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Spatial Assessment of Groundwater Drought in Godagari Upazilla of Northwestern Region, Bangladesh

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Abstract: The declining trend of groundwater (GW) table below the operating range of shallow tube-wells during the dry period is a frequent and recurrent phenomenon in the northwestern region of Bangladesh. It highly affects the GW-based irrigation system in the Godagari Upazilla (sub-district) of Rajshahi District in this region and consequently GW scarcity increases day by day. Thus, the main objective of this study is to investigate the groundwater scarcity as well as the spatial and temporal distributions of GW droughts in Godagari Upazilla. The well-known cumulative deficit approach from a threshold GW level has been applied for computing the severity of GW droughts. Another well-established approach, standardized precipitation index (SPI) has been used to quantify the meteorological droughts for developing appropriate correlations between the two drought types. Weekly GW level fluctuation data obtained from twelve monitoring stations as well as monthly rainfall and temperature data collected from one meteorological station are used for GW drought and meteorological drought analysis, respectively. The study shows that GW scarcity in 30% area is a common event almost in every year. Analysis of GW hydrographs demonstrates that there is a significant increase in the declining trend of both minimum and maximum GW level. The estimated SPI values reveal that GW drought is directly related to the meteorological drought and high deficiency of rainfall in the dry period is an every year phenomenon in the study area. Based on the analysis of GW hydrographs and precipitation time series, the study finally concludes that extensive withdrawal of GW for dry season irrigation activities and recurrent drought events are the major causes of continuous declining of GW level in the northwestern region of Bangladesh.

1. INTRODUCTION

Natural droughts are recurring phenomena generally affecting all components of the water cycle. It can be classified into meteorological, agricultural and hydrological droughts, where hydrological droughts include both stream flow and groundwater droughts (Hisdal et al., 2001). Hydrological drought occurs due to the deficiencies in surface and subsurface water supplies leading to a lack of water availability to meet usual and specific water demands (Demuth and Bakenhus, 1994). However, groundwater (GW) drought is a very specific type of hydrological drought that occurs when groundwater recharge, heads or discharge deviate from normal (Tallaksen and van Lanen 2004). Calow et al. (1999) referred GW drought as a circumstance of failing GW sources as a direct consequence of drought. It is now well-recognized that GW drought occurs, when the GW heads in an aquifer fall below a critical or threshold level over a

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certain period of time resulting in several adverse effects. Like other drought types, GW droughts are caused by low precipitation possibly in combination with high evapotranspiration, as their combined effect causes low GW recharge of underground aquifer. However, a deficit in precipitation often termed as meteorological drought can result by a recharge deficit, which in turn causes lowering of GW heads and a deficit in GW discharge. Another cause of GW drought is GW abstraction and overexploitation of GW creates GW droughts (van Lanen and Peters, 2000). The consequences of GW drought are diverse and the direct effects include lowering of GW heads and a consequent decrease of GW flow to the riparian areas, springs and streams.

GW is the main source of irrigation in the northwestern districts of Bangladesh. About 75% water for irrigation in the region comes from GW (Bari and Anwar, 2000). The national water policy of Bangladesh also encouraged GW development for irrigation in both the public and private sectors. BMDA (Barind Multi-purpose Development Authority) have taken necessary protective measures to ensure the annual withdrawal less than the annual recharge to keep the GW level in position. They have estimated GW recharge in the area at least one-third of the annual rainfall and that is about 500 mm per annum (Asaduzzaman and Rushton, 2006). Islam and Kanungoe (2005) estimated the long-term annual average recharge of 152.7 mm using water balance study and aquifer simulation modeling. For this reason, study related to GW depletion and drought caused by this phenomenon is an urgent requirement in the northwestern region of Bangladesh. Therefore, the main objective of this study is the analysis and assessment of GW droughts in a selected area in the northwestern region of Bangladesh as a case study basis.

