

Trends in the Rainfall Pattern Over the Gangetic Plain

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Abstract

In recent years, the Gangetic Plain of India has witnessed a noticeable decline in the number of rainy days⁴⁸. This study explores this phenomenon by analysing meteorological data from the Indian Meteorological Department (IMD), specifically utilizing the IMD's grid with a resolution of 0.25 degrees by 0.25 degrees dataset. Through rigorous data analysis and statistical methods, we reveal a significant and quantifiable reduction in how frequently rainy days in⁴⁹ this agriculturally crucial region. We calculated the rainy days decadal-wise that is 1901-10 to 2011-20 and found the decrease in rainy days. This declination in rainy days is more in the month of August (sen's slope = -0.125) while June and September have less while July has no such declination type trends (sen's slope = 0.0). This decline in rainy days has raised concerns about its potential impact on agriculture, water resources, and the livelihoods of the millions of people dependent on the Gangetic Plain's agrarian sector. Also, we found that the eastern part of Gangetic Plain receives more amount of rain while the western part less. So, this study emphasizes the need to comprehend how climate change is affecting rainfall patterns and the necessity of taking proactive steps to solve the problems brought about by fewer rainy days in the Gangetic Plain.⁴⁸



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Introduction


The Gangetic Plain, an enormously productive region in northern India, stands as a testament to the harmonious coexistence of nature and humanity. Home to over 400 million people, this region is not only densely populated but also more than a simple agriculturally significant areas globally.⁴⁸

Its sprawling landscapes are adorned with a rich tapestry of crops, ranging from the golden fields of wheat to the emerald rice paddies, and the towering stalks of sugarcane. Indeed, the Gangetic Plain is the breadbasket of India, sustaining both its populace and its agricultural economy. However, amidst the bucolic beauty and the rhythmic pulse of life in this

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region, a disquieting trend has emerged in recent years—a noticeable decline in the number of rainy days.⁴⁹ For a region whose agricultural rhythms are intricately attuned to the monsoon, this shift in rainfall patterns is more than just a meteorological curiosity; it's a cause for profound concern.

This paper embarks on a journey to understand the intricacies of this phenomenon—the decrease in rainy days in the Gangetic Plain—within the broader context of climate change. Our path is illuminated by the light of data, specifically meteorological records meticulously gathered through the Indian Meteorological Department (IMD) over several decades.⁴⁸

These documents offer a wealth of knowledge, allowing us to scrutinize the frequency of rainy days in this region.

Historically, the Gangetic Plain has been a region blessed with a bountiful and well-distributed monsoon rainfall. Studies by Gadgil *et al.* (2002) and Parthasarathy *et al.* (1995) have emphasized the significance of the Indian monsoon system in delivering timely and adequate rainfall to support the diverse agricultural practices in the region. The monsoon system, driven by complex atmospheric and oceanic interactions, has, for generations, provided a degree of predictability to the local climate.

Recent research, however, paints a different picture. Studies such as those conducted by Goswami *et al.* (2006) and Dash *et al.* (2007) have noted a shift in rainfall patterns in India. There is evidence to suggest a reduction in the number of rainy days, which is particularly alarming in the context of the Gangetic Plain. Global climate change emerges as a pivotal factor. Kumar *et al.* (2011) and Ghosh and Mujumdar (2018) highlight the influence of climate change on Indian monsoon dynamics.⁴⁸ Elevated sea surface temperatures, changing circulation patterns, and altered moisture material in the environment are believed to be contributing to the observed shifts in regional rainfall patterns. It's worth noting that the decrease in rainy days is not uniform across the entire Gangetic Plain. Studies like that of Rajeevan *et al.* (2012) have pointed to regional variations, where some areas are experiencing more

pronounced declines than others. These variations may be attributed to local geographical and climatic factors. Agriculture, the backbone of the region's economy, is acutely vulnerable to shifts in rainfall patterns. Research by Singh *et al.* (2015) and Sharma *et al.* (2019) underscores the detrimental effects on crop yields, planting schedules, and overall agricultural productivity. Reduced rainy days challenge traditional farming practices and necessitate adaptations. The socio-economic implications are profound. Mishra *et al.* (2020) highlight how the livelihoods of millions of farmers are at stake, potentially leading to increased poverty and rural-to-urban migration. The economic stability of the region is also under threat, given the strong ties between agriculture and the local economy. Addressing the decrease in rainy days necessitates evidence-based policy formulation. Kumar and Jain (2017) discuss the importance of adaptive strategies, including improved water management, crop diversification, and climate-resilient farming practices. Effective policies should be founded on a comprehensive understanding of the changing climate dynamics in the Gangetic Plain.

