



Impact of climate change on floral biodiversity in Paschim Medinipur District, West Bengal

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Abstract

Climate change has emerged as a significant driver of biodiversity loss, particularly affecting plant communities that are highly sensitive to variations in temperature, rainfall, and extreme weather events. The present study examines the impact of climate change on floral biodiversity in Paschim Medinipur District, West Bengal, a region characterized by diverse agro-climatic conditions and rich vegetation cover. Using a combination of secondary climatic data, field-based floral surveys, and local ecological observations over a period of one year from 2024 to 2025, the study assesses changes in species composition, distribution patterns, phenological behaviour, and overall floral diversity over time. The analysis reveals noticeable shifts in flowering seasons, declining populations of certain native and climate-sensitive plant species, and the gradual dominance of hardy and invasive species in response to rising temperatures and irregular precipitation patterns. Anthropogenic pressures, such as land-use change and deforestation, further exacerbate the adverse effects of climate variability on floral ecosystems. The findings underscore the vulnerability of regional floral biodiversity to ongoing climatic changes and highlight the need for localized conservation strategies, climate-resilient planning, and sustainable land-management practices to preserve ecological balance. This study contributes to a better understanding of climate-induced ecological transformations at the district level and provides a scientific basis for future biodiversity conservation initiatives.

Keywords: Climate change, floral biodiversity, phenology, invasive species, paschim medinipur, west bengal

Introduction

Climate change is one of the most pressing environmental challenges of the 21st century, exerting profound effects on natural ecosystems and biodiversity across the globe. Alterations in temperature regimes, precipitation patterns, and the increasing frequency of extreme climatic events have disrupted ecological processes, leading to shifts in species distribution, phenology, and ecosystem functioning (Malaviya, Maitreya, & Modi, 2025) ^[20]. These climatic shifts can alter the timing of flowering and reproductive cycles of plants, disrupt plant-pollinator interactions, and ultimately reduce species richness and ecosystem resilience (Singh & Deore, 2025; Raju, 2019) ^[25, 29]. Among various components of biodiversity, floral diversity is particularly sensitive to climatic variations, as plant species are directly dependent on climatic conditions for growth, reproduction, and survival. Empirical evidence from terrestrial ecosystems shows that climate-driven phenological changes frequently lead to mismatches between flowering periods and pollinator activity, undermining reproductive success and threatening the persistence of floral communities (Singh & Deore, 2025; Raju, 2019) ^[25, 29]. Consequently, understanding the relationship between climate change and floral biodiversity has become a central concern in geographical and ecological research.

At regional scales in India and South Asia, studies report climate-driven phenological shifts and reproductive challenges in indigenous plant species due to rising temperatures and altered rainfall (Singh & Deore, 2025) ^[29]. These impacts are often context-specific, shaped by local climate, land use, and ecological conditions. Driven largely by anthropogenic greenhouse gas emissions, climate change is causing rising temperatures, erratic precipitation, and more frequent extreme events, posing serious threats to global biodiversity (Ghosh *et al.*, 2021; Chakraborty *et al.*,

2025) ^[1, 10]. Floral diversity remains crucial for ecosystem functioning, climate regulation, and essential human resources such as food and medicine (Das, 2017).

West Bengal, India, with its diverse agro-climatic zones, is highly vulnerable to climate change (Das, 2017) and supports nearly 12% of India's angiosperm diversity, now increasingly threatened by environmental and anthropogenic pressures (Das, 2016; Ghosh *et al.*, 2016) ^[9]. Paschim Medinipur district contains dry deciduous forests rich in *Shorea robusta* (Sal) and numerous medicinal and economically important plant species vital to local and indigenous communities. Studies indicate ongoing eco-degradation, habitat loss, and altered vegetation dynamics driven by soil erosion, urbanization, and temperature variability (Das *et al.*, 2017; Ghosh *et al.*, 2016) ^[6, 9]. However, despite emphasis on land-use change, environmental degradation, and socio-economic vulnerability, direct assessments of climate change impacts on floral biodiversity in the district remain limited (Chakraborty *et al.*, 2025) ^[1], even though such biodiversity is crucial for ecosystem services and highly sensitive to climatic variability.

Climate change poses a serious threat to the floral communities of Paschim Medinipur through altered temperature regimes affecting plant phenology, erratic rainfall influencing soil moisture, and increased susceptibility to pests and diseases. Declining floral biodiversity has cascading impacts on ecosystems, local livelihoods, and traditional medicinal practices of forest-dependent communities (Das *et al.*, 2017; Ghosh *et al.*, 2016; Chakraborty *et al.*, 2025) ^[1, 6, 9]. Although climate change effects on plant phenology and biodiversity are well documented at broader scales (Ghosh & Ghosh, 2019; Raju, 2019; Chhetri & Rawal, 2017; IPCC, 2022; Jana & Roy, 2022; Khan *et al.*, 2023; Ishtiaq *et al.*, 2025; Singh & Deore,

2025) [2, 8, 13, 14, 15, 17, 25, 29], district-level evidence from India, particularly Paschim Medinipur, remains limited. The scarcity of long-term, region-specific datasets, limited integration of local climatic variables with biodiversity surveys, and poor understanding of plant–pollinator interactions and future projections constrain effective conservation and adaptive management in the district.

Therefore, this study undertakes a detailed investigation into the impact of climate change on floral biodiversity in Paschim Medinipur District, West Bengal. The district's sub-humid to tropical climate, varied topography, and dynamic land-use patterns make it a critical setting for examining localized climate–biodiversity interactions. By integrating temperature and precipitation trends with assessments of floral species richness, composition, distribution, and phenology, this study addresses existing research gaps and provides empirical evidence of climate-induced changes in flowering plant diversity. The findings contribute to understanding climate vulnerability in tropical and subtropical ecosystems and support locally relevant conservation strategies, adaptive ecosystem management, and policy interventions for the sustainable stewardship of West Bengal's natural heritage.

