Assessing and Forecasting of Groundwater Level Fluctuation in Joypurhat District, Northwest Bangladesh Using Wavelet Analysis and ARIMA Modeling

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Assessing and forecasting of groundwater level fluctuation in Joypurhat district, northwest Bangladesh using wavelet analysis and ARIMA modeling

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Abstract:

Groundwater resource plays a crucial role for agricultural crop production and socio-economic development in some parts of the world including Bangladesh. Joypurhat district, the northwest part of Bangladesh, a crop production hub, is entirely dependent on groundwater irrigation. A precise assessment and prediction of groundwater level (GWL) can assist long-term GWR management, especially in drought-prone agricultural regions. Therefore, this study was carried out to identify trends and magnitude of GWL fluctuation (1980-2019) using the Modified Mann-Kendall test, Pettitt's Test, and Sen Slope estimators in the drought-prone Joypurhat district, northwest Bangladesh. Time-series data analysis was performed to forecast GWL from 2020 to 2050 using the Auto-Regressive Integrated Moving Average (ARIMA) model. The findings of the MMK test revealed a significant declining trend of GWL, and the trend turning points were identified in the years 1991, 1993, 1997, and 2004, respectively. Results also indicate that the declining rate of GWL varied from 0.104 m/yr to 0.159 m/yr and the average rate of GWL declination was 0.136 m/yr during 1980-2019. The outcomes of wavelet spectrum analysis depicted two significant periods of the declining trend in Khetlal and Akkelpur Upazilas. The results obtained from the optimal identified model ARIMA (2,1,0), indicating that GWL will decline at a depth of 13.76 m in 2050, and the average declination rate of GWL will be 0.143 m/yr in the study area. The predicted results showed a similar declining tendency of GWL from 2020 to 2050, suggesting a disquieting condition, particularly for Khetlal Upazila. This research would provide a practical approach for GWL assessment and prediction that could help decision-makers implement long-term GWR management in the study area.

Keywords: ARIMA modeling, Pettit test, GWL declination, groundwater resource and northwest Bangladesh

1. Introduction

Groundwater is one of the top valuable natural resources in the world. It plays a pivotal role in the economic, social, and environmental sustainability context. The potential use of groundwater, particularly in agricultural-based developing countries like Bangladesh, is a paramount concern to the policy-makers on groundwater resources (GWR) management perspective (Morris et al. 2003; Mackay et al. 2015; Salam et al., 2020a; Islam et al. 2021a). In recent times, climate variability (e.g., rainfall infiltration rate, surface runoff, evaporation, and increase in temperature), rapid population increase, and over-exploitation have a detrimental effect on this valuable GWR in many drought-prone regions worldwide (Shahid and Hazarika, 2010; Cheng et al., 2016; Kalhor and Emaminejad, 2019; Yadav et al., 2020; Ajibade et al. 2021). This is primarily genuine for northwest region of Bangladesh, where high population density and increasing agricultural crop production raise water demand (Shahid 2011; Husna et al. 2016; Islam et al., 2020). As a result, GW levels (GWL) are declining and rising water scarcity in the drought-prone Barind tract region. However, groundwater scarcity is another challenge around the globe. GWL assessment and prediction is an integrated part of the investigation for sustainable GWR management. In addition to management concerns, the long-term prediction will be helpful to close missing dataset too. Thus, accurate GWL assessment and prediction are crucial for effective and sustainable GWR management in water-stressed regions, especially in Bangladesh's northwest drought-prone region.

The use of groundwater in the irrigation sector for crop production is increasing significantly in Bangladesh. In such a case, the northwest region of Bangladeshis is facing the critical condition of groundwater due to the impact of over-exploitation. Abstraction of groundwater from deep tube wells has resulted in substantial increases in agricultural production and significant falls in aquifers' groundwater heads (Patle et al. 2015; Rushton et al. 2020; Mallick et al. 2021). More than 75% of irrigation water is managed by the groundwater withdrawal in the northwest part of Bangladesh (Shahid and Hazarika 2010). During the dry season, most surface water resources like rivers, canals, beels (static water bodies), ponds, and other reservoirs get dried because of limited rainfall and other adverse climatic factors that compel people to use groundwater in the northwest part of Bangladesh. When groundwater withdrawal exceeds the natural recharge to groundwater storage for a long time in a considerable area, the declination of GWL occurs. The falling trends of groundwater levels indicate that groundwater exploitation exceeds the recharge, indicating unsustainable withdrawal (Zannat et al. 2019). The GWL declining rate is higher in the northern region than in the southern part (Sumiya and Khatun 2016). The groundwater table has reduced noticeably in northwest part of Bangladesh due to the over-exploitation of groundwater (Dey et al. 2017).

Joypurhat district is an agricultural hub of the country. In this area, farmers use many irrigation equipment to withdraw groundwater for irrigation purposes to boost up cropping intensity (Islam et al. 2018). Rice and potato are the main crops in this area which are both high water-consuming crops, and their cultivation relies on groundwater irrigation. The groundwater table in most of the Kalai, Khetlal, Panchbibi, and Akkelpur Upazilas goes below suction limit causing hand tube-wells and shallow tube-wells partially/fully operable (Hossain et al. 2015). Intensive agricultural, rapid industrial development, and domestic demand have put more pressure on groundwater use and accelerated the rate of water table declination in this area. These conditions demand the proper monitoring and investigations in GWL depletion. The trend analysis will help in understanding the variation, changing direction, and trend of GWL and GWL projection for future management.

Few researchers in Bangladesh have studied GWL depletion at the natural and regional levels (Jahan et al. 2010; Rahman et al. 2016; Dey et al. 2017; Salam et al. 2020a). Many research scholars have been investigated the reasons and magnitudes of GWL depletion in NW Bangladesh. For example, Zafor et al. (2017) concentrated on the falling trend direction in GWL, which implies an unbalanced groundwater setting in northern Bangladesh. Zahid (2015) reported that the tendency of GWL fluctuation is elevated in Bangladesh's northwest Barind area. Rahman et al. (2016) stated a rising tendency of GWL in the Barind tract region. Besides, Dey et al. (2017) reported that the GWL has decreased noticeably in northwest Bangladesh due to over-withdrawn of groundwater, increasing Boro rice farming, decreasing river water levels, lessening in wetland area, and scarcity of water reservoir. Although the rapid rise in the irrigated cropping area during the last two decades, poorer performance and lack of groundwater efficacy and surface water utilization are yet hindrances for substantial GWR management. Groundwater is mostly used in the irrigated cultivation areas; however, its sustainability is at higher risk according to quality and quantity of groundwater in northwest Bangladesh (Shahid 2011). Yet, irregular trend pattern and changing characteristics of GWL are unexplored in the vital drought-prone region. Therefore, it is essential to better insight into the unusual trend behavior, changing pattern in GWL, and future situations of groundwater fluctuation in northwest Bangladesh.

No such comprehensive study has been performed before in the drought-prone region, part of Barind Tract, Joypurhat district of northwest Bangladesh. This type of study is urgently required due to severe water-stressed condition. In this study, the modified Mann-Kendall test, Sen Slope estimator, Pettitt’s test, and Wavelet power spectrum analyses have been applied first time to find out the spatial and temporal trend patterns of GWL variation in the Joypurhat district, northwest Bangladesh. On the other hand, statistical analyses require a more in-depth understanding of future GWL characteristics. Due to the oversimplification of complicated hydrological mechanisms and the scarcity of groundwater datasets, achieving precise forecasting through statistical methods, such as the Auto-Regressive Integrated Moving Average (ARIMA), is a promising task (Rahman et al. 2017 Akhter et al. 2019; Salam et al. 2020a). Another aim of this study is to forecast the GWL from 2020 to 2050 in the study area using the ARIMA modeling. The novelty of this work is that an integrated statistical approach is applied to assess and predict GWL for sustainable GWR management at the regional level. The findings of this study can aid in accepting the proper decision to policymakers in the further installation of irrigation equipment and sustainable use of groundwater resources in this area or similar region around the world.

2. Data and Methods

2.1 Study area description

Joypurhat district has been selected for the study area located in the Barind tract in the North-West region of Bangladesh. It is situated between 24°46' N to 25°22' N latitude and 88°56' E to 89°14' E longitude shown in Fig. 1. Joypurhat district is bounded on the north by Gaibandha district, Dinajpur district and India border, on the south by Bogra district and Naogaon district, on the east by Bogra district and Gaibandha district, and on the west by Naogaon district and India border. The total area of the district is 965.88 km^2 (Islam et al. 2018) It consists of five Upazilas, namely Joypurhatsadar, Akkelpur, Khetlal, Kalai, and Panchbibi. The economy of Joypurhat district is entirely dependent on agriculture and is famous for its granaries. There are 1978 nos shallow, deep tube-wells (DTW) and 8050 nos. Shallow tube-wells (STW) are used for irrigation purposes in agricultural production (BADC 2019). The study region shows a rich agricultural hub of about 80270 ha net cultivatable site, which depends on groundwater irrigation. Rice and potatoes are the main cash crops of this area. Both crops are highly water-consuming in an irrigated field. Water scarcity is a common problem during the dry winter period in the study area.

2.2 Geology and hydrological conditions

The Joypurhat district is the portion of the Tista floodplain that belonged to the shelf region (Bogra slope), encompassing Himalayan Foredeep region of Bengal Basin (Reimann and Hiller 1993). The study area lies in the sub-humid area bounded by geological formations deposited from the DupiTila Sandstone Formation. The sediment is deposited as an older alluvial fan where different rivers flowing through the study areas like: Chiri River and Haraboti River cross via Panchbibi Upazila. Small Jamuna River crosses via Joypurhat Sadar and Panchbibi Upazilas. Tulshiganga River passes via Joypurhat Sadar, Khetlal, and Akkelpur Upazilas. Sree River crosses via Joypurhat Sadar Upazila.

