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SOIL NUTRIENTS CONTROL THE ECOLOGICAL CHARACTERISTICS OF THE RIPARIAN VEGETATION

SHAKIL AHMAD ZEB[1], ABDULLAH ABDULLAH[1], ZEESHAN AHMAD[1], ZAHOOR UL HAQ[1], SHAHAB ALI[1], TUFAIL AHMAD ZEB[3], RABIA AFZA[4], ISRAR AHMAD[4], TAHIRA JATT[5] AND SHUJAUL MULK KHAN[1,2*]

[1]Department of Plant Science, Quaid-i-Azam University Islamabad, Pakistan
[2]Pakistan Academy of Sciences, Pakistan
[3]Deparment of Botany, University of Peshawar, Pakistan
[4]Department of Botany, Hazara University Mansehra, Pakistan
[5]Department of Botany, Shah Abdul Latif University Khairpur, Sindh Pakistan

*Corresponding author's email: shuja60@gmail.com

Abstract

Evaluating an area's biological spectrum and phenological behavior is crucial for analyzing its vegetation and responses to climatic variations. This study aimed to assess the floral diversity, biological spectrum, and phenological patterns of the riparian vegetation along the river Panjkora. Data was collected using quadrat quantitative ecological techniques. The size of quadrats varied, with 1×1m², 5×5m² and 10×10m² established for herbs, shrubs, and trees, respectively. In total, 163 genera and 215 species were documented. The dominant class was herbs (82%), followed by trees (11%) and shrubs (7%). Asteraceae was the dominant family, comprising 27 plant species. Based on life form spectra, therophytes were the most abundant, with 114 species out of 215, while nanophylls were the most dominant, with 91 species based on leaf spectra. Multivariate statistical analyses, such as canonical correspondence analysis (CCA) and detrended correspondence analysis (DCA), were used to determine relationships among environmental variables (EC, pH, TDS, K, Na, Ca, Mg, and Fe) and plant species. Our findings revealed that higher concentrations of EC, pH, TDS, K, Na, Ca, Mg, and Fe were associated with an increased abundance of Therophytes, Chamaephytes, Hemicryptophytes, and Geophytes. The study region exhibits high herb diversity, followed by trees and shrubs, with a substantial mid-domain impact on species and family richness. Furthermore, observations on leaf size and biological spectrum collectively reflect characteristics typical of a widely distributed temperate environment. This study concluded that various environmental and soil gradients influence riparian vegetation, which is clearly linked to the species' genetic processes and natural selection. Future research should explore additional factors affecting riparian vegetation abundance and diversity, such as hydrological dynamics or specific human pressures.

Key words: Floral diversity; Riparian; Nanophylls; Geophytes; Detrended correspondence analyses

Introduction

Riparian vegetation is classified as one of the 15 biomes globally (Meragiaw *et al*., 2018). These riparian areas are a type of wetland that includes land permanently or temporarily linked to aquatic ecosystems (Gashaw *et al*., 2015), and form a vital part of the staging ecosystem. This vegetation is primarily composed of hydrophilic plants and acts as a bridge between the land and water environments. The riparian biome is one of the most diverse and productive regions on Earth (Naima *et al*., 1993). Protecting these zones is critical, as they are hotspots of plant diversity and host a wide variety of flora that are vastly different from those in upland areas (Graziano *et al*., 2022; Spackman & Hughes, 1995; Decocq, 2002). In regions such as the Southwestern United States, riparian ecosystems support biodiversity, stabilize banks, and sustain productivity, particularly aiding Neotropical migratory birds (Rosenberg *et al*., 1982). These zones also perform significant ecological and economic functions, including filtering pollutants, stabilizing stream banks, controlling floods, and providing habitats for aquatic and terrestrial species. They also store water, supply foodand enhance soil fertility (Singh *et al*., 2021). River flow variability closely reflects changes in riparian systems (Vesipa, Camporeale *et al*., 2017). Changes in river shape, soil nutrient levels, and suspended matter significantly affect riparian plant communities (Bejarano *et al*., 2018). Pakistan is also home to big rivers, streams, and lakes that lead into many riparian zones.

In Sindh and the Punjab province of Pakistan, many riparian zones are increasingly vulnerable to climate change and human activities. Studies suggest that the distribution of riparian vegetation worldwide is influenced by both natural factors and anthropogenic activities (Richardson *et al*., 2007; Kent, 2011; Njue *et al*., 2016; Sunil *et al*., 2016). Environmental factors, such as soil type, altitude, rainfall length, temperature, significantly affect the structure and composition of plant communities in riverine ecosystems (Abbas *et al*., 2021). However, riparian vegetation is overexploited at a rate far exceeding its natural replenishment. This is driven by agricultural expansion, deforestation of timber, the invasion of non-native species, and overgrazing, all of which contribute to biodiversity loss

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in these ecosystems (Meragiaw *et al*., 2016). Thus, it is essential to understand how specific soil characteristics, such as total dissolved solids, pH, available nutrients (K, Na, Mg), electrical conductivity, and exchangeable cations, regulate riparian vegetation. Understanding this can help determine the critical drivers of community composition, manage riparian buffers, and forecast vegetation trajectories amid current environmental change.

Material and Methods

Study area: The study area is situated in the Malakand division of northern Pakistan. The geographic coordinates of the study region lie between 34º, 37´ and 35º, 07´N, and 71º, 31´ and 72º, 14´E The region is bounded on the north by Afghanistan, on the west by Malakand, on the east by Swat, and on the west by Bajaur district. It lies 2700 ft (823m) above sea level. The high mountain ranges along the river Panjkora create an intricate network in the study area. The Panjkora River provides many streams in Upper Dir. The main source of the River Panjkora is the snow-covered mountains of the Hindu Kush. Its length is 220 km. River Panjkora joins River Swat at Bosaq Village in District Malakand. Moreover, the climate of the study area is more like the other regions of the Indian subcontinent, with a substantial portion of annual precipitation originating from frontal cloud bands throughout the summer (Fig. 1).

Sampling of vegetation: Comprehensive field trips were conducted from April 2019 to August 2020 to examine the floristic composition of the riparian plants along the River Panjkora, with a total area of 27.14 km. The study area was divided into seven stations (Station 1, Tormang and Khall; Station 2, Sucha mera, Rabat and Rani; Station 3, Danwa, Odigram and Mainbanda; Station 4, Timergara, Khungi and Sado; Station 5, Khazana, Shaokas and Zolam; Station 6, Shahazdi and Konhaye stream; Station 7, Munda and Rud stream (Bajaur). We established 135 quadrats, with sizes of 1×1m² for herbs, 5×5m² for shrubs, and 10×10m² for trees (Bano *et al*., 2018; Ahmad *et al*., 2023; Zeb *et al*., 2025).

