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Influence of soil physicochemical properties on diversity and distribution of aquatic vegetation in the riverine forested habitats

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Abstract
The riverine flora is one of the most dynamic aspects of a landscape, and it encompasses species which are adapted and specialised to grow in a range of environmental conditions. An ecological analysis was conducted to describe the phyto-sociological and floristic structure of the plant species in the riverine forest at Balloki along moisture gradients caused by river bank. A random quadrat method with a quadrat size of 1 × 1 m was used for sampling of the riverine site. All plant species growing in the riverine habitats were collected and identified. A detailed survey was conducted to record the ecological attributes such as density, frequency, cover, and importance value. These values were then used to calculate the relative values of the ecological indicators. The ecological indicators were correlated with various soil physical parameters (soil texture, moisture contents and saturation percentage), chemical properties (ECe and pH), and nutrients (Na, Ca, K and N). Most of the species were linked to sites 3 and 4 with high moisture content, low ECe, acidic pH and moderate nutrient composition. The species with the highest ecological importance were *Cynodon dactylon*, *Rumex dentatus* and *Saccharum spontaneum* which accounted for more than 80% of the total abundance. It was concluded that species distribution differed significantly along the four study sites mainly depending on the soil physicochemical features of the study sites.

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Introduction

Riverine systems serve as transitional zones between terrestrial and aquatic ecosystems, forming interconnected networks across these landscapes. These areas hold significant socio-biological, ecological and economic importance (Bibi et al., 2021). They encompass a spectrum of environments, ranging from intricate stream networks to the fluctuating water level of adjacent riverbanks. Here, vegetation can experience fluctuations between flooding and drought conditions, and hence, need to be highly adaptive to these environments (Naiman and Décamps, 1997; Nilsson and Swedmark, 2002; Dunlop et al., 2005; Leigh et al., 2015). The soils found within the riverine forests typically have elevated mineral content, although some deeper sites and wet regions might have limited accumulation of peat (Giese et al., 2000). In Pakistan, particularly in District Kasur, Punjab, there exists a riverine site called Balloki. Its precise geographical coordinates are 31°22'25" North and 73°86'40" East. The district's natural surface elevation is 195 m above sea level, featuring a general slope from the northeast to the southwest. Balloki is fed by the flow of River Ravi, resulting in a region abundant with diverse vegetation (Akmal et al., 2014).

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Plant communities reflect underlying environmental conditions and act as indicators of the biological resources present in the habitat (Akbar and Arshad, 2000). Within terrestrial biodiversity, these forest ecosystems play a crucial role (Carnus et al., 2006). The diversity of plant communities is predominantly influenced by water resources, edaphic conditions, and climatic factors (Hegazy et al., 2007; Leigh et al., 2015). Among these, edaphic factors play a primary role in shaping both community structure and distribution of plants (Kluse and Allen-Diaz, 2005). Each plant species has specific habitat requirements, leading to variations in species distribution, diversity, coverage, and richness, particularly in relation to the steepness of slopes and other environmental gradients (Uniyal et al., 2006).

Within the ecosystem of riverine forests, plant species encounter a range of natural disruptions like floods, waterlogging and rarely limited water supplies due to altered water flow in rivers. These disturbances, coupled with abiotic stresses, have a significant impact on biodiversity (Ferreira and Stohlgren, 1999; Weiher, 2003). In response, plant species adopt various survival strategies, including adaptations in morphology, structure, physiology, and timing of reproductive and vegetative phases. These adaptations contribute to the diversity of plant species in these habitats (Budke et al., 2010). The seasonal flooding patterns in these forest areas bring about a cyclic shift between aerobic and anaerobic soil conditions. This alternation facilitates numerous biochemical and nutrient cycling processes, such as nitrification, denitrification, ammonification, methanogenesis, sulfate reduction, and overall nutrient mineralization (Thayer et al., 2005). Notably, these processes are distinct from those occurring in upland forests (Wharton et al., 1982). These biochemical actions lead to either enhance the nutrient availability for direct absorption within a forest or the conversion of nutrients into biologically inactive forms. In both scenarios, the quality of downstream water remains safeguarded, as long as human-induced inputs do not suppress the system. As an instance, nitrates (NO_3) present in water or soil can be assimilated by plants, transformed into nitrites (NO_2) by microorganisms, or remain bound to sediments (Walbridge, 1993). The pivotal capacity of riverine forests to function as nutrient transformers, preserving the quality of downstream water within reasonable bounds, could be perceived as their most invaluable role for ecology and society (Walbridge, 1993; Wang et al., 2018; Weigelhofer et al., 2018).