The topography of the study area varies from 24 m in Panchbibi to 14.4 m in Akkelpur. The study area is relatively flat, sloping from North to South direction. The topsoil of the study area is mainly clay and the aquifer properties like Transmissivity varies from 1240 m^2 /day to 1700 m^2 /day (IWM 2009). The principal aquifers of the study area consist of fine sands, medium sands, and coarse sands with mild stone particles, as shown in Fig. 2 (a-e).

Considering the lithological characteristics of five selected wells in the study area, the average thickness of the aquifers in the Joypurhat district varies from about 40m to 51m. The screenable thickness of the study area is ranged from 29.39 m to 35.06 m, with a bore depth up to 65 m from the ground surface. Joypurhat is a district of sub-tropical climate. The average annual temperature is 24.4 °C, and the average annual rainfall is 1673 mm. More than 60% of rains occur in July-August, with an average of 364 mm (Das and Islam, 2021). The pre-monsoon period occurs from March to May, and the monsoon period occurs from June to October. The warmest month of the year is May, with the mean temperature of 28.9°C (Das 2021). The coldest month of the year is January, with the average temperature are 18°C, and the average annual evaporation of the study area is around 1060 mm (Salam et al. 2020b).

2.3 Data source and quality control check

The monthly GWL data (1980-2019) of the different stations under Joypurhat district were collected from Bangladesh Water Development Board (BWDB), Dhaka. Since there is no station of BWDB at Akkelpur and Kalaiupazila for measuring GWL data (1980-2019), the Nearest station such as Parbotipur and Nischinta of the study area are used respectively for Akkelpur and Kalai Upazila. The monthly rainfall, evaporation, and temperature data from Bangladesh Meteorological Department (BMD) are used for the study area. In all cases, systematic quality control techniques are applied to evaluate data quality. All the data used in the study area are significant at 99% confidence level (p-value <0.001) in the Buishand Range test, Normality, and Homogeneity test. These tests also revealed that the data remain of good quality.

2.4 Modified Mann-Kendall test

Modified Mann-Kendall test is the modified version of the non-parametric Mann-Kendall test, which is robust tool in the presence of autocorrelation. This test may be used to identify trend detection in hydro-meteorological data series when datasets are non-random and impacted by autocorrelation (Mann, 1955; Kendall 1975). Hamed and Rao (1998) have first developed a variance correction method to address serial correlation in trend assessment. Praveen et al. (2020) have also suggested the same approach in this respect. Datasets are primarily detrended, and the adequate sample size is computed using the ranks of significant serial correlation analysis which are then used to correct the test statistic's inflated (or deflated) variance.

The Mann-Kendall test statistics S is given as

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(Xj - Xi) \quad (1)$$

Where, S is Mann-Kendall statistic and sgn is the signum function. Each of the data point xi is taken as a reference point which is compared with the rest of the data points xj as follows:

$$\text{sgn (Xj-Xi)} = \begin{cases} 1\ if(Xj - Xi) > 0 \\ 0 if(Xj - Xi) = 0 \\ -1\ if(Xj - Xi) < 0 \end{cases} \quad (2)$$

The value S shows the direction of trend. A positive value of S indicates an upward trend and negative value indicates downward trend (Islam et al., 2021b; Jerin et al. 2021). The test statistics S is expressed as

$$V(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} ti(i)(i-1)(2i+5)}{18} \quad (3)$$

Where, $t_i$is the number of ties up to sample i. The modified variance $V^*(S)$ is given by the following equation proposed by Yue and Wang (2004).

$$V^*(S) = V(S) \cdot \frac{n}{n*} \quad (4)$$

Where $\frac{n}{n*}$ is considered as correction factor and it is calculated by the following equation derived by Bayley and Hammersley (1946).

$$\frac{n}{n*} = 1 + 2 \cdot \sum_{k=1}^{n-1} (1 - \frac{k}{n}) \cdot \rho k \quad (5)$$

In time series analysis, the presence of a statistically significant trend is calculated using Zc value.

$$Zc = \begin{cases} \frac{S-1}{\sqrt{V*(S)}} ifS > 0 \\ 0\ ifs = 0 \\ \frac{s+1}{\sqrt{V*(S)}} ifS < 0 \end{cases} \quad (6)$$

In this method, a positive value of indicates an increasing trend a negative value indicates decreasing trend. The trend is considered as statistically significant in this study when $p \leq 0.05$ at 5% significance level.

2.5 Sen's Slope Estimator

Sen's slope estimator test is a non-parametric method (Sen,1968) which is used to estimate the magnitude of trends (change per unit time) in time series data. The magnitude of trend is expressed as Q calculated by the Eq. (7):

$$Q = \frac{Xj - Xk}{j-k} \quad (7)$$

Where, X_j and X_k are denoted by data values at times j and k (j>k) respectively. A positive value of Q indicates an increasing trend and negative value indicates decreasing trend in time series data.

2.6 Pettitt's test

The pettitt's test is a common non-parametric technique which was used to detect an abrupt change point in hydrological time series datasets (Pettitt 1979). The non-parametric statistics is defined as follows:

$$K_T = MAX \mid U_{t,T} \mid \quad (8)$$

Where, $U_{t,T} = \sum_{i=1}^{t} \sum_{j=t+1}^{T} sgn(Xi - Xj)$ (9)

K_T is the location point where the abrupt change point of time series data occurred. The probability of significance level of $K_T$is approximately lied on $p \leq 0.05$ followed by equation (10).

$$p \cong 2 \exp \left(\frac{-6KT2}{T3+T2}\right) \quad (10)$$

2.7 Wavelet transform analysis

Wavelet analysis is a common tool to analyze local spectral and temporal variations of power within a time series for a particular scale and location. It contains non-stationary power at various frequencies (Jerin et al. 2021; Rahman et al., 2021). Depending on time and non-dimensional frequency Morlet wavelet consists of a plane wave modulated by Gaussian following by the equation (11).

$$\Psi_0(\eta)=\pi^{-1/4} e^{i\omega 0\eta} e^{-\eta 2/2} \tag{11}$$

Where $\Psi_0(\eta)$ is denoted by wavelet value at non-dimentional time η and $\omega 0$ is the non-dimensional frequency, here taken to be (equation 6) in this study in order to satisfy the admissibility condition (Farge 1992). According to the function of basic wavelet, the scaled wavelets are ascertained as follows:

$$\Psi\left[\frac{(n'-n)\delta t}{s}\right]=\left(\frac{\delta t}{s}\right)^{1/2} \cdot \Psi_0\left[\frac{(n'-1)\delta t}{s}\right] \tag{12}$$

Where S is dilation parameter used to change the scale and n is the translation parameter used to slide in time. The wavelet transform $W_n(S)$ is expressed as the convolution of the wavelet function which is defined by the following equation (13):

$$W_n(S)=\sum_{n'}^{N-1} xn' \Psi * \left[\frac{(n-n')\delta t}{s}\right] \tag{13}$$

Where $\Psi*$ indicates the complex conjugate and n is the localized time index.

2.8 ARIMA modeling

Auto-Regressive Integrated Moving Average (ARIMA) model is the popular technique for modeling time series data and predicting future data in a series (Box and Jenkins 1976; Rahman et al., 2017; Akhter et al., 2019; Islam et al., 2020). In this study, a non-seasonal ARIMA model is subjected to understand past data for forecasting. It consists of three statistics parts such as autoregressive (AR) terms, Integrated (I) term, and moving average (MA) term. These terms are classified as ARIMA(p,d,q) in which p is an autoregressive part that forecasts future values based on past value, d is integrated part used for removing non-stationarity in forecasting, and q is the moving average part used for maintaining lagged forecast errors in the prediction system. In this study, the time series of GWL data (denoted by Y) was used to assign appropriate models and forecasting. In terms of Y, the general forecasting equation could be expressed as follows with the convention introduced by Box and Jenkins (1976).

$$\hat{Y}_t = = \mu + \varphi_1 Y_{t-1} + \ldots + \varphi Y_{t-p} - \theta_1 e_{t-1} - \ldots - \theta_q e_{t-q} \tag{14}$$

Where $\hat{Y}t$ is the forecasted value at time t, Y_{t-1} is the previous forecasted value, μ is constant term, φ is autoregressive parameter and θ is the moving average parameter.

The Box and Jenkins method of ARIMA modeling follows four steps to choose the best model and forecasting. These steps are model identification, parameter estimation, diagnostic checking, and forecasting. In the first step, the time series must be standardized and normalized by proper order differencing. The most popular method for identifying the appropriate demands of an ARIMA model is the adjustment behavior of autocorrelation function (ACF) and partial autocorrelation function (PACF). In 2nd step, model parameters are estimated by the maximum likelihood method. Model adequacy is performed with diagnostic checking if the errors of model assumptions are satisfied. When the model seems inadequate, a new tentative model is assigned. The steps described above are repeated until the model assumption associated with the error is satisfied, and a satisfactory model is finalized. At last, the finally selected model is used for ARIMA fitting and forecasting.

In the present study, SPSS software was used for ARIMA modeling. Time series data of GWL were partitioned as the ratio 30:10. The first part of time series data from 1980-2009 was used for model identification, and 2nd part of the time series from 2010-2019 was used for model validation and model performance and predictability testing. Bayesian Information Criteria (BIC) is firstly considered for the efficiency evaluation of model performance. Lastly, the most appropriate forecasting model was finally chosen based on model fit statistics value of R^2, RMSE, MAPE, MaxAPE, MaxAE, and Ljung-Box statistics.

