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ABSTRACT

Due to growing climate variability, environments are becoming more susceptible to the impact of climactic change, especially locally upon the biodiversity and especially the more ecologically sensitive species, including the butterfly. The current work examines the climate change and butterfly diversity with regard to three types of habitats (urban habitat, wetland landscape, and the periphery landscape) in the city of Indore, Madhya Pradesh, India, between 2021 and 2023. The 71 butterfly species collected during the study fell under five families using standardized ecological survey techniques such as Pollard Walks and Transect Walks as well as the use of photographs. Diversity measures of butterflies were presented as species richness, abundance, Shannon-Wiener Index, Simpson Index, and evenness (Pielou), which were sampled and calculated on an annual basis and analyzed in respect to climate parameters: average temperature, total annual rainfall, and relative humidity. Climate information pointed to a slow rise in the mean annual temperature (25.1°C in 2021 to 25.5°C in the year 2023) and precipitation and minor variations of humidity. The abundance and diversities of butterflies were highest in 2022, which was also a year of highly moderate temperatures and precipitation, and declined in 2023, especially at an urban level. Correlation analysis indicated a high positive relationship between temperature and richness ($r = 0.93$) and abundance ($r = 0.92$), but the association of rainfall and humidity is complex, where there is a negative relationship with excess rain and richness. Certain habitats were more resilient, such as peripheral and wetland ones, and some were steeper, such as urban ones, because of habitat fragmentation and urban heat island activity. Trends at the species level indicated that generalists such as *Eurema hecabe* were stable, whereas specialists were decreasing. Although the study relies on a relatively short dataset of three years, its results confirm how flexible butterfly communities can be to pursue

the minor changes of the climate condition and emphasize the ecological significance of semi-natural environments within the urban matrices.

KEYWORDS: Butterfly Diversity, Climate Change, Community Structure, Indore, Species Richness, Urban Ecology

1. INTRODUCTION

Two intersecting global trends (climate change and accelerated urbanization) have become the features of the 21st century that are putting a new and previously unknown level of pressure on biodiversity. The anthropogenic greenhouse gas emission has caused climate change that has been experienced through increasing the world temperature, fluctuations in precipitation, and an increase in extreme weather conditions. The effects are directly on the physiology, behaviour, distribution, and survival of the species and are more so on the organisms sensitive to microclimatic changes. Butterflies (Order: Lepidoptera) are among representatives of such nature and can be viewed as good bioindicators since they have a short life cycle, they have narrow temperature limits, and they are dependent on certain host plants.

However, butterflies are important components of ecosystems because of their ecosystem functions as pollinators and prey species and can be used to assess environmental health and ecological stability. Their population dynamics are closely related to the climatic factors so that they tend to be very sensitive to slight changes in the environment and are closely associated with temperature, humidity, and rainfall. Their metabolism, flight activity, mating, and oviposition depend on temperature, and their availability on rainfall not only determines the availability of nectar and the general state of their larval host plants but also affects their habitat structure. Therefore, the abundance, diversity, and spatial distribution of butterflies can easily change along with any climate alterations. The cities, hitherto viewed as biodiversity-depleted, are increasingly viewed as actually capable of holding large amounts of insect diversity, particularly in the managed greenspace, wetlands, and woodlands along the urban fringe. They, however, face ecological obstacles posed by urban microclimates, which are typified by increased temperature (urban heat island effect), drier air, disconnected patches, and shifted hydrological regimes. The ability of butterflies to respond to climatic change is further complicated by the synergistic effect of land-use change, and the changes can destabilize phenology and host plant abundance and population fragmentation. Irrespective of these difficulties, specific urban biotopes, and especially the ones with heterogeneous vegetation

cover and water bodies, can be regarded as refugia, sheltering a diverse community of butterflies and mitigating climate pressure.

The occurrence of more than 1,800 butterfly species together with diverse climatic and ecological zones in India makes India a rich background to study biodiversity response to variations in the environment. Nevertheless, the better part of studies on butterflies in India has been focused on the well-protected areas, such as the national parks and wildlife sanctuaries. The gap related to the longitudinal research within the context of butterfly diversity in the condition of rampant urbanization, especially that regarding the relationship between climate and biodiversity, is conspicuous. The city of Indore, located in Central India, the largest city in Madhya Pradesh, and constituting a tier-2 city, has a complex ecological city mosaic that includes dense urban cores, wetland systems, fragments of several woods, and educational campuses, as well as agricultural fringes. It has a combination of tropical climates due to having definite summer, monsoon, and winter seasons; therefore, it represents a desirable case example of temporal and spatial biodiversity changes in terms of climate change.

Based on this ecological context, our central hypothesis is that butterfly diversity in Indore responds positively to moderate climatic conditions, particularly balanced temperature and rainfall, and that wetland and peripheral habitats will show greater resilience to climate variability than urban habitats due to their richer vegetation structure and microclimatic stability.

In the present study, the question was to determine the effect of climate variability, that is, average temperature, total annual rainfall, and relative humidity, on butterfly diversity with a three-year study in Indore (2021 to 2023). The range of anthropogenic pressure and habitat heterogeneity is bracketed by the chosen study habitats: urban (e.g., Holkar Science College), wetland (e.g., Sirpur Lake), and peripheral (e.g., Choral and Jamli). The objectives of the research are directly linked to this hypothesis as follows:

i. To catalog the species richness and abundance of butterflies in various habitats of Indore to establish baseline diversity patterns under different levels of anthropogenic pressure.

ii. To analyze the dynamics of temporal change in the structure of a butterfly community with the help of ecological indices (Shannon-Wiener, Simpson's, and evenness of Pielou) to assess whether diversity stability differs among habitat types.

iii. To compare the metrics of butterfly diversity to local climatic variables over time to test the predicted positive response of diversity to moderate temperature and rainfall.
iv. To determine species-scale patterns to climate change and habitat type to identify indicator species for climate resilience and vulnerability.

