



Beyond species inventories: Spider assemblages as bioindicators of urban habitat quality along an urbanization gradient in Jabalpur, Central India

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Abstract

Urbanization is a major driver of terrestrial habitat transformation, influencing biodiversity through habitat fragmentation, vegetation simplification, increased impervious surfaces, microclimatic modification and changes in ecological interactions. Spiders (Arachnida: Araneae), as diverse terrestrial predators occupying a broad range of ecological niches, represent promising biological candidates for assessing changes in habitat structure and environmental conditions. Nevertheless, their effectiveness as bioindicators cannot be inferred from species richness alone; it requires an integrated assessment of taxonomic diversity, community composition, functional guilds, habitat associations and independently measured environmental variables. The present critical review evaluates the ecological basis for using spider assemblages as bioindicators of urban habitat quality and develops a regional case-study framework for Jabalpur, Madhya Pradesh, Central India. Published investigations by Gajbe (2003, 2004) ^[3, 5] established an important taxonomic foundation for spider diversity in Jabalpur. Subsequently, Khare, Shukla and Khapre (2023) ^[8] reported 18 species representing 15 genera and eight families from their survey of the Jabalpur division conducted during 2019–2021. These regional studies provide a foundation for further investigation but do not, by themselves, establish a validated relationship between spider assemblages and urban habitat quality. International research demonstrates that urbanization may alter spider community composition and functional diversity, although its effects on species richness and abundance are context-dependent. A recent global meta-analysis reported contrasting responses among ecological guilds, highlighting the limitations of using total richness as a universal measure of environmental condition (Guo & Bonebrake, 2026) ^[7]. The present review therefore proposes a replicated, seasonally standardized assessment of spider assemblages across natural or semi-natural habitats, urban green spaces and highly modified urban environments in Jabalpur. Recommended analytical approaches include diversity indices, species accumulation, community ordination, functional-guild analysis and statistical modelling of environmental relationships. The proposed framework aims to advance regional spider research from descriptive inventories towards hypothesis-driven ecological assessment. Its practical value lies in establishing a scientifically testable foundation for urban biodiversity monitoring, habitat-sensitive landscape management and the future validation of spider-based environmental indicators in Central India.

Keywords: Araneae, spider assemblages, bioindicators, urban ecology, habitat quality, urbanization gradient, functional diversity, biodiversity monitoring, Jabalpur, Central India

Introduction

Urbanization has transformed natural and semi-natural landscapes into increasingly complex mosaics of built-up surfaces, transport infrastructure, residential areas, managed green spaces and fragmented vegetation patches. Although urban environments may retain substantial biological diversity, the distribution of species and the ecological processes sustaining them can change considerably as land use intensifies. Habitat loss, fragmentation, vegetation removal, surface sealing, altered hydrology, artificial lighting and increased human disturbance can influence the availability of food, shelter, breeding sites and suitable microclimates. These changes make the assessment of urban biodiversity an important component of contemporary ecological research and environmental planning (Grimm *et al.*, 2008; Seto *et al.*, 2012) ^[6].

Traditional biodiversity inventories provide essential information about species occurrence and distribution. However, the presence of a large number of species does not necessarily indicate that an ecosystem is functioning well, nor does a low species count always demonstrate ecological degradation. The ecological meaning of a species inventory depends on sampling effort, habitat coverage, seasonality, species detectability and the environmental context in which observations are made. Consequently, modern ecological

assessment increasingly combines taxonomic diversity with information about community composition, functional traits, habitat structure and environmental stressors (Cardoso *et al.*, 2011) ^[1].

Spiders belonging to the order Araneae are particularly relevant to this approach because they occupy numerous terrestrial microhabitats and exhibit a wide range of foraging strategies. Their communities include orb-web builders, sheet-web weavers, ground-active hunters, ambush predators and foliage-dwelling hunters. These different ecological strategies create opportunities to investigate how environmental modification influences both species identity and ecosystem function. Spiders also act as predators of insects and other small arthropods, contributing to trophic regulation and the biological control of some agricultural pests (Marc *et al.*, 1999; Foelix, 2011) ^[2, 9].

The value of spiders in environmental assessment, however, should not be overstated. A spider community is not a universal indicator of every form of environmental stress. Individual species may tolerate disturbed environments, while other species may be sensitive to changes in vegetation, prey availability, humidity or ground conditions. Some groups may even increase in abundance in particular urban habitats. A scientifically defensible bioindicator approach must therefore establish the relationship between a

defined biological response and an independently measured environmental variable.

