ajami *et al.,* 2012). The main sources of GW recharge are precipitation, monsoon floods, and many other surface sources. The effective management of GW resources requires adequate knowledge of the extent of the storage, the rate of discharge, the rate of recharge to GW body and the use of economical extraction (Ahmeduzzaman *et al.,* 2012). GW management should be more strategic to cope with the potential impacts of climate change. However, GW has not received sufficient attention compared to SW resources.

The effect of climatic variables on GW recharge is poorly understood. The response of GW to climate variability is a complex matter because it does not only rely on the climatic parameters, but also on some other important factors such as vegetation, land use patterns, soil types, and geology (Green *et al.,* 2011). Understanding climate variability is vital for society and ecosystems, particularly with regard to complex changes influencing the availability and sustainability of GW resources (Dragoni and Sukhija, 2008). A few numbers of scientific research works relating the effect of different climatic variables on the response of GW recharge and ET has been conducted worldwide. Many researchers are trying to relate various climatic parameters and GW recharge still now. But in Bangladesh, research work in this field is still very limited compared to the other parts of the world. So, there is a huge scope to conduct research in the field of GW recharge in relation to climatic variables in Bangladesh. To diagnose the effects of climatic parameters on GW recharge and evapotranspiration is very much important for understanding the spatial variability of GW recharge for effective water-resource management. By taking this into considerations, it was decided to conduct this study to relate the variability of important climatic parameters with GW recharge and ET because GW is the most reliable source of water for the utilization in various purposes.

Materials and Methods

***Study area*:** The study was conducted in Mymensingh sadar upazila covers an area of 388.45 km^2, located in between 24°38' and 24°54' N latitudes and in between 90°11' and 90°30' E longitudes, as shown in Figure 1. The elevation from the mean sea level of the study area is 19 m. The climate of the study area is moderate, much cooler than Dhaka, as it is closer to the Himalayas. The temperature drops below 15 °C in winter which is spread over December and January, and the highest temperature is felt during April - May period, when the temperature may be as high as 40 °C. The annual average rainfall is 2,249 mm (Wikipedia, 2019). As Mymensingh sadar upazila is located in Madhupur Tract, the soil type of the study area is clayey texture and contains a large quantity of iron and aluminum, which are highly aggregated. The pH value of the soil of the area ranges from 5.5 to 6.0. The predominant land use of this area is *Aus, T. Aman*, Jute in *Kharif* season and Mustard, Wheat, Pulses, Potato, Onion, etc. in *Rabi* season.

Figure 1. Location of the study area (Banglapedia, 2015).

***Data collection*:** The study was conducted by using historical data of various meteorological parameters (maximum and minimum temperature, rainfall, humidity, wind velocity, sun hours and solar radiation) over the period of 2006 - 2015. The required data were collected from the weather station, Bangladesh Agricultural University (BAU), Mymensingh, Bangladesh for the study area. These data were used to estimate the GW recharge and ET. Missing data in time series were estimated using the arithmetic mean of the adjacent month (Backundukize *et al.,* 2011).

***Methods for GW recharge and evapotranspiration estimation*:** Soil-moisture balance method was used to estimate GW recharge. In this method, the concept of the water balance of the unsaturated zone (Thornwaite and Matter, 1957) was applied. Applying continuity at the soil surface, a balance equation can be written as:

$$P = I + E + RO \quad \text{.....(1)}$$

Mathematically, the balance equation of the soil moisture zone can be expressed by the following equation:

$$I - ET - R = \pm \Delta SM \quad \text{.....(2)}$$

From the above two equations,

$$R \pm \Delta SM = (P - RO - E) - ET \text{ or,}$$
$$R \pm \Delta SM = P - RO - (E + ET) \text{ or,}$$
$$R \pm \Delta SM = P - RO - AET \quad \text{.....(3)}$$

Where, AET = (E+ET) *i.e.* Actual Evapotranspiration, E = Evaporation, ET = Evapotranspiration, I = Infiltration, P = Rainfall, RO = Runoff, R = Recharge, and ΔSM = Change in soil-moisture.