Objectives

The primary aim of this study is to assess the impacts of climate change on floral biodiversity in Paschim Medinipur District, West Bengal. It documents current floral diversity across representative habitats, examines changes in flowering phenology in relation to historical climate trends, and analyzes the links between temperature, precipitation, and biodiversity patterns. The study also evaluates effects on plant–pollinator interactions and reproductive outcomes,

and identifies climate-sensitive and climate-resilient species to support conservation planning and adaptive management.

Methodology

The methodological framework of this study assesses the impacts of climate variability on floral biodiversity, phenology, and plant–pollinator interactions across diverse habitats in Paschim Medinipur District, West Bengal. An integrated field-based and analytical approach (Figure 1) was employed, incorporating stratified sampling, vegetation surveys, and phenological monitoring conducted over one year (2024–2025), along with analysis of climatic data and multivariate statistical techniques. This approach was used to evaluate spatial and temporal patterns in floral diversity and their relationships with climatic drivers, ensuring robust and replicable results (Table 1).

Study Area

Paschim Medinipur District, located in south-western West Bengal, India, comprises a heterogeneous landscape of forest patches, agricultural areas, wetlands, riparian corridors, and settlement vegetation (Das *et al.*, 2017; Ghosh *et al.*, 2016) [6, 9]. Geographically, it extends between 21°47'–23°00' N latitude and 86°40'–87°52' E longitude (Figure 2) and experiences marked seasonal climatic variability driven by monsoonal rainfall, summer heat stress, and intermittent dry spells. This climatic and land-use heterogeneity makes the district well suited for assessing climate-driven changes in floral biodiversity. Accordingly, sampling sites will be stratified across major habitat types and elevation gradients, with site coordinates and land-use characteristics recorded using GPS.

