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Assessment of Temperature of Ramgarh District, Jharkhand, India: A Case Study of Coalfield's Temperature

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Authors' contributions

This work was carried out in collaboration among all authors. Authors Vibhanshu Kumar, RA and ART conceptualized the study. Authors Vibhanshu Kumar, RA and KA did the formal analysis. Authors Vibhanshu Kumar, Vivek Kumar and RA investigated the study. Authors Vibhanshu Kumar, RA and KA did literature searches. Authors Vibhanshu Kumar and RA performed software related work. Authors Vibhanshu Kumar and ART supervised the study. Authors Vibhanshu Kumar, RA and Vivek Kumar did validation/visualization of the work. Authors Vibhanshu Kumar, RA and ART wrote the original draft of the manuscript. Authors Vibhanshu Kumar, RA, ART and Vivek Kumar reviewed and edited the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Global interest in climate variability, especially annual temperature changes, necessitates an analysis of spatiotemporal meteorological dynamics, particularly in regions relying on rain-fed coal field agriculture areas. This study examines the impacts of temperature trends and climate change in Jharkhand's Ramgarh district, India. Six sub-divisions, such as Ramgarh, Gola, Chitarpur,

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Mandu, Patratu, and Dulmi, are under-examined, exploring long-term temperature changes from 1981 to 2022. Leveraging the Mann–Kendall test and Sen's slope Test, a 42-year data set analysis uncovers a decrease in average and maximum temperatures, contrasting an increasing minimum temperature trend. Applying Sen's slope for each temperature category Maximum, Minimum, and Average at Six sub-divisions of the Ramgarh district where Mandu has the highest increasing slope of 0.01 was observed in minimum temperature. However, Gola’s maximum and average temperature observed the highest decreasing slope among all stations. Similar patterns were found at other stations. Hence, our study suggests that additional attention should be given to the variability of temperature, and it is imperative to consider the increasing temperature trend to mitigate its effects on human well-being.

Keywords: Mann–Kendall; Sen's slope; spatiotemporal; temperature; trend.

1. INTRODUCTION

Climate change, one of the most pressing concerns of our era, has starkly manifested through escalating ocean levels, melting polar ice caps, rampant wildfires, and extreme dry seasons observable globally [1]. Indeed, rising temperatures, particularly in urban regions, predominantly affect residents' health, economy, recreational activities, and overall well-being [2]. For an agricultural nation like India, the ramifications of climate change, including altering the intensity and frequency of climate extremes, are deeply felt [3]. These climatic variations and their effects on physical and biological systems have been thoroughly examined by the Intergovernmental Panel on Climate Change [4].

Understanding regional temperature variations is crucial as the global community grapples with climate change, particularly in economically significant regions [5, 6, 7]. Within this global context, the Ramgarh district in Jharkhand, India, a significant coal-producing area with an influential role in the India's economy, comes into sharp focus [8, 9, 6]. Urbanization dynamics, such as population in-migration from rural to urban areas and significant industrial activity like coal production, might be contributing to local climate change effects, necessitating a thorough investigation of temperature trends in this district [6, 10]. The juxtaposition of industrial activity and its potential climatic implications warrants a comprehensive study of temperature trends in this region. Coal mining activities release greenhouse gases, such as carbon dioxide and methane, into the atmosphere [11]. These gases trap heat, which contributes to climate change and global warming [12]. Coal mining often involves removing trees and other vegetation from the land. This vegetation helps to regulate the local temperature by absorbing carbon dioxide and releasing water vapor into the atmosphere [13, 14]. Coal mining can also lead to changes in land use and landscape, such as the development of mines, new roads and infrastructure. These changes can alter the way that the land absorbs and reflects sunlight, which can also affect local temperatures [15,16].

While previous studies have illuminated aspects of regional and global climate change, there's a distinct lack of research conducted at a district level, especially in regions comparable to Ramgarh. Previous research on climate change and its influence on temperature variability has primarily focused on global or larger regional scales [17]. For instance, Kumar et al. (2023) Tirkey et al. (2018) conducted a broader analysis of climate change impacts in Jharkhand and India, but a detailed study focusing on the effects in coal-producing districts like Ramgarh is yet to be done [18, 19, 20]. Likewise, studies like Pandey et al. (2015) and Pandey et al. (2016), which analyzed temperature trends in the agrarian and habitat context, provide a relevant foundation but leave a gap for district-specific investigations of the Ramgarh district of Jharkhand [21, 6, 22]. Few have investigated the intricate climate dynamics at the district level, especially in areas like Ramgarh, where significant industrial activity, such as coal production, might be affecting local temperature patterns.