Floodplain flora additionally impacts the movement of water and the quality of water. As floodwaters extend into the more wooded area, the speed of the water reduces and slows down herein. Soil particles and nutrients settle onto this forest ground. A higher density of plants can enhance this outcome by more effectively slowing down water speed (Bedient and Huber, 1992). Plant life with herbaceous qualities also boosts moisture levels in the upper layers of soil by providing shade to the surface and by drawing water upwards from deeper soil layers through rhizomes' capillary action (Tabacchi et al., 2000). Vegetation, woodier in nature, can enhance the soil's hydraulic conductivity via root growth and decay (Thorne, 1990). The influence of floodplain vegetation on water-related processes changes depending on the kind, vitality, and irregularity of plant communities, as well as the duration for which these communities have been able to modify soil traits. Ultimately, these soil and atmospheric conditions impact the variety and distribution of plants in these areas abundant in diversity (Rolls et al., 2012; Zeiringer et al., 2018).

It was hypothesized that the diverse soil and atmospheric conditions should have supported rich plant biodiversity and phytology of the study area. Thus, the primary objective of the current study was whether or not species distribution differed significantly along the four study sites depending on the soil-physicochemical features of the study sites. The information collected in this study can be utilized to chalk out plans for management of these natural riverine plains.

Materials and Methods

Study site

The objective of this project was to eco-physiologically analyze the vegetation found in the riverine forest at Balloki located in the Nankana Sahib District of Punjab, Pakistan. Here, at Balloki, a head barrage system is maintained by the Irrigation Department that splits the main flow of the Ravi River into a number of major canals used for irrigation. Due to blockage of water at the head, a massive water body is formed. Thick riverine forest develops here housing a rich diversity of flora that supports a variety of fauna including waterfowl and sometimes endangered migratory birds.

Sampling method

To achieve this goal, four distinct locations were chosen in the summer season (May to August) of the year 2021; each site was situated 50 meters apart. Within each of these study sites, five separate quadrats were delineated with a 2-m gap between them (**Figure 1**). Plant specimens were collected from these quadrats for the purpose of identification and then affixed onto herbarium sheets. Following the drying process, these plant samples were identified by the Flora of Pakistan. The specimens were subsequently added to the herbarium collection belonging to the Department of Botany, University of Agriculture, Faisalabad, and voucher numbers were assigned to each plant species (**Table 1**). Ecological data encompassing measurements such as density, cover, frequency, relative density, relative frequency, relative cover, and importance value was measured. These measurements were calculated using the formulae outlined by Reynolds and Ludwig (1988).

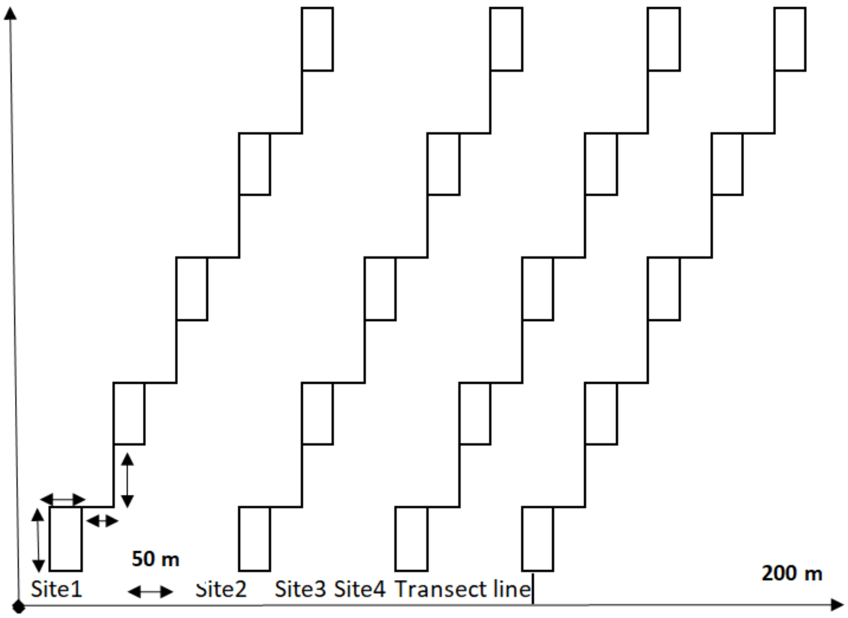

Figure 1. Sampling layout of vegetation of transect and placement of quadrats

Soil analysis

A soil borer was used to gather soil samples at a depth of 30 cm in 5 replicates. Soil texture was determined through the application of the soil textural triangle technique (Shirazi and Boersma, 1984). The moisture content of the soil was determined using the Schmugge et al. (1980) method. A soil saturation paste was prepared using a vacuum filtration apparatus. The electrical conductivity (ECe) and pH of the soil extract were determined using pH and EC meters (WTW series InoLab pH/Cond 720, USA). The analysis of soil nutrient composition followed the Wolf's sulphuric acid-hydrogen peroxide method (Wolf, 1982) involving the acid digestion technique. Sodium (Na^+), potassium (K^+), and calcium (Ca^{2+}) levels were assessed using a flame photometer (Jenway, PFP7, Japan). Nitrogen contents were evaluated through the micro-Kjeldahl method (Bremner, 1965).