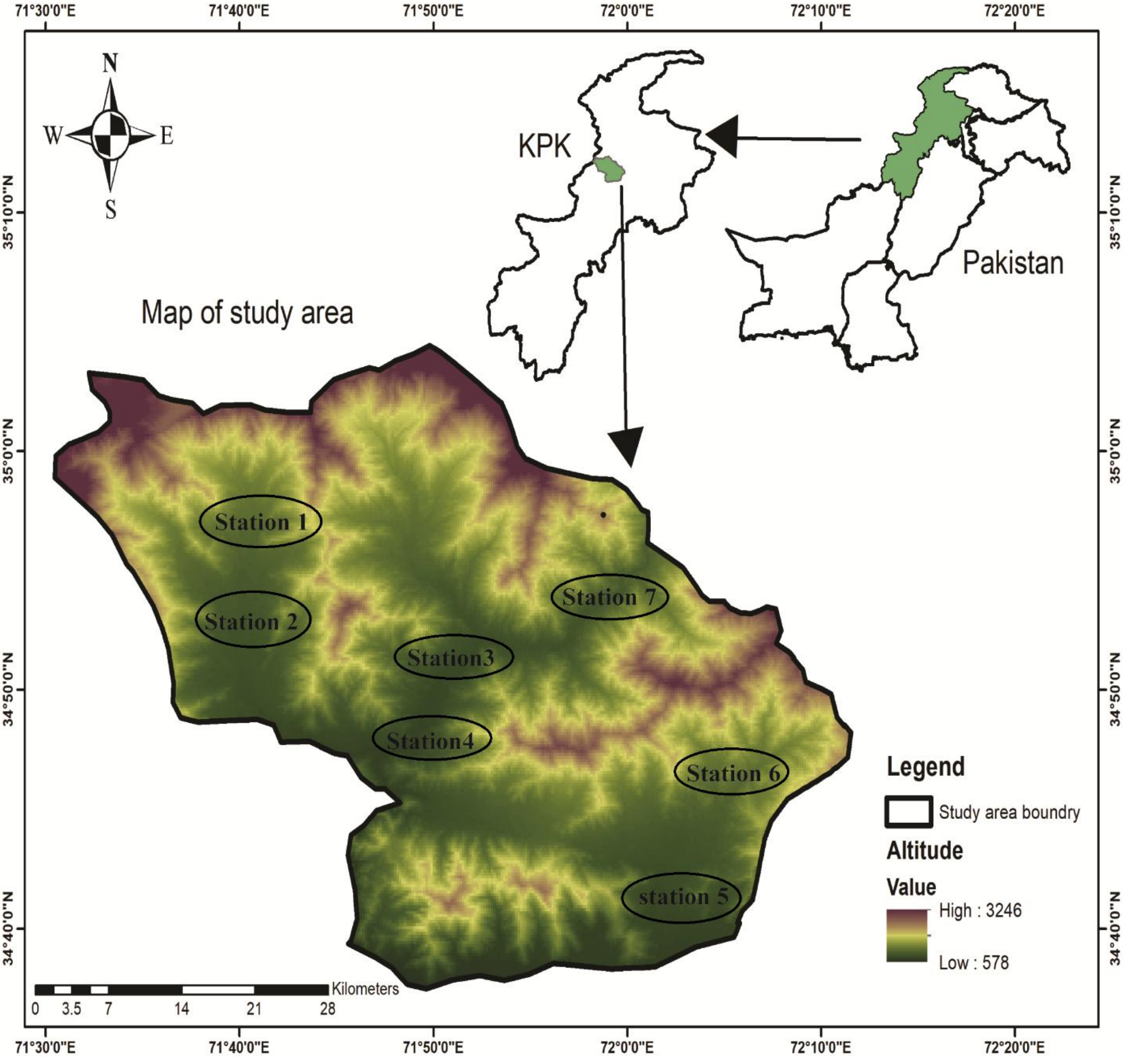

Fig. 1. The study area is shown on a physiographic map (created using ArcGIS), along with its location, elevation zones, and settlement locations.

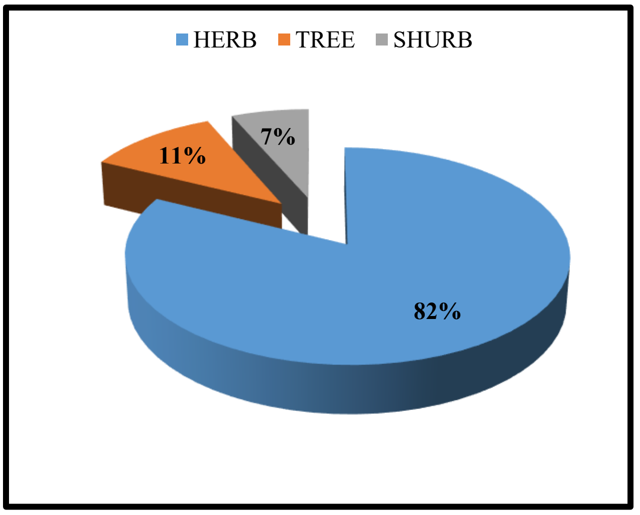

Fig. 2. Showing the Habit of the flora.

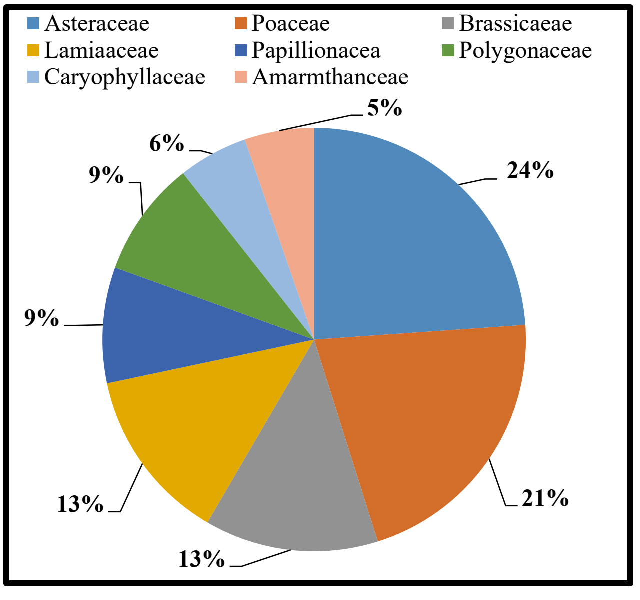

Fig. 3. Dominant families of the study area.

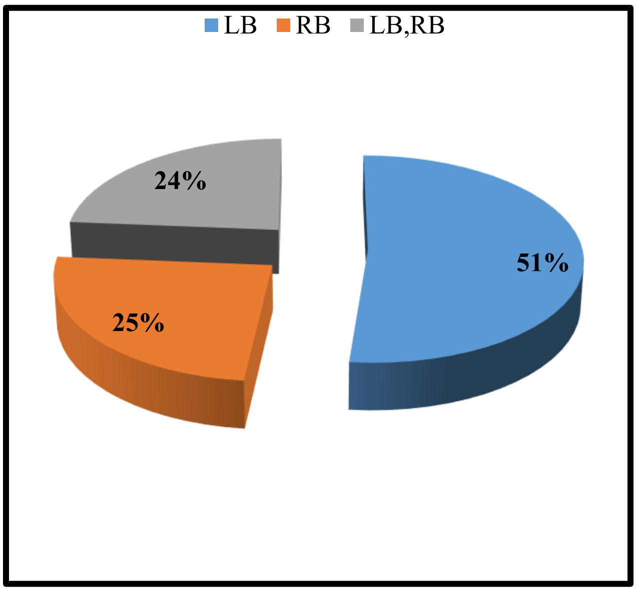

Fig. 4. Species Distribtion along the River Panjkora.

A GPS device (A-GPS) was used to record the latitude, longitude, and altitude data for each quadrat. Phytosociological properties, such as density, cover, and frequency, were recorded for all species present (Zeb *et al*., 2021). The plant specimen was preserved by poisoning it with mercuric chloride and ethanol. Perennating buds served as the primary indicator for classifying plant species into different life form groups. According to Raunkiaer's classification system, phanerophytes have buds located more than 25 cm above the ground, chamaephytes bear buds up to 25 cm above the soil, hemicryptophytes keep buds at the soil surface, geophytes have buds buried within the soil, and therophytes complete their entire life cycle from germination to seed production within a single growing season. Based on these observations, a biological spectrum was created to infer the paleoclimatic conditions in the study area. Additionally, Raunkiaer's leaf-size classification system was used to categorize leaves into the following classes: Leptophyll, Nanophyll, Microphyll, Mesophyll, Macrophyll, and Megaphyll (Khan *et al*., 2013).

Data analysis: Multivariate statistical analyses like DCA (Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA), were used via CANOCO version 4.5 software to compress community data into lower dimensional space. These statistical tools arrange samples and species with similar properties in close proximity, while those with different traits are placed further apart. These techniques are frequently used to analyze the ecological community structure because they effectively portray the linkages and patterns found in the data Greig-Smith, 1983; Ter Braak & Barendregt, 1986; Ter Braak & Prentice, 1988; Jongman *et al*., 1995; Digby & Kempton, 2012: Palmer, 2019; Zeb *et al*., 2021). In most ecological studies, researchers prefer detrended correspondence analysis (DCA) because it is employed without the use of environmental data, resulting in conclusions that are devoid of distortion (Ter Braak & Barendregt, 1986, Ter Braak & Prentice, 1988). DCA was used to illustrates the distribution of plant species within the studied region (Ullah *et al*., 2024; Ter Braak & Prentice, 1988). Canonical Correspondence Analysis (CCA), a robust and widely used ordination technique, reveals the relationship between plant species and environmental variables in a study area. This further legitimizes the data on the results of DCA and ISA (Dufrêne & Legendre, 1997; McCune & Grace, 2002; Kent, 2011). In this study, we used CCA with the abundance data of all species and quadrats with the following objectives: (i) to show the relationship between life form and leaf form with various environmental variables. (ii) Confirm whether the DCA-based plant community pattern is attributable to measurable variations in the environment.

