Spatial and Temporal Trends in Precipitation and Temperature and their Influence on Groundwater in Ballia

ABSTRACT

A study examined the impact of long-term pre- and post-monsoon precipitation and temperature on groundwater level fluctuations in 17 blocks of Ballia District. The study used 100 years of daily precipitation data (1917-2016) and 62 years of daily temperature data (1951-2012) from the Indian Meteorological Department. Seasonal analysis was performed using pre-monsoon, monsoon, post-monsoon, and winter data. The Mann-Kendall method and Sen's slope were applied. The spatial variability of rainfall and temperature was mapped using the IDW technique in ArcGIS. Significant annual precipitation decreases were found in Murlichapra and Sear blocks. Maniar and Pandah blocks showed precipitation increases. An increasing pre-monsoon trend was observed in several blocks, while post-monsoon trends varied. Groundwater levels fluctuated across Ballia, with a notable decrease of 2.1 m in Bairia Block from 2006 to 2016.

Keywords: Precipitation, Temperature, Trend analysis, Mann-Kendal, Sen’s Slope, Ballia District.

UNDER PEER REVIEW

1. Introduction

Groundwater which is the second largest reservoirs of freshwater in the world, has already been under tremendous pressure to meet the human needs owing to anthropogenic activities around various parts of the world. The footprints of human activities can be witnessed in terms of looming climate change, water pollution and changes in available water resources. Climate change also affects groundwater quantity and quality (Odwori, 2022). In today’s analytic and scientific era analysing long-term trends in climatic parameters helps to find the possible solution of various challenges in climate change monitoring research and Precipitation and temperature are the two most significant physical variables in the climate. These variables determine the climatic conditions of any region which influences the present available water resources and future trends(Patle et al., 2015). The biggest obstruction to effective water resource planning in India is the uneven distribution of fresh surface and ground water resources across the country due to the pattern and trend of occurrence of precipitation which varies significantly spatially and temporally(Akhtar, 2023).

Agricultural products are the backbone of millions of swarming populations in India, which depends heavily on periodic rainfall and other available water resources in any region. The south-western (SW) monsoon is responsible for more than 80% of all rain in the country. Variations in SW monsoon distribution, intensity and unpredictability **(Panda and Sahu, 2019)** will substantially influence agricultural productivity, water conservation, and the nation's prosperity overall **(Panda and Sahu, 2019; Panda et al., 2007)**. In light of the preceding, several researchers have sought to study the nation's (metropolitan cities and its surrounding areas) meteorological tendency as trend analysis aids in understanding current and historical weather patterns and thus several studies have investigated nationwide.

Because these data would be valuable for planners in executing good planning that considers future variations in meteorological parameters; on the other hand, regional and local-scale research is equally important in urban areas over a complex climate model that works on a global scale for strengthening ongoing development and adaptability strategy to address the negative consequences of climate change, the present study was taken to study the spatial and temporal analysis of long-term precipitation and temperature.

For evaluating weather extremes and patterns in forecasting rainfall and temperature extremes various tools were used which includes Mann–Kendall test and Sen's slope estimator. As a result, the study will be highly beneficial because it worked on a micro level, *i.e.,* Ballia district of Uttar Pradesh state of India over the entire Indian subcontinent.

2. Material and Methods

2.1. Description of the Study Area

The study was conducted in Ballia district of Uttar Pradesh, which is bounded by the Ghaghra and Ganga rivers on both the north and south. Ballia district comprises 17 administrative blocks with areal extent of 3008.19 square kilometres. It is situated between 25.76 °N latitude and 84.14 °E longitude (**Fig.1**). The topography of the entire region is flat, especially where the Ganga and Ghaghra rivers converge. Piedmont and flood plains make up the bulk of the central Gangetic plain regions. Dendritic drainage created the basin and recent organic muck deposits filled the channels **(Ravenscroft et al., 2005)**. There is a thin layer of soil in the Gangetic alluvium along with older and younger alluvium. These formations date from the Holocene to the upper Pleistocene **(Chappell et al., 2001)**. The large-scale characteristics of the basin are consistent with the significant climatic transition that took place in the late Quaternary. The district's primary irrigation sources are tube wells (groundwater) and the Dharighat Lift Irrigation Canal, which together supply 72.61% and 27.39% of the district's irrigation requirements, respectively. The average annual temperature in the research region is 27 ^{o}C, with a range of 5.4 ^{o}C to 41.5 ^{o}C, and the average annual rainfall is 983 mm.

2.2.Data Collection

UNDER PEER REVIEW

Daily temperature gridded datasets for 62 years (1951–2012), and daily precipitation gridded datasets for 100 years (from 1917 to 2016) were all provided by the Meteorological Department (IMD). A daily gridded precipitation dataset (0.25°x 0.25°) has been developed by IMD utilising information from 6955 networks of rain gauge stations spread over India. High quality gridded datasets have been examined and made accessible by IMD. Additionally, a number of quality checks, such as those for homogeneity, consistency and missing data, were performed on these datasets. Prior to trend analysis, the daily data were converted into monthly data and four major seasonal series: winter (Dec.–Feb.), post-monsoon (Oct.–Nov.), pre-monsoon (March–May) and monsoon(June–Sept.). The four seasons of pre-monsoon (March to May), monsoon (June to September), post-monsoon (October and November) and winter (December to February) were applied to the monthly temperature data in order to perform a seasonal analysis. Additionally, the Kendal method and Sen's slope are applied. The spatial variability of average yearly rainfall and temperature was plotted on a grid using the IDW technique in ArcGIS software.

2.2.1. Mann-Kendal's Test

Parametric and non-parametric tests were conducted to find the future trends of Precipitation and temperature. For parametric test, the time series data was distributed independently and on the other hand, for non-parametric test data does not require regular distribution to confirm to any certain statistical distribution (**Hamed and Rao, 1998; Kisi and Ay, 2014).**

One popular non-parametric technique for identifying monotonic non-linear trends is the Mann-Kendall (MK) test. Since the MK test only indicates a trend's direction and significance rather than its quantitative measure, it does not require assumptions about the normal distribution **(Helsel& Hirsch, 1992).** The MK approach makes the assumption that the time series is random, stable and independent with an equal probability distribution **(Yue et al., 2002).** In order to prevent an inaccurate rejection of the null hypothesis due to serial correlation, the time series data utilised in the MK test should be uncorrelated **(Yue &Pilon, 2003).** It is frequently applied to the analysis of patterns in time series data related to hydrology and climate. As a result of his proposal, the test has been applied extensively to environmental time series **(Mann, 1945).** In this test, the null hypothesis H_0 postulates that there is no pattern and that the data is ordered randomly and independently. As opposed to the alternative hypothesis H1, which presupposes the existence of a pattern, this has been demonstrated. The following formula were used for MK test.

