Spatio-Temporal Assessment of Climate Variability and Its Implications for Regional Environmental Sustainability

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Abstract: ***This study explores the spatio-temporal variability of the climate and the implications for the sustainability of the environment in two regions of Maharashtra- Marathwada and Vidarbha, during 2000-2020. The aim is to identify climate trends as well as analyze ecological vulnerability based on geospatial techniques, ensuring the accurate spatial and temporal assessment of climate variability. The methodology combined the satellite (MODIS NDVI and LST) data together with precipitation information provided by the CHIRPS dataset. Further, Geospatial and remote sensing analyzes are carried out using the GIS method and Google Earth Engine (GEE) for satellite data processing. The findings showed a rising trend of temperatures in both regions, although Vidarbha experienced higher warming. Meanwhile, Marathwada showed significantly lower rainfall levels and greater variability. NDVI data indicated deterioration of vegetation cover in Marathwada and improvement in forests in Vidarbha. The study concludes that climate variability has a major impact on regional sustainability trends, making it crucial to adopt adaptation measures such as "water management, afforestation, and climate-resilient" agricultural practices to enhance environmental sustainability and regional resilience.***

Keywords: Climate Variability, Environmental Sustainability, Spatio-Temporal Analysis, Remote Sensing, Climate Vulnerability

1. Introduction

Across the world, climate change refers to long-term shifts in temperatures and weather patterns, which create serious threats to the densely populated regions of developing countries, especially in India. Like, the urban areas face increased danger from heatwaves, droughts, and floods, which endanger water supplies, agricultural production, natural ecosystems, and human survival [24]. Further, the "Intergovernmental Panel on Climate Change (IPCC)" 6th Assessment Report estimates a 1.5 °C global temperature rise, which will exacerbate climate-related risks and natural disasters [9]. These concerns highlighted that there is a need for strategies to adapt to climate change, including measures that can be taken to consider the new climatic conditions. These strategies can improve resource efficiency and climate resilience. Further, research in this area is expanding to reduce carbon footprints by more than 50% by 2030 and eliminate them by 2050, potentially addressing climate change and promoting sustainability [27]. In this context, this study aims to examine climatic variables such as temperature and rainfall, which are important in the
understanding of climate variability.

1.1 Climate Variability Patterns and Drivers

Climate variability refers to the changes in the average conditions and other statistical aspects of climate and spatial scales beyond individual weather events. These changes resulted from natural internal processes of the climate system as well as from external forces. It included both changes due to natural climate variability and changes resulting from human activities [25].

Many natural factors were included in climate change, such as solar radiation fluctuation, volcanic eruptions, and ocean cycles, which influenced the Earth's climate throughout history. Fossil fuel combustion and land-use changes were predominant in natural factors. Furthermore, anthropogenic drivers such as the recognition that population growth, increased economic production, and changes in technology were the main factors showed that climate variability was a part of socio-economic systems rather than environmental [23], [11].

Furthermore,[8] used a variety of statistical tools (Mann-Kendall and Sen's slope methods) over a long-term (1901-2018) time span in Jharkhand, with the focus on precipitation, temperature maxima-minima, and Potential Evapotranspiration to show the fluctuations and declining precipitation trends. Similarly,[12] studied the spatial-temporal distribution of temperature trends in Madhya Pradesh (1951-2021) based on gridded "India Meteorological Department (IMD)" data and found clear warming trends in mean, maximum, and minimum temperatures. On the other hand, [14] investigated the spatio-temporal variability of various climatic factors such as temperature, precipitation, relative humidity, and wind speed in Bangalore (1992-2022) by statistical trend analysis and "Geographic Information System (GIS)" tools, revealing rising temperature and humidity trends. These studies highlight the spatial and temporal variability of climate patterns.

1.2 Environmental Sustainability Indicators and Assessment

The idea of sustainability has emerged as a critical inquiry into how societies could use their natural resources safely. However, two main ways of studying sustainability were identified in literature, which are the weak and the strong. Weak sustainability, a concept that was derived from the natural sciences, especially environmental economics, assumed that natural capital could be substituted perfectly and focused on measuring the economic impacts of environmental externalities. In contrast, strong sustainability, a concept from the social sciences and illustrated by political ecology, examined the economic and social inequalities created by past consumer patterns and capitalist economies.