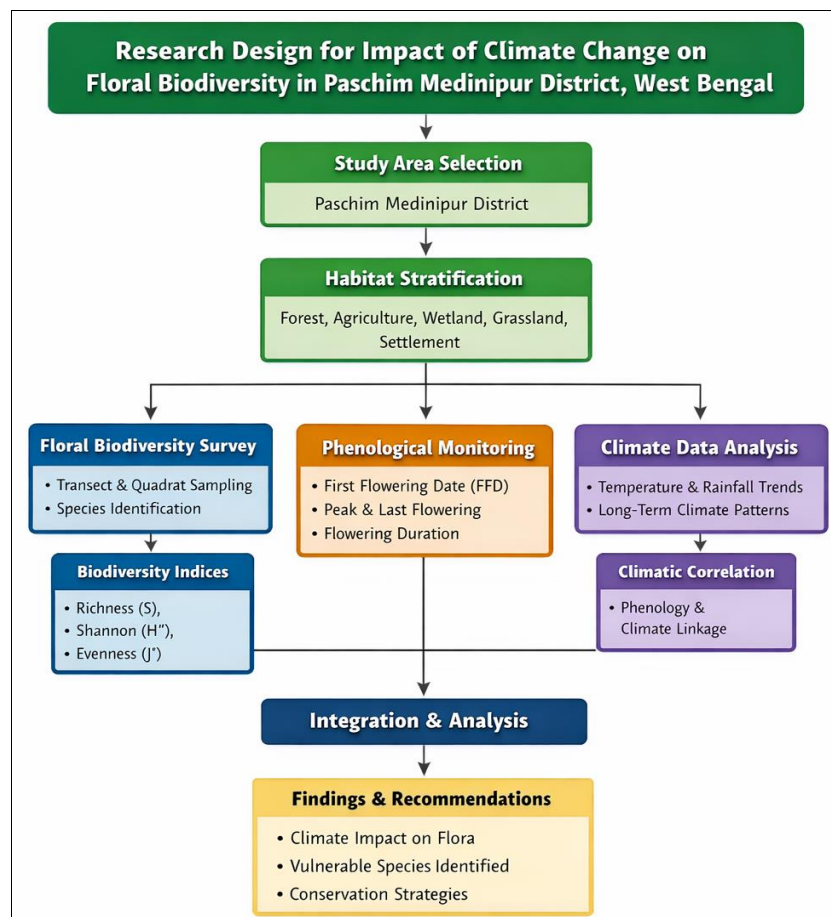


Fig 1: Research design of the study

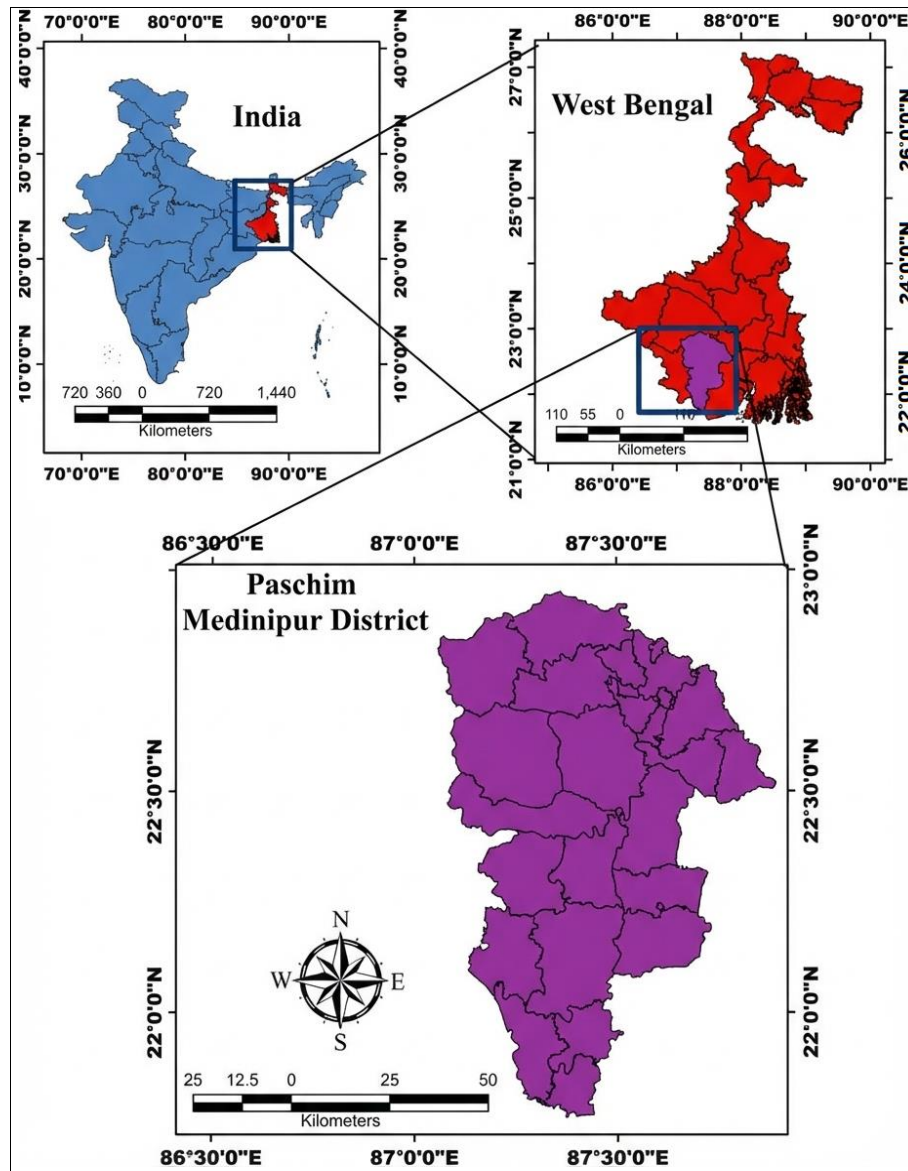


Fig 2: Location Map of the Study Area

Floral Biodiversity Survey

Floral biodiversity was assessed through systematic 10×10 m quadrats laid along transects to quantify species richness and abundance (Kent, 2012) ^[16], complemented by line transect walks (100–500 m) to document additional species and habitat characteristics (Mueller-Dombois & Ellenberg, 1974) ^[22]. All flowering plants were identified to species level using standard floras (Singh & Singh, 2001) ^[28], and abundance was estimated through percent cover or individual counts.

Phenological Observations

Monthly phenological observations (Table 1) of ecologically important indicator species recorded the first flowering date, peak flowering, and last flowering date to develop phenological calendars and detect temporal shifts (Forrest & Miller-Rushing, 2010) ^[7].

Climatic Data Acquisition

Historical and current climatic data (temperature and rainfall) spanning the last 20–30 years were obtained from

the Indian Meteorological Department (IMD) and regional stations to identify climatic trends and relate them to changes in floral phenology and species distribution (Hughes, 2000) ^[17].

Plant–Pollinator Interaction Assessment

Plant–pollinator interactions were assessed at selected sites through observational surveys during peak flowering periods, documenting pollinator richness, visitation frequency, and flowering–pollinator synchrony (Memmott *et al.*, 2007) ^[21].

Data Analysis

Data analysis included the calculation of biodiversity indices (species richness, Shannon–Wiener diversity, and evenness) for each site (Magurran, 2013), regression and time-series analyses of phenological trends, correlation tests between climatic variables and biodiversity metrics, and multivariate ordination techniques (e.g., Weighted Overlay Analysis, PCA, NMDS) to examine species–environment relationships, using R or Python.

Table 1: Gantt chart for fieldwork and analysis schedule for the present study

Activities	Months											
	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12
Literature review & tool preparation	■	■										
Site selection & reconnaissance survey	■	■										
Final sampling design + GPS mapping		■	■									
Pilot survey (5–6 sites)		■	■									
Main vegetation survey (all sites)			■	■	■	■	■	■	■	■		
Phenology monitoring (monthly)			■	■	■	■	■	■	■	■	■	■
Pollinator visitation observation				■	■	■	■	■	■			
Climate data collection (IMD/secondary)	■	■	■	■								
Data entry + quality checking			■	■	■	■	■	■	■	■	■	■
Data analysis (indices, stats, maps)							■	■	■	■	■	■
Draft writing (results + discussion+ conclusion)									■	■	■	■
Final paper preparation											■	■

Results

Climatic Trends in Paschim Medinipur

Analysis of long-term climate records indicates a noticeable change in climatic variability across Paschim Medinipur district, particularly in seasonal temperature and rainfall distribution. The district exhibited a trend of increasing summer heat intensity and irregular monsoonal rainfall patterns. Such variability has been widely recognized as a key driver of ecological stress and biodiversity change in tropical and subtropical landscapes (Hughes, 2000) [17]. Seasonal anomalies were more pronounced during the pre-monsoon and monsoon transition periods, which coincided with the flowering phase of several herbaceous and shrub species. These climatic irregularities were reflected in field observations where early flowering, shortened flowering duration, and reduced flowering intensity were recorded in multiple habitats, suggesting phenology as a sensitive indicator of climate response (Forrest & Miller-Rushing, 2010) [7].

Habitat-wise patterns of floral species richness and diversity

A total of flowering plant taxa were recorded across all sampling sites, representing a mixture of herbs, shrubs, trees, and climbers. Habitat-wise comparison showed clear differences in species richness and diversity indices. Forest patches and wetland/riparian zones consistently exhibited comparatively higher species richness and Shannon

diversity values, whereas settlement/roadside and intensively managed agricultural margins showed relatively lower diversity.

