Chapter 17
Impact of Climatic Changes on Groundwater Regime: A Case Study of Tinsukia District, Assam, India

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Abstract Hydro-climatic changes can significantly disturb the balance between natural parameters, leading to difficulty predicting trends in groundwater system. Rainfall and temperature variations can affect all other climatic elements; therefore, identification of trends of these two elements becomes relevant to studying the globally increasing effect of climate change. In the past decades, scientific research on the impact of climate change on the various hydro-climatic parameters has identified trends in the extreme seasonal and annual values. The most accepted statistical tool for examining trends was the Mann–Kendall test, Sen's slope and linear regression. The whole planet is struggling with water crises due to climate change, so groundwater is the only resource to lie on to fulfill fresh water needs. Thus, studying trends in groundwater levels becomes the necessity of the coming era. This research's main objective is applying the Mann–Kendall test and Sen's slope method to identify the trends and magnitude of groundwater levels under the climate conditions in Tinsukia District, Assam, India. This objective is important in analyzing groundwater resources in close connection with their efficient management. The study is based on the secondary data of the monthly groundwater level (mbgl) obtained from the Central Water Commission, India and climatic data (average annual rainfall, maximum and minimum temperature) for the period 2012–2021 from India Meteorological Department (IMD). The findings suggested that the average yearly rainfall, maximum temperature and minimum temperature have an increasing trend along with the groundwater levels in the study area. This leads to saturation in the recharge system and storage capacity. The higher intensity of rainfall and greater saturation level in the groundwater system may lead to a higher runoff rate, thereby initiating a major flood-like situation in the study area.

Keywords Groundwater · Trend analysis · Mann–Kendall · Sen's slope · Climate change