Goswami, B. N., *et al.* (2006) states that the increase in⁴⁹ extreme rainfall events in India due to global warming. Meehl, G. A., *et al.* (2007) highlights the potential implications of changing climatic conditions, including alterations in precipitation patterns. While not specific to the Gangetic Plain, it underscores the global nature of consequences of environmental degradation on rainfall. While it doesn't focus exclusively on the Gangetic Plain, it provides insights into the broader regional climate change's effects on rainfall. Zhang, X., *et al.* (2007) provides a comprehensive analysis of trends in global precipitation patterns from 1900 to 2004.⁴⁸ It identifies significant alterations in severity on top of how often rainy days across different regions, highlighting the complexity of precipitation trends.⁴⁸ Dai, A. (2011) primarily focusing on drought, has discusses the interplay between increased temperatures, changing precipitation patterns, as well as how frequently rainy days. It offers insights into the potential impact the repercussions of climate change on rainy day trends. Alexander, L. V., *et al.* (2006) examines changes in daily climate extremes, encompassing the quantity of rainy days, based on observational data from globally. It provides a global

perspective on precipitation trends. Trenberth, K. E., *et al.* (2007) assesses the noted modifications in climate variables, including precipitation. It discusses anomalies in the happenstance of of rainy days in⁴⁹ different regions. Kumar, K. K., *et al.* (2011) investigates temperature swings that were observed and precipitation patterns in India,⁴⁸ including the impacts on the monsoon system. While it doesn't specifically address the Gangetic Plain, it contributes to the understanding of the Indian subcontinent's shifting climate. Ghosh, S., & Mujumdar, M. (2018) employs high-resolution climate models to project future precipitation extremes in India. Although it does not narrow down to the Gangetic Plain, it provides valuable insights into regional climate change impacts. Kumar, P. *et al.* (2023) study the effects of fluctuating precipitation patterns on rice productivity in Bihar, which is situated in the Gangetic Plain. It highlights the agricultural repercussions of decreased rainy days.

Wang, G., *et al.* (2019) examines changes in severe daily precipitation scenarios, including the frequency of rainy days.⁴⁹ It highlights regional variations in precipitation trends. Peterson, T. C., *et al.* (2008) discusses changes in precipitation patterns, including the number of rainy days, and the⁴⁹ importance of data quality in trend analysis. Sun, S., *et al.* (2019) explores the relationship between

changing precipitation patterns, including rainy days, and vegetation productivity in a semi-arid region, offering insights into ecological consequences.

These studies collectively suggest a complex interplay between climate change and precipitation patterns in India,⁴⁸ with potential consequences for the Gangetic Plain's rainfall dynamics. While the reviewed literature provides valuable insights into the broader context of climate change and regional impacts, further research specifically addressing the Gangetic Plain's changing rainy-day trends is warranted to provide a comprehensive understanding of this critical issue.

In summary, changes in rainy day frequency have multifaceted impacts on agriculture, water resources, ecosystems, and human societies. By comprehensively studying these changes, scientists, policymakers, enabling stakeholders to make informed decisions and take proactive measures to tackle the challenges presented by changing precipitation patterns,⁵⁴ ultimately promoting resilience and sustainability with the backdrop of a changing climate.