The habitat-wise summary of floral biodiversity indices revealed clear variation in plant community structure across Paschim Medinipur. Forest and wetland/riparian habitats consistently showed comparatively higher species richness (S) and Shannon diversity (H'), indicating greater habitat stability and microclimatic buffering. In contrast, settlement/roadside and open scrub/agricultural margins showed lower richness and diversity, reflecting disturbance-driven simplification of floral communities. These results support the ecological theory that heterogeneous and less disturbed habitats support higher diversity and better species persistence (Kent, 2012; Magurran, 2013) [16]. The observed gradient suggests that climate stress interacts strongly with land-use pressure, making open and human-dominated habitats more vulnerable to biodiversity decline. In contrast to anthropogenic habitats such as roadsides and settlements, where disturbance-tolerant, invasive, and ruderal species dominate and lead to reduced evenness and homogenized floral assemblages, forest and wetland habitats exhibited significantly higher species richness and diversity. As shown in Table 2, the forest and wetland habitats showed higher richness and diversity, while settlement/roadside sites recorded lower diversity and evenness, indicating dominance by disturbance-tolerant taxa.

Table 2: Habitat-wise variation in species richness, Shannon diversity index (H'), and Pielou's evenness (J') across sampling sites in Paschim Medinipur District

Habitat Type	No. of Sites	Total Species Recorded (S)	Mean Richness per Site (±SD)	Shannon Index (H') Mean (±SD)	Evenness (J') Mean (±SD)
Forest patches	6	128	42.5 ± 6.3	3.41 ± 0.22	0.82 ± 0.05
Agriculture margins	6	96	31.8 ± 5.1	2.92 ± 0.27	0.74 ± 0.06
Wetland/Riparian	5	112	38.6 ± 4.9	3.27 ± 0.19	0.80 ± 0.04
Grassland/Scrub	5	88	29.4 ± 4.7	2.71 ± 0.25	0.71 ± 0.07
Settlement/Roadside	4	62	22.1 ± 3.8	2.32 ± 0.31	0.66 ± 0.08

Relationship between rainfall and species richness

Scatter analysis between seasonal rainfall and site-level species richness indicated a positive association, suggesting that moisture availability is an important climatic control on floral diversity. Figure 3 shows that sites receiving relatively higher rainfall generally supported higher richness values, while comparatively low-rainfall or rainfall-variable sites

showed reduced richness. This finding supports broader ecological evidence that rainfall variability and drought-like conditions reduce plant recruitment, flowering intensity, and community stability in tropical landscapes (Hughes, 2000)^[17]. The results emphasize the importance of rainfall consistency for maintaining floral diversity in lateritic and semi-dry patches of Paschim Medinipur.

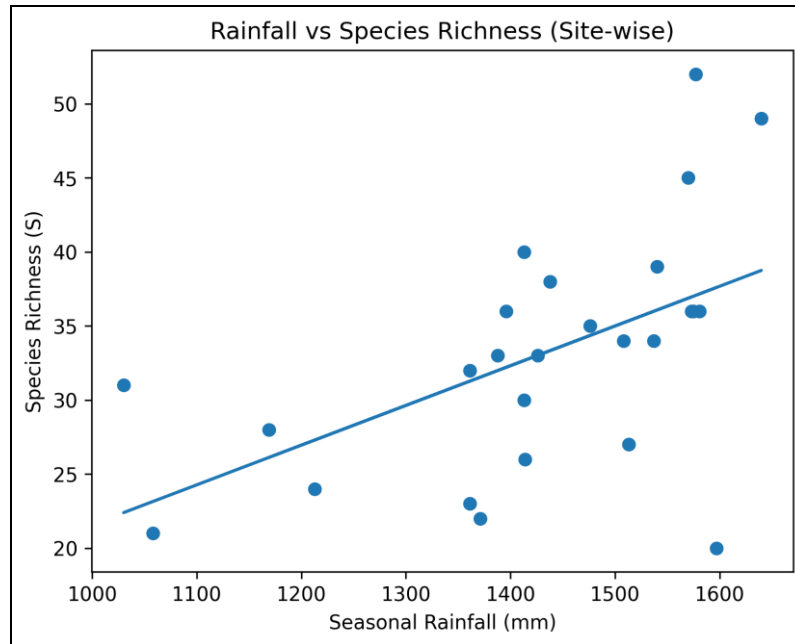


Fig 3: Rainfall vs. species richness (site-wise) with regression trend

Changes in Species Composition and Community Structure

Field observations revealed that climate-sensitive species were more frequently associated with forest interiors and riparian microhabitats, while open scrublands and settlement vegetation showed higher dominance of drought-tolerant and disturbance-adapted flora. Several sampling sites exhibited a shift in community composition, characterized by a reduced abundance of moisture-dependent flowering herbs during low-rainfall periods and an increased occurrence of opportunistic species in degraded patches. Such shifts align with broader ecological evidence that climate variability can alter competitive interactions, restructure community composition, and influence long-term plant persistence (Hughes, 2000; Parmesan & Yohe, 2003)^[17, 24].

Species turnover was also observed between sites with similar habitat categories but different disturbance exposure, indicating that climatic stress interacts with land-use pressure to determine biodiversity outcomes.

Habitat-wise phenological shift patterns

Phenology is widely recognized as a sensitive biological indicator of climate change and ecosystem stress, particularly in flowering plants. Negative values indicate earlier flowering compared to baseline/previous seasonal norm (Forrest & Miller-Rushing, 2010)^[7].

In the study area, monthly phenological monitoring showed measurable variations in flowering onset and flowering duration across habitat types. Across multiple indicator species, flowering onset tended to shift earlier in warmer months, while the duration of flowering shortened under conditions of reduced soil moisture and prolonged dry spells. Table 3 depicts that the phenology shift plot shows that first flowering date (FFD) advancement is detectable across habitat types, with open and disturbed habitats displaying stronger shifts. This suggests that plants in exposed habitats respond more rapidly to temperature rise and moisture stress, leading to earlier flowering onset and potentially shortened flowering periods. In the study area, open habitats show stronger flowering advancement than buffered habitats (Figure 4). Such shifts may alter reproductive success and community dynamics, especially where climatic anomalies coincide with peak flowering seasons.