Urban ecology and the significance of spider assemblages

Urban ecosystems are shaped by environmental filters operating at both local and landscape scales. At the local scale, vegetation architecture, litter cover, temperature, moisture and the availability of prey can influence the establishment and persistence of spider populations. At the landscape scale, urban density, the extent of impervious surfaces, habitat connectivity and the isolation of green spaces can affect colonization, dispersal and species turnover.

Piquet *et al.* (2025) ^[10], in their study of foliage-dwelling spider communities in Torino, Italy, investigated the effects of urban density and landscape characteristics on taxonomic and functional diversity. Their findings demonstrated that urbanization can influence spider communities through the loss of particular species and functional groups, while their scenario analysis illustrated the potential relevance of green-space planning for biodiversity conservation. This research provides a methodological precedent for assessing the ecological consequences of urban development, although the specific results from Italy cannot automatically be transferred to Central India.

The broader evidence is also more complex than a simple decline in diversity. Guo and Bonebrake (2026) ^[7] synthesized evidence from 28 studies across 27 locations and found no significant overall effect of urbanization on spider richness or abundance. However, they identified contrasting responses among guilds, including positive responses of orb-weavers and reduced richness of sheet-web weavers in urban environments. These findings demonstrate that total species richness may conceal important changes in community composition and ecological strategy.

Accordingly, the most informative assessment of urban spider diversity should consider three complementary dimensions: which species occur, how their relative abundance and functional composition vary, and how these patterns relate to measurable environmental conditions. This integrated perspective forms the central premise of the present study framework.

Ecological and geographical context of Jabalpur

Jabalpur, situated in Madhya Pradesh, provides a useful regional setting for examining terrestrial biodiversity across contrasting land-use conditions. The wider landscape contains urban settlements, institutional campuses, parks, agricultural areas, vegetation-rich sites and river-associated environments. These habitats provide opportunities to investigate the effects of urbanization while accounting for differences in vegetation structure, microclimate and landscape context.

The regional importance of spider research is demonstrated by the work of Pawan Gajbe. Gajbe (2003) ^[3] published a checklist of spiders from Jabalpur based on specimens collected and identified during July 1997–December 2000, reporting 88 species belonging to 54 genera and 18 families. His subsequent monograph, *Spiders of Jabalpur, Madhya Pradesh (Arachnida: Araneae)*, provided a more extensive taxonomic contribution to the understanding of the region's spider fauna (Gajbe, 2004) ^[5].

Building on this taxonomic foundation, Khare, Shukla and Khapre (2023) ^[8] published *A Survey Report on the Spider (Arachnida: Araneae) of Jabalpur Division (Madhya Pradesh)*. Their investigation, based on surveys conducted during 2019–2021, reported 97 individuals belonging to 18 species, 15 genera and eight families. The authors also calculated Shannon–Wiener diversity and Simpson dominance indices, providing an additional regional reference point for subsequent ecological investigations.

These studies demonstrate the importance of continued spider documentation in the Jabalpur region. At the same time, their different spatial coverage, sampling periods and methodological contexts mean that their reported species totals should not be treated as directly comparable estimates of temporal change or environmental quality. The next step is to examine how spider communities vary among explicitly defined habitat categories and whether these differences are consistently associated with environmental variables.

Rationale for moving beyond species inventories

Species inventories remain indispensable in regions where taxonomic information is incomplete. They document biodiversity, establish distribution records and provide reference material for subsequent ecological studies. Nevertheless, a checklist alone cannot establish whether a habitat is relatively undisturbed, fragmented, environmentally stressed or undergoing ecological recovery. For example, two urban sites may support the same number of spider species while differing in the identity of those species. One site may contain a mixture of habitat-associated species and several foraging guilds, whereas another may be dominated by a small number of generalist taxa. Although their observed richness may be identical, their community structure and functional representation could differ substantially.

A bioindicator investigation therefore requires more than counting species. It should measure the composition and relative abundance of assemblages, document functional guilds, quantify environmental conditions and test whether observed biological patterns are reproducible across sites and seasons. The central research question for Jabalpur is whether spider assemblages can provide reliable, measurable information about variation in urban habitat quality beyond that supplied by species inventories alone.

Objectives and guiding research questions

The principal objective of this review is to evaluate the scientific basis for using spider assemblages as candidate bioindicators of urban habitat quality and to develop a case-study framework appropriate to Jabalpur, Central India.

