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Impact Of Indian Ocean Climate Indicates On Monsoonal Rainfall In India

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Abstract
The present study investigates the influence of the Pacific Decadal Oscillation (PDO) on the Indian monsoon using a linked climate model. The PDO is characterized by temperature fluctuations in the tropical Pacific Ocean, exhibiting shifts between cool (negative phase) and warm (positive phase) conditions, which can significantly impact global weather systems. In the Asia-Pacific region, the PDO primarily affects sea surface temperatures and oceanic circulation patterns, with secondary effects on regional climate, precipitation, and atmospheric dynamics. This study aims to examine the relationship between the PDO and monsoonal rainfall at five meteorological stations across India. The findings reveal both positive and negative correlations between PDO phases and monsoonal precipitation at the selected locations. Overall, the results suggest that a strong PDO signal is often associated with a weaker Indian monsoon. A better understanding of the interplay between large-scale ocean-atmosphere indices and land-surface hydrological processes could enhance the accuracy of monsoon forecasting in India.
Keywords: *Indian Monsoonal Rainfall; PDO Index; Modeling and Climate change.*

1. INTRODUCTION

The rainy weather season its periodic change in the dominant winds' direction, which is frequently connected to tropical regions' wet and dry seasons. The intertropical Convergence Zone's yearly latitudinal oscillation is the cause of it. The monsoon, which originates in the southwest during the warmer months of the year and the northeast during the cooler months, covers India and the adjacent marine regions. Through southwester lies, the wind direction's seasonal reversal that happens in May transports an abundance of dampness caused by warm tropical Sea waters for the Indian continent. An Emergence of a strong system of low pressure above the Tibetan Plateau has the cause of a former.
The latter being the outcome of high pressure cells forming throughout the Siberian and Tibetan. Most of India's annual precipitation occurs by the summertime monsoon, sometimes known as the monsoon season in southwest, which lasts June to September.
The winter monsoon season includes another name for the northeast monsoon, adds a minor portion of India's yearly precipitation to the northeastern regions of the country from October to December. Large volumes of heat and moisture are transported across the equator by the summer monsoon in India; it is a part of the vast monsoon season in Asia circulation system, from South Asia to the Indian Ocean, and even farther south as China's eastern region. There are notable differences between the tropical monsoon circulations in East Asia and Southern Asia, which includes India-Pakistan and Southeast Asia. Monsoons are primarily in charge of the weather patterns above the North Indian Ocean and the adjacent mainland. The temperatures of the sea surface India's eastern ocean coast is home to warmer than those on the western side because of the monsoons. The wind's dynamics flows within the Indian Ocean's equatorial area differ from those in The Sea of Arabia and Vanga Sagar. Across the Indian Ocean's equatorial zone, a winds are weaker during the monsoon season, but in the spring (mid in summer and fall (start winter), rather powerful winds from the west begin to form (Wyrtki, 1973).Positive where the Dipole of the Indian Ocean (IOD) has negative are two phases for IOD. In the course of the former stage, the Indian Ocean's western region gets abnormally warm while across the equator; the eastern Indian Ocean turns into abnormally chilly. This typically lasts from September to October. El Niño denotes the ocean's warming phase, while La Niña denotes its cooling phase. A substantial when powerful westerly winds blow across the Pacific basin, El Niño is identified, and it is further amplified by easterly winds.
According to the study, the western Pacific becomes drier as El Niño develops both hurricane and

convection thunderstorms throughout the Midwest Pacific, and the amount of rain on equatorial South American coast. La Niña, which enters the eastern and central Pacific with robust trade winds and chilly water, follows a severe El Niño. Tropical monsoons and the Zone of Intertropical Convergence closely connected too globally. Seasons within tropical region are mostly determined by the global circulation's shift towards the Sun's greater radiation. The region's zone of greatest solar input energy, which determines when precipitation and heavy seasonal rains occur, is noticeably vast. The southern hemisphere's southeast trade winds traverse
the equator and begin to blow southwest due to the Orioles force towards the Indian subcontinent. The Indian subcontinent heats up during the ITCZ shift, creating generating a region of low pressure that pulls humid air from the sea. A region of low pressure that attracts humid air from the Sea. Known also as the monsoon trough, the equatorial depression lies across the plain of the Ganga approximately 25 degrees north of the equator. Over 68% of India's population works in agriculture, and the country's big famines are largely caused by drought and related agricultural activities. Based on the Economic Survey 2019–2020, the farming sector employs over 62% of the population and accounts for approximately 16% of India's GDP.

A comprehensive study is necessary to evaluate the relationship between SST changes and drought conditions in order to understand how drought reacts to ocean variability in the influence of ENSO and the IOD, such as land surface characteristics in terms of anomalies in solar-induced chlorophyll fluorescence (SIF), particularly terrestrial photosynthesis. Because each step in this cause-and-effect chain has a time lag, Meteorological parameters do not predict terrestrial photosynthesis variations as well as SST indicators do. Numerous studies have demonstrated that using SST, plant greenness in the tropical belt's dry and semi-arid climatic zones may be forecast three to six months in advance. Not all of the particular dynamics of these two years were looked into. El Niño years were notable in 2009 and 2015, with a positive IOD indicating a strong El Niño year. Severe droughts were brought on by below-average rainfall on the Indian landmass. To gain a deeper comprehension of how the ENSO affects shifts from dry to rainy throughout the two PDO phases and maybe enhance dry-wet change predictions, we examine the combined global-scale impact of various PDO stages on the patterns of dry-wet anomalies associated with ENSO. Since the tropical Pacific has the greatest impact on the climate during Just December, January, and February (DJF) are considered to constitute the boreal winter (18, 19, and 20) Covered here.

