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Invasive Plants Diversity, Ecological Status, and Distribution Pattern in Relation to Edaphic Factors in Different Habitat Types of District Mandi Bahauddin, Punjab, Pakistan

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Highlights:

- Varied ecological circumstances of the range enlightening the suitable eco-zone for alien invasive species.
- Abiotic dynamics are supportive for exploring diversity patterns of alien invasive species.

Abstract: Our understanding of the diversity and distribution of living things is crucial to the conservation and sustainable use of biodiversity. Because biological invasions by alien species pose a significant threat to native biodiversity, tracking alien species at various geographical scales has recently gained prominence. The current study is designed to evaluate the diversity and composition of invasive plants in different habitats of Mandi Bahuddin, Punjab, Pakistan. The investigation explores the impact of environmental factors on the distribution of alien species in association with edaphic and geographic patterns. Diversity patterns, ecological impact, and the distribution of alien species with respect to environmental variables were recorded. A randomized sampling technique was used taking data from 120 sites with triplet quadrates in each, 360 overall, between 2019 and 2021 to record the data on alien flora and associated environmental variables. Important value indices for each alien species were determined with respect to environmental data, by cluster and ordination analysis. Overall, 43 invasive alien plants from 37 genera and 18 families were documented in the district Mandi Bahuddin. The prominent family was Poaceae with ten species (23.25%) followed by Leguuminosae with six species (13.95%), Compositae with five species (11.62%), Amaranthaceae with three species (6.97%), and Convolvulaceae, Euphorbiaceae, Malvaceae, Polygonaceae, and Scrophulariaceae with two species each (4.65%). Out of 65 alien species comprised herbs 52.13%, grasses 23.25%, shrubs 9.30%, and trees 9.30%. In case life form Therophyte (48.83%) was leading, followed by Chamaephyte with (16.27%) species, Nanophanerophyte and Megaphanerophyte with (11.62%) species each, Geophyte with (6.97%) species, and Hemicryptophyte with (4.65%) species. With leaf size spectra, microphylls (41.86%) were dominating and followed by mesophylls (27.90%), leptophylls (13.95%), nanophylls (11.62%), and macrophylls (4.65%). PCA was applied in order to further understand the species distribution and abundance pattern and to find significant connections among the species with sampling locations comprising various habitats. Ward's agglomerative clustering technique classified the one hundred and twenty transects into four major groups. Ordination analysis showed that different ecological factors had a significant ($p \leq 0.002$) influence on vegetation. The current study provides a foundation from which to comprehend the influences of environmental variables on alien plants' composition, diversity, structure, and links. These will be useful for developing scientifically informed management strategies for use by administrative agencies in the ecological restoration of the degraded habitat of the studied area.

Keywords: invasive alien species; diversity; environmental practices; Mandi Bahauddin

1. Introduction

Biological invasion [1] has been regarded as the key global change component responsible for biotic exchange and consequent homogenization of habitat. This invasion comprises the displacement of species by anthropogenic measures, once permanently established [2], with fast colonization and uncontrolled spreading [3] altering innate diversity, ecosystem services, and related functions. To manage and implement action policies, understanding and predicting invasion mechanisms is indispensable. Understanding the familiar pattern among different invasion cases has created a hefty quantity of literature concentrating on the inherent procedures of invaders, the tendency of local and natural communities to be invaded, and the association in distribution [4] and natural environmental features. This study has addressed inadequacies by enhancing our knowledge of invasion and improving the development of approaches used to screen and consistently predict invading mechanisms.

The chief challenge in predicting the geographical location of appropriate habitat for invasive species is to identify suitable links in both effective and ineffective invasion, e.g., biotic interaction with environmental factors. The establishment of a species in a region involves the intersection of (i) ecological conditions suitable [5] for survival and reproduction, (ii) biotic contacts that are not adequately harmful to create local extinction (i.e., adverse biotic factors such as competition, allelopathy, predation, disease, and lack of positive biotic interactions such as a lack of pollinators), and (iii) the capability of species to scatter to regions having favored ecological conditions and biotic factors [6]. This infers that the distribution of species could be, in some cases, securely achieved with environmental factors only, particularly in the non-presence of solid biotic relations [7]. Modeling a species distribution is challenging work, further complicated when trying to correlate the invasive species of a known environmental area (which comprises species existence records) to an unidentified environmental space (non-native geographical areas).