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17.1 Introduction

Throughout history and throughout the world, the ubiquitous resource of groundwater has played a central part in ecosystem sustainability and helping human adaptation to climate change. Variability in the major climatic parameters (precipitation, soil moisture and surface water) will aggravate the risk of climate extremities (droughts and floods), thereby intensifying the strategic importance of groundwater (Taylor et al. 2012). Rapid population growth along with surface water pollution escalates groundwater demand (Wu et al. 2020) which results in the lowering of groundwater levels. The groundwater crisis in the coming years shows the global concern as its vulnerability increases with the substantial extraction of groundwater for various purposes (Halder et al. 2020). In Tinsukia, Assam, India, according to District Irrigation Plan, 2016–2020 by NABARD Consultancy Services, the water budget shows a negative gap between water availability and requirement that indicates sufficient water resources available for various purposes (irrigation, domestic and industrial) with no deficit in the water potential. Meanwhile, the poor domestic wastewater management paints a situation of looming water crises in Tinsukia. Around 97% of household wastewater is untreated and discharged to the environment with no proper secondary and tertiary treatment facility arrangement (CSE-2020, SFD Lite Report—Tinsukia, India). Therefore, examining how trends in groundwater level change in response to the changing trends in rainfall and temperature becomes crucial. Fluctuations in an area's annual and seasonal rainfall patterns may lead to stress on groundwater levels with consequent implications in strategizing groundwater development and management for sustainable water use in the region (Goswami and Radha 2020). Out of all methods applied to identify hydro-meteorological time series (Duhan and Pandey 2013), trend analysis of rainfall and temperature (by parametric and non-parametric tools) shows the direction and magnitude of the trend and its statistical significance (Jain and Kumar 2012). Researchers confirmed the Mann–Kendall test (Mann 1945; Kendall 1975) and Sen's slope (Sen 1968) as one of the best methods used to analyze the temporal change in an area (Aditya et al. 2021). Pathak and Dodamani (2018) applied cluster analysis on long-term monthly groundwater levels and opted Standardized Groundwater Level Index (SGI) for evaluating groundwater drought along with Mann–Kendall tests to investigate annual and seasonal trends of groundwater levels in the groundwater drought-prone Ghataprabha River basin of India. Le Brocque et al. (2018) applied a modified Mann–Kendall test and Sen's slope estimator to data of 381 groundwater bores in southern Queensland in Australia for 26 years (1989–2015). They found a significant overall decline in groundwater levels due to highly irrigated areas. Patle et al. (2015) recognized pre- and post-monsoon groundwater level trends using the Mann–Kendall test and Sen's slope estimator in the Karnal district of Haryana in India from 1974 to 2010. Fenelon and Moreo (2002) used Locally Weighted Scatterplot Smooths for graphical representation and Mann–Kendall trend tests on groundwater levels and spring discharge for statistical purposes from 1960 to 2000 in the Yucca Mountain Region, USA. Jain and Kumar (2012) studied trends in rainfall from 1950 to 2000 and temperature for the period of 1900–2000 in the context of various river basins of India, addressing the need for a baseline station network for climatic studies. Aswad et al. (2020) also applied the Mann–Kendall test and Sen's slope estimator to study the annual and monthly rainfall trend in the Sinjar district of Nineveh, Iraq, for a 70-year period (1940–2010). Thakur and Thomas (2011) applied Kendall's rank correlation test to identify trends in groundwater level data and a linear regression test to identify the significance of the slope in the Sagar district of Madhya Pradesh in India. Engelenburg et al. (2018) applied the AZURE hydrological model to assess the effect of climate change and extensive groundwater extraction in the Veluwe aquifer of the Netherland to analyze the groundwater level in the nearby dependent ecosystem. Sishodia et al. (2016) analyzed the bi-decadal groundwater level trend in three administrative districts of semi-arid South India. They briefed it through variability in rainfall, irrigation and agricultural power subsidy. Tiwari et al. (2011) utilized GRACE satellite and in-situ groundwater and Gravity Recovery data to study groundwater levels and compare them to Cumulative Rainfall Departure (CRD) and Standardized Precipitation Index (SPI) in Andhra Pradesh. They found a net increase on account of variability in rainfall. Patra et al. (2018) performed Kendall's Tau to examine the relation of hydro-climatic parameters (e.g., rainfall, temperature) with hydrological components (e.g., groundwater level). Normalized Built-up Index was used to evaluate land cover and use change and the inverse distance weighting (IDW) interpolation method for the spatial distribution of temperature, rainfall and groundwater level analysis. These tools identified the effects of urban sprawl on groundwater recharge, and the study suggested clustering wells for effective groundwater level and recharge patterns. Salem et al. (2018) focused on the result of climate change on irrigational cost for a region in North-West Bangladesh by using a hydrological and general circulation model, which requires analysis of present and future trends to replicate the groundwater level from climatic variables. Bora et al. (2022) analyzed the changes in annual and seasonal rainfall patterns in seven North-East Indian states for the period 1901–2020, using non-parametric tests like Mann–Kendall, trend-free pre-whitening Mann–Kendall, modified Mann–Kendall (MMK) and innovative trend analysis (ITA) revealing almost identical results for all the tests with. The study revealed the variable cities in annual and seasonal rainfall in these seven states. In most cases, the tests' results were almost identical, which helps policymakers frame crucial climatic and water resource management decisions. Bahadur et al. (2017) conducted a study to assess the significance of three hydro-climatic variables, viz., temperature, rainfall and runoff over the Rangoon watershed in the Dadeldhura, Nepal. Monthly, seasonal and annual data were evaluated using the Mann–Kendall test and Sen's slope estimate for rainfall and temperature (1979–2010) and 1967–1996 for runoff. The study's main objective is to apply the Mann–Kendall test to predict the existing trend direction and Sen's slope method to detect the trend direction and the magnitude of change over time in groundwater levels under varying rainfall and temperature conditions in Tinsukia District, Assam, India. This cardinal objective is necessary for interpreting the growing effect of climate change on groundwater resources and is considered an opening move to analyze groundwater resources in close connection to well-structured management.

17.2 Study Area

Study area Tinsukia is an administrative district in the eastern parts of Assam, India. The spatial stretch is 27° 14′03″–27° 48′05″ N latitude and 95° 13′03″–96° 00′00″ E longitude covering 3790 km^2 in Brahmaputra Basin. It comprises three sub-divisions, seven blocks and 88 g Panchayats for transparent and smooth governance. The great river the Brahmaputra is the major drainage source feeding the study area along with Dibru and Burhi-Dihing. Being a huge water resource for Tinsukia, all these drainage systems also prove to be the misery of Tinsukians carrying loads of sediments and voluminous water during monsoons to the low-lying area and creating a flood-like situation. The area enjoys a humid subtropical climate with high humidity in the rainy season. The mercury ranges from 21 to 35 °C in summers and falls to as low as 13 °C in winters. A high rainfall pattern also accounts for around 65% of rainfall during monsoons. The spectacular geomorphic landforms in the area are Brahmaputra plains, structural hills in the southern part and young and old alluvium plains. Paddy, the major crop in the area, has now been accompanied by other cash crops, which ultimately grow at the cost of irrigation and groundwater utilization. As per CGWB, the groundwater level in 2021 is 3.546 mbgl, decreasing compared to 2020, which stands at 3.802. The water quality of Tinsukia is fresh and portable on average, but iron (Fe) is found in some areas more than permissible. The groundwater development in Tinsukia is low-key, which may gain pace with coming management strategies (Fig. 17.1).