The soil-moisture, at the beginning of a period (day or month), is illumined by runoff and diminished by the AET for the period. When ΔSM becomes negative it represents an increase in soil moisture deficits (SMD), when SMD develops no recharge occurs according to this concept. In this method, when SMD within the soil zone is fully satisfied *i.e.* SMD = 0, then only the excess *i.e.* positive ΔSM represents partial recharge to the saturated zone *i.e.* aquifer. According to the soil moisture balance method, when ΔSM is positive, then the only recharge occurs (Rushton and Ward, 1979). Therefore, according to the principle of soil moisture balance, GW recharge to the aquifer becomes, R = P – RO – AET ……………………………… (4)

For the above equation, AET was estimated from the PET, calculated from CROPWAT-8.0 model using all the previously mentioned meteorological parameters (minimum temperature, maximum temperature, humidity, wind speed, and sun hours), and runoff was determined using a standard method. The FAO Penman–Monteith equation was used for computing daily reference evapotranspiration in CROPWAT-8.0 model (Allen et al, 1998). The equation is as follows for day steps-

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad \text{……………… (5)}$$

Where, ET_o is reference evapotranspiration [mm day^{-1}], R_n is net radiation at the grass surface [MJ m^{-2} day^{-1}], G is soil heat flux density [MJ m^{-2} day^{-1}], T is air temperature at 2 m height [°C], Δ is saturation slope vapor pressure curve [kPa $°C^{-1}$] , γ is psychrometric constant [kPa $°C^{-1}$], u_2 is wind speed at 2 m height [m s^{-1}], e_s is saturation vapor pressure [kPa], e_a is actual vapor pressure [kPa], and (e_s − e_a) is the saturation vapor pressure deficit of the air [kPa].

The AET was estimated by using Grindly method (Grindley, 1967) under two conditions, mentioned below.

1. When, P > PET, then AET = PET

   Where P = Rainfall, and PET = Potential evapotranspiration.

2. When, P < PET, then AET = P + f (PET–P)

   Where f = Slope of the drying curve of PET vs. AET, usually taken as 0.1.

Khosla's formula (Subramanya, 1994) was used to estimate direct runoff, expressed by the following equation:

$R_m = P_m – L_m$ ……………………………......................(6)

Where, R_m = Monthly runoff in cm, P_m = Monthly rainfall in cm, and L_m = 0.48 T_m for T_m > 4.5˚C.

The loss factor L_m is used to reflect the losses of rainfall due to ET if loss L_m > P_m, then R_m = 0.

After estimating AET and direct runoff, GW recharge was calculated by using the soil moisture balance method for the study area.

Results and Discussion

***Trend of annual average climatic parameters*:** The climatic variables are particularly important because they directly influence GW recharge and indirectly affect human GW withdrawals or discharge. Even a small variation in these parameters may lead to large changes in recharge in some semiarid and arid regions (Green *et al.,* 2007; Woldeamlak *et al.,* 2007). The annual average major climatic parameters (temperature, humidity, and rainfall) of the study area over the period of 2006 - 2015 are presented in Table 1, and their trends are shown in Figure 2.

Table 1. Annual average climatic parameters over the period of 2006 – 2015.

Year	Average Temperature, ^{0}C	Average Humidity, %	Rainfall, mm
2006	25.70	84	2016.20
2007	25.25	84	2779.40
2008	25.45	84	2202.90
2009	25.90	83	1658.30
2010	25.95	83	1959.70
2011	25.25	81	2144.80
2012	25.40	81	1520.40
2013	25.55	80	1665.90
2014	25.75	82	3236.00
2015	25.55	82	2070.70
Mean	25.58	82.40	2125.43
Standard deviation	0.25	1.43	527.60

In case of annual average temperature, it varied from 25.25 to 25.95 ^{0}C over the 10 years of study with a mean value of 25.58 ^{0}C and standard deviation of

0.25^0C, while it indicates that there was low variability in temperature having no special trend over the study period. A declining trend of humidity was found from the year 2006 to 2013 and again, increased from the year of 2014 with a coefficient of determination (R^2) value of 0.5929.