2. LITERATURE REVIEW

It is common knowledge that butterflies are excellent indicators of environmental shift since they are dependent on environmental factors and the host plant (Kunte, 2000; Ehrlich & Murphy, 1987). Many field studies in the world indicated that climate variables, especially the temperature and precipitation, directly influence butterfly phenology, distribution, and community structure (Parmesan et al., 1999; Forister et al., 2010). Minor climatic changes are known as a cause of disrupted life cycles of butterflies in tropical areas, especially by a shift in accessibility to larval host plants and nectar sources (Bonebrake et al., 2010).

Original texts by Kunte (2000, 2008) and Kehimkar (2008) have documented the diversity of butterflies in different ecosystems in India and pointed out their conservation value. Tiple et al. (2007) publications in Maharashtra demonstrated that there were seasonal effects and that abundance of butterflies was significantly correlated with the environment (temperature and rainfall). Equally, Singh and Pandey (2004) reported the diversity of butterflies at semi-urban and forest edges and behaviors relative to environmental circumstances.

There has been progressive coverage on urban butterfly diversity. Several studies by Trivedi, Vishwakarma, Sharma, and colleagues have explored butterfly diversity in Indore, documenting species richness across urban, wetland, and peripheral habitats. Their findings revealed the presence of butterflies from five major families out of the six known in the region, highlighting significant habitat variation and conservation value (Trivedi et al., 2022; Vishwakarma et al., 2022; Nair et al., 2023; Trivedi et al., 2024). Research in Bangalore (Nagendra, 2016) finds that even in the context of habitat isolation, urban greenspace, and, in particular, those close to water bodies can have rich butterfly fauna. Indore's Sirpur Lake, which was just awarded a Ramsar status, is also known as a very diverse place in terms of butterfly and bird populations. Nonetheless, there is limited longitudinal data regarding butterflies and diversity with real-time climate records in Indian cities. The majority of research has involved snapshot surveys or species inventories with no incorporation of climatic variables. This gap highlights the importance of persistent data-based monitoring to comprehend how butterfly communities in urban India adapt to the growing climate variability to gain a better grasp of

why and how this is occurring, which is critical with the intensification of the urban expansion and global warming processes.

3. MATERIALS AND METHODS

3.1 Study Area

This was done at Indore, Madhya Pradesh, India (22.7196 N, 75.8577 E), a city with a high rate of urban encroachment and a wide range of microhabitats. It is also subjected to a tropical climate and has three seasons, namely the monsoon season (July-October), the winter (November-February), and the summer (March-June). It has an average of 10 degrees C during winter months and 42 degrees C during summer months, with an annual average of 25 degrees C. The rainfall averages are 9501,100 mm, with most of the rainfall during the months of the monsoon, and the relative humidity is usually 60–70 percent.

Three major types of habitats were chosen:

Urban Sites: Government Holkar Science College (GHSC), located at central Indore. The campus of 35 acres comprises gardens, lawns, and local vegetation with medium green cover and high-density human traffic.

Wetland Sites: Sirpur Lake, an 800-acre wetland, which was considered one of the Ramsar Sites in 2022. It is situated 7 km away, in the outskirts of the city center, which nurtures the various types of aquatic and semi-aquatic plants together with the migratory birds and butterflies.

Peripheral Sites: Choral and Jamli in the periphery of Indore. Choral is in the Vindhyan range with a lot of forest and riparian forest cover, whereas Jamli is a mixture of cultivated lands and natural forests. Such habitats are less disturbed ones as well as ecological buffers.

3.2 Survey Design and Period of Sampling

A number of surveys were conducted over three years, made between January 2021 and December 2023. To take seasonal differences in the emergence and activity of the butterflies into consideration, every habitat was visited according to a predetermined schedule: GHSC - Twice per month (approximately 72 visits in 3 years); Sirpur Lake and Ralamandal Wildlife Sanctuary - Once every two months (18 visits altogether); Choral and Jamli - Three months (12 visits per three months). They were visited at the most active time of the butterflies, 07:00-11:00 AM and 03:00-05:00 PM, according to Kunte (2000).

3.3 Methods of Butterfly Survey

Pollard Walk Method

Monitoring was done systematically by use of the Pollard Walk Method (Pollard, 1977). Transects of 500 meters laid down at regular intervals were walked at constant speed (12-1.5 km/h), and all the butterflies observed 2.5 meters on either side and 5 meters in front and above were recorded. The technique is non-destructive and can be counted on throughout an extended period of time in case of remote biodiversity surveillance.

Opportunistic Sampling and Transect Walk

Further transect walks were done in and around the main study areas in order to obtain elusive and habitat-specific species. A photograph was used to identify difficult-to-recognize butterflies, and special care was taken to capture them using insect nets with soft handles and used to take a snapshot and then to release them back into their natural habitat without harm.

Species Identification and Recording

Field guides were used in identifying these species, such as Kehimkar (2008): The Book of Indian Butterflies; Kunte (2000): Butterflies of Peninsular India; Smetacek (2017): Butterflies of India. The high-resolution photographic documentation was done using a Nikon P1000 to capture the species belonging to families such as Lycaenidae and Hesperiidae that, in most of the cases, may need extensive study of the markings on the wings and of the shape of the genitalia.

Floral and Host Plant Surveys

Species of plants that were observed on a 5-meter radius along each of the butterflies transects were also documented. The identity was confirmed by Botany with the Flora of Madhya Pradesh (Botanical Survey of India, 1993). Larval-host associations and habit fidelity were determined by observation of butterflies in the process of feeding, oviposition on plants, or eclosion.

3.4 Climate Data Acquisition

The years 2021 and 2023 climate data was obtained using:

i. Madhya Pradesh Pollution Control Board (MPPCB)
ii. Central Pollution Control Board (CPCB)

iii. Indian Meteorological Department (IMD)

These three variables were taken into account:

i. Average annual temperature (degree Celsius)
ii. Total Yearly Rains (mm)
iii. Mean percent relative humidity

This was done to be able to analyze the trends and correlations that can be drawn with butterfly diversity.