3. Results

3.1 Variation in climatic parameters

Rainfall, temperature, and evaporation distributions play an essential role in GWL fluctuating in a specific area. Fig. 3(a-c) showed the monthly maximum and minimum temperature and rainfall distributions of the northwest region, Joypurhat district. The hottest month is identified as April to May, and the coldest month is January. The highest rainfall occurred in July, and the lowest rainfall occurred in January. It is observed that heavy rain happened in temperature 24°-35°C in July. It is also noticeable that GWL started depletion in the hottest month due to high temperature and evaporation differences. Again, groundwater level started rising toward the ground surface when temperature and evaporation decreased at a favorable condition to increase rainfall.

3.2 Apparent variation in groundwater level

Consecutive records of GWL are essential for assessing groundwater fluctuation and its trend, as well as groundwater potentiality. The observed GWL data generally represent the apparent variation of groundwater table in a study area. To understand the noticeable variation of GWL, the following Fig. 4(a-e) are produced. It is observed that the groundwater table is highly depleted in April due to groundwater pumping for irrigation, high temperature, evapotranspiration, and other related climatic factors. But GWL is raised towards the ground surface in September for high monsoon rainfall which enhances the recharging groundwater storage. According to the Fig. 4(a-e) annual groundwater depth variation limit is maximum (7.07 m) in Khetlal and minimum (4.6 m) in Panchbibi Upazila. It was also observed that the highest GWL declination from the ground surface is 12.82 m in Khetlal and the lowest GWL declination is 2.35 m in Akkelpur Upazila. It can be mentioned that amount of groundwater pumping, temperature, evapotranspiration, and rainfall distribution might affect the apparent variation of GWL. During the dry season, adverse climate and rate of groundwater pumping for irrigation reach the extreme level, and rainfall is limited; thus, GWL declination is increased.

On the other hand, favorable climatic conditions, limited groundwater irrigation, and heavy rainfall create an auspicious situation during the wet season, so GWL declination started decreasing, and GWL rose towards the ground surface successively. Therefore, GWL is highly depleted in April and increasing towards the ground surface in September-October. The highest decreasing rate of GWL was found in Khetlal Upazila. The lowest decreasing rate was found in Panchbibi Upazila of Joypurhat district, situated in the northwest region of Bangladesh.

3.3 Trend of groundwater level fluctuation

The modified Mann-Kendal test is carried out in time-series data (1980-2019) on a monthly scale. The Modified Mann-Kendal test is carried out in time-series data (1980-2019) on the monthly GWL in selected stations of different Upazilas of Joypurhat district. To find out the trend in time series GWL, MMK 'Zc' statistics were determined shown in Table 2. In all cases, 'Zc' values are at a 5% level of significance. So, it can be said that the null hypothesis was rejected, and there was found a significant trend in time series data of groundwater levels. The positive sign 'Zc' statistics were suggested that GWL was declining for the ground surface.

The 'Zc' statistics values obtained from the MMK test are varied from 7.37 to 17.78 in different stations, respectively. It is observed that the lowest declining trend (Zc=17.78) of GWL level is found at Panchbibi Upazila. The comparatively highest declining trend (Zc=7.37) is found at Khetlal Upazila of the study area, which is shown in Fig. 5.a. After determining the trend, Sen's slope estimator was applied to calculate the slope of trend/ rate of groundwater level declination (Q) in m/decade (Table 1) during the period 1980-2019. The Sen's slope value (Q) obtained from the MMK test varies from 0.10405 to 0.15964 m/yr. Fig. 5.b shows that the high rate of GWL level declination(Sen's slope, Q) is found at ketal and Kalai Upazilas, medium changing rate at Joypurhat Sadar and Akkelpur, low at Panchbibi Upazila, which is illustrated in Fig. 5.c.After determining trend status and trend slope, the change point of GWL was identified at the time of Dec '91, Dec '93, Jan '97, Feb '97, and Dec '04 for Akkelpur, Joypurhatsadar, Khetlal, Kalai, and Panchbibi Upazila, respectively following the result of Pettitt's test which is shown in Fig. 6. GWL level declination trend was started the first atAkkelpur in 1991 and then Joypurhat sadar in 1993, Khetlal and Kalai in 1997, and Panchbibi in 2004, respectively. It can be said that the groundwater pumping in Khetlal and Kalaiupazila during the dry season is more than in the other Upazilas. Two Upazilas are more vulnerable to groundwater resources than others.

3.4 Wavelet transformation of groundwater level

Morlet wavelet power spectrum of GWL level is shown in Fig. 7(a-f). The black contour line identifies the significance level, and the black line marks the cone of influence. An analysis of the wavelet power spectrum, it is observed that two significant periods of increasing trend were detected in Khetlal Upazila in a scale range 4.0-6.0 from 1980-1992, scale range 11.4-16 from 1992-2019, and Akkelpur Upazila in a scale range 6.9-11.2 from 1980-1993, range 11.4-16 from 1994-2019. Only one significant period of increased GWL level is detected in Joypurhat Sadar, Panchbibi, and Kalai Upazila. However, one significant period of GWL level increasing trend started from 1991-2019 in Joypurhat district.

3.5 ARIMA model selection and validation

Plots of the autocorrelation function (ACF)and partial autocorrelation (PACF) are crucial for ARIMA model selection. Based on plots of ACF and PACF, the order p and q were decided to develop the tentative ARIMA models for the 1980-2019 time series of groundwater levels. For each station, tentative ARIMA models were selected for every 10 (Ten) years with different orders of p,d,q with reasonable ranges. The tested models were as follows:(0,0,0), (0,1,0),(0,1,1),(1,1,0),(1,1,1),(1,1,2),(2,1,1),(2,1,2),(0,1,2),(2,1,0).To analyze the ACF and PACF residuals plots within the confidence limit, some tentative suitable models for each station were selected based on normalized BIC. Out of these selected models, the best appropriate models for time series groundwater levels of each station were chosen based on the lowest R squared, RMSE, MAPE, MaxApE, MAE, MaxAE, and Ljung-Box Q statistics shown in Table 3.

Similarly, the best model for the Joypurhat district was identified as the ARIMA model (2,1,0) by evaluation of ACF and PACF plots and model goodness of fit statistics. This model's ACF and PACF plots for the Joypurhat district are shown in Fig.8(a-c). Comparison of observed GWL during 2010-2019 was accomplished for further validation of selected ARIMA model for each station and Joypurhat district. Comparison plot of observed GWL vs. forecasted GWL during 2010-2019 of Joypurhat district average are in good consistency with obtained R squared value of 0.7544 for Joypurhat district Fig. 9. So, the selected ARIMA model for the study area was considered for forecasting GWL.

3.6 Forecasting of groundwater levels

The selected best models for each station and Joypurhat district were applied to forecast GWL shown in Fig. 10 (a-f). It is found that GWL would decline linearly from 2020 onwards in Joypurhat Sadar, Panchbibi, Akkelpur, Kalai, and Khetlal Upazilas. These forecasting results reveal a sharp trend of increasing from the ground surface in Khetlal, Kalai, and Akkelpur upazila. A moderate trend in GWL decreasing from the ground surface is located in Joypurhat Sadar and Panchbibi upazila.

Overall, a moderate increasing trend of GWL levels from the ground surface was found in the Joypurhat district. As seen from Fig. 10(a-c), the predicted GWL levels would reach 12.18m, 10.72m,11.17m, 16.27m, and 18.44m in 2050 concerning the observed value of 7.89m,7.54m,7.48m, 11.69m, and 12.82m in 2019 in Joypurhat sadar, Panchbibi, Akkelpur, Kalai and Khetlal Upazilas, respectively. Overall, the GWL level of Joypurhat district would reach 13.76m in 2050 over the observed value of 9.48 m in 2019. In Joypurhat district, the observed average rate of declination in GWL level was found 0.136 m/yr from 1980 to 2019 as per Sen's estimator. The forecasted rate of declination during 2020-2050 was determined0.143 m/yr, which shows a moderate increasing trend. The climate change effect, groundwater irrigation, and rainfall distribution were evaluated to examine the predicted results. There was a slight adverse effect on rainfall distribution and climate. But major factor affecting on groundwater level declination trend might be the burning question for increased groundwater irrigation in the agriculture development of the study area. In this area, rice and potato production are the main crops entirely dependent on groundwater irrigation.

4. Discussion

This study explores the GWL fluctuation in a drought-prone Barint tract, namely the Joypurhat district of northwest Bangladesh. GWL in Joypurhat district of northwest Bangladesh is declining gradually. It is observed that the declining trend of GWL is more significant in Khetlal and Kalaiupazilas than the other Upazilas. The main reason is that the flow of the Atria River occurs in the upper part of the Joypurhat districts. The base flow happens in the SW direction because of the average slope, triggering the minimum aquifer recharge from river water in this region. Besides, soil texture in this region is dominated by silty clay soil, which belongs to relatively lower hydraulic conductivity characteristics (Zannat et al. 2019). Consequently, groundwater recharge from rainfall is very low.