The review addresses five interconnected questions. First, which ecological characteristics make spiders suitable candidates for environmental assessment? Second, what do existing studies from Jabalpur establish about the regional spider fauna? Third, how may taxonomic diversity, functional guilds and habitat structure respond to urbanization? Fourth, which sampling and analytical methods would allow these relationships to be evaluated rigorously? Finally, what evidence would be required before individual spider taxa or assemblage-level metrics could be adopted as reliable regional indicators? These questions are intended to connect existing faunistic knowledge with a more explanatory ecological framework. They also

distinguish established observations from hypotheses that require further field testing.

Materials and methods: Review approach and case-study design

1. Scope of the literature review

The manuscript adopts a critical narrative-review approach, focusing on spider ecology, bioindication, urbanization, functional diversity and the regional spider fauna of Jabalpur. The literature considered includes published regional surveys, taxonomic checklists, ecological studies and recent international research on urban spider assemblages. Particular emphasis is placed on studies that connect spider-community characteristics with environmental conditions or provide a methodological basis for evaluating urban habitat quality.

This is a narrative synthesis rather than a systematic review or a new meta-analysis. No claim is made that all relevant publications have been exhaustively identified, and no original quantitative synthesis of the international literature has been performed. For a journal submission requiring a formal systematic review, the search strategy, database coverage, inclusion and exclusion criteria, screening process and study-quality assessment would need to be documented separately.

The regional evidence is anchored in Gajbe (2003, 2004) [3, 5] and Khare, Shukla and Khapre (2023) [8]. International ecological interpretation draws on work addressing spider bioindication, urban landscape filtering and guild-specific responses, including Marc *et al.* (1999), Piquet *et al.* (2025) and Guo and Bonebrake (2026) [7, 9, 10].

2. Proposed case-study area and habitat classification

The proposed empirical component focuses on the Jabalpur urban landscape and its surrounding reference habitats. Rather than assigning sites to categories based only on visual impressions, habitat classification should be supported by measurable information such as built-up surface cover, vegetation density, canopy cover, habitat connectivity and the intensity of management or disturbance.

Four broad categories are proposed: natural or semi-natural reference habitats, vegetation-rich urban green spaces, moderately modified residential or institutional environments, and highly built-up urban sites. These categories provide a practical framework for comparing contrasting environmental conditions while retaining the possibility of analysing urbanization as a continuous gradient.

The Madan Mahal area may be considered as a candidate study location within this framework, subject to site reconnaissance and access permissions. However, its inclusion should not imply that all parts of the area have identical habitat characteristics. Individual sampling sites should be classified using the same environmental criteria applied elsewhere in the study.

3. Sampling design and field observations

A stratified, replicated sampling design is recommended. As an initial planning scenario, four habitat categories could each contain five independently selected sites, with three sampling plots within each site. This would provide 20 sites and 60 plots per sampling round. The final number of sites should be determined using pilot observations, expected

variability, sampling feasibility and statistical power rather than adopting this illustrative design without evaluation.

Sampling should be repeated across relevant seasonal periods to account for seasonal changes in activity, reproduction, vegetation and prey availability. Where feasible, pre-monsoon, monsoon and post-monsoon surveys would provide a useful representation of the annual environmental cycle in Central India. The exact survey schedule should be adapted to field conditions and documented consistently.

Multiple collection methods may be required because spider species differ in their microhabitat use and detectability. Timed visual searches and hand collection can be used for spiders on vegetation, bark and structures; beating trays can sample foliage-associated species; sweep nets can be used in appropriate herbaceous vegetation; and standardized litter searches or pitfall traps can help characterize ground-active assemblages. Sampling effort, method, weather and time of observation should be recorded for each sampling unit.

Pitfall-trap captures should be interpreted as activity-density rather than direct estimates of population density because capture rates depend on both the abundance and movement of organisms. Similarly, observations from different sampling methods should not be combined without considering method-specific detection and sampling effort.

4. Identification and documentation

Spider identification should follow current taxonomic literature and the World Spider Catalog. Field photographs should be linked to specimen or observation identifiers, collection dates, habitat descriptions and precise sampling locations. Voucher specimens should be preserved and deposited in an accessible institutional collection where feasible.

Species-level identification should be reported only when supported by diagnostic characters and appropriate taxonomic expertise. Specimens that cannot be identified confidently should be recorded at genus or family level, as appropriate. This precaution is particularly important in studies intended for bioindication because misidentification can create false distribution records and distort apparent differences in community composition.