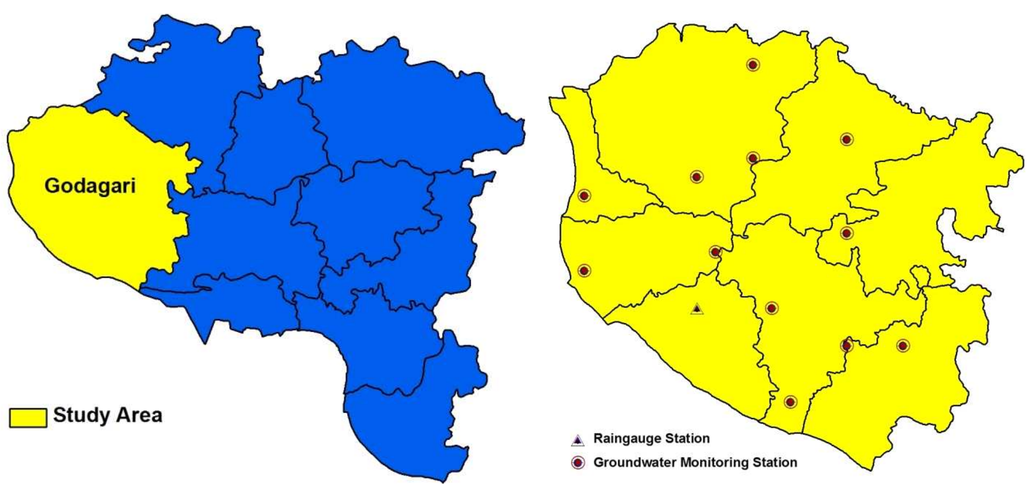

Fig. 1: The study area (Godagari Upazilla) location in Rajshahi district of Northwestern Bangladesh

2. MATERIALS AND METHODS

Godagari Upazilla in Rajshahi District under northwestern region of Bangladesh has been taken as a case study area for this study. The location of study area along with observation wells and rainfall stations are shown in Fig. 1. Climatologically, the study area belongs to dry humid zone with annual average rainfall varying between 1,400 and 1,650 mm, among which almost 83% rainfall occurs in monsoon (June to October). Rainfall in the area varies widely from year to year and as an example, the rainfall recorded at Rajshahi in 1997 was 2,062 mm, whereas in

1992, it was 798 mm only. Average temperature ranges from 25^0C to 35^0C in the hottest season and 9^0C to 15^0C in the coolest season. In summer, some of the hottest days experience a temperature of about 42^0 C or even more. In winter, it falls to about 5^0 C. Thus, the study area experiences extremes that are clearly in contrast to the climatic condition with the rest of the country. Unlike other region of the country, most part of the study area is free from flood. The economy of the study area is completely agriculture based which directly depends on GW. GW in the study area is mainly recharged by rainwater (Saha, 2012). In this study, GW levels that contribute to GW recharge and discharge are used for studying GW drought. The cumulative deficit (CD) approach from threshold GW levels which is proposed by Van Lanen and Peters (2000) is used to measure the severity of droughts. GW level data are collected from the Groundwater Circle (GWC) of Bangladesh Water Development Board (BWDB), Dhaka for twelve GW monitoring stations. The metrological data (temperature and rainfall) are also collected from Bangladesh Metrological Department (BMD), Dhaka. After processing and analysis the GW time series data by threshold level approach, the cumulative deficit is calculated. Monthly rainfall data is used to identify meteorological drought event and develop any possible relationship with GW drought. GW droughts can be identified using three variables viz. recharge, GW levels and discharge from GW to the surface water system (Van Lanen and Peters, 2000). However, it is not possible to measure GW recharge and discharge directly and hence they are calculated by another method or through simulation. There are several methods of GW droughts measurement and two most common methods used among them are Threshold Level Method (TLM) and Sequent Peak Algorithm (SPA) technique. The present study applies TLM for the assessment of GW droughts in the study area.

