

Spatial distribution and relative abundance of aquatic entomofauna in Man Sagar Lake, Jaipur

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Abstract

Aquatic entomofauna are important bioindicators for monitoring freshwater ecosystem health due to their ecological sensitivity and functional roles. The present study aimed to assess the spatial distribution and relative abundance of aquatic insect communities across four distinct sites of Man Sagar Lake, Jaipur. Sampling was conducted using standardized entomological techniques targeting diverse microhabitats, and identification was performed using established taxonomic keys. Relative abundance at the family level was calculated using Microsoft Excel, and multivariate analyses including Bray–Curtis similarity and chord diagram visualization were carried out using PAST software (version 4.03). A total of 28 species and 12 insect families representing four major orders, *viz.*, Odonata, Hemiptera, Coleoptera, and Diptera were recorded. Site 2 exhibited the highest abundance, contributing 65% of the total individuals, predominantly represented by families like Gerridae, Libellulidae, and Coenagrionidae. Followed by Site 4 and Site 3 accounting for 22% and 9%, respectively and Site 1 recorded the lowest (4%) representation across most families. It was also recorded that families such as Libellulidae, Gerridae, and Chironomidae were widely distributed, while Aeshnidae and Hydrophilidae were restricted to specific sites. The chord diagram showed strong species-site associations in Site 2, while Sites 1 and 3 exhibited limited connectivity, suggesting reduced diversity. Bray–Curtis analysis confirmed that Sites 2 and 4 shared the highest similarity, while Site 1 was most dissimilar from Site 2. Site 2 demonstrated high species diversity, low dominance, even distribution of individuals and elevated species richness, as reflected by favorable Shannon, Simpson, Evenness, and Margalef indices. The presence of sensitive families, Aeshnidae, Coenagrionidae, and Dytiscidae further indicated ecological stability and optimal habitat conditions. In contrast, Site 1 exhibited low species diversity, high dominance, and uneven distribution, with elevated Dominance and Berger–Parker indices. The community was overwhelmingly composed of pollution-tolerant Dipterans families like Chironomidae and Culicidae, reflecting severe ecological degradation due to eutrophication and anthropogenic stress. The study highlighted significant spatial variability in aquatic insect distribution and emphasized their value in ecological assessment and freshwater habitat monitoring in urban lake systems.

Keywords: Aquatic entomofauna, Man Sagar Lake, relative abundance, freshwater bioindicators, species distribution, bray–curtis similarity, urban freshwater ecosystem

Introduction

Freshwater ecosystems are among the most productive and dynamic environments, supporting a wide range of biodiversity, including aquatic insects that are vital to ecological balance. Aquatic entomofauna perform critical functions in nutrient cycling, organic matter decomposition, and energy transfer across trophic levels (Rosenberg & Resh, 1993; Wallace & Webster, 1996) [31, 38]. Due to their sensitivity to physical, chemical, and biological changes in aquatic habitats, these organisms are considered effective bioindicators of water quality and ecosystem health (Bonada *et al.*, 2006; Arimoro & Muller, 2010) [4, 12]. Consequently, they have been increasingly employed in monitoring and assessment programs across diverse freshwater systems globally.

Urban freshwater bodies, such as lakes and reservoirs, are particularly vulnerable to anthropogenic pressures including untreated sewage discharge, sedimentation, habitat alteration, and nutrient loading. Man Sagar Lake, located in Jaipur, Rajasthan, exemplifies a semi-urban freshwater system impacted by such stressors. Despite its ecological, cultural, and hydrological importance, the aquatic insect fauna of this lake remains understudied. In India, previous research on freshwater entomofauna has primarily focused

on rivers, hill streams, and forest wetlands (Subramanian & Sivaramakrishnan, 2007; Kodarkar, 1992) [19, 36], while urban water bodies have received comparatively less attention.

Assessing the diversity and relative abundance of aquatic insect families across different sites within a lake can offer valuable insights into habitat quality and biotic integrity (Bouchard, 2004; Merritt *et al.*, 2008) [13, 23]. Such studies are essential not only for ecological monitoring but also for formulating conservation strategies in rapidly urbanizing landscapes. The present study documented the species composition and spatial distribution of aquatic entomofauna across four sites within Man Sagar Lake, using species-level data and statistical methods to evaluate patterns in community diversity.

Material and Methods

Study Area: Man Sagar Lake, Jaipur

Man Sagar Lake, a 121-hectare artificial freshwater reservoir located in Jaipur, Rajasthan, India (26°57'22"N, 75°50'46"E), was built in 1610 by damming the Dravyavati River to mitigate severe water scarcity. The lake is surrounded by the Aravalli Hills on three sides and

densely populated urban settlements on the south. The lake's volume varies seasonally, reaching a peak of approximately 3.13 million cubic meters during the monsoon season and dropping significantly to 360,000 cubic meters during the dry season. The corresponding water depth ranges from 4.5 to 1.5 meters. The catchment area of 23.5 km² includes 325 seasonal streams and two perennial municipal streams

(Brahmpuri and Nagtalai), which contribute significant amounts of untreated sewage and sediment to the lake. A two-year study (2021-2023) was carried out on four distinct study sites based on habitat characteristics and accessibility. The spatial context for study area is provided through multi-scale cartographic representations and high-resolution satellite imagery (Figure 1).