Study Area, Data and Methodology

Study Area and Data Sources

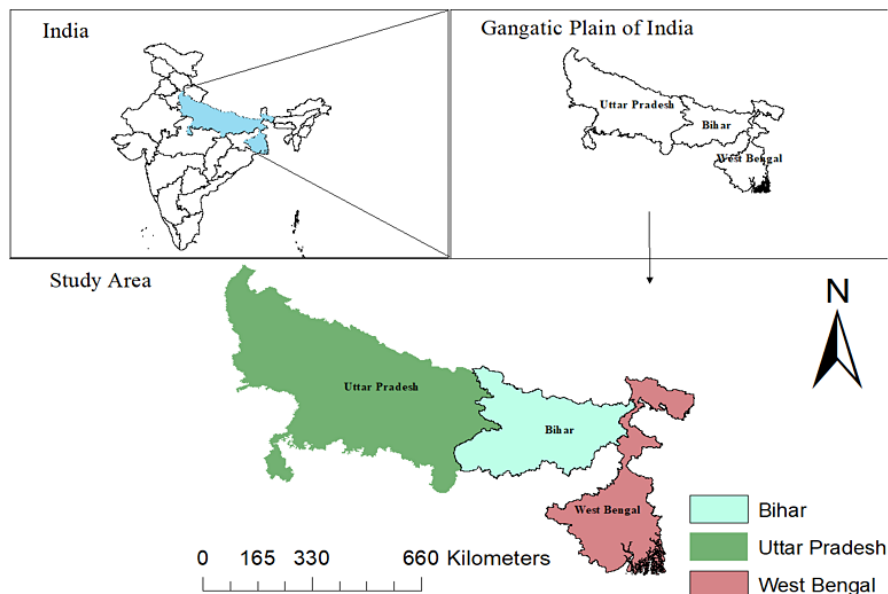


Fig. 1: Study area map

The present study area encompasses the Gangetic Plain of India, including West Bengal, Bihar, and Uttar Pradesh states, as depicted in Figure 1. The study area experiences a subtropical climate characterized by hot summers and mild winters. This region is heavily influenced by the Indian summer monsoon,⁴⁸ with the majority of its rainfall occurring during the monsoon season from June to September.

Precipitation data used throughout this probe were obtained from the⁵¹ India Meteorological Department (IMD).⁴⁵ The dataset covers the years 1901 to 2020 for the month of June, July, August and September (JJAS) i.e., summer monsoon season of India (SMSI) and is available at a nominal spatial resolution of 0.25° x 0.25°. For study area purpose the dataset used were obtained from Diva-GIS.

Methodology

The number of rainy days⁴⁹ count as the IMD criterion i.e. daily rainfall is larger than or close to 2.5mm.⁵¹ in the month of June, July, August and September for the decadal period 1901-10 to 2011-20. The mean of the data⁴⁸ is calculated by the formula

$$\pi = \frac{\sum_i x_i N_i}{N}, \text{ where } i \text{ vary from } 1 \text{ to } 12 \text{ and } N = 12.$$

X define as the amount of precipitation while N is the number of decadal period.

The standard error of the mean (SEM) is a measure of the variability of sample means around the population mean. The calculation entails utilizing both the standard deviation of the sample and the square root of its size. The formula for the standard error of the mean is

SEM = s/\sqrt{n} , where s = standard deviation for the sample, n = sample size.

The standard deviation (σ) can give us an idea of how much individual no. of rainy days values deviate from the average. It is calculated using⁴⁸ the following formula

$$\sigma = \sqrt{\frac{\sum_{i=1}^N (x_i - \bar{x})^2}{N}}, \text{ where } N = \text{number of data points.}$$

x_i = individual data point, \bar{x} = mean (average) of the data set.

Minimum = Smallest worth inside the collection.

Maximum = highest worth inside the collection.

Quartile 1 (Q1): Q1 = Median of first n/2 observations.

Quartile 3 (Q3): Q3 = Median of last n/2 observations.

And median of the data set is calculated by

- If the data point is odd then median is middle value.
- If data point is even then median is calculated by the formula: median = {value at position (n/2)+ value at position (n/2+1)}/2.

The climate Data were extracted using CDO and 5-D environment in GrADS software. And data extraction on study area and spatial plot were drawn by using GrADS. Sen's slope estimator is employed to determine the extent of linear trends, commonly utilized within the examination of hydro-meteorological data sequences. Sen's slope estimator (β)⁴⁷ is the least square regression and is widely used for calculating the extent of linear trends in large data.⁴⁶

Where

$$B = \text{median} \left(\frac{x_i - x_j}{i - j} \right), \forall j < i^{46}$$

Here $1 < j < i < n$

And x_i and x_j are two data set at the point i and j.