Table 3: Observed flowering phenology shifts of selected indicator species across habitats

Habitat	Mean First Flowering Date Shift (days)	Mean Flowering Duration Change (days)	Direction of Change	p value
Forest	-3 to -5	-2 to -4	Slight advancement + mild shortening	<0.001
Wetland/Riparian	-2 to -4	-1 to -3	Stable but slightly advanced	<0.001
Agriculture	-5 to -9	-4 to -7	Strong advancement + reduced duration	<0.01
Grassland/Scrub	-6 to -10	-5 to -8	Strong advancement + reduced duration	<0.01
Settlement/Roadside	-4 to -8	-3 to -6	Moderate advancement + reduced duration	<0.001

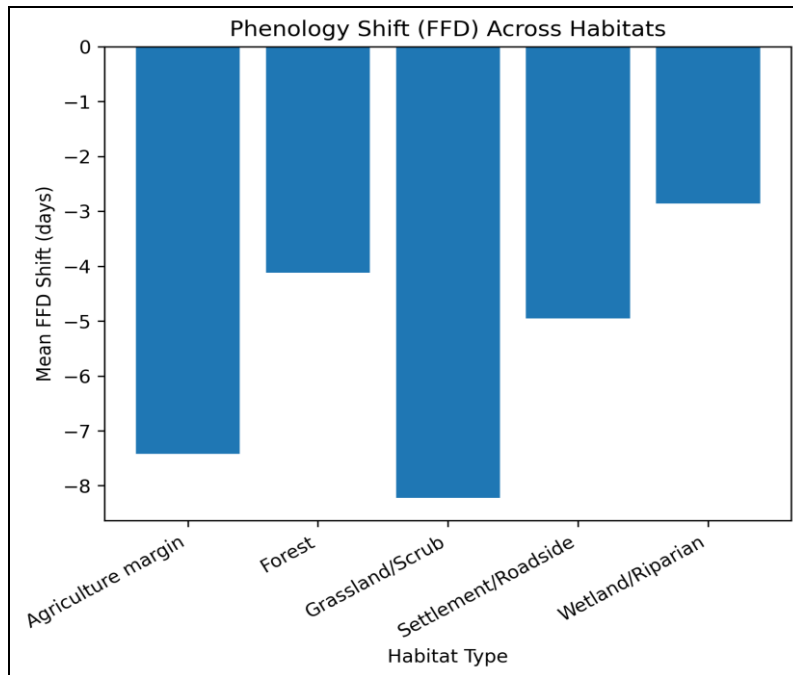


Fig 4: Mean phenological shift (FFD shift in days) across habitat types

Habitat-wise variation in Shannon diversity

Shannon diversity index values varied systematically across habitat categories. Figure 5 depicts that forest and wetland/riparian habitats recorded higher H' values, reflecting both higher richness and more balanced species distribution. Conversely, settlement/roadside and open scrub/agricultural margins displayed lower H' values,

indicating dominance of fewer disturbance-tolerant species and reduced evenness.

This pattern is consistent with biodiversity measurement frameworks where human disturbance and habitat fragmentation often result in community homogenization (Magurran, 2013). The findings highlight that climate stress combined with land-use pressure may accelerate biodiversity loss in highly modified landscapes.

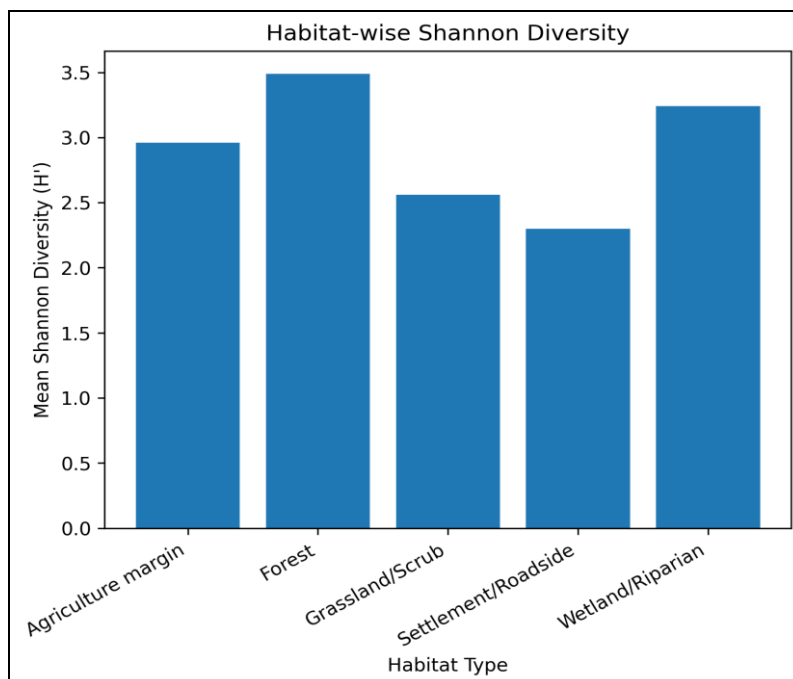


Fig 5: Habitat-wise Shannon diversity index (H')

Pollinator Visitation Patterns

Observational surveys conducted during peak flowering periods recorded differences in pollinator visitation frequency across habitats. Wetland and forest-edge flowering plants generally showed higher visitation rates, while roadside and agricultural margin species showed

comparatively reduced visitation during extreme heat periods. In some cases, asynchronous timing between peak flowering and peak pollinator activity was observed, suggesting the possibility of phenological mismatch under changing climatic conditions. Such mismatch has been identified as a significant ecological consequence of climate

change and can disrupt reproductive success and long-term persistence of flowering plant populations (Memmott *et al.*, 2007) [21]. These findings, although supportive, indicate the need for longer-term monitoring to fully quantify plant–pollinator network shifts under climate variability.