3.5 Indices and Data Analysis of Biodiversity

Ecological indices computed were as follows:

Species Richness (S): The number of different species that are seen in one habitat in a year.

Shannon-Wiener Index (H'): Assesses species diversity considering both richness and evenness.

Simpson's Index (1-D): A parameter of species dominance; the larger the value, the more the diversity.

Pielou evenness (J'): It gives the measure of how well individuals were spread out across the recorded species.

Analysis of data was done via Microsoft Excel. Statistical methods comprised:

i. Pearson Correlation Coefficient: To test the correlation among climate variables and the biodiversity indices.
ii. Simple Linear Regression: In order to evaluate the strength of climate variables as predictors of diversity indices.
iii. Species Turnover Analysis: To visualize the variation involving the interannual changes in species presence or absence and abundance.

4. RESULTS

This section presents the results of the butterfly surveys conducted from 2021 to 2023 across three habitat types—urban, wetland, and peripheral—within Indore, Central India. The analysis integrates species richness, abundance, ecological indices, and climate variables (temperature, rainfall, humidity) to understand the impacts of climate change on butterfly diversity. Correlation matrices, regression models, and species-level trends were employed to uncover

patterns and infer relationships. Given the short study period (n = 3 years), these results should be interpreted as indicative trends rather than definitive long-term patterns.

4.1 Climate Trends (2021–2023)

Annual climate data over the three-year study period showed subtle but consistent shifts:

Table 1. Climate Data: Indore City

Year	Mean Temperature (°C)	Rainfall (mm)	Relative Humidity (%)
2021	25.1	1,130	62
2022	25.3	1,240	63
2023	25.5	1,095	61

The temperature steadily increased from 25.1°C in 2021 to 25.5°C in 2023. Rainfall increased between 2021 and 2022 but declined slightly in 2023. Relative humidity followed a similar upward trend initially, then decreased in the final year.

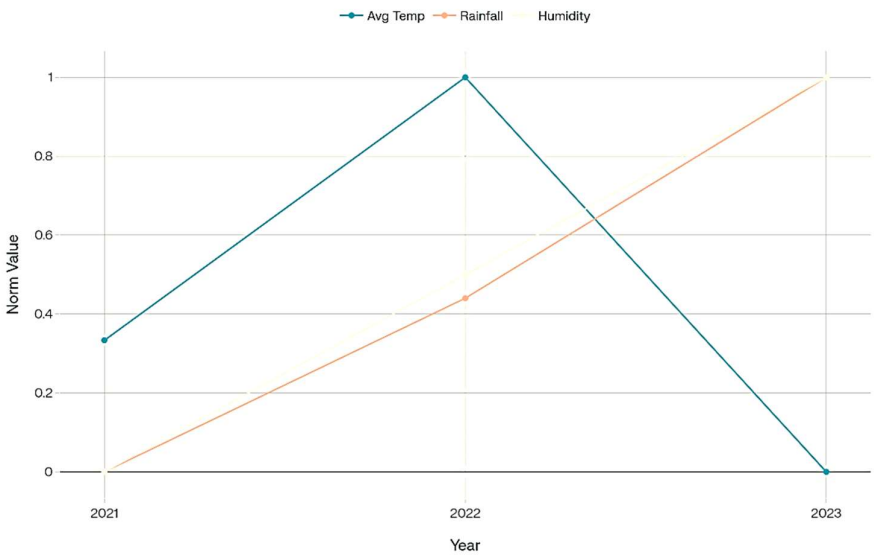


Figure 1. Annual trends in climate variables in Indore (2021-2023)

4.2 Butterfly Diversity and Abundance

Across all sites and years, a total of 71 butterfly species were documented, with representation from five families: Nymphalidae, Pieridae, Lycaenidae, Hesperiidae, and Papilionidae.

Year	Total Abundance	Species Richness	Shannon H′	Simpson's D	Pielou's J′
2021	1,792	66	3.454	0.938	0.824
2022	2,257	67	3.545	0.946	0.843

2023	1,832	64	3.486	0.941	0.838

The year 2022 recorded the highest species richness and abundance, which may be linked to its relatively moderate temperature and above-average rainfall, creating favourable conditions for nectar availability and host plant growth. However, in 2023, a decline in both richness and abundance was observed, corresponding to higher temperatures and slightly lower humidity. Given the limited dataset, such year-to-year changes should be viewed cautiously as they may also reflect short-term variability rather than sustained trends.

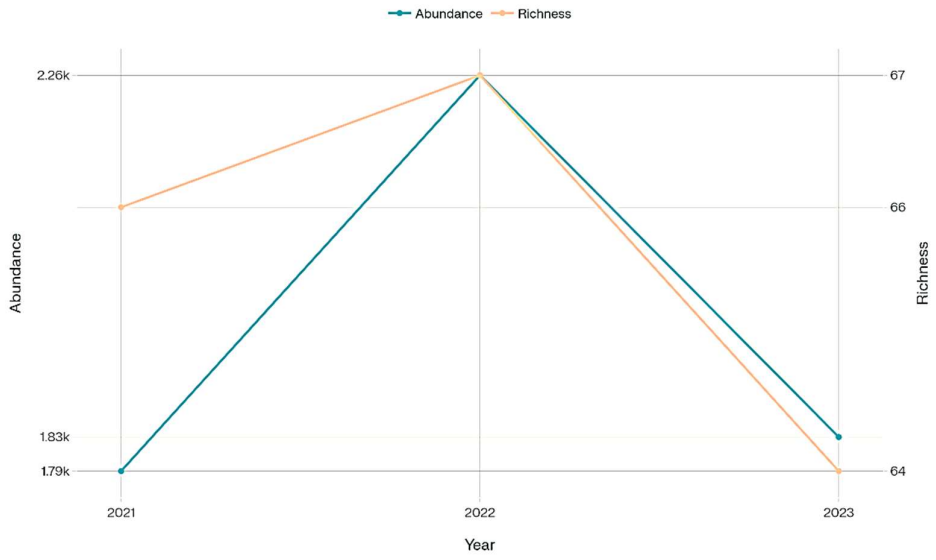


Figure 2. Butterfly abundance and species richness trends in Indore (2021-2023)

