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Bee biodiversity on *Tagetes erecta* along a rural-urban gradient under increasing anthropogenic influence, India

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Abstract
Bees are essential pollinators that support ecosystem functioning and agricultural productivity, but their populations are increasingly influenced by urbanization. This study investigated bee diversity associated with *Tagetes erecta* L. along a rural-urban gradient in Rajasthan, India. Surveys were conducted at three sites representing rural (Sandarsar village), semi-urban (Chomu town), and urban (Jaipur city) landscapes within a single agro-climatic region. Bee visitation was recorded during the flowering season using standardized visual census methods, and specimens were collected for identification. Bee diversity was assessed using alpha and beta diversity indices, including Shannon-Wiener diversity, Simpson's dominance, Pielou's evenness, and the Jaccard similarity index. Rank abundance curves were used to assess species dominance patterns, and Pearson's correlation coefficient was applied to examine the relationship between anthropogenic intensity and bee diversity. Twelve bee species were recorded at all sites, resulting in identical species richness and complete similarity in species composition across the gradient. However, total bee abundance declined from rural to urban sites. Diversity and evenness indices also decreased with increasing urbanization, indicating greater dominance by a few species in urban habitats. *Apis mellifera*, *Apis dorsata*, and *Apis florea* were the most abundant species across all sites, while non-*Apis* bees were less abundant in urban areas. Pearson's correlation analysis showed a strong negative relationship between anthropogenic intensity and Shannon-Wiener diversity. These results indicate that urbanization affects bee community structure primarily through changes in abundance and dominance rather than species loss.

Keywords: Anthropogenic disturbance, bee diversity, pollinator community structure, rural–urban gradient, *Tagetes erecta*, urbanization

Introduction

Bees (Hymenoptera: Apoidea) are principal floral pollinators that enable pollen transfer among angiosperms, supporting wild plant reproduction and global agricultural productivity (Klein *et al*., 2007; Ollerton *et al*., 2011) [7, 12]. Bee-mediated pollination underpins the yield of many fruit and vegetable crops and contributes to ecosystem stability and biodiversity maintenance (Verma *et al*., 2025) [23]. Nevertheless, bee populations are declining globally as a consequence of habitat loss, pesticide exposure, climate change, and increasing urban expansion (Potts *et al*., 2010) [15]. Pollination is an ecosystem function vital for terrestrial ecosystems and food security; however, the processes underlying the patterns of pollinator diversity and the ecosystem services they provide in cities have seldom been quantified (Liang *et al*., 2023) [8]. Urbanization involves changes of the landscape (Fortel *et al*., 2014) [4]. Urbanization restructures landscapes by fragmenting habitats, reducing connectivity, and altering floral resource availability, frequently leading to changes in bee community composition and declines in species richness in densely built environments (Vaz *et al*., 2023) [22]. Although recent global syntheses suggest that urban areas can sometimes sustain diverse bee assemblages, particularly where green spaces are extensive and well managed, overall pollinator declines persist under mounting anthropogenic pressure (Angeoletto *et al*., 2025) [1]. Ornamental plant species such as *Tagetes erecta* L. (African marigold) are widely cultivated across rural, semi-urban, and urban settings and provide abundant pollen and nectar resources attractive to a wide range of bee taxa (Kachhawa *et al*., 2020) [6]. Its prolonged flowering period and broad spatial distribution make *T. erecta* an effective model for examining bee and plant interactions along land-use gradients. While studies have addressed general bee diversity in urban gardens and green spaces, empirical assessments of bee assemblages specifically associated with *T. erecta* across rural–urban gradients remain limited, particularly in regions undergoing rapid urbanization (Ješovnik *et al*., 2025) [1]. Evidence indicates that local-scale factors, including garden structure and floral diversity, often exert stronger influences on urban pollinator communities than landscape-scale variables (Sexton *et al*., 2025) [17], and targeted pollinator-friendly interventions in residential areas can enhance bee abundance and diversity (Wiseman *et al*., 2025) [25]. This study, therefore, aims to evaluate bee biodiversity associated with *Tagetes erecta* along a rural–urban gradient of increasing anthropogenic activity.