This study, therefore, bridges this gap in the existing literature, providing a granular view of temperature trends in the Ramgarh district, employing sophisticated statistical methods, including the Mann-Kendall test and Sen's slope test. The study focuses on three key temperature measures: average, minimum, and maximum temperatures, thus providing a holistic understanding of the temperature dynamics in the region. The study aims to accomplish two primary objectives. First, it seeks to identify and analyze the trend in temperature variation in the Ramgarh district over a defined study period. Second, the study will explore the potential correlation between these temperature trends and broader climate change patterns.

The outcomes of this study bear substantial significance. This study will contribute to the growing body of knowledge on the localized impacts of climate change and provide policymakers with evidence-based insights for crafting climate-sensitive policies in the coal-producing regions of India. As such, this research serves as a vital step towards understanding and addressing the intricate tapestry of climate change impacts on a regional scale.

2. MATERIALS AND METHODS

2.1 Description of Study Area

Ramgarh is the solitary regulatory district of Jharkhand, India, having longitude 23^{o}63’ and Latitude 85^{o}52’ [9]. Ramgarh area comprises of six squares specifically – Ramgarh, Gola, Chitarpur, Mandu, Patratu, and Dulmi. It stands firm on the main Foothold in the mining area of Jharkhand [8,9]. It is restricted in the N-W through the Hazaribagh region, in the N-E through the Bokaro, in the E through the Purulia space of WB state and in the S through the Ranchi regions. The region is part of the Chotanagpur Plateau with a Huge topographic feature of space. The study area falls in the Damodar Basin.

2.2 Methods

2.2.1 Mann–Kendall Test (MK)

The Mann-Kendall (MK) test, crafted by statisticians Henry B. Mann and Donald R. Kendall, is a widely recognized non-parametric technique for spotting trends in time series datasets [23, 24]. Its non-parametric nature means it doesn't assume any specific data distribution, making it versatile for various applications. The MK test primarily identifies consistent upward or downward trends over time, especially those that don't change steadily.

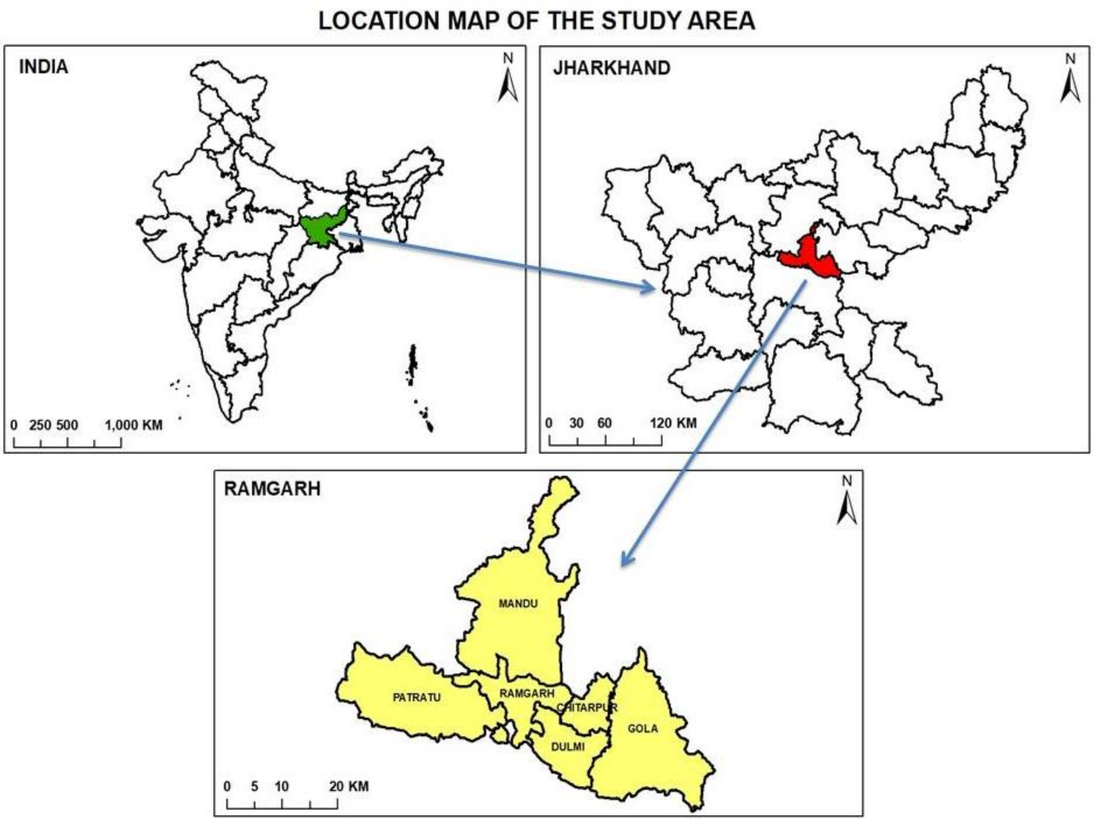

Fig. 1. Location map of Study Area

Every pair of data points in the time series is analyzed to conduct the MK test. The later data point's value is compared to the earlier one. These pairwise comparisons lead to the S-statistic, which nears zero if there's no discernible trend. A positive S-statistic indicates a rising trend, while a negative one points to a declining trend.