The idea of sustainable development changed according to the three pillars of sustainability (social, economic, and environmental), with environmental sustainability being mostly affected at the level of the Earth's ecology. This shift from descriptive to quantitative understanding has led to the rising use of sustainability indicators, revealing the necessity of a variety of indicators [19]. Recent studies assessed environmental sustainability using many indicators. [2] utilised "Ecological Footprint (EFP)" to examine how urbanization, energy usage, natural resources, economic growth, and technological innovation influenced sustainable development, urban policies, and natural resource management, which were most related to environmental goals.[16] measured environmental degradation worldwide using the ecological footprint. They discovered that the depletion of natural resources and financial development were the primary causes of environmental sustainability issues.

Additionally,[13] utilised the "Standardized Precipitation Evapotranspiration Index (SPEI) and Normalized Difference Vegetation Index (NDVI)" to examine the relationship between drought and vegetation activities, discovering that drought intensity worsened vegetation condition and disrupted ecosystem processes. [21] noted that climate variability shifted ecosystems over crucial ecological thresholds at which even low temperature or rainfall changes caused substantial ecological stress and ecosystem change.

1.3 Climate Change and Environmental Sustainability Linkages

[10] examined "climate change and its impact on the ecological sustainability and economic growth of Morocco and indicated that water stress and rising temperatures negatively affected the country's Gross Domestic Product (GDP)." Further, [6] studied how climate change impacted water resources and what measures smallholder farmers in Ethiopia took to adapt. One of their findings indicated that 58.6% of the households in the country had experienced water scarcity.

However, in various regional studies, such as [1], it was highlighted that climate change emerged as a major issue for the agrarian economy of Maharashtra. The findings indicated that there had been differences in exposure, sensitivity, and adaptive capacity across various districts. Among the factors that influenced vulnerability were water access, credit availability, and drought incidence. Similarly, [3] developed a multi-indicator index for agricultural vulnerability at the district level, and their results supported the fact that the regions of Marathwada and western Vidarbha were more vulnerable with significant crop losses and exposure to weather changes, while other areas, on the contrary, had greater capacity and resilience to adapt. Furthermore, many studies, such as Manjula and [15], proposed resource conservation in nature as the main basis for soil and water conservation, micro-irrigation practices, and climate-resilient activities. To enhance adaptive capacity, consider institutional support, livelihood diversification, and improved access to credit and infrastructure as equally important measures.

While the existing literature on climate variability and environmental sustainability is growing, most researchers focus on climate trends, impacts on agriculture, or water scarcity issues as separate themes. Very few studies integrate climatic factors, changes in vegetation, and environmental indicators in one study. In India, especially the semi-arid regions of Marathwada and Vidarbha, existing studies are quite scattered geographically, and a comprehensive spatial study has not been carried out. Therefore, a combined geographic approach is needed for integrating climate variation, ecological indicators, and vulnerability mapping for understanding environmental changes at the regional level.

Several studies researched the topic, but only a few of them attempted to analyze together climate changes, different environmental indicators, and the vulnerability of various locations on a large scale. Therefore, this study investigated climate change and its environmental consequences in the selected locations. Further, the study structure is as follows: after the introduction and review of previous studies, section 2 presents the research objectives, and section 3 provides the description of the "methodology". Then, section 4 presents "the results, and section 5 discusses the findings." Finally, the last "section 6 provides the concluding remarks" of the study, along with references at the end.

2. Research Objectives

Obj1: To examine the temporal trends of key climatic variables (temperature and rainfall) in the Marathwada and Vidarbha regions during the period 2000–2020.

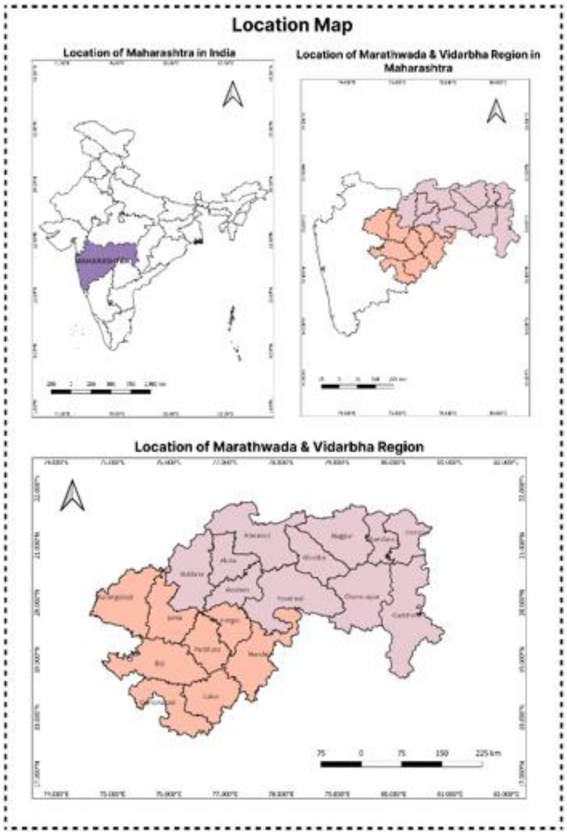
Obj2: To analyze the spatial variability of climatic parameters using GIS-based techniques