The PDO is an extended climate pattern that fluctuates throughout decadal to multi-decadal durations, with each phase usually lasting 20 to 30 years. A change within the North warmth of the Pacific Ocean's sea surface trends is what defines the PDO. It consists from the transition among cool negative while warm positive phases. Within the North Asia, the PDO mostly affects oceanic patterns and sea surface temperatures. It may have secondary impacts on local temperature conditions, precipitation patterns, and air circulation. A shorter-term climatic
phenomenon is ENSO, having erratic cycles, usually lasting two to seven years. El Niño and La Niña have its 2 main stages, with a neutral period in between. The tropical Pacific Ocean, particularly the middle and eastern tropical Pacific, ENSO causes changes within the temperature from the sea surface as well as the pressure of air patterns. Significant changes within air circulation brought on by ENSO have the potential to modify precipitation, temperature anomalies, and weather patterns throughout the Pacific basin and beyond. Despite being a single climate event, ENSO can exist in three different states, or phases. Due of ENSO's connection to the climate, the pair opposing phases, "El Niño" as well as "La Niña," necessitate specific alterations in the atmosphere as well as ocean. In the center of the spectrum is "neutral."El Niño: Those eastern and central regions within the tropical Pacific Sea are heating, as evidenced by above-normal temperatures of the sea surface. Rainfall usually diminishes throughout Indonesia and increase across The Pacific Ocean's tropical climate. Known as "easterly winds," these typically, low-level Surface breezes blow from east to west near the center of the earth, either weaken or begin to blow away a different guidance. ("Westerly winds," or east to west) under specific circumstances. La Niña: A decrease within the eastern or central portions on the tropical indo-Pacific Sea, defined beside the sea surface temperatures that are below average (SST). Rainfall tends to increase over Indonesia while it tends to decrease Throughout the Pacific Ocean's tropical centre. Usually breeze from east get much stronger around the equator. El Niño and La Niña are both neutral. Sea surface anomaly the tropical Pacific is home to often close to average. Nevertheless, there are times when the atmosphere

and oceans are not working together appearance of being in a condition of El Niño or La Niña, or opposite. You may have noticed by now that although "ENSO" is a good catch-all acronym for all three states, the word "La Niña" isn't actually included in that acronym.

2. LITERATURE REVIEW

A trend of climatic fluctuation in the Pacific known as Decadal Oscillation in the Pacific [7] alternates between Inter-decadal timeframe periods frame, often between 20 to 30 year's old. In addition to the ENSO index, it is a significant large-scale climatic indicator. In their investigation, Gershunov et al. [6] discovered that the wintry occurrences of severe temperatures and a lot of rain were a characteristic of ENSO. This is obtained for the contiguous United States actual experiences as well as the output of the general movement of the atmosphere models. ENSO's suitability as a key variable in stream flow forecasting was discovered by Garen [8].

A topic of significant practical importance has been the assessment of the effects of massive climatic indicators regarding meteorological phenomena in various parts of around the globe. Numerous studies around the globe have concluded that there is a strong relationship between precipitation and large climate indices (4, 5). It was discovered that ENSO events change the frequency and amount of rainfall on a daily basis [6, 21]. Throughout many regions of the globe, agricultural productivity is dependent on rainfall due to ineffective irrigation. In India, rainfall during the monsoon season has a significant impact on irrigation output. Knowledge via basin- scale weather engines, like those created by Burn and Sharif [23,24] and Sharif et al. [22], is frequently used in agricultural output forecasts.

From differences in precipitation from yearly According to the monsoons result in serious droughts as well as floods. El Nino events in 2014 as well as their effects on rainfall during the southern monsoon were examined in an investigation by Gautam et al. [9]. and Deng et al. [10] examined the internal variability in precipitation in several Chinese locations. The geographic makeup effects ENSO across Australia had evolved during the previous several decades, according to Roy and Collins [11]. Thus, it is likely that changes in regional Storm rotation are what have influenced the rainfall during the past Indian midsummer rainy (ISM) few years.

Amudha et al**.** [1] investigated Using INSAT OLR information, the geographical variance of influencing and precipitation across the southeast Indian coast and the nearby Bay of Bengal is linked to both strong and dry northeastern rainy periods, 559–570. The relative significance considering the different rainfall data in the random precipitation correction Production algorithms is discussed by Olivera and Kim [2]. Guhathakurta and Rajeevan. [3] examined the changes in the pattern of rainfall across India Using a System of roughly the monthly, cyclical, and yearly precipitation time series of 36 Indian meteorology sub divisions have been generated using 1476 rain-gauge points. To look into the historical trends of rainfall over a number of sub-divisions, trend analysis was done. It has been discovered that, in a few subdivisions, the input of rainfall in Compared to the yearly precipitation, JJA were declining, whereas in several other subdivisions, the contribution of the rainfall in August is rising.

Within the Oceania location, An ENSO event has been connected with fluctuations in air pressure and anomalies in sea surface temperature (SST). By what are known as environmental links [12], impact on the weather seasons in several parts of the planet [15 &16], Argentina is among them [13 & 14]. The impact of ENSO on Córdoba's rains Provincial results in values that are equivalent to or higher than usual throughout the pleasant temperatures period (El Niño) as well as the reverse impact in the season of cold (La Niña), which has been linked to the frequency of drought of varying lengths and severity.

El Niño occurrences have recently been classified into two categories [17, 18, 19 & 20]. Although the eastern to mid tropical the seafloor of the Pacific Ocean is typically thought to warm during El Niño, Additionally, another El Niño event could occur when temperatures rise is limited to the worldwide date line zone. Other names for this kind of El Niño include hot pool El Niño [34], timeline El Niño [19], and Central Pacific El Niño [33].

Although a complete understanding of variations in rainfall is still a long way off, temporary component forecasting based on its association with oceanic and meteorological states provides some tangible opportunities to lower the degree of volatility and risk in agriculture output in the Pacific Ocean region. This understanding may be utilized as strategic data to determine ahead of time the best agricultural or

environmental management methods based on each predicted climatic situation [32].
During the dipole of the Indian Ocean (IOD; Webster et al. [28]. episodes, flow Airflow drifting Indian Ocean area may also reorganize, involving changes in the ITCZ. Increased upwelling, chilly SST anomaly away from Sumatra and abnormally hot On the Indian Ocean's southwestern region, SST is characteristics of positive IOD episodes. Are linked to unusually dry conditions over Indonesia and a stronger southwest monsoon throughout India**.** Ding et al. [26] discovered that an abnormally weak subtropical high in the Western Pacific Ocean that began in 1953 to 1975 was linked to IOD episodes and a greater East Asian summer rainfall. As demonstrated to Indians precipitation on an interannual basis Ashok et al. [30 & 31]; Saji and Ashok [27]. As
well as decadal timeframes Ummenhofer et al. [27], IOD phenomena also possess the ability to modify the ENSO-Asian monsoon association.