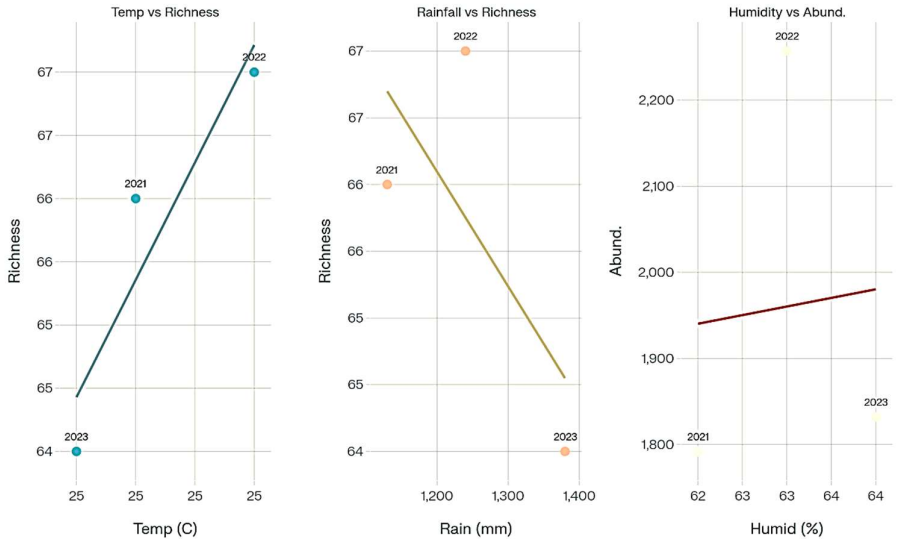


Figure 3. Scatter plots showing relationships between climate variables and butterfly diversity metrics with regression lines and clear year annotations

4.3 Habitat-Wise Diversity Patterns

Analysis of butterfly diversity by habitat revealed distinct ecological responses:

- Urban Habitat (GHSC & Ralamandal):
    - Showed declining richness from 54 species (2021) to 45 species (2023).
    - Declines were accompanied by lower evenness, likely due to dominance by a few generalist species.
- Wetland Habitat (Sirpur Lake):
    - Species richness remained relatively stable (60–62 species annually).
    - High evenness and consistent presence of aquatic vegetation supported stability.
- Peripheral Habitat (Choral & Jamli):
    - Maintained the highest richness (66–67 species) and abundance.
    - These habitats served as ecological buffers with minimal human disturbance.

Overall, wetlands and peripheral areas showed resilience under varying climatic conditions, supporting the study's hypothesis, though confirmation would require a longer monitoring period.

4.4 Diversity Indices Across Habitats and Time

Shannon-Wiener Index (H′):

- Urban: 2.98 → 2.62 (2021–2023)
- Wetland: 3.35 → 3.42
- Peripheral: 3.45 → 3.48

Simpson's Index (1–D):

- Urban: 0.884 → 0.861
- Wetland: 0.932 → 0.934

- Peripheral: 0.938 → 0.941

Pielou's Evenness (J′):

- Urban: 0.784 → 0.712
- Wetland: 0.835 → 0.833
- Peripheral: 0.824 → 0.838

These results indicate that peripheral and wetland habitats retained high diversity and balance in community structure. Urban zones exhibited a clear decline in evenness and richness. However, the observed differences between habitats represent a short temporal window and should not be extrapolated without additional multi-year data.

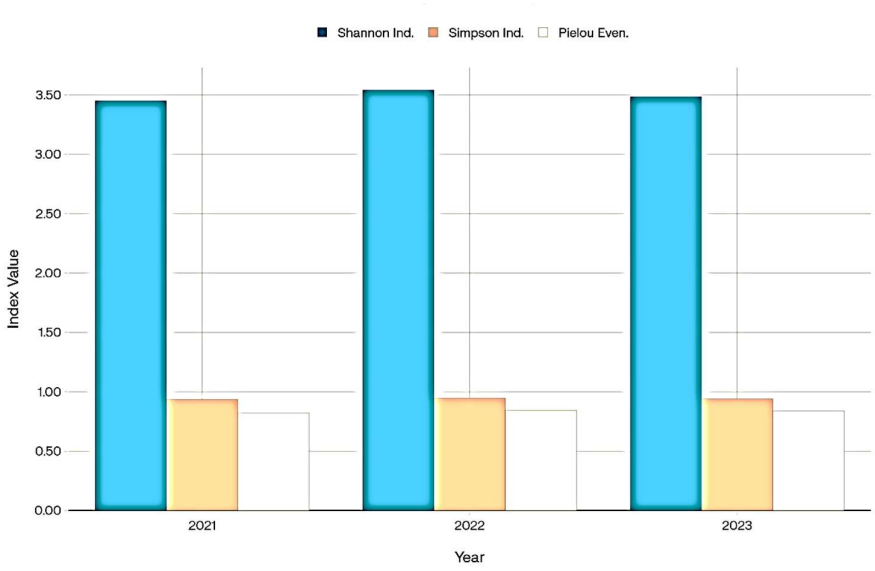


Figure 4. Butterfly diversity indices across years in Indore (2021-2023)