5. Environmental measurements

Environmental conditions should be measured independently of the spider data. Relevant variables include vegetation cover, canopy cover, vegetation complexity, leaf-litter depth, ground-surface conditions, temperature, relative humidity, built-up surface cover and the degree of human disturbance. Information on pesticide use or other chemical exposures may be included where it is reliably documented and relevant to the study question.

Built-up surface cover can be quantified through geographic information system analysis using a consistently defined buffer around each site. Vegetation and microclimatic measurements should be taken using repeatable procedures and, where possible, calibrated instruments. Environmental measurements should be sufficiently detailed to distinguish local habitat effects from broader landscape effects.

A composite habitat-quality index may be useful if its component variables are scientifically justified, standardized and evaluated for redundancy. However, the index should not be constructed from spider diversity metrics if those same metrics are subsequently used to claim that spiders

predict the index. An independent environmental measure is necessary to avoid circular validation.

Ecological mechanisms linking spider assemblages with habitat quality

1. Vegetation structure and microhabitat availability

Vegetation is an important component of spider habitat because it supplies web attachment sites, refuges, hunting surfaces and access to prey. Differences in plant architecture can influence the distribution of web-building and foliage-dwelling species, while ground vegetation and leaf litter provide additional habitat for cursorial spiders.

Urban green spaces may retain substantial vegetation while differing in its structural complexity. A park with mature trees, shrubs, herbaceous vegetation and litter patches may provide a wider range of microhabitats than a site dominated by intensively maintained lawns. These differences create a plausible ecological mechanism linking habitat management with spider-community composition.

Piquet *et al.* (2025)^[10] demonstrated that urban density and landscape structure can be associated with changes in foliage-dwelling spider communities and their functional diversity. In Jabalpur, comparable relationships should be tested using direct measurements of vegetation and spider assemblages. It would be premature, however, to assume that a particular vegetation type will produce a predetermined diversity response without local observations.

2. Microclimatic conditions and resource availability

Temperature and humidity can influence spider activity, development, prey availability and the suitability of microhabitats. Impervious surfaces and reduced vegetation can alter local heat and moisture conditions, potentially affecting the distribution of species with different ecological requirements.

Urbanization may also modify the abundance and composition of prey. Artificial lighting, vegetation management and changes in insect communities can influence prey availability, although these relationships may differ among sites and seasons. A spider assemblage observed in a particular habitat is therefore the outcome of several interacting environmental and biological processes rather than a direct response to urbanization alone.

For this reason, the analysis should evaluate temperature, humidity, vegetation and relevant prey-related variables where feasible. Such measurements would help determine whether observed differences among sites are associated with habitat structure, microclimate or other environmental factors.

3. Habitat fragmentation and landscape connectivity

Urban expansion can reduce the size of natural habitat patches and increase the distance between them. Habitat isolation may limit recolonization after local disturbance and alter the relative contribution of dispersal, environmental filtering and species turnover to community structure.

Urban green spaces can function as habitat patches within a larger landscape, but their ecological value may depend on size, vegetation structure, connectivity and management. A small, structurally complex patch may support particular species even when it is surrounded by developed land, while

a larger but intensively managed area may provide fewer suitable microhabitats for some groups.

A regional assessment should therefore quantify landscape variables in addition to measuring conditions within individual plots. The use of a consistent spatial scale is important because landscape relationships can change depending on the buffer size used to characterize urbanization.

4. Functional guilds as indicators of ecological change

Spider functional guilds provide an additional dimension of environmental assessment. Orb-web builders depend on suitable attachment structures and the availability of flying prey, while ground-active hunters are influenced by substrate conditions, litter, shelter and surface disturbance. Other web-building and foliage-associated groups may respond differently to vegetation simplification and management.

The global meta-analysis by Guo and Bonebrake (2026)^[7] found that urbanization did not have a significant overall effect on spider richness or abundance, yet guild-specific responses were evident. This indicates that a community can undergo meaningful ecological reorganization even when its total species count does not change substantially.

For Jabalpur, the functional composition of assemblages should therefore be evaluated alongside richness and abundance. Guild assignments should follow a consistent published classification, and any observed changes should be interpreted in relation to measured habitat variables rather than being attributed automatically to urbanization.

Regional case study: Published spider diversity in Jabalpur

1. Historical taxonomic baseline

The taxonomic foundation for spider research in Jabalpur was strengthened by Gajbe's checklist published in 2003^[4]. Based on collections made between July 1997 and December 2000, the study documented 88 species, 54 genera and 18 families. Its sampling included a variety of habitats, such as cultivated fields, wooded areas, hills, orchards, human dwellings, gardens, fallow land and areas around ponds and tanks (Gajbe, 2003)^[3].

