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THE CORRELATIONS BETWEEN HEATWAVE EVENTS AND DEFORESTATION IN RAJASTHAN FROM 2000 TO 2024: AN ANALYTICAL STUDY

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ABSTRACT

*Rajasthan, characterized by its semi-arid to arid climate and extreme temperature trends, has been increasingly affected by the rising frequency and intensity of heatwaves over the past two decades. This study analyzes the relationship between heatwave events and deforestation in Rajasthan during the period **2000–2024.** Based on data obtained from the Forest Survey of India (FSI) and the NASA POWER datasets, regression analysis was employed in this research. The results indicate that Rajasthan's total forest cover increased by only **1.11% (181.21** sq. km) between **2001** and **2023**, while some districts (such as Chittorgarh and Banswara) witnessed up to a **30%** decline. During the same period, there was a significant increase in heatwave events, particularly in desert districts such as Karauli, Jaisalmer, and Barmer. The regression analysis revealed a moderate positive correlation (R = **0.466**, R^2 **= 21.7%)**, suggesting that reduction in forest cover is a significant factor contributing to the rise in heatwave occurrences. The ANOVA results (p-value = **0.0063<0.05)** confirmed the statistical significance of this relationship. In conclusion, this study affirms the connection between deforestation and heatwaves in Rajasthan, though other factors like climate change and urbanization also play a role. The research underscores the need for forest conservation and climate adaptation policies.*

***KEYWORDS**: Heatwave, Deforestation, Rajasthan, Regression Analysis, Climate Change.*

Introduction

The state of Rajasthan is known for its distinct geographical and climatic diversity. A major portion of the state falls under semi-arid to arid climatic zones, where summer temperatures often exceed 45°C. In recent decades, due to the impact of climate change, not only has the frequency of heatwave events increased in Rajasthan, but their intensity has also become more severe. Particularly since the year 2000, many parts of the state have experienced prolonged periods of extreme heat, directly affecting human health, agriculture, livestock, water resources, and the socio-economic structure.

According to the India Meteorological Department (IMD), temperatures above 45°C are categorized as heatwaves, while those exceeding 47°C are considered severe heatwaves. Several factors are responsible for the intensifying heatwaves in Rajasthan, among which climate change, urbanization, industrialization, and deforestation are key. Deforestation, in particular, directly impacts the local microclimate—absence of vegetation leads to increased surface temperatures, reduced soil moisture, and greater atmospheric heat retention, thereby worsening heatwave conditions. Continuous degradation of forested areas, including the Aravalli ranges, has exacerbated the issue in the state.

Global studies have also established links between deforestation and heatwaves. Alves de *Oliveira et al. (2021)* confirmed rising temperatures and heat stress in the Amazon due to deforestation.

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Costa et al. (2022) highlighted the impact of deforestation on heatwave intensity under dry conditions. *Lloret & Batllori (2021)* warned of ecosystem collapse due to the combined effects of heatwaves and drought. *Ul Hassan et al. (2021)* observed rising temperatures due to declining forest cover in the Himalayan region. *Leon et al. (2022)* emphasized the bidirectional relationship between deforestation and climate change. *Masuda et al. (2020)* found that deforestation-induced heat affects human cognitive capacity. *Xiao et al. (2025)* reported increased drought vulnerability in various biomes due to forest loss. *Silveira et al. (2023)* analyzed demographic impacts of heatwave-related mortality, while *Maillard et al. (2022)* provided evidence of local temperature rise due to deforestation in Bolivia.

While various studies have addressed the relationship between heatwaves and climate change, there remains a lack of comprehensive analysis specifically linking deforestation and heatwaves in arid regions like Rajasthan. This research paper seeks to bridge that gap.

Objective of the Study

The primary objective of this research is to analyze the relationship between heatwave events and deforestation in Rajasthan during the period 2000–2024. Specifically, the study focuses on the following aspects:

- Assessment of Heatwave Trends – Analyze changes in the frequency, duration, and intensity of heatwaves in Rajasthan over the past 24 years.
- Evaluation of Forest Cover Changes – Study the spatial distribution of forest cover based on State of Forest Reports.
- Correlation Between Heatwaves and Deforestation – Explore the relationship between both phenomena through statistical and geospatial analysis.
- Policy Recommendations – Suggest potential measures to mitigate the impact of heatwaves and promote forest conservation.