Results

Statistical Analysis

From Table-1 the no. of rainy days counted for the month of (a) June, (b) July, (c) August and (d) September⁵⁶ (JJAS) and their respective statistical analysis considering the mean, median, standard deviation and quartiles' analysis.

Noteworthy is the fact that the the standard deviation serves as a measure of how much the rainfall values vary from the mean. A higher standard deviation demonstrates that the rainfall values are more spread out⁵⁷ Nevertheless, a reduced standard deviation suggests that the rainfall values are more concentrated around the mean²⁵ The data also shows that the median rainfall for June, July, August, and September is higher than the mean rainfall for these months. This indicates that there is a slight positive skewness (Positive skewness in

a distribution refers to the situation where the right tail (the larger values) of the distribution is longer or fatter than the left tail (the smaller values).⁵¹ Stated differently, the distribution has a longer or stretched-out tail on the positive side of the mean.⁴³) in the rainfall distribution, meaning that there are more years with above-average rainfall than there are years with below-average rainfall.

Overall, the data suggests that rainfall during the summer months in India is relatively predictable, with a mean rainfall of around 230-295 mm per month. However, there is also a significant amount of variations in precipitation annually, as demonstrated by the standard deviation values

Table 1: Number of rainfall days in decadal year in the month of (a) June, (b) July, (c) August and (d) September⁵⁶

	1901 -10	1911 -20	1921 -30	1931 -40	1941 -50	1951 -60	1961 -70	1971 -80	1981 -90	1991 -2000	2001 -10	2011 -20
June	221	243	227	239	227	235	236	232	226	231	224	226
July	293	293	303	300	301	297	296	301	298	303	293	295
August	299	298	304	287	301	302	298	287	289	300	290	285
September	229	226	240	238	251	240	238	231	240	238	229	226

Table 2: Statistical values for the no. of rainfall event

Variable	N	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum	Sen's Slope (at 95% confidence level)	Nature
June	12	230.58	1.90	6.60	221.00	226.00	229.00	235.75	243.00	-1	D
July	12	297.75	1.10	3.82	293.00	293.50	297.50	301.00	303.00	0	N
August	12	295.00	1.97	6.84	285.00	287.50	298.00	300.75	304.00	-1.125	D
September	12	235.50	2.14	7.42	226.00	229.00	238.00	240.00	251.00	-0.2792208	D

D = Decreasing, N= Neither decreasing nor increasing

Trend analysis of the data in my study area was employed to examine the temporal evolution of rainy days in the Gangetic Plain³⁵. We used linear regression to assess patterns in the quantity of rainy days over the specified time period (1901-2022). The analysis focused on quantifying the direction and significance of trends, indicating whether there's been an discernible increase or reduction in the quantity of rainy days. This study, we saw that in longer period (decadal period) the trend of three months i.e. June, August and September are decreasing but the month of August are much more

decreasing in terms of rainy days (IMD criteria for rainy days is at least 2.5 mm of daily rainfall)²⁰ while July has no any significant trend. The same is also verified aided by the value of r-square which shows that the corelation in the month of august is high while rest of the other is low. The value of Sen's slope shows that in the month of June, August and September the trend nature is decreasing while in the month of July it is neutral. Seasonal trends were explored to capture variations in different time frames.