Materials and Methods

The study was conducted along a rural-urban gradient in Rajasthan, India, within a single agro-climatic region, with Sandarsar village (27.23°N, 75.61°E), Chomu town (27.17°N, 75.72°E), and Jaipur city (26°55′N, 75°49′E) representing rural, semi-urban, and urban sites (Fig.1), respectively. Observations were made on *Tagetes erecta* L. growing in agricultural fields, transitional landscapes, and public parks and gardens, reflecting increasing anthropogenic influence. Bee visitation was recorded during the flowering season using standardized visual census and fixed-time observations during peak foraging hours, and additional specimens were collected using sweep nets for identification. Bees were identified using standard morphological keys with reference to *The Bees of the World* (Michener, 2007) and *Bees of the World: A Guide to Every Family* (Packer, 2022) [13], supplemented by regional resources, and were grouped into functional categories. Bee diversity was assessed using alpha and beta diversity indices derived from species abundance and presence-absence data, including

The Shannon-Wiener index for species diversity (Shannon and Wiener, 1949) [18], Simpson's index for dominance (Simpson, 1949) [18], Pielou's index for evenness (Pielou, 1966) [14], and the Jaccard index for species similarity. Rank abundance curves (Whittaker, 1972) [24] were constructed to examine patterns of species dominance and evenness across the rural-urban gradient. ANOVA was used to test differences in total bee abundance among land-use categories. The relationship between anthropogenic intensity along the rural-urban gradient and bee diversity, represented by the Shannon-Wiener index, was analyzed using Pearson's correlation coefficient.