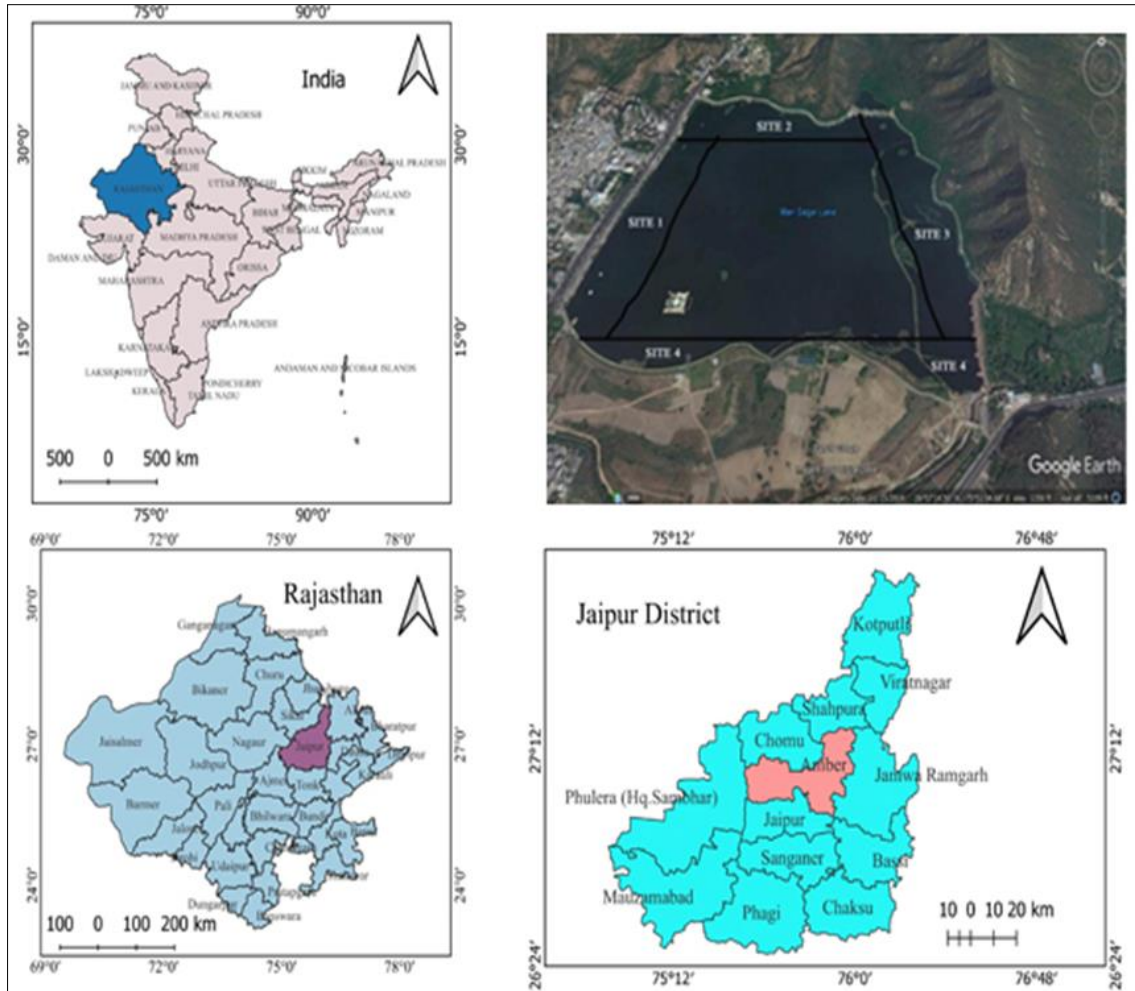


Fig 1: Location of Man Sagar Lake including India, Rajasthan, Jaipur District, and satellite image (QGIS version 3.40.2)

b. Collection, Preservation, and Identification of Aquatic Entomofauna

Aquatic entomofauna were collected from Man Sagar Lake, Jaipur, over a continuous two-year period (2021–2023). Four fixed sampling sites (Sites 1–4) were strategically selected to represent distinct regions of the lake as illustrated in Figure 1. All sites were located near the shoreline to allow access and ensure effective aquatic entomofauna collection. Sampling was carried out fortnightly for over 2 years, exclusively in the morning hours between 7:00 AM and 12:00 PM to maintain consistency and minimize diurnal variation. To ensure a comprehensive and representative collection of aquatic entomofauna, three standardized sampling methods were employed at four sites of the lake: Nylon Pond Net Method (Subramaniana and Sivaramakrishnan, 2007) [36], All-Out Search Method (Subramanian and Sivaramakrishnan, 2005) [37], 1-Minute Kick Method

(Brittain, 1974) [14]. Collected specimens were promptly sorted and counted in the field. Preservation was performed using 70% ethanol or dry preservation techniques, depending on the morphological characteristics of the taxa. Taxonomic identification was carried out to the lowest possible level using a stereo zoom microscope and standard taxonomic keys and references, including: Winterbourn and Gregson (1981) [39], Bal and Basu (1994a, 1994b) [5, 6], Biswas and Mukhopadhyay (1995) [11], Biswas *et al.* (1995a, 1995b) [9, 10], Needham and Needham (1996) [29], Bouchard (2004) [13].

c. Data Analysis

Relative abundance of aquatic entomofauna was calculated at both species and family levels using Microsoft Excel (Microsoft 365), with values expressed as percentages for each sampling site. The distribution of aquatic insect species across different sites was also analyzed and visualized using

Microsoft Excel. A pie chart was prepared to show the percentage contribution of each site to the total entomofaunal abundance. A bar graph was used to depict the relative abundance of different insect families across the four sampling sites. Species-site associations were illustrated through a chord diagram based on abundance data. Community similarity among the four sites was assessed using hierarchical clustering with the Bray–Curtis similarity index, and the resulting dendrogram was produced using PAST software version 4.03. Diversity indices (Shannon, Simpson, Evenness, Margalef, Dominance, Berger–Parker) were calculated using PAST software (version 4.03), and the bar graph was prepared using Microsoft Excel (Microsoft 365).

