

Study of Vegetation Resilience in Ecological Autocatalysis under Climate Change in India

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Abstract

The necessity of implementing enough adaptation strategies to maintain ecosystem sustainability Droughts, along with other hydroclimatic disturbances, are on the rise, as demonstrated by recent studies. Climate change is predicted to cause events to occur more frequently and with greater intensity due to global warming. Droughts hurt crop yield and vegetation growth, which increases the threats to a nation like India's food security, which must feed more than a billion people. Given the growing threats posed by climate change, it is imperative to analyze the relationship between extreme climate conditions and terrestrial ecosystem productivity, also known as Net Primary Productivity or NPP. The study was conducted across 10 types of vegetation and 25 river basins in India. Additionally, the potential of the terrestrial environments to withstand severe disruptions were assessed every year as well as during the monsoon and non-monsoon seasons. Only five river basins' terrestrial ecosystems were found to be resistant to extremely harsh weather, according to the results, which indicated that 15 of the 25 river basins were in danger. Furthermore, it was discovered that eight out of ten types of vegetation cover were unable to withstand extreme environmental conditions and that at least 50% of the area covered by four out of ten vegetation cover types faced a significant risk of a sharp decline in NPP. Our findings make it easier to determine which areas of the nation are most vulnerable to climate change and ecosystem management, and they emphasize.

KEYWORDS

Droughts, Net Primary Productivity, Climate Change, Ecosystem Sustainability, and Adaptation Strategies

Introduction

Climate change has a significant impact on ecosystem functioning in addition to its effects on the atmosphere and hydrosphere. Hydroclimatic disturbances like droughts harm the productivity of terrestrial ecosystems. Through photosynthesis and water loss, terrestrial plants remove CO2 from the environment, producing energy from the many exchanges between the atmosphere and the plant. The difference between autotrophic respiration and plant photosynthesis is known as terrestrial net primary production, or NPP. According to [1], NPP is a useful indicator of how well ecosystems are functioning and the fluxes of carbon from physiological and ecological processes. Primary productivity is determined by environmental variables like temperature, solar radiation, and precipitation [2].

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One important measure of how well an ecosystem is working is net primary productivity (NPP), which represents the speed at which biomass energy moves from autotrophs to consumers in ecosystems on land. Climate variation has a direct impact on the distribution and occurrence of NPP. An understanding of the vulnerability and adaptability of the terrestrial environment can be gained by examining how NPP respond to changes in extreme weather. For example,[3] discovered that variations in climate lead to changes in biomes, the growth and death of forests, and the conditions of ecosystems, all of which influence variations in NPP. In evaluating the ecosystem's resilience to climatic disturbances, [4] found that the response of NPP to alterations in weather patterns is also dependent on the kinds of vegetation present. According to [5], variations in temperature, precipitation, and other climatic factors are responsible for variations in various NPP locations around the globe. According to a recent study, quantifying the spatiotemporal NPP variability is essential to understanding how the ecology reacts to upcoming variations in land use and climate.

Large-scale droughts in the early 21st century were blamed for the decline in NPP, highlighting water's importance as a constraint on crop growth. In 2003, the severe summer heat and rainfall deficit were blamed for the decline in gross primary productivity in Europe. Therefore, drought or water stress have a major effect on terrestrial ecosystems by limiting the growth of vegetation. The terrestrial ecosystem's water use efficiency (WUEe), determined by dividing the rate of absorption of carbon by the rate of water loss, specifies the relationship between water and carbon fluxes between the atmosphere and ecosystem. In a dry environment, it is one of the most significant factors regulating plant productivity. The hydroclimatic conditions have a significant impact on transpiration in the ecosystem, evaporation, and absorption of carbon, which in turn influences spatiotemporal variation in WUEe.