3. Study Area and Data collection

The yearly mean maximum Index (Tmax), yearly means minimum Index (Tmin) and The Pune- based India Meteorological Department offers monthly precipitation (PPT) information regarding various stations. Five stations in all were considered consideration in this research; Figure 1 displays the geographic locations of the various stations taken into consideration in this investigation. At all stations Ajmer, Bhopal, Gorakhpur, Hyderabad and Kolkata, the precipitation data is available from 1950-2015. Table 1 displays the features of several stations. The PDO figure-7. The Climate Analysis Section provided the index which is the anomaly in SST within the North Pacific Ocean over the PDO area north of 20° N, North American Climate and the Pacific Basin's the National Centers of Environmental Information. As seen in Figure 7, the PDO in the Pacific Ocean.

Table 1 Area, elevation, latitude, and longitude of each of the five stations

Station	Longitude	Latitude	Elevation (Mtr)	Area Sq.km.
Ajmer	74° 42' E	26° 27' N	200	8481
Bhopal	77° 45' E	23° 15' N	527	2772
Gorakhpur	83° 24' E	26° 45' N	84	3483.8
Hyderabad	78° 47' E	17° 366' N	505	217
Kolkata	88° 21' E	22° 82' N	9.1	185

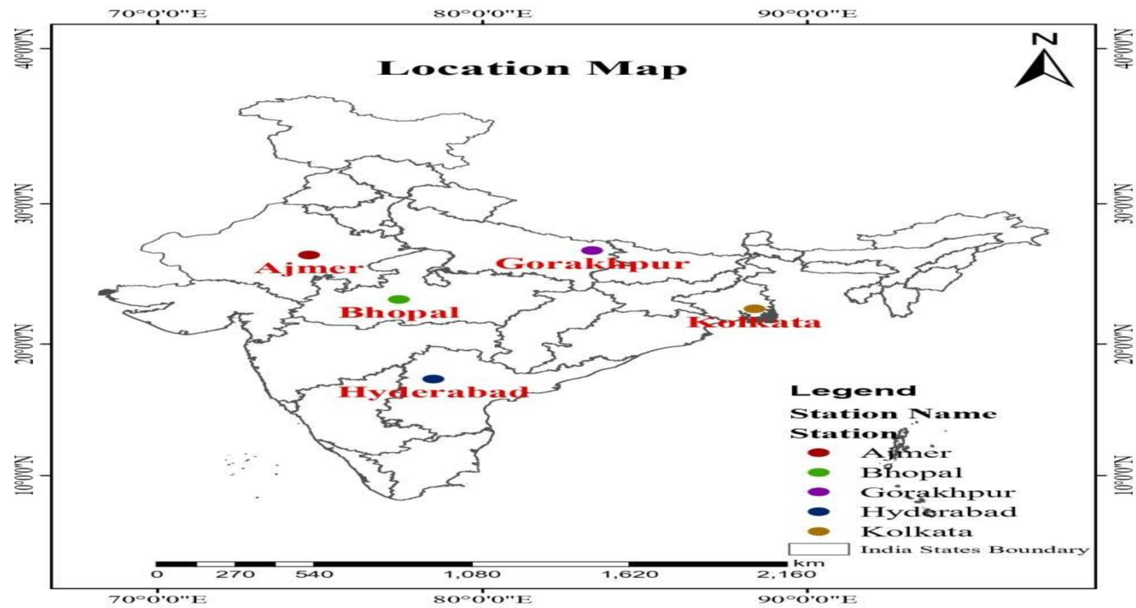

Figure 1 Geographical locations of stations**.**

4. METHODOLOGY

Many techniques have being employed to investigate the correlation Among the temperature of the ocean's surface in relation to Indian Ocean as well as the Indian Ocean monsoon, including the first step in the proposed project is the assortment of monsoonal statistics on precipitation from locations in different parts of India. The data shall be procured from Indian Meteorological Department (IMD), and Pacific Decadal Oscillation (PDO). Next step is to identify an approach that could be used regarding the identification of connections among monsoonal rainfall and extensive climate indices. Finally to develop seasonal monsoon rainfall over five stations will be made through developing statistical relationships.

The study employed Annual rainfall data from the IMD (Pune) for 60 years (1955–2015) and temperature data from 1950–2024 for 74 years, Monthly, winter season, pre-monsoon, the monsoon June to September, and the after the monsoon October to November and yearly patterns were assessed for each and every one of India's five major sub division. Likewise, the trend change was displayed using the percentage of change. Using various colours and symbols,

the rainfall and temperature diagram displayed the trend of increasing and decreasing with the level of significance and change.

5. RESULTS AND DISCUSSIONS

the findings are displayed in a variety of graphs that display India's average monsoonal rainfall throughout 1955 – 2015 (shown Figure 2 – 6) and sea surface temperature throughout the 1950– 2024 (shown Figure 7) timeframe. The index's abnormalities in temperature index 8–12 region were calculated using the average monsoonal temperature for the years 1950–2015. The association among monsoonal rainfall in five station (cities) and Indian Ocean climate variables was evaluated using the method of Pearson correlation assessment.

The correlation coefficients values shown are in Table 3. A weak negative connection that was not highly significant was observed in Ajmer. A very modest negative connection that was likewise not statistically significant was shown by Bhopal. A very modest negative connection that was likewise not statistically significant was shown by Gorakhpur. Hyderabad displayed a statistically significant slight negative correlation. Kolkata showed a slight positive association that wasn't statistically significant.

To ascertain the effect of PDO on the monsoonal precipitation at the various sites under investigation, a correlation study was conducted. At few stations, the connection was found to be negative and few have found positive. Demonstrating that, on average, India's monsoonal precipitation falls as the PDO temperature raises shown Table 2. The correlation's p-value was calculated to evaluate its statistical importance. The correlation coefficient values and corresponding p-values are displayed in Table 3. At the 4.5% significance level, if a trend's the

P-value is below 0.05, it's deemed significant in terms of statistics. It is commonly known that PDO has an impact on global weather conditions. It is still unclear, though, exactly how PDO affects monsoonal precipitation. The present study's analysis's findings unequivocally demonstrated the inverse relationship between monsoonal precipitations and correlated with the El Nino phenomenon in other regions of the planet in India.