The rates of GWL change ranged from 1.04 to 1.59 m/decade during 1980-2019 in Joypurhat district. Salam et al. (2020a) found that the rates of GWL change vary from 0.1 to 1.3 m/decade during 1981-2017in the Northwest part of Bangladesh. The outcome is in line with Zahid (2015) and Rahman et al. (2016). The highest change point was detected at Khetlal Upazila in 1997. After the 2000s, the GWL declines rapidly due to climatic effects (Islam et al. 2021b). This may be happened due to huge boro rice and potato cultivation dependent on groundwater irrigation. Wavelet analysis exhibits two significant periods of GWL in Khetlal and Akkelpur, whereas Pahnchbibi shows no considerable period of GWL. Khetlal Upazila reveals a drier condition than the wet condition of groundwater. The results of the ARIMA model reveals a rising trend of declining GWL in Khetlal, and the trend of declining GWL is lower in Panchbibi than Kalai. The rate of GWL declined from 2020 to 2050 will be 0.143 m/decade compared to the present period (0.136 m/decade). These findings coincided with the outcome of Dey et al. (2017) and Gibrila et al. (2018), where they observed significant variations in GWL across the North-West region of Bangladesh. Salam et al. (2020a) found similar results in which GWL is going downwards in pre-monsoon time and is rising upwards in post-monsoon in the northwestern region of Bangladesh.

In recent times, the drought-prone humid region of northwest Bangladesh has experienced severe scarcity of GWL due to the over-extraction of GW. Overexploitation of aquifer to offset the balance between demand and supply and the variations in surface water flow rate are considered the major cause of GWL declination. The interaction of surface-groundwater is a complicated system that relies on several factors, including the altitude of the groundwater table compared to the altitude of the stream water, aquifer types, soil texture, and so on.

The long-term GWL fluctuation is a function of many-fold parameters, including annual rainfall, annual groundwater withdrawal, and local subsurface geological conditions. The increase or decrease of the precipitation can significantly affect GWL as it is the primary source for groundwater recharge (Park et al., 2011). Consistent with a widespread and prevailing decreasing trend in GWL over the study area, the decreasing trend of precipitation cannot be ignored as a responsible factor. Local geology characterizes shallow aquifers in Bangladesh and essentially controls the timing and pathways of groundwater recharge to aquifers (WARPO 2000). The declining shallow groundwater storage in northwestern Bangladesh relates to the intensity of abstraction of GW and areas of the high thickness of surface clay where rainfall-fed recharge rates are low due to the low hydraulic conductivity of this subsurface geology (Shamsudduha et al. 2011). Hence, earlier evidence indicates that rigorous abstraction of groundwater for irrigation, decreasing precipitation that is one of the impacts of climate change and local geology of the study region, can be attributed to rapidly declining GWL in the drought-prone urban area.

The decreasing rate of GWTs may be due to decline recharge resulted from low rainfall, an expanding plough pan triggering from enhancing conservation agriculture practices, and a thick silty clay surface in the Khetlal Upazila. In this Upazila, the rainfall has reduced by 12−80 mm/year, decreasing natural recharge over the past ten years (Jahan et al. 2010). The abuse of existing GWL, primarily being extracted for paddy farming, rice mill operations, and other industrial purposes, is an alarming issue that affects the Khetlal Upazila, where groundwater provides 80% of the water needed for rice irrigation. Here, random use of water in industry and agriculture is causing GWL declination. Inefficient use of water for domestic and irrigation purposes leads to over-extraction of groundwater and also contributes, to some extent, to declining GWTs. On average, GWL varies between 1 and 6 m in the northern region, consistent with the Master Plan Organization (MPO 1987) claim, which states that groundwater is mainly available within 5 m of ground within alluvial aquifers. Evidence suggests that aquifer replenishment slowly ends during the dry season due to low rainfall in the short monsoon season and less available soil moisture (Jahan et al., 2010; Zinat et al. 2020). This is primarily because of more groundwater mining than aquifer recharge (Salam et al. 2020b). The over-exploitation of groundwater for irrigation without any rise in rainfall triggered a decline in GWLs to some degrees. They cannot be replenished naturally, which has caused a groundwater deficit in this drought-prone region of Bangladesh (Hasanuzzaman et al., 2017).

Our study has some implications for sustainable groundwater development. Utilizing underutilized rivers, measuring aquifers' safe yields, recharging the aquifers by natural and artificial ways, harvesting rainwater, and using wastewater are the possible choices for this alternative (Jahan et al. 2010; Dey et al. 2017; Islam et al. 2019). Suppose rainfall collects in sustainable ways during the monsoon season used for domestic purposes, after the low-cost filtering process. In that case, this will substantially lessen the water shortage issue in the northwest region in the long run. To aid this, rainwater harvesting facilities should be properly planned and designed based on our findings (Islam et al. 2019), a substantial performance in the Khetlal and Kalaiupazilas that need collaborative efforts among governments non-government organizations, and hydro-geologist. Also, practices such as mulching can increase the water-holding capacity of field soils and decrease evaporation. Organic mulching can also aid groundwater recharge by increasing soil organic matter, especially drought-prone Upazilas such as Khetlal, Kalai. Rapid urbanization, climate change, and poor water management policy threaten groundwater resources in the study area, perplexing their sustainable management. Thus, strategies such as artificial recharge of aquifers, rainwater harvesting, water-saving technologies, and integrated water resources management must be implemented.

Groundwater study must be coupled with other geoscience and hydro-engineering researches. Multi-disciplinary tools should require managing in case of GWL depletion in a sustainable manner. Groundwater should be used as a supplement to surface water. Deep insight and protection of groundwater for future communities, particularly overexploitation, should be monitored from time to time and a strengthened legal approach (Bhattacharjee et al. 2019). GWR management must persistent forthcoming period; thus, future groundwater problems cannot be neglected (Dey et al., 2017). Thus, sustainable GWR management depends on precisely evaluating groundwater resources' current and future trend patterns (Richter et al., 2006). This study concentrates on assessing the present and forthcoming trends of GWL in the Joypurhat district of northwest Bangladesh, which covers how decision-makers take the right initiative for combined sustainable GWR management. The increased irrigation coverage linkage with increased groundwater extraction from the aquifers over the recent past has attributed to a decrease in GWLs. Hence, the northwest region, especially the Barind area, is of most alarming over dropping GWL, which leads to a lack of access to water for drinking and irrigation in several regions. GWL declination can have an irreversible concern on the drinking water and particularly on the human health issues. Hence, continuous monitoring of GWL fluctuation using an easy but practical tool is essential for GWR management.

Some of the vital indicators of GWL fluctuations, including bore-well depths closeness of well from sink or source and hydrogeological features, e.g., aquifer porosity and permeability, are ignored in this study due to unavailability data. Further investigation is essential by incorporating these critical hydrogeological parameters in data-driven tools to enhance short and mid-term prediction accuracy and confirm these hybrid methods agree well with the theoretical and numerical-based approaches. Such understanding could give further numerical insights and would probably lead to a higher acceptance of soft computing methods in the sustainable management of GWR. Further study should consider all the wells for predicting regional and national levels GWL.

5. Conclusion

Groundwater declination has been a burning issue globally as well as regionally in recent times. This study represents how alarming the GWL depletion is in the study area. This research proves the magnitudes of GWL fluctuation scenarios obtained from the modified Mann- Kendall test, Sen's slope estimator, Pettitt's test. The ARIMA modeling outcomes are realistic and consistent with the present condition. The study shows a decreasing trend of GWL, and the declination rate of GWL in Joypurhat district is 0.136 m/yr from 1980 to 2019. Out of five Upazilas, the groundwater declination rates of Khetlal and Kalai are higher than the district average, which is liable to excessive groundwater abstraction in high water-consuming crop production like rice and potato. The forecasted results revealed that the GWL will go down from 2020-2050 at a rate of 0.143 m/yr, which is very more alarming in the future sustainability of groundwater resources. In this study area, proper crop water management should be emphasized to avoid such adverse impacts. Though rainwater harvesting is recommended as a long-time remedy to cope with drought effects, simultaneous monitoring can be a short-term remedy. Future research should concentrate on GWL fluctuation tele-connected with large-scale atmospheric oscillation in the study region. Our study provides sustainable groundwater potentiality under current and future climate change scenarios in the northwest region of Bangladesh.

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Ethical approval

Not applicable

Consent to Participate

Not applicable

Consent to Publish

Not applicable

Data availability

Data are available upon request on the corresponding author

Code availability

Not applicable

Author contributions

A.R, A.I and A.R.M.T, designed, planned, conceptualized, drafted the original manuscript, and R.S., and A.R., M.A., were involved in statistical analysis, interpretation; M.T.A., R.S., and A.R., contributed instrumental setup, data analysis, validation; A.R.M.T., M.A. A.I., and A.R., contributed to editing the manuscript, literature review, proofreading; A.R. and A.R.M. T.I., were involved in software, mapping, and proofreading during the manuscript drafting stage.

Conflict of interest

There is no conflict of interest to publish this work.