Results

The distribution pattern of aquatic entomofauna species across four freshwater sites reveals considerable spatial heterogeneity in their occurrence and diversity as shown in

table 1. The order Odonata was moderately represented, with Coenagrionidae and Libellulidae species primarily occurring at Sites 2 and 4, while Aeshnidae appeared only at Site 2. Widespread taxa like *Brachythemis contaminata*, *Bradinopyga geminata*, and *Orthetrum sabina* were observed at multiple sites, reflecting their ecological tolerance. The order Hemiptera exhibited broad distribution, particularly the Gerridae family, whose species were recorded at all sites, suggesting ecological generalism. In contrast, other families like Nepidae and Notonectidae had more limited occurrences. Coleoptera species were concentrated mainly at Site 2, with a few detected at Site 4, and were absent from Sites 1 and 3, indicating site-specific preferences. Diptera, especially *Aedes albopictus*, *Culex sp.*, and *Chironomus*, were present at all sites, highlighting their adaptability and widespread distribution. Among all locations, Site 2 recorded the highest species richness, while Site 1 had the lowest, demonstrating significant habitat-related variability in entomofaunal composition.

Table 1: Presence (+) and absence (–) of aquatic entomofauna species across four freshwater sampling sites

| Order | Family | Species Name | Site 1 | Site 2 | Site 3 | Site 4 |
|--------------|-------------------------------------|---|---|--------|--------|--------|
| Odonata | Aeshnidae | <i>Anax sp.</i> | - | + | - | - |
| | Coenagrionidae | <i>Agriocnemis pygmaea</i> (Rambur, 1842) | - | + | - | + |
| | | <i>Ceriagrion coromandelianum</i> (Fabricius, 1798) | - | + | - | + |
| | | <i>Ischnura aurora</i> (Brauer, 1865) | - | + | - | + |
| | | <i>Ischnura senegalensis</i> (Rambur, 1842) | - | + | - | + |
| | Libellulidae | <i>Acisoma panorpoides</i> Rambur, 1842 | - | + | - | + |
| | | <i>Brachythemis contaminata</i> (Fabricius, 1793) | + | + | + | + |
| | | <i>Bradinopyga geminata</i> (Rambur, 1842) | + | + | + | + |
| | | <i>Orthetrum sabina</i> (Drury) Drury, 1770 | - | + | - | + |
| | | | <i>Pantala flavescens</i> (Fabricius, 1798) | - | + | - |
| Hemiptera | Belostomatidae | <i>Diplonychus rusticus</i> Fabricius, 1871 | - | + | - | + |
| | Corixidae | <i>Sigara sp.</i> | - | + | - | - |
| | Gerridae | <i>Aquarius adelaidis</i> (Dohrn, 1860) | + | + | + | + |
| | | <i>Limnogonus fossarum</i> (Fabricius, 1775) | + | + | + | + |
| | | <i>Limnogonus nitidus</i> (Mayr, 1865) | + | + | + | + |
| | Nepidae | <i>Nepa sp.</i> | - | + | - | - |
| | | <i>Ranatra filiformis</i> Fabricius, 1790 | - | + | - | + |
| Notonectidae | <i>Notonecta undulata</i> Say, 1832 | - | + | - | + | |
| Coleoptera | Dytiscidae | <i>Dytiscus sp.</i> | - | + | - | + |
| | | <i>Eretes sticticus</i> (Linnaeus, 1767) | - | + | - | - |
| | | <i>Hydaticus sp.</i> | - | + | - | + |
| | | <i>Laccophilus sp.</i> | - | + | - | - |
| | Hydrophilidae | <i>Hydrophilus olivaceus</i> Fabricius, 1781 | - | + | - | + |
| | | <i>Sternolophus rufipes</i> (Fabricius, 1792) | - | + | - | - |
| | | <i>Tropisternus lateralis</i> (Fabricius, 1775) | - | + | - | + |
| Diptera | Culicidae | <i>Aedes albopictus</i> (Skuse, 1894) | + | + | + | + |
| | | <i>Culex sp.</i> | + | + | + | + |
| | Chironmidae | <i>Chironomus sp.</i> | + | + | + | + |

Among the four freshwater sampling sites, Site 2 exhibited the highest relative abundance of aquatic entomofauna, comprising 65% of the total recorded individuals as shown in figure 2. Site 4 contributed 22% to the overall abundance,

indicating a moderately diverse entomofaunal presence. Site 3 accounted for 9%, while Site 1 registered the lowest share at just 4%, reflecting comparatively limited entomofauna populations.