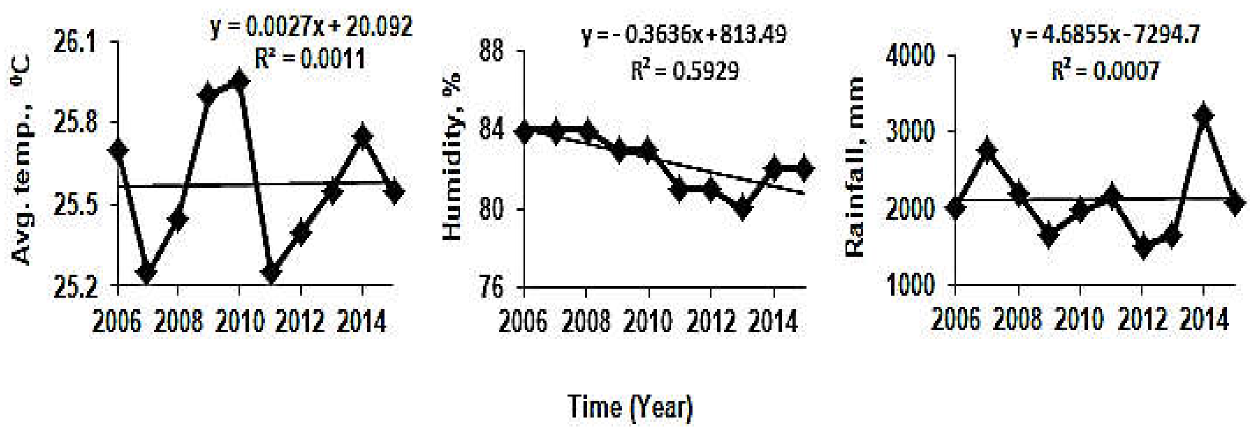


Figure 2. Trend of annual average temperature, humidity and rainfall over the period of 2006 – 2015.

In case of annual rainfall, it ranged from 1520.40 to 3236.00 mm but having no special trend over the whole study period. Also, a mean value of 2125.43 mm rainfall was observed for the 10 years of study, while a standard deviation of 527.60 mm represents that there was high variability in rainfall within the study period, and the result also revealed that the rainfall data were deviated largely from their average value of 2125.43 mm. The trend of variation of annual rainfall can also be observed from the line graph in Figure 2, however, there were 6 dry years (*i.e.* years below normal rainfall of 2125.43 mm), while the remaining 4 were wet years.

***Trend of annual potential and actual evapotranspiration*:** The annual PET and AET for the study area over the period of 2006 - 2015 are presented in Table 2 and their trends are shown in Figure 3.

The maximum annual PET of 1403.76 mm was observed in 2006 and the minimum of 1115.76 mm was found in 2013; the standard deviation of 108.96 mm indicates a large deviation of annual PET from the mean value of 1290.12 mm per year. On the other hand, the annual AET of the study area for the study period ranged from 772.92 to 1014.24 mm with a standard deviation of 83.52 mm, which reveals a large deviation of annual AET from the mean value of 891.84 mm per year. However, the mean annual AET of 891.84 mm compared to the mean annual rainfall of 2125.43 mm indicates that about 41.96 % of the annual rainfall was lost to both evaporation and transpiration from plants.

Table 2. Annual PET and AET over the period of 2006 to 2015.

Year	PET, mm	AET, mm
2006	1403.76	915.96
2007	1367.76	1014.24
2008	1171.56	852.60
2009	1385.40	808.56
2010	1358.16	975.84
2011	1361.76	847.68
2012	1356.60	858.96
2013	1115.76	772.92
2014	1203.36	1008.84
2015	1177.20	863.16
Mean	1290.12	891.84
Standard deviation	108.96	83.52

A dramatic declining trend of PET was found, whereas there was a slightly declining trend of AET over the study period, shown in Figure 3.