Result

Floristic composition: Floristic composition: A total of 215 plant species belonging to 163 genera were reported along the River Panjkora in the Dir Lower District, Pakistan. The flora includes 178 herbs (82%), 24 trees (11%), and 14 shrubs (7%) (Fig. 2). A list of plant specimens, along with their family, habit, habitat, life form, and leaf form, is provided (Table 1). Pinus roxburghii is the only gymnosperm, whereas the remaining 214 species are angiosperms. The most dominant families in the study area are Asteraceae, which contributes the highest number of species (27), followed by Poaceae with 24 species, Brassicaceae and Lamiaceae with 15 species each, Polygonaceae and Papilionaceae with 9 species each, and Caryophyllaceae and Amaranthaceae with six species each. The remaining families had fewer than six species (Fig. 3). The cumulative count showed that 111 (51%) plant species were present on the left bank of the River Panjkora, 53 (25%) on the right bank, and both sides hosted 51 (24%) species (Fig. 4). Trees and shrubs predominantly grow on the right side, whereas herbs are mainly found on the left bank of the Panjkora River.

Raunkaier life form classes: All plant species were classified into different life form classes following Raunkaier's (1934) classification. Therophyte among all life form classes was found dominant class having 114 species, followed by Hemicryptophyte with 28 species, Geophyte 23 species, Chamaephyte 14 species, Microphanerophyte 14 species, Nanophanerophyte 13 species, Mesophanerphyte 6 species respectively, while the Megaphanerophyte was represented by 3 species only (Fig. 5).

Leaf spectra classes: Our findings showed that Nanophylls was the dominant leaf spectra class with 90 species. The second class was Microphylls with 60 species, followed by Mesophylls with and Leptophylls with 27 species, Macrophylls with 10 species, while the aphyllous class is represented by 1 species (Fig. 6).

The DCA ordination diagram depicts the distribution of species in the study area according to Raunkiaer's life form classification, offering insights into ecological composition and gradients. The eigenvalues for the first four axes (0.788, 0.694, 0.653, and 0.579) show that axis 1 captures the greatest variation in species distribution, followed by the other axes. The gradient lengths (6.967, 5.600, 5.985, and 5.071) indicate a relatively long ecological gradient (Table 1) reflecting significant species turnover across the area. However, the total percentage of variance explained by the first four axes is modest (9.3%), which is typical in community ecology data due to high species diversity and complex environmental interactions. The ordination also reveals the spatial separation of different life forms, such as therophytes, hemicryptophytes, chamaephytes, nanophanerophytes, and megaphanerophytes, highlighting their ecological strategies and adaptations. Overall, these results emphasize the heterogeneity of species distribution and the role of Raunkiaer's life forms in shaping vegetation patterns throughout the study area (Table 2; Fig. 7).

Canonical correspondence analysis: The Canonical Correspondence Analysis reveals the impact of environmental factors on the distribution of phytogeographical components (Table 1; Fig. 8). Therophytes and chemophytes in the CCA plot are highly influenced by K, EC, and TDS. Na and Ca on the second axis again influenced both therophytes and chemophytes. The third axis depicts the major elements, therophytes and hemicrpytophytes, which have a favourable relationship with Mg and pH. While on the fourth axis elements like, therophytes and geophytes have significantly relationship with Fe.

The first axis shows that with the increase in the concentration of Electric conductivity (EC) (0.995 to 111), Total dissolved solids (TDS) (1.1 to 121) and Potassium (K) (0.006 to 4.688) increases the number of therophyte and chaemophytes are increased. In the 2nd axis, an increase in the concentration of Na (0.0013 to 7.3466) and Ca (0.032 to 6.975) shows that increase in the number of therophytes and chaemophytes. In the 3rd axis increase in the concentration of pH (4.26 to 9.52) and Mg (0.0277 to 9.9972) increases the number of therophytes and hemicrpytophytes and decreases in chaemophytes. In the 4th axis, the concentration of Fe (0.030 to 2.064) increases in therophytes and geophytes.

All four eigenvalues reported above are canonical and correspond to axes that are constrained by the environmental variables(Table 3).

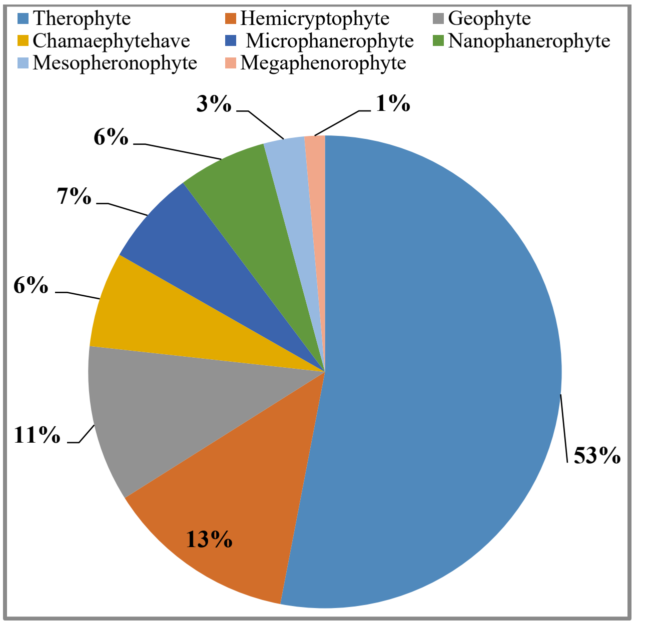

Fig. 5. Life form classes of the flora of River Panjkora.

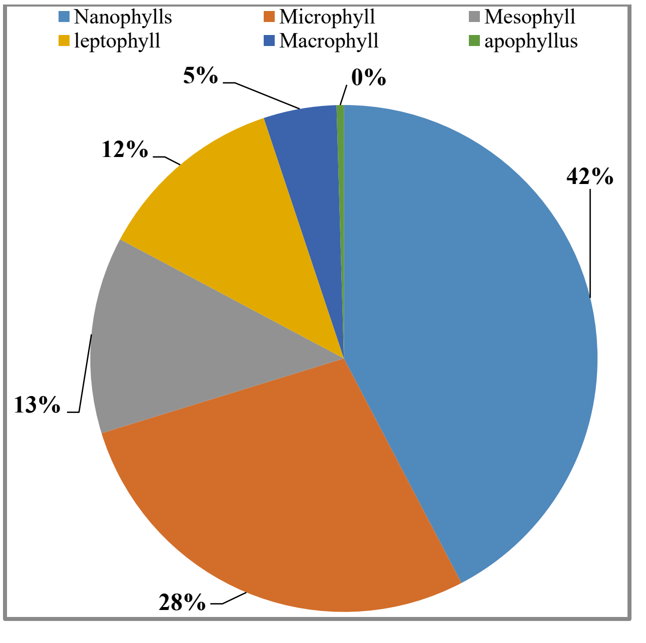

Fig. 6. Leaf size spectrum of the flora of River Panjkora Detrended Correspondence Analysis.

Table 1. Floristic diversity, biological spectrum and phenology of the Riparian vegetation along the River Panjkora.