Since the majority of India has a tropical or temperate climate, precipitation, and water control the amount of vegetation that grows. Nonetheless, reports from India and around the world indicate that droughts are occurring more frequently and are becoming more severe. In recent times, Droughts in India have moved to the economically important Indo-Gangetic region, central Maharashtra, and the southern coastline**.** This increases the risk for future food security, which has already been a major concern due to overexploitation of groundwater and unpredictable monsoon rainfall. When an ecosystem is water-limited due to lower annual precipitation, by enhancing or sustaining WUE, a resilient environment improves or preserves efficiency in the face of issues, whereas a non-resilient ecosystem is unable to do so. Therefore, the adaptability of India's vegetation to climate change has been examined in this study.

Objectives of this study

- Assessing the probability of a sharp decline in ecosystem productivity in the event of severe weather variations;
- Examining the susceptibility of the terrestrial environment throughout the nation at various time-based as well as spatial (various vegetation types, river basins) scales;

- Determining the primary climatic factor contributing to increased harm to ecosystem productivity
- Evaluating how resilient terrestrial ecosystems are to hydro-climatic shocks.

Methodology

For the years 2011–2020, the impact of abnormally low temperatures, soil moisture content, and mean monthly precipitation on the NPP in India's various river basins and vegetation types. This analysis utilized daily rainfall records from the country's extensive network of 6,955 rain gauges and included gridded information on precipitation (0.25° × 0.25°).
After performing quality control on the simplest rain gauge stations, the set of data was ready. The IMD4 data was discovered to be equivalent to current gridded sets of daily rainfall data, including IMD1, IMD2, APHRO, and IMD3. The geographical distribution of precipitation in areas of India with high rainfall, such as the Western Ghats as well as the northeast of the country, is very well captured by IMD4 data. IMD4 has been utilized in numerous studies on climate change due to its efficiency in obtaining the spatiotemporal fluctuations during the Indian rainy season. IMD was also the source of the thermal data created utilizing Shepard's methodology, which was applied to 395 observational stations nationwide.

After computation, it was discovered that the error associated with these data sets was below 0.5 °C. In addition, the set of data was validated as well as contrasted with additional high-definition information sets that were accessible. The information was discovered to be comparable and to describe the frequency and temperature anomalies and the strength of temperature indices, including warmth and cold waves. This data, which was made available by the National Data Centre in Pune, has been used in many different ways by researchers.
In a similar vein, the soil moisture values have been taken from the extensively used information sets of the Climate Prediction Centre (CPC), which have been created utilizing the National Oceanic and Atmospheric Administration's ESRL-NOAA. Using temperature from the worldwide reanalysis and international precipitation at 17,000gauge stations globally, a bucket water balance version is used to put together the CPC soil moisture data. The statistics's capability to correctly seize temporal and spatial variability is validated through validation at both the once-a-year and interannual ranges. Several studies conducted across the globe have proven the validity and applicability of CPC soil moisture facts in knowledge of atmosphere-climate interactions.
The MOD17A2 datasets of the NASA EOS program offer the global annual NPP values. Prior research has shown the effectiveness of MODIS data in representing the state of terrestrial ecosystems. In a noteworthy study, for example, Nayak and Dadhwal examined the consistency of NPP estimates derived from field-based observations, MODIS data, and the CASA model. It was discovered that there was good agreement between the ground-based NPP, MODIS data-derived NPP, and CASA-based annual NPP. According to[6] take a look at, MODIS facts become powerful in capturing the circumstances of ecosystems on land because they looked at the dynamics of drought and how they have an effect on internet production on land globally through the use of SPEI.

Using the MODIS NPP product, [7] and [8] investigated the relationship between carbon and the water cycle to recognize how climate change influences the productivity of terrestrial ecosystems. Their findings had been noteworthy. After looking into capacity reasons for the very best annual NPP growth seen in 2011, [9] and [10] concluded that the primary purpose of this anomaly was prolonged rainfall in dry areas. [11] investigated how NPP controls the worldwide biogeochemical cycle. Furthermore, for the reason there hasn't been a lot of exchange in NPP in recent years, running proposed that the worldwide NPP is probably because of the planetary boundary of the carbon cycle.[12] provided evidence on how MOD 17 information may be used to investigate local food protection research.
We computed correlations amongst NPP as well as temperature, precipitation, and moisture content material of the soil at special time scales to give a summary of the connection between NPP and climatic variables. Climate variables, as well as terrestrial ecological efficiency, have been observed to be considerably correlated. It's been determined that there's a fine and massive correlation between soil moisture content material and NPP, regardless of the season. The correlation between precipitation and NPP all through the non-monsoon period turned out to be extremely fine in the majority of the state, excluding the arid and precipitation-wealthy southern areas in addition to the northeastern areas of the country.