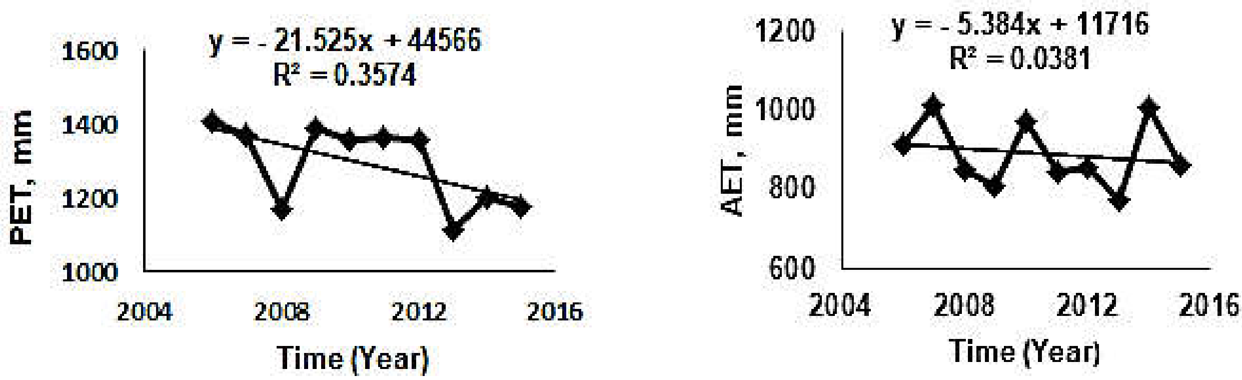


Figure 3. Trend of annual PET and AET over the period of 2006 to 2015.

***Variation in annual GW recharge and its relationship with different climatic parameters*:** Understanding the process of GW recharge is essential for GW resources management. Investigating the influence of climatic variability on GW resources requires not only changes in the major climatic parameters but also the accurate estimation of GW recharge (Jyrkama and Sykes, 2007). The change in GW recharge of the study area for the period of 2006 - 2015 is presented in Table 3. The trend of annual GW recharge and the change in GW recharge over the period of 2006 - 2015 are shown in Figure 4.

It was observed that the GW was recharged during the year of 2006, 2007, 2008, 2010, 2012 and 2013, and the GW level was depleted during the year of 2009, 2011, 2014 and 2015. The percentage of GW recharge ranged from 2.41 to 14.58 % of mean annual rainfall over the 10 years of study. The same kind of increasing and declining trend of groundwater recharge in western United States with wide range of uncertainty has been observed by Meixner *et al.* (2016). The maximum GW recharge of 309.96 was found in 2013, while the maximum depletion of 136.8 mm was observed in 2014. Consequently, the standard variation of 80.06 mm represents that the calculated values of GW recharge for the study area deviated moderately from the mean value of 119.00 mm, and a positive trend was found over the study period with a coefficient of determination (R^2) value of 0.210.

Table 3. Variation in annual GW recharge over the period of 2006 – 2015.

Year	Annual GW recharge, mm	Change in GW recharge, mm
2006	51.12	-
2007	90.66	39.54
2008	154.84	64.18
2009	51.42	-103.42
2010	112.92	61.50
2011	58.08	-54.84
2012	62.10	4.02
2013	309.96	247.86
2014	173.16	-136.80
2015	125.76	-7.40
Mean	119.00	-
Standard deviation	80.06	-

The relationship among annual GW recharge and different climatic parameters for the study area over the year of 2006 - 2015 is shown in Figure 5. It was found that there was no direct relationship between the annual average temperature and GW recharge. The study also revealed that an inverse relationship was observed between annual average humidity and GW recharge, whereas there was a direct relationship between rainfall and annual GW recharge over the study period. From the rainfall-recharge relationship in this study, it can be mentioned that the amount of GW recharge highly relies on the rate and duration of rainfall, as rainfall is the principal means for replenishment of moisture in the soil water system and recharge to ground water (Oke *et al.,* 2014).