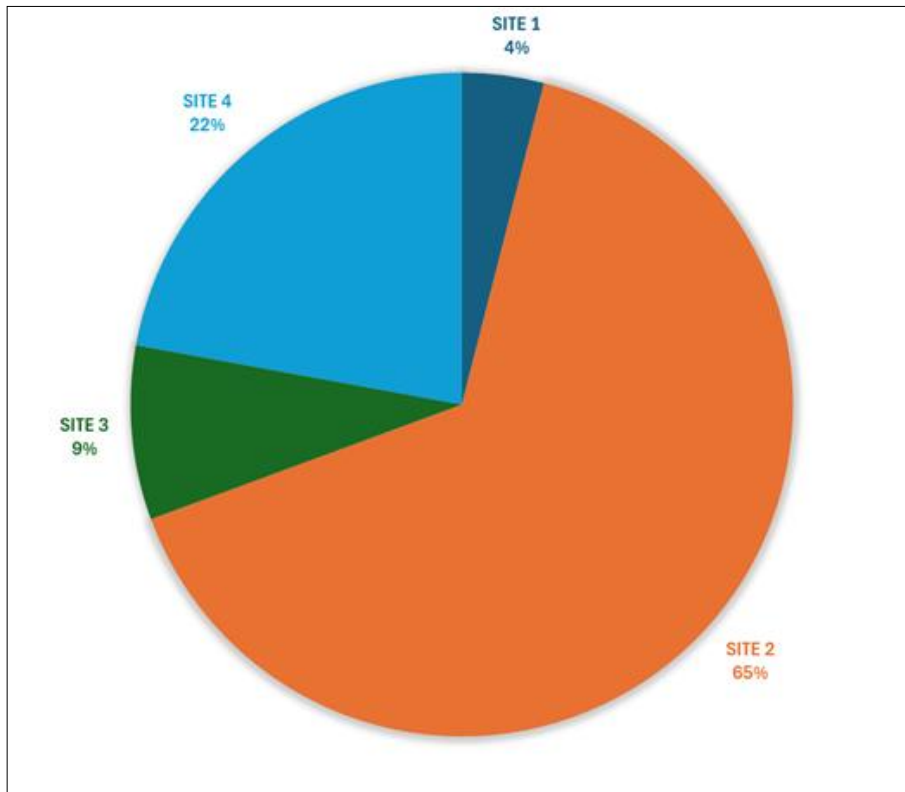


Fig 2: Relative abundance (%) of aquatic entomofauna across four freshwater sampling sites.

The distribution of aquatic entomofaunal families across the four freshwater sampling sites revealed distinct spatial variations in relative abundance as mentioned in figure 3. Most families showed a dominant presence at Site 2, suggesting that this location provides favorable ecological conditions for a wide range of taxa. Families such as Aeshnidae, Coenagrionidae, Notonectidae, Dytiscidae, and Hydrophilidae were almost exclusively represented at Site 2. Libellulidae, Gerridae, and Chironomidae demonstrated

broader distribution, with noticeable representation across all sites, though still highest at Site 2 and Site 4. In contrast, families like Corixidae and Belostomatidae exhibited a more balanced distribution between Sites 2 and 4. Chironomidae and Culicidae were the only families showing considerable contributions from Site 1 and Site 3, highlighting their adaptability to variable or possibly degraded environmental conditions.

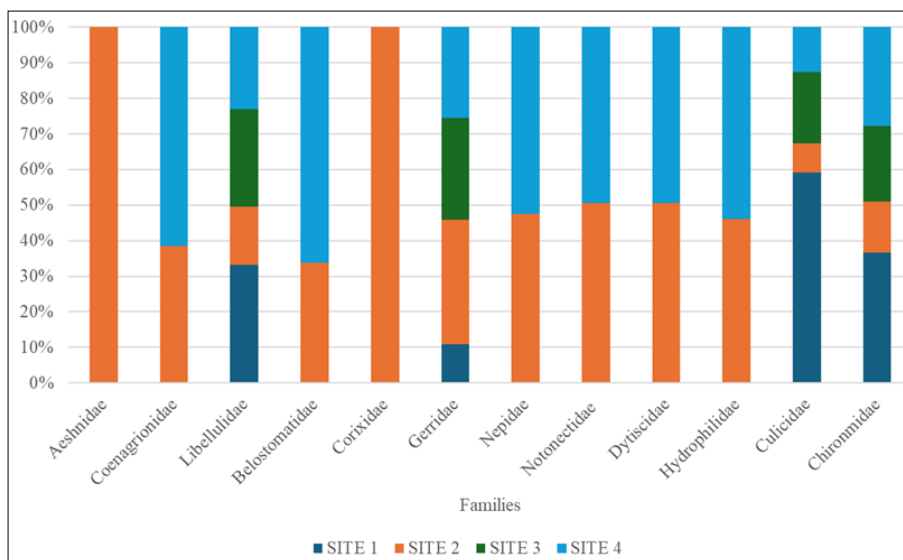


Fig 3: Relative abundance (%) of aquatic entomofauna families across four freshwater sampling sites.

The chord diagram (figure 4) revealed intricate patterns of association between aquatic entomofaunaspecies and the four freshwater sampling sites, highlighting both species dominance and site-specific richness. Site 2 displayed the

strongest connectivity, with thick chords linking it to a wide array of species, most notably *Limnogonus forrorum*, *Limnogonus nitidus*, and *Chironomus sp.*, indicating its role as a biodiversity hotspot. Site 4 exhibited moderate

associations, particularly with species like *Aquarius adalaidis* and members of the Coenagrionidae and Libellulidae families, suggesting favorable yet slightly less diverse conditions. Site 3 maintained limited but distinct

linkages with a few dominant taxa, while Site 1 showed minimal species associations, confined mainly to *Chironomus sp.* and *Culex sp.*, reflecting its relatively low ecological diversity.