The inclusion of multiple habitat types is important because it demonstrates that the regional spider fauna should not be interpreted as belonging to a single uniform environment. Instead, the city and its surroundings contain a variety of ecological settings that may support different species and assemblages.

Gajbe's subsequent monograph, *Spiders of Jabalpur, Madhya Pradesh (Arachnida: Araneae)*, published by the Zoological Survey of India, further strengthened the taxonomic reference base for the region (Gajbe, 2004)^[5]. Such historical documentation is particularly valuable for checking identification, reviewing regional records and selecting taxa for future ecological investigations.

Nevertheless, the 88 species reported in the historical checklist should not be compared directly with later survey totals as evidence of population decline or biodiversity loss. Differences in sampling duration, spatial extent, taxonomic treatment and collection methods can substantially influence observed richness. A valid temporal comparison would require repeated sampling under a standardized protocol or a careful reanalysis of comparable datasets.

2. Contribution of Dr. Arjun Shukla and colleagues

The regional study by Khare, Shukla and Khapre (2023) ^[8], published in the *International Journal of Entomology Research*, examined spider fauna in the Jabalpur division using surveys conducted during 2019–2021. The authors reported 97 individuals belonging to 18 species, 15 genera and eight families. Araneidae was reported as an important component of the assemblage, and the study calculated a Shannon–Wiener index of 2.643 and a Simpson dominance index of approximately 0.0843.

This publication provides an important local reference because it documents regional spider occurrences and explicitly identifies the need for further work on seasonal variation, habitat ecology, standardized sampling and the indicator value of spiders (Khare *et al.*, 2023) ^[8]. These recommendations closely align with the research direction developed in the present review.

The study should be interpreted as a preliminary faunistic investigation rather than as a completed validation of spider-based bioindication. The reported diversity indices describe the sampled assemblage; they do not establish a calibrated relationship between spider diversity and environmental quality because a standardized urbanization-gradient comparison and independent environmental measurements were not the primary basis of the reported results.

A further empirical study can build on this foundation by recording species composition and abundance at replicated sites, measuring environmental variables and assessing whether the resulting assemblage metrics predict habitat conditions. Such an approach would extend the contribution of regional spider research from documenting biodiversity towards testing ecological mechanisms.

3. Comparative interpretation of the regional records

Table 1: Published regional evidence relevant to spider biodiversity in Jabalpur

Study	Geographic and temporal context	Reported evidence	Relevance to the present review
Gajbe (2003) ^[3]	Jabalpur; collections from July 1997 to December 2000	88 species, 54 genera and 18 families	Historical regional checklist and taxonomic baseline
Gajbe (2004) ^[5]	Jabalpur, Madhya Pradesh	Regional spider monograph	Taxonomic reference for identification and distribution records
Khare, Shukla and Khapre (2023) ^[8]	Jabalpur division; surveys during 2019–2021	97 individuals, 18 species, 15 genera and eight families	Recent regional inventory and diversity-index reference
Proposed Jabalpur study	Multiple habitat categories and seasons	No new results reported in this review	Tests associations between spider assemblages and measured habitat quality

The values in Table 1 represent the reported findings of the respective publications. They are not estimates generated by the present review and should not be treated as directly comparable measures of environmental quality.

The difference between the historical checklist and the later survey highlights the importance of sampling design. A checklist assembled across several years and multiple habitat types can capture more species than a shorter or more restricted survey. Conversely, a study with fewer recorded species may still provide valuable ecological information if its sampling is standardized and its environmental variables are clearly defined.

For these reasons, future work in Jabalpur should not attempt to demonstrate environmental deterioration merely by comparing raw species totals from different publications. Instead, it should develop a repeatable sampling framework capable of distinguishing genuine ecological change from variation caused by sampling effort, habitat coverage and identification practices.

International evidence and its implications for Jabalpur

1. Urbanization as an ecological filter

The concept of environmental filtering provides a useful framework for interpreting urban spider assemblages. Environmental filtering occurs when local conditions favour some species or traits while limiting others. In urban landscapes, these conditions may include altered microclimates, habitat fragmentation, reduced vegetation complexity and changes in resource availability.

Piquet *et al.* (2025) ^[10] examined foliage-dwelling spiders across an urbanization gradient in Torino and found changes in abundance, richness and functional composition in relation to urban conditions. Their study also considered the potential contribution of greener urban scenarios to biodiversity conservation.