	Botanical name	Family	Habit	Habitat	Life form	Leaf spectra	Flowering
1.	*Acacia modesta* Wall	Fagaceae	Tree	RB	Mesp	Mic	March-May
2.	*Adiantum capillus-veneris* L.	Pterideaceae	Herb	LB, RB	H	N	May-June
3.	*Ailanthus altissima* (Mill.) Swingle	Salicaceae	Tree	RB	Mp	Mes	May-June
4.	*Ajuga bracteosa* Wall. ex Benth.	Lamiaceae	Herb	RB	H	Mic	May-June
5.	*Ajuga parviflora* Benth.	Lamiaceae	Herb	RB, LB	Th	Mes	May-June
6.	*Alisma plantago-aquatica* L.	Alismataceae	Herb	LB	H	N	June-August
7.	*Allium carolinianum* DC.	Alliaceae	Herb	LB	Geo	Mes	July-August
8.	*Alnus nitida* (Spach) Endl.	Fabaceae	Tree	RB	Th	N	May-June
9.	*Alopecurus myosuroides* Huds.	Poaceae	Herb	RB	Th	Mac	May-August
10.	*Alternanthera pungens* Kunth	Amaranthaceae	Herb	LB, RB	Mesp	N	May-Sept.
11.	*Alyssum desertorum* Stapf	Brassicaceae	Herb	LB	Ch	L	April-July
12.	*Amaranthus viridis* L.	Amaranthaceae	Herb	LB, RB	Th	N	June-August
13.	*Anagallis arvensis* L.	Primulaceae	Herb	LB	Th	N	June-July
14.	*Androsace rotundifolia* Hardw.	Primulaceae	Herb	RB	H	Mes	June
15.	*Arabidopsis thaliana* (L.) Heynh.	Brassicaceae	Herb	RB	Th	N	June-July
16.	*Arabis nova* Vill.	Brassicaceae	Herb	LB	Th	N	April-June
17.	*Arenaria serpyllifolia* L.	Caryophyllaceae	Herb	LB	Th	N	June-August
18.	*Artemisia brevifolia* Wall.	Asteraceae	Herb	RB	H	L	May-June
19.	*Artemisia scoparia* Waldst. & Kitam.	Asteraceae	Herb	RB	Th	N	May-June
20.	*Artemisia vulgaris* L.	Asteraceae	Herb	RB	CH	Mic	July-Sept.
21.	*Arundo donax* L.	Poaceae	Herb	RB	Ch	Mic	Sept-October
22.	*Asparagus racemosus* Willd.	Asparagaceae	Herb	RB	Ch	L	April-June
23.	*Avena sativa* L.	Poaceae	Herb	LB	Th	N	June-July
24.	*Bongardia chrysogonum* (L.) Spach	Berberidaceae	Herb	LB	H	N	Feb-April
25.	*Bowlesia incana* Ruiz & Pav.	Umbelliferaeae	Herb	LB	Th	N	March-April
26.	*Bromus japonicus* Thunb.	Poaceae	Herb	LB	Th	Mic	June-August
27.	*Bromus pectinatus* Thunb.	Poaceae	Herb	LB	Th	Mic	April-August
28.	*Broussonetia papyrifera* (L.) L'Hér. ex Vent.	Salicaceae	Tree	LB	Mp	Mes	March-Aug.
29.	*Calendula arvensis* M.Bieb.	Asteraceae	Herb	LB, RB	Th	N	June-Nov
30.	*Campanula pallida* Wall.	Campanulaceaea	Herb	LB	H	Mic	April-July
31.	*Cannabis sativa* L.	Cannabaceae	Herb	LB, RB	Th	Mic	May-June
32.	*Capsella bursa-pastoris* (L.) Medik.	Brassicaceae	Herb	LB	Th	Mes	April-May
33.	*Cardamine flexuosa* With.	Brassicaceae	Herb	LB, RB	Th	N	March-June
34.	*Carex sp*	Cyperaceae	Herb	RB	Geo	N	May-Sept
35.	*Carthamus oxyacantha* M.Bieb.	Asteraceae	Herb	RB	Th	Mic	March-June
36.	*Celtis caucasica* Willd.	Salicaceae	Tree	LB	Mp	Mac	August-Sept
37.	*Celtis eriocarpa* Decne.	Salicaceae	Tree	LB	Mp	Mac	August-Sept
38.	*Centaurea benedicta* (L.) L.	Asteraceae	Herb	LB, RB	Th	Mes	April-August
39.	*Centaurea iberica* Trevir. ex Spreng.	Asteraceae	Herb	LB	Th	N	June-Sept
40.	*Cerastium glomeratum* Thuill.	Caryophyllaceae	Herb	LB	Th	L	Feb-May
41.	*Cheilanthes pteridioides* C. Chr.	Pterideaceae	Herb	LB	H	L	March-Sept
42.	*Chenopodium album L.*	Amaranthaceae	Herb	LB	Th	N	June-July
43.	*Chenopodium murale* L.	Amaranthaceae	Herb	RB	Th	L	January-July
44.	*Chrozophora tinctoria* (L.) A.Juss.	Euphorbiaceae	Herb	LB	Th	Mic	April-Sept
45.	*Chrysopogon serrulatus* Trin.	Poaceae	Herb	RB	Th	N	June-Sept
46.	*Cirsium arvense* (L.) Scop.	Asteraceae	Herb	LB	Th	Mic	June-August
47.	*Cirsium vulgare* (Savi) Ten.	Asteraceae	Herb	LB, RB	Th	Mic	June-Sept
48.	*Cleome viscosa* L.	Cleomaceae	Herb	LB	Th	Mic	June-August
49.	*Conyza bonariensis* var. leiantha	Asteraceae	Herb	LB, RB	Th	N	August
50.	*Coronopus didymus* (L.) Sm.	Brassicaceae	Herb	LB, RB	Th	Mic	July-Sept
51.	*Cymbopogan Arcuri*	Poaceae	Herb	RB	H	N	April-Sept
52.	*Cynodon dactylon* (L.) Pers.	Poaceae	Herb	LB, RB	H	L	All year
53.	*Daphne mucronata* Royle	Rutaceae	Shrub	RB	Mp	N	April-May
54.	*Debregeasia saeneb* (Forssk.)	Rosaceae	Shrub	RB	Np	Mes	May-June
55.	*Debregeasia salicifolia* (D.Don) Rendle	Punicaeae	Shrub	RB	Mp	Mic	May-June

Table 1. (Cont'd.).