Obj3: To analyze vegetation dynamics using NDVI across land use categories and compare environmental vulnerability zones in Marathwada and Vidarbha

3. Research Methodology

3.1 Study Area

The study area includes the Marathwada region of Maharashtra, which is situated around the Godavari River basin and whose headquarters are Chhatrapati Sambhajinagar. This region, whose area is about "64,590 square kilometres", accounts for 21% of Maharashtra's total area. In addition to Aurangabad (Chhatrapati Sambhajinagar), the districts of "Jalna, Parbhani, Hingoli, Nanded, Latur, Beed, and Osmanabad (Dharashiv) comprise Marathwada" [7]. Vidarbha, which is part of the Maratha region, consists of the Nagpur and Amravati Divisions. This region of central India covers an area of 97,950 km2 and is made up of 11 districts and 120 sub-districts (tehsils). The latitude and longitude of this region are 19.05 - 21.25 N and 75.59 - 79.11 E, respectively [17].



Map 1- Location of the Study Area
Source: https://data.opencity.in/dataset/district-maps-for-states-of-india/resource/10a9e732-4e2e-4740-bb57-0533b6abf101/view/80f32264-689c-44c9-bba4-c9ede5bd58ce)

3.2 Study Period

The study period extends from 2000 to 2020, offering enough time span to reveal major climatic changes, patterns of variation, and related environmental transformations.

3.3 Data Sources and Variables

3.3.1 Climate Variables (2000–2020).

The main climatic factors that the study uses are annual precipitation (mm), maximum temperature (C), and minimum temperature (C) over the period 2000-2020 to study climate patterns and changes over time.

3.3.2 Data Source

The combination of satellite and climatic data is used for a spatio-temporal study. Changes in vegetation are measured using "Moderate Resolution Imaging Spectroradiometer (MODIS) MOD13Q1 NDVI (250 m), and temperature trends are analyzed through MODIS MOD11A2 L and Surface Temperature (1 km). The Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) precipitation dataset (~5 km) is employed to detect changes in rainfall." "Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (30 m)" is utilised to obtain topographic information such as slope and elevation. Thematic maps and tables are prepared using these datasets to illustrate changes in NDVI, temperature trends, rainfall distribution, and environmental vulnerability.

3.3.3 Spatio-Temporal Analysis

The research adopts a spatio-temporal analytical methodology that merges temporal and spatial techniques. For a temporal analysis, the long-term trends and the variability of climatic parameters are examined. Spatial analysis based on GIS methods is for mapping and studying spatial distribution and regional differences in climatic and environmental variables.

4. Tools

Geospatial and remote sensing analyzes are carried out using:

- **ArcGIS / QGIS** for spatial mapping, interpolation, and visualization.
- **Google Earth Engine (GEE)** for satellite data processing, NDVI computation, and large-scale temporal analysis

5. Results and Finding

Obj 1: To examine the temporal trends of key climatic variables (temperature and rainfall) in the Marathwada and Vidarbha regions during the period 2000–2020.

The regional variations are observed from the climate trend results table 1 (2000-2020) between the Marathwada and Vidarbha regions. In terms of NDVI trends, Marathwada has NDVI trends ranging between -0.05 and -0.15, implying vegetations are stressed, while the NDVI trend for Vidarbha is +0.05 to +0.20 in the eastern parts that are heavily forested. Temperature trends in Marathwada have shown a positive trend of +0.02 to +0.06 °C/year, while Vidarbha shows an increase of +0.04 to +0.08 °C/year. In terms of rainfall patterns, the Marathwada region experiences low and variable rainfall between 500-900 mm, while Vidarbha receives heavy and uniform rainfall of 800-1300 mm. From the observed climatic trends, differences in the vulnerability pattern emerge. Marathwada is moderate to highly vulnerable, while Vidarbha has a low to moderate vulnerability level.