In the MK test, the null hypothesis (H0) suggests no trend exists, while the alternative hypothesis (Ha) suggests a trend, be it upward or downward. The test yields a Z-score, measured against a critical value from a standard normal distribution to decide on the validity of the null hypothesis. Key benefits of the MK test include its resilience to anomalies, not needing normally distributed data, ability to work with gaps in data, and managing tied data points. Yet, a limitation is its assumption that data points are independent. This may not hold true for time series data with autocorrelation.

The Mann-Kendall statistics (S) is given in equation (i).

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} sgn\left(x_j - x_i\right) \quad \text{(i)}$$

Where,

x_j and x_i are the annual values at different time j and i, respectively and 'N' is the dataset length.

$$sgn(x_j - x_i) = \begin{cases} 1 & ;\ if\ x_j - x_i > 0 \\ 0 & ;\ if\ x_j - x_i = 0 \\ -1 & ;\ if\ x_j - x_i < 0 \end{cases} \quad (ii)$$

If the datasets show a positive value of S, the trend will increase, whereas the negative values show a decreasing trend. The more significant value indicates the Trend is more reliable in its direction, and the smaller values indicate that the Trend is less reliable.Under the assumptions that data are dependent or independent, the variance of the S statistics is provided in equation (iii)

$$var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{n} t_i(t_i-1)(2t_i+5)}{18} \quad \text{(iii)}$$

Where n represents the total number of tied rank groups and t_i is the number of data points in the i^th tied group, and Σ shows the summation over all tied groups.

After obtaining the data variance, the standard normal distribution Z-Statistics is calculated using equation (iv)

$$Z = \begin{cases} \frac{S-1}{\sqrt{var(s)}} & ;\ if\ S > 0 \\ 0 & ;\ if\ S = 0 \\ \frac{S+1}{\sqrt{var(S)}} & ;\ if\ S = 0 \end{cases} \quad \text{(iv)}$$

Further, with a two-tailed significance level at α= 0.05, the calculated standard Z value is compared to the standard normal distribution table. If the calculated Z is greater than z α/2, the null hypothesis (H_o) of no trend is rejected, and the trend is statistically significant; otherwise, the H_o hypothesis is accepted, which indicates that the trend is not statistically significant.

2.2.2 Sen's Slope Test

Sen, (1968) provided a method to calculate the magnitude of the slope of the trend in hydro meteorological data series [21, 19]. The non-parametric, linear slope method performs effectively on monotonic data. Despite linear regression, it is unaffected by missing data, outliers, or large data errors. So, the linear slopes T_i and all data sets are determined by using equation (v).

$$T_i = \frac{x_j - x_k}{j-k} \quad for\ i = 1,2,3 \ldots .n, j > k \quad \text{(v)}$$

Where x_j and x_k are data values at time j and k ($j > k$). On the other hand, the median of these N values of T_i is implies to the slope of trend, which is calculated using equation (vi)

$$Q_i = \begin{cases} T_{\frac{N+1}{2}} & if\ N\ is\ odd \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right) & if\ N\ is\ even \end{cases} \quad (vi)$$

An increase in trend is depicted if Q_i show positive value; conversely, a negative value shows that the trend in the time series is declining. Sen's slope is estimated in the RStudio.

3. RESULTS AND DISCUSSION

The Mann-Kendall (MK) Trend Test and Sen's Slope estimator were employed in tandem with descriptive statistics to determine the temperature trend. The MK trend test parameters such as the MK statistic (s), Kendall's tau, test statistic (Z), and P-value were calculated using R Studio. Sen's slope (Q) also facilitated the graph representation of the Sen's slope test. Descriptive statistics encompassed parameters like minimum, maximum and average temperature, facilitating trend detection in climate change.

Ramgarh station has a decreasing trend for the maximum temperature, supported by a Z Value of -1.572, which is statistically significant with a p-value of 0.08, falling below the 0.05 significance threshold (Table 1). This led to rejecting the null hypothesis in favors of the alternative for this station. The minimum temperature trend, characterized by a Z Value of 1.739, is statistically significant (p=0.043). A similar significance is observed in the average temperature trend, as depicted by a Z Value of -0.227 and a p-value of 0.039.

For Patratu station, also presented in Table 1, results revealed a mildly significant decreasing trend for the maximum temperature, indicated by a Z Value of -1.697 and a p-value of 0.09. Although the p-value exceeds the 0.05 threshold, it resulted in the null hypothesis rejection for the Mandu station. Chitarpur station station has the highest decreasing trend for the maximum temperature, supported by a Z Value of -2.161, which is statistically significant with a p-value of 0.032, falling below the 0.05 significance threshold. This led to rejecting the null hypothesis in favor of the alternative for this station. Furthermore, Table 1 encompass Sen's slope tests for all the six station between 1981 and 2022.