	Botanical name	Family	Habit	Habitat	Life form	Leaf spectra	Flowering
56.	*Delphinium uncinatum Hook.f. & Thomson*	Ranunculaceae	Herb	LB, RB	H	N	March-May
57.	*Descurainia sophia* (L.) Webb ex Prantl	Brassicaceae	Herb	RB	Th	L	April-July
58.	*Desmostachya bipinnata* (L.) Stapf	Poaceae	Herb	RB	H	N	July-October
59.	*Dodonaea viscosa* (L.) Jacq.	Rosaceae	Shrub	RB	Np	Mic	Jan-March
60.	*Dysphania ambrosioides* (L.) Mosyakin & Clemants	Amaranthaceae	Herb	LB	Th	L	April-January
61.	*Dysphania botrys* (L.) Mosyakin & Clemants	Amaranthaceae	Herb	RB	Th	Mic	April-August
62.	*Eleocharis palustris* (L.) Roem. & Schult.	Cyperaceae	Herb	LB, RB	Th	N	May-June
63.	*Emex spinosa* (L.) Campd.	Polygonaceae	Herb	LB	Th	Mic	Dec-May
64.	*Epilobium* Linn	Onagraceae	Herb	LB	Th	N	July-Sept
65.	*Equisetum arvense* L.	Equisetaceae	Herb	RB	Geo	Ap	Non-flower
66.	*Erigeron canadensis* L.	Asteraceae	Herb	LB, RB	Th	Mic	May-June
67.	*Erodium cicutarium* (L.) L'Hér.	Geraniaceae	Herb	LB	Th	Mes	June- July
68.	*Eruca vesicaria* (L.) Cav.	Brassicaceae	Herb	LB	Th	Mic	May-August
69.	*Eryngium billardieri* Delile	Apicaceae	Herb	LB	H	N	May-August
70.	*Eucalyptus camaldulensis* (Blakely) Brooker & M.W. McDonald	Sapotaceae	Tree	RB	Mp	Mic	May-June
71.	*Euphorbia helioscopia* L.	Euphorbiaceae	Herb	LB	Th	N	July-August
72.	*Euphorbia hirta* L.	Euphorbiaceae	Herb	LB, RB	Th	L	July-Dec
73.	*Euphorbia prostrata* Aiton	Euphorbiaceae	Herb	LB	Th	N	July-October
74.	*Ficus carica* L.	Platanaceae	Tree	LB	Megp	Mes	July-August
75.	*Ficus palmata* Forssk.	Moraceae	Tree	LB	Mesp	Mes	July-August
76.	*Filago arvensis* L.	Asteraceae	Herb	RB	Th	L	July-Sept
77.	*Filago germanica* (L.) Huds.	Asteraceae	Herb	LB	Th	L	March-Oct
78.	*Filago hurdwarica* (Wall. ex DC.) Wagenitz	Asteraceae	Herb	LB, RB	Th	L	March-Oct
79.	*Fumaria indica* (Hausskn.) Pugsley	Fumariaceae	Herb	LB, RB	Th	N	May-June
80.	*Galium aparine* L.	Rubiaceae	Herb	LB	Th	L	July
81.	*Geranium collinum* Stephan ex Willd.	Geraniaceae	Herb	LB	H	Mic	July-August
82.	*Geranium mascatense* Boiss.	Geraniaceae	Herb	LB	Ch	Mic	March-April
83.	*Geranium rotundifolium* L.	Geraniaceae	Herb	LB, RB	Th	N	March-April
84.	*Gymnosporia royleana* Wall. ex M.A.Lawson	Apocynaceae	Shrub	RB	Np	Mes	January-Dec
85.	*Helianthus annuus* L.	Asteraceae	Herb	RB	Th	Mes	July-Sept
86.	*Heliotropium europaeum* L.	Boroaginaceae	Herb	RB	Th	Mic	April
87.	*Hemarthria compressa* (L.f.) R.Br.	Poaceae	Herb	LB	Th	N	July-Sept
88.	*Heteropogon contortus* (L.) P.Beauv. ex Roem. & Schult.	Poaceae	Herb	LB	Geo	Mic	June-October
89.	*Hordeum murinum* L.	Poaceae	Herb	LB	Th	Mic	April-July
90.	*Hydrilla verticillata* (L.f.) Royle	Hydrocharitaceae	Herb	LB, RB			October-Jan
91.	*Isatis costata* C.A.Mey.	Brassicaceae	Herb	RB	Th	Mic	May-August
92.	*Isodon rugosus* (Wall. ex Benth.) Codd	Labiatae	Shrub	RB	Ch	L	September
93.	*Juncus sp* L.	Juncaceae	Herb	RB	Geo	L	Through year
94.	*Justicia adhatoda* L.	Acanthaceaea	Shrub	RB	Np	Mic	April-May
95.	*Koeleria macrantha* (Ledeb.) Schult.	Poaceae	Herb	LB	H	N	April-Sept
96.	*Lactuca dissecta* D.Don	Asteraceae	Herb	LB	H	N	June
97.	*Lamium amplexicaule* L.	Lamiaceae	Herb	LB	Th	N	Dec.-April
98.	*Lamium maculatum* (L.) L.	Lamiaceae	Herb	LB	Th	N	April-Nov
99.	*Laphangium luteoalbum* (L.) Tzvelev	Asteraceae	Herb	LB, RB	Th	N	June-Sept.
100.	*Lathyrus aphaca* L.	Papilionaceae	Herb	LB	Th	N	June-August
101.	*Leonurus cardiaca* L.	Lamiaceae	Herb	LB	Th	Mes	June-August
102.	*Lepidium pinnatifidum* Ledeb.	Brassicaceae	Herb	LB	Ch	N	May-June
103.	*Limonium macrorhabdon* Kuntze	Plumbaginaceae	Herb	LB	Mp	N	July-Sept
104.	*Malva neglecta* Wallr.	Malvaceae	Herb	LB, RB	Th	Mic	March-April
105.	*Marsilea quadrifolia* L.	Marsileaceae	Herb	LB, RB	H	Mes	Non-flower
106.	*Mazus japonicus* (Thunb.) Kuntze	Scrophulariaceae	Herb	LB	Th	N	May-October
107.	*Mazus pumilus* (Burm.f.) Steenis	Scrophulariaceae	Herb	LB	Th	N	May-October
108.	*Medicago denticulata* Willd.	Papilionaceae	Herb	LB	Th	L	March-May
109.	*Medicago lupulina* L.	Papilionaceae	Herb	LB, RB	Th	N	March-June
110.	*Medicago minima* (L.) L.	Papilionaceae	Herb	LB, RB	Th	N	April-July

Table 1. (Cont'd.).

	Botanical name	Family	Habit	Habitat	Life form	Leaf spectra	Flowering
111.	Medicago polymorpha L.	Papilionaceae	Herb	LB, RB	Th	N	March-May
112.	*Melia azedarach* L.	Oleaceae	Tree	LB, RB	Mesp	Mic	April-May
113.	*Melilotus indica* (L.) All.	Fabaceae	Herb	LB	Th	N	March-Aug
114.	*Mentha arvensis* L.	Lamiaceae	Herb	LB	Geo	N	July-Sept
115.	*Mentha longifolia* (L.) L.	Lamiaceae	Herb	LB	Geo	N	May-June
116.	*Mentha royleana* Wall. ex Benth.	Lamiaceae	Herb	LB	Geo	N	July-October
117.	*Mentha spicata* L.	Lamiaceae	Herb	LB	Geo	N	August-Sept.
118.	*Micromeria biflora* (Buch.-Ham. ex D.Don) Benth.	Labiatae	Herb	LB	Th	L	March-April
119.	*Morus alba* L.	Moraceae	Tree	LB, RB	Mp	Mac	April-May
120.	*Morus laevigata* Wall. ex Brandis	Moraceae	Tree	RB	Mp	Mac	April-May
121.	*Morus nigra* L.	Moraceae	Tree	LB	Mp	Mac	April-May
122.	*Nasturtium officinale* R.Br.	Brassicaceae	Herb	LB, RB	Geo	N	April-May
123.	*Nerium odorum* Aiton	Lamiaceae	Shrub	RB	Np	Mes	April-October
124.	*Nonea caspica* (Willd.) G.Don	Boroaginaceae	Herb	LB	Th	Mic	March-April
125.	*Nonea edgeworthii* A. DC.	Boroaginaceae	Herb	LB	H	N	March-April
126.	*Oenothera rosea* L'Hér. ex Aiton	Onagraceae	Herb	LB	Th	N	April-May
127.	*Olea ferruginea* Wall. ex Aitch.	Meliaceae	Tree	RB	Mp	N	April-May
128.	*Otostegia limbata* (Benth.) Boiss.	Celastraceae	Shrub	RB	Np	Mic	April-May
129.	*Oxalis corniculata* L.	Oxalidaceae	Herb	LB, RB	Th	N	March-April
130.	*Papaver pavoninum* C.A. Mey.	Papaveraceae	Herb	LB	Th	N	April-June
131.	*Papaver rhoeas* L.	Papaveraceae	Herb	LB	Th	Mic	April-July
132.	*Parietaria lusitanica* L.	Urticaceae	Herb	LB	Th	N	April-May
133.	*Parthenium hysterophorus* L.	Asteraceae	Herb	LB	Th	Mes	April-August
134.	*Paspalum distichum* L.	Poaceae	Herb	LB	H	L	April-May
135.	*Pennisetum orientale* Rich.	Poaceae	Herb	LB	H	L	April-October
136.	*Persicaria glabra* (Willd.) M.Gómez	Polygonaceae	Herb	LB, RB	H	N	April-Nov
137.	*Persicaria hydropiper* (L.) Delarbre	Polygonaceae	Herb	LB	Geo	Mes	April-Sept
138.	*Persicaria nepalensis* (Meisn.) Miyabe	Polygonaceae	Herb	RB	Th	N	June-Sept
139.	*Phragmites karka* (Retz.) Trin. ex Steud.	Poaceae	Herb	RB	Ch	Mac	April-Nov
140.	*Physalis divaricata* D. Don	Solanaceae	Herb	LB	Mp	N	August-Oct
141.	*Pinus roxburghii* Sarg.	Pinaceae	Tree	RB	Np	L	May
142.	*Piptatherum aequiglume* (Duthie ex Hook.f.) Roshev.	Poaceae	Herb	LB	H	Mic	July-August
143.	*Piptatherum laterale* (Regel) Nevski	Poaceae	Herb	LB	H	L	July-August
144.	*Plantago lanceolata* L.	Polygonaceae	Herb	LB	Th	N	May-August
145.	*Plantago major* L.	Polygonaceae	Herb	LB	Th	Mic	August-Sept
146.	*Platanus orientalis* L.	Moraceae	Tree	LB	Megp	Mes	April-May
147.	*Poa annua* L.	Poaceae	Herb	LB.RB	Th	L	March-Sept
148.	*Poa bulbosa* L.	Poaceae	Herb	LB,RB	Th	N	April-July
149.	*Polygonum aviculare* L.	Polygonaceae	Herb	LB	Th	N	March-Sept
150.	*Polygonum plebeium* R.Br.	Polygonaceae	Herb	LB	H	N	June-Sept
151.	*Polygonum hydropiper* L.	Polygonaceae	Herb	LB	Geo	Mic	May-Sept
152.	*Polypogon viridis* (Gouan) Breistr	Poaceae	Herb	LB, RB	Th	N	May-August
153.	*Populus alba* L.	Ulmaceae	Tree	LB	Megp	Mic	May-July
154.	*Populus ciliata* Wall. ex Royle	Ulmaceae	Tree	LB	Mesp	Mic	May-July
155.	*Populus nigra* L.	Moraceae	Tree	LB, RB	Th	Mes	April-May
156.	*Potentilla supina* L.	Rosaceae	Herb	LB	Ch	L	June-August
157.	*Punica granatum* L.	Thymelaceae	Shrub	RB	Np	N	April-May
158.	*Quercus incana* Bartram	Mimosaaceaea	Tree	RB	Mp	L	March-April
159.	*Ranunculus arvensis* L.	Ranunculaceae	Herb	LB, RB	Th	N	March-April
160.	*Ranunculus laetus* Wall. ex Hook. f. & J.W. Thomson	Ranunculaceae	Herb	LB	Geo	N	April
161.	*Ranunculus muricatus* L.	Ranunculaceae	Herb	LB, RB	Geo	Mic	April
162.	*Ranunculus sceleratus* L.	Ranunculaceae	Herb	LB	Geo	Mic	March-April
163.	*Raphanus raphanistrum* L.	Brassicaceae	Herb	LB	Th	N	January-April
164.	*Ricinus communis* L.	Rhamnaceae	Shrub	LB	Np	N	June
165.	*Robinia pseudoacacia* L.	Simaroubaceae	Tree	RB	Np	Mic	April-May