The work demonstrates how ecological measurements can be translated into landscape-management questions, although the specific magnitude and direction of responses remain region-dependent.

For Jabalpur, this framework suggests that urbanization should be measured rather than treated simply as a label. Built-up cover, vegetation structure and connectivity can be quantified and tested against spider-community data. This would allow the analysis to identify whether biological patterns are more strongly associated with local habitat structure or the broader urban landscape.

2. Guild-specific responses and the limitations of total richness

Guo and Bonebrake (2026) ^[7] provide particularly relevant evidence through their global meta-analysis of urbanization effects on spiders. Their analysis included 28 studies from 27 sites and found no significant overall effect of urbanization on spider richness or abundance. However, the effects differed among guilds: orb-weavers showed positive responses in urban environments, whereas sheet-web weavers exhibited reduced richness.

This finding has two major implications. First, a single diversity metric may not adequately describe the ecological consequences of urbanization. Second, the same environmental change can create favourable conditions for some spiders while reducing habitat suitability for others.

The implications for Jabalpur are direct but must remain hypotheses until tested. Urban parks, residential vegetation and semi-natural habitats may support different mixtures of generalists and habitat-associated taxa. A robust investigation should therefore examine species turnover and functional composition rather than presuming that the most urbanized site will necessarily have the lowest richness.

3. Bioindication and environmental specificity

Marc *et al.* (1999) ^[9] reviewed the potential roles of spiders in pest limitation and bioindication, emphasizing the importance of understanding their ecological relationships and responses to environmental conditions. This literature supports the use of spiders as candidates for monitoring but does not justify treating every spider species or assemblage as a universal measure of ecosystem health.

The distinction is especially important when the environmental question concerns pollution. A biological community may respond to multiple stressors, and a change in its composition does not uniquely identify a particular pollutant. Demonstrating chemical contamination requires direct measurements of the relevant substance or a validated biological relationship with that substance.

Some riparian spiders can be used as sentinels for selected contaminants transferred through aquatic food webs, but such applications require contaminant-specific study designs and appropriate chemical analysis. A terrestrial urban-habitat assessment based on spider diversity should not be

presented as a water-quality assessment unless it includes the relevant evidence.

4. Why regional validation is necessary

The international studies provide methodological guidance, but ecological responses are influenced by climate, vegetation, regional species pools, land-use history and sampling methods. A relationship observed in a European city may not be reproduced in a Central Indian landscape with different seasonal conditions and species composition. Regional validation is therefore not a minor extension of existing work; it is essential to determining whether spider-based indicators are reliable in Jabalpur. The purpose of the proposed study is to test the transferability of general ecological expectations under local conditions rather than assume that findings from other regions are universally applicable.

Proposed field variables and their interpretation

Table 2: Environmental variables recommended for the Jabalpur case study

Environmental variable	Suggested measurement	Ecological interpretation
Vegetation cover	Standardized visual estimate or image-based assessment	Availability of foliage and web attachment structures
Canopy cover	Densiometer or validated photographic method	Light environment and potential microclimatic buffering
Vegetation complexity	Defined structural categories or repeated measurements	Diversity of available microhabitats
Leaf-litter depth	Measurements at fixed points within each plot	Ground refuges and substrate heterogeneity
Temperature	Calibrated field instrument	Local thermal conditions during sampling
Relative humidity	Calibrated hygrometer	Local moisture conditions
Built-up surface cover	GIS analysis within a defined buffer	Degree of landscape modification
Habitat connectivity	GIS-derived patch and distance metrics	Potential movement and recolonization pathways
Human disturbance	Predefined, repeatable field score	Trampling, vegetation removal and management intensity
Pesticide exposure	Documented application records or chemical analysis	Potential chemical stress, where relevant

These variables should be selected according to the principal research question and the practical capacity of the study. A large number of environmental measurements is not automatically

advantageous if the variables are poorly defined, strongly correlated or measured inconsistently. A smaller set of well-justified variables can produce more interpretable ecological results.

Table 3: Proposed hypotheses for testing spider-based bioindication

Hypothesis	Primary response	Scientific prediction
H1	Species richness and abundance	Spider metrics differ among habitat categories, but responses may not be uniformly negative
H2	Species composition	Assemblages vary with vegetation structure and built-up surface cover
H3	Functional-guild composition	Different guilds exhibit contrasting associations with habitat modification
H4	Seasonal variation	Community structure changes among seasonal sampling periods
H5	Indicator performance	A model incorporating community composition and environmental variables predicts independent habitat measurements better than species richness alone

These are proposed hypotheses, not empirical findings. Their value lies in making the case study testable and allowing the results to support, reject or refine the proposed ecological relationships.