Research Hypothesis

The researcher hypothesizes that “There is a direct relationship between deforestation and extreme temperature events in Rajasthan, i.e., the increase in heatwave incidents in the state is linked to deforestation.”

Research Methodology

This study utilizes secondary data on forest cover and temperature. Forest cover data was sourced from the State of Forest Reports available on the Forest Survey of India website (https://fsi.nic.in/forest-report-2023), while temperature-related data was retrieved from NASA’s POWER Data Access Viewer (https://power.larc.nasa.gov/data-access-viewer/). Regression analysis was employed to test the validity of the research hypothesis.

Study Area

Rajasthan is the largest state in India, spanning an area of 342,239 sq. km. It exhibits diverse geographical features, including the Thar Desert, the Aravalli mountain range, eastern plains, and southern plateaus. The western part houses the Thar Desert (Great Indian Desert), known for its sand dunes, saline lakes, and extremely low rainfall (<25 cm annually). The Aravalli range, one of the oldest mountain ranges in India, divides the state into northeast and southwest regions and contains its highest peak, Guru Shikhar (1,722 meters) in Mount Abu. The eastern plains are fertile due to the Chambal, Banas, and Banganga rivers and receive comparatively more rainfall (50–100 cm). The southern plateau includes the Mewar and Hadoti regions, known for their granite and marble reserves. Rajasthan’s climate is predominantly arid to semi-arid, with summer temperatures rising to 45°C and winter temperatures dropping to 0°C. Rainfall is unevenly distributed—less than 20 cm in the west and up to 80–100 cm in the southeast. Natural resources include forests (about 9% of the total area), as well as rich reserves of marble, zinc, copper, and mica. Key water resources include seasonal rivers like Chambal, Banas, Luni, and Mahi, and important lakes such as Sambhar (saline), Pichola, Udaipur’s Fatehsagar, and Udaisagar. This diverse geographic makeup profoundly influences the state’s climate, agriculture, economy, and cultural life.

Research Findings and Discussion

According to Table 1, data from various years of the Forest Survey of India reveals fluctuations in forest cover across Rajasthan. In 2001, the state had a total forest cover of 16,367 sq. km, accounting

for 4.78% of the total geographical area. In 2003, forest cover dropped by 3.31% to 15,826 sq. km (4.62%). It then increased by 1.02% in 2005, reaching 15,987 sq. km. This incremental rise continued in 2007 (0.31%) and remained stable in 2009. A slight increase (0.32%) was observed in 2011, bringing the forest cover to 16,087 sq. km. The situation remained almost unchanged in 2013, but in 2015, a 0.53% positive growth was recorded, increasing the forest area to 16,171 sq. km.