Although the fixed threshold provides quite acceptable results, the cumulative deficit is preferred as the major droughts can be identified more clearly. The best results can be obtained for a fixed threshold level and the cumulative deficit (Peters and van Lanen, 2000, Shahid and Hazarika, 2009). Therefore, in the present study, the cumulative deficit (CD) approach from threshold GW levels is used for GW droughts assessment. The cumulative deficit is the summation of GW level departed below a threshold level over a period. GW drought events in a year are identified by calculating the cumulative deficit in meter below a threshold GW level and can be expressed by equation (1).

$$CD_t = CD_{t-1} + \begin{cases} (\varphi_x - \varphi_t)\Delta t & \text{if } \varphi_t < \varphi_x \\ 0 & \text{Otherwise} \end{cases} \qquad (1)$$

Where CD_t and CD_{t-1} are cumulative deficit at day t and t-1 (m/day), φ_t is GW level at day t (m), φ_x is threshold GW level (m), and Δt is the time step (day). The time step to be used in the analysis of a GW drought should necessarily be large, usually more than a week or a month (Peters and Van Lanen, 2000) because of slow response of GW level to rainfall and other hydrologic parameters. Therefore, collected weekly data of GW level converted to monthly basis and in the present study, monthly time step is used during GW drought assessment. Three-threshold levels such as 20, 10 and 5% of the mean GW level of the study area are computed to visualize the severity of GW scarcity or drought at each location. Cumulative deficit (CD) values at different locations are interpolated to show the spatial extent of GW droughts of different severity. Krigging method in the geostatistical analysis tool of ArcGIS is used for producing spatial GW drought maps. Standardized precipitation index (SPI) method proposed by McKee et al., 1993 has been used to identify meteorological drought and wet events from time series data of precipitation records in the study area. SPI has also been used to correlate drought and wet events with groundwater level. SPI can be calculated simply by taking the difference of the precipitation (*Xi*) from the mean (*P*) for a particular time step, and then dividing it by the standard deviation (*S*), which can be presented by equation (2).

$$SPI = \frac{X_i - P}{SD} \tag{2}$$

3. RESULTS AND DISCUSSIONS

3.1 Assessment of GW Hydrograph with Different Threshold Levels

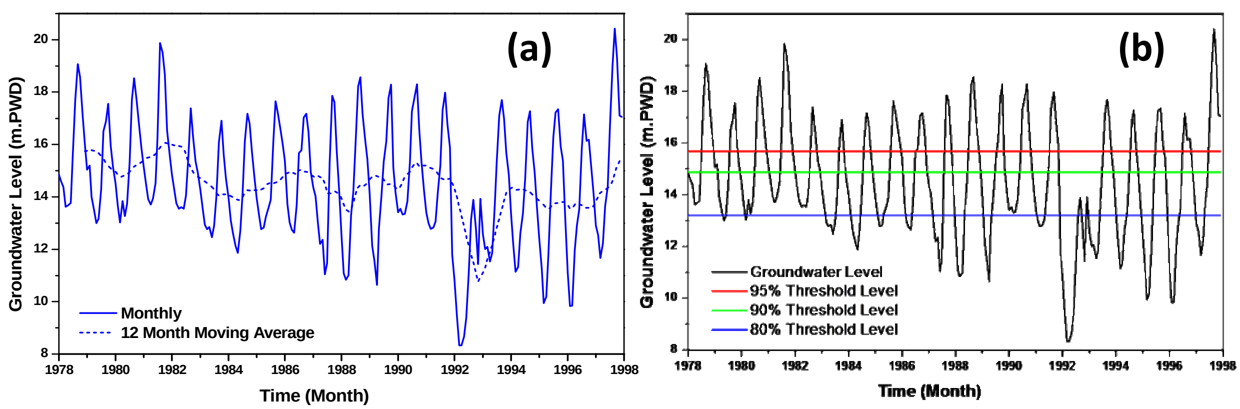

Fig. 2: Plots of (a) GW hydrograph and (b) GW level time series with different threshold level of a sample monitoring station (RAJ018) in the study area

In the present study, 20 years GW level data from 1978 to 1997 are analyzed. The patterns of GW hydrograph and time series with different threshold levels of RAJ018 monitoring station are shown in the Fig. 2. The hydrograph shows the pattern of gradual decreases of both minimum and maximum GW level at RAJ018 monitoring station. In the period 1992-1993, the minimum GW level falls below 9 m according to m.PWD (public works datum, which is located 0.45 m below mean sea level in the Bangladesh) in the monitoring station RAJ018 that causes extensive drought events in that time period.

