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Investigation of Droughts using Indices in Katni and Rewa, Madhya Pradesh, India

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Abstract: *This study investigates the increasing frequency and intensity of droughts in Madhya Pradesh, India, under the influence of global warming, and their impact on the sustainability of ecosystem services. The study area includes Katni and Rewa districts, which experience a predominantly dry and warm climate with seasonal variations in precipitation. Using two drought indices—IMD (1971) and SPI (1993)—drought events were analyzed over the period 1901-2010. The methodology involved the use of these indices to assess the frequency and severity of meteorological droughts based on precipitation data. Results show that both districts experienced frequent mild to moderate droughts, with Katni experiencing slightly more severe droughts than Rewa. The SPI analysis further revealed a predominance of near-normal conditions with occasional droughts ranging from moderately dry to extremely dry conditions. The study highlights the significant role of tropical forests in carbon sequestration and their vulnerability to recurring droughts, which exacerbate declines in biomass productivity and functional diversity. The results also underscore the importance of precise drought assessment for effective water resource management and ecosystem service preservation. The findings contribute valuable insights into the impacts of climate change on drought dynamics and the critical need for adaptive strategies to mitigate drought-induced challenges in tropical regions.*

Key Words: *Drought Analysis, Katni, Rewa, Standard Precipitation Index*

1. INTRODUCTION: The growing intensity and frequency of droughts due to global warming present a significant threat to the sustainability of terrestrial ecosystem services [1]. These events result in profound consequences, including substantial reductions in vegetation productivity—declining by 2.3 to 3.5 times—which ultimately transform terrestrial ecosystems from carbon sinks into carbon sources [2]. Efforts such as protecting natural forests and establishing planted forests, as seen in countries like China, support initiatives to enhance carbon sequestration and achieve sustainability goals [3]. However, recurring droughts continue to threaten the functional diversity and biomass productivity of tropical forests worldwide, with climate change further intensifying their impacts. Consequently, precise assessments of drought severity and duration are critical for formulating effective strategies to mitigate these adverse effects and ensure the long-term sustainability of ecosystem services.

Meteorological droughts, though often short-lived, can have cascading impacts due to insufficient precipitation. Severe droughts, defined as annual precipitation falling below 25% of the normal levels for a region, can lead to far-reaching consequences [4]. Understanding the interplay between drought and climate change necessitates the analysis of key climatological factors such as precipitation, temperature, and evapotranspiration. These analyses are typically carried out using various statistical methods, including parametric approaches like linear regression and non-parametric methods such as the Mann-Kendall test [5]. The recurrence of droughts significantly affects critical sectors, causing declines in agricultural productivity, reduced energy production, water scarcity, mass migration, and even loss of life [6].

To characterize and quantify drought severity, various drought indices have been developed and widely used. These indices are based on hydroclimatic parameters such as precipitation, temperature, and river flow, enabling comprehensive drought evaluations. Common indices include the Standardized Precipitation Index (SPI), which measures precipitation anomalies [7; 8], and the Standardized Precipitation Evapotranspiration Index (SPEI), which accounts for both precipitation and evapotranspiration [9]. Other indices, such as the Reconnaissance Drought Index

and the Palmer Drought Severity Index, have also been applied across different regions to monitor and assess drought conditions [10]. These tools are indispensable for understanding drought dynamics, guiding resource management, and developing strategies to mitigate their impacts. By leveraging these indices, researchers and policymakers can better address the challenges posed by recurring droughts in a changing climate.

2. Study Area: Katni and Rewa cities are located in the central Indian state of Madhya Pradesh, a region characterized by its unique geographical and climatic conditions. Situated within a tropical climatic zone, the area experiences a predominantly dry and warm climate throughout the year. The temperature varies significantly across seasons, ranging from a minimum of 6°C to 20°C during the winter months to a maximum of 21°C to 48°C during the peak summer season. The region receives moderate rainfall, with an average annual precipitation of 75–85 cm, primarily occurring during the monsoon months between June and September.

The selection of Katni and Rewa as study sites was driven by the presence of diverse and contrasting land-use patterns, influenced by both natural and anthropogenic factors. These cities represent a confluence of industrial, agricultural, and natural environments, making them ideal for assessing the interplay between human activities and environmental health. The area is a hub for various industrial operations, including mining and stone crushing, which contribute significantly to local economic development but also pose potential environmental challenges such as air and water pollution. Additionally, the presence of the automobile industry further exacerbates emissions and particulate matter in the atmosphere.