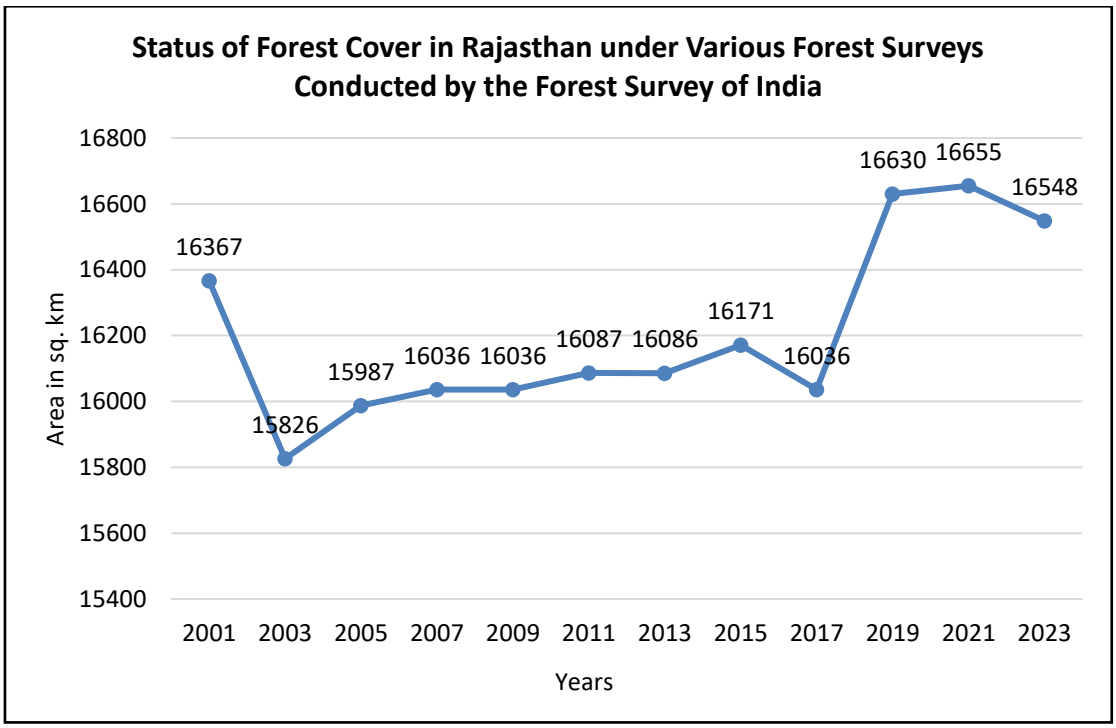
However, in 2017, there was again a decline of 0.83%, reducing the forest area to 16,036 sq. km, suggesting that despite conservation efforts, forest cover remained under pressure. In 2019, there was a significant increase of 3.70%, raising the forest area to 16,630 sq. km. This was followed by a slight increase (0.15%) in 2021, reaching 16,655 sq. km, the highest percentage (4.87%) of forest cover recorded for the state. But in 2023, there was a 0.64% decline, bringing the forest cover down to 16,548 sq. km, which represents 4.84% of the state's total area.

Table 1: Status of Forest Cover in Rajasthan under Various Forest Surveys Conducted by the Forest Survey of India

Year	Total Forest Cover (in sq. km)	Change (in %)	% of Rajasthan's Total Geographical Area
2001	16,367		4.78%
2003	15,826	-3.31%	4.62%
2005	15,987	1.02%	4.67%
2007	16,036	0.31%	4.69%
2009	16,036	0.00%	4.69%
2011	16,087	0.32%	4.70%
2013	16,086	-0.01%	4.70%
2015	16,171	0.53%	4.73%
2017	16,036	-0.83%	4.69%
2019	16,630	3.70%	4.86%
2021	16,655	0.15%	4.87%
2023	16,548	-0.64%	4.84%

Source: Website Forest Survey of India, https://fsi.nic.in/forest-report-2015

Fig. 1



According to Table 2, significant changes have been observed in forest cover across various districts of Rajasthan between 2001 and 2023. At the state level, the total forest cover increased by 181.21 sq. km, representing only a 1.11% rise. The highest increase in forest cover was recorded in Jaisalmer district, where forest cover grew from only 156 sq. km in 2001 to 341.31 sq. km in 2023—an increase of 185.31 sq. km, or 118.79%, which is the highest percentage change in any district. Additionally, districts such as Barmer (83.34%), Sri Ganganagar (59.80%), Nagaur (51.26%), Pratapgarh (37.31%), Bikaner (30.37%), and Bundi (25.52%) also showed notable increases in forest cover. On the other hand, several districts witnessed significant declines in forest cover. Chittorgarh district experienced the greatest decline of 468.92 sq. km (32.18%), which is a cause of concern for the state. Other districts showing decreases include Banswara (-27.64%), Baran (-9.96%), Bharatpur (-9.20%), Jaipur (-9.38%), Udaipur (-10.59%), and Kota (-13.39%).