UNDER PEER REVIEW

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(xj - xk) \qquad \textbf{(1)}$$

The trend test is applied to a time series x k, which is ranked from k = 1,2, 3…, n−1, which is ranked from j= i + 1,i + 2,i + 3…..n. Each of the data pointsxj is taken as a reference point (**Eq 2**).

$$\mathrm{sgn}(xj - xk) = \begin{cases} = 1, & \text{if } xj - xk > 0; \\ = 0, & \text{if } xj - xk = 0 \\ = -1, & \text{if } xj - xk < 0 \end{cases} \qquad \textbf{(2)}$$

2.2.2. Sen’s Slope Estimator Test

Sen's estimate is a nonparametric method for determining the magnitude of a trend in a time series**(Sen, 1968)**. A positive Sen's slope value shows an upward or increasing trend in the time series, whereas a negative value suggests a downward or decreasing trend. **Sen (1968)** developed the non-parametric procedure for estimating the slope of trend in the sample of N pairs of data:

$$Qi = \frac{Xj - Xk}{j - k} \; for\, i = 1, \ldots, N, \qquad \textbf{(3)}$$

Where X_j and X_k are the data values at times j and k (j>k), respectively.

$$\mathbf{Qmed} = \begin{cases} Q\left[\frac{N+1}{2}\right], & if\ N\ is\ odd \\ \frac{Q\left[\frac{N}{2}\right] + Q\left[\frac{N+2}{2}\right]}{2}, & if\ N\ is\ even \end{cases} \qquad \textbf{(4)}$$

$$C\alpha = Z\left(1 - \frac{\alpha}{2}\right)\sqrt{VAR(s)} \qquad \textbf{(5)}$$

Then,

$M1 = \frac{N - C\propto}{2}andM2 = \frac{N + C\propto}{2}$ are computed in **Eq 4.**and**Eq. 5**. The lower and upper limits of the confidence interval, $Q_{min}$and $Q_{max,}$ are the M_1^{th} largest and the $(M_2+1)^{th}$ largest of the N ordered slope estimates. The slope Q_{med} is statistically different than zero if the two limits ($Q_{min}$and Q_{max}) have similar sign.

UNDER PEER REVIEW

2.2.3. Box and Whiskers Plot

A box plot is used to examine the direction and extent of data skewness, as well as to identify and quantify outliers, assess data symmetry, and gauge how closely the data are clustered. Boxplots are also very useful for comparing or using multiple data sets. Stated differently, a box or whiskers plot is a method for visually expressing numerical data sets based on their quartiles. They can also have lines extending from the boxes or whiskers that show the variability outside the lower and higher quartiles; these are referred to as box-and-whisker plots and box-and-whisker diagrams. Outliers can be identified by individual points.

The components of Box-Plots, as indicated in the **Fig.2(a)**., consist of the Minimum, which is the dataset's lowest value; the First Quartile (Q1), which is the dataset's lower half's median; the Median, which is the dataset's middle number and the second quartile when it comes to splitting it into equal sections; the Third Quartile (Q3), which is the dataset's upper half's median; and the Maximum, which is the dataset's highest value.

In addition to these five terms, other terms used in the box plot (**Fig.2(b))** are Outliers, or data points that fall on the extreme left or right of the sorted data and typically deviate from the first and third quartiles by more than a given amount (e.g., outliers are larger than Q3 + 1.5 * IQR or smaller than Q1 - 1.5 * IQR). Interquartile Range (IQR) is the difference between the first and third quartiles (IQR = Q3 - Q1).

UNDER PEER REVIEW

3. Result and Discussion

Globally various decision taking bodies, researcher and policy makers faces difficulty while forming policies due to huge temporal and spatial variability and erratic predictability of climatic characteristics. Since precipitation is the primary climatic factor which not only determine that how much water is available in a particular region but also governs its precise conservation techniques whether it’s on surface or in underground aquifers. Temperature is the other key factor affecting the environment and climate analysis of its behaviour is crucial for prediction of available surface and ground water resource. Therefore, for precise prediction and strategy formulation, future trend of these parameters is needed.

3.1.Trend analysis of Precipitation

Trend and Slope data of precipitation for the five seasons viz. Winter, Monsoon, Pre-Monsoon, Post-Monsoon and average annual monsoon data in four locations of Ballia district (Maniar, Murlichapra, Sear and Pandah blocks) is given in **Table.1**

- **Annual Precipitation**

Trend analysis of annual precipitation data (1917 to 2016) as shown in thematic maps **(Fig. 3)** shows a significantly decreasing trend in Murlichapra and Sear blocksat 95 % significance and 99% significance levels respectively. In these blocks, the slope for the precipitation during annual scale was found 2.1112 mm/season and 3.0428 mm/season for 100 years respectively. Similarly, inManiar and Pandah blocks, a decreasing trend was observed with the slope of 0.0.1042 mm/season and 0.7973mm/season for 100 years respectively however, this decreasing trend is non-significant. The total change for the Maniar, Murlichapra, Sear and Pandahblocks ofBalliadistrictwas found to be 10.42 mm /season ,211.12 mm /season,304.28 mm /season and 79.73 mm /season for 100 years.

- **Winter Precipitation**

Trend analysis of Winter season precipitation data also indicates a significant decreasing trend in Murlichapra, Sear and Pandah blocks at 95% Significance, 99 % Significance and 90% Significance respectively. However, in Maniar block a non-significant decreasing trend was observed. In these blocks, the slope for the Precipitation during Winter season for Maniar, Murlichapra, Sear and Pandahblocks ofBalliadistrictwas found to be 0.1101 mm/season, 0.1483mm/season,0.1893 mm/season and 0.1175 mm/season for 100 years respectively. Also, the total change for Maniar, Murlichapra, Sear and Pandah found to be 11.01 mm/season,14.83 mm/season,18.93 mm/season and 11.75 mm/season for 100 years respectively as depicted in **Fig 4.**

- **Pre-Monsoon Precipitation**

During the Pre-monsoon season, the analysis of trend shows an Increasing trend inManiarblock at 99% level of significance with the slope value as 0.2597mm/season for 100 years. Likewise, there has been found an increasing trend of pre monsoon precipitation in Murlichapra, Sear, Pandahblocks ofBalliadistrictrespectively although these trends were observed non-significant and the slopes for these blocks were observed 0.0844 mm/season,0.1105 mm/season and 0.1835 mm/season for 100 years respectively. Also, the total change found for Maniar, Murlichapra, Sear and Pandahblocks ofBalliadistrictare 25.97mm/season,8.44mm/season,11.05mm/season and 18.35 mm/season for 100 years respectively (**Fig 5**).

- **Monsoon Precipitation**

Results of trend analysis for precipitation during monsoon season shows decreasing trend inMurlichapra block at 95% Significance and in Sear block at 99 % Significance levels

UNDER PEER REVIEW

prospectively. In both the blocks, the slope for the precipitation during Monsoon season for Murlichapra and Sear was found 1.8757mm/season and 3.6048mm/season for 100 years respectively **(Fig 6)**. The slope values inManiar and Pandahwas observed 0.2283mm/season and 0.9715mm/season for 100 years. The total change for Maniar, Murlichapra, Sear and Pandahblocks ofBalliadistrict was found 22.83mm/season,187.57 mm/season,360.48 mm/season and 97.15 mm/seasonfor 100 years respectively.