Ecological analysis of the vegetation

The quadrat sampling technique was used to measure ecological data. Five quadrats, each measuring 1 x 1 m, were established at four distinct locations spaced at 2 x 2 m apart. Within these quadrats, data were documented for computation of various ecological indicators such as density, frequency, cover, relative density, relative frequency, relative cover, and importance value, utilizing the relevant formulae.

Table 1. List of species inhabiting the riverine forest at different sites in Balloki, Pakistan

Abb.	Species	Abb.	Species	Abb.	Species
Ase	*Alternanthera sessilis*	Iar	*Indigofera argentea*	Ppl	*Polygonum plebeium*
Ado	*Arundo donax*	Ica	*Ipomoea carnea*	Pcr	*Pulicaria crispa*
Bre	*Brachiaria reptans*	Ktr	*Kyllinga triceps*	Rsc	*Ranunculus sceleratus*
Bca	*Brassica campestris*	Lap	*Lathyrus aphaca*	Rde	*Rumex dentatus*
Cdi	*Coronopus didymus*	Mla	*Medicago laciniata*	Sbe	*Saccharum bengalense*
Cda	*Cynodon dactylon*	Min	*Melilotus indica*	Ssp	*Saccharum spontaneum*
Cex	*Cyperus exaltatus*	N	*Naphalium* spp.	Sla	*Schoenoplectus lacustris*
Dbi	*Desmostachya bipinnata*	Oco	*Oxalis corniculata*	Tap	*Tamarix aphylla*
Eal	*Eclipta alba*	Pka	*Phragmites karka*	Tal	*Trifolium alexandrinum*
Ecr	*Eichhornia crassipes*	Pno	*Phyla nodiflora*	Tre	*Trifolium resupinatum*
Eci	*Eragrostis ciliaris*	Pst	*Pistia stratiotes*	Tdo	*Typha domingensis*
Gsp	*Gnaphalium spathulatum*	Pba	*Polygonum barbatum*	Vci	*Vernonia cinerea*
Heu	*Heliotropium europaeum*	Pgl	*Polygonum glabrum*		
Icy	*Imperata cylindrica*	Pmo	*Polygonum monspeliensis*		

Statistical analysis

The data was analyzed using the multivariate analysis. A canonical correspondence analysis (CCA) was run by keeping sites (independent factors) affecting the distribution of different plant species (dependent factors). The CCA was run using Canoco for Windows software (v. 4.56, Biometris, The Netherlands). The visualization of CCA graphs was done in CanoDraw for Windows (v 4.14).

Results

Soil analysis

The soil texture of the study sites varied from clay at site 4 to clay loam at site 3 (**Table 2**). The soil moisture was the maximum (62.16%) at site 4 and the minimum (28.16%) at site 1, away from the main river. The same trend was observed for soil saturation percentage. The soil pH was acidic at all study sites possibly due to high soil moisture conditions or partially/fully waterlogged conditions. It ranged from 6.9 at site 2 to the most acidic 6.1 at site 4. Moreover, the soil was non-saline at all sites with ECe ranging from 1.1 dS m^{-1} at site 4 to 1.34 dS m^{-1} at site 2. Accordingly, soil Na^+ varied from 8.06 mg kg^{-1} dry soil at site 4 to 13.62 mg kg^{-1} dry soil at site 3. Soil K^+ was the maximum at site 3 (3.84 mg kg^{-1} dry soil) and the minimum at site 2 (1.61 mg kg^{-1} dry soil). Soil K^+ and Ca^{2+} were the maximum at site 3 (3.84 mg kg^{-1} dry soil and 8.15 mg kg^{-1} dry soil, respectively) and the minimum at site 2 (1.61 mg kg^{-1} dry soil and 7.13 mg kg^{-1} dry soil, respectively). Soil total N was the maximum at site 3 (2.83 mg kg^{-1} dry soil) but the minimum (1.13 mg kg^{-1} dry soil) was at site 4, possibly due to waterlogged soil conditions (**Table 2**).

Table 2. Soil characteristics of the riverine forest located at Balloki

Soil Characteristics	Site 1	Site 2	Site 3	Site 4	LSD	*P* values
Soil texture	Sandy loam	Loam	Clay loam	Clay	-	-
Moisture content (%)	28.16^c	30.12^b	33.6^b	42.16^a	3.72	**
Soil saturation (%)	25.86^d	28.56^c	30.74^b	33.12^a	1.34	***
Soil ECe (dS m^{-1})	1.2	1.34	1.28	1.1	-	ns
Soil pH	6.7^b	6.9^a	6.3^c	6.1^d	0.11	***
Na^+ (mg kg^{-1} dry soil)	9.05^b	11.16^b	13.62^a	8.06^c	1.59	**
K^+ (mg kg^{-1} dry soil)	2.62	1.61	3.84	2.11	-	ns
Ca^{2+} (mg kg^{-1} dry soil)	7.34	7.13	8.15	6.45	-	ns
Total N (mg kg^{-1} dry soil)	2.66^b	1.14^c	2.83^a	1.13^c	0.13	**

*: significant at $P < 0.05$, **: significant at $P < 0.01$, ***: significant at $P < 0.001$, ns: non-significant. Means sharing similar letters are statistically not significant.