Exotic plant species are those that are new to the nation or a particular region and have been purposely introduced for reasons of economic gain, aesthetic appeal, or conservation without taking into account their ecological implications through trade or aid shipments [8]. The effects of biological invasion on the ecosystem and human health can be very diverse. Invasive plants in ecosystems have been known to change species composition and decrease species diversity, thus harming global biodiversity [9]. Threats to the environment and human health may arise as a result of the emergence of new invasive alien plant species (IAPS) in novel environments [10]. Recent worldwide environmental changes, particularly biotic invasions of flora and animals caused by land use and climate change, are impeding biomedical advancement to protect human health [11,12]. The ornamental and multipurpose invasive plants, which were intentionally or unintentionally introduced, subsequently spread and have a negative impact on ecosystems and human health. Invasive plants transform human health and the environment in a very complex way, which must be understood in order to develop integrated eco-restoration solutions [13].

Invasive alien species are exotic plant species [2] that have the capability to flourish, establish in new environmental conditions, and bring a lot of detrimental effects on native plants and their habitat. Accidental and deliberate introductions of these plant species are possible. According to the International Union for Conservation of Nature (IUCN) and Natural Resources [14], alien plant species establish themselves in a semi-natural ecosystem having greater adaptability to various environmental conditions and endanger the biological variety of the host species by competing for its resources and habitat. Trees and shrubs make up almost 0.5 to 0.7% of the world's species that are invasive and they can be introduced outside of their natural environment.

Natural groups and ecological features are altered dramatically by biological invaders. IAPS ecosystem changes have negative effects on human health because they change the natural healthy environment, ecosystem chain, and economic expenses. IAPS are degrading habitats and their native plant species by competing for the resources of native plants [10]. They use soil nutrients and occupy space preventing native flora from flourishing. Over time, there has been a noticeable increase in biotic invasions and some of the main reasons are the growing market globalization, increased international trade, rapid travel, and tourism industry [12]. Invasive plants are spreading throughout the protected zones of the Himalayan region, creating an alarming situation for wildlife by using nutrients and degrading their natural habitats.

Subtropical regions have always been inundated by invasive plants. Diverse and abundant vegetation may thrive there because of the diverse landscape and range of climate zones, which support the rich and diversified vegetation of this region [15]. Very few studies have reported on the diversity and distribution of invasive plants in Pakistan [16,17]; in addition, there is a research gap in the comprehensive investigation of invasive plants in subtropical regions of Pakistan. It is essential to comprehend the diversity, habitat, and origin of invasive species in order to implement effective invasive plant management [18,19]. This study attempted to: (i) evaluate the diversity and composition of invasive plants in different habitats of Mandi Bahuddin; (ii) investigate the impact of abiotic variables on the distribution of invasive plants in various habitats by using a multivariate approach; (iii) identify key invasive species in the study area for improved monitoring and ecological restoration of ecosystems.

2. Methodology

2.1. Study Area

District Mandi Baha-Ud-Din, situated between latitude 32°34′47′′ N and longitude 73°28′53′′ E, is bounded by the Chenab River separating it into the Hafzabad and Gujranwala districts. The Gujrat district lies towards the eastern side while on the northern side the Jhelum River [20] acts as a boundary separating Jhelum from the Sargodha district. The plain's alluvial areas have been changed into agricultural lands where major crops such as wheat, sugar cane, rice, and vegetables are grown. The silt and sandy areas are considered barren land (Figure 1).