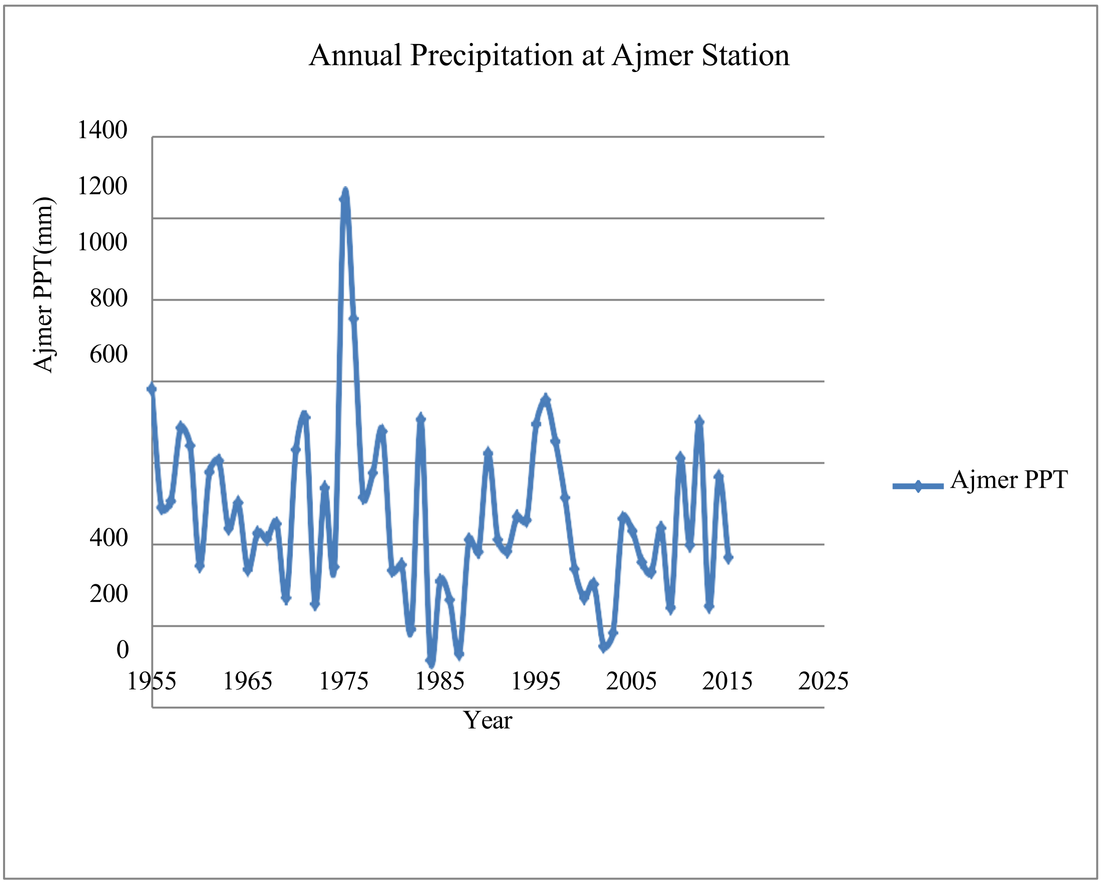

Figure 2 Annual Precipitation at Ajmer station for 1955 to 2015

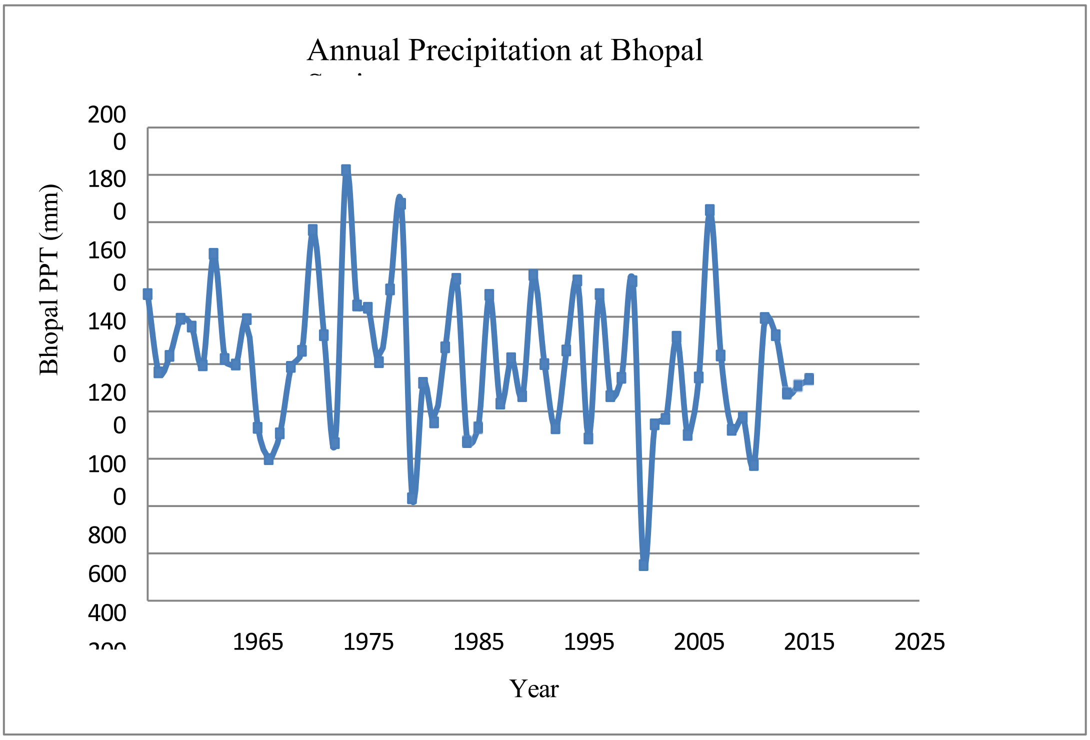

Figure 3 Annual Precipitation at Bhopal station for 1955 to 2015.