Vegetation composition and community structure

The vegetation type of the study area included aquatic, semi-aquatic and partially terrestrial species (**Figure 2**). The most dominant species based on species architecture, number and high ecological impact included *Cynodon dactylon*, *Rumex dentatus* and *Saccharum spontaneum*. Three most abundant species occurring at four sites but with less ecological impact than dominant species included *Imperata cylindrica*, *Polygonum monspeliensis*, *Typha domingensis*. Five species were categorized as frequently occurring at three sites (*Alternanthera sessilis*, *Eichhornia crassipes*, *Phragmites karka*, *Polygonum barbatum*, *Trifolium alexandrinum*). Among others, 8 species were classified as occasional (found at two sites) and 14 as rare (found only at one site with IV ≥ 5). Seven species were categorized as extremely rare found only at one site with IV ≤ 5. Two grasses, i.e., *Desmostachya bipinnata* (IV 2.2) and *Eragrostis ciliaris* (IV 2.86) and a dicot *Melilotus indica* (IV 2.52) had the least importance value (**Table 3**).

Ecological analysis

The canonical correspondence analysis (CCA) of data (**Figure 3**) showed that the density and relative density of different plant species were associated with different sites of the riverine forest. The species associated with site 1 were *Rumex dentatus* (Rde), *Saccharum bengalense* (Sbe), *Polygonum glabrum* (Pgl), *Brachiaria reptans* (Bre) *and Naphalium* spp. (N). The species associated with site 2 were *Desmostachya bipinnata* (Dbi)*,* *Vernonia cinerea* (Vci), *Trifolium resupinatum* (Tre), *Pistia stratiotes* (Pst), *Schoenoplectus lacustris* (Sla) and *Imperata cylindrica* (Icy). The species associated with site 3 were *Eragrostis ciliaris* (Eci), *Tamarix aphylla* (Tap), *Ranunculus sceleratus* (Rsc), *Ipomoea carnea* (Ica) and *Typha domingensis* (Tdo) and those associated with site 4 were *Phyla nodiflora* (Pno), *Gnaphalium spathulatum* (Gsp), *Indigofera argentea* (Iar), *Kyllinga triceps* (Ktr), *Polygonum monspeliensis* (Pmo), and *Heliotropium europaeum* (Heu).

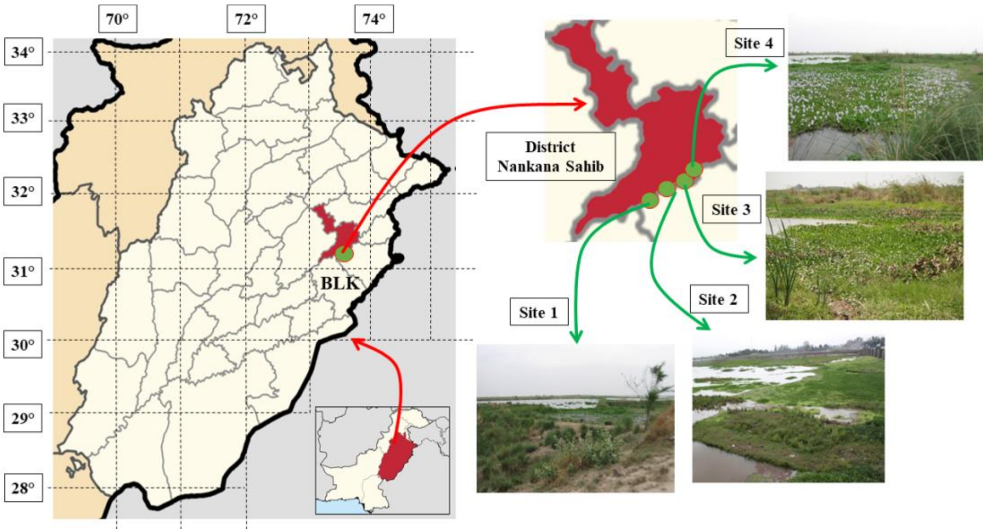

Figure 2. Location of the study site along with pictorial view of vegetation structure at all four sampling points (BLK = Balloki Site)

Table 3. Occurrence, species distribution and ecological role determined from relative importance value.