2.2. Vegetation Sampling

To work out the plant diversity in the Mandi Bahuddin district of Punjab province, Pakistan, comprehensive field visits were conducted in the study area from 2019 to 2021. The entire district was divided into 120 grids based on topography, climate, physiography, and physiognomy. Each grid was subdivided into 3 sites based on the heterogeneity of the vegetation. In the research area, 360 sample sites were randomly selected for collecting quantitative phytosociological data. A total of 9 plots (3 alien species) were investigated at each sample site. To attain abundance data for individual plant species, quantitative phytosociological data, the rate of recurrence, cover values, density, and the significance value index were documented in every plot for each plant species, and the mean values for each of the 270 sampled quadrats were calculated. During field surveys, samples were gathered from the forest, wetland, grassland, mountain summits, arable land, dry land, roadsides, sandy area, and scrubby land in each site of the Mandi Bahuddin district. Triplet quadrats, each 1×1 m^2 in size, were laid in each study site randomly [19]. The important phytoecological data [21] such as the biological spectra (life form, leaf size), flowering seasons, and cultivation status of each plant were noted [5]. The geographic aspects such as altitude, latitude, and longitude for each site were determined by a Garmin eTrex, Global Positing System (GPS) [22] from district Mandi Bahuddin, Punjab, Pakistan.