Table 1: Climate Trend Results (2000–2020)

Parameter	Indicator Used	Marathwada Region	Vidarbha Region	Interpretation
Vegetation Trend (NDVI Change)	NDVI (MODIS)	Slight to Moderate Decrease (−0.05 to −0.15) in the western and central parts	Mixed Trend; Increase in eastern forested areas (+0.05 to +0.20), slight decline in western parts	Indicates vegetation stress in Marathwada; relatively stable to improving vegetation in parts of Vidarbha
Temperature Trend (Sen's Slope)	LST (MODIS)	Positive trend (+0.02 to +0.06 °C/year)	Stronger warming (+0.04 to +0.08 °C/year), especially in	Rising temperature across both regions, higher warming

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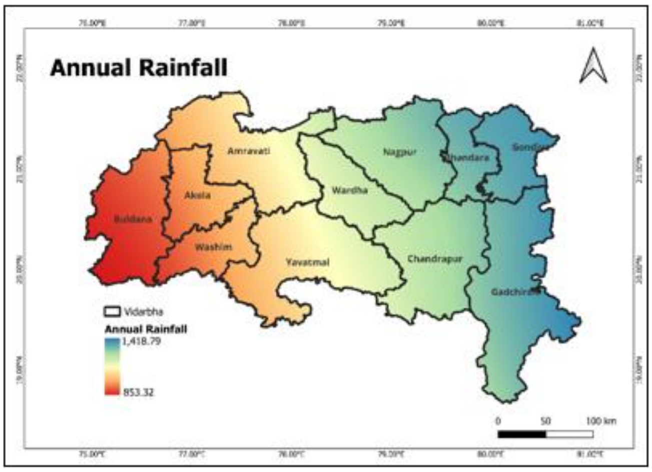
			eastern districts	intensity in Vidarbha
Mean Annual Rainfall	CHIRPS Rainfall	Low to Moderate (500–900 mm/year)	Moderate to High (800–1300 mm/year)	Vidarbha receives significantly higher rainfall compared to Marathwada
Rainfall Variability (Qualitative)	Annual Variability	High variability and frequent dry spells	Moderate variability with relatively stable rainfall patterns	Marathwada is more drought-prone compared to Vidarbha
Environmental Vulnerability Index	NDVI + LST + Rainfall + Slope	Moderate to High Vulnerability	Low to Moderate Vulnerability	Marathwada is more environmentally stressed; Vidarbha is relatively resilient
High Vulnerability Zones	Composite Index Classification	Western and central Marathwada districts	Limited pockets in central Vidarbha	Priority intervention areas are identified mainly in Marathwada
Low Vulnerability Zones	Composite Index Classification	Few scattered zones	Eastern Vidarbha (forested regions)	Better ecological stability in forest-dominated areas

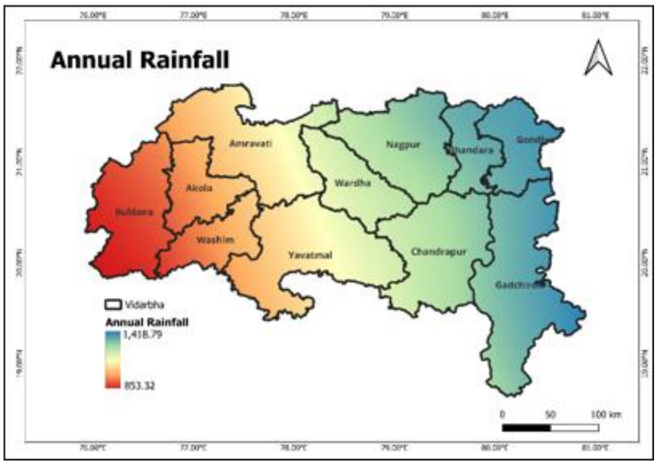
(Sources: MODIS MOD13Q1 (NASA EOSDIS), MODIS MOD11A2 (NASA EOSDIS), UCSB Climate Hazards Center and derived from CHIRPS annual rainfall)

Obj 2: To analyze the spatial variability of climatic parameters using GIS-based techniques.