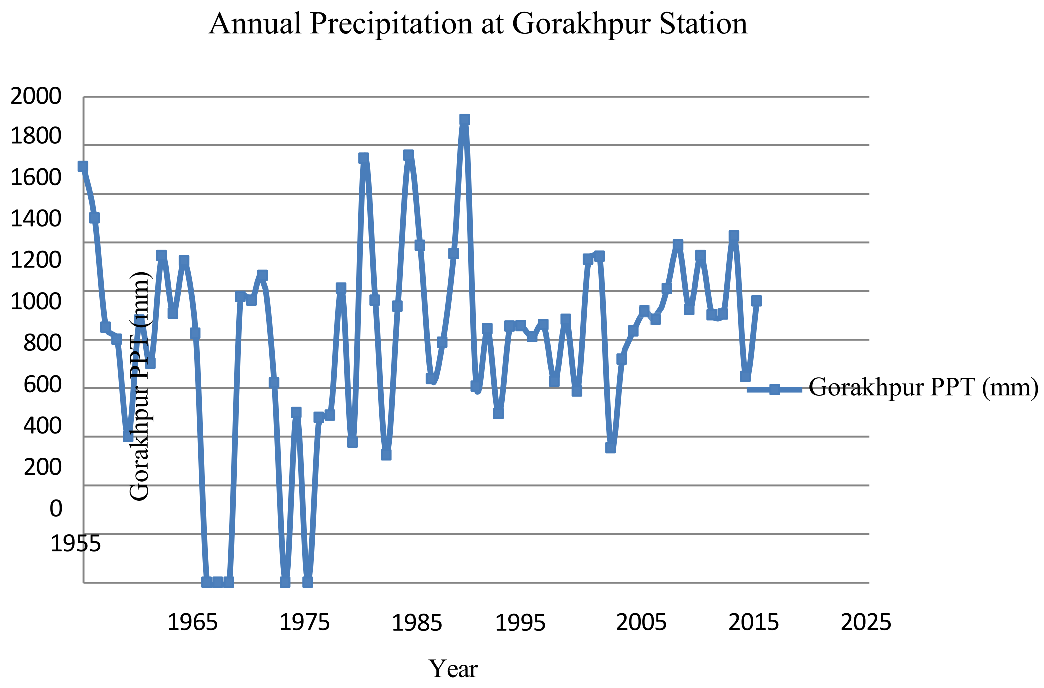

Figure 4 Annual Precipitation at Gorakhpur station for 1955 to 2015

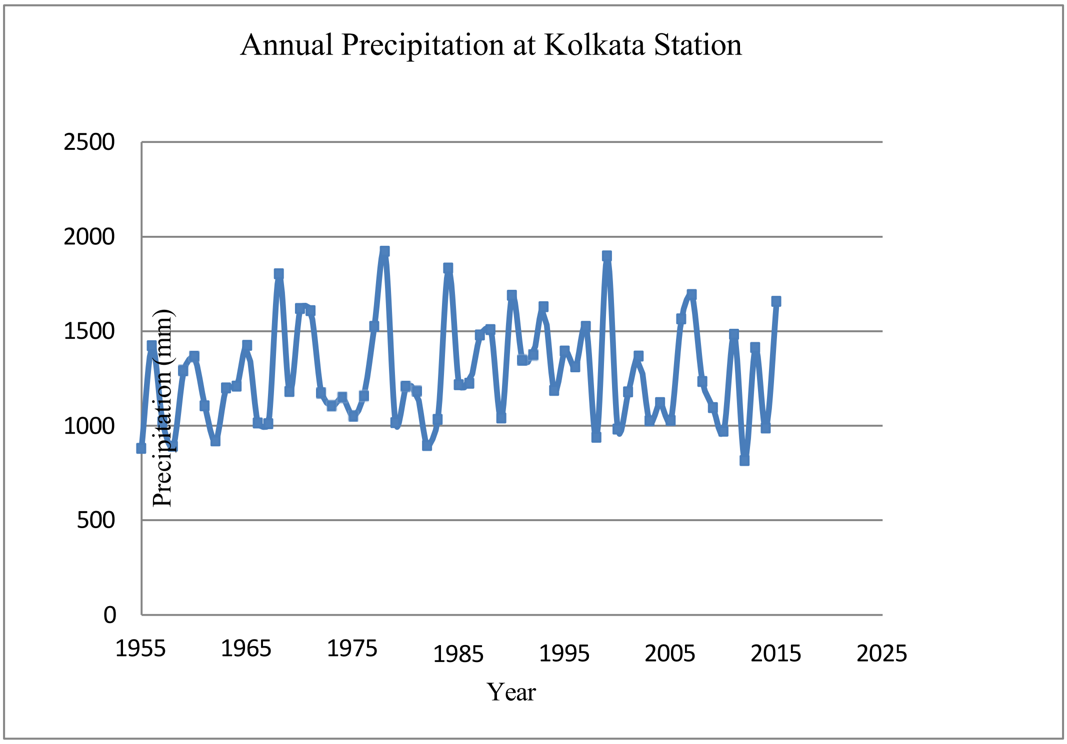

Figure 5 Annual Precipitation at Kolkata station for 1955 to 2015

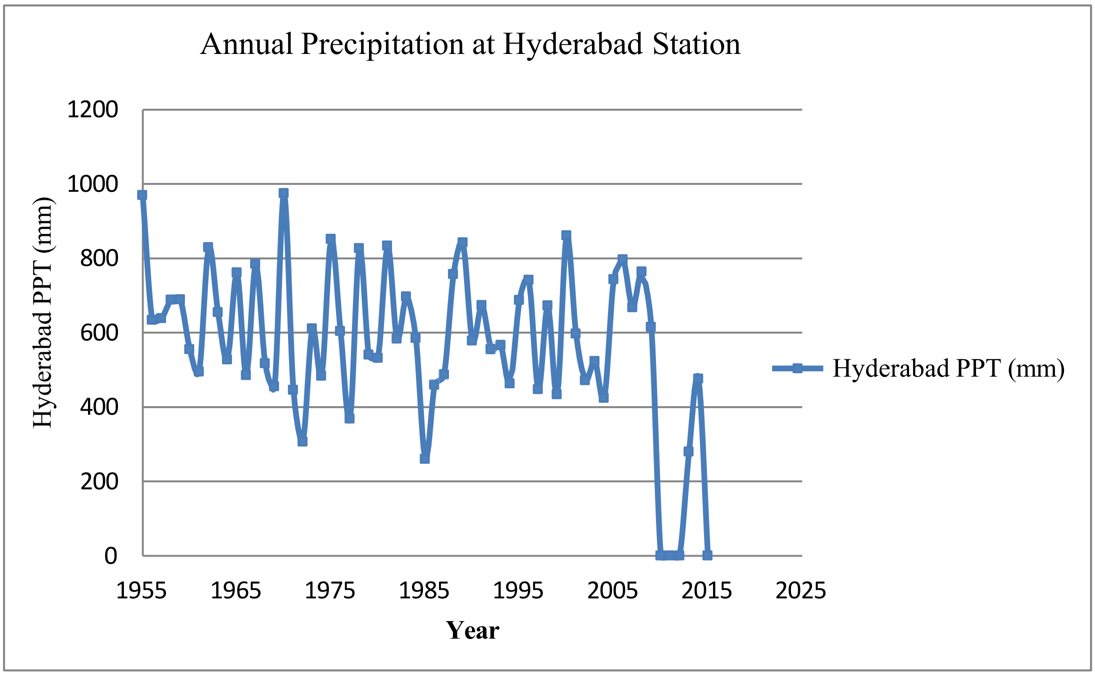

Figure 6 Annual Precipitation at Hyderabad station for 1955 to 2015

Table 2 Pacific Decadal Oscillation (PDO) years (1950 – 2024)