Agriculture remains a dominant activity in the surrounding rural areas, with intensive farming practices potentially influencing soil and water quality. Despite these anthropogenic pressures, the region also includes pockets of preserved forested areas, which serve as vital ecological buffers. These forests play a crucial role in maintaining biodiversity and regulating local climate conditions, offering an opportunity to study their mitigating effects on environmental degradation caused by human interventions.

Overall, the geographical diversity, coupled with the variety of human activities and natural ecosystems, makes Katni and Rewa critical sites for studying the impact of anthropogenic pressures on environmental parameters. These findings will provide valuable insights for sustainable resource management and environmental conservation in similar semi-arid regions.

3. Data Collection: The basic data used in the study is the monthly mean rainfall data of Katni and Rewa for the period 1901–2010. The monthly mean temperature data for a period 1901-2002 is also used. The data are obtained from Indian Meteorological Department (IMD) site www.indianwaterportal.org. The district rainfall was computed as the simple arithmetic average of the rainfall of the stations in the district.
Some of the data were unavailable, due to which missing data has been assumed as follow:
If the data for the particular district for a particular year or month is unavailable then average of previous and next 2 years is used and if large number of data of a particular district is unavailable then data of the neighboring district is used.

4. METHODOLOGY:

Computation of Indices

To assess the variability and frequency of droughts in Katni and Rewa districts, two widely recognized drought indices were employed: the India Meteorological Department (IMD) Drought Classification (1971) [11] and the Standardized Precipitation Index (SPI) proposed by McKee (1993)[7]. These indices were selected for their ability to quantify drought characteristics, including intensity, duration, and frequency, while offering complementary perspectives on rainfall variability and hydrological extremes.

IMD Drought Classification (1971): This index categorizes droughts into four distinct classes—no drought, mild drought, moderate drought, and severe drought—based on the deviation of annual rainfall from the long-term mean. It provides a simple yet effective framework for identifying drought severity, commonly used for large-scale regional assessments.

Standardized Precipitation Index (SPI): The SPI is a probability-based index that measures precipitation anomalies over different timescales, enabling a detailed classification of both wet and dry conditions. SPI values are divided into categories such as "extremely wet," "very wet," "moderately wet," "near normal," "moderately dry," "severe dry," and "extremely dry." This index is particularly useful for capturing the temporal variability of rainfall and identifying extreme hydrological conditions.

By employing these indices, the study aims to provide a comprehensive understanding of historical drought patterns and precipitation variability, offering critical insights for water resource planning and climate resilience strategies.

Indices Used

I. Drought Index (IMD 1971):

$DI = \frac{Pi-\mu}{\mu} \times 100$ …. …. …. …. …. …. …. …. …. (2)

Where

DI= Percentage deviation from the long-term mean,

Pi= Annual rainfall, mm

μ= Long term mean of the annual rainfall, mm

Table 1: Drought Index Codification

Intensity	Value of DI
No drought	0.0 or above
Mild drought	0.0 to -25.0
Moderate drought	-25.0 to -50.0
Severe drought	-50.0 or less

II. Standardized Precipitation Index (McKee, 1993):

$SPI = \frac{X_{ij}-X_{im}}{SD}$ …. …. …. …. …. …. …. …. …. (3)

Where,

X_{ij}= Seasonal precipitation at the ith rain gauge and jth observation,

X_{im}= Long term seasonal mean

SD = Standard deviation

Table 2: Standardized Precipitation Index Classification

Intensity	Value of SPI
Extremely Wet	2 or more
Very Wet	1.5 to 1.99
Moderately Wet	1.0 to 1.49
Near Normal	0.99 to -0.99
Moderately Dry	-1.0 to -1.49
Severe Dry	-1.5 to -1.99
Extremely Dry	-2.0 or less

5. RESULT AND DISCUSSION: The frequency of drought events in Katni and Rewa districts from 1901 to 2010, based on the India Meteorological Department's (IMD) classification, reveals significant insights into the historical patterns of drought in the region (Table 3). Katni experienced 53 years with no drought, accounting for the majority of the study period. Mild drought conditions occurred in 46 years, indicating a relatively frequent but less severe impact. Moderate drought conditions were observed in 9 years, while severe drought was recorded in only 2 years. Rewa exhibited a similar trend, with 53 years without drought and 47 years classified under mild drought. However, moderate drought occurred in 10 years, and no severe drought events were recorded during the study period.