- **Post-Monsoon Precipitation**

Results of trend analysis for precipitation during post-monsoon season indicated an increasing trend in Maniar and Pandahblocks ofBalliadistrict, however the difference was foundnon-significant. In these blocks the slope was estimated 1.25mm/season and 0.14mm/season for 100 years respectively. In Murlichapra and Sear blocks, non-significant decreasing trendwas observed. The slope values for these blocks was found 2.55mm/season and 4.52mm/season for 100 years. Also, the total change for Maniar, Murlichapra, Sear and Pandahblocks ofBalliadistrict were found 1.255mm/season, 2.55 mm/season,4.52 mm/season and 0.14 mm/season for 100 years respectively. (**Fig 7**).

- **Box-Plot for Average Annual Precipitation**

An outline of the precipitation distribution its central tendency and range for each grid was estimated and represented using Box-plot analysis. The average values provide the centre tendency, while the minimum and maximum represent the smallest and biggest observed values, respectively. The interquartile range, median and any possible outliers would all be displayed visually in the Box plot in **Fig 8**, which would provide this data a visual representation. Whereas, the Average Annual Precipitation determines the minimum precipitation for Maniar (333.67 mm) followed by Murlichapra (117.46 mm), Sear (339.07 mm) and Pandah (341.454 mm)for 100 years. Similarly, for the maximum precipitation for Maniar (1738.3 mm) followed by Murlichapra (1685.38 mm), Sear (1706.7 mm) and Pandah (2006.55 mm)for 100 years. Whereas the average precipitation for respective Maniar (1056.6 mm), Murlichapra (892.176 mm), Sear (965.381 mm) and Pandah (1102.86 mm)for 100 years.

3.2. Trend analysis of Temperature

3.2.1 Analysis of Maximum Temperature

Trend analysis for the maximum temperature was conducted for the time series data of duration 1951-2012 for selected locations of the Balliadistrict whichexhibited a mix trend

UNDER PEER REVIEW

during the study period. A decreasing trend was observed during winter and pre-monsoon periods whereas an increasing trend was observed during monsoon, post-monsoon season and on annual scale. The detailed description of the results is mentioned below in **Table 2**.

- **Annual**

During Annual scale in Maniar, Sear and Pandahblocks ofBalliadistrict, an increasing trend (non-significant) was observed. In these blocks, the slope of the Tmax during annual scale was found to be 0.0013°C/season,0.0014°C/season and 0.0008°C/season was found respectively. Likewise, for Murlichapra, a decreasing trend (non-significant) was observed with the slope of 0.0015°C/season. Also, the total change for Maniar, Murlichapra, Sear andPandahblocks ofBalliadistrictwas found to be 0.0806°C/season, 0.093°C/season, 0.0868°C/season and 0.0496°C/season respectively **(Fig 9).**

- **Winter Season**

During winter season, a significantly decreasing trend (at 90 % significance) was observed in Maniar and Sear blocks ofBalliadistrict. In these blocks, the slope of the Tmax during winter season was found to be 0.0095°C/season and 0.0117°C/season respectively. Likewise, for Murlichapra and Pandah blocks a significantly decreasing trend (at 95 % Significance) was observed with the slope of 0.0107 °C/season and 0.011 °C/season. Also, the total change for the Winter season observed for Maniar, Murlichapra, Sear and Pandahblocks ofBalliadistrict was found to be 0.589°C/season ,0.6634°C/season, 0.7254°C/season and 0.682°C/season respectively **(Fig 10).**

- **Pre-Monsoon Season**

During Pre-monsoon season in Maniar, Murlichapra, Sear and Pandahblocks ofBalliadistrict, a non-significant decreasing trend was observed. In these blocks, the slope of the Tmax during Pre-monsoon season was found to be 0.0027°C/season,0.0062°C/season,0.0033°C/season and 0.0057°C/season respectively. The total change for the Maniar, Murlichapra, Sear and Pandahblocks ofBalliadistrictwas found to be 0.1674°C/season,0.3844°C/season,0.2046°C/season and 0.3534°C/season respectively **(Fig 11)**.

- **Monsoon Season**

During the Monsoon Season, a significantly increasing trend (non-significant) was observed in Maniar, Murlichapra, Sear and Pandahblocks ofBalliadistrict. In these blocks, the slope of the Tmax during Monsoon Season was found to be 0.0053°C/season, 0.0048°C/season, 0.0077°C/season and 0.0069°C/season respectively. Also, the total

UNDER PEER REVIEW

change for the Monsoon season observed for Maniar, Murlichapra, Sear and Pandahblocks ofBalliadistrict are found to be 0.3286°C/season, 0.2976°C/season, 0.4774°C/season and 0.4278°C/season respectively (**Fig 12**).

- **Post-Monsoon Season**

During the Post-monsoon in Sear and Pandah, a significantly increasing trend (at 90 % Significance) was observed. In these blocksofBalliadistrict, the slope of the Tmax during Post-Monsoon was found to be 0.0084°C/season and 0.5146°C/season. Similarly, for the Maniar and Murlichapra an increasing trend (non-significant) was observed with the slope of 0.0083°C/season and 0.0062°C/season was found. Also, the total change for Maniar, Murlichapra, Sear and PandahblocksofBalliadistrict are 0.5146°C/season, 0.3844°C/season, 0.5208°C/season and 0.5146°C/season respectively **(Fig 13).**

- **Box and Whiskers-Plot for Average Annual Temperature (Tmax)**

According to box-whiskers method, the minimum Temperature in **Fig.14** for the Tmax, for Maniar (30.53°C) followed by Murlichapra (30.324°C), Sear(30.454°C) and Pandah (30.157°C)blocks ofBalliadistrictfor 62 years. The maximum Temperature for Maniar (32.913°C) followed by Murlichapra (32.571°C), Sear (32.577°C) and Pandah(32.23°C)for 62 years. Whereas the average Temperature for respective Grids are Maniar (31.85°C), Murlichapra (31.49°C), Sear (31.543°C) and Pandah (31.186°C)blocks ofBalliadistrict for 62 years.

3.2.2.Analysis of Minimum Temperature (T_{min})

The Tmin exhibited a mix trend during the study period (1951-2012) for Balliadistrict. A decreasing trend was observed during Winter season, Monsoon season, Pre-Monsoon season and Annual Scale. An increasing trend was observed during the Post-Monsoon season. The detailed description of the results is mentioned below in **Table 2**.