S. No	Year	Avg. Monthly Temperature	S. No	Year	Avg. Monthly Temperature
1	1950	-2.24	45	1991	-0.88
2	1951	-1.12	46	1992	0.76
3	1952	-1.55	47	1993	1.04
4	1953	-0.64	48	1994	-0.49
5	1954	-0.40	49	1995	0.44
6	1955	-2.07	50	1996	0.68
7	1956	-1.81	51	1997	1.32
8	1957	0.29	52	1998	-0.48
9	1958	0.86	53	1999	-1.84
10	1959	0.27	54	2000	-1.13
11	1960	0.04	55	2001	-1.13
12	1961	-0.57	56	2002	-0.44
13	1962	-1.08	57	2003	0.38
14	1963	-0.24	58	2004	-0.22
15	1964	-0.89	59	2005	-0.19
16	1965	-0.14	60	2006	-0.35
17	1966	-0.44	61	2007	-0.70
18	1967	-0.74	62	2008	-1.66

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19	1968	-0.15	63	2009	-1.03
20	1969	-0.34	64	2010	-1.06
21	1970	-0.40	65	2011	-1.81
22	1971	-1.32	66	2012	-1.73
23	1972	-1.14	67	2013	-1.17
24	1973	-1.14	68	2014	0.55
25	1974	-0.30	69	2015	0.92
26	1975	-1.41	70	2016	0.67
27	1976	-0.15	71	2017	-0.10
28	1977	0.05	72	2018	-0.37
29	1978	0.07	73	2019	-0.16
30	1979	0.11	74	2020	-1.14
31	1980	0.31	75	2021	-1.88
32	1981	0.84	76	2022	-1.71
33	1982	-0.26	77	2023	-2.25
34	1983	1.25	78	2024	-2.60
35	1984	0.60			
36	1985	0.03			
37	1986	1.01			
38	1987	1.14			
39	1988	-0.04			
40	1989	-0.50			
44	1990	-0.83			

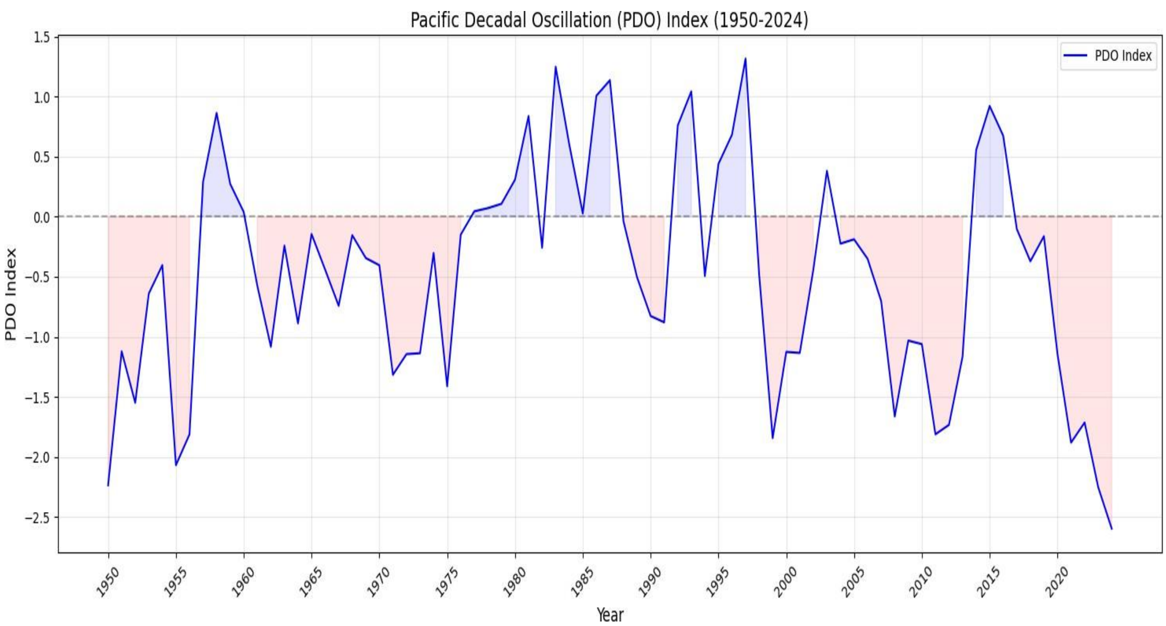


Figure 7 Pacific decadal oscillation (POD) Index (Temperature) 1950 to 2024.