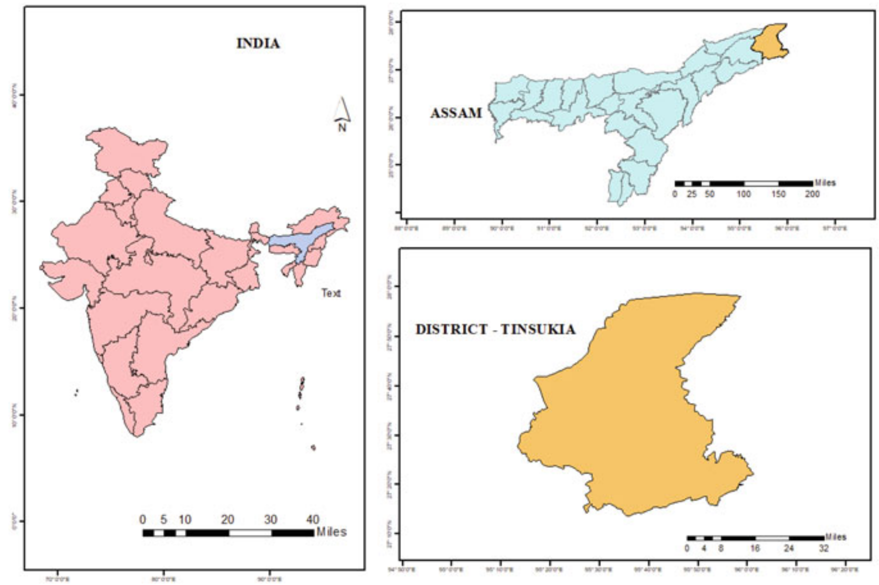

Fig. 17.1 Study area (Tinsukia district)

17.3 Data Source

Yearly meteorological parameter temperature and rainfall of the Tinsukia district in Assam were collected from the India Meteorological Department for a decade, i.e., from 2012 to 2021. The maximum, minimum and average temperatures were considered for temperature. The rainfall data were collected from three different IMD stations in Tinsukia situated at Udaipur, Dholabazar and Margherita. Trend analysis for groundwater includes data from the Central Ground Water Board, Govt. of India for the same study area and period.

17.4 Data Processing

The major climatic variables, temperature and rainfall, along with a significant hydrological parameter groundwater level, were assessed for trend analysis in the current study. The most widely accepted time series analysis in climatic and hydrological trends includes the Mann–Kendall test and Sen's slope estimator. The calculations have been done in the coming sections to establish a relationship between the testing parameters. For ease of calculation, the MS-Excel program MAKESENS 1.0 is used.

17.4.1 MK Test

MK test or Mann–Kendall test (Mann 1945; Kendall 1975; Gilbert 1987) is a widely recognized non-parametric test to detect monotonic trends in a series of climate and hydrological data. Data following a monotonic trend confirm the existence of a trend using an alternative hypothesis (H_1). Independently and identically distributed data are given by the null hypothesis (H_0) for this statistical test. H_0 represents the non-existence of any trend. The presence of a significant trend is identified using the values of a test statistic Z, the positive and negative values indicating an upward and downward trend, respectively. "Mann–Kendall test does not require that datasets to follow a normal distribution and show homogeneity in variance; transformations are not required if data already follow a normal distribution, and in skewed distribution, greater power is achieved" (Duhan and Pandey 2013). The test helps evaluate the slope's nature in a trend, coefficient of variation and type of probability distribution. "Mann–Kendall test is used for trend analysis as it eliminates the effect of serial dependence on auto-correlated data which modifies the variance in datasets" (Hamed and Rao 1998). The mathematical explanation can be read from various literature mentioned in the reference section.