- **Annual**

During Annual scale for Maniar, Murlichapra, Sear and Pandahblocks ofBalliadistrict, decreasing trend (non-significant) was observed. In these blocks, the slope of the Tmin during Annual scale was found to be 0.0041°C/season,0.0043°C/season,0.0042°C/season and 0.0031°C/season for 62 years. Also, the total change for Maniar, Murlichapra, Sear and Pandahblocks ofBalliadistrictwas found to be 0.2542°C/season, 0.2666°C/season, 0.2604°C/season and 0.2418°C/season for 62 years **(Fig 15).**

- **Winter Season**

UNDER PEER REVIEW

During Winter season for Maniar, Murlichapra, Sear and Pandahblocks ofBalliadistrict, a decreasing trend (non-significant) was observed. In these blocks, the slope of the Tmin during Winter season was found to be 0.0048°C/season,0.0039°C/season, 0.0039°C/season and 0.0037°C/season for 62 years respectively. Also, the total change was observed for Maniar, Murlichapra, Sear and Pandahblocks ofBalliadistrict was found to be 0.2976°C/season,0.2418°C/season,0.2418°C/season and 0.2294°C/season for 62 years respectively (**Fig 16**).

- **Pre-monsoon Season**

During Pre-monsoon season for Maniar and Sear, a decreasing trend (at 90% significance) was observed. In these blocks, the slope of the Tmin during Pre-monsoon season was found to be 0.0101°C/season and 0.0105°C/season for 62 years respectively. Likewise, a decreasing trend (at 95% significance) was observed for theMurlichapra and Pandah. The slope for Murlichapra and Pandahare observed as 0.0105°C/season and 0.0106°C/season for 62 years respectively. Also the total change for the Pre-monsoon season for Maniar, Murlichapra, Sear and Pandah was found to be 0.6262°C/season, 0.651°C/season, 0.651°C/season and 0.6572°C/season for 62 years (**Fig 17**).

UNDER PEER REVIEW

- **Monsoon Season**

During Monsoon season for Maniar, Murlichapra, Sear and Pandahblocks ofBalliadistrict, a decreasing trend (at 90% significance) was observed. In these blocks, the slope of the Tmin during Monsoon season was found to be 0.0065°C/season,0.0074°C/season,0.0062°C/season and 0.0069°C/season for 62 years respectively. Also, the total change for the Monsoon season was observed for Maniar, Murlichapra, Sear and Pandah was found to be 0.403°C/season, 0.4588°C/season, 0.3844°C/season and 0.4278°C/seasonfor 62 years **(Fig 18).**

- **Post-monsoon Season**

During Post-monsoon season for Maniar, Murlichapra, Sear and Pandahblocks ofBalliadistrict, an increasing trend (non-significant) was observed. In these blocks, the slope of the Tmin during Post-monsoon season was found to be 0.0034°C/season,0.001°C/season,0.0022°C/season and 0.0.0031°C/season for 62 years respectively. Also the total change for Maniar, Murlichapra, Sear and Pandah was found to be 0.2108°C/season, 0.062°C/season, 0.1364°C/season and 0.1922°C/season for 62 years (**Fig 19**).

- **Box-Plot for Average Annual Temperature (Tmin)**

According to box-whiskers method, the minimum Temperature in **Fig 20** during Monsoon for Maniar (17.894°C) followed by Murlichapra (17.71°C), Sear (17.984°C) and Pandah (17.87°C)blocks ofBalliadistrict for 62 years. The maximum Temperature for Maniar (20.1946°C) followed by Murlichapra (20.24°C), Sear (20.24°C) and Pandah (20.33°C) for 62 years. Whereas the average Temperature for respective Grids are Maniar (19.113°C), Murlichapra (19.1186°C), Sear (19.187°C) and Pandah (19.215°C)blocks ofBalliadistrictfor 62 years.

Conclusions

Analysing temperature and precipitation trends over long time periods indicates notable changes in the climate of the study area. Maniar and Pandah blocks shows non-significant decreasing trend in precipitation during last century i.e. 1917 to 2016, whereas Murlichapra and Sear blocks shows substantial decreasing tendency in both annualand monsoon precipitation. In particular, the rates at which the yearly precipitation decreases during the monsoon season are 1.87 mm/season and 3.60 mm/seasonin Murlichapra and Sear, blocks respectively, are 2.11 mm/season/100years and 3.04 mm/season/100years.Maximum

UNDER PEER REVIEW

temperature rise was seenduring the monsoon, post-monsoon and annualseasons while decreasing trend during the winter and pre-monsoon seasons during 1951 to 2012. In winter, monsoon, pre-monsoon and annual season falling tendency of minimum temperature was recorded but during post-monsoon season, it exhibits an increasing trend. If the similar trend will continue in future.The increasing trend will denote the increasing of temperature which will result into warming of the atmosphere during the Pre-monsoon (March, April and May), Monsoon (June, July, August and September) and Post-monsoon (October and November) months.

Maximum summer temperatures significantly impact soil and water conservation. High heat exacerbates soil erosion, dries soil and reduces fertility, leading to lower agricultural productivity and increased irrigation needs. Elevated temperatures increase evaporation rates, deplete water resources and degrade water quality, harming aquatic life. Prolonged heat causes droughts, wildfires and water shortages, harming agriculture, ecosystems and wildlife. Human health suffers from heat-related illnesses and worsened air pollution, increasing mortality, especially in urban areas. Infrastructure faces higher maintenance costs due to road, rail and building damage and power grids are strained by increased cooling demands. Economically, agriculture and livestock productivity decline, outdoor work becomes hazardous and tourism drops in hot regions. Socially, communities may be displaced, mental health issues rise and daily life is disrupted.

Due to decreasing trend of precipitation and rising trend of minimum and maximum temperature in future shall increase the evaporation and less runoff water will be available for recharge through surface spread and shall ultimately affect the ground water recharge adversely. Mitigation and adaptation strategies are essential to address these impacts. Effective strategies include soil conservation practices like cover cropping, mulching, no-till farming and efficient irrigation methods such as drip irrigation. Integrated water resource management and climate-resilient infrastructure are essential to mitigate the impacts of high temperatures and ensure sustainable soil and water resource management.

UNDER PEER REVIEW

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

Option 2:

Author(s) hereby declare that generative AI technologies such as Large Language Models, etchave been used during writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1.

2.

3.

References

- Chappell, W. R., Abernathy, C. O., Eds, R. C., & Science, E. (2001). *In: Arsenic Exposure and Health Effects IV*. *. *5*, 1–20.
- Hamed, K. H., & Rao, A. R. (1998). A modified Mann-Kendall trend test for auto correlated data. *Journal of hydrology*, *204*(1-4), 182-196.
- Helsel, D. R., & Hirsch, R. M. (1993). *Statistical methods in water resources*. Elsevier.
- Kisi, O., & Ay, M. (2014). Comparison of Mann–Kendall and innovative trend method for water quality parameters of the Kizilirmak River, Turkey. *Journal of Hydrology*, *513*, 362-375.
- Mann, H.B. (1945) Non-parametric tests against trend. Econometrica, 13, 163–171.
- Panda, A., &Sahu, N. (2019). Trend analysis of seasonal rainfall and temperature pattern in Kalahandi, Bolangir and Koraput districts of Odisha, India. *Atmospheric Science Letters*, *20*(10), e932.
- Ravenscroft, P., Burgess, W. G., Ahmed, K. M., Burren, M., & Perrin, J. (2005). Arsenic in groundwater of the Bengal Basin, Bangladesh: Distribution, field relations, and hydrogeological setting. *Hydrogeology Journal*, *13*, 727-751..