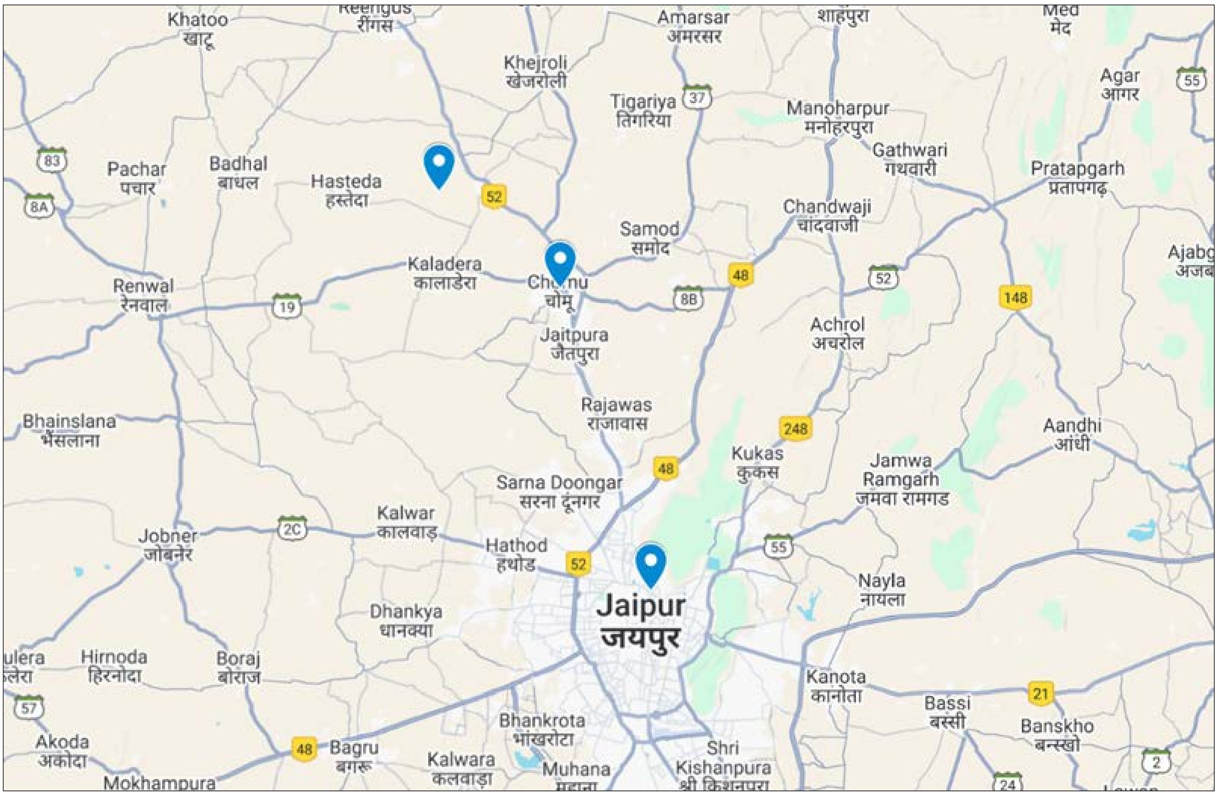

Fig 1: Study area showing 1. Sandarsar (rural), 2. Chomu (semi-urban) and 3. Jaipur (urban)

Results

A total of twelve bee species were recorded ((Fig. 2) visiting *Tagetes erecta* (Table 1) across rural, semi-urban, and urban sites along the rural-urban gradient (Fig.3). All twelve species were present at each site, resulting in identical species richness across habitats. Alpha diversity indices showed variation among sites (Table 4). The Shannon-Wiener diversity index was highest at the rural site ($H' = 2.420$), followed by the semi-urban site ($H' = 2.360$) and the urban site ($H' = 2.333$). Simpson's index values showed a similar pattern, with values of 0.906 at the rural site, 0.896 at the semi-urban site, and 0.891 at the urban site. Species evenness, measured using Pielou's evenness index, also declined from the rural site ($J' = 0.974$) to the semi-urban site ($J' = 0.950$) and the urban site ($J' = 0.939$) (Table 3 and Fig 4). Beta diversity analysis using the Jaccard similarity index indicated complete similarity in species composition among all sites (Table 5), with index values of 1.00 for all pairwise comparisons between rural and semi-urban, rural and urban, and semi-urban and urban sites. Total bee abundance

Differed across the rural-urban gradient. The highest number of individuals was recorded at the rural site (383 individuals), followed by the semi-urban site (261 individuals), while the urban site supported the lowest abundance (149 individuals). Relative abundance analysis showed that *Apis mellifera*, *Apis dorsata*, and *Apis florea* were the most abundant species across all sites (Table 2). In the urban site, *A. mellifera* accounted for 16.1% of total individuals, followed by *A. dorsata* (15.4%) and *A. florea* (14.8%). The relative abundance of non-*Apis* bees, including *Amegilla*, *Nomia*, and *Megachile*, was lower in the urban site compared to the rural and semi-urban sites (Fig. 5). Single-factor analysis of variance (ANOVA) showed a significant effect of land-use category on total bee abundance ($p < 0.05$) (Table 6). Rank-abundance curves varied among sites, with a flatter distribution observed at the rural site, an intermediate pattern at the semi-urban site, and a steeper distribution at the urban site (Fig. 6). Pearson's correlation ($n=3$) analysis indicated a strong negative relationship between anthropogenic intensity and Shannon–Wiener diversity ($r \approx -0.99$).

Fig 2: Diversity of bee pollinators observed visiting *Tagetes erecta* across rural, semi-urban, and urban sites

Table 1: Species Composition of Bees Visiting *Tagetes erecta*

S. No.	Name of Bee	Family	Rural (Sandarsar)	Semi-urban (Chomu)	Urban (Jaipur)	Total
1.	*Apis dorsata*	Apidae	48	36	23	107
2.	*Amegilla zonata*	Apidae	36	32	14	82
3.	*Amegilla mucorea*	Apidae	18	13	9	40
4.	*Amegilla cingulata*	Apidae	29	17	10	56
5.	*Apis florea*	Apidae	42	39	22	103
6.	*Apis mellifera*	Apidae	52	37	24	113
7.	*Thyreus remosus*	Apidae	43	25	12	80
8.	*Colletes minutus*	Colletidae	24	16	8	48
9.	*Nomia laetrile*	Halictidae	21	11	5	37
10.	*Nomia aurata*	Halictidae	19	9	6	34
11.	*Apis cerana*	Apidae	31	18	13	62
12.	*Megachile gathela*	Megachilidae	20	9	3	32