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Figures

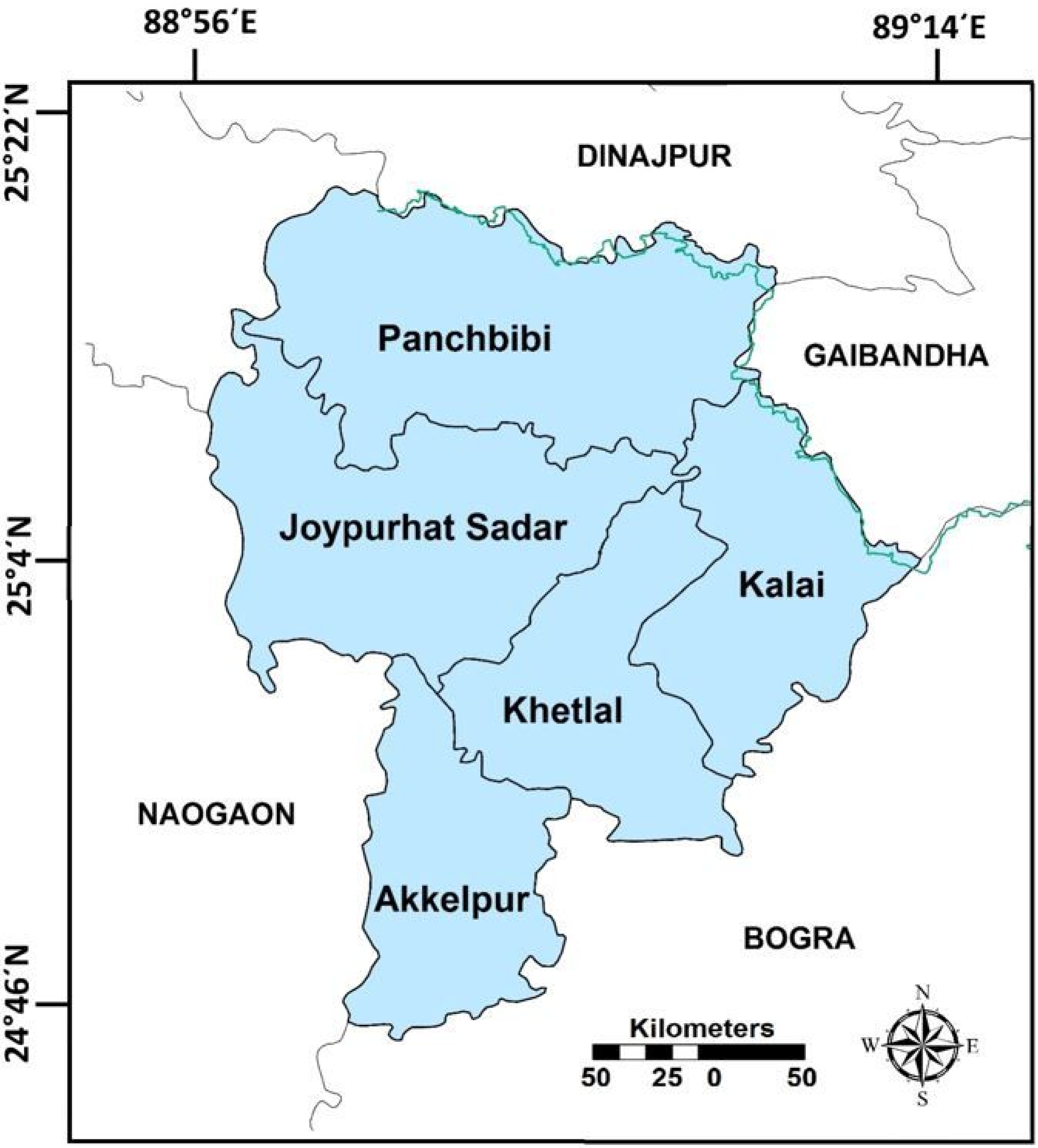

Figure 1

Location of study area (Joipurhat, Bangladesh) map

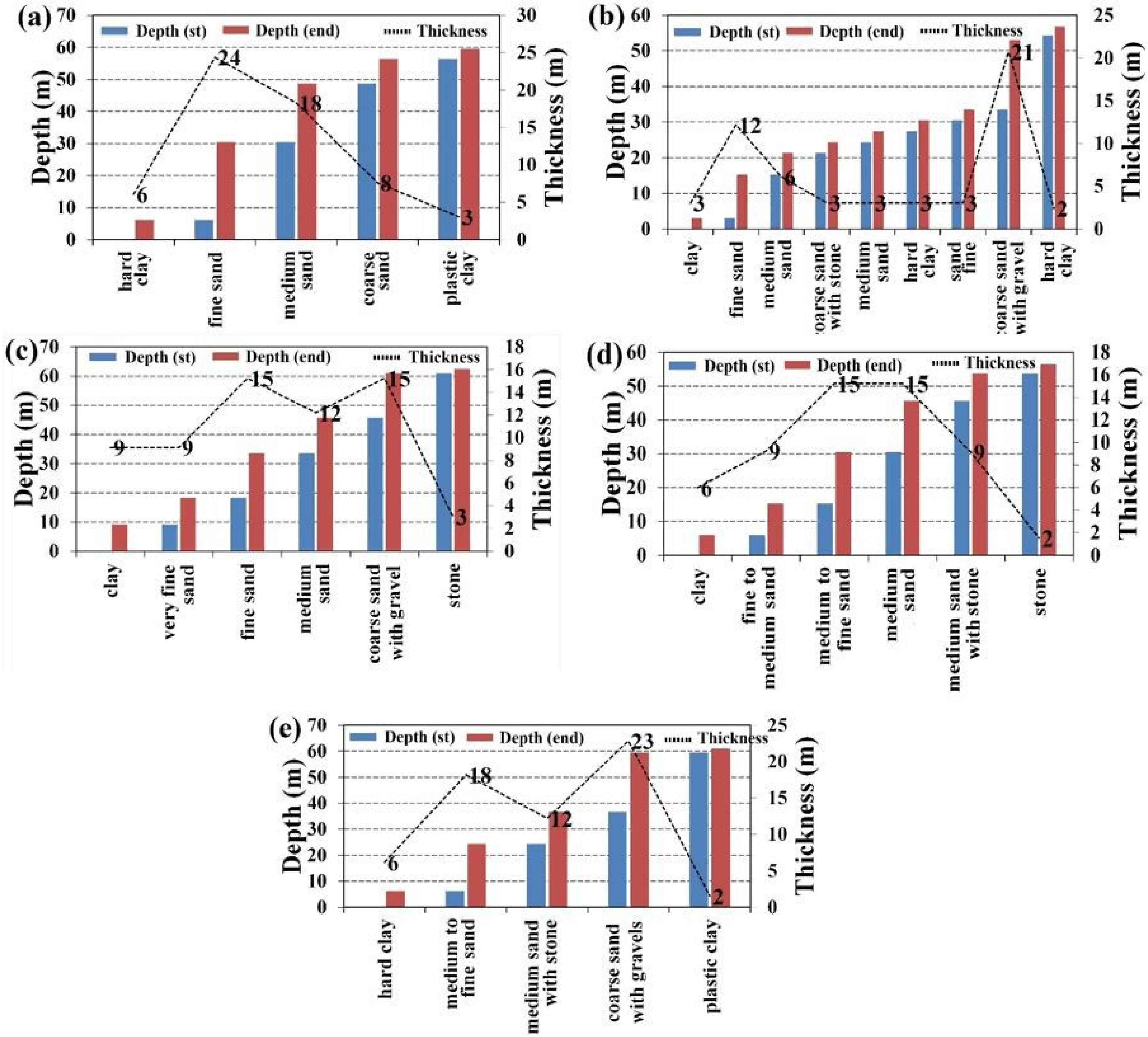

Figure 2

Lithological characteristics of (a) Akkelpur; (b) Panchbibi; (c) Khetlal; (d) Kalai; and (e) Joypurhat sadar

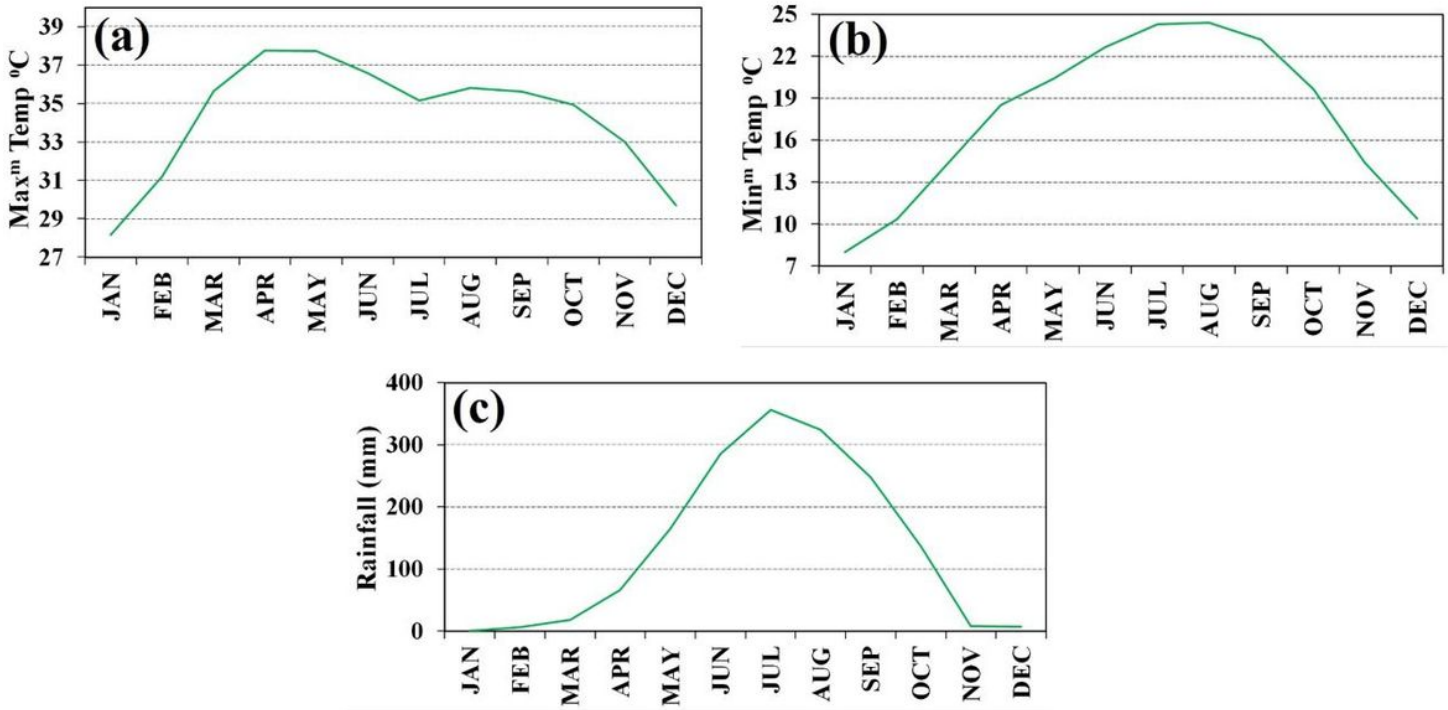

Figure 3

Monthly average (a) Maximum; and (b) Minimum temperature, and (c) rainfall (1980-2019)