Table 1. Encompass Sen's slope tests for all the six station between 1981 and 2022

Station (↓)	**Parameters (↓)**	**Minimum Temperature**	**Maximum Temperature**	**Average Temperature**
Patratu	Z	1.811	-1.697	-0.427
	P Value	0.07	0.09	0.669
	Mann-Kendall Stat(S)	145	-136	-35
	Kendall's Tau	0.207	-0.194	-0.05
	Alpha	0.05	0.05	0.05
	Sen's Slope (Q)	0.008	-0.015	-0.004
	Var (s)	6322.333	6324	6325
	Trend	Increasing	Decreasing	Decreasing
Dulmi	Z	1.661	-2.257	-1.051
	P Value	0.048	0.036	0.062
	Mann-Kendall Stat(S)	112	-153	-76
	Kendall's Tau	0.146	-0.253	-0.217
	Alpha	0.05	0.05	0.05
	Sen's Slope (Q)	0.007	-0.015	-0.005
	Var (s)	6332.34	6225.6	6313.58
	Trend	Increasing	Decreasing	Decreasing
Mandu	Z	1.679	-1.873	-0.197
	P Value	0.048	0.057	0.039
	Mann-Kendall Stat(S)	147	-134	-48
	Kendall's Tau	0.314	-0.168	-0.32
	Alpha	0.05	0.05	0.05
	Sen's Slope (Q)	0.01	-0.012	-0.003
	Var (s)	6372.333	6334	6327
	Trend	Increasing	Decreasing	Decreasing
Gola	Z	1.345	-2.1127	-1.031
	P Value	0.178	0.035	0.302
	Mann-Kendall Stat(S)	108	-169	-83
	Kendall's Tau	0.154	-0.241	-0.118
	Alpha	0.05	0.05	0.05
	Sen's Slope (Q)	0.006	-0.018	-0.008
	Var (s)	6322	6323	6323
	Trend	Increasing	Decreasing	Decreasing

Station (↓)	Parameters (↓)	Minimum Temperature	Maximum Temperature	Average Temperature
Ramgarh	Z	1.739	-1.572	-0.227
	P Value	0.043	0.08	0.039
	Mann-Kendall Stat(S)	142	-129	-43
	Kendall's Tau	0.238	-0.176	-0.25
	Alpha	0.05	0.05	0.05
	Sen's Slope (Q)	0.008	-0.015	-0.004
	Var (s)	6372.333	6334	6327
	Trend	Increasing	Decreasing	Decreasing
Chitarpur	Z	1.32	-2.161	-0.982
	P Value	0.037	0.032	0.053
	Mann-Kendall Stat(S)	119	-147	-79
	Kendall's Tau	0.168	-0.201	-0.086
	Alpha	0.05	0.05	0.05
	Sen's Slope (Q)	0.009	-0.016	-0.006
	Var (s)	6349.42	6251.67	6326.81
	Trend	Increasing	Decreasing	Decreasing