Species	Abbr.	Site 1	Site 2	Site 3	Site 4	Abundance
Alternanthera sessilis	Ase	-	10.51	15.53	12.88	Frequent
Arundo donax	Ado	-	-	10.15	3.52	Occasional
Brachiaria reptans	Bre	6.08	-	-	-	Rare
brassica campestris	Bca	5.02	-	-	17.54	Occasional
coronopus didymus	Cdi	13.03	-	-	5.34	Occasional
Cynodon dactylon	Cda	73.15	118.35	97.62	40.95	Dominant
Cyperus exaltatus	Cex	-	-	-	31.82	Rare
Desmostachya bipinnata	Dbi	-	2.2	-	-	Extremely Rare
Eclipta alba	Eal	8.41	-	-	-	Rare
Eichhornia crassipes	Ecr	5.02	-	23.53	11.82	Frequent
Eragrostis ciliaris	Eci	-	-	2.86	-	Extremely Rare
Gnaphalium spathiolatum	Gsp	0	0	0	11.92	Rare
Heliotropium europaeum	Heu	-	-	-	4.48	Extremely Rare
Imperata cylindrica	Icy	3.39	21.2	5.38	4.48	Abundant
Indigofera argentea	Iar	-	-	-	8.29	Rare
ipomoea carnea	Ica	-	-	5.38	-	Rare
kyllinga triceps	Ktr	-	-	-	12.88	Rare
Lathyrus aphaca	Lap	-	-	4.77	-	Extremely Rare
Medicago laciniata	Mla	5.49	-	-	21.35	Occasional
Melilotus indica	Min	-	-	2.52	-	Extremely Rare
Naphalium spp.	N	3.39	-	-	-	Extremely Rare
oxalis corniculata	Oco	4.43	13.76	-	-	Occasional
Phragmites karka	Pka	9.57	-	8.24	4.46	Frequent
phyla nodiflora	Pno	-	-	-	9.42	Rare
Pistia stratiotes	Pst	-	10.78	-	-	Rare
Polygonum barbatum	Pba	26.98	25.82	-	8.23	Frequent
Polygonum glabrum	Pgl	13.43	-	-	-	Rare
Polygonum monspeliensis	Pmo	16.55	12.38	8.29	26.17	Abundant
Polygonum plebeium	Ppl	-	4.1	-	12.78	Occasional
Pulicaria crispa	Pcr	-	-	4.14	10.96	Occasional
ranunculus sceleratus	Rsc	-	-	11.82	-	Rare
Rumex dentatus	Rde	58.45	14.62	40.14	7.33	Dominant
Saccharum bengalense	Sbe	8.88	-	2.52	-	Occasional
Saccharum spontaneum	Ssp	7.59	16.52	4.99	20.49	Dominant
Schoenoplectus lacustris	Sla	-	21.2	-	-	Rare
Tamarix aphylla	Tap	-	-	4.85	-	Rare
Trifolium alexandrinum	Tal	26.14	9.44	24.43	-	Frequent
Trifolium resupinatum	Tre	-	11.22	-	-	Rare
Typha domingensis	Tdo	4.67	4.45	22.97	12.82	Abundant
Vernonia cinerea	Vci	-	4.12	-	-	Extremely Rare

Dominant = The most contributory species based on species architecture, number and high ecological impact; Abundant = Found at four sites but with less ecological impact than dominant species; Frequent = Found at three sites; Occasional = Found at two sites; Rare = Found only at one site with IV ≥ 5; Extremely Rare = Found only at one site with IV ≤ 5. Species not found at particular sites are marked as absent (-).

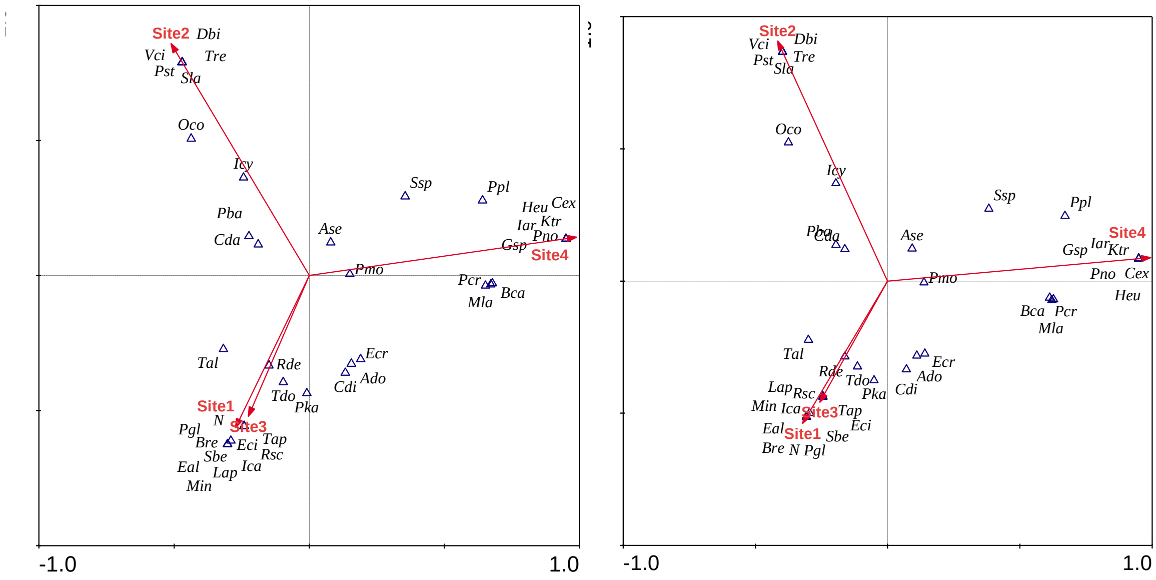

Figure 3. Canonical Correspondence Analysis (CCA) ordination biplot showing the relationship between sites and (a) density and (b) relative density values of plant species located at riverine forest. Please see Table 1 for the list of species and abbreviations.