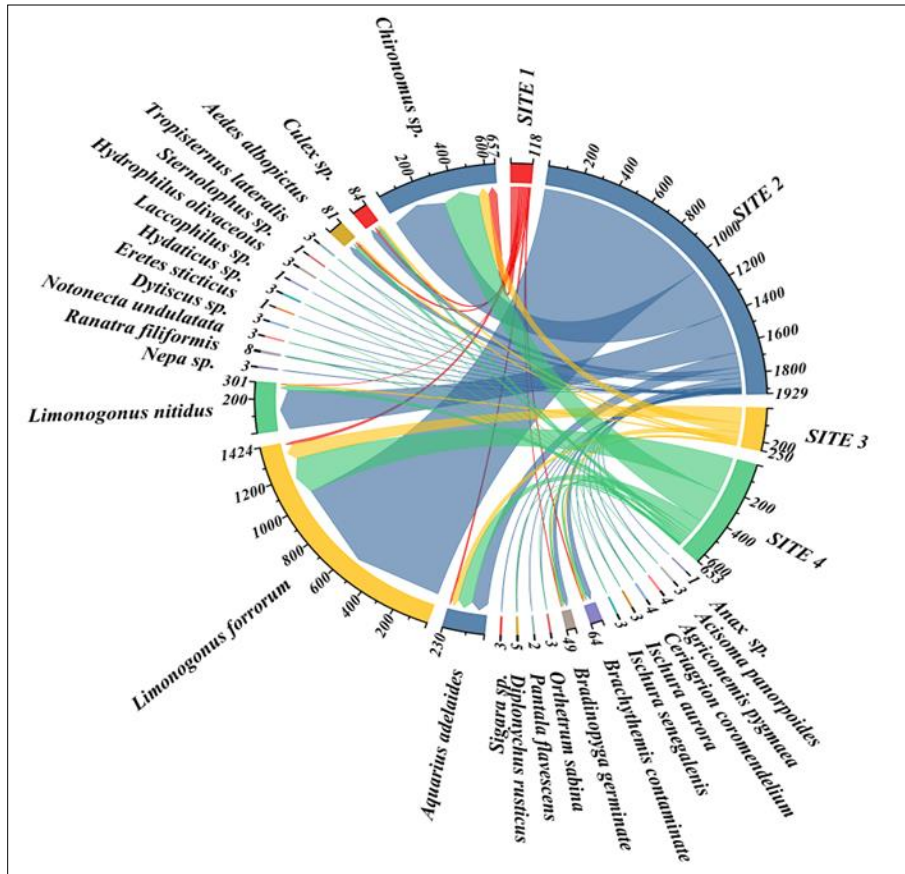


Fig 4: The chord diagram illustrates the abundance-based relationships between aquatic entomofauna species and four sampling sites.

Based on Bray-Curtis similarity analysis of species composition, distinct patterns of community structure were observed among the four freshwater sampling sites, as illustrated in Figure 5. Sites 2 and 4 exhibited the highest degree of resemblance in their aquatic entomofaunal

communities, clustering closely together in the dendrogram. In contrast, Sites 1 and 3 formed a distinct cluster, indicating a different but internally consistent community structure.

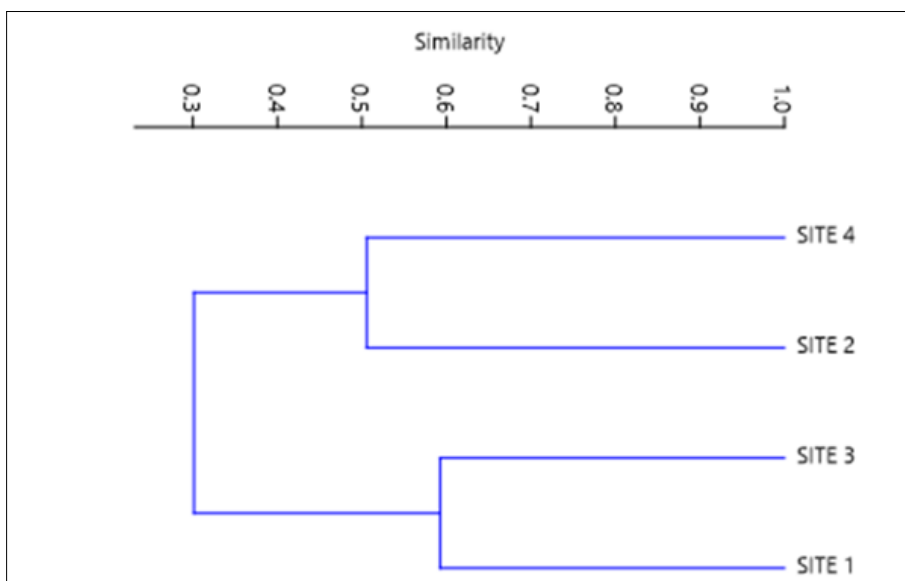


Fig 5: Cluster dendrogram showing the similarity in aquatic entomofauna community composition among the four freshwater sampling sites

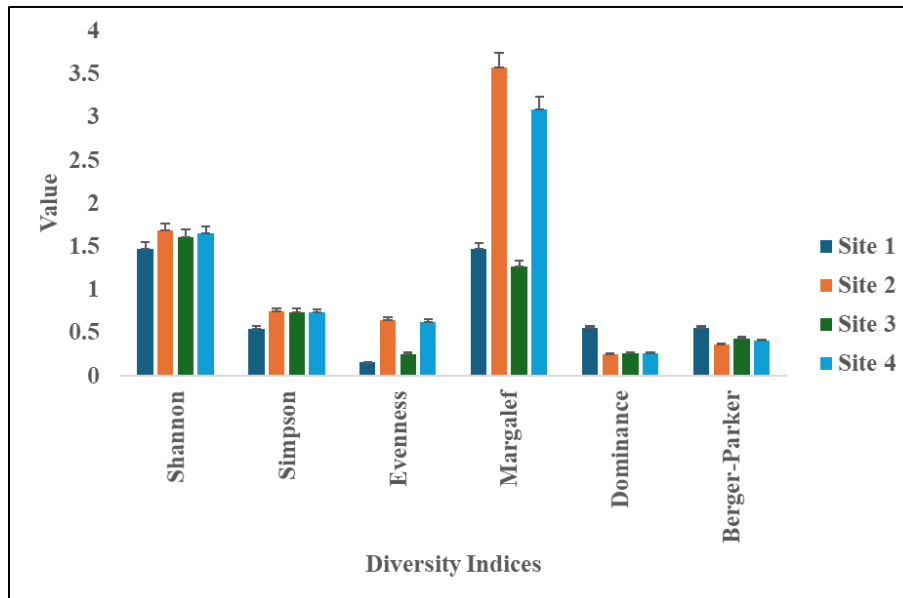


Fig 6: Comparative analysis of biodiversity indices across four study sites (SITE 1 to SITE 4), including Dominance (D), Simpson's Index (1-D), Shannon Index (H), Evenness (e^H/S), Margalef, and Berger-Parker indices.