The differences in climatic features define the spatial variability of climate. The pattern of the annual rainfall (Map 2) reveals a definite trend from west to east. The Marathwada region receives an annual rainfall between 776.65 mm and 1,129.53 mm, with comparatively low levels in districts like Osmanabad, Latur, and Beed. These areas are more prone to drought. The rainfall in Aurangabad and Nanded districts is relatively moderate. However, the Vidarbha region (Map 3) receives a wider range of precipitation between 853.32 mm and 1,418.79 mm, with higher amounts towards districts like Gadchiroli, Gondia, and Chandrapur, while low precipitation in Buldana and Akola. The pattern indicates that the climate and ecology of eastern Vidarbha, remaining due to its favorable monsoon impact and presence of forests, are relatively more stable than those of the arid regions of Marathwada.

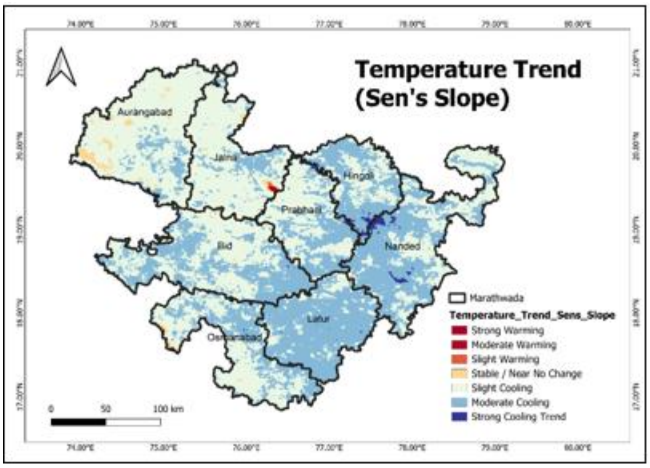


Map 3: Mean Annual Rainfall of Vidarbha
(Source: Climate Hazards Center, University of California, Santa Barbara and Dataset: CHIRPS Daily Precipitation)

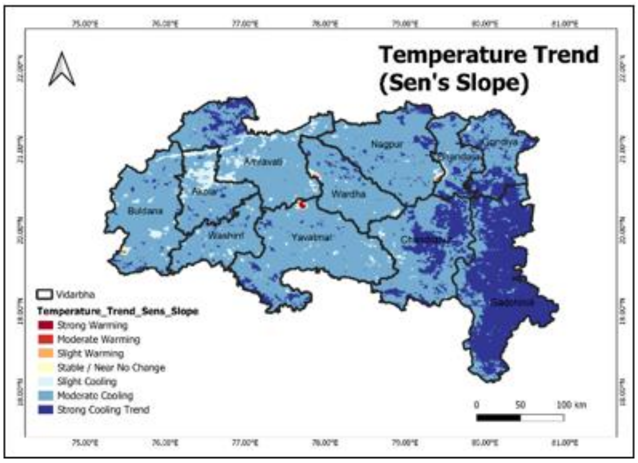


Map 2: Mean Annual Rainfall of Marathwada
(Source: Climate Hazards Center, University of California, Santa Barbara and Dataset: CHIRPS Daily Precipitation)

In Maps 4 and 5, Sen's slope temperature trend has indicated mainly cooling to near-neutral trends, with some warm areas in the region. Marathwada consists mostly of moderate cooling for most districts, except for some stable to marginal warming in Aurangabad and Jalna, while Bid, Latur, and Osmanabad are experiencing mild cooling trends. For Vidarbha, there is an indication of mainly weak to moderate cooling trends in western areas, including Gadchiroli, Chandrapur, Gondia, and Bhandara, with other districts in eastern and northern parts remaining stable. From this data, it is evident that vegetation cover and moisture content play a critical role in determining the temperature trends in this region, where forests and areas of high rainfall experience cooling trends, while those with little moisture experience warming.



Map 4: Temperature Trend (Sen's Slope) of Marathawada (Source: NASA Earth Observing System Data and Information System (EOSDIS) and Dataset: MODIS MOD11A2 Land Surface Temperature)



Map 5: Temperature Trend (Sen's Slope) of Vidarbha (Source: NASA Earth Observing System Data and Information System (EOSDIS) and Dataset: MODIS MOD11A2 Land Surface Temperature)

Overall, the spatial analysis clearly indicates that there is a strong climatic trend from west to east, such that Marathwada receives less rainfall (≈776-1129 mm) with greater variability compared to Vidarbha, which experiences higher rainfall (≈853-1418 mm) with stability, especially in the eastern part of Vidarbha. About temperatures, there is cooling towards stability that is much stronger in forested high-rainfall zones in the eastern parts of Vidarbha than in dry areas like Marathwada.