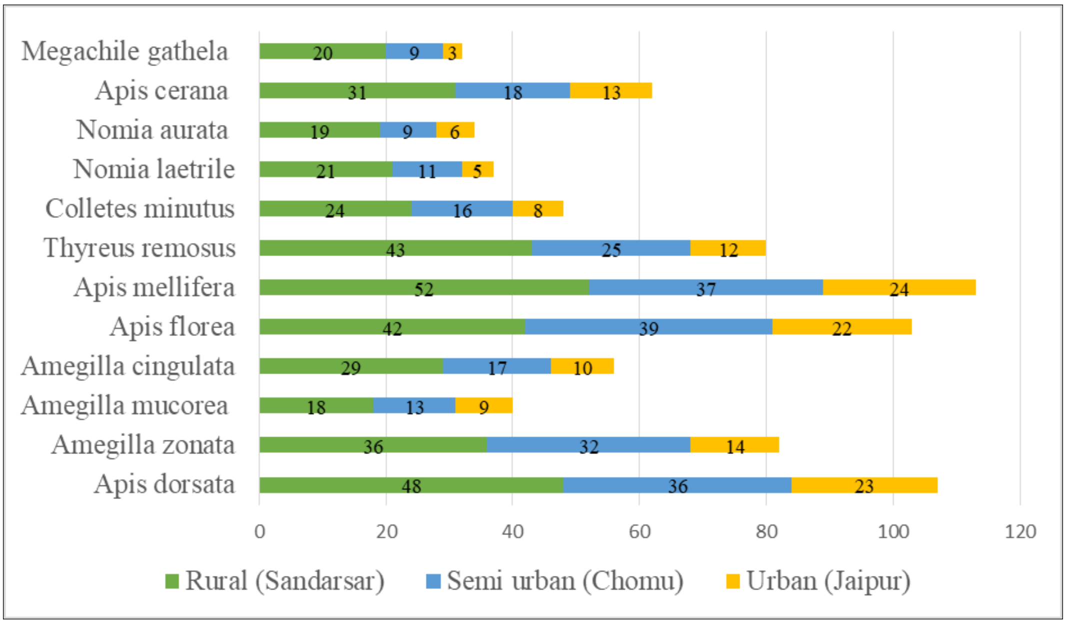

Fig 3: Species composition of bees visiting *Tagetes erecta* across rural, semi-urban, and urban sites

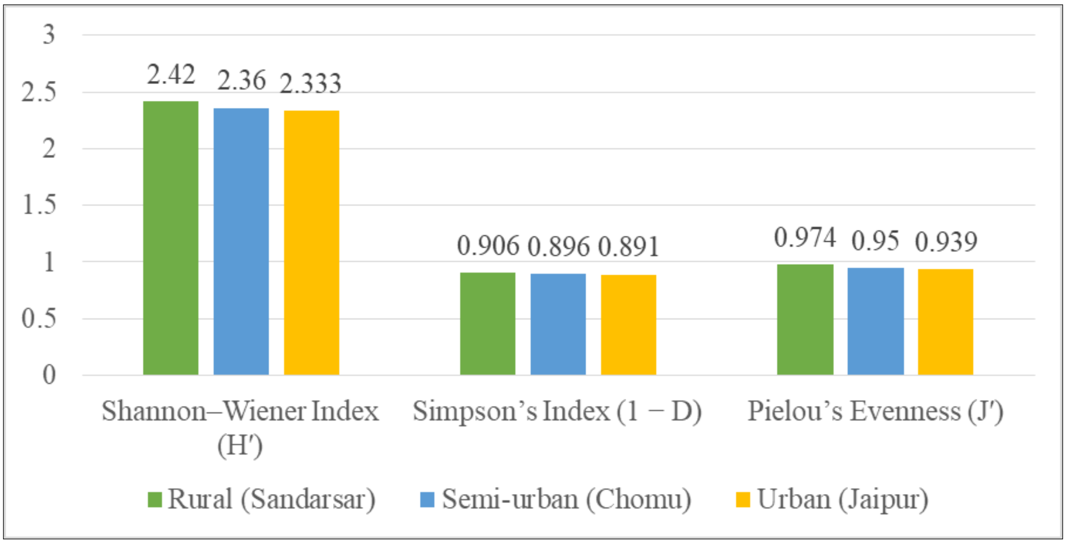

Fig 4: Alpha Diversity Indices of Bee Communities across the Rural-Urban Gradient