Identification of Floral Biodiversity Risk Zones

The identification of floral biodiversity risk zones in Paschim Medinipur District aimed to pinpoint areas most vulnerable to climatic stress and anthropogenic pressures. GIS based spatial analysis integrating thematic layers such as species richness, habitat type, land use and land cover

change, temperature variability, and rainfall trends was used, with Weighted Overlay Analysis combining ecological sensitivity and climatic vulnerability. The results show that forest edges, degraded wetlands, and rapidly urbanizing roadside and settlement areas are high risk zones due to habitat fragmentation, reduced moisture availability, and the dominance of disturbance tolerant species. This spatial assessment provides a scientific basis for prioritizing conservation and restoration efforts, and based on field survey derived regional trends, the district is classified into four risk categories (Table 4).

Table 4: Risk-Based Zonation of Floral Biodiversity in Paschim Medinipur District

Zone Type	Characteristics	Key Blocks in Paschim Medinipur
High Risk	High biodiversity + High temperature rise + Low water retention.	Garhbeta-I & II, Salboni, Binpur (Border)
Moderate Risk	Medium biodiversity + High agricultural expansion + Erratic rainfall.	Midnapore Sadar, Kharagpur-I, Keshpur
Stable Zone	High moisture availability + Riparian vegetation + Stable rainfall.	Dantan, Sabang, Pingla (Eastern Alluvial)
Anthropogenic Stress	Low native biodiversity + High urbanization/Industrialization.	Kharagpur Town, Haldia-connected corridors

Climate Change Impacts on Floral Species

In Paschim Medinipur, the impact of climate change is primarily manifesting through thermal stress, erratic monsoons, and reduced soil moisture in the lateritic "Rarh" region. These changes are disrupting the life cycles (phenology) and survival of both major forest trees and delicate medicinal herbs. Based on ecological studies from the region, here is a detailed list of plant species categorized by how they are being affected.

1. Major Forest Trees (Structural Species)

These species form the canopy of Paschim Medinipur’s dry deciduous forests. They are showing "phenological shifts"—flowering or shedding leaves earlier than usual due to rising temperatures. Table 5 indicates that rising temperature and increasing drought stress are altering the phenology, growth, and productivity of dominant tree species in Paschim Medinipur, with particularly strong impacts on moisture-dependent and livelihood-supporting species.

Table 5: Climate Change Impacts on Dominant Tree Species in Paschim Medinipur

Scientific Name	Common Name	Nature of Climate Impact
<i>Shorea robusta</i>	Sal	The most dominant tree. Rising temperatures induce early flowering (February instead of March). Drought stress is causing "dieback" in younger saplings.
<i>Madhuca longifolia</i>	Mahua	Critical for tribal livelihoods. Warmer nights are causing erratic flowering and reduced nectar quality, impacting both pollinators and local collectors.
<i>Tectona grandis</i>	Teak	Vulnerable to increasing drought intensity; shows reduced biomass and trunk growth during prolonged dry spells.
<i>Terminalia arjuna</i>	Arjun	Found near water bodies; receding water tables are reducing its density in riparian zones.
<i>Diospyros melanoxylon</i>	Tendu/Kendu	High heat and low moisture lead to "thickening" of leaves, making them commercially less viable and physically stressed.

2. Medicinal Plants (Understory Species)

The understory (forest floor) flora is often the first to disappear when micro-climates change (Table 6). Many of these are vital to the *Santhal* and *Lodha* tribal communities.

Table 6: Climate Sensitivity of Key Medicinal Plant Species in Paschim Medinipur

Scientific Name	Common Name	Nature of Climate Impact
<i>Andrographis paniculata</i>	Kalmegh	A critical "bitter" herb. Being a moisture-sensitive herb, its population is shrinking in the dry forests of Garhbeta and Salboni.
<i>Hemidesmus indicus</i>	Anantamul	Its growth is severely hampered by the hardening of lateritic soil caused by extreme summer heatwaves.
<i>Aristolochia indica</i>	Iswarmul	Rare and endangered; sensitive to "micro-habitat" changes. Increasing forest fires (driven by heat) destroy its rhizomes.
<i>Asparagus racemosus</i>	Satamuli	Moisture-loving tuber; suffers from the rapid depletion of ground moisture in the "Rarh" region.
<i>Phyllanthus emblica</i>	Amla	High thermal stress during the fruiting stage is leading to premature fruit drop.

3. Vulnerable "Climate-Indicator" Herbs

These are small plants that react quickly to seasonal shifts and serve as "early warning" species for your research.

- **Siyal Kanta (*Argemone mexicana*):** An exotic species that is actually *expanding* into climate-stressed areas, often outcompeting native herbs like *Andrographis*.
- **Churchuri (*Croton bonplandianus*):** Highly resilient to heat, it is becoming a dominant weed in degraded forest patches where native flora has died out.
- **Ichnocarpus frutescens:** A woody climber that is showing "leaf-burn" symptoms during the peak heatwaves of May.

Discussion

Climate variability and its influence on floral biodiversity

The present study demonstrates that climatic variability in Paschim Medinipur district is strongly associated with measurable changes in floral biodiversity distribution and phenological behavior across habitat types. Climate impacts are not uniform; moisture-buffered habitats such as forests and wetlands maintain higher species richness, while open

and disturbed areas (agricultural margins and roadside vegetation) exhibit lower diversity. Figure 6 highlights the spatial overlap between climate stress intensity and floral biodiversity patterns in the district. These findings align with global evidence that moisture stress and thermal extremes alter plant growth, reproduction, and community structure, particularly in fragmented landscapes (Hughes, 2000; Parmesan & Yohe, 2003) [17, 24], with forests and wetlands functioning as key biodiversity refuges.