Table 1. (Cont'd.).

	Botanical name	Family	Habit	Habitat	Life form	Leaf spectra	Flowering
166.	*Rorippa islandica* (Oeder) Borbás	Brassicaceae	Herb	LB, RB	Th	N	April-July
167.	*Rosa multiflora* Thunb.	Urticaceae	Shrub	RB	Np	Mic	May-June
168.	*Rostraria cristata* (L.) Tzvelev	Poaceae	Herb	RB	Th	N	March-June
169.	*Rubus fruticosus* auct. [L.]	Salicaceae	Shrub	LB	Np	Mes	May-August
170.	*Rumex dentatus* L.	Polygonaceae	Herb	LB, RB	Geo	Mes	April-May
171.	*Saccharum bengalense* Retz.	Poaceae	Herb	LB, RB	Ch	N	October-Jan
172.	*Saccharum spontaneum* L.	Poaceae	Herb	RB	Ch	L	July-Sept
173.	*Salix tetrasperma* Roxb.	Betulaceae	Tree	LB, RB	Mesp	Mes	Oct-March
174.	*Salvia moorcroftiana* Wall. ex Benth.	Lamiaceae	Herb	LB	Th	Mac	April-June
175.	*Salvia plebeia* R.Br.	Labiatae	Herb	LB	H	Mes	August
176.	*Scandix pecten-veneris* L.	Umbelliferaeae	Herb	LB, RB	Th	Mic	April-July
177.	*Sedum sp* L.	Crassulaceae	Herb	RB	Geo	N	July-Sept
178.	*Sideroxylon buxifolium* Hutch.	Myrtaceae	Tree	RB	Ch	Mic	April-May
179.	*Silene apetala* Willd.	Caryophyllaceae	Herb	LB	Th	N	March-April
180.	*Silene conoidea* L.	Caryophyllaceae	Herb	LB	Th	N	June-July
181.	*Silybum marianum* (L.) Gaertn.	Asteraceae	Herb	LB	Th	Mic	June-Sept
182.	*Sisymbrium irio* L.	Brassicaceae	Herb	LB	Th	N	March-May
183.	*Sisymbrium officinale* (L.) Scop.	Brassicaceae	Herb	LB	Th	N	April-June
184.	*Solanum nigrum* L.	Solanaceae	Herb	LB, RB	Th	Mic	March-April
185.	*Solanum surattense* Burm. f.	Solanaceae	Herb	LB	H	N	June-July
186.	*Sonchus arvensis* L.	Asteraceae	Herb	LB	Th	Mes	March-June
187.	*Sonchus asper* (L.) Hill	Asteraceae	Herb	LB	Th	Mic	March-April
188.	*Sonchus oleraceus* (L.) L.	Asteraceae	Herb	LB, RB	Th	Mic	May-Dec
189.	*Sonchus wightianus* DC.	Asteraceae	Herb	LB	Th	Mic	Jan-October
190.	*Spinacia oleracea* L.	chenopodiaceae	Herb	LB, RB	Th	Mic	Feb-May
191.	*Stellaria media* (L.) Vill.	Caryophyllaceae	Herb	LB, RB	Th	L	April-Aug
192.	*Taraxacum officinale* (L.) Weber ex F.H.Wigg.	Asteraceae	Herb	LB	Th	Mic	March-April
193.	*Teucrium stocksianum* Boiss.	Labiatae	Herb	LB	H	Mic	May-August
194.	*Tithonia sp* Oerst.	Asteraceae	Herb	LB	Geo	Mic	Sept-January
195.	*Torilis leptophylla* (L.) Rchb.f.	umbelliferaeae	Herb	LB, RB	Th	Mic	April-May
196.	*Trifolium pratense* L.	Papilionaceae	Herb	LB	Geo	N	April-May
197.	*Trifolium resupinatum* L.	Papilionaceae	Herb	LB	H	Mic	April-May
198.	*Trigonella incisa* Benth.	Papilionaceae	Herb	LB	Th	N	May-June
199.	*Trigonella monantha* C.A.Mey.	Papilionaceae	Herb	LB	Th	N	May-June
200.	*Typha domingensis* Pers.	Typhaceae	Herb	RB	Geo	Mac	January-Dec
201.	*Urtica dioica* L.	Urticaceae	Herb	LB, RB	Th	Mic	April-May
202.	*Vaccaria hispanica* (Mill.) Rauschert	Caryophyllaceae	Herb	LB	Th	N	Febr-March
203.	*Valerianella szovitsiana* Fisch. & C.A. Mey.	Valerianaceae	Herb	LB	Geo	Mic	April-May
204.	*Verbascum thapsus* L.	Scrophulariaceae	Herb	RB	Geo	Mac	April-May
205.	*Veronica anagallis-aquatica* L.	Scrophulariaceae	Herb	LB, RB	Geo	Mes	June
206.	*Veronica polita* Fr.	plantaginaceae	Herb	LB	Th	Mic	March-Oct
207.	*Vicia faba* L.	Fabaceae	Herb	LB	Th	N	August-Feb
208.	*Vicia hirsuta* (L.) Gray	Fabaceae	Herb	LB	Th	N	Feb-August
209.	*Vicia sativa* L.	Papilionaceae	Herb	LB, RB	Th	N	July-Aug
210.	*Vinca major* L.	Apocynaceae	Herb	LB	Ch	N	Dec-March
211.	*Xanthium strumarium* L.	Asteraceae	Herb	RB	Th	N	July-August
212.	*Youngia japonica* (L.) DC.	Asteraceae	Herb	LB	Th	N	Feb-Dec
213.	*Zanthoxylum armatum* DC.	Sapindaceae	Shrub	LB, RB	Np	N	March-April
214.	*Zeuxine strateumatica* (L.) Schltr.	Orchidaceae	Herb	LB	Th	Mic	March-April
215.	*Ziziphus nummularia* (Burm.f.) Wight & Arn.	Euphorbiaceae	Tree	RB	Ch	Mes	May-June