The canonical correspondence analysis (CCA) performed on the data (**Figure 4**) illustrates the frequency and their relative values of various plant species linked to distinct locations within the riverine forest. Site 1 was characterized by the presence of *Naphalium* spp. (N), *Polygonum glabrum* (Pgl), *Eclipta alba* (Eal), *Saccharum bengalense* (Sbe), *Trifolium alexandrinum* (Tal), *Brachiaria reptans* (Bre), and *Rumex dentatus* (Rde). At site 2, the observed species include *Pistia stratiotes* (Pst), *Schoenoplectus lacustris* (Sla), *Tamarix aphylla* (Tap), *Polygonum barbatum* (Pba), and *Imperata cylindrica* (Icy). Site 3 was characterized by the species such as *Tamarix aphylla* (Tap), *Ranunculus sceleratus* (Rsc), *Eragrostis ciliaris* (Eci), *Melilotus indica* (Min), *Lathyrus aphaca* (Lap), and *Ipomoea carnea* (Ica). Lastly, species like *Phyla nodiflora* (Pno), *Medicago laciniata* (Mla), *Heliotropium europaeum* (Heu), *Brassica campestris* (Bca), *Gnaphalium spathulatum* (Gsp), *Kyllinga triceps* (Ktr), and *Cyperus exaltatus* (Cex) dominated site 4.

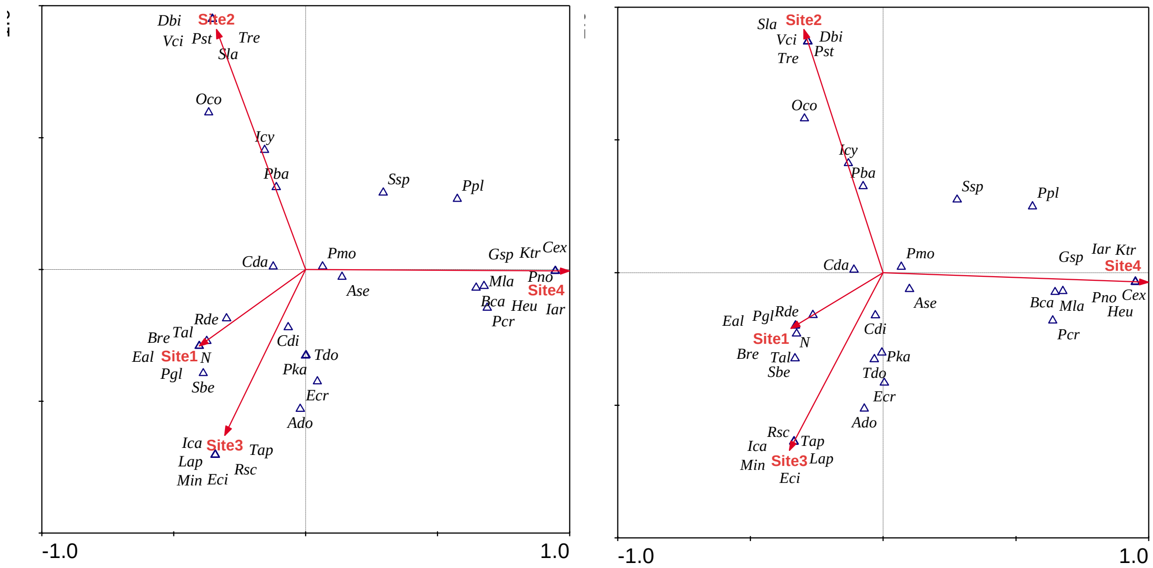

Figure 4. Canonical Correspondence Analysis (CCA) ordination biplot showing the relationship between sites and (a) frequency, and (b) relative frequency values of plant species located at riverine forest. Please see Table 1 for list of species and abbreviations.

The canonical correspondence analysis (CCA) conducted on data for cover (**Figure 5**) revealed a relationship between cover and relative cover of various plant species across distinct sites within the riverine forest. Site 1 exhibited a connection with plant species such as *Polygonum glabrum* (Pgl), *Saccharum bengalense* (Sbe), *Naphalium* (N), *Brachiaria reptans* (Bre), *Eclipta alba* (Eal), and *Polygonum glabrum* (Pgl). Site 2 displayed an association with *Desmostachya bipinnata* (Dbi), *Vernonia cinerea* (Vci), *Schoenoplectus lacustris* (Sla), *Pistia stratiotes* (Pst), and *Trifolium resupinatum* (Tre). The species linked with site 3 were *Melilotus indica* (Min), *Lathyrus aphaca* (Lap), *Ranunculus sceleratus* (Rsc), *Tamarix aphylla* (Tap), *Eragrostis ciliaris* (Eci), *Ipomoea carnea* (Ica), and *Trifolium alexandrinum* (Tal). Lastly, site 4 displayed an association with *Heliotropium europaeum* (Heu), *Indigofera argentea* (Iar), *Kyllinga triceps* (Ktr), *Medicago laciniata* (Mla), *Cyperus exaltatus* (Cex), and *Phyla nodiflora* (Pno).