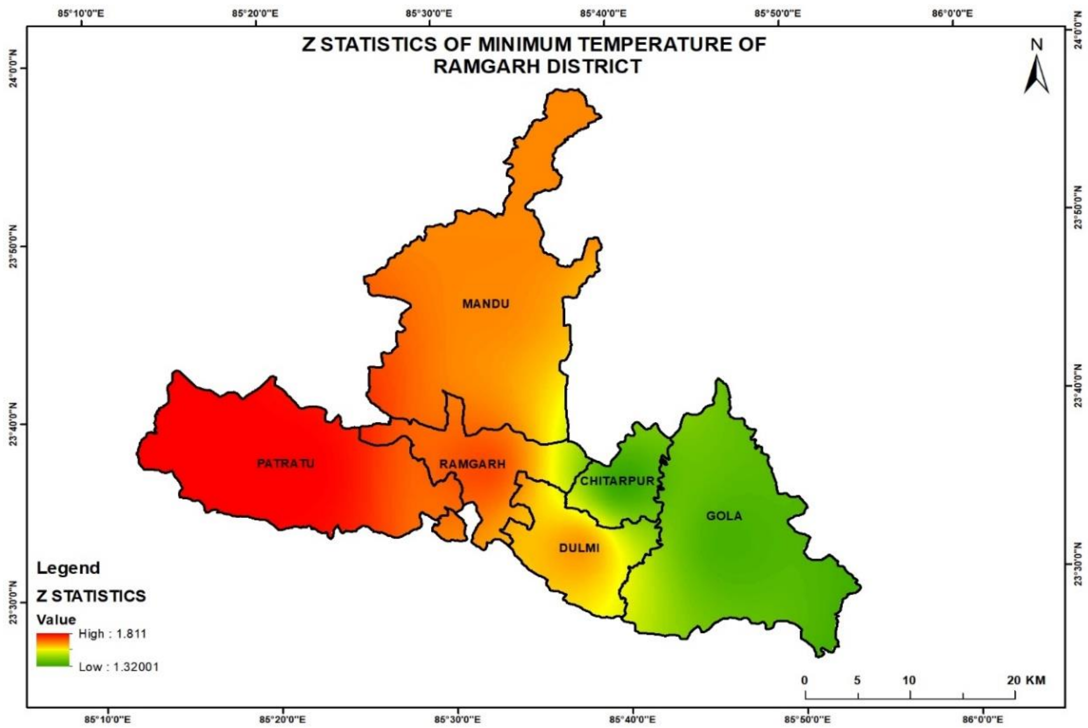

Fig. 2. Z Statistics of minimum temperature of Ramgarh district

Positive and negative signs corresponded with ascending and descending trends, respectively, while a null slope underscored a static dataset throughout the assessment duration. When the derived p-value remained under the 0.05 significance level, this signified robust statistical significance. The interplay between the Sen's slope estimate and the MK statistic (Z) was evident in Fig. 2, 4 and 6, revealing an augmenting trend from 1981 to 2022 for the Ramgarh sub-divisional block station. Such trends were consistent for the Dulmi station as per Table 1.

The spatial representation of Kendall's tau and test statistic (Z) for minimum, maximum, and average temperature, using inverse distance weighted interpolation, is illustrated in Fig. 2 to 7, offering a visual representation of the inter-station variabilities.