17.4.2 *Sen's Slope Estimation*

Sen's (1968) slope estimator is a significant statistical tool to establish linear relationships having the advantage over the slope of regression. "This method assumes the trend line is a linear function in the time series. In Sen's slope model, the slope value shows the rise and fall of the variable" (Jain and Kumar 2012). "Another advantage of using Sen's slope is that it is not affected when outliers and single data errors are present in the dataset" (Salmi et al. 2002). For mathematical understanding, literature from the reference section can be read.

17.5 Result and Discussion

Trend analysis of annual temperature, rainfall and groundwater level was carried out using the MK test and Sen's slope for ten years (2012–2021) in the Tinsukia district of Assam. Results are discussed separately for each parameter in this section to establish a legit relationship.

17.5.1 *Trend Analysis for Temperature*

17.5.1.1 Minimum Temperature

The result of the annual minimum temperature during 2012–2021 is given in Table 17.1. From the table, the *Z*-value of 0.36 and *Q*-value of 0.02 indicate the existence of the H_1 hypothesis. A positive value reveals a significant upward trend which implies an increasing trend over time in the annual minimum temperature pattern. The trend is not so strong as the *Q*-value indicates a weak magnitude of a movement.

Table 17.1 Tinsukia district—trend result of temperature, rainfall and groundwater level by Mann–Kendall test and Sen's slope estimator from 2012 to 2021

Parameters	*n*	*Z*-value	*Q*-value	Significance	*B* value
Temperature_Max (°C)	10	0.64	0.021	–	29.48
Temperature_Min (°C)	10	0.36	0.020	–	16.53
Temperature_Avg (°C)	10	0.00	0.003	–	24.47
Rainfall_Dholabazar (mm)	10	1.97	110.728	*	1771.37
Rainfall_Udaipur (mm)	10	0.54	17.644	–	978.89
Rainfall_Margherita (mm)	10	1.43	39.844	–	2063.03
Groundwater level (mbgl)	10	−0.18	−0.025	–	3.72

"*" represents a significant trend at 0.05 level of significance

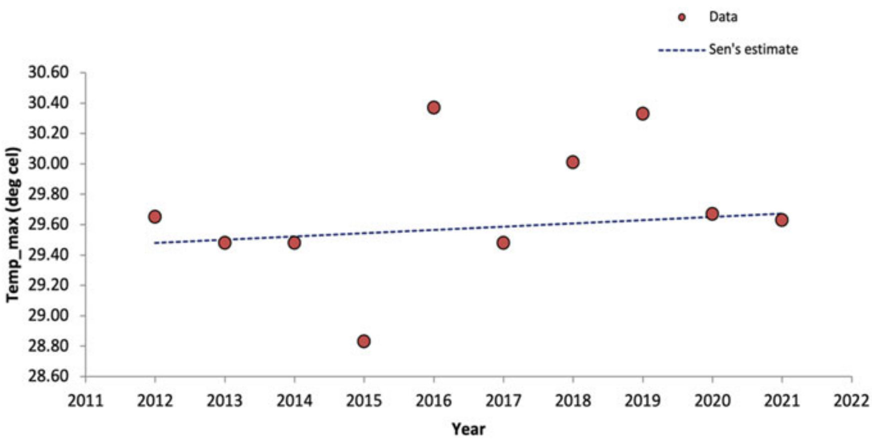

Fig. 17.2 Linear maximum temperature trends for the period 2012–2021

17.5.1.2 Maximum Temperature

The result of the MK test and Sen's slope of annual maximum temperature during 2012–2021 is given in Table 17.1. From the table, the *Z*-value of 0.64 and *Q*-value of 0.021 indicate the existence of the H_1 hypothesis. A positive value reveals a significant upward trend which implies an increasing trend over time in the annual maximum temperature pattern. The trend is not so strong as the *Q*-value indicates a weak magnitude of a trend. The maximum temperature variation is shown in Fig. 17.2.

17.5.1.3 Average Temperature

The result of MK test and Sen's slope of annual average temperature during 2012–2021 is given in Table 17.1. From the table, the *Z*-value of 0.00 and *Q*-value of 0.003 indicate no trend in the annual average temperature pattern. Here, the H_0 hypothesis is valid.