The comparative analysis of diversity indices across the four sampling sites in Man Sagar Lake revealed distinct patterns in aquatic entomofaunal community structure. Site 2 exhibited the highest overall biodiversity, with a Shannon index of 1.682 ± 0.084 , Simpson index of 0.7472 ± 0.037 , and the greatest Evenness (0.6489 ± 0.032). It also recorded the highest Margalef index (3.569 ± 0.178), along with the lowest dominance values: Dominance_D = 0.2528 ± 0.013 and Berger-Parker = 0.3614 ± 0.018 . Site 4 showed similarly high diversity, with a Shannon index of 1.647 ± 0.082 , Simpson index of 0.7383 ± 0.037 , Evenness of 0.6269 ± 0.031 , and a Margalef index of 3.086 ± 0.154 . Dominance remained low with Dominance_D = 0.2617 ± 0.013 and Berger-Parker = 0.4040 ± 0.020 .

Site 3 recorded moderate diversity, with a Shannon index of 1.612 ± 0.081 , Simpson index of 0.7413 ± 0.037 , and Evenness = 0.2559 ± 0.013 . It had lower species richness (Margalef = 1.268 ± 0.063) and moderately low dominance values (Dominance_D = 0.2587 ± 0.013 , Berger-Parker = 0.4322 ± 0.022). In contrast, Site 1 displayed consistently low diversity values across all indices: Shannon index = 1.476 ± 0.074 , Simpson index = 0.5416 ± 0.032 , Evenness = 0.1562 ± 0.008 , and Margalef = 1.467 ± 0.073 . It exhibited the highest dominance among all sites with Dominance_D = 0.5584 ± 0.018 and Berger-Parker = 0.5547 ± 0.028 .

Discussion

The spatial distribution of aquatic entomofaunal species across the four freshwater sampling sites in Man Sagar Lake revealed marked heterogeneity, underscoring the influence of site-specific ecological conditions, habitat complexity, and level of anthropogenic impact on community assembly. Odonata, a widely studied bioindicator order, showed moderate representation overall, with Coenagrionidae and Libellulidae taxa such as *Brachythemis contaminata*, *Bradinopyga geminata*, and *Orthetrum sabina* recorded at multiple sites. These species were recognized for their tolerance to a broad range of environmental conditions, often persisting in semi-urban aquatic habitats (Roy & Homechaudhuri, 2017) [32]. However, the presence of Aeshnidae at Site 2, a family typically associated with clean,

oxygen-rich, and well-vegetated lentic environments, served as a strong bioindicator of favorable physicochemical conditions and minimal ecological disturbance at this site (Mukherjee & Mandal, 2024) [24].

Among Hemipterans, Gerridae family were recorded at all four sites, reinforcing their reputation for wide ecological tolerance across diverse physicochemical conditions. In contrast, Nepidae and Notonectidae showed restricted distributions, primarily inhabiting the structurally complex habitats of Site 2. This observation aligns with findings from other Indian lentic systems, where these families are sensitive to vegetation heterogeneity and substrate complexity (Naz & Saxena, 2025) [28].

The Coleopteran families, particularly members of *Dytiscidae* and *Hydrophilidae*, were confined to Sites 2 and 4. These beetles were generally associated with structurally complex, oxygen-rich, and ecologically stable aquatic environments. Their absence in Sites 1 and 3 likely reflected habitat degradation and elevated anthropogenic pressures. Sharma and Behera (2022) [33] documented similar assemblages' beetle families in the Upper Ganga Basin, where their presence was tightly linked to favorable water quality and low anthropogenic stress.

Dipterans, represented by families such as Chironomidae and Culicidae, were ubiquitous but dominated Sites 1 and 3. These taxa were resilient to degraded water quality and thrive under conditions of low dissolved oxygen, high organic loads, and eutrophication (Abhijna & Kumar, 2012) [1]. Their abundance in these sites indicated high ecological stress and confirms the presence of pollution-tolerant communities. Similar dipteran dominance was observed in Vellayani Lake (Abhijna, 2013) [2] and Bakhira Lake's eutrophic zones (Pandey & Chandra, 2015), and in urban lakes of Tripura where Dipterans proliferate under nutrient-enriched, stagnant conditions (Majumder *et al.*, 2013) [21].

Quantitative assessment revealed that Site 2 contributed 65% of the total aquatic insect abundance, identifying it as the ecological hotspot within Man Sagar Lake. This site also exhibited the highest species richness and supporting taxa across Odonata (*Aeshnidae*, *Coenagrionidae*), Hemiptera (*Notonectidae*), and Coleoptera (*Dytiscidae*,

Hydrophilidae). These patterns suggested favourable physicochemical conditions and structural habitat complexity. Similar abundance peaks in stable aquatic environments were also documented in Fateh Sagar Lake, Rajasthan (Naz & Saxena, 2025) [28], and in the lakes of Purba Bardhaman, West Bengal (Mukherjee & Mandal, 2024) [24], where insect richness was closely tied to habitat integrity. Further parallels existed with the freshwater systems of the Western Ghats, where insect assemblages were influenced by physicochemical water quality and hydromorphology (Kubendran & Ramesh, 2016) [20].