UNDER PEER REVIEW

- Sen.K. (1968) Estimates of the regression coefficient based on Kendall's tau. Journal of the American Statistical Association, 63, 1379–1389.
- Yue, S. and -kendall test. Water Resources and Research, 38(6), doi:10.1029/ Wang, C.Y. (2002) Applicability of pre-whitening to eliminate the influence of serial correlation on the mann 2001WR000861.
- Yue S, Pilon P (2003) Interaction between deterministic trend and autoregressive process. Water Resources and Research. 39(4), doi:10.1029/ 2001WR001210.
- Akhtar ,Seemab. 2023. “Spatial-Temporal Trends Mapping and Geostatistical Modelling of Groundwater Level Depth Over Northern Parts of Indo-Gangetic Basin, India”. Journal of Geography, Environment and Earth Science International 27 (10):96-112. https://doi.org/10.9734/jgeesi/2023/v27i10719.
- Odwori, Ernest Othieno. 2022. “Impact of Temperature Changes on Groundwater Levels in Nzoia River Basin, Kenya”. Asian Journal of Geographical Research 5 (1):10-36. https://doi.org/10.9734/ajgr/2022/v5i1119
- Patle GT, Singh DK, Sarangi A, Rai A, Khanna M, Sahoo RN. Time series analysis of groundwater levels and projection of future trend. Journal of the Geological Society of India. 2015 Feb;85:232-42.
- Panda DK, Mishra A, Jena SK, James BK, Kumar A. The influence of drought and anthropogenic effects on groundwater levels in Orissa, India. Journal of hydrology. 2007 Sep 20;343(3-4):140-53.

- Akhtar ,Seemab. 2023. “Spatial-Temporal Trends Mapping and Geostatistical Modelling of Groundwater Level Depth Over Northern Parts of Indo-Gangetic Basin, India”. Journal of Geography, Environment and Earth Science International 27 (10):96-112. https://doi.org/10.9734/jgeesi/2023/v27i10719.
- Odwori, Ernest Othieno. 2022. “Impact of Temperature Changes on Groundwater Levels in Nzoia River Basin, Kenya”. Asian Journal of Geographical Research 5 (1):10-36. https://doi.org/10.9734/ajgr/2022/v5i1119.
- Patle GT, Singh DK, Sarangi A, Rai A, Khanna M, Sahoo RN. Time series analysis of groundwater levels and projection of future trend. Journal of the Geological Society of India. 2015 Feb;85:232-42.
- Panda DK, Mishra A, Jena SK, James BK, Kumar A. The influence of drought and anthropogenic effects on groundwater levels in Orissa, India. Journal of hydrology. 2007 Sep 20;343(3-4):140-53.

UNDER PEER REVIEW

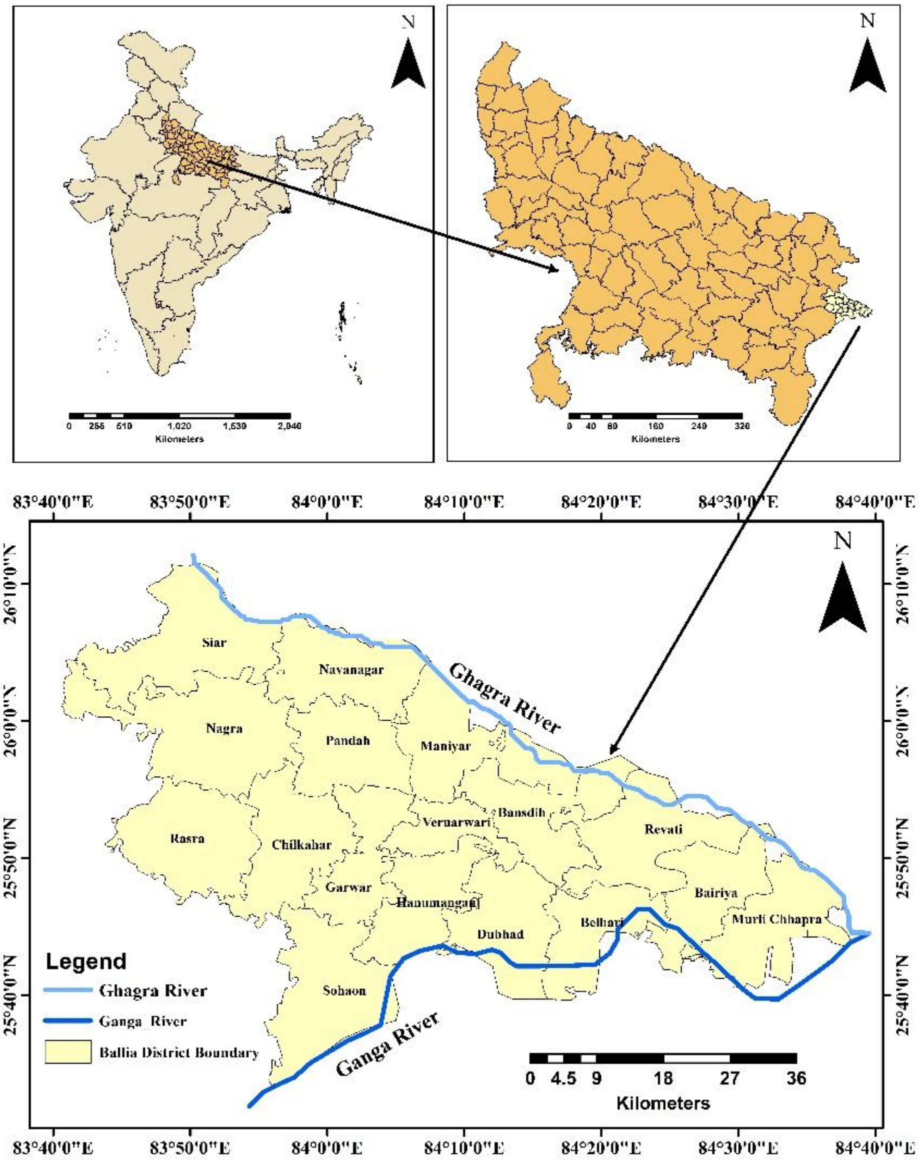
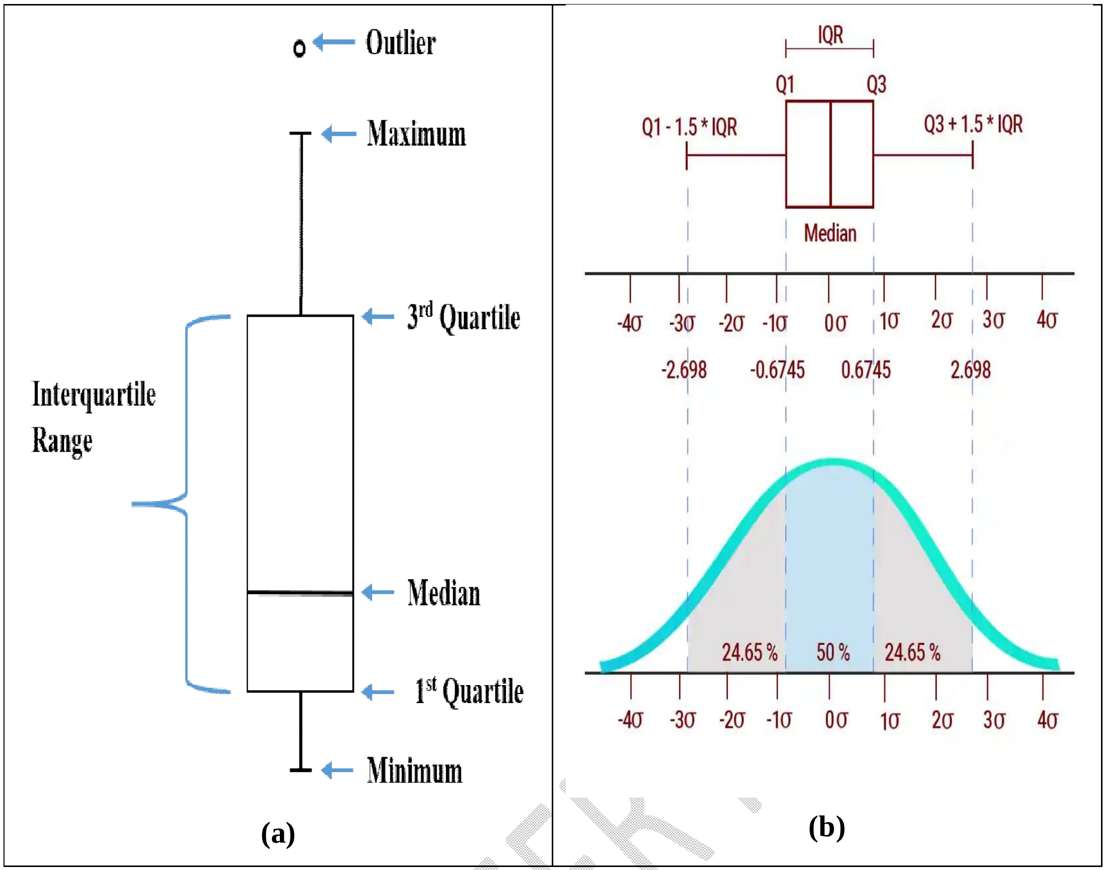