17.5.2 Trend Analysis for Rainfall

The total rainfall for ten years (2012–2021) for three specific station—Dholabazar, Udaipur and Margherita is shown in Table 17.1. The *Z*-value and *Q*-value for Dholabazar are 1.97 and 110.728, respectively, marking a significant positive trend at 0.05 level of significance having 95% significance interval of *Q*. For Margherita, the *Z*-value and *Q*-value are 1.43 and 39.844, respectively, signifying a positive trend in the rainfall distribution. Similarly, a positive trend exists for Udaipur station as the *Z*-value and *Q*-value are 0.54 and 17.644, respectively. Here also, the null hypothesis (H_0) rules out, indicating the presence of a trend in the rainfall pattern in Tinsukia, Assam. Rainfall variations in these stations are shown in Figs. 17.3, 17.4 and 17.5.

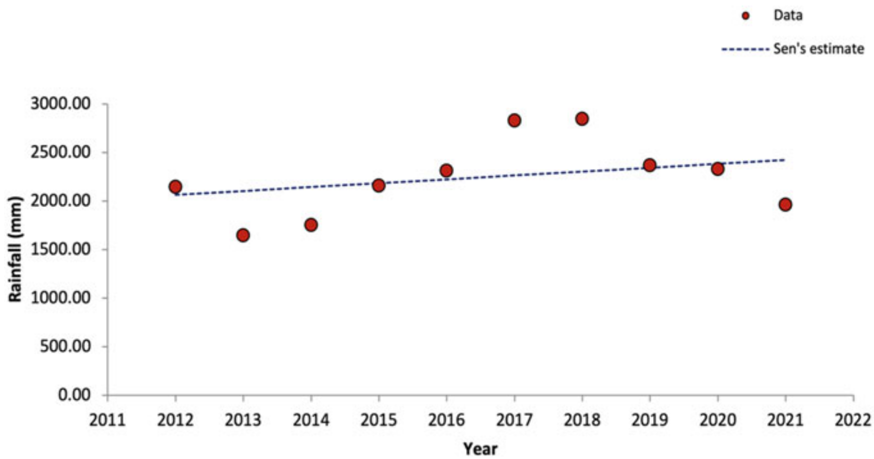

Fig. 17.3 Linear rainfall trends for the period 2012–2021, Dholabazar

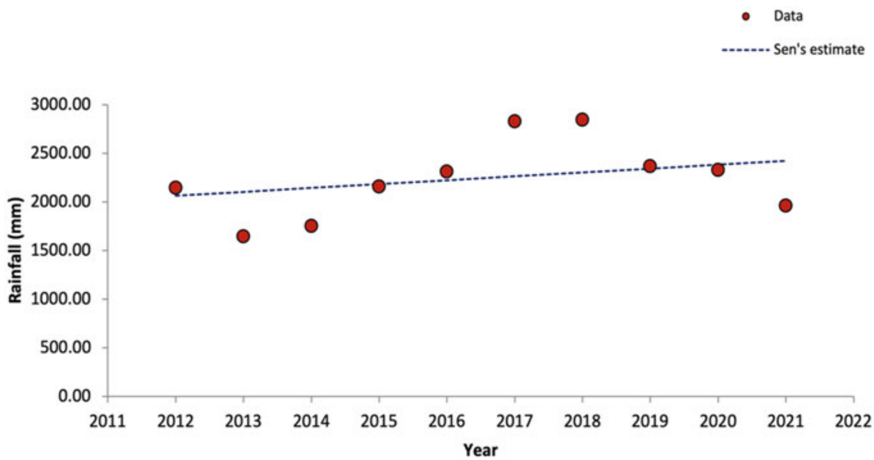

Fig. 17.4 Linear rainfall trends for the period 2012–2021, Margherita

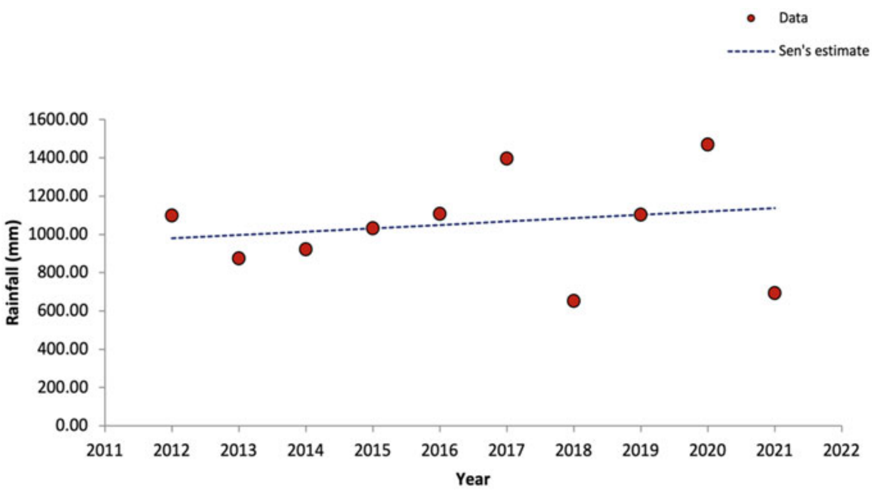

Fig. 17.5 Linear rainfall trends for the period 2012–2021, Udaipur

17.5.3 Trend Analysis for Groundwater Level

The result of the annual groundwater level in Tinsukia studied for ten years (2012–2021) using the MK test and Sen's slope is summarized in Table 17.1. As for groundwater level in mgbl, a negative value of Z and Q indicates an increasing trend in water availability from the ground level. The Z-value and Q-value are −0.18 and −0.025, respectively, which means the groundwater level is increasing at a higher rate in Tinsukia, Assam. Variations in groundwater level are shown in Fig. 17.6.