Obj 3: To analyze vegetation dynamics using NDVI across land use categories and compare environmental vulnerability zones in Marathwada and Vidarbha.

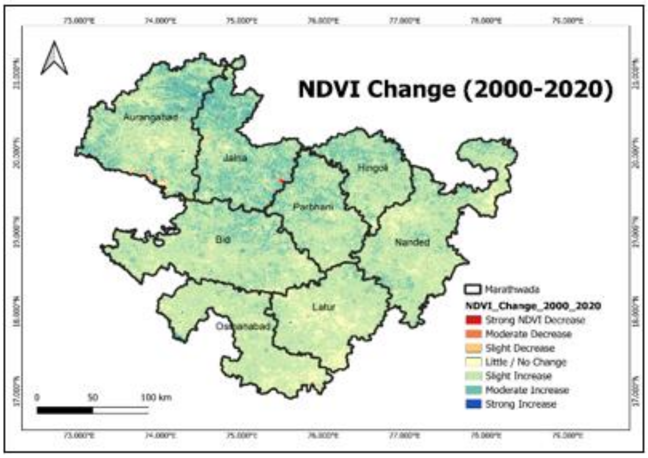
The results of the NDVI and land use change study from 2000 to 2020 reveal regional differences in environmental sustainability. Table 2 reveals that there are positive changes in NDVI (+0.05 to +0.20) in the forested areas of Vidarbha, which represents environmental improvement, while in Marathwada, NDVI decreases slightly (−0.02 to −0.08). Agricultural lands in Marathwada have moderate decreases in NDVI (−0.05 to −0.15), suggesting stress in agriculture, while in Vidarbha, there is little change. The fallow and barren lands in Marathwada show low values of NDVI with high variation, which suggests degradation of the land; urban areas of Marathwada and Vidarbha both show significant decreases in NDVI up to −0.25 due to development.

Table 2: NDVI and Land Use Change (2000–2020)

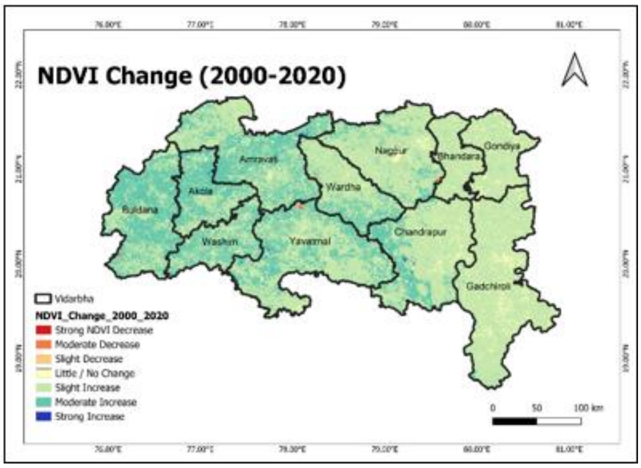
Land Use Category	NDVI Change (Marathwada)	NDVI Change (Vidarbha)	Observed Trend	Possible Cause	Environmental Implication
Forest / Vegetation	Slight decrease to stable (−0.02 to −0.08)	Moderate increase (+0.05 to +0.20)	Vegetation is improving in Vidarbha, slightly declining in Marathwada	Better forest cover in Vidarbha, afforestation and natural vegetation regeneration	Improved ecological stability in Vidarbha; mild degradation in Marathwada
Agricultural Land	Moderate decrease (−0.05 to −0.15)	Slight increase or stable (−0.02 to +0.08)	Crop stress in Marathwada is relatively stable in Vidarbha	Rainfall variability, irrigation differences	Higher drought sensitivity in Marathwada agriculture
Fallow / Barren Land	Increase in NDVI variability, but overall low NDVI	Slight improvement in some areas	Expansion of fallow areas in Marathwada	Land degradation, water scarcity	Reduced land productivity and increased vulnerability
Urban / Built-up Area	Decrease in NDVI (−0.10 to −0.25)	Decrease in NDVI (−0.08 to −0.20)	Vegetation loss in urban expansion zones	Urbanization and infrastructure growth	Heat island effect and ecological imbalance
Water Bodies	Slight decrease or seasonal variability	Mostly stable	Minor fluctuations	Rainfall variability, water storage changes	Impacts on irrigation and local ecosystems
Scrubland / Sparse Vegetation	Declining NDVI	Mixed trend	Degradation in Marathwada, partial recovery in Vidarbha	Climate stress, land-use pressure	Increased desertification risk in Marathwada