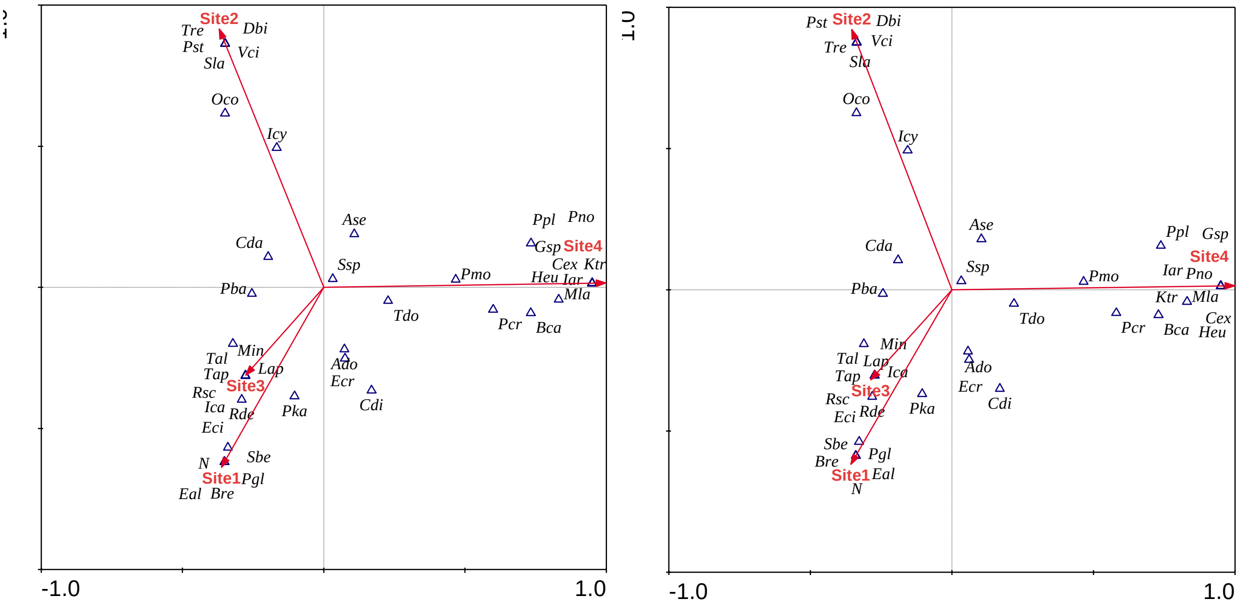

Figure 5. Canonical Correspondence Analysis (CCA) ordination biplot showing the relationship between sites and (a) cover, and (b) relative cover values of plant species located at riverine forest. Please see Table 1 for the list of species and abbreviations.

The canonical correspondence analysis (CCA) performed on importance value data (**Figure 6**) displayed the significance of various plant species linked with distinct areas within the riverine forest. At site 1, the plant species comprised *Polygonum glabrum* (Pgl), *Saccharum bengalene* (Sbe), *Trifolium alexandrinum* (Tal), and *Rumex dentatus* (Rde). Site 2 was characterized by the importance value of *Pistia stratiotes* (Pst), *Trifolium resupinatum* (Tre), *Desmostachya bipinnata* (Dbi), and *Vernonia cinerea* (Vci). The importance value of species linked at site 3 included *Ranunculus sceleratus* (Rsc), *Eragrostis ciliaris* (Eci), *Melilotus indica* (Min), and *Ipomoea carnea* (Ica). Finally, importance value of species at site 4 was characterized by *Phyla nodiflora* (Pno), *Brassica campestris* (Bca), *Kyllinga triceps* (Ktr), and *Cyperus exaltatus* (Cex).

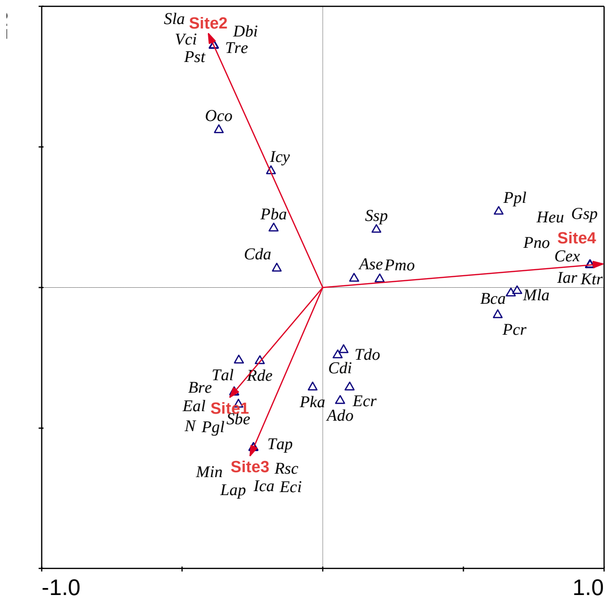

Figure 6. Canonical Correspondence Analysis (CCA) ordination biplot showing the relationship between sites and importance value of plant species located at riverine forest. Please see Table 1 for the list of species and abbreviations.