Similarly, the northeastern and northernmost areas of the state benefit from growing temperatures, as indicated by the Pearson correlation values derived from the NPP and temperature evaluation. Except for these regions, the correlation was terrible, suggesting that low temperatures beautify the productivity of terrestrial ecosystems. According to the correlation analysis, there is a large and correct affiliation between NPP and weather facts, reflecting the general functions of the state's eco-climatic relationships.

Literature Review

1. Increasing drought intensity and frequency have been reported globally [13],[14] and in India [15]. Moreover, Indo-Gangetic, central, and coastal Maharashtra agriculturally important plains in southern India have recently experienced drought.This has increased the risk of future food security, which has already become a major concern due to subsidence due to overuse of water [16] and the variability of monsoon rainfall.

2. [17] used WUEe to measure ecologies, specifically focusing on less popular ecosystems that have demonstrated remarkable cross-biome resilience despite being in the early years of the 21st century. These ecosystems were found to be less susceptible to shocks and less affected by decreased annual rainfall contrasts. Under water-limited conditions, resilient organisms are capable of increasing or maintaining WUEe.

3. Quantification of WUEe patterns is required to assess the impacts of human and natural sources on the nation's ecosystems on land. Understanding how WUEereacts to variations in hydroclimate will help us understand in what way carbon as well as water cycles will vary as a result of hydroclimatic changes caused by worldwide climate shifts [18].

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Results

As a sign of the sharp decline in ecosystem efficiency at a certain point, an NPP value threshold corresponding to the 30th percentile (NPP 30%) was set. Temperature and soil moisture content in stressed climate scenarios were used to estimate the conditional probability distribution corresponding to this NPP threshold. The temperature, soil moisture content, and precipitation all contribute 20% to define the stressed climatic scenario.

A bivariate probabilistic model based on copulas was created to ultimately estimate the conditional likelihood of extremely low NPP (nNPP 30%) by modeling the combined actions of climate variables and NPP. Two seasons and a yearly measure of land cover and river basin were analyzed for India's ten main types of land cover and twenty-five major river basins. Most river basins were found to be high-risk when exposed to extremely low soil moisture values, according to the annual time scale study.

Excluding cold, high-altitude areas, lowering the temperature had the least impact on ecosystem productivity. On an annual basis, the risks associated with temperature stress were only slightly elevated in four of the 25 river basins, accounting for less than 10% of the country's total area. However, in most river basins, reducing precipitation causes moderate risks of serious damage (i.e., NPP 30th percentile) to productivity.

Extreme changes in annual precipitation were most likely to affect efficiency in the Mahi and Tapi river basins, with 22.11% as well as 21.05%, accordingly, of their region is in significant danger**.** Perhaps crucially, an examination of soil moisture content and yearly NPP values indicates that all three river basins are at high risk. The eastern seaboard and northeastern river basins, on the other hand, were relatively safe. Godavari and Ganga river basins were the most vulnerable in terms of area, with an overall 476798.5 km2 region falling within the high-risk category.