Table 2: District-wise Forest Cover in Rajasthan (2001 and 2023)

S. No.	District	Forest Cover (2001)	Forest Cover (2023)	Change (in sq. km)	Change (in %)
1	Ajmer	272	335.01	63.01	23.17%
2	Alwar	1211	1198.74	-12.26	-1.01%
3	Banswara	370	267.75	-102.25	-27.64%
4	Baran	1083	975.13	-107.87	-9.96%
5	Barmer	169	309.84	140.84	83.34%
6	Bharatpur	236	214.28	-21.72	-9.20%
7	Bhilwara	220	236.97	16.97	7.71%
8	Bikaner	199	259.44	60.44	30.37%
9	Bundi	445	558.58	113.58	25.52%
10	Chittorgarh	1457	988.08	-468.92	-32.18%
11	Churu	80	62.73	-17.27	-21.59%
12	Dausa	102	121.8	19.8	19.41%
13	Dholpur	419	400.23	-18.77	-4.48%
14	Dungarpur	252	301.99	49.99	19.84%
15	Hanumangarh	72	92.29	20.29	28.18%
16	Jaipur	623	564.58	-58.42	-9.38%
17	Jaisalmer	156	341.31	185.31	118.79%
18	Jalore	197	222.41	25.41	12.90%
19	Jhalawar	395	440.04	45.04	11.40%
20	Jhunjhunu	188	196.83	8.83	4.70%
21	Jodhpur	92	111.23	19.23	20.90%
22	Karauli	722	760.42	38.42	5.32%
23	Kota	613	530.91	-82.09	-13.39%
24	Nagaur	113	170.92	57.92	51.26%
25	Pali	619	692.87	73.87	11.93%
26	Pratapgarh	726	996.86	270.86	37.31%
27	Rajsamand	418	513.36	95.36	22.81%
28	Sawai Madhopur	512	517.42	5.42	1.06%
29	Sri Ganganagar	71	113.46	42.46	59.80%
30	Sikar	189	218.55	29.55	15.63%
31	Sirohi	885	899.45	14.45	1.63%
32	Tonk	167	170.43	3.43	2.05%
33	Udaipur	3094	2766.3	-327.7	-10.59%
34	Total (Rajasthan):	16,367	16,548.21	181.21	1.11%

Source: Website Forest Survey of India, https://fsi.nic.in/forest-report-2015

According to Table 3, there has been a remarkable change in the frequency and intensity of heatwave incidents across various districts of Rajasthan from 2000 to 2024. Comparing the years 2000–2001 with 2021–2023 reveals an increase in both frequency and severity of heatwaves in most districts. The highest total number of heatwave incidents has been recorded in districts such as Karauli (330),

Churu (278), Jaisalmer (275), Barmer (271), and Bikaner (266). These districts are spread across the semi-arid to arid zones of Rajasthan, which already tend to experience high temperatures. Notably, there has been an increase in the number of incidents in the recent period (2021–2023) compared to 2000–2001—such as +2 in Jaisalmer, +3 in Bikaner, and +2 in Barmer—indicating increasingly extreme heat conditions in desert regions.

Additionally, districts like Hanumangarh, Nagaur, and Sri Ganganagar have shown an increase of 4 heatwave incidents each in recent years. On the contrary, some districts like Bhilwara, Chittorgarh, Dungarpur, Jhalawar, Sirohi, and Udaipur showed no change between the two periods, while a few districts recorded minor declines in heatwave events, such as Banswara (-1), Dholpur (-1), Jhunjhunu (-1), Jodhpur (-1), Tonk (-1), Sawai Madhopur (-2), and Sikar (-2). Although these changes are small, they may indicate local climatic changes or the impact of effective urban/rural climate management strategies.

Table 3: District-wise Status of Forest Cover and Heatwave Events in Rajasthan in 2001 and 2023