Fig 1. Location Map of the study area (Ballia District, Uttar Pradesh)

UN



(a)

(b)

Fig. 1.(a) Five components of Box-whiskers plot **(b)** outliers and interquartile range

UNDER PEER REVIEW

Table 1.Values of various parameters of precipitation trend analysis and Sen's-Slopeat various grids during the five precipitation durations (Seasons)

Grid	Season	Parametric values of Precipitation trend analysis			
		Zmk	**Trend**	**Sen's-Slope**	**Change**
Maniar	**Winter**	-1.5576	0	-0.1101	-11.01
Murlichapra		-2.171	-5	-0.1483	-14.83
Sear		-2.9845	-1	-0.1893	-18.93
Pandah		-1.6899	-10	-0.1175	-11.75
Maniar	**Monsoon**	-0.2293	0	-0.2283	-22.83
Murlichapra		-2.1532	-5	-1.8757	-187.57
Sear		-4.3034	-1	-3.6048	-360.48
Pandah		-1.0334	0	-0.9715	-97.15
Maniar	**Pre-Monsoon**	2.3706	1	0.2597	25.97
Murlichapra		1.2121	0	0.0844	8.44
Sear		1.1823	0	0.1105	11.05
Pandah		1.5188	0	0.1835	18.35
Maniar	**Post-Monsoon**	0.0685	0	0.0125	1.25
Murlichapra		-0.3995	0	-0.0255	-2.55
Sear		-0.4735	0	-0.0452	-4.52
Pandah		0.0655	0	0.0014	0.14
Maniar	**Annual**	-0.134	0	-0.1042	-10.42
Murlichapra		-2.2127	-5	-2.1112	-211.12
Sear		-3.404	-1	-3.0428	-304.28
Pandah		-0.7535	0	-0.7973	-79.73

UNDER PEER REVIEW

Table 2.**Values of various parameters of temperature trend analysis and Sen's-Slopeat various grids during the five durations (Seasons)**

Temperature		**Parametric values of Temperature(T_{max}) trend analysis**				**Parametric values of Temperature(T_{min}) trend analysis**			
Grid	**Season**	**Zmk**	**Trend**	**Sen's-Slope**	**Change**	**Zmk**	**Trend**	**Sen's-Slope**	**Change**
Maniar	**Winter**	-1.6764	-10	-0.0095	-0.589	-1.0326	0	-0.0048	-0.2976
Murlichapra		-2.0409	-5	-0.0107	-0.6634	-1.069	0	-0.0039	-0.2418
Sear		-1.9194	-10	-0.0117	-0.7254	-0.8504	0	-0.0039	-0.2418
Pandah		-2.1988	-5	-0.011	-0.682	-0.899	0	-0.0037	-0.2294
Maniar	**Monsoon**	0.8868	0	0.0053	0.3286	-1.6886	-10	-0.0065	-0.403
Murlichapra		0.9233	0	0.0048	0.2976	-1.7736	-10	-0.0074	-0.4588
Sear		1.4578	0	0.0077	0.4774	-1.7615	-10	-0.0062	-0.3844
Pandah		1.555	0	0.0069	0.4278	-1.7493	-10	-0.0069	-0.4278
Maniar	**Pre-Monsoon**	-0.4495	0	-0.0027	-0.1674	-1.8344	-10	-0.0101	-0.6262
Murlichapra		-0.9111	0	-0.0062	-0.3844	-2.1381	-5	-0.0105	-0.651
Sear		-0.6196	0	-0.0033	-0.2046	-1.9437	-10	-0.0105	-0.651
Pandah		-0.8747	0	-0.0057	-0.3534	-1.9802	-5	-0.0106	-0.6572
Maniar	**Post-Monsoon**	1.6279	0	0.0083	0.5146	0.5224	0	0.0034	0.2108
Murlichapra		1.3363	0	0.0062	0.3844	0.1336	0	0.001	0.062
Sear		1.7979	10	0.0084	0.5208	0.2551	0	0.0022	0.1364
Pandah		1.7858	10	0.0083	0.5146	0.4616	0	0.0031	0.1922
Maniar	**Annual**	0.3401	0	0.0013	0.0806	-1.2999	0	-0.0041	-0.2542
Murlichapra		-0.243	0	-0.0015	-0.093	-1.3363	0	-0.0043	-0.2666
Sear		0.3401	0	0.0014	0.0868	-1.3484	0	-0.0042	-0.2604
Pandah		0.1944	0	0.0008	0.0496	-0.9233	0	-0.0039	-0.2418