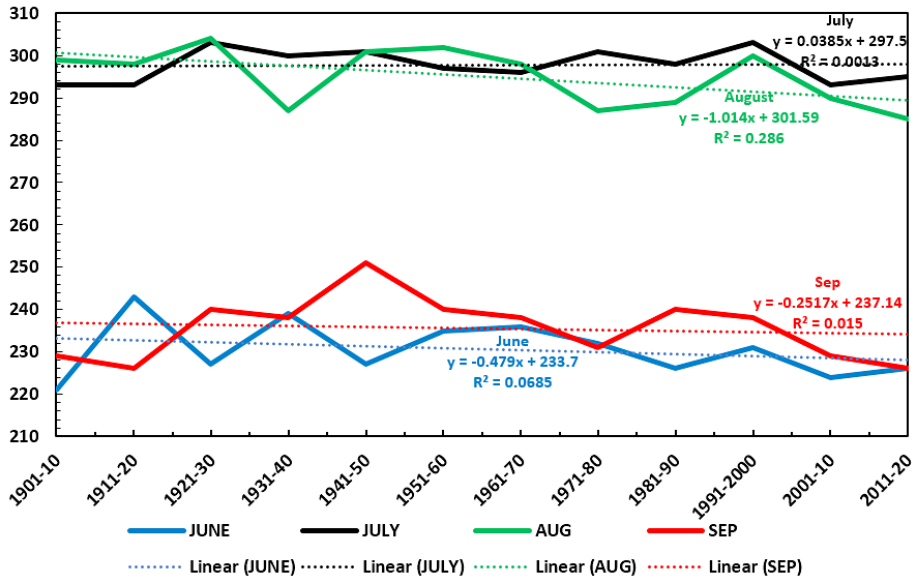


Fig. 2: Decadal time series of rainy days from 1901-10 to 2011-20

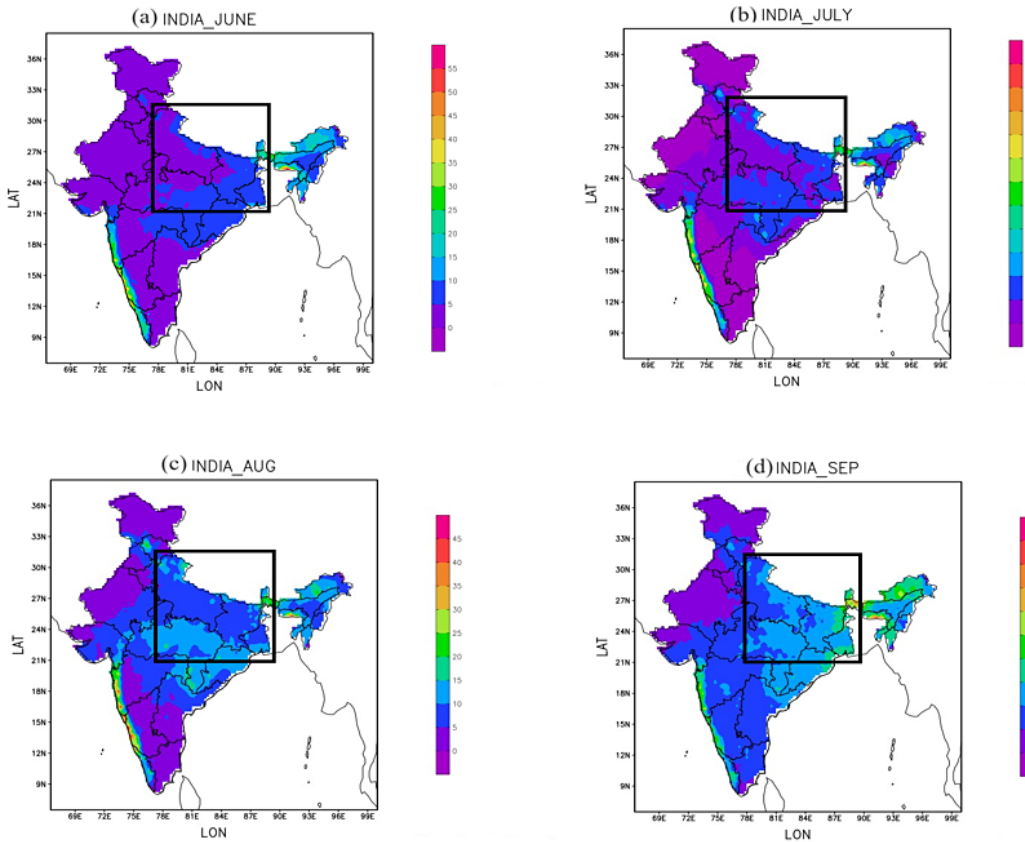


Fig. 3: Spatial distribution of rainfall for the month of (a) June, (b) July, (c) August and (d) September⁵⁶

Spatial and Temporal Scope

The spatial scope of this study encompasses the entirety of the Gangetic Plain, encompassing Uttar Pradesh, West Bengal and Bihar. The analysis considers the entire time series from 1901 to 2022 to comprehensively capture long-term precipitation trends. Analysis of the spatial and temporal aspects of rainfall⁴⁸ (IMD) over the Gangetic Plain of India for the month of JJAS in decadal variation from 1901-10 to 2011-20 can suggest the following