3.2 Spatial Assessment of GW Droughts

Spatial extent of GW droughts for two threshold levels viz. 90% and 80% of mean GW level for the years from 1988-1997 are presented in the Fig. 3 and 4 respectively. The mean GW level is calculated from 20 years (1978-1997) monthly GW level fluctuation data over 12 monitoring well stations in the study area. The figures show that GW scarcity is a regular phenomenon in the Godagari Upazilla of northwestern region of Bangladesh. Though, the north-western part of the study area, which include RAJ016, RAJ019 and RAJ020 well stations are shown as the no drought zones in all spatial extent maps. It may occur due to less extraction of GW and available recharge from the river Padma. Due to the scarcity of the monthly extraction of GW and the discharge of Padma River, no analysis was possible to correlate this event.

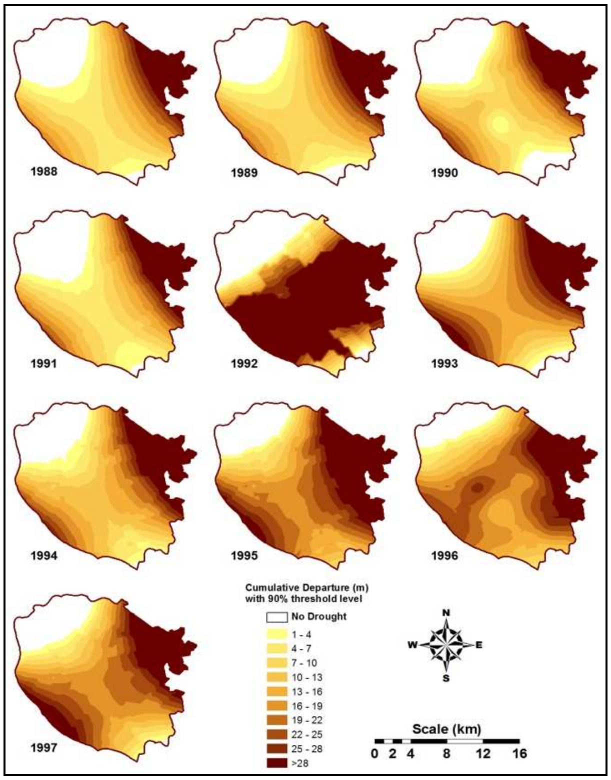

Fig. 3: Spatial extent of GW droughts computed for a 90% threshold of the mean GW level

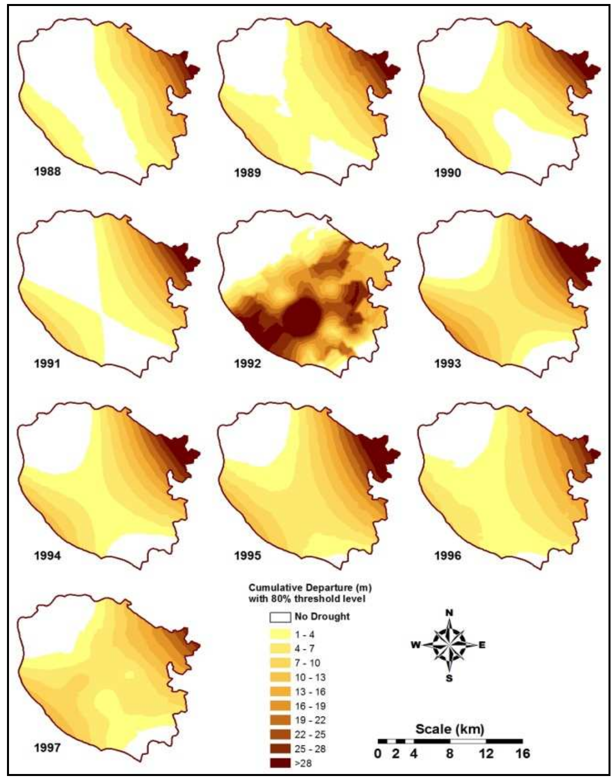

Fig. 4: Spatial extent of GW droughts computed for a 80% threshold of the mean GW level.