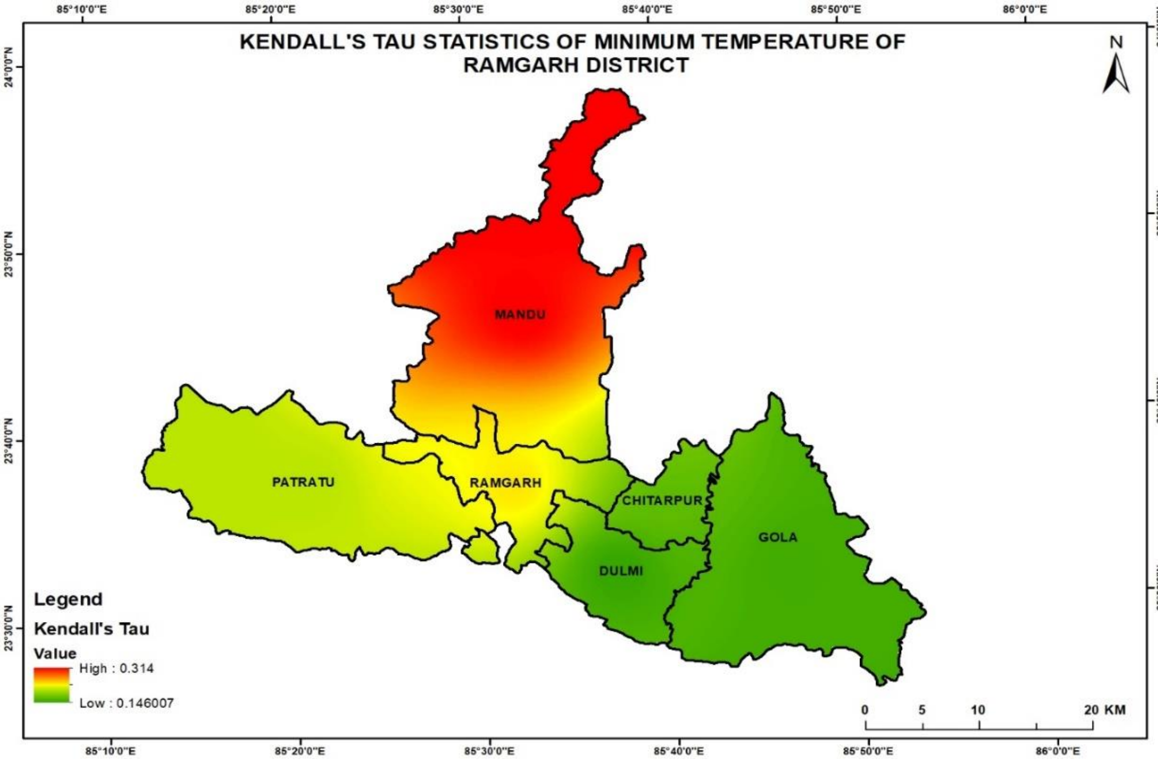

Fig. 3. Kendall's tau statistics of minimum temperature of Ramgarh District

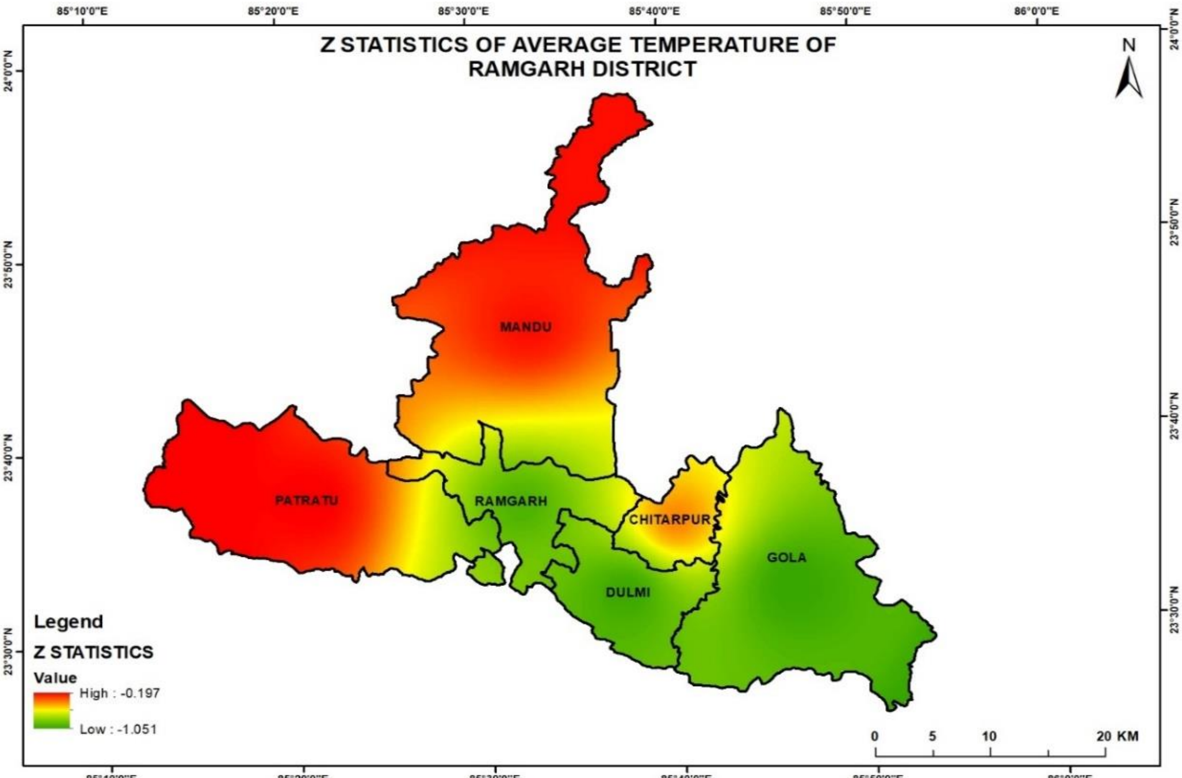

Fig. 4. Z Statistics of average temperature of Ramgarh District

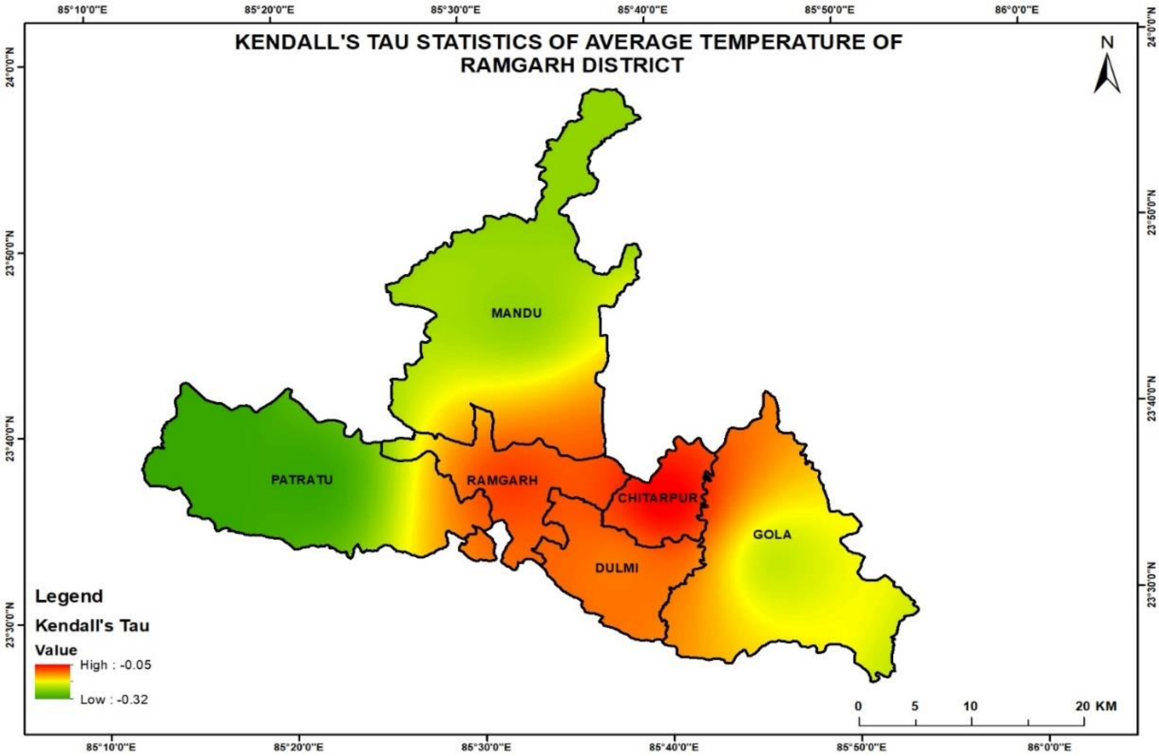

Fig. 5 Kendall's tau Statistics of average temperature of Ramgarh District

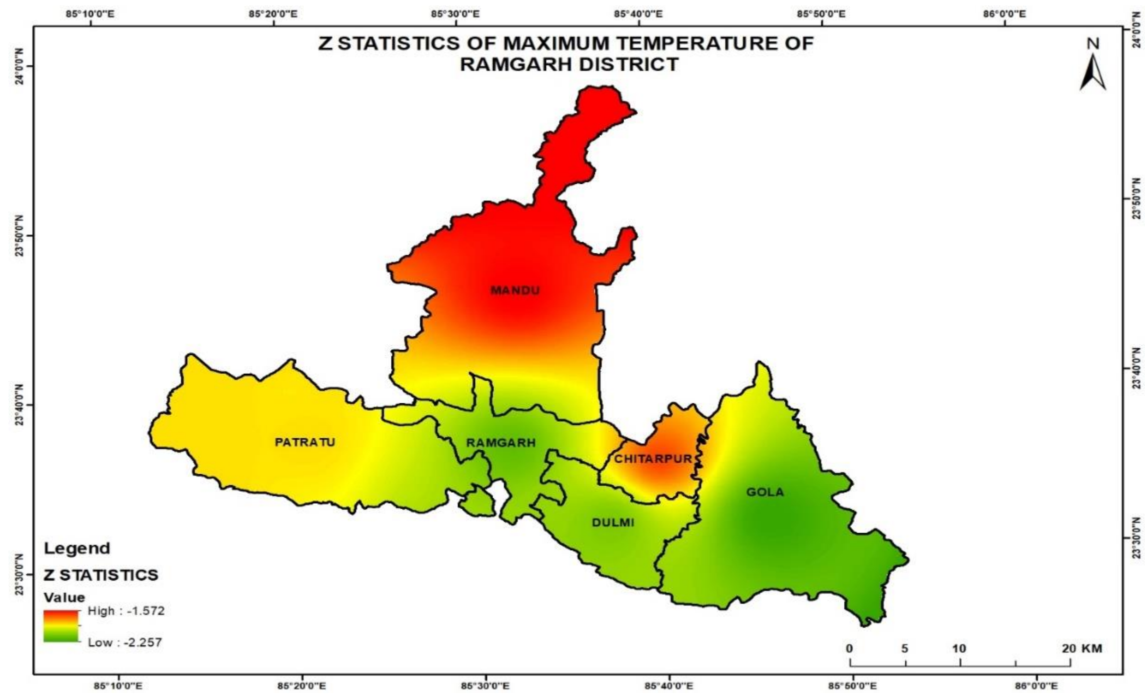

Fig. 6. Z Statistics of maximum temperature of Ramgarh District

Our study shows an increasing trend in temperatures in our study area. Increasing temperatures can have some negative effects on human health. These effects can be direct or indirect. However, Heat stress is a condition that occurs when the body is unable to cool itself properly. This can lead to some health problems, including heat cramps, heat exhaustion, and heat stroke [25, 26]. Rising temperatures can worsen cardiovascular diseases such as heart disease