The Gangetic Plain receives the highest rainfall during the JJAS months, with the heaviest rainfall occurring in the eastern and northeaster parts of the region. There is a general decrease in rainfall from east to west, with the western parts of the Gangetic Plain receiving less rainfall than the eastern and northeastern parts.³ The spatial arrangement of rainfall over the Gangetic⁵² Plain has shown some variability over the past century, with some regions experiencing higher rainfall levels and others experiencing a decrease in rainfall.³⁶

The overall trend in rainfall over⁴⁸ the Gangetic Plain during the JJAS months has been one of a slight increase. However, There's been an significant interdecadal variability in rainfall, with some decades experiencing above-average rainfall and others experiencing below-average rainfall.¹¹

In recent decades, There's been an trend towards more extreme rainfall events over⁴⁹ the Gangetic Plain. This means that there are more days with very heavy rainfall, as well as more days with very little or no rainfall.²⁸

Conclusion

The typical quantity of days with rain has decreased⁴⁸ in three monsoon months (June, August, and September) while July has no trend over the Gangetic Plain, with the decrease being most pronounced in August.²⁰ We calculated the rainy days decadal-wise that is 1901-10 to 2011-20 and found the decrease in rainy days. This declination in rainy days is more in the month of August (sen's slope = -0.125) while June and September have less while July has no such declination type trends (sen's slope = 0.0). The rainy days are more frequent in July and August while less in June and September which is quite obvious as June is the month in which

monsoon starts in that region while September is the withdrawing month of the monsoon season. The standard deviation for July is 3.82 which is small compared to other three months. It indicates that variability in July is less while for the September, it is 7.42 which means variability is high in September. The data also shows that the⁵¹ median rainfall for all four months is higher than the mean rainfall, indicating a slight positive skewness in the rainfall distribution. The spatial as well as the chronological trends of rainfall in the⁴⁹ Gangetic Plain note that the region receives the highest rainfall during the JJAS months, with the heaviest rainfall occurring in the eastern and north-eastern parts.³ There is a widespread decline in rainfall from east to west, and the arrangement of the rainfall has shown some variability over the past century. The overall trend in rainfall over⁴⁸ the Gangetic Plain during the JJAS months has been one of a slight increase, but there has been significant interdecadal variability.¹¹ In recent decades, there has been trend towards more extreme rainfall events, with more days of very heavy rainfall and more days of very little or no rainfall.

- The decreasing number of rainy days⁴⁸ throughout the monsoon season can provide valuable insights for devising mitigation and adaptation measures in several ways: Understanding Climate Trends: It is beneficial to comprehend the long-term climate trends and variations, which are essential for designing effective adaptation strategies. Water Resource Management: Knowing about the decrease in rainy days can inform water resource management policies and practices, helping authorities plan for water scarcity and drought conditions throughout the monsoon season.
- Agricultural Planning: Farmers can adjust their cropping patterns and irrigation strategies based on the changing rainfall patterns, minimizing the impact of reduced rainy days on agricultural productivity.
- Infrastructure Planning: Urban planners and engineers can use this information to create robust infrastructure that can endure extreme weather conditions and addressing potential challenges posed by decreased rainfall.
- Disaster Preparedness: It aids in disaster preparedness efforts by allowing communities

and emergency responders to anticipate and mitigate the dangers connected with changing precipitation patterns, include flooding and landslides.

- Ecosystem Management: Conservation efforts can be tailored to address the impacts of reduced rainfall on ecosystems and biodiversity, preserving critical habitats.

So, the results of this study⁵⁰ have important implications for water management and⁵⁵ agriculture, Urban planning, Risk assessment and insurance, awareness and education and last but not least Research and Development in the Gangetic Plain. The dwindling quantity of rainy days⁴⁹ and the trend towards more extreme rainfall events pose challenges for water managers. Adaptation strategies are needed to address these challenges and protect people and property from flooding and drought.

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Conflict of interest

There is no Conflict of interest for this article.

Data Availability Statement

The manuscript incorporates all datasets produced or examined throughout this research study.

Ethics Approval Statement

There is no study involving an experiment on humans and animals in the paper.

Authors' Contribution

All work is done by the first author Mr. Devendra Kumar Tiwari under the guidance of the corresponding author Professor P. Parth Sarthi.

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