Positive Z- and Q-value for maximum and minimum temperature shows an increasing trend for an annual temperature rise in Tinsukia. The increase in temperature bears witness to a growing rainfall trend for the period of 2012–2021. The groundwater level is also increasing at a higher rate, leading to saturation in the recharge system and storage capacity. The higher intensity of rainfall and greater saturation level in the groundwater system may lead to a higher runoff rate, thereby initiating a major flood-like situation in the study area. The vast network of river Brahmaputra, along with its tributaries, supplements the devastating floods in Assam. The recent 2022 flood in Assam testifies to the statement enhancing high alerts for the Tinsukia inhabitants.

17.6 Conclusion

The work incorporated in this chapter was a mere study to analyze the effect of climate change on groundwater levels in Tinsukia district of Assam which lies on the banks of the river Brahmaputra. Verifying unattempted study of climate change

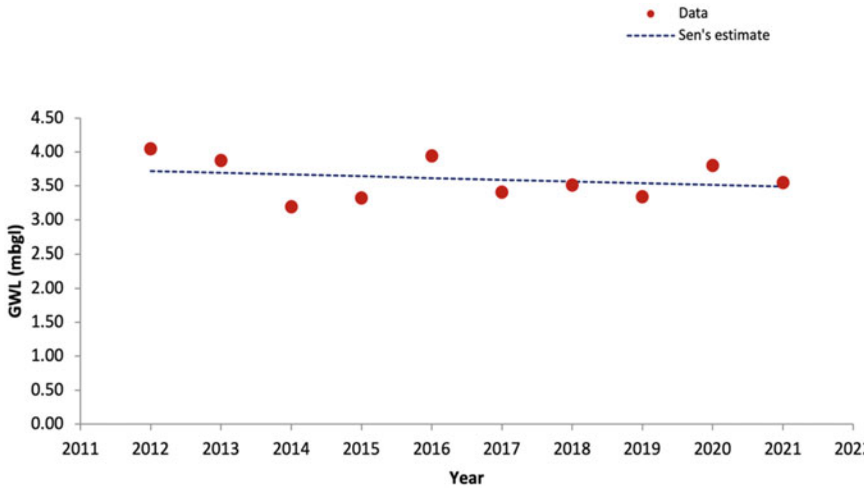

Fig. 17.6 Linear groundwater level trends for the period 2012–2021

in the area with respect to temperature and rainfall, trends for a time period of 2012–2022 were studied using the above suitable non-parametric methods. Following this, to establish a robust relationship between climate change and groundwater, trend analysis for groundwater levels was also computed. The obtained results show an increasing trend in all the calculated variables which should not be a matter of concern. But increasing rainfall and groundwater levels can also be a noteworthy reason for frequent flood events in Assam. So further study may take up to assess the trends in sedimentation, runoff and land use patterns to study the realistic viewpoint of such catastrophic events. Increasing surface water contamination in the area also endangers groundwater levels. Thus, the study caters to the need for effective water management along with the adoption of necessary policies and implementations for sustainable development.

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