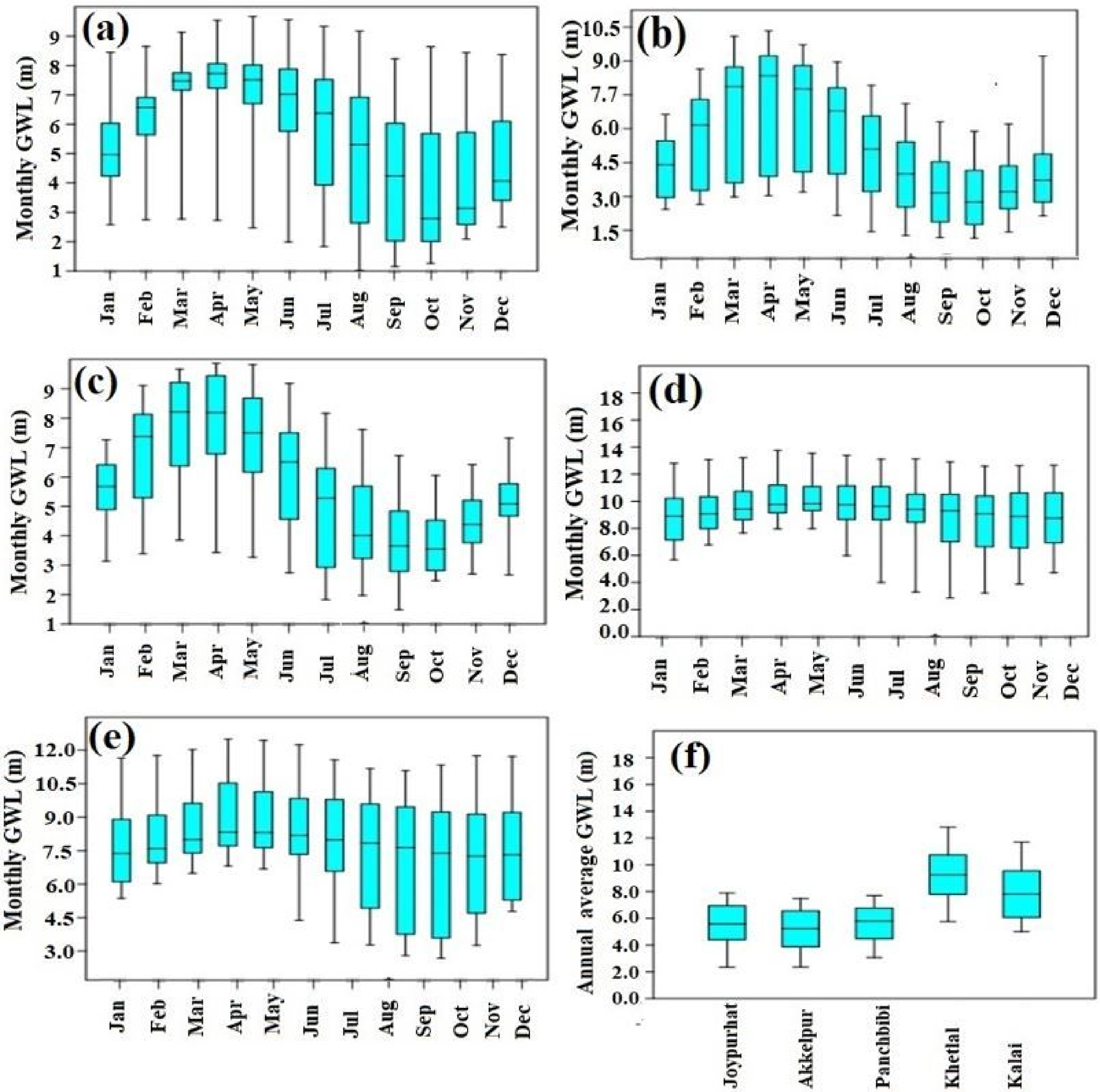

Figure 4

Monthly ground water level variation in (a)Joypurhat Sadar; (b) Akkelpur;(c) Panchbibi; (d) Khetlal;(e) Kalai; and (f) Apparent variation of GWL Joypurhat district

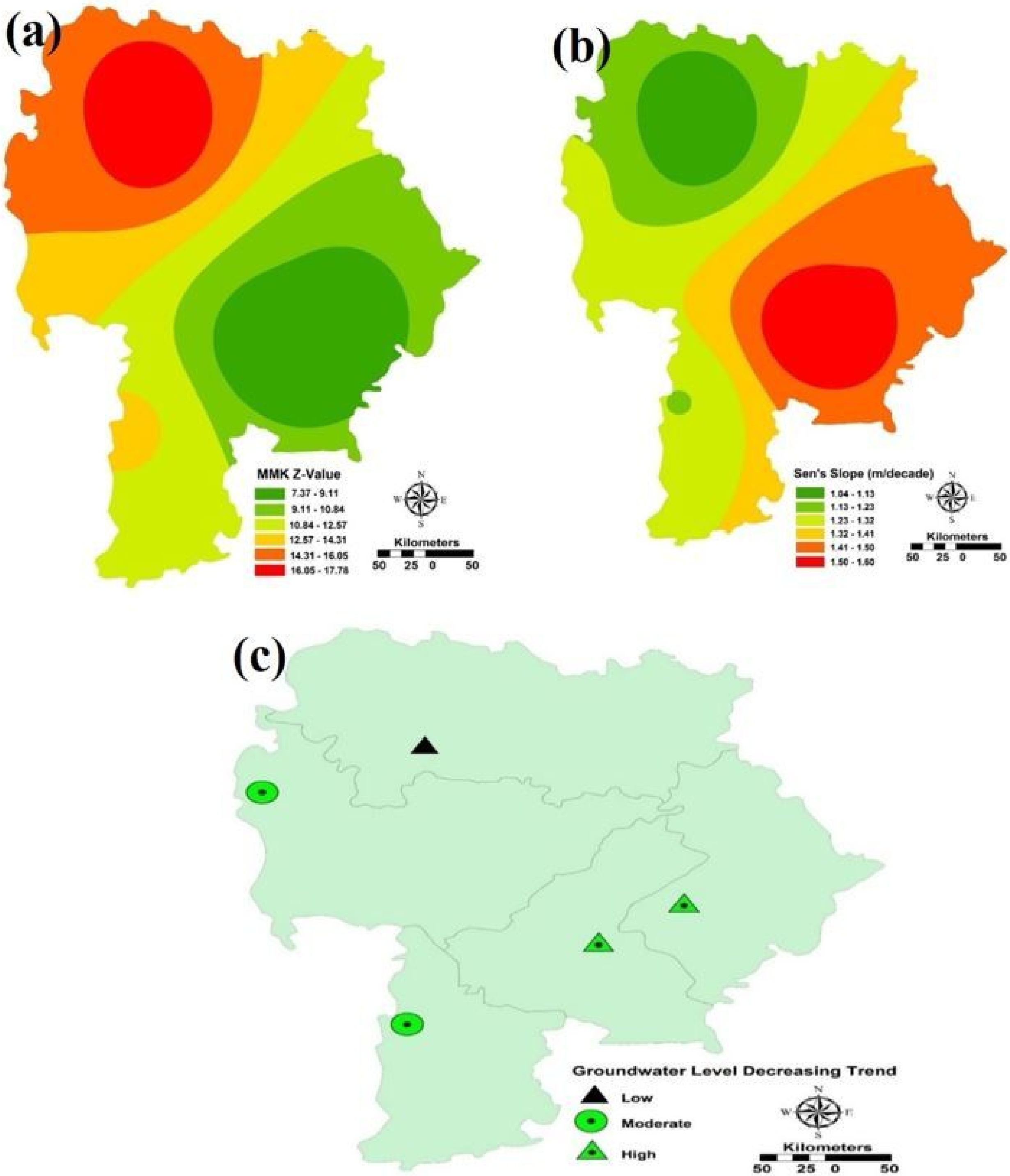

Figure 5

(a) GWL declining trend analysis based on MMK test; (b) GWL trend slope analysis; and (c) Monthly GWL trend analysis (1980-2019)