UNDER PREVIEW

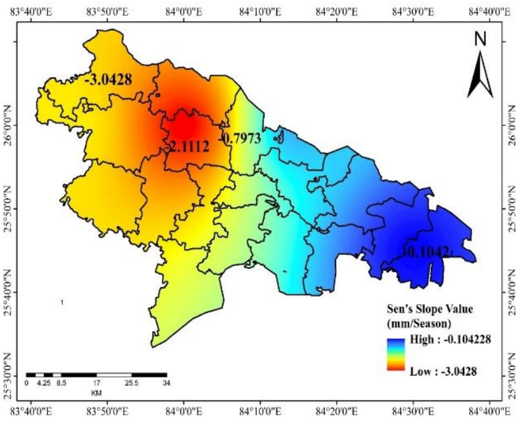


Fig.3 Sen'sSlope Map for the AnnualPrecipitation of Ballia

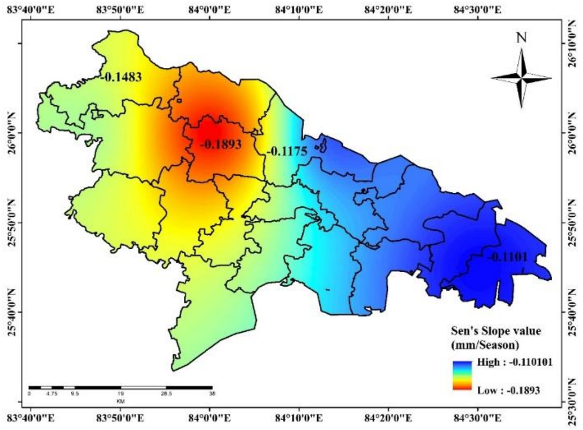


Fig.4. Sen'sSlope Map for the winterPrecipitation of Ballia

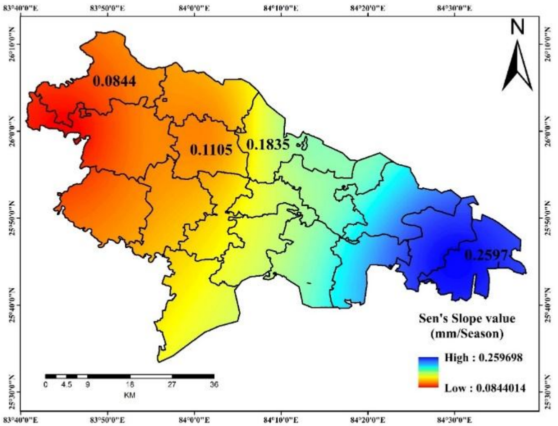


Fig.5. Sen's Slope Map for the Pre-Monsoon Precipitation of Ballia District

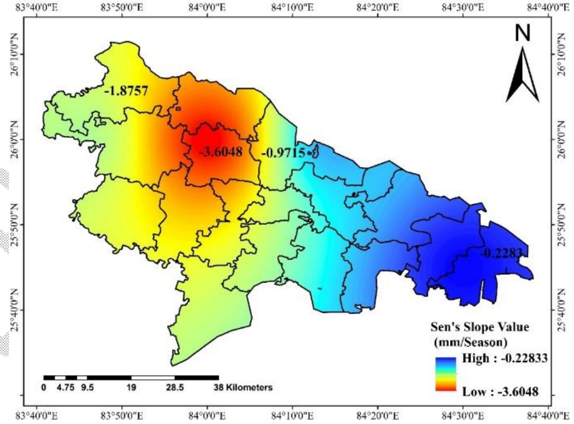


Fig.6. Sen's Slope Map for the Monsoon Precipitation of Ballia District

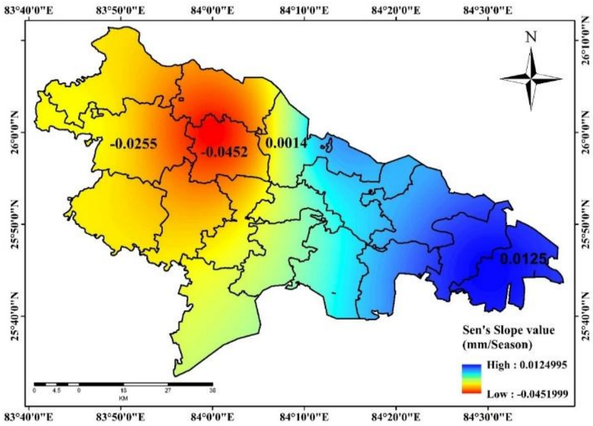


Fig.7. Sen's Slope Map for the Post-Monsoon Precipitation of Ballia District

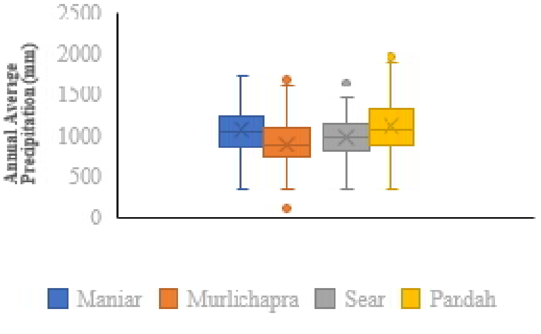
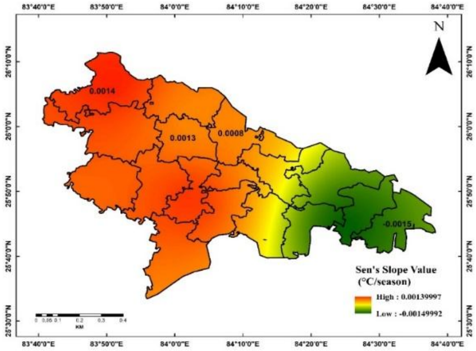


Fig.8 Box- Plot for the Precipitation (1917-2016) for all the 4-grid locations

Fig.9. Sen’s Slope Map of Annual maximum temperature of Ballia District



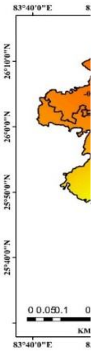


Fig.10 Sen’s Slope Map of maximum temperature during winter season in Ballia District