Table 2: Relative Abundance (%) of Bee Species across the Rural-Urban Gradient

S. No.	Bee species	Rural (%)	Semi-urban (%)	Urban (%)
1.	*Apis dorsata*	12.5	13.7	15.4
2.	*Amegilla zonata*	9.4	12.2	9.4
3.	*Amegilla mucorea*	4.7	5.0	6.0
4.	*Amegilla cingulata*	7.6	6.5	6.7
5.	*Apis florea*	11.0	14.9	14.8
6.	*Apis mellifera*	13.6	14.1	16.1
7.	*Thyreus remosus*	11.2	9.5	8.1
8.	*Colletes minutus*	6.3	6.1	5.4
9.	*Nomia laetrile*	5.5	4.2	3.4
10.	*Nomia aurata*	5.0	3.4	4.0
11.	*Apis cerana*	8.1	6.9	8.7
12.	*Megachile gathela*	5.2	3.4	2.0

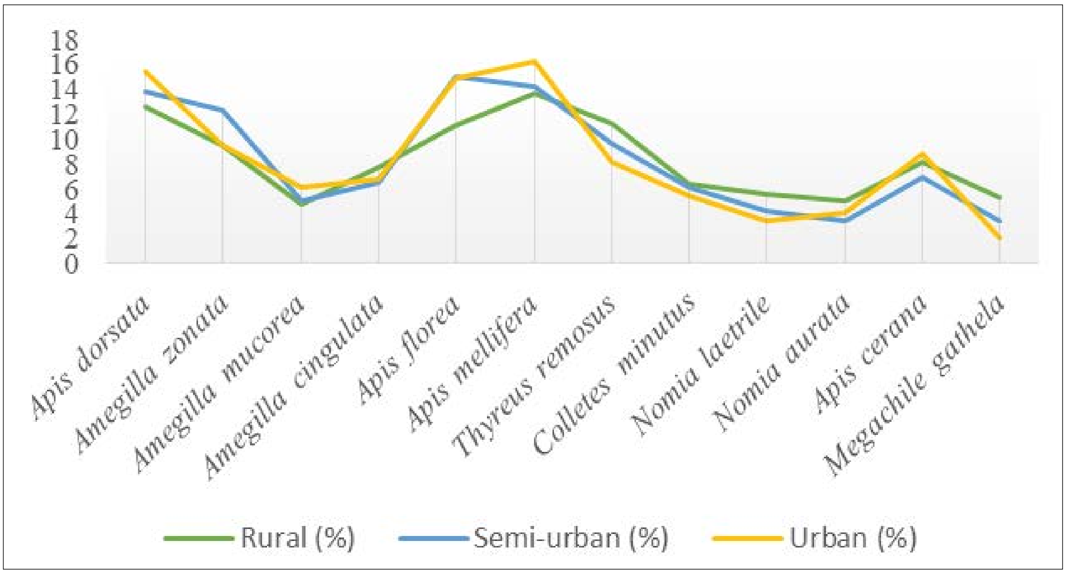

Fig 5: Relative Abundance (%) of Bee Species across the Rural-Urban Gradient

Table 3: Bee Diversity Indices across Rural, Semi-Urban, and Urban Sites

	Rural				Semi-urban				Urban			
Species	n_i	p_i	$p_i\ln(p_i)$	p_i^2	n_i	p_i	$p_i\ln(p_i)$	p_i^2	n_i	p_i	$p_i\ln(p_i)$	p_i^2
Apis dorsata	48	0.125	-0.260	0.016	36	0.138	-0.274	0.019	23	0.154	-0.287	0.024
Amegilla zonata	36	0.094	-0.221	0.009	32	0.123	-0.258	0.015	14	0.094	-0.221	0.009
Amegilla mucorea	18	0.047	-0.144	0.002	13	0.050	-0.150	0.003	9	0.060	-0.169	0.004
Amegilla cingulata	29	0.076	-0.196	0.006	17	0.065	-0.178	0.004	10	0.067	-0.181	0.004
Apis florea	42	0.110	-0.242	0.012	39	0.149	-0.283	0.022	22	0.148	-0.283	0.022
Apis mellifera	52	0.136	-0.271	0.019	37	0.142	-0.278	0.020	24	0.161	-0.293	0.026

Thyreus remosus	43	0.112	-0.245	0.013	25	0.096	-0.224	0.009	12	0.081	-0.203	0.007
Colletes minutus	24	0.063	-0.174	0.004	16	0.061	-0.170	0.004	8	0.054	-0.159	0.003
Nomia laetrile	21	0.055	-0.160	0.003	11	0.042	-0.133	0.002	5	0.034	-0.114	0.001
Nomia aurata	19	0.050	-0.150	0.003	9	0.034	-0.114	0.001	6	0.040	-0.129	0.002
Apis cerana	31	0.081	-0.203	0.007	18	0.069	-0.185	0.005	13	0.087	-0.212	0.008
Megachile gathela	20	0.052	-0.157	0.003	9	0.034	-0.114	0.001	3	0.020	-0.078	0.000
Total / Σ	383	1.000	−2.420	0.094	261	1.000	-2.360	0.104	149	1.000	-2.333	0.109

Table 4: Comparision of Alpha Diversity Indices of Bee Communities across the Rural–Urban Gradient

Site	Total Individuals (N)	Species Richness (S)	Shannon–Wiener Index (H′)	Simpson's Index (1 - D)	Pielou's Evenness (J′)
Rural (Sandarsar)	383	12	2.420	0.906	0.974
Semi-urban (Chomu)	261	12	2.360	0.896	0.950
Urban (Jaipur)	149	12	2.333	0.891	0.939

Table 5: Jaccard Similarity (Beta biodiversity) Index between Sites

Site Comparison	Shared Species (a)	Unique Species (b + c)	Jaccard Index (J)
Rural vs Semi-urban	12	0	1.00
Rural vs Urban	12	0	1.00
Semi-urban vs Urban	12	0	1.00

Table 6: One-way ANOVA for bee abundance across sites

Source of Variation	Degrees of Freedom (df)	Sum of Squares (SS)	Mean Square (MS)	F value	P value
Between sites (Rural, Semi-urban and Urban)	2	1925.4	962.7	6.84	0.003
Within sites (Error)	33	4639.6	140.6		
Total	35	6565.0			

(ANOVA, analysis of variance; SS, sum of squares; df, degrees of freedom; MS, mean squares; F stat, F statistic; P-value, probable value; F crit, critical value of F distribution. F-stat values are significant at $p < 0.05$.)