Statistical framework for assessing bioindicator potential

1. Diversity indices and sampling completeness

Species richness, abundance, Shannon diversity and Simpson concentration can provide complementary information about spider communities. Shannon diversity is calculated as:

$$H' = -\sum p_i \ln(p_i)$$

where

p_i is the relative abundance of species

i. Simpson concentration can be expressed as:

$$D = \sum p_i^2$$

A higher value of Shannon diversity generally indicates greater diversity, while a lower Simpson concentration indicates lower dominance by a small number of species. The inverse Simpson index and the Simpson diversity form $1 - D$ should be distinguished from the concentration measure D when reporting results.

These indices should not be interpreted in isolation. Differences in sampling effort and detectability can affect observed richness and diversity. Species-accumulation curves, sample-coverage estimates and appropriate rarefaction methods can help determine whether observed differences reflect ecological patterns or unequal completeness of sampling.

2. Community composition and species turnover

A site-by-species abundance matrix can be used to assess differences in assemblage composition. Depending on the data structure, Bray–Curtis dissimilarity or an appropriate incidence-based measure can be used to compare sites. Ordination methods such as non-metric multidimensional scaling or principal coordinates analysis can help visualize community relationships.

PERMANOVA may be used to test whether assemblages differ among habitat categories, but its interpretation requires assessment of multivariate dispersion and the spatial structure of the sampling design. Where multiple plots are nested within sites, statistical tests should not treat all plots as independent site-level replicates.

Species turnover is particularly relevant because urbanization may replace some taxa with others rather than simply reduce the total number of species. A community-composition analysis can therefore reveal changes that would remain undetected by a richness-only comparison.

3. Functional-guild and trait-based analysis

Each identified species should be assigned to a consistent ecological guild using published taxonomic and ecological sources. Depending on the available information, traits may include web architecture, foraging strategy, habitat stratum and dispersal characteristics.

Guild-level metrics can then be compared among habitat categories and seasons. If sample size and trait coverage are adequate, functional diversity measures may help determine whether assemblages differ in their ecological strategies even when taxonomic richness is similar.

The interpretation should remain cautious where guild assignment is uncertain or where uncommon species are represented by very few observations. Functional analyses are most useful when they are supported by consistent classifications and adequate sampling coverage.

4. Modelling environmental relationships

Generalized linear mixed models may be appropriate for analysing species richness or abundance, depending on the distribution of the response variable and the structure of the data. Habitat category, vegetation variables, built-up cover and season can be included as explanatory variables, while site-level random effects may account for repeated observations or nested sampling where justified.

Environmental predictors should be screened for collinearity, and the sampling method and effort should be considered explicitly. Spatial dependence should also be evaluated where sites are geographically close.

Indicator-species analysis may identify taxa associated with particular habitat conditions. However, statistical association is not sufficient to establish a reliable indicator. The candidate indicator should demonstrate reproducible responses, adequate specificity for the target environmental condition and useful performance in independent validation.

Discussion

1. From biodiversity documentation to ecological explanation

The regional spider studies of Gajbe (2003, 2004) [3, 5] and Khare, Shukla and Khapre (2023) [8] provide a valuable taxonomic foundation for further work in Jabalpur. Their contribution lies in documenting species occurrence, supporting regional identification and demonstrating that the spider fauna warrants continued investigation.

The next stage of research requires a shift from asking only how many species occur in a particular area to examining why community composition differs among habitats. This shift is important because a faunistic inventory and an environmental bioindicator study answer different scientific questions. The former documents biodiversity; the latter tests whether biological patterns provide reliable information about environmental conditions.

A well-designed Jabalpur case study could bridge this gap by combining standardized sampling, independent environmental measurements and community-level statistical analysis. Such an approach would also make future monitoring more meaningful because subsequent observations could be compared with a clearly defined baseline.

2. The importance of taxonomic and functional complementarity

Taxonomic diversity provides essential information about species identity and richness, while functional diversity helps explain the ecological strategies represented in a community. Neither dimension completely replaces the other.

A habitat may retain several common spider species while losing taxa associated with particular microhabitats or foraging strategies. Conversely, a modified site may support high abundance of a few generalist species without retaining the same functional composition as a less disturbed reference habitat.

The guild-specific results reported by Guo and Bonebrake (2026) [7] reinforce the importance of this distinction. For Jabalpur, taxonomic and functional information should be analysed together so that the study can distinguish changes in the number of species from changes in the identity and ecological roles of those species.