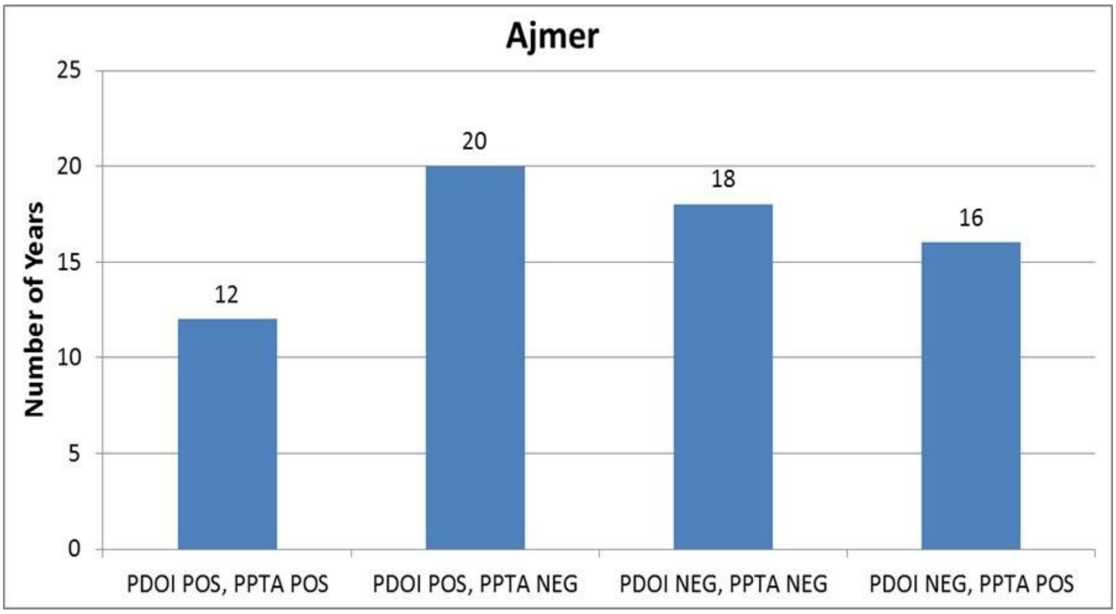


Figure 8 PDO index with rainfall anomalies at Ajmer station for 1955 to 2015

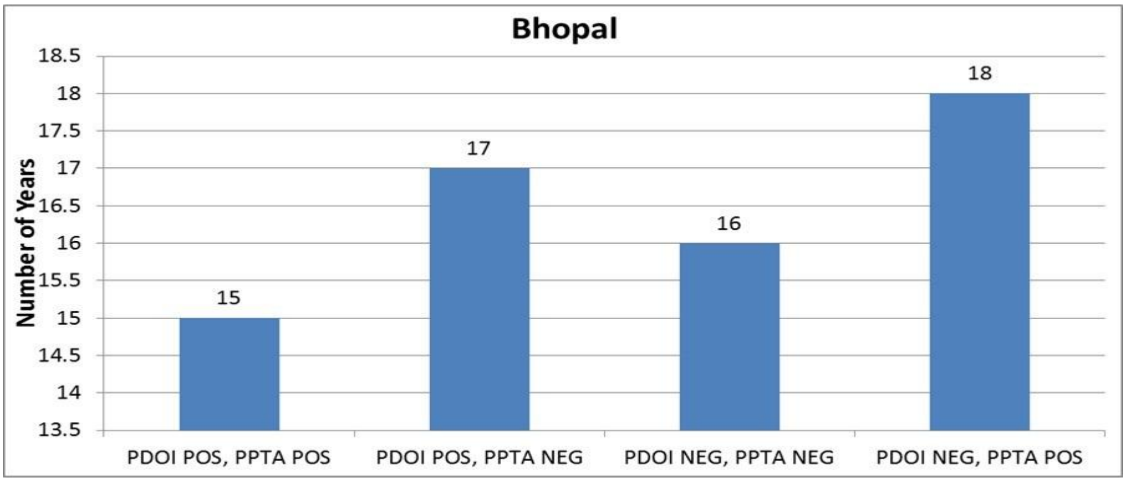
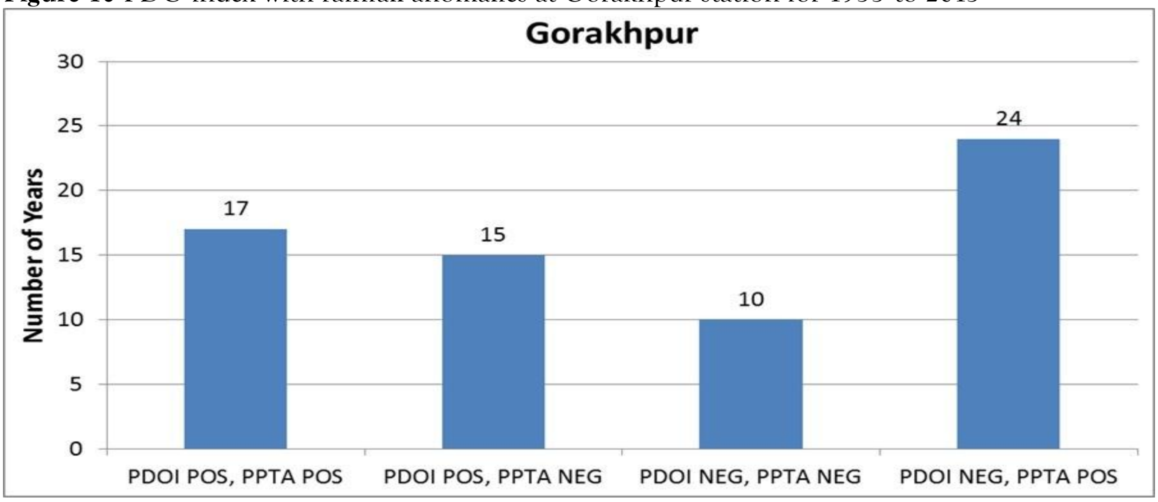


Figure 9 PDO index with rainfall anomalies at Bhopal station for 1955 to 2015

Figure 10 PDO index with rainfall anomalies at Gorakhpur station for 1955 to 2015