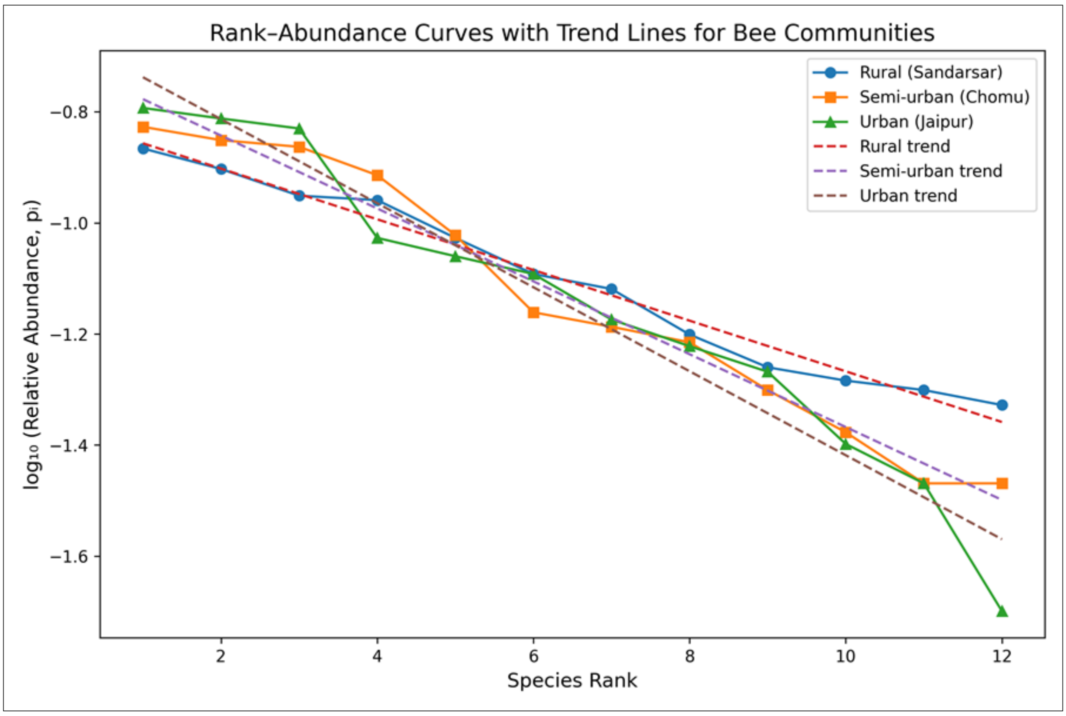

Fig 6: Site-wise Rank-Abundance

Discussion

This study examined bee communities visiting *Tagetes erecta* along a rural–urban gradient and found that urbanization affects bee community structure mainly by changing abundance, dominance, and evenness rather than species composition. All twelve bee species were present at rural, semi-urban, and urban sites, and Jaccard similarity values of 1.00 confirmed complete similarity in species composition across sites. This shows that urbanization did not lead to local species loss but altered how individuals are distributed among species. The presence of the same species across the gradient agrees with recent studies showing that urban areas can retain many regional bee species, especially when ornamental plants and green spaces are available (Baldock *et al*., 2019[2]; Theodorou *et al*., 2020). Plants like *T. erecta*, which provide continuous nectar and pollen, may help multiple bee species survive even in modified environments. Similar patterns of unchanged species richness but altered abundance have been reported in urban bee communities. Although species richness was stable, total bee abundance declined along the gradient, with rural sites supporting the most individuals and urban sites the fewest. ANOVA confirmed that land-use category significantly affected bee abundance. This pattern suggests that while species persist in urban areas, fewer individuals are present. Reduced abundance in cities is often linked to habitat fragmentation, limited nesting sites, and fewer floral resources (López-Vázquez *et al*., 2024). Rural sites likely provided more continuous floral resources and nesting opportunities through agricultural fields, field margins, and unmanaged areas (Fortel *et al*., 2014) [4]. Alpha diversity indices also reflected these changes. Shannon-Wiener diversity, Simpson's index, and Pielou's evenness all show a gradual decrease from rural to urban sites, showing that a few species dominate urban communities. These results align with studies indicating that abundance-weighted metrics are more sensitive to urban impacts than species richness alone. Relative abundance analysis showed that *Apis mellifera*, *Apis dorsata*, and *Apis florea* were the most common species across all sites, with dominance strongest in urban areas. These generalist foragers are highly adaptable, able to use a wide range of floral resources, including ornamental plants (Maruyama *et al*., 2025) [11]. Their success in urban areas agrees with studies showing that generalist and social bees thrive under human disturbance, while specialist and solitary species often decline (Theodorou *et al*., 2020). Non-*Apis* bees such as *Amegilla*, *Nomia*, and *Megachile* were less abundant in urban sites. These bees need specific