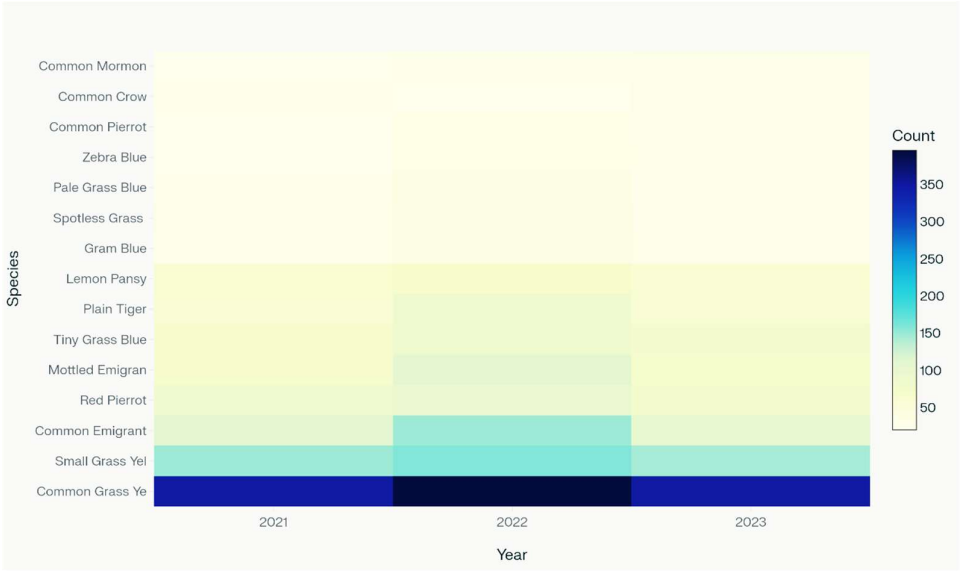


Figure 5. Heatmap of top 15 butterfly species abundance across years (2021-2023)

4.5 Correlation Analysis: Climate vs. Diversity

A Pearson correlation matrix was developed to assess the relationships between climatic variables and butterfly diversity metrics:

Climate Variable	**Species Richness (r)**	**Abundance (r)**	**Shannon H′ (r)**	**Simpson's D (r)**	**Pielou's J′ (r)**
Temperature	0.93	0.92	0.77	0.79	0.43
Rainfall	–0.71	0.01	0.28	0.26	0.66
Relative Humidity	–0.65	0.08	0.35	0.33	0.71

- Temperature showed the strongest positive correlation with species richness and abundance.
- Rainfall showed a moderate negative correlation with species richness but a positive link with evenness.
- Humidity was strongly associated with Pielou's J′, suggesting its role in maintaining balance among species.

These correlations should be interpreted with caution due to the small sample size (n = 3 years), which limits statistical robustness and increases the risk of spurious relationships.

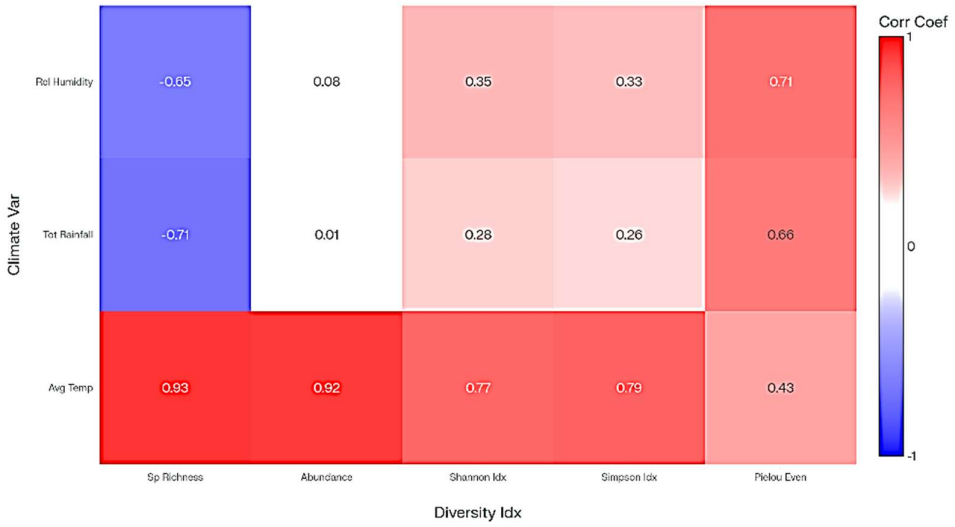


Figure 6. Correlation matrix heatmap between climate variables and butterfly diversity indices

4.6 Regression Analysis

Simple Linear Regression Results:

- Temperature as predictor:
    - Richness: $R^2 = 0.86$
    - Abundance: $R^2 = 0.84$
    - Shannon Index: $R^2 = 0.60$
- Rainfall as predictor:
    - Richness: $R^2 = 0.50$
    - Abundance: $R^2 = 0.0001$
- Humidity as predictor:
    - Pielou's J′: $R^2 = 0.65$

While the dataset (n = 3) limits statistical power, these models suggest temperature as a potential climatic driver of butterfly diversity. However, the apparent strength of these models should not be taken as definitive evidence due to low degrees of freedom; results are indicative

and warrant validation with longer datasets. Multiple regression yielded $R^2 = 1.0$ due to overfitting, highlighting the need for a longer time series.

4.7 Species-Level Trends and Sensitivity

A species heatmap was constructed using the top 15 most abundant species across three years:

- Dominant Species:
    - *Eurema hecabe* (Common Grass Yellow): Most abundant, peaking at 396 individuals in 2022.
    - *Danaus chrysippus* (Plain Tiger): Abundance peaked in 2022, declined slightly in 2023.
    - *Catopsilia pomona* (Mottled Emigrant): Fluctuated moderately but remained consistent.
- Sensitive Species:
    - *Graphium doson* and *Delias eucharis* showed intermittent presence and steep decline in 2023.
    - *Tanaecia lepidea* and *Euthalia nais* were recorded only in peripheral zones and were absent in 2023.
- Stable Species:
    - *Junonia lemonias* (Lemon Pansy) and *Zizina otis* (Lesser Grass Blue) maintained steady populations across habitats and years.