3.3 Analysis of GW Level Response to Rainfall and Temperature

The relation between GW levels and rainfall amounts **(a)** and GW levels and temperature **(b)** of the RAJ018 monitoring station are shown in the Fig. 5. The plot (a) shows that about 1 to 3 months lag between maximum GW level height and the peak of the rainfall amount. The 1 to 3 month lag of GW level with rainfall means that a deficit of monsoon rainfall or early departure of monsoon in 1-year may cause GW drought in following pre-monsoon period. The plot (b) shows that GW drought is directly related to the temperature rises. In the years 1992-1996, the temperature was more than 32^0 C and minimum GW level depletes significantly in that period.

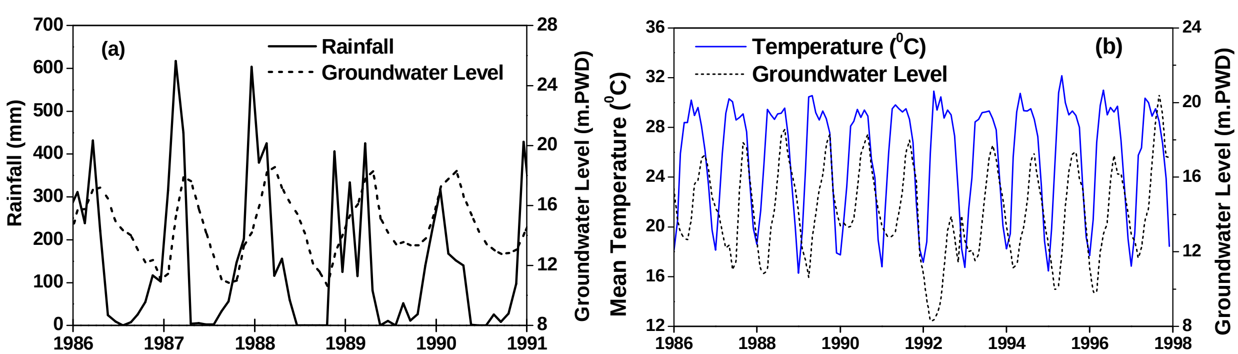

Fig. 5: Relationship between (a) GW table and rainfall amounts and (b) GW table and temperature at RAJ018 monitoring station in the study area

3.4 Relationship between Meteorological Drought and GW Drought

The Standard Precipitation Index (SPI) for 6-month and 1-year time steps are calculated and presented in the Fig. 8, for the period from 1986 to 2002. The figure demonstrates that severe drought (SPI > -1.5) occurs in the study area on 1992 and 1995 for both 6-month and 1-year time steps. The SPI provides a comparison of the precipitation over a specific period with the precipitation totals from the same period for all the years in the historical record.