(**Source:** NDVI Source: MODIS MOD13Q1)

Further Map 6 and 7 show the distribution of the change in NDVI (2000-2020) demonstrates distinct differences from one region to another. The area of Marathwada has mostly an NDVI decline to nearly stable NDVI, but there are also some moderate declines in NDVI in the districts of Bid, Latur, and Osmanabad. These districts represent vegetation stress and lack of recovery. However, in Vidarbha, most changes in NDVI are positive, but the eastern part of the region is characterized by NDVI increases, whereas the western part shows moderate NDVI values. NDVI decline in Vidarbha between the study period of 2000-2020 is minimum. Vegetation improvement is associated with precipitation and forests, while vegetation decline correlates with climatic stress and water shortage.



Map 6: NDVI Change (2000–2020) in Marathawada (Source: NASA Earth Observing System Data and Information System (EOSDIS) and Dataset: MODIS MOD13Q1 Vegetation Indices)



Map 7: NDVI Change (2000–2020) in Vidarbha (Source: NASA Earth Observing System Data and Information System (EOSDIS) and Dataset: MODIS MOD13Q1 Vegetation Indices)

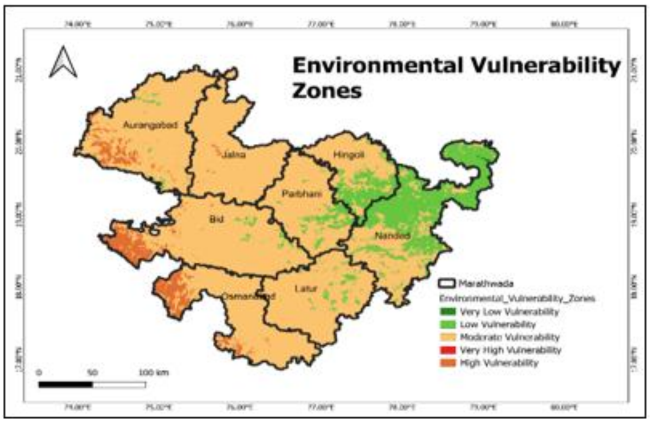
It is clearly shown by the vulnerability assessment (Table 3) that there are significant variations between the study regions in terms of vulnerability levels. Marathwada region displays mostly moderate to high vulnerabilities (0.40 – 0.80), and even very high vulnerability (0.80 – 1.00) in some western parts as a result of low vegetation cover, high temperature levels, and low rainfall levels. Vidarbha region displays much better vulnerability scores since it consists of low to moderate vulnerabilities (0.20 – 0.60) and even very low vulnerabilities (0.00 – 0.20) in the eastern forests.

Table 3: Vulnerability Classification (2000–2020)

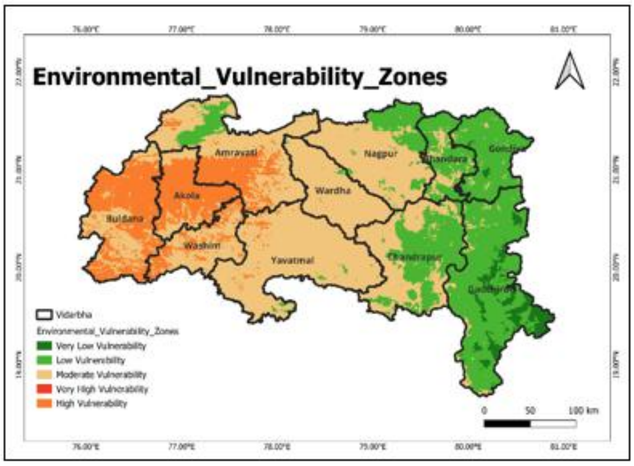
Vulnerability Class	Index Range	Marathwada Region	Vidarbha Region	Key Characteristics	Environmental Interpretation
Very Low	0.00 – 0.20	Very limited areas	Eastern Vidarbha (forested zones)	High NDVI, low temperature, adequate rainfall	Stable and ecologically resilient areas
Low	0.20 – 0.40	Small scattered patches	Moderate presence in the eastern and central parts	Good vegetation cover, moderate rainfall	Relatively low environmental stress
Moderate	0.40 – 0.60	A significant portion of the region	Widely distributed	Mixed vegetation, moderate climate stress	Transitional zones with moderate vulnerability
High	0.60 – 0.80	Large parts of central and western Marathwada	Limited patches in central Vidarbha	Low NDVI, higher temperature, lower rainfall	Environmentally stressed zones requiring attention
Very High	0.80 – 1.00	Western and drought-prone areas	Very limited occurrence	Very low vegetation, high temperature, poor rainfall	Critical zones with severe environmental vulnerability