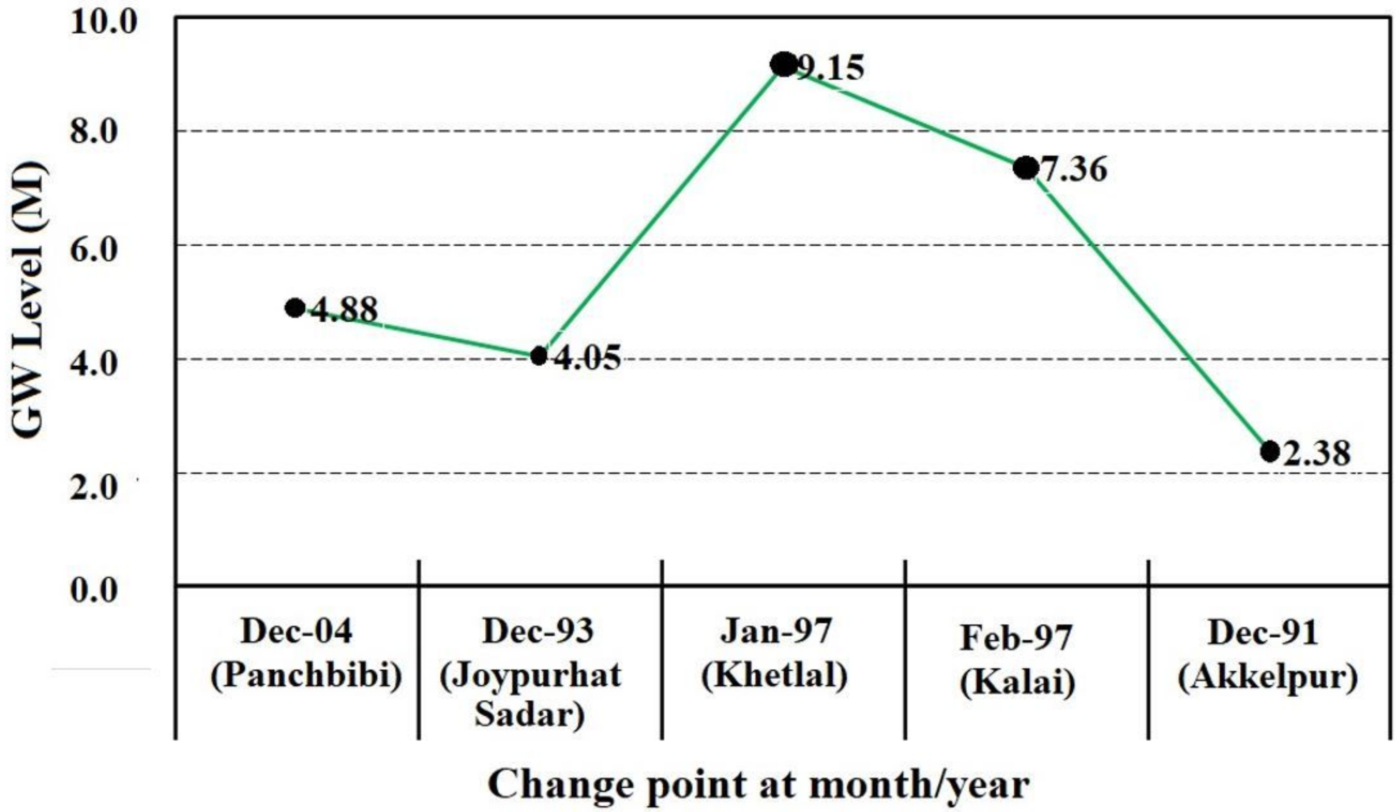

Figure 6

Change point detection time of GWL declination in Joypurhat district.

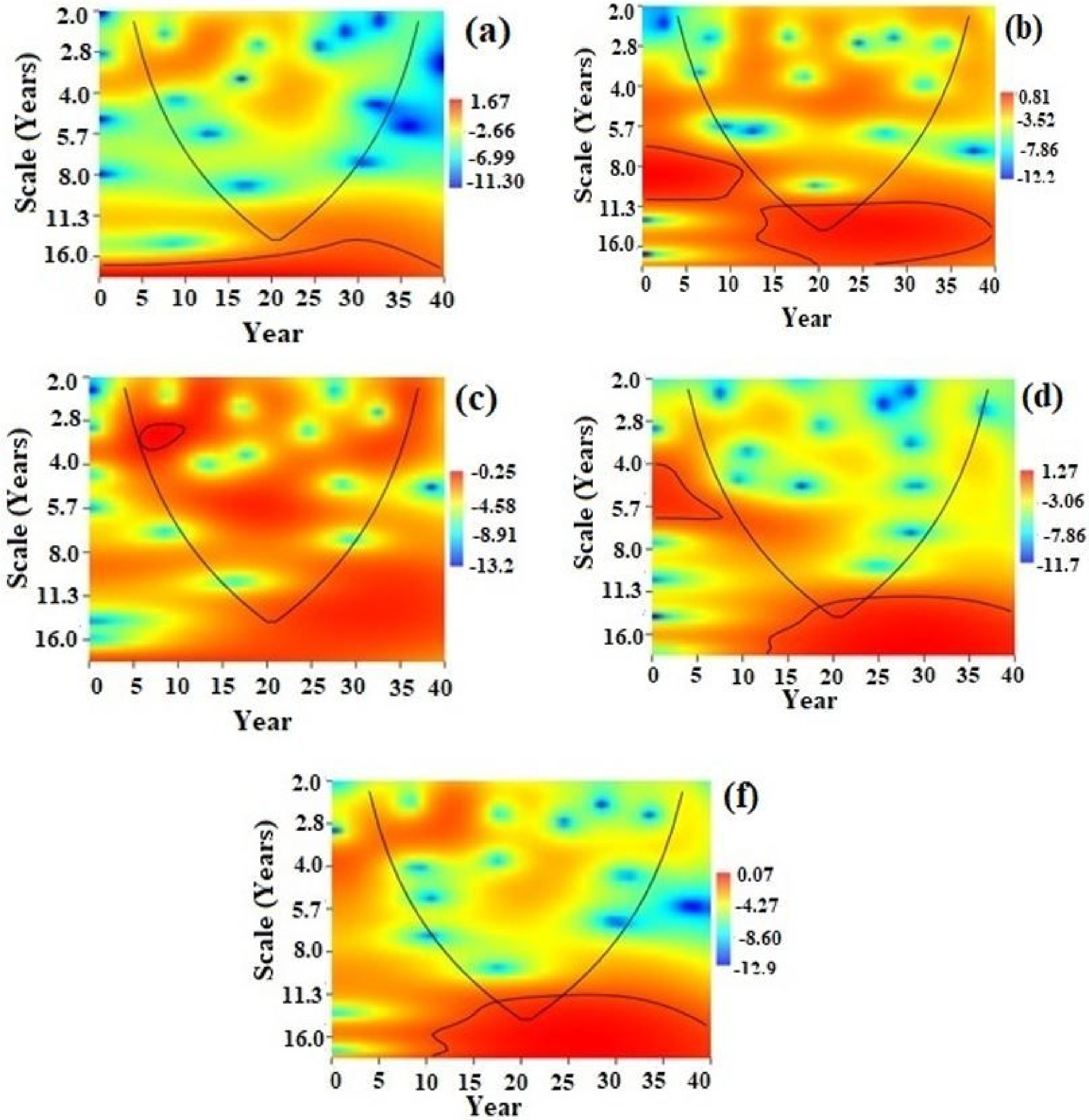

Figure 7

Wavelet power spectrum of ground water level (a) Joypurhat sadar; (b) Akkelpur; (c) Panchbibi; (d) Khetlal; (e) Kalai; and (f) Joypurhat District