Key; Th, Therophytes, H, Hemicryptophyte, Geo, Geophyte, Ch, Chamaephyte, Mp, Microphanoerophyte, Np, Nanophanerophyte, Mega, Megaphernoophyte, N Nanophyll, Mic Microphyll, Mes Mesophyll, L Leptophyll, Mac Marophyll, Ap Apophyllus, LB, Left bank, RB Right bank, LB, RB, Left & Right bank

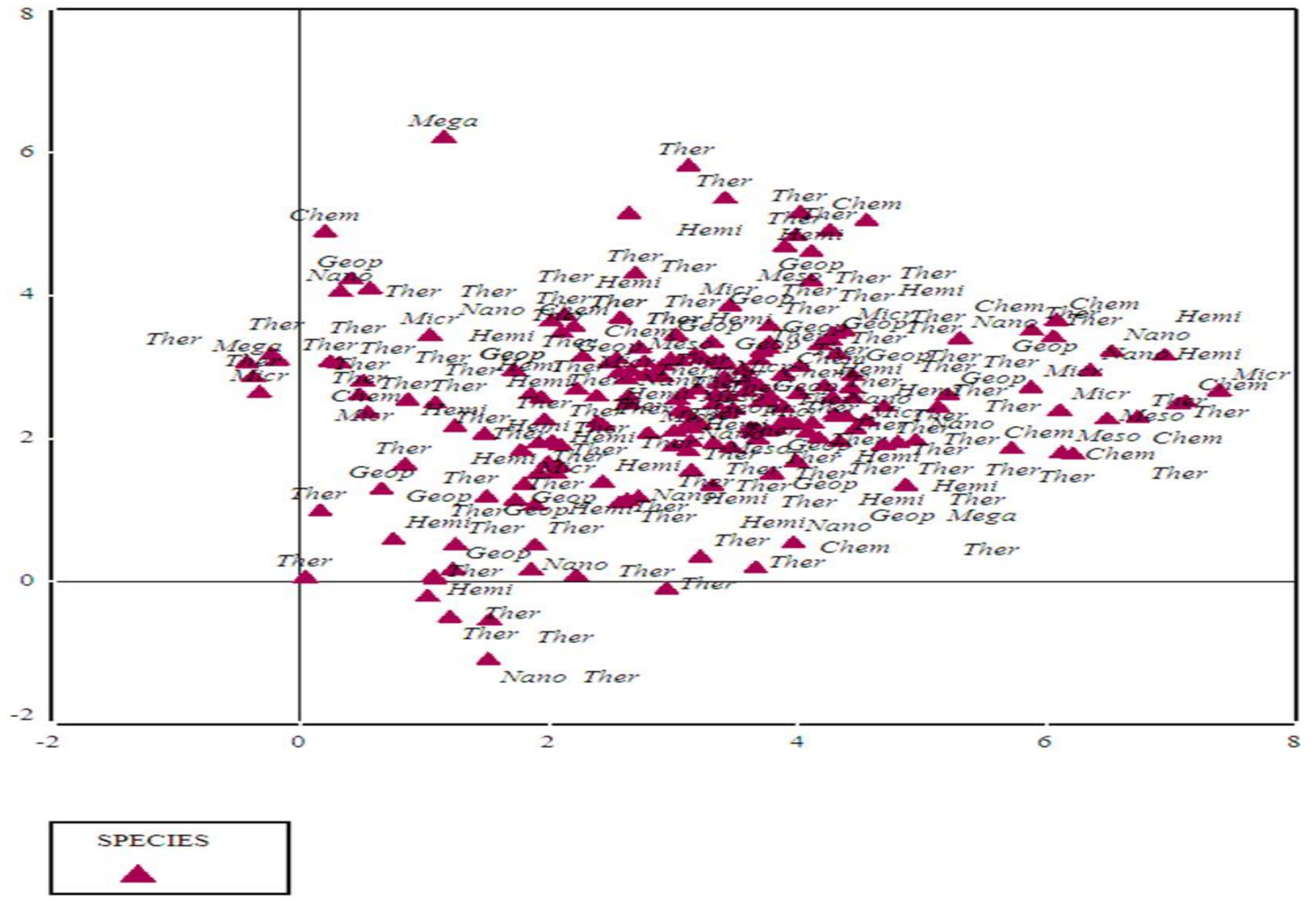

Fig. 7 Show Raunkiaer life forms distribution across 135 stations/habitat categories using Detrended Correspondence Analysis (DCA).

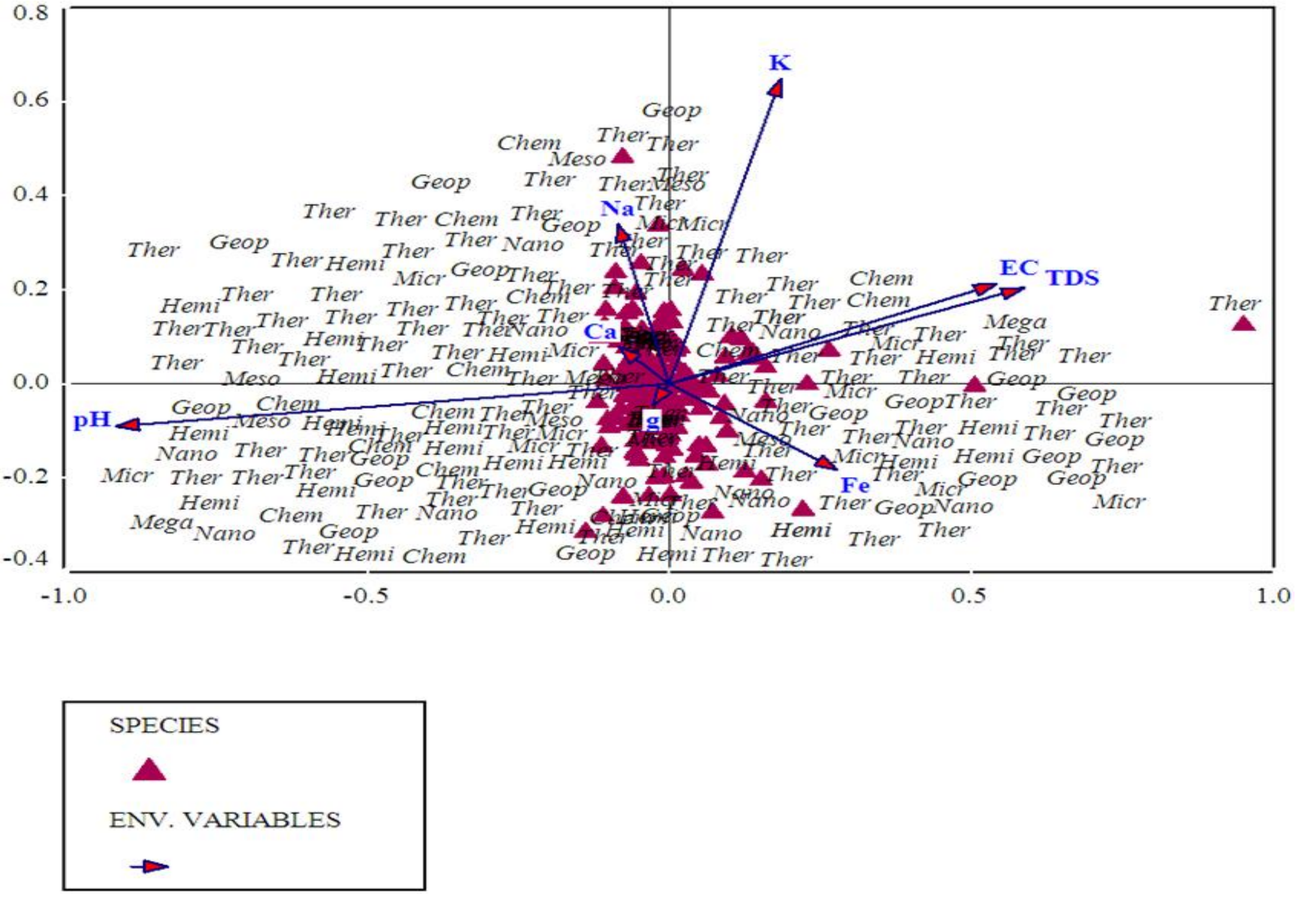

Fig. 8. Canonical Correspondence Analysis (CCA) biplots, showing the life forms among 216 plant species and 8 environmental variables.