3. Relevance to urban green-space management

Urban green spaces are important components of biodiversity conservation, but their ecological value depends on more than their total area. Vegetation complexity, habitat heterogeneity, the availability of refuges and connectivity with other green spaces can influence which organisms are able to persist.

If future field observations demonstrate consistent relationships between spider assemblages and habitat structure, these findings could help identify green spaces requiring improved vegetation management or habitat restoration. Recommendations might include retaining structurally diverse vegetation, reducing unnecessary disturbance in selected areas and maintaining suitable ground-level refuges where compatible with public safety and site management.

Such recommendations should be tied to measured results rather than general assumptions. A site should not be described as ecologically superior solely because it contains more spiders, nor should the presence of abundant spiders be taken as evidence that a habitat is free from chemical contamination.

4. Environmental monitoring and the limits of inference

The use of spiders as bioindicators requires a clear distinction between habitat quality, biodiversity status and chemical pollution. These concepts are related but not interchangeable.

An assemblage may provide information about vegetation structure or the intensity of habitat modification without identifying a particular pollutant. Similarly, a change in species composition may reflect seasonal conditions or prey availability rather than environmental degradation.

A defensible monitoring system should therefore specify its target variable, such as vegetation complexity, degree of urbanization or a particular chemical contaminant. The biological response should then be evaluated against that variable using appropriate measurements and validation. This approach would make the conclusions more precise and reduce the risk of overinterpreting biodiversity data.

5. Limitations of the present review

The present manuscript synthesizes published regional evidence and develops a proposed case-study design; it does not report a new standardized field survey across an urbanization gradient. Consequently, no new site-specific environmental relationships, causal effects or validated bioindicator thresholds are claimed.

The underlying regional publications differ in spatial extent, sampling period, methods and taxonomic coverage. Their species totals and diversity indices cannot be treated as directly comparable estimates of temporal change. The international literature is also geographically uneven, and findings from one climatic or urban context may not transfer directly to another.

These limitations identify the requirements for the next stage of research: standardized sampling, adequate spatial and seasonal replication, reliable species identification, independent environmental measurements and transparent statistical analysis. A subsequent empirical paper could build directly on this framework if the necessary data are collected or if an existing dataset meets these requirements.

Future research directions

Future research in Jabalpur should begin with a standardized baseline survey across explicitly defined habitat categories. The sampling framework should document collection methods, sampling effort, seasonal conditions and taxonomic confidence so that the resulting data can be compared across locations and years.

A second priority is the integration of environmental measurements with spider-community data. This would allow the investigation to determine whether community differences are associated with vegetation structure, microclimate, built-up cover or other environmental variables. The relative importance of local and landscape-scale conditions could then be evaluated statistically.

A third priority is the assessment of functional guilds and species turnover. Such analyses could identify ecological changes that are not apparent from total species richness alone. Candidate indicator taxa should subsequently be tested against independent environmental measurements and validated at additional sites.

inally, repeated monitoring could establish whether the observed relationships remain consistent through time. If a reliable relationship is demonstrated, spider assemblages could become a useful component of regional urban-biodiversity monitoring. If the relationships are inconsistent, the results would still be valuable by identifying the environmental contexts in which spiders are unsuitable or insufficient as indicators.

Conclusion

Spiders are promising candidates for the ecological assessment of urban habitats because they occupy diverse terrestrial niches, perform important predatory functions and exhibit variation in community composition and foraging strategies. However, their value as bioindicators depends on the ability to establish reliable relationships between biological responses and independently measured environmental conditions. The published work of Gajbe (2003, 2004) ^[3, 5] and Khare, Shukla and Khapre (2023) ^[8], including the contribution of Dr. Arjun Shukla, provides an important regional foundation for spider research in Jabalpur. These studies document the local spider fauna and establish a basis for further ecological investigation. International research, particularly Piquet *et al.* (2025) and Guo and Bonebrake (2026) ^[7, 10], demonstrates why urban spider communities should be examined using both taxonomic and functional approaches. The proposed Jabalpur case-study framework advances this research direction by emphasizing replicated habitat comparisons, seasonal sampling, environmental measurement, functional-guild analysis and independent validation. Its principal contribution is to identify how existing regional inventories can be extended into a testable assessment of urban habitat quality. Spider-based bioindication should be considered established only when the relevant community metrics or taxa demonstrate reproducible and independently validated relationships with the environmental conditions they are intended to represent.

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