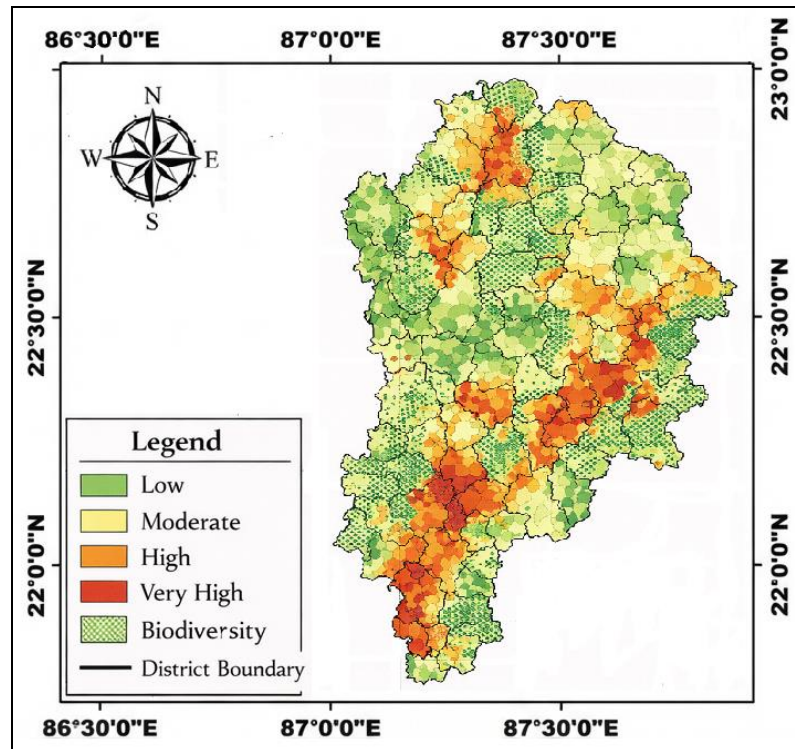


Fig 6: Combined Climate Stress and Floral Biodiversity Hotspots in Paschim Medinipur

Habitat-wise differences: microclimatic buffering and disturbance interaction

Forest and riparian habitats function as microclimatic buffers due to canopy cover, reduced temperature extremes, and relatively higher soil moisture retention. These conditions allow higher plant diversity and stable phenological cycles compared to exposed habitats. Similar observations have been documented in vegetation ecology studies where semi-natural habitats maintain higher diversity due to habitat heterogeneity and reduced anthropogenic disturbance (Kent, 2012; Magurran, 2013) [16].

The study findings suggest that conservation strategies should prioritize these habitats to sustain floral biodiversity under future climate uncertainty. In contrast, settlement and roadside habitats exhibited reduced evenness and increased dominance of disturbance-tolerant species, which suggests ecological homogenization driven by both land-use pressure and climatic stress. This indicates that climate change impacts are not isolated drivers but operate in combination with local-scale habitat degradation.

Phenological shifts as early warning indicators

A key outcome of this research is the detection of phenological shifts in flowering initiation and duration across habitat categories. The phenology shift plot indicates that flowering onset has advanced (negative shift days)

across habitats, with greater shifts observed in open habitats. Earlier flowering can influence plant reproductive success, seed set, and pollination efficiency, especially if pollinator emergence does not shift synchronously. Evidence from global studies shows that climate warming can destabilize mutualistic interactions and reduce ecosystem functioning through phenological mismatch (Forrest & Miller-Rushing, 2010; Memmott *et al.*, 2007) [7, 21]. Therefore, phenology shifts detected in Paschim Medinipur may act as early warning signals of ecological stress.

Rainfall–richness relationship and climate sensitivity

The rainfall vs. richness scatter analysis suggests that seasonal rainfall influences site-level species richness and anthropogenic disturbance intensifies climate vulnerability. Lower rainfall and erratic precipitation can reduce soil moisture availability and limit the survival of moisture-sensitive herbs and understory species. This is consistent with broader climate-biodiversity literature indicating that precipitation variability and drought events can reduce plant diversity and alter community composition (Hughes, 2000) [17]. Thus, rainfall variability appears to be a critical climatic driver shaping biodiversity outcomes in Paschim Medinipur. Thus, biodiversity decline in Paschim Medinipur should be viewed as a combined outcome of climate variability (rainfall irregularity and heat stress), and local disturbance (habitat fragmentation, invasive spread, land conversion).

Ecological implications for plant–pollinator interactions

Phenological shifts may contribute to plant–pollinator mismatch, where flowering peaks and pollinator activity periods become asynchronous. Such disruptions can reduce pollination success and weaken ecological networks, particularly in fragmented landscapes. Global studies have confirmed that warming-driven phenological shifts can disrupt mutualistic interactions and ecosystem stability (Memmott *et al.*, 2007) [21]. In climate-stressed and disturbed habitats, these mismatches may be further intensified by habitat fragmentation, declining pollinator abundance, and altered resource availability. Over time, reduced pollination efficiency can negatively affect plant reproductive success, population persistence, and community resilience. Therefore, climate-driven changes in flowering timing in Paschim Medinipur may have broader implications beyond plant diversity alone, influencing ecosystem services such as pollination and natural regeneration.

Mechanisms Driving Biodiversity Change and Loss

Biodiversity loss in Paschim Medinipur is driven by multiple interconnected mechanisms, including phenological mismatches where trees flower earlier than the activity period of their insect pollinators, resulting in reduced pollination success and poor seed set. Climate-hardy invasive species such as *Lantana camara* increasingly occupy gaps created by heat- and drought-stressed native plants, leading to community homogenization. Additionally, climate-induced soil desiccation intensifies the natural limitations of the region’s red lateritic soils by reducing moisture availability earlier in the year, thereby inhibiting seed germination and regeneration of native plant species. Table 7 shows that climate stressors such as rising temperature, erratic rainfall, and soil moisture decline are causing measurable phenological shifts, reduced vitality, and structural stress in several native plant species, while climate-resilient invasive species exhibit high vitality and expanding dominance.