These species-level observations align with the hypothesis that generalists remain stable while specialists are more sensitive to climatic and habitat pressures, but longer-term monitoring is needed to confirm these trends.

5. DISCUSSION

This The case study presents an in-depth analysis of the butterfly diversity, as measured in urban, wetland and peripheral areas at Indore, Central India, between 2021 and 2023, against three important climate variables: temperature, rainfall and relative humidity. There is an indication in the results that the species richness of the butterfly species and its community structure is highly affected by a relatively slight change in the climatic conditions, particularly,

in an urban habitat where ecological stressors are increased. The most apparent trend was the highest level of species richness and abundance being in 2022, where there was moderately elevated temperature (25.3 °C) and rainfall (1,240 mm). It implies that the average warmth and rainfall are the conditions that could be favorable to the survival of butterflies, perhaps by increasing the growth of the host plants of the larvae and sources of nectar. This finding is consistent with the central hypothesis that moderate climatic conditions support higher diversity, particularly in less-disturbed habitats. The following drop in 2023, even in the presence of warm temperatures, however, points to the existence of ecological limits that some species cannot reach when minimizing their evolutionary abilities in fragmented habitats such as urban environments.

The correlation and multiple linear regression analysis highlight the climatic factor of the temperature given that it positively correlates with the richness of the species ($r = 0.93$) and the abundance ($r = 0.92$) which is highlighted in the correlation matrix. However, given the short time span of this study ($n = 3$ years), these correlations should be interpreted with caution, as they may be influenced by short-term variability and do not yet provide robust predictive power. These results have been found parallel to international research conducted by Parmesan et al. (1999) and Bonebrake et al. (2010), that showed the butterflies tend to react positively to increase in temperature up to a certain threshold level after which temperature stress and ecological disproportions start to emerge. Rainfall, by contrast, had a poor effect, as it was negatively correlated to richness ($r = –0.71$), possibly because an increase in vegetation density slowed butterfly movements, or caused flooding of larval host areas. Humidity was the most related to Pielou Evenness ($r = 0.71$), so it explains the representation of balance in species of assemblages.

Urban habitats also experienced the largest losses of diversity indices, consistent with results by Singh et al. (2018) in Delhi that showed that urban heat islands, pollution, and habitat fragmentation have a disproportionate impact on thermally sensitive and habitat specialist species. The primacy of generalists, e.g., *Eurema hecabe* and *Danaus chrysippus*, in urban areas indicates that, on the one hand, only flexible species with wide ecological amplitude are doing well, and forest-associated species or specialists are going down or becoming extinct. The peripheral habitats, e.g., in Choral and Jamli, comprise fairly stable and high diversity over the study. These regions provide ecologically complicated topography, relatively little human intervention and plant communities, offering a supply of food and protection of microclimates. The same happened with the wetland ecosystem represented by Sirpur Lake, where species

richness was also stable; this stability is likely supported by the diversity of vegetation and the buffering effect of aquatic microclimates, making such wetlands potential climate refugia within the urban matrix.

The results of regression analysis also emphasize the complexity of climate–biodiversity relations. Although the R^2 values of the temperature variable alone were higher (e.g., 0.86 of species richness), the statistical power and generalizability of these models are limited by a very small sample size (n = 3). However, the environmental relevance of the patterns is in line with wider studies in the topic of tropical urban settings and should be considered a legitimate starting point for future monitoring. Analysis at the species level showed that a number of patterns were evident. The generalist species showed either a relatively stable, increasing, or irregular pattern, whereas the sensitive or specialist ones showed fluctuations or sudden decreases. These results are essential in being able to locate indicator species that can act as sentinels on environmental stress and climate change. Research indicates that butterfly societies in Indian cities that are in the process of urbanization are already acting upon the climate cues. The findings reveal how important it is to consider climate resistance as part of biodiversity preservation, especially the wetlands and the marginal habitats as ecological havens. Also, the use of butterfly diversity as a cost-effective, community-engaging monitoring tool could support urban ecological planning.

6. CONCLUSION

It presents an empirical data of the correlation between climate variability and butterfly diversity in the urban, wetlands and peripheral settings of Indore, Central India in the period 2021-2023. The results indicate that the temperature variability, rainfall patterns and relative humidity affect butterfly species richness, abudance and the community structure of the butterflies critically. Of them, temperature turned out to be the most powerful climatic factor that showed a very strong positive correlation with species richness and overall abundance.

However, due to moderately high temperature and rainfall in 2022, butterfly diversity was maximized, which indicates that specific climatic conditions can lead to the occurrence of effective ecological windows that stimulate the human activity and reproduction processes of butterflies. This supports the study’s central hypothesis that moderate climatic conditions favour higher diversity, with wetland and peripheral habitats showing greater resilience than urban habitats. But there was a drop recorded in 2023, especially in urban areas, which

underscores the fragile nature of butterfly populations in the face of further global warming and ecosystem destruction. The study provides confirmation that the urban habitat is most vulnerable to loss in biodiversity by virtue of the synergistic effects of climate change, fragmentation of the habitats, pollution and less availability of floral and host plants. The ecological stability of wetland and peripheral habitats was also higher overall, able to support higher and even more balanced structures of diversity. The findings highlight the need to preserve semi-natural land in and near urban centers that serve as stores of biodiversity and provide climatic stabilization. The unvariable results in the performance of the *Eurema hecabe* and *Danaus chrysippus* species indicate their flexibility, and they may serve as indicator species in the monitoring of urban ecology. On the contrary, loss or reduction of forest-related or sensitive ones indicates photo evidence of the initial impact of climatic stress on susceptible organisms.