(Source: Environmental Vulnerability Map (Map 6))

Further, Maps 8 and 9 indicate that the spatial pattern reveals sharp differences between regions, where Marathwada is characterized by medium to high vulnerability, particularly in the western and southern parts of the region, implying poor resilience. On the other hand, eastern Vidarbha represents very low vulnerability zones due to good forest coverage and precipitation levels, whereas western Vidarbha exhibits local vulnerability, highlighting uneven biological stability.



Map 8: Environmental Vulnerability Zones in Marathawada (Source (DEM): NASA Jet Propulsion Laboratory (JPL))



Map 9: Environmental Vulnerability Zones in Vidarbha (Source (DEM): NASA Jet Propulsion Laboratory (JPL))

6. Discussion

This study provides empirical evidence of significant variation in climate variables and environmental sustainability across Marathwada and Vidarbha. The rising temperatures recorded in the two zones confirm the findings of the previous studies. [4] found an increasing trend of temperatures in maximum and minimum temperatures analyzed in Maharashtra through the Mann-Kendall test and Sen's slope analysis. [5] stressed that temperature variation is one of the drivers of climate change, causing negative effects on ecosystems and water sources in Maharashtra.

The detection of rainfall variability and frequent dry spells in Marathwada is consistent with the findings of [4] that showed an increased frequency of dry spells in Marathwada and Vidarbha through the use of the Rainfall Anomaly Index (RAI). Similarly, [22] indicated the impact of climate variability, specifically drought and inconsistent rainfall, on agriculture in Vidarbha. However, this study contributes to previous studies by showing spatial variability in rainfall with higher levels of rainfall in Vidarbha.

The climate-vegetation relationship can be demonstrated through empirical support using the analysis based on the NDVI index. The negative correlation between climate and NDVI for Marathwada (−0.05 to −0.15) and the positive correlation between the two for Vidarbha (+0.05 to +0.20) are consistent with the [20] study regarding the fact that vegetation depends significantly on moisture content. This statement is further reinforced by the land surface temperature data, indicating that areas with less vegetation will have high temperature levels, whereas areas with vegetative cover will have moderated temperature conditions [18].

In addition to these patterns, this study's results on environmental vulnerabilities are consistent with previous studies. As shown by [26], climate variations, especially monsoons and temperature changes, play an important role in the increase of agricultural vulnerability in Maharashtra, as influenced by exposure, sensitivity, and adaptation. Further, groundwater in semiarid zones like Marathwada and Vidarbha has high water stress due to precipitation variations and over-extraction, increasing vulnerabilities even more. The current study verifies these patterns by considering Marathwada as a zone of medium to high vulnerability, whereas Vidarbha shows lower vulnerability levels.

Nevertheless, this study provides a holistic perspective of analyzing NDVI and geospatial variables through geographic information systems (GIS). This study differs from other similar research in that it is able to recognize the interlinked aspects of climatic and environmental changes. Moreover, from a practical perspective, the results provide insights into how better decisions can be made based on understanding regional vulnerability patterns. The result can facilitate better policies and planning related to drought mitigation, reforestation programs, and climate-smart agriculture. Additionally, the study is a significant step toward better resource management and long-term environmental planning.

7. Conclusion

This study shows major differences in climatic variability and sustainability in the Marathwada and Vidarbha regions for the period from 2000 to 2020. As noted above, Marathwada is characterized by deforestation, higher rainfall variability, and increased susceptibility, whereas Vidarbha has more stable climatic parameters and lower vulnerability rates. In general, climatic variability can be seen as one of the critical determinants of regional environments. Further considering policy and academic considerations of this study, it offers an important contribution to scientific knowledge in the field through the elaboration of the integrated GIS-based approach, which allows linking the considered climatic factors with those environmental characteristics of the region under consideration. Additionally, some of the main limitations associated with the study include its dependence on remote sensing data and the limited inclusion of socio-economic parameters. Therefore, future studies in this area may involve expanding research into other regions and longer time periods with remote sensing data for a more comprehensive assessment.

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