Site 4, contributing 22% of total abundance, presented a moderately productive environment. Although less diverse than Site 2, it supported semi-tolerant taxa such as *Libellulidae*, *Gerridae*, and *Notonectidae*. These groups were frequently associated with intermittent ecological disturbances, possibly driven by fluctuating water levels or localized human activity. Comparable patterns were noted in urban lakes of Tripura, where moderate disturbance regimes sustained semi-tolerant assemblages (Majumder *et al.*, 2013) [21]. Additionally, families such as *Corixidae* and *Belostomatidae* were evenly distributed between Sites 2 and 4, reflecting their affinity for habitat heterogeneity, particularly variations in depth and aquatic vegetation, rather than strict physicochemical thresholds.

In contrast, Site 3 exhibited markedly lower abundance (9%) and reduced diversity. The dominance of Dipterans particularly *Chironomus* and *Culex* pointed to environmental stressors such as eutrophication, sedimentation, and organic pollution. This pattern mirrors the degradation observed in lentic water bodies like Vellayani Lake, Kerala (Abhijna, 2013) [2] and the dipteran-rich, low-diversity zones of Bakhira Lake, Uttar Pradesh (Pandey & Chandra, 2015).

Site 1 had the lowest recorded abundance (4%), with an insect assemblage dominated by pollution-tolerant Dipterans such as *Chironomus sp.*, *Culex sp.*, and *Aedes albopictus* and a stark absence of sensitive taxa. This site represented a highly degraded ecosystem characterized by organic contamination, nutrient enrichment, and habitat fragmentation. These findings are consistent with reports from nutrient-overloaded urban lakes in India, where Dipteran prevalence were symptomatic of poor ecological conditions (Musani *et al.*, 2021) [26]. Similar assemblage patterns were recorded in semi-urban freshwater streams of Uttar Pradesh and the Western Ghats, where Diptera dominated under low-quality water conditions (De *et al.*, 2021; Harinagaraj & Joseph, 2024) [16, 17].

The chord diagram offers an insightful visualization of the relationships between aquatic entomofaunal species and the four freshwater sampling sites in Man Sagar Lake. Site 2 emerged as the most ecologically significant node, forming strong associations with a wide range of aquatic insects, including *Limnogonus forrorum*, *L. nitidus*, and *Chironomus sp.* The dominance of these taxa indicated high habitat heterogeneity, stable hydrological conditions, and a structurally complex environment with submerged vegetation and adequate oxygen levels. Similar biodiversity hotspots was been reported in minimally disturbed wetlands, such as those in Purba Bardhaman, West Bengal, where *Limnogonus* and other *Gerridae* taxa thrived in perennial, low-impact sites (Mukherjee & Mandal, 2024) [24].

Site 4 displayed moderately diverse yet selective associations, particularly with *Aquarius adelaidis* and

members of *Coenagrionidae* (damselflies) and *Libellulidae* (dragonflies). Comparable patterns were observed in Udaipur's Fateh Sagar Lake, where odonate richness reflected water clarity and habitat openness (Naz & Saxena, 2025) [28], and in Kashmir Valley, where odonate assemblages were structured by gradients in vegetation and elevation (Dar *et al.*, 2021) [15]. Site 3 exhibited limited species diversity but displayed distinct associations with dominant and likely stress-tolerant taxa. This mirrors community structures in North Bengal river systems, where intermediate disturbance and nutrient enrichment resulted in simplified but distinct macroinvertebrate assemblages (Roy & Homechaudhuri, 2017) [32].

In contrast, Site 1 had the sparsest species associations, dominated by *Chironomus sp.* and *Culex sp.* classic indicators of poor water quality and eutrophication. These Dipteran taxa thrived in hypoxic, organically polluted habitats and were been documented as dominant fauna in degraded urban freshwater ecosystems, including Vellayani Lake in Kerala (Abhijna *et al.*, 2013) [2] and urban lakes of Tripura (Majumder *et al.*, 2013) [21]. Further corroborating this pattern, Chironomidae and Culicidae dominance was directly linked to organic pollution in Veli-Akkulam Lake (Abhijna & Kumar, 2012) [1].

The Bray–Curtis similarity analysis provided key insights into the ecological structure of aquatic insect communities across the four sampling sites of Man Sagar Lake. Notably, Sites 2 and 4 exhibited the highest similarity, clustering closely due to shared community composition. This clustering aligned with their elevated diversity indices, low dominance, and high evenness, indicating stable, diverse communities likely supported by favorable ecological conditions such as better water quality, structural habitat complexity, and reduced anthropogenic disturbance. These findings resonated with earlier studies from Mysore and Chandrapur, where comparable hydrological and vegetative environments were associated with similar aquatic insect assemblages (Abhilash, 2023; Site, 2013) [3, 35].

Conversely, Sites 1 and 3 formed a distinct cluster, suggesting a shared ecological stress profile despite differing in overall diversity metrics. High dominance at Site 1 and reduced evenness at Site 3 highlighted the prevalence of pollution-tolerant taxa, characteristics of environments subjected to urban runoff, nutrient loading, or habitat alteration. Ecological isolation of Site 1 reflected patterns observed in heavily polluted urban lakes of Udaipur and Indore, where anthropogenic pressures led to reduced richness and community balance (Naz *et al.*, 2021; Sharma *et al.*, 2010) [27, 34]. This biogeographic segregation, revealed through Bray–Curtis similarity, was consistent with studies in various Indian freshwater systems. Majumder *et al.* (2013) [21] demonstrated that lakes in Tripura with similar pollution loads grouped together in community analyses, independent of geographic distance. Similarly, Dar *et al.* (2021) found that in Kashmir Valley, insect community similarity followed habitat quality gradients closely. In Tamil Nadu coastal systems, Balakrishnan *et al.* (2014) [8] reported distinct community clusters shaped by tidal regimes and salinity variations. Roy and Homechaudhuri (2017) [32] further used Bray–Curtis matrices in North Bengal to show strong correlations between macroinvertebrate distribution patterns and environmental gradients.