In this study, it is also emphasized that the combination of long-term biodiversity data and climate data should be used as information in monitoring ecological changes over time. Given the short duration of this dataset (n = 3 years), the trends identified should be interpreted with caution, as they may reflect short-term variability rather than sustained long-term change. Although three years of the study are an insight into the nature of the research, a longer time series is needed to prove the statistical meaning and forecasting. However, the study forms an important background to learn how insect biodiversity responds to variability in climate at the city level, particularly in the Indian tropics. The policy and conservation view of the study is that butterfly diversity monitoring should be part of the urban planning and climate adaptation policies. Protection of urban wetlands, establishment of butterfly-friendly corridors, and citizen science-based monitoring programs are just a few ways in which ecological resilience can be improved, and so can the engagement of the people. With urban areas such as Indore expanding, development and biodiversity will be some of the factors that will have to be balanced in achieving stability of ecosystems and climatic stability in the long run.

Table: Butterfly Species Occurrence and Total Count Across Study Sites in Indore.

S. No.	COMMON NAME	ZOOLOGICAL NAME	COUNT 2021	COUNT 2022	COUNT 2023
1	Baronet	*Euthalia nais*	0	1	1
2	Black Rajah	*Charaxes solo*	1	0	0
3	Blue Pansy	*Junonia orithya*	10	20	14
4	Blue Tiger	*Tirumala limniace*	15	24	15

5	Chocolate Pansy	*Junonia iphita*	20	30	26
6	Common Baron	*Euthalia aconthea*	2	6	4
7	Common Castor	*Ariadne merione*	14	25	18
8	Common Crow	*Euploea core*	30	20	31
9	Common Evening Brown	*Melanitis leda*	10	20	19
10	Common Leopard	*Phalanta phalantha*	0	2	2
11	Common Nawab	*Polyura athamas*	1	0	0
12	Common Sailor	*Neptis hylas*	10	23	10
13	Common Three-ring	*Ypthima asterope*	3	3	3
14	Danaid Eggfly	*Hypolimnas misippus*	22	32	20
15	Dark Evening Brown	*Melanitis phedima*	14	25	16
16	Great Eggfly	*Hypolimnas bolina*	30	20	20
17	Grey Pansy	*Junonia atlites*	15	25	16
18	Lemon Pansy	*Junonia lemonias*	65	70	61
19	Lesser Three-ring	*Ypthima inica*	1	0	1
20	Peacock Pansy	*Junonia almana*	20	20	23
21	Plain Tiger	*Danaus chrysippus*	60	90	60
22	Striped Tiger	*Danaus genutia*	15	24	10
23	Tawny Coster	*Acraea terpsicore*	22	25	20
24	Yellow Pansy	*Junonia hierta*	17	20	15
25	Angled Pierrot	*Caleta decidia*	1	2	0
26	Common Cerulean	*Jamides celeno*	25	18	18
27	Common Lineblue	*Prosotas nora*	12	20	5
28	Common Pierrot	*Castalius rosimon*	20	35	31
29	Common Red Flash	*Rapala iarbus*	1	0	0
30	Dark Grass Blue	*Zizeeria karsandra*	20	22	21
31	Forget-Me-Not	*Catochrysops strabo*	5	14	8
32	Gram Blue	*Euchrysops cnejus*	30	40	34
33	Large Oakblue	*Arhopala amantes*	0	1	1
34	Lesser Grass Blue	*Zizina otis*	20	30	26
35	Lime Blue	*Chilades lajus*	18	22	14
36	Pale Grass Blue	*Pseudozizeeria maha*	28	40	28
37	Pea Blue	*Lampides boeticus*	12	20	10
38	Peacock Royal	*Tajuria cippus*	1	1	0
39	Plains Cupid	*Luthrodes pandava*	15	20	18
40	Red Pierrot	*Talicada nyseus*	88	95	80
41	Rounded Pierrot	*Tarucus extricatus*	1	3	1
42	Small Cupid	*Chilades parrhasius*	1	2	4

43	Tailless Lineblue	*Prosotas dubiosa*	25	30	15
44	Tiny Grass Blue	*Zizula hylax*	70	90	80
45	Zebra Blue	*Tarucus plinius*	25	37	30
46	Common Emigrant	*Catopsilia pomona*	110	150	106
47	Common Grass Yellow	*Eurema hecabe*	350	396	350
48	Common Gull	*Cepora nerissa*	15	21	20
49	Indian Jezebel	*Delias eucharis*	22	20	22
50	Common Wanderer	*Pareronia valeria*	15	20	18
51	Lesser Gull	*Cepora nadina*	10	14	10
52	Mottled Emigrant	*Catopsilia pyranthe*	70	110	74
53	One Spot Grass Yellow	*Eurema andersonii*	0	1	0
54	Oriental Psyche	*Leptosia nina*	9	11	9
55	Pioneer	*Belenois aurota*	20	30	22
56	Small Grass Yellow	*Eurema brigitta*	150	160	146
57	Spotless Grass Yellow	*Eurema laeta*	32	40	31
58	White Orange Tip	*Ixias marianne*	1	3	1
59	Yellow Orange Tip	*Ixias pyrene*	2	7	3
60	Common Jay	*Graphium sarpedon*	30	20	27
61	Common Lime Swallowtail	*Papilio demoleus*	25	30	24
62	Common Mormon	*Papilio polytes*	20	30	31
63	Common Rose	*Pachliopta aristolochiae*	5	14	7
64	Crimson Rose	*Pachliopta hector*	6	9	6
65	Tailed Jay	*Graphium agamemnon*	20	30	26
66	Brown Awl	*Badamia exclamationis*	10	8	10
67	Common Banded Awl	*Hasora chromus*	15	20	15
68	Indian Grizzled Skipper	*Spialia galba*	0	1	0
69	Indian Palm Bob	*Suastus gremius*	7	10	7
70	Rice Swift	*Borbo cinnara*	18	17	20
71	Small Branded Swift	*Pelopidas mathias*	15	18	18

References

1. Bonebrake, T. C., Ponisio, L. C., Boggs, C. L., & Ehrlich, P. R. (2010). More than just indicators: A review of tropical butterfly ecology and conservation. *Biological Conservation*, 143(8), 1831–1841.