Discussion

Environmental heterogeneity plays a crucial role in shaping the structure, functioning, and diversity of ecosystems. Such heterogeneity can be classified as either endogenous, occurring repeatedly over long evolutionary timelines, or frequently caused by human activities that lead to irreversible species change and significant changes in the landscape (Mcintyre and Hobbs, 1999; McCluney et al., 2014; Peipoch et al., 2015). On a local scale, the topography of an area is recognized as the most influential abiotic factor driving spatial variations in the structure of riverine forests. This is because topography often correlates with other key environmental factors, including soil properties, groundwater levels, and physico-chemical attributes of the soil (Bourgeron, 1983; Lee et al., 2014; Panda and Mahanta, 2019; Mwamburi et al., 2020). Among the various environmental factors impacting vegetation, the moisture content of the soil stands out as the primary factor influencing plant growth and distribution. Moisture levels in the soil are the primary determinant of this process, as noted by Skarpe (1990) and Laporte et al. (2002). Moreover, soil composition, type, and mineral nutrient content have been extensively studied by multiple researchers for different locations, contributing to the control of vegetation distribution (Smitheman and Perry, 1990; McCluney et al., 2014; Tanaka et al., 2021). The findings from the current study highlight that species with a preference for moist conditions, such as *Cynodon dactylon*, *Polygonum barbatum*, and *Rumex dentatus*, predominantly inhabit sites with higher moisture content.

Vegetation in a riverine forest occurs in permanently or seasonally wet environments. They include a diverse group of macrophytes, aquatic plants including angiosperms, ferns, mosses, liverworts, and some freshwater macroalgae (Tripathi and Singh, 2009). In physico-chemical analysis in the current study, the levels of sodium, potassium, calcium and total N at all sites of the riverine forest were determined. The results indicated that the levels of these nutrients varied significantly among the study sites. These variations along with other soil physical and chemical properties like soil pH, texture, and moisture contents were mainly influenced by the partial or complete waterlogged conditions varying through different seasons (Lim et al., 2016).

The soil of the study sites had a high clay content containing adequate amount of mineral nutrients. In physico-chemical analysis, the major macronutrients like nitrogen (N), phosphorus (P), potassium (K), and calcium (Ca) were determined. The results show that all sites had reasonable amounts of all these nutrients except K, which reflect the capacity of soil to supply mineral nutrients to plants growing therein (Wang et al., 2018). In this research, the level of potassium was found to be adequately low, which could have been due to the flooded condition that might have washed away most of the nutrients, hence, causing nutrient deficiency.

The preceding discussion led to the conclusion that the riverine forest at Balloki harbors a wide variety of plants, exhibiting variations in terms of density, frequency, cover, relative density, relative cover, relative frequency, and importance value. Among all plant species present at the sites, *Cynodon dactylon* and *Rumex dentatus* demonstrated significantly higher values of all these parameters. The variation in the actual and quantitative occurrence of distinct vegetation components across different sites is associated with environmental factors such as the concentration of river salts in the vicinity, the presence of water, the type of substrate, and the degree of exposure (Neves et al., 2017).

Conclusion

The factors influencing the vegetation were primarily linked to the moisture levels in the soil, which played a pivotal role in determining how plants grew and were distributed. These aspects were also influenced by soil composition, types, and the mineral nutrients present in the soil. The variations in the density of species revealed that the majority of species were spread throughout the riverine forest. Notably, this forest exhibited a high field capacity, enabling it to retain more moisture even during dry periods. Among the species, *Cynodon dactylon*, *Rumex dentatus,* and *Saccharum spontaneum* displayed the highest density across all sites, as these species primarily thrived in locations with high moisture content. Additionally, these species were known for their resilience to salt and had a preference for, or moderate requirement of, moisture. In conclusion, the vegetation across different sections of the forest displayed diverse growth and distribution characteristics. Both these aspects were strongly influenced by factors like nutrients, salinity, and pH levels. The species observed around all four sites had a preference for moisture. This emphasizes the significant correlation between the presence of plant species and the availability of moisture and nutrients in the riverine environments.

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Handling of bio-hazardous materials
The authors certify that all experimental materials were handled with care during collection and experimental procedures. After completion of experiment, all materials were properly discarded to minimize any types of bio-contamination(s).

Availability of primary data and materials
As per editorial policy, experimental materials, primary data, or software codes are not submitted to the publisher. These are available with the corresponding author and/or with other author(s) as declared by the corresponding author of this manuscript.

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All authors contributed in designing and writing the entire article. All contributors have critically read this manuscript and agreed for publishing in IJAaEB.

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