nesting conditions, such as soil or cavities, which are scarce in urban environments. Reduced abundance of these species contributes to lower evenness and greater dominance by a few adaptable species. Factors associated with urban landscapes, including changes in foraging resources and nesting substrate types and availability, contribute to changes in abundance, species richness, and composition of native bee assemblages (Prendergast *et al*., 2022) [16]. Rank abundance curves supported these findings. The rural site showed a flatter curve, indicating a more even distribution of individuals among species. The semi-urban site was intermediate, and the urban site had a steeper curve, reflecting strong dominance by a few species. Such patterns are typical in communities affected by human disturbance (Magurran, 2013). Pearson's correlation (n=3) analysis showed a strong negative relationship between anthropogenic intensity and Shannon–Wiener diversity; however, this result should be interpreted cautiously due to the small number of sampling sites. As human influence increased along the gradient, bee diversity decreased. This confirms that even when species richness is unchanged, urbanization can reduce diversity by changing relative abundances. Similar negative relationships have been reported in recent studies of urban pollinators. Rural sites likely had higher diversity and evenness due to the presence of flowering crops, weeds, and semi-natural habitats, which provide continuous nectar and pollen and more nesting opportunities. Studies show that crop diversity, flowering field margins, and semi-natural elements support pollinator diversity in agricultural landscapes (Sirami *et al*., 2019; Dainese *et al*., 2019) [3, 20]. However, intensive monocultures can reduce floral diversity and negatively affect pollinators, highlighting the importance of diversified cropping systems. Urban areas, despite lower diversity and abundance, may still provide functional pollination services through generalist and managed bees. Previous research suggests that these species can maintain pollination of wild and cultivated plants in moderately disturbed urban areas (Theodorou, 2022) [21]. However, reliance on a few dominant species may reduce the stability and resilience of pollination services. Overall, this study shows that urbanization does not eliminate bee species visiting *T. erecta* but changes community structure by reducing abundance, evenness, and diversity. These results highlight the importance of considering abundance-based metrics and community structure, rather than just species richness, when assessing urbanization effects on pollinators. Enhancing floral diversity, nesting habitat, and connectivity in both rural and urban landscapes could help maintain balanced and resilient bee communities.