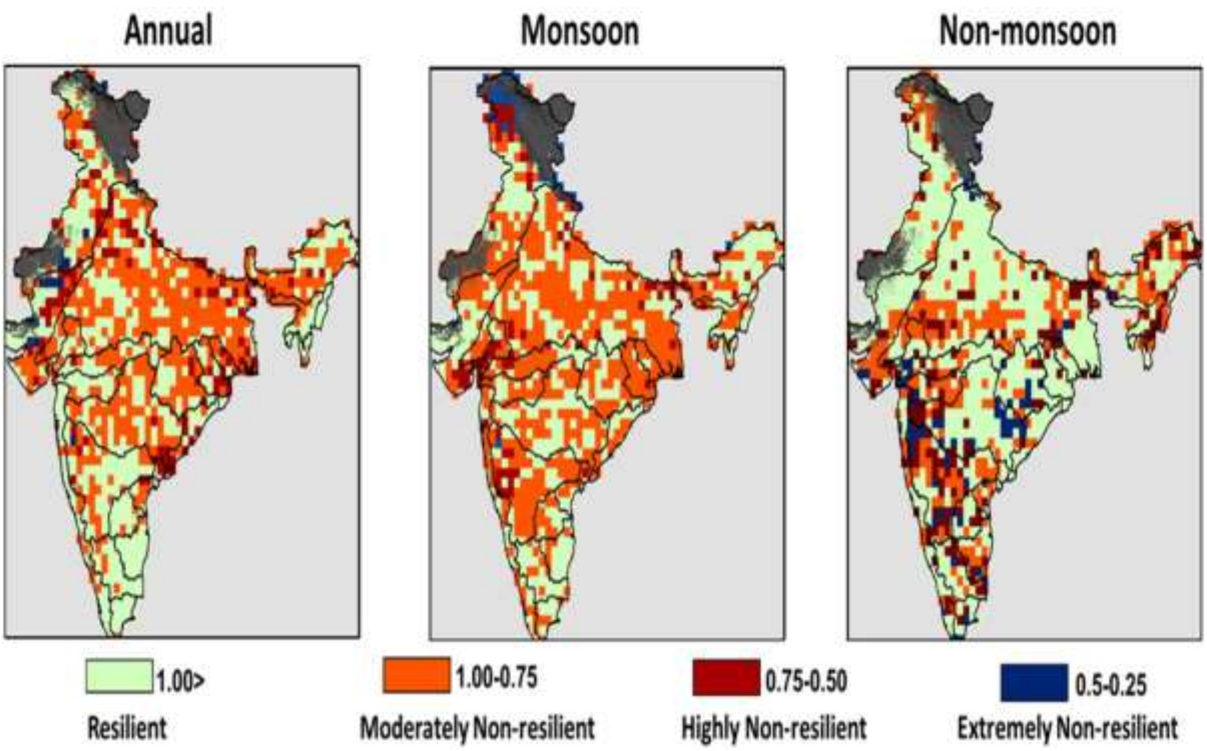
The monsoon season is when India receives the majority of its rainfall. Similarly to the annual results, the scenario of stressed temperatures posed little threat during the rainy season, with just roughly 6.5% of the nation's land at risk. However, extreme reductions in soil humidity, even throughout the monsoon season, have been observed, triggering substantial harm and contributing to the productivity decline of approximately 38% of the nation's ecosystem. In the non-monsoon season, more than 50% of the area in 8 out of 25 river basins experiences reduced humidity, and lowering the temperature to the same level (i.e., 20%) dramatically lowers productivity. When compared to the annual scale, temperature during the non-monsoon months may pose a greater threat to the productivity of ecosystems in high-altitude basins than during the monsoon season.

About 61.54% of the Brahmaputra River and 28.18% of the Indus River were found to be high-risk. Furthermore, in the non-monsoon season, ecosystem productivity was at risk in approximately 24% of the country, in contrast to 1% during the monsoon period. The productivity of the Krishna River Basin was determined to be the most susceptible, with 68.17% of its area being at high risk outside of the monsoon season.

It was discovered that evergreen coniferous forests were the most susceptible to extreme weather events, with 28.57% and 35.71% of sites likely to reach the 30th percentile in soil moisture and rainfall conditions, respectively. Almost half of the croplands (49.61%) were under severe threat due to annual soil erosion. Cropland was also more at risk during the rainy season, with 54.58% of their area falling in high-risk zones. Severe stress precipitation, on the other hand, could cause high risks only in a small percentage of Deciduous Needleleaf Forests (3.12%) and Deciduous Broadleaf Forests (3.52%).