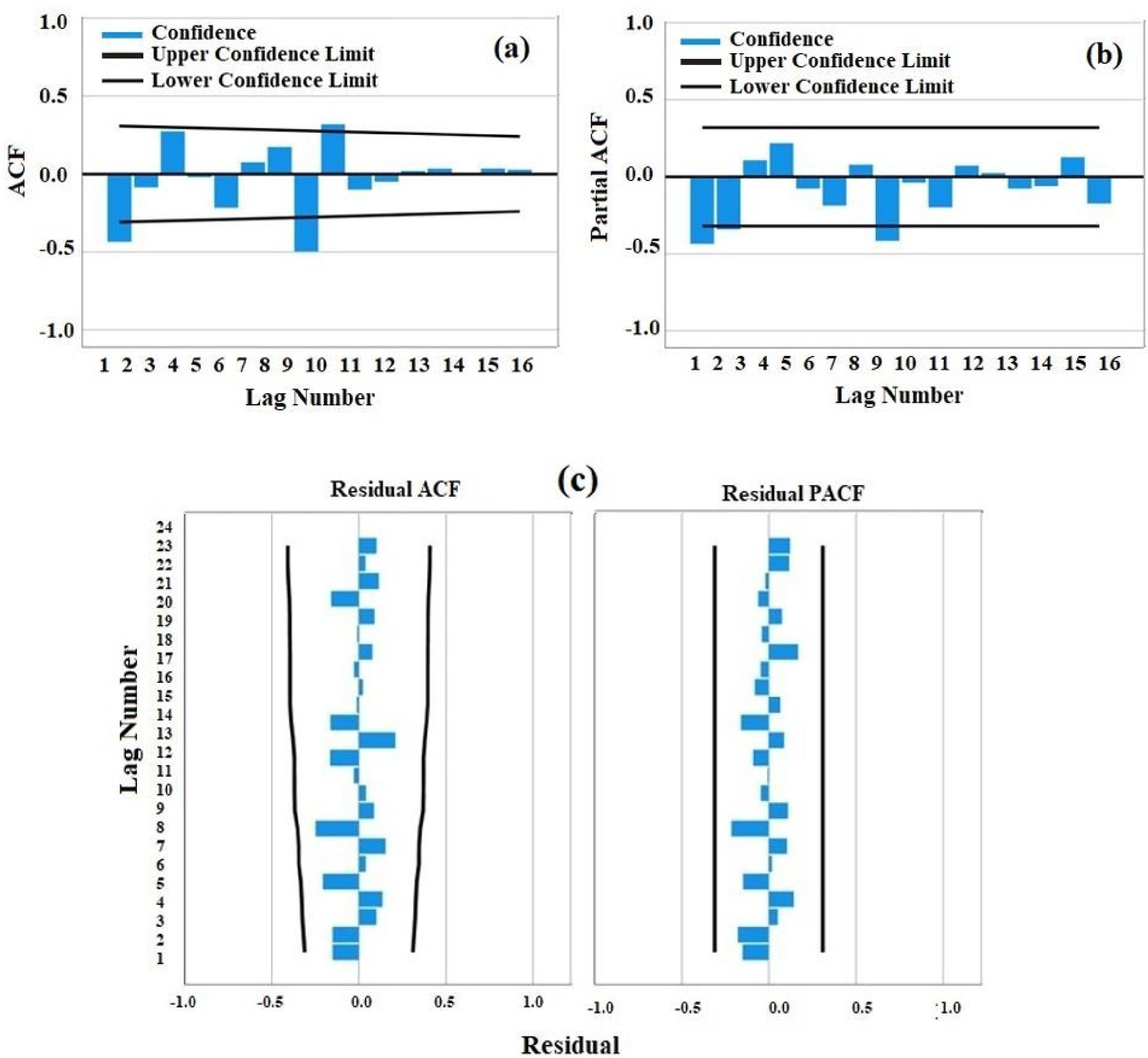

Figure 8

Autocorrelation plot (a) ACF without differentiating; (b) PACF without differentiating; and (c) ACF and PACF with differencing of ground water levels in Joypurhat district

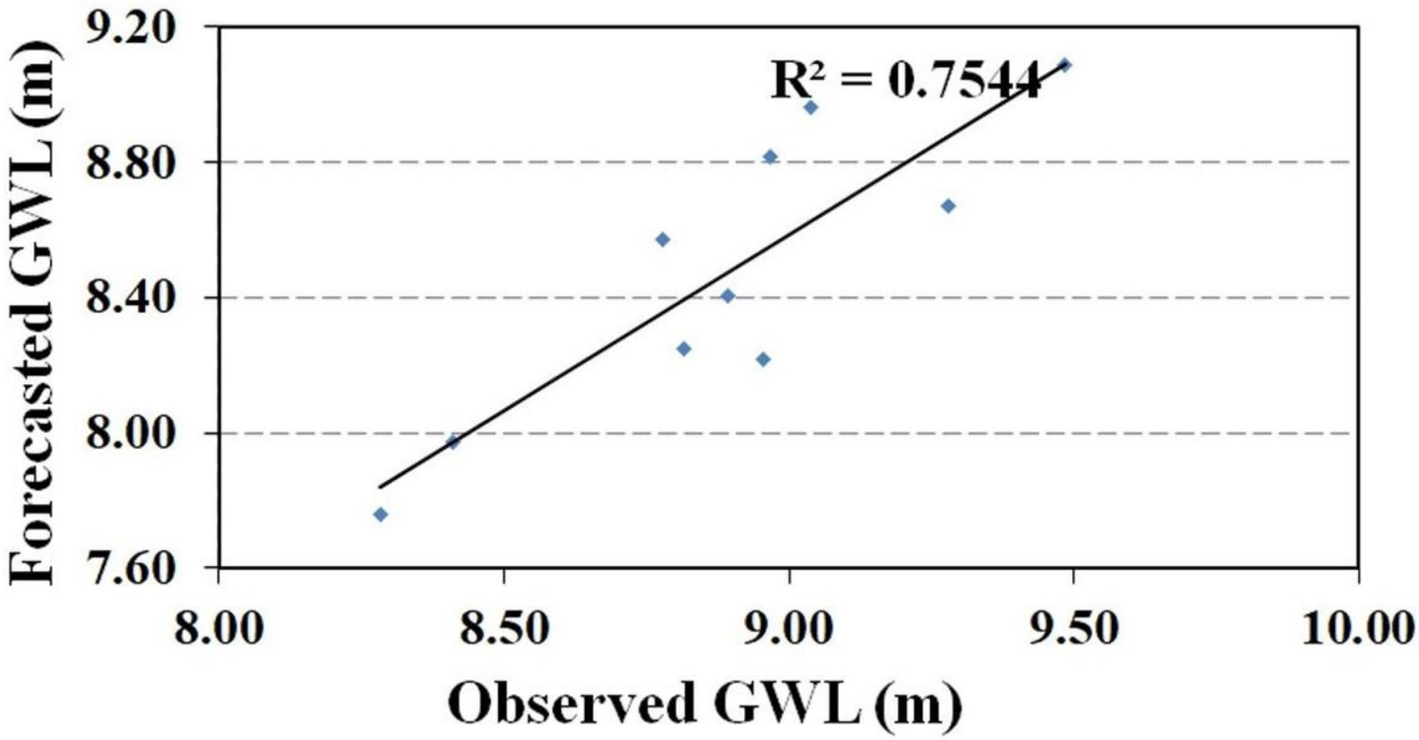

Figure 9

Comparison plot of observed versus forecasted ground water levels (2010-2019) of Joypurhat district.

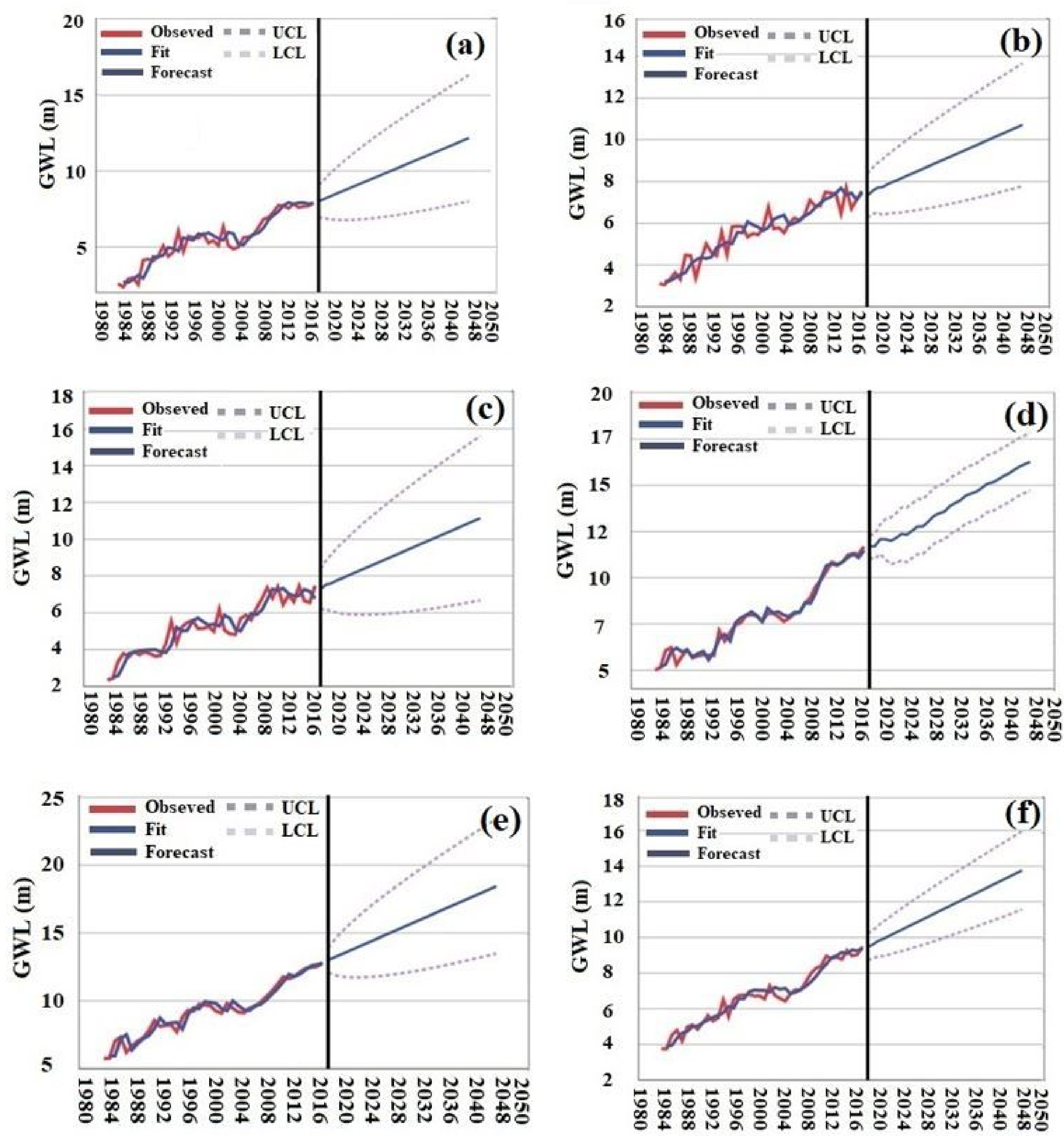

Figure 10

Forecasting of groundwater level by best ARIMA model fitting(a)Model 1,1,0 (Joypurhat sadar); (b) Model 2,1,0 (Panchbibi); (c)Model 1,1,0 (Akkelpur); (d) Model 8,1,8 (Kalai); (e) Model 0,1,0 (Khetlal); and (f) Model 2,1,0 (Joypurhat district)