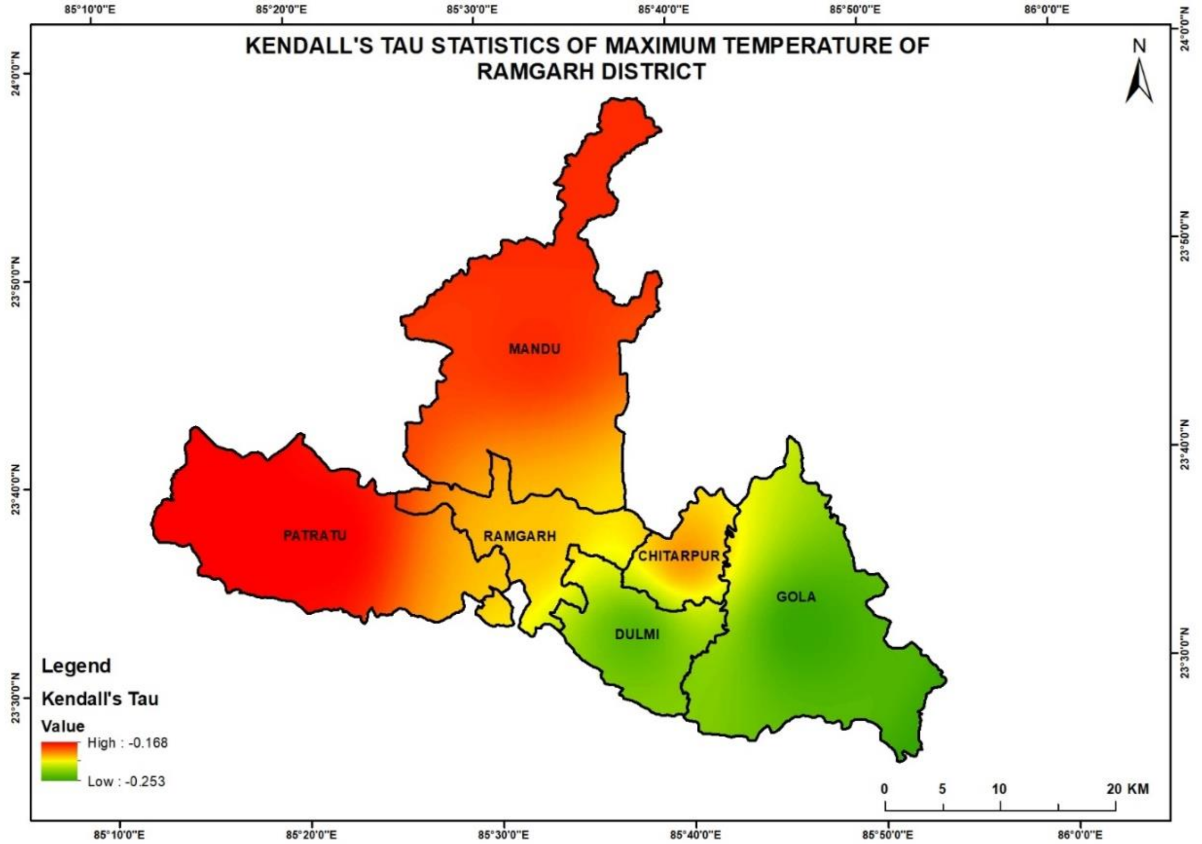

Fig. 7 Kendall's tau Statistics of maximum temperature of Ramgarh District

and stroke [25]. This is because heat stress can strain the heart and circulatory system. Rising temperatures can also worsen respiratory problems, such as asthma and chronic obstructive pulmonary disease [27]. This is because heat stress can irritate the airways and make breathing difficult. Rising temperatures can also lead to mental health problems such as anxiety and depression [28]. This is because heat stress can make it difficult to sleep and concentrate.

4. CONCLUSION

In conclusion, our study has shed light on the vulnerability of Ramgarh District to environmental fluctuations, particularly with regard to temperature variations. The study area has experienced significant changes in temperature patterns, with a notable increase in minimum temperatures and a decrease in maximum temperatures. This shift has potential implications for the region's climate limits and can significantly impact the lives of its residents. Furthermore, our findings emphasize the interconnectedness of environmental fluctuations with social and economic challenges within the study area. These changes intensify existing struggles and push communities to rely on resources that are sensitive to climate fluctuations. Agriculture, for instance, is increasingly dependent on unpredictable rainfall patterns, which poses a significant risk to food security. In the context of our research, it is crucial to consider the coal industry and its impacts or lack thereof on the environmental changes observed in Ramgarh District. While our study primarily focuses on temperature variations, it is essential to recognize that industries like coal mining can play a significant role in altering local ecosystems and contributing to climate change. The coal industry's practices, emissions, and land use can have long-lasting effects on the environment and local communities. As we move forward, it is imperative for policymakers, environmental organizations, and local authorities to take our research into account. The increasing temperature trend and its impacts on the region's vulnerable population should be a call to action. Measures need to be implemented to monitor and mitigate the effects of rising temperatures and to reduce the environmental footprint of industries such as coal mining. Additionally, efforts should be made to diversify economic activities in the region to reduce reliance on climate-sensitive resources. In conclusion, our research highlights the pressing need for a comprehensive strategy to address environmental change in Ramgarh District. This includes not only understanding and adapting to temperature variations but also considering the broader implications of industries like coal mining. By taking proactive steps to address these challenges, we can work towards safeguarding the well-being of the local population and preserving the environment for future generations.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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