Even during the monsoon season, however, reduced warmth posed a threat to the Evergreen Needleleaf Forest. As previously discussed, it was found that the worst time of year for the country's terrestrial ecosystems to function normally is during the non-monsoon season. 85.71% of the Evergreen Needleleaf Forests were determined to be at high risk in a scenario with lower temperatures.

The interrelated effects of vegetation diversity cover and river basins on the ability of land ecosystems to recover from crop losses were examined. The Krishna River (71.55%) was identified as having the highest annual resistance, followed by the EFRKPB Basin (63.89%), with the Tapi River Basin (71.58%) ranking as the most resilient. In contrast to our annual observations, the monsoon drought had a delayed effect on biomass production at the EFRGKB site, leaving 84.62% of its area as rainy as the East Ghats, East Coast, and Northeast. Positive field changes indicated that less than 20% of the area in these rivers was not drought-tolerant. Furthermore, since 92.31% of the EFRGKB streams were determined to be of low quality, the drought conditions during the non-monsoon season were particularly unsustainable. In dry non-monsoon months, approximately half of 16 out of 25 rivers were found to be adversely affected. Resilience is also linked to biome diversity, with needle-leaf evergreen forests being the most susceptible to annual degradation.



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Discussions

The goal of this research was to investigate possible changes in ecosystem efficiency caused by extreme temperatures. The data's initial correlation analysis revealed that climatic conditions have a significant and high influence on terrestrial ecosystem productivity. This dependence, however, is complex, necessitating the development of a productive structure for calculating the resilience and risk of ecosystems on Earth.

Applying a multivariate probabilistic method annually and across different seasons, we examined the probability of NPP falling below the threshold conditions at 30 percent, where temperature, soil moisture, and precipitation are emphasized. The findings support previous research indicating that variations in climate have a significant impact on the productivity of terrestrial ecosystems. Stressed soil moisture levels in many areas influenced ecosystem productivity the most. This conclusion is in line with earlier research showing that soil moisture has a significant impact on the productivity of terrestrial ecosystems.

Productivity was especially susceptible to harm in harsh circumstances during the non-monsoon season. This makes sense because the country experiences droughts during the non-monsoon season, and low water availability reduces plant productivity. River basins in the peninsular and northwestern areas were particularly vulnerable under conditions of stressed soil moisture.

The months with the lowest temperatures are also included, not during the monsoon, making it the most unfavorable season for high-altitude zone ecosystems. Winter droughts in India's Himalayan region, according to Kusre and Lalringliana, are a serious source of worry, necessitating immediate administrative actions. In other regions, decreasing the warmth had the least effect on productivity, just on NPP, which was impacted in a small number of elevated-altitude river basins. This indicates that India's NPP exhibits the lowest coherence at its lowest temperatures. According to research, the Godavari River basin experiences very high rainfall and temperature variability, making it vulnerable to risks associated with changing climatic conditions. Soil moisture was found to be a more significant factor in severely impairing ecosystem efficiency in 18 of the 25 river basins than precipitation. It suggests that incident precipitation is not controlled in the majority of India's river basins and increases output.

It's been said that maintaining rainfall is the most significant component of managing ecosystems sustainably. The theory that rainfall and soil moisture levels are related through a variety of feedback processes and that variations in one impact the incidence and dispersion of the other is further supported by several studies. The results show that India's low levels of precipitation cause the soil moisture content to drop dangerously, which lowers ecosystem output. The outcomes correspond with those of other Indian studies that show that the main factor influencing NPP change is the availability of water.

During the monsoon season, similar behavior was observed. The main reason for possible declines in primary productivity during the monsoon months was not abnormally low precipitation. In more than 50% of 8 out of 25 river basins, there was a high risk due to water scarcity, which caused insufficient soil moisture availability for plant growth. Only a small portion of some river basins had high risks due to extremely stressed precipitation over an annual time scale. Only two river basins (Mahi and Tapi) have considerable danger of sharp declines in ecosystem productivity exceeding 20%.