Table 3: Frequency of Drought as per IMD (1971) for Madhya Pradesh during period 1901-2010

Name of District	No Drought	Mild Drought	Moderate Drought	Severe Drought
Katni	53	46	9	2
Rewa	53	47	10	0

The predominance of "no drought" and "mild drought" years highlights the region's relative resilience to extreme drought conditions over the century. However, the occurrence of moderate and severe droughts underscores the vulnerability of the area to climatic variations, which could have significant socio-economic implications, particularly in agriculture-dependent regions.

Table 4: Frequency of Drought as per SPI (McKee, 1993) in Madhya Pradesh for period 1901-2010

Name of District	Extremely Wet	Very Wet	Moderately Wet	Near Normal	Moderately Dry	Severe Dry	Extremely Dry
Katni	2	6	7	81	6	5	3
Rewa	4	3	13	73	9	5	3

Using the Standardized Precipitation Index (SPI), a more nuanced classification of drought and wet conditions was achieved (Table 4). In Katni, "near normal" conditions dominated, accounting for 81 years out of the 110-year period. The distribution of wet conditions ranged from "extremely wet" (2 years), "very wet" (6 years), and "moderately wet" (7 years), indicating occasional surplus rainfall. Dry conditions included 6 years of "moderately dry," 5 years of "severely dry," and 3 years of "extremely dry."

In Rewa, a similar pattern emerged, with 73 years classified as "near normal." Wet conditions spanned 4 years of "extremely wet," 3 years of "very wet," and 13 years of "moderately wet." Dry conditions included 9 years of "moderately dry," 5 years of "severely dry," and 3 years of "extremely dry."

The SPI results provide a comprehensive view of rainfall variability, showing that while the majority of years remained within normal bounds, extreme conditions, both wet and dry, were observed periodically. The slightly higher frequency of wet years in Rewa compared to Katni suggests spatial variability in precipitation patterns within Madhya Pradesh.

Comparative Analysis and Implications

The comparative analysis of IMD and SPI-based drought frequencies highlights the utility of multiple indices for a robust understanding of drought variability. IMD's classification provides a broad overview of drought severity, while SPI offers a more granular categorization, including wet periods. This dual approach allows for a better understanding of hydrological extremes and their implications.

The dominance of "near normal" and "mild drought" conditions suggests that the region's water resources have historically been less affected by extreme droughts. However, the periodic occurrence of severe droughts and dry spells underscores the need for proactive water resource management and adaptive strategies to mitigate the potential impacts of climate change. The spatial differences between Katni and Rewa also highlight the importance of localized strategies for drought mitigation, accounting for the variability in precipitation patterns.

The findings emphasize the need for integrating historical data with modern climate models to improve forecasting and planning. Given the reliance on agriculture in the region, understanding drought patterns is critical for ensuring food security and sustainable water management in Madhya Pradesh.

6. CONCLUSIONS: The analysis of drought frequencies and rainfall patterns in Katni and Rewa districts over the period 1901 to 2010 reveals critical insights into the hydrological variability and climatic conditions of the region. The findings indicate that both districts predominantly experienced years with "no drought" or "mild drought" conditions, as classified by the IMD. This suggests a relative stability in the annual rainfall for most of the study period, with limited occurrences of severe droughts. In Katni, severe droughts were recorded in only two years, while no such events were observed in Rewa. Similarly, the SPI analysis confirms the dominance of "near normal" conditions, further emphasizing the region's relative resilience to prolonged and extreme dry spells.

The SPI analysis adds an additional dimension to understanding rainfall patterns by identifying periods of excessive rainfall. Both Katni and Rewa experienced several years of "extremely wet" and "very wet" conditions, with such events aligning with peaks in the rainfall trends. These wet extremes could pose risks such as flooding and waterlogging, highlighting the need for adaptive water resource management strategies. Furthermore, the differences in the frequency of wet and dry years between Katni and Rewa suggest spatial variability in rainfall distribution, likely influenced by local factors such as topography and land-use patterns.

Overall, the study underscores the importance of adopting sustainable water resource management practices to address the challenges posed by increasing rainfall variability. Proactive measures, such as improving irrigation

efficiency, implementing rainwater harvesting systems, and afforestation efforts, can help mitigate the impacts of both droughts and excessive rainfall. The integration of IMD and SPI indices provides a robust framework for understanding historical drought and precipitation variability, offering valuable insights for developing localized strategies to enhance climate resilience in the region.

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