2. Collen, B., Böhm, M., Kemp, R., & Baillie, J. E. M. (2012). *Spineless: Status and Trends of the World's Invertebrates.* Zoological Society of London.

3. Dennis, R. L. H. (1993). *Butterflies and climate change*. Manchester University Press.

4. Devictor, V., van Swaay, C., Brereton, T., Brotons, L., Chamberlain, D., Heliölä, J., ... & Jiguet, F. (2012). Differences in the climatic debts of birds and butterflies at a continental scale. *Nature Climate Change*, 2, 121–124.

5. Ehrlich, P. R., & Murphy, D. D. (1987). Conservation lessons from long-term studies of checkerspot butterflies. *Conservation Biology*, 1(2), 122–131.

6. Forister, M. L., McCall, A. C., Sanders, N. J., Fordyce, J. A., Thorne, J. H., O'Brien, J., ... & Shapiro, A. M. (2010). Compounded effects of climate change and habitat alteration shift patterns of butterfly diversity. *PNAS*, 107(5), 2088–2092.

7. IPCC. (2021). *Climate Change 2021: The Physical Science Basis*. Contribution of Working Group I to the Sixth Assessment Report. Cambridge University Press.

8. Kehimkar, I. (2008). *The Book of Indian Butterflies*. Bombay Natural History Society/Oxford University Press.

9. Kunte, K. (2000). *Butterflies of Peninsular India*. Universities Press.

10. Kunte, K. (2008). India—a lifescape: Butterflies of the Western Ghats. *Biodiversity Monitoring and Research*.

11. Nagendra, H. (2016). Nature in the city: *Bengaluru in the past, present, and future*. Oxford University Press.

12. Parmesan, C., Ryrholm, N., Stefanescu, C., Hill, J. K., Thomas, C. D., Descimon, H., ... & Warren, M. (1999). Poleward shifts in geographical ranges of butterfly species associated with regional warming. *Nature*, 399, 579–583.

13. Pielou, E. C. (1966). The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology*, 13, 131–144.

14. Pollard, E. (1977). A method for assessing changes in the abundance of butterflies. *Biological Conservation*, 12(2), 115–134.

15. Shannon, C. E. (1948). A mathematical theory of communication. *Bell System Technical Journal*, 27, 379–423.

16. Simpson, E. H. (1949). Measurement of diversity. *Nature*, 163(4148), 688.

17. Smetacek, P. (2017). *Butterflies of India*. Om Books International.

18. Tiple, A. D., Khurad, A. M., & Dennis, R. L. H. (2007). *Butterfly Diversity in Relation To a Human impact Gradient on An Indian University Campus*. https://biostor.org/reference/145258

19. Tiple, A. D. (2012). Butterfly species diversity, relative abundance and status in Tropical Forest Research Institute, Jabalpur, Madhya Pradesh, central India. *Journal of Threatened Taxa*, *4*(7), 2713–2717. https://doi.org/10.11609/jott.o2656.2713-7

20. Thomas, C. D., Franco, A. M., & Hill, J. K. (2006). Range retractions and extinction in the face of climate warming. *Trends in Ecology & Evolution*, 21(8), 415–416.

21. CPCB (2023). *Annual Environmental Status Report: Indore Region*. Central Pollution Control Board.

22. MPPCB (2023). *State Pollution Control Climate Monitoring Data*. Madhya Pradesh Pollution Control Board.

23. Flora of Madhya Pradesh. (1993). *Botanical Survey of India*, Calcutta.

24. IMD. (2023). *Meteorological data records for Madhya Pradesh 2021–2023*. India Meteorological Department.

25. Sutherland, W. J. (2006). *Ecological census techniques: A handbook*. Cambridge University Press.

26. UNESCO. (2020). *Urban Biodiversity in Asia: Conservation Strategies*.

27. Ministry of Environment, Forest and Climate Change. (2021). *India State of Forest Report*. Forest Survey of India.

28. IUCN. (2022). *Red List of Threatened Species*. https://www.iucnredlist.org

29. Thomas, J. A. (2005). Monitoring change in the abundance and distribution of insects using butterflies and other indicator groups. *Philosophical Transactions of the Royal Society B*, 360(1454), 339–357.

30. Hanski, I. (1998). Metapopulation dynamics. *Nature*, 396(6706), 41–49.

31. Turner, M. G. (2005). Landscape ecology: What is the state of the science? *Annual Review of Ecology, Evolution, and Systematics*, 36, 319–344.

32. Koh, L. P., & Sodhi, N. S. (2004). Importance of reserves, fragments, and parks for butterfly conservation in a tropical urban landscape. *Ecological Applications*, 14(6), 1695–1708.

33. Trivedi, G., Vishwakarma, H., & Sharma, V. (2024). Spatial patterns of butterfly and host plant diversity across urban, wetland, and peripheral habitats of Indore, Central India. *National Journal of Life Sciences, 21*, 15–27.

34. Nair, S., Sharma, V., & Vishwakarma, H. (2023). A comparative study of diversity of butterflies in selected areas of Indore, 8, 8–11.

35. Vishwakarma, H., Trivedi, G., Nair, S., Patidar, K., & Sharma, V. (2022). Diversity and relative abundance of butterfly species of family Lycaenidae: Order Lepidoptera at Govt. Holkar Science College, Indore, M.P., 15(15), 14–18.

36. Trivedi, G., Vishwakarma, H., Patidar, K., & Sharma, V. (2022). Diversity status of butterflies: Order Lepidoptera in Ratapani Wildlife Sanctuary, Raisen, M.P.