S. No.	District	Total Heatwave Events (2000–2024)	Heatwave Events (2000–2001)	Heatwave Events (2021–2023)	Difference (2021–2023 vs. 2000–2001)
1	Ajmer	237	10	12	2
2	Alwar	226	8	9	1
3	Banswara	203	6	5	-1
4	Baran	182	6	7	1
5	Barmer	271	16	18	2
6	Bharatpur	234	7	8	1
7	Bhilwara	229	6	6	0
8	Bikaner	266	17	20	3
9	Bundi	204	4	5	1
10	Chittorgarh	194	4	4	0
11	Churu	278	15	17	2
12	Dausa	222	5	6	1
13	Dholpur	228	8	7	-1
14	Dungarpur	201	3	3	0
15	Hanumangarh	217	9	13	4
16	Jaipur	223	9	11	2
17	Jaisalmer	275	20	22	2
18	Jalore	186	13	14	1
19	Jhalawar	188	5	5	0
20	Jhunjhunu	254	13	12	-1
21	Jodhpur	259	20	19	-1
22	Karauli	330	5	5	0
23	Kota	183	7	8	1
24	Nagaur	253	12	16	4
25	Pali	238	10	12	2
26	Pratapgarh	182	3	4	1
27	Rajsamand	205	3	4	1
28	Sawai Madhopur	195	8	6	-2
29	Sri Ganganagar	214	11	15	4
30	Sikar	257	15	13	-2
31	Sirohi	155	3	3	0
32	Tonk	191	9	8	-1
33	Udaipur	184	3	3	0

Source: Website NASA's POWER Data Access Viewer

https://power.larc.nasa.gov/data-access-viewer/

Based on the regression analysis of changes in forest cover between 2001 and 2023 and changes in heatwave events between 2000–2001 and 2021–2023, it is clear that there is a statistically

significant correlation between deforestation and extreme temperature events in Rajasthan. The regression statistics reveal a moderate positive correlation between the two variables (Multiple R = 0.466), with deforestation explaining approximately 21.7% (R^2 = 0.217) of the change in extreme temperature events. Likewise, the ANOVA results confirm that this relationship is statistically significant (Significance F = 0.00627, which is less than 0.05), validating the research hypothesis.

The regression equation derived from the coefficients table ($\hat{Y}$ = 0.4699 + 0.0242X) indicates that a one-unit decrease in forest cover results in an average increase of 0.0242 units in extreme temperature events. This effect is statistically significant (p-value = 0.0063), although the intercept is not statistically significant (p-value = 0.0984). Thus, the regression analysis supports the research hypothesis that deforestation has contributed to the rise in heatwave events. However, it is important to note that other factors such as greenhouse gas emissions, air pollution, and climate change also influence heatwave events, as the R^2 value remains relatively low at 21.7%.

Table 4: Regression Statistics

Metric	Value
Multiple R	0.46596622
R Square	0.217124518
Adjusted R Square	0.19187047
Standard Error	1.429434171
Observations	33

Sources: Self-calculation

Table 5: ANOVA Results

Source	df	SS	MS	F	Significance F
Regression	1	17.5673	17.5673	8.5976	0.0063
Residual	31	63.3417	2.0433		
Total	32	80.9091			

Sources: Self-calculation

Table 6: Coefficients Results

Term	Coefficient	Std. Error	t-Stat	P-value	Lower 95%	Upper 95%
Intercept	0.4699	0.2757	1.7042	0.0984	-0.0925	1.0322
X Variable 1	0.0242	0.0082	2.9322	0.0063	0.0074	0.0410

Sources: Self-calculation

Conclusion

This study conducted in Rajasthan during 2000–2024 clearly indicates a statistically significant correlation (R = 0.466, p-value = 0.0063) between deforestation and increasing heatwave events. Between 2001–2023, the forest cover increased by only 1.11%, whereas districts like Chittorgarh, Banswara, and Udaipur witnessed a decline of 10–30%. Simultaneously, the frequency and intensity of heatwaves rose, particularly in desert districts such as Jaisalmer, Barmer, and Bikaner. According to the regression analysis, a one-unit reduction in forest area results in an average increase of 0.0242 units in heatwave events. However, this relationship explains only 21.7% of the variability (R^2).

This suggests that deforestation is a key factor in rising heatwaves, although other factors (like climate change, urban heat island effect) also play significant roles. Therefore, to mitigate the impact of heatwaves in Rajasthan, immediate attention is required toward forest conservation, sustainable land use planning, and climate adaptation strategies. This research provides a crucial foundation for protecting forest-based ecosystems and guiding policy interventions.

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