The comparative analysis of aquatic entomofaunal diversity across four sampling sites in Man Sagar Lake revealed significant spatial variation in community structure, biodiversity, and ecological health indicators. Among all sites, Site 2 emerged as the most biodiverse, exhibiting the highest values across Shannon, Simpson, Evenness, and Margalef indices. This suggested a relatively stable and equitable ecosystem with low dominance, indicating minimal anthropogenic disturbance and suitable habitat complexity. Site 4, with slightly lower but still elevated diversity indices, supported this trend, hinting at similar ecological conditions, potentially buffered from intense pollution or habitat degradation. In contrast, Site 1 had low biodiversity and high dominance indices pointing to environmental stress, possibly due to eutrophication, domestic waste influx, or shoreline alteration. These findings aligned with other regional studies. A comparative study on Lake Pichhola in Udaipur revealed similar trends where areas with better water quality and lesser anthropogenic pressure showed significantly higher Shannon and Margalef indices, emphasizing the impact of habitat quality on insect diversity (Naz *et al.*, 2021) [27]. Additionally, in Fateh Sagar Lake, Udaipur, diversity was highest in less polluted sites, confirming the sensitivity of aquatic insects to chemical and physical parameters of water (Naz & Saxena, 2025) [28].

The observed diversity patterns in Man Sagar Lake also mirrored studies across other Indian states. In the Jedarpalayam Dam of Tamil Nadu, high Shannon and Margalef values were found in clean, stable habitats, while disturbed areas recorded reduced diversity and evenness (Murugesan *et al.*, 2020) [25]. Similarly, in Guwahati, Assam, moderately disturbed ponds exhibited intermediate Shannon and Simpson indices, comparable to Site 3 of Man Sagar Lake (Hasan *et al.*, 2016) [18]. In Kerala, relatively pristine sections of Vellayani Lake exhibited higher diversity indices compared to degraded zones, paralleling the dominance and low evenness observed at Site 1 (Abhijna *et al.*, 2013) [2]. The Kodiveri Dam in Tamil Nadu also revealed high Simpson and Margalef values in low-impact zones (Raj *et al.*, 2022) [30]. In contrast, a study in West Bengal demonstrated that aquatic habitats with high dominance had extremely low Simpson values, reflecting the type of ecological imbalance found at Site 1 (Mallick & Ghorai, 2024) [22].

Site 3, though showing moderate Shannon and Simpson indices, had low Evenness, possibly reflecting dominance by a few tolerant taxa amidst habitat heterogeneity. This intermediate condition was also commonly observed in ecotones or semi-disturbed areas. Collectively, these observations reinforced that aquatic insect diversity is a sensitive and reliable proxy for freshwater ecosystem health, governed strongly by pollution gradients, habitat complexity, and anthropogenic interference.

The entomofaunal composition and abundance patterns across Man Sagar Lake illustrate the strong influence of ecological integrity on aquatic insect communities. Sensitive families such as *Aeshnidae*, *Dytiscidae*, and *Notonectidae* were restricted to stable, vegetated, oxygen-rich sites, while Dipterans families such as *Chironomidae* and *Culicidae* were widespread in ecologically impaired zones. The diversity patterns of aquatic entomofauna across the four sites of Man Sagar Lake revealed pronounced spatial heterogeneity shaped by habitat complexity,

physicochemical parameters, and varying degrees of anthropogenic influence. Site 2 stood out as the most species-rich and ecologically balanced area, reflected in its high diversity indices and presence of sensitive taxa. In contrast, Sites 1 and 3 were characterized by low richness, high dominance, and the prevalence of pollution-tolerant species, indicating environmental stress and habitat degradation. Site 4 represented an intermediate condition, supporting a mix of generalist and moderately sensitive taxa. These findings are consistent with broader ecological patterns observed in Indian freshwater systems, reaffirming the strong link between habitat quality and aquatic insect diversity. The results contributed meaningful baseline data for future diversity assessments and conservation planning in urban lake ecosystems.

Conclusion

This study underscores the spatial heterogeneity and ecological relevance of aquatic insect communities across four distinct sites in Man Sagar Lake, Jaipur. The presence of 28 species and 12 insect families spanning four major orders revealed distinct patterns in species richness, relative abundance, and ecological tolerance. Site 2 emerged as the most ecologically stable and biodiverse zone, exhibiting the highest values across all diversity indices (Shannon, Simpson, Margalef) and supporting a broad spectrum of sensitive taxa such as *Aeshnidae*, *Coenagrionidae*, and *Dytiscidae*. Conversely, Site 1, characterized by low species richness, high dominance, and prevalence of pollution-tolerant dipterans like *Chironomus* and *Culex*, reflected significant ecological degradation.

Multivariate analyses (Bray–Curtis similarity and chord diagrams) corroborated these findings by highlighting strong species-site associations and ecological clustering. Sites 2 and 4 shared a closely related community structure, while Sites 1 and 3 grouped separately, indicative of shared environmental stressors. Diversity indices not only quantified community evenness and dominance but also serves as complementary tools for assessing biological integrity.

Overall, the study confirms the utility of aquatic insects as effective bioindicators of habitat quality, especially in urban freshwater ecosystems. Their distributional patterns, coupled with diversity metrics, provide critical insights into the ecological health and anthropogenic stress gradients within Man Sagar Lake. These findings establish a strong baseline for future monitoring, urban lake restoration strategies, and biodiversity conservation planning in semi-arid urban landscapes.

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