Lower soil moisture, on the other hand, posed serious threats to the entire river basins of Tapi and Mahi. This is consistent with the findings of additional research that has demonstrated that the country's western regions are highly vulnerable to weather patterns. Furthermore, the research contributes to a better understanding of seasonal changes and how the functioning of India's terrestrial ecosystems varies over time. The reaction to severe conditions varies according to the biome type. We investigated the possibility of ecosystem productivity falling to the 30th percentile in harsh circumstances and found that every type of vegetation reacts differently to climate stress.

It was discovered that forests with evergreen needle leaf motifs were the most vulnerable to temperature drops during the non-monsoon season. Previous research has found that temperature is a major factor that influences how the Evergreen Forest NPP varies. We discovered that 85.71% of these different kinds of forests were extremely vulnerable to sudden changes in temperature, which is worrisome for the local wildlife and plants. However, in extremely low soil moisture levels and precipitation scenarios, these forest types were entirely shielded from high risks. Furthermore, a large portion of Indian crops were susceptible to severe productivity damage at the yearly and seasonal time scales. Previous research has identified this threat to Indian croplands, lending credence to the findings. Furthermore, studies suggest that the amount of precipitation found to control over 60% of variations in net primary productivity (NPP) can significantly decrease in the event of a prolonged water deficit, especially in India. The delicate nature of efficiency raises concerns about the food security of India's large population.

Because the majority of central and peninsular India lacked resilience and was subject to extreme or high risks, the extreme conditions may have an impact on the cultivation of staple foods like wheat, cotton, millet, and pulses. Low temperatures in these areas are linked to increased soil moisture availability and decreased evapotranspiration, which may promote crop growth.

According to research, Indian forests will suffer greatly as a result of climate change. The resilience of different forest types was studied, and it was discovered that it had a strong correlation with the type of forest and time scale. We found that, at some point in time, over half of all forest types lacked resilience. The three types of vegetation cover were wooded savannas, croplands, and evergreen needle leaf forests, with half of their areas exhibiting high risk and resilience. Eight of the ten vegetation types were discovered to be resilient in more than their respective areas.

Our study advances our understanding of how India's terrestrial ecosystems are impacted by extreme weather. The goal of the investigation was to identify the particularly vulnerable areas and the seasons that presented the greatest risk to ecosystem productivity. The study of land cover and river basin scales provides crucial resources for managing terrestrial ecosystems and creating sustainable policy by thoroughly identifying and characterizing risk factors.

The study suggested evaluating the effects of worldwide climate change on ecosystem operation in different kinds of land cover as well as river basins across all of India. The outcomes contribute to route climate factors influencing ecosystem productivity in multiple spatial and temporal dimensions, which is essential to comprehending the intricate ecosystems on land reacting to climate change. To manage these ecosystems sustainably, coping mechanisms will be developed with the help of the framework.

Conclusion

A comprehensive study of the relationship between extreme weather and terrestrial ecosystem productivity in different parts of India reveals serious risks associated with climate variability. This study sheds light on the complex interplay of temperature, soil moisture, precipitation, and net primary production (NPP). The results confirm that disturbed soil moisture levels, along with other climate-related factors, have a significant impact on terrestrial biomass production, especially in areas where drought occurs during the non-monsoon season and is very sensitive, as low water levels greatly reduce vegetative production. This study is notable for the unique response of plant species to climate stress and the extreme sensitivity of some forest ecosystems, such as evergreen coniferous forests, to temperature gradients. The implications of these findings go beyond environmental issues; food availability and biodiversity conservation may also be affected. Addressing these vulnerabilities requires a multi-pronged approach that incorporates sustainable land management strategies, well-informed policy interventions, and adaptive approaches that take nature seriously, including specific organisms. Going into the future, the study highlights the need for immediate action to mitigate the negative impacts of climate change on India's terrestrial ecosystems. It emphasises the importance of continued research, active monitoring, and collaborative efforts to foster ecological resilience and sustainable practices in the face of a changing climate. The key findings of the study are summarised in this conclusion, which also highlights the need for further research and preliminary steps to mitigate the impact of climate change on India's terrestrial environment, emphasizing the living.

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