UNDER PEER REVIEW

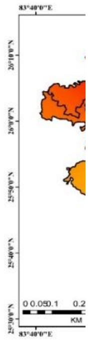
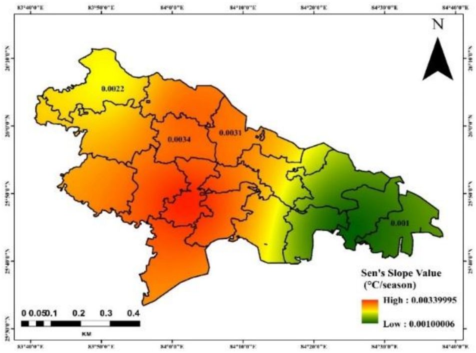


Fig.11. Sen'sSlope Map of maximum temperature during pre-monsoon period in Ballia District

Fig.12. Sen's Slope Map of maximum temperature during monsoon period in Ballia District



UNDER PEER REVIEW

Fig.13. Sen's Slope Map of maximum temperature during post-monsoon period in Ballia District

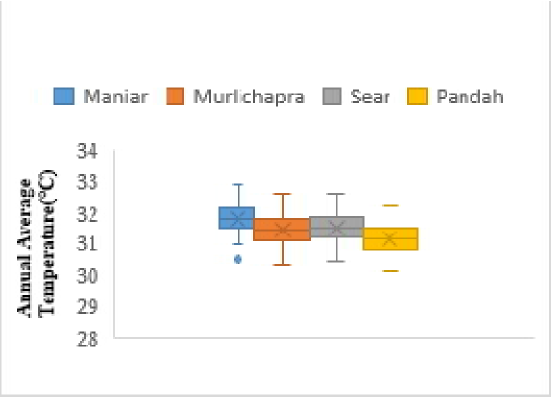
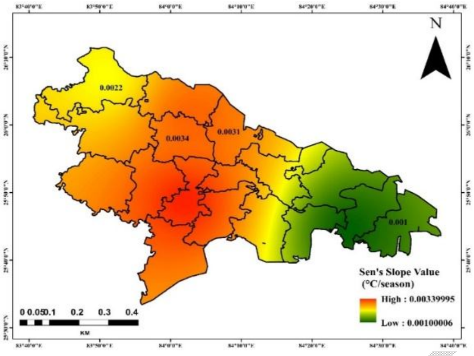


Fig.14. Box- Plot for the maximum temperature (1951-2012)) for all the 4-grid locations



PEER REVIEW

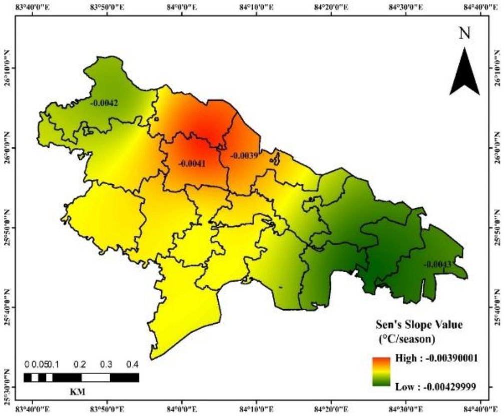


Fig.15. Sen's Slope Map of Annual minimum temperature of BalliaDistrict

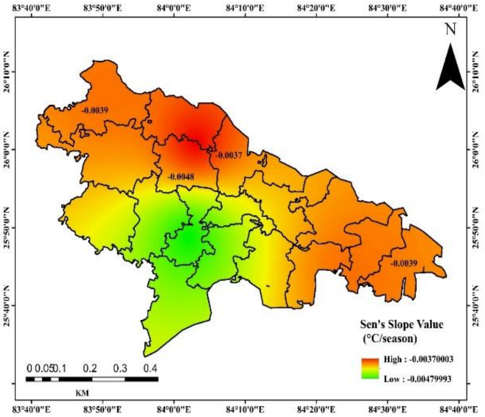


Fig.16 Sen's Slope Map of minimum temperature during winter season in Ballia District

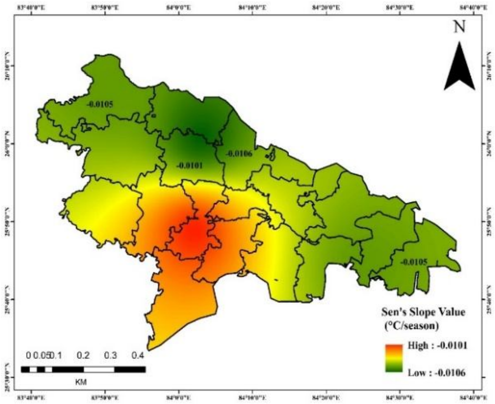


Fig.17. Sen’s Slope Map of minimum temperature during pre-monsoon

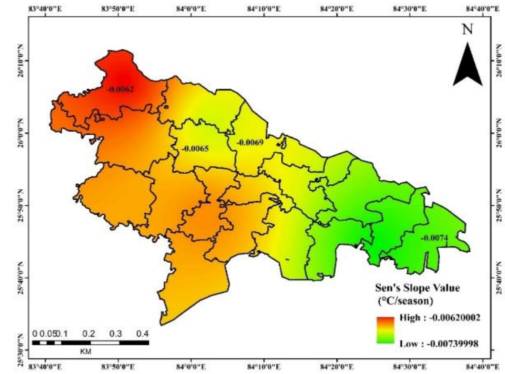


Fig.18. Sen’s Slope Map of minimum temperature during monsoon period

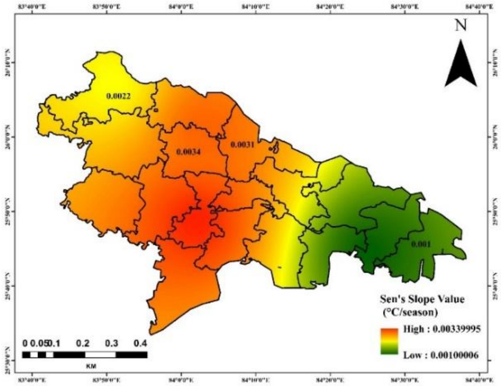


Fig.19. Sen’s Slope Map of minimum temperature during post-monsoon period in Ballia District

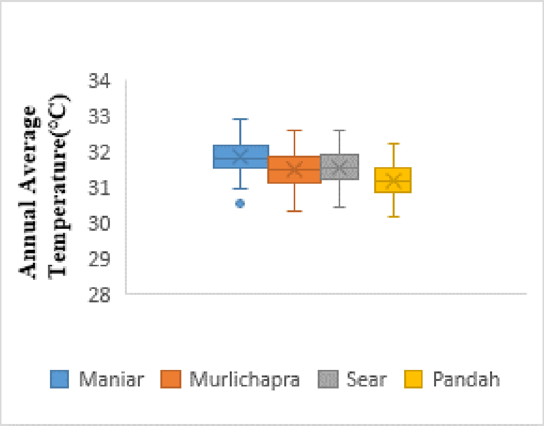


Fig.20. Box- Plot for the minimum temperature (1951-2012)) for all the 4-grid locations

UNDER