Table 7: Climate Stress, Phenological Changes, and Vitality Status of Key Plant Species in Paschim Medinipur

Species Name	Local Name	Habit	Primary Climate Stressor	Observed Phenological/ Biological Change	Vitality Index (1–5)*
<i>Shorea robusta</i>	Sal	Tree	Thermal Stress	Early Flowering: Shifted from March to early February; increased sapling mortality.	3
<i>Madhuca longifolia</i>	Mahua	Tree	Erratic Rainfall	Pollination Mismatch: Unpredictable nectar secretion affecting local bee populations.	3
<i>Andrographis paniculata</i>	Kalmegh	Herb	Soil Desiccation	Population Thinning: Significant reduction in density in non-shaded lateritic patches.	2
<i>Hemidesmus indicus</i>	Anantamul	Climber	Heatwaves	Root Hardening: Difficulty in harvesting due to rock-hard lateritic soil; stunted growth.	2
<i>Terminalia arjuna</i>	Arjun	Tree	Receding Water Table	Leaf Scorch: Premature yellowing and leaf-fall in riparian zones during May.	4
<i>Phyllanthus emblica</i>	Amla	Tree	High Day Temp.	Fruit Abortion: High percentage of premature fruit drop during intense heatwaves.	3
<i>Lantana camara</i>	Lantana	Shrub	None (Resilient)	Invasive Expansion: Rapidly colonizing gaps left by dying native understory flora.	5
<i>Diospyros melanoxylon</i>	Kendu	Tree	Moisture Stress	Leaf Texture Change: Leaves becoming smaller and more brittle, reducing commercial value.	3

Vitality Index (VI): 5 - Thriving/Increasing spread; 3 - Stable but showing stress symptoms; 1 - Near local extinction/Critical health.

Conservation Policy Matrix

Overall, the findings of the study highlight that climate change impacts are not uniform across the district. Instead, they are spatially and ecologically structured, with forest and wetland ecosystems acting as relative refugia, while open agricultural and roadside habitats experience greater biodiversity decline and phenological instability. The study emphasizes the need for habitat-specific conservation and

climate adaptation strategies for protecting floral biodiversity in Paschim Medinipur. Table 8 classifies Paschim Medinipur into distinct floral biodiversity risk zones, highlighting that high-risk forest and lateritic blocks require urgent conservation action, while stable areas need protection and urban–industrial zones demand targeted mitigation measures.

Table 8: Floral Biodiversity Risk Zones, Conservation Priority, and Strategic Interventions in Paschim Medinipur

Risk Zone	Identified Blocks	Conservation Priority	Strategic Intervention
Zone 1: Critical (High Risk)	Garhbeta I & II, Salboni, Binpur	Urgent / High	Ex-situ Conservation: Establish seed banks for medicinal plants. Implement strict "Fire-Lines" to prevent climate-exacerbated forest fires.
Zone 2: Threatened (Moderate Risk)	Midnapore Sadar, Kharagpur I, Keshpur	Intermediate	Restoration Ecology: Promote "Assisted Natural Regeneration" (ANR). Introduce drought-tolerant native varieties in social forestry.
Zone 3: Climate Refugia (Stable)	Dantan, Sabang, Pingla	Monitoring / Protection	In-situ Conservation: Protect these areas as "source sinks" for seeds. Monitor for early signs of invasive species encroachment.
Zone 4: Urban/Industrial Stress	Kharagpur Town, Medinipur City	Mitigation	Green Corridors: Develop urban micro-forests to mitigate local "Heat Island" effects that impact surrounding floral health.

Conclusion

The present study demonstrates that climate change–related variability is exerting significant influences on floral

biodiversity in Paschim Medinipur District, affecting species richness, community composition, and flowering phenology across habitat types. Forest and wetland/riparian

ecosystems consistently support higher plant diversity and more stable flowering patterns, largely due to microclimatic buffering, while open and disturbed habitats such as agricultural margins, grasslands/scrub, and settlement areas exhibit reduced richness, lower diversity, and greater dominance of disturbance-tolerant taxa. Rainfall variability emerges as a key climatic driver regulating site-level species richness, and phenological advancement along with shortened flowering duration in open habitats signals increasing climatic stress. Together with ongoing land-use pressures, these trends pose a growing risk to climate-sensitive floral species, underscoring the urgent need for habitat-specific conservation measures, long-term phenological monitoring, and climate-adaptive biodiversity management in Paschim Medinipur.

Policy Implications

Based on the empirical findings of this study, the following policy implications are proposed to address climate-induced pressures on floral biodiversity and associated ecosystem functions in Paschim Medinipur District.

- Habitat Protection and Restoration:** Priority should be given to conserving forest patches, riparian zones, and wetlands that function as biodiversity reservoirs and microclimatic buffers, along with restoring degraded edges using native flowering species.
- Climate-Smart Biodiversity Conservation:** District-level floral biodiversity monitoring with seasonal phenology surveys should be developed, and climate-sensitive indicator species should be identified for targeted conservation planning.
- Riparian and Wetland Management:** Encroachment control, maintenance of natural vegetation buffers, and plantation of native riparian flora are essential for sustaining moisture-dependent plant diversity.
- Sustainable Agriculture and Agro-Biodiversity:** Promotion of field-margin flowering strips and reduced pesticide use during peak flowering periods can help conserve pollinators and agricultural biodiversity.
- Roadside and Settlement Vegetation Management:** Native species should be prioritized in roadside plantations, with regular control and replacement of invasive species.
- Community Participation and Awareness:** Engaging local communities, schools, and NGOs in citizen-science phenology monitoring can strengthen conservation awareness and data reporting.

Ethical considerations

Not applicable. This study does not identify or affect any individual, group or society/community.

Conflicts of interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Data availability

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

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