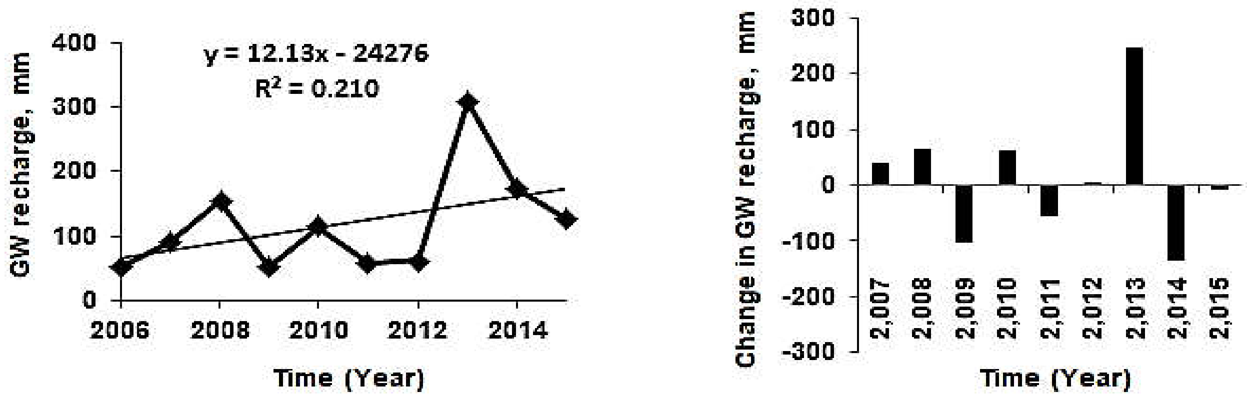
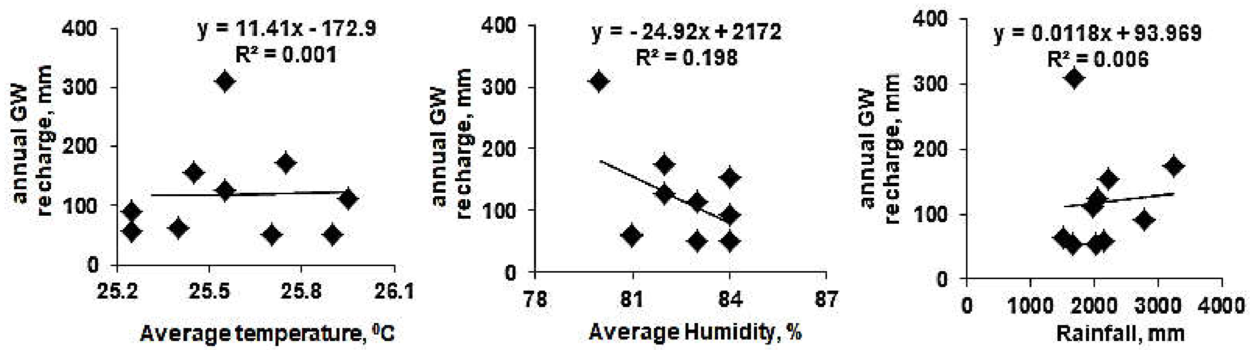


Figure 4. (a) Trend of annual GW recharge (a) Changes in GW recharge over the period of 2006 – 2015.



(a) **(b)** **(c)**

Figure 5. Relationship among annual GW recharge and different climatic parameters.

Conclusions

There was no special trend (almost constant) of average temperature and rainfall for the study area, whereas a declining trend of humidity was observed over the period of 2006-2015. The maximum recharge of 247.86 mm was found in 2013, while the maximum depletion of 136.8 mm was found in 2014. An increasing trend of GW recharge was observed over the whole study period. A dramatic declining trend of PET was observed over the period and its maximum value of 1403.76 mm was found in 2006, whereas the minimum of 1115.76 mm was in 2013. The study also revealed that there a slightly declining trend of AET over the whole period and the highest annual AET of 1014.24 mm was found in 2007, while the lowest of

772.92 mm was in 2013. The general conclusions drawn from this study that there was no specific relationship between average temperature and GW recharge but the GW recharge showed an inverse and a direct relationship with humidity and rainfall, respectively, and the recharge ranged from 2.41 to 14.58 % of mean annual rainfall over the 10 years of study.

Recommendations

This study encountered a number of limitations that could be taken into account in any relevant future investigation. In order to reach a final conclusion on the effects of climatic variability on GW recharge, more investigations over a longer study period at different locations across Bangladesh should be undertaken. In addition to soil moisture balance method, other methods, such as - water-table fluctuation method can be used to estimate GW recharge in further future researches. For drawing a better conclusion, soil types across the study area should be considered in the future investigation in the soil water system and recharge to GW.

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