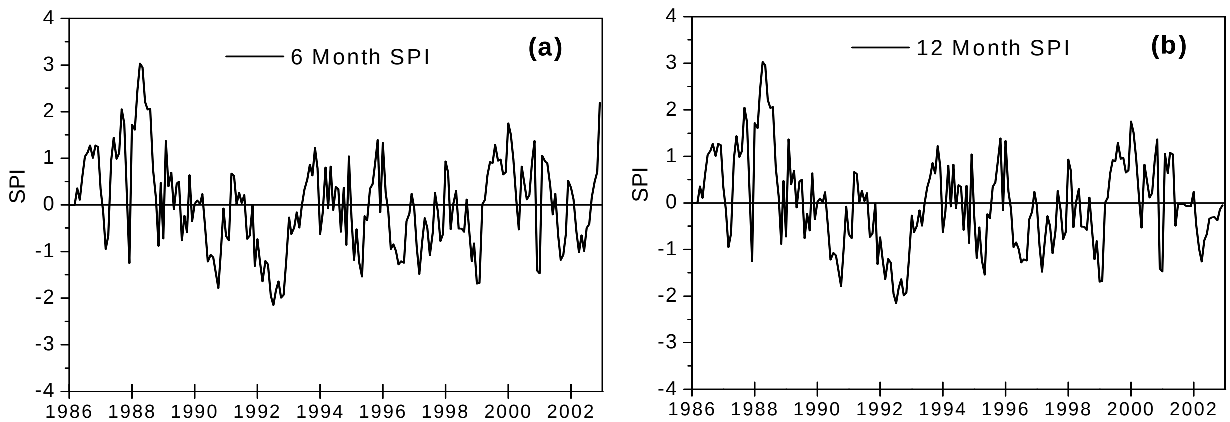

Fig. 8: Standardized precipitation index for (a) 6-month and (b) 1-year time steps

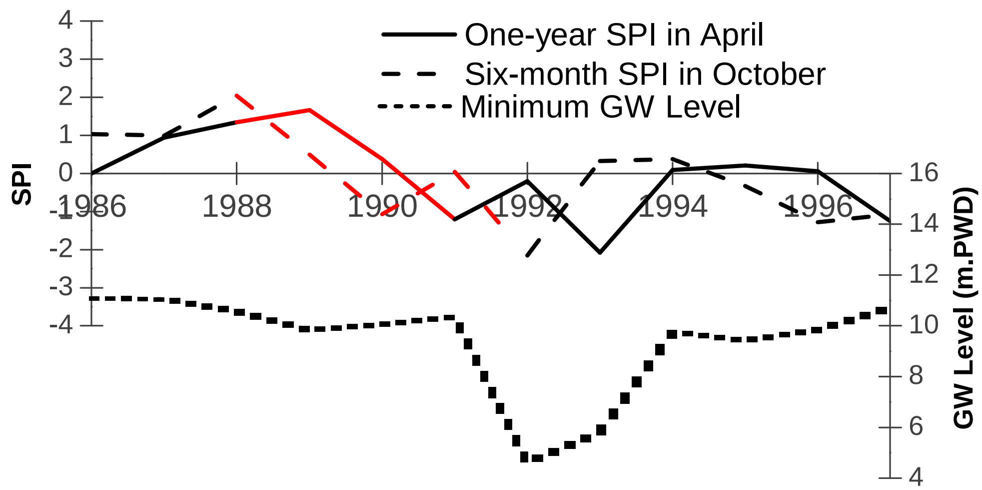

Fig. 9: Comparison of 6-month SPI of October and 1-year SPI of April with minimum GW level

The GW drought is the last reaction of hydrological drought sequence. The comparison of SPI values with the minimum GW level for the time period 1986-1997 is shown in Fig. 9. The 6-month SPI values of October and 1-year SPI values of April are used for comparison. The comparison indicates that the meteorological drought is directly responsible for GW declination in the study area. However, in 1992 the value of 6-month SPI in October was -2.15, which is classified as extreme drought and subsequently the GW level falls rapidly in that period. In 1993, the value of 1-year SPI in April was -2.08 and the GW level also falls adversely in that period. Therefore, both meteorological and GW drought are highly correlated in the study area, affecting each other.

4. CONCLUSIONS

Based on the analysis and findings obtained in the present study, the following conclusions can be drawn:

- The spatial maps indicate that GW drought in the study area is a regular phenomenon.
- GW drought is directly related to the meteorological drought. If there is no severe anthropogenic intervention in GW system, the cause of GW droughts is mainly due to deficiency in precipitation.
- In 1992-1994 periods, the drought occurs extensively in the study area due to high rainfall deficits and rising temperature. GW hydrograph of some stations shows maximum declination of GW table in these periods. The annual rainfall was only 973 mm in 1992 compared to 2180 mm in 1988.
- The GW drought in the study area is also caused by the reduction of recharge as well as the prolonged increase of water withdrawal from underground aquifer. The hydrographs show the gradual decrease of GW level after 1992, though some well-defined rainfall occurs in those periods.
- Based on the analysis, the study finally suggests that development of surface water resources for irrigation is indispensable to reduce the growing pressure on GW reserves in the study area.

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