Table 2. The first four axes of the DCA for vegetative data (using Raunkiaer life form species matrix for 135 sites) are described.

Axes	1	2	3	4	Total inertia
Eigenvalues	0.788	0.694	0.653	0.579	29.317
Lengths of gradient	6.967	5.600	5.985	5.071	
Cumulative percentage variance of species data	2.7	5.1	7.3	9.3	

Table 3. Summary table.

Axes	1	2	3	4	Total inertia
Eigenvalues	0.537	0.338	0.303	0.251	29.317
Species environment correlation	0.915	0.794	0.759	0.732	
Cumulative percentage variance of species data	1.8	3.0	4.0	4.9	
Cumulative percentage variance of species-environment relation	25.9	42.2	56.8	68.8	
Sum of all eigenvalues			29.317		
Sum of all canonical eigenvalues			2.077		

Discussion

Flora indicates climatic conditions, soil characteristics, and biodiversity of a region (Badshah *et al*., 2010). Water, vegetation, and soil are essential components of human well-being, providing habitats, food, timber, and various ecosystem services (Khan *et al*., 2016). Freshwater ecosystems are vital for sustaining life. Rivers like the Panjkora exemplify this, being essential for agriculture, drinking water, and flour mills, and supporting a diverse array of species along their banks. Our study recorded a total of 215 plant species, comprising 177 herbs, 24 trees, and 14 shrubs (Table 1). These findings are consistent with studies such as Sharma *et al*., (2022), who investigated riparian vegetation along the Hill Stream in Jammu and Kashmir. Similarly, Shuaib *et al*., (2019) identified 38 herbs, 15 trees, and 6 shrubs in Tehsil Timergara, District Dir Lower, supporting our findings. In our study, Asteraceae was the most dominant family with 27 species, followed by Poaceae with 24 species, while Brassicaceae and Lamiaceae each had 15 species. These findings align with Elshikh *et al*., (2019), who reported Asteraceae and Poaceae dominance in Egypt's Sohaq canal riparian vegetation. Furthermore, Sharma & Sharma (2020) observed Asteraceae as the leading family along the Bhaderwah Hill Stream in Jammu and Kashmir. Chanamé-Zapata *et al*., (2019) found Asteraceae and Poaceae to dominate riparian vegetation in high Andean wetlands. Our findings are further supported by Khan *et al*., (2020), who reported Asteraceae as dominant, followed by Poaceae and Lamiaceae, and by Badshah *et al*., (2016), who observed similar patterns with Asteraceae, Poaceae, Brassicaceae, and Lamiaceae being predominant families. The prominence of Asteraceae may be due to its widespread presence globally, light and easily dispersed seeds, and characteristic inflorescence, the capitulum, which bears many flowers on a single receptacle. These traits, along with moist habitats and wind dispersal, have expanded the ecological range of these species. Poaceae, another key family, propagates through various seeds dispersed by water, animals, and wind, and adapts well to both moist and dry conditions. Analysis of species distribution revealed 111 species (51%) on the left bank of the River Panjkora, 53 species (25%) on the right bank, and 51 species (24%) common to both sides (Fig. 4). Herbaceous plants mainly occupy the left bank due to cultivated fields and farmland, whereas trees and shrubs are more abundant on the right bank. Several factors contribute to decreased floral diversity on the right bank of the river, including (1) surrounding mountains, (2) the Koto hydropower project (5 km long) construction, (3) the presence of Afghan refugees, and (4) urban expansion of Timergara city. Life-form analysis offers insights into plant adaptation to different ecological conditions. Based on Raunkiaer's (1934) classification, 215 species were categorized into various life-form classes. Therophytes were dominant, with 114 species (53%), followed by hemicryptophytes with 28 species (13%), geophytes with 23 species (11%), chamaephytes and microphanerophytes with 14 species each (7%), nanophanerophytes with 13 species (6%), mesophanerophytes with six species (3%), and megaphanerophytes with three species (1%). Therophyte dominance reflects human activity and harsh climatic conditions in this region Ahmad *et al*., (2019), Khan *et al*., (2018), and Sharma & Sharma (2020) also reported the prevalence of therophytes in riparian vegetation. According to Malik *et al*., (2007), severe environmental conditions promote therophyte dormancy. Similarly, Qureshi (2008), Khan *et al*., (2011), and Hussain *et al*., (2005) highlighted the predominance of therophytes in disturbed ecosystems. Habitat disturbance tends to favor therophytic vegetation (Manhas *et al*., 2010). As noted by Shimwell (1971) and Cain & Castro (1959), hemicryptophytes tend to dominate temperate zones, whereas therophytes are more common in desert environments. In our study, therophytes were dominant owing to floods, trampling, browsing, and grazing pressures from Afghan refugee cattle herding along the riverbanks. This reduces palatable species while increasing non-palatable species. Similar outcomes were observed by Ahoudji *et al*., (2014) in Benin grasslands and Malik *et al*., (2007) in Neelum Valley and Dhirkot, Azad Kashmir, where therophytes and hemicryptophytes were dominant under moist temperate conditions. These studies support our findings that overexploitation, deforestation, and overgrazing contribute to habitat degradation and therophyte dominance in the study area. Leaf spectra analysis further supports this ecological interpretation. Nanophylls were dominant, with 91 species (42%), followed by microphylls with 60 species (28%), mesophylls with 27 species (13%), leptophylls with 26 species (12%), macrophylls with 10 species (5%), and apophylls with 1 species. Nanophylls and leptophylls typically indicate hot desert conditions, whereas microphylls represent plain vegetation (Tareen & Qadir, 1993; Cain & De Castro, 1959). Small-leaved species suggest adaptation to dry and cold conditions, whereas broad-leaved species indicate moist and warm climates. Our findings are consistent with those of Ali *et al*., (2017), who reported nanophyll dominance in Sherpo village, District Charsadda. Similarly, Amjad *et al*., (2017) observed nanophylls dominating subtropical forests in the Kotli District, AJK. Badshah *et al*., (2013) also noted similar results from the rangelands of District Tank. The analysis of Raunkiaer life forms and ordination patterns illustrates how the environment shifts from moist temperate to dry temperate ecosystems in the region. Species diversity was higher in the eastern part of the study area because of the deeper soils and lower elevations, where therophytes, geophytes, and chamaephytes were prevalent. On the other hand, hemicryptophytes and microphanerophytes dominate the southwestern region, which is characterized by herbaceous vegetation. This pattern aligns with studies conducted in other moist temperate regions of the Himalayan and Hindu Kush ranges. In summary, our Raunkiaer life form analysis revealed distinct vegetation patterns linked to soil depth, altitude, and environmental transition. These insights enhance our understanding of local habitat changes and are consistent with previous research (Dasti *et al*., 2007; Wazir *et al*., 2008; Saima *et al*., 2009; Shaheen *et al*., 2011; Khan, 2012; Khan *et al*., 2013).

Conclusion

Our study concluded that riparian vegetation plays an essential role in ecosystem services. Plants on riverbanks are not only important for resources like food, fuel, lumber, and medicinal uses, but also contain wild cousins that have stress and disease resistance qualities. Our findings revealed that various environmental gradients influence the composition and distribution of riparian flora. However, it is critical to understand that even species with negligible economic value perform essential ecological roles by aiding in erosion management, preventing floods and snow sliding, and regulating ecosystem services. We found that higher soil gradient values (e.g., pH, EC, TDS, Mg, Ca, Na, and K) correlated with increased abundance of therophytes, chamaephytes, hemicryptophytes, and geophytes. Therefore, we concluded that there is a direct relationship between the Raunkiaer life form and soil variables. Further research is needed to determine the cause of the association between soil factors and the Raunkier life form.

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