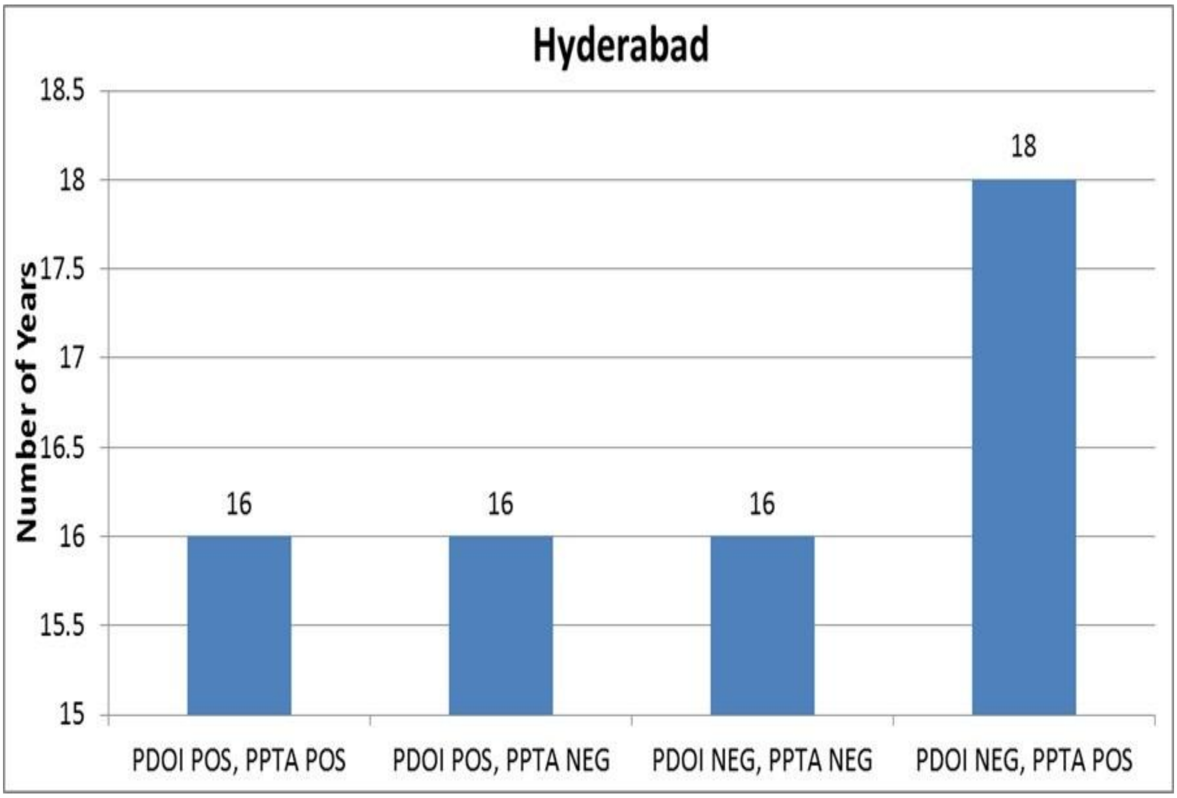


Figure 11 PDO index with rainfall anomalies at Hyderabad station for 1955 to 2015

Figure 12 PDO index with rainfall anomalies at Kolkata station for 1955 to 2015

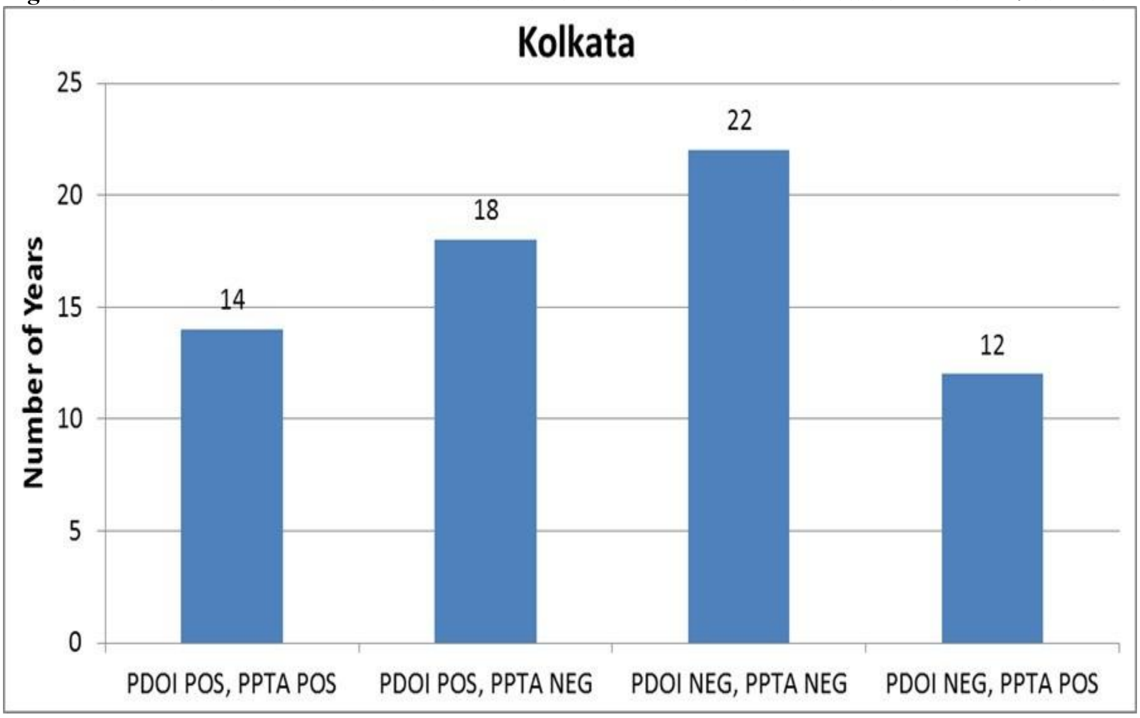


Table 3 Correlation co-efficient and associated p-values for various stations.

Slr.	Station	Correlation Co-efficient	p-value
i	Ajmer	-0.227	0.067
ii	Bhopal	-0.080	0.521
iii	Gorakhpur	0.184	0.140
iv	Hyderabad	-0.235	0.058
v	Kolkata	0.202	0.103

6. CONCLUSIONS

The current study's primary objective is to investigate the relationships between Monsoonal and PDO and Precipitation at 5 Indian meteorological stations. At most of the stations taken in to this study to demonstrate a negative or positive relationship between monsoonal precipitation and PDO. Analysis of the relationships between PDO and monsoonal precipitation at several sites leads to the conclusion that PDO is linked to a weak Indian monsoon. Improved knowledge of various links between enduring climatic anomaly and sea surface temperature and the surface of the land should help India forecast monsoons more accurately.

The current research has a practical utilize within the agriculture area where the production of crops could be predicted using rainfall projections influenced by PDO. Therefore, it is imperative that studies on the El-Nino phenomenon as well as its detrimental effects on the production of agriculture receive the attention it deserves. Since indigenous crops are crucial to a developing nation's food security, more attention must be paid to crops that are noticeably more resilient to unfavourable weather conditions. Therefore, it can be said that the current study's findings could help with effective agricultural production management.

According to the correlation research, monsoonal rainfalls in the chosen states and Indian Ocean climatic indicators have a usually poor link. Hyderabad station was the only one of the five to exhibit a statistically significant negative association, suggesting that a minor decline in monsoonal rainfall in this area could be linked to an increase in Indian Ocean SST anomalies.

However, the associations were weak and statistically insignificant for Kolkata, Ajmer, Bhopal and Gorakhpur, suggesting that other local variables may be of greater significance or that precipitation in these regions may not be significantly influenced by Indian Ocean climatic variability.

These findings emphasize the requirement for local climate models and additional research into other air causes, as well as the regional variability of the monsoonal reaction to oceanic impacts.

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