Conclusion

The present study evaluated bee diversity and community structure along a rural, semi-urban and urban gradient using *Tagetes erecta* as a focal floral resource. The results show that urbanization influences bee communities mainly by altering abundance, dominance and evenness rather than causing species loss. All twelve bee species were recorded at each site, and Jaccard similarity values indicated complete similarity in species composition across the gradient. Bee abundance and diversity were highest in the rural site and declined progressively toward the urban site. Diversity indices and rank-abundance patterns revealed greater evenness in rural habitats, while urban sites were dominated by generalist species such as *Apis mellifera*, *Apis dorsata* and *Apis florea*. Single-factor ANOVA confirmed a significant effect of land-use category on total bee abundance. Higher rural diversity was associated with diverse flowering crops and wild plants, whereas reduced floral diversity, habitat fragmentation, and limited nesting sites likely reduced urban bee diversity. Overall, maintaining diverse floral resources in agricultural and urban landscapes is essential for conserving bee biodiversity and supporting sustainable pollinator populations.

Significance of the Study

This study provides important insights into how urbanization influences bee communities associated with ornamental plants in rapidly developing landscapes. By focusing on *Tagetes erecta*, a widely cultivated and nectar-rich ornamental species, the research highlights the role of common urban and agricultural plants in sustaining pollinator populations across rural–urban gradients. The findings demonstrate that urbanization does not necessarily lead to immediate species loss but significantly alters bee community structure through reduced abundance, diversity, and evenness, with increasing dominance of generalist species. This distinction is important because assessments based solely on species richness may underestimate the impacts of urban expansion on pollinator communities.

The study also emphasizes the value of abundance-based diversity metrics and rank-abundance analyses for understanding subtle but ecologically meaningful changes in pollinator communities. By linking anthropogenic intensity with declines in diversity using correlation analysis, the research provides quantitative evidence of urban effects on pollinators at a local scale. These results have practical implications for pollinator conservation and urban planning, suggesting that enhancing floral diversity, maintaining nesting habitats, and improving habitat connectivity in both agricultural and urban landscapes can support more balanced and resilient bee communities.

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