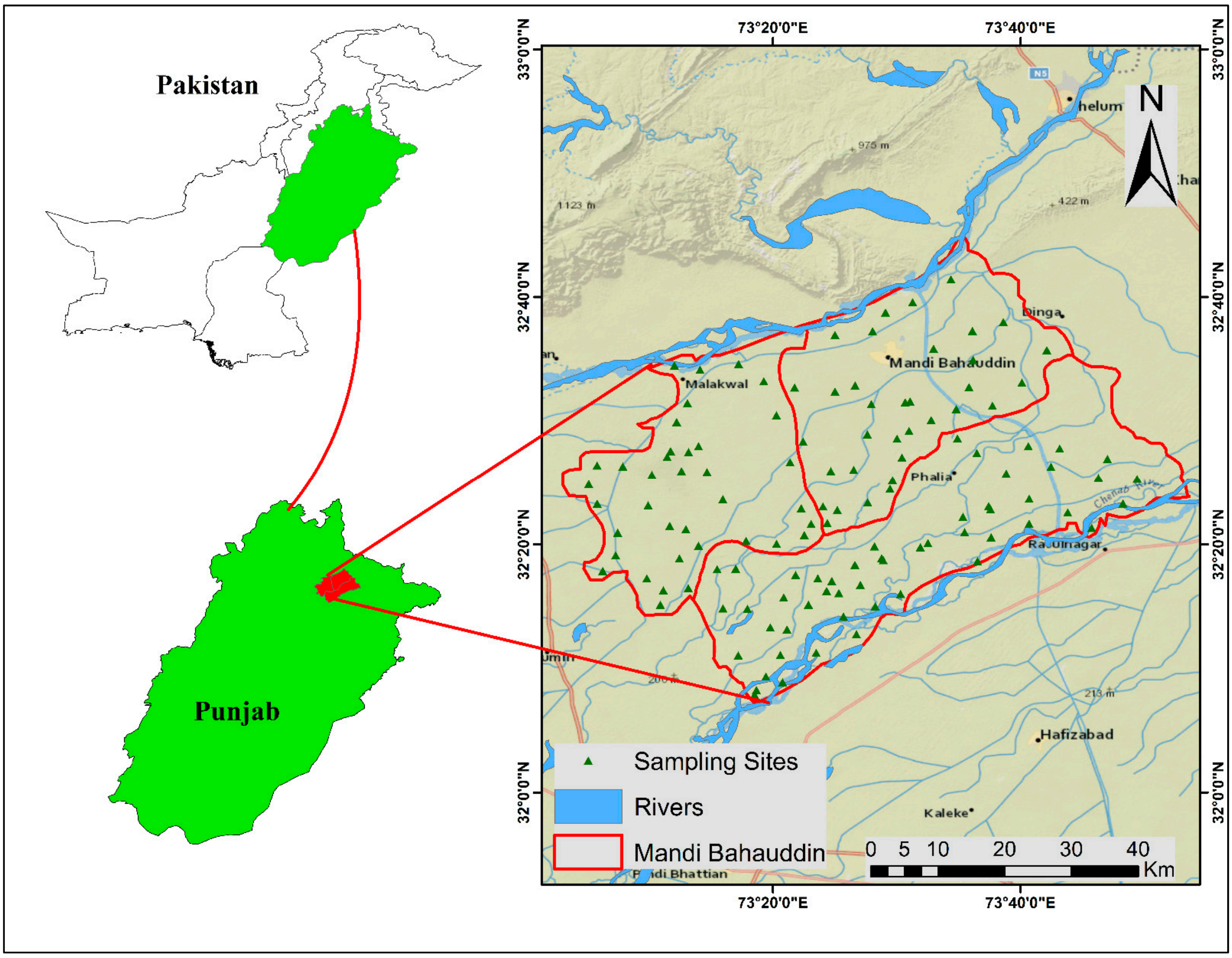

Figure 1. Study area map of district Mandi Bahauddin Punjab, Pakistan.

During the field surveys, grass specimens were taken, pressed, dried, photographed, and finally mounted on international standard-sized herbarium sheets [11]. All samples were cross-indexed with the floral literature [23] after identification following the Flora of Pakistan online (http://www.efloras.org/, accessed on 1 March 2021). To avoid any taxonomic confusion related to classifying species, binomials as well as the family nomenclature was used following the plant list ver. 1.1 (URL: http://www.theplantlist.org/ accessed on 6 March 2021) after the preliminary identification of specimens.

2.3. Soil Sampling

The location data of the plots under consideration were recorded by handheld GPS. The physicochemical qualities of the soil determine the spatial distribution of plant communities [24]. Soil samples were collected from a depth of 6 to 9 cm at each sampling site and placed in a polythene bag. The dust was well mixed, then air-dried, and rock, rubbish, and gravel particles which are larger than 2 mm in size were removed by sieving the soil samples [25]. Soil moisture, soil pH, electrical conductivity, organic matter, macronutrients such as calcium carbonate ($CaCO_3$), nitrogen (N), phosphorus (P), and potassium (K), and saturation were measured in the soil samples [26]. The electrical conductivity of soil samples was determined with a conductivity meter, while pH was determined by a pH meter. The total N was calculated following the Kjeldahl method [27], and the organic matter (OM) using the Walkley–Black method was determined [27]. The levels of P and K were calculated and $CaCO_3$ was assessed using the acid-base neutralization method. The Scal Tec moisture analyzer, which was set to 110 °C, was applied to measure the moisture content (MC) of soil samples. The percentage of saturation was estimated following the formula;

$$\% \text{ moisture} = \frac{\text{Wet soil} - \text{Dry soil}}{\text{Dry soil}} \times 100 \quad (1)$$

2.4. Ordination Analysis

The relative influence of each alien species in the established vegetative associations was evaluated by means of cluster analysis [28]. This study correspondingly helped in finding the diagnostic and sporadic plants of each floral category, as well as their degree of association with their corresponding groups. The results of the vegetation classification were confirmed by detrended correspondence analysis (DCA). The impacts of ecological variables in the alterations in the species data were further investigated by canonical correspondence analysis (CCA) [29]. Ward's technique and Euclidean distances were applied to locate precise pruning points for the dendrogram, as described by DCA and CCA, as were employed on the data sets to correlate alien vegetation structure with environmental factors [30].

2.5. Data Analysis

The collected phytosociological data for plants and environmental variables were organized and further processed in Microsoft Excel 2016 for subsequent analysis, following the CANOCO and PAST software [31]. The cluster analysis was based on the importance value index (IVI) of each wild grass type found in the 270 sampled spots. The optimum pruning point for the dendrogram was determined using Ward's technique and Euclidean distances [19]. PAST software (version 4.07) was used to cluster and calculate the diversity indices (Simpson's Index, Shannon–Wiener Index (H), species dominance, and species evenness) for each habitat type. CANOCO software of (version 4.5) [32], applied to perform CCA and DCA [19].

The overall working layout in this study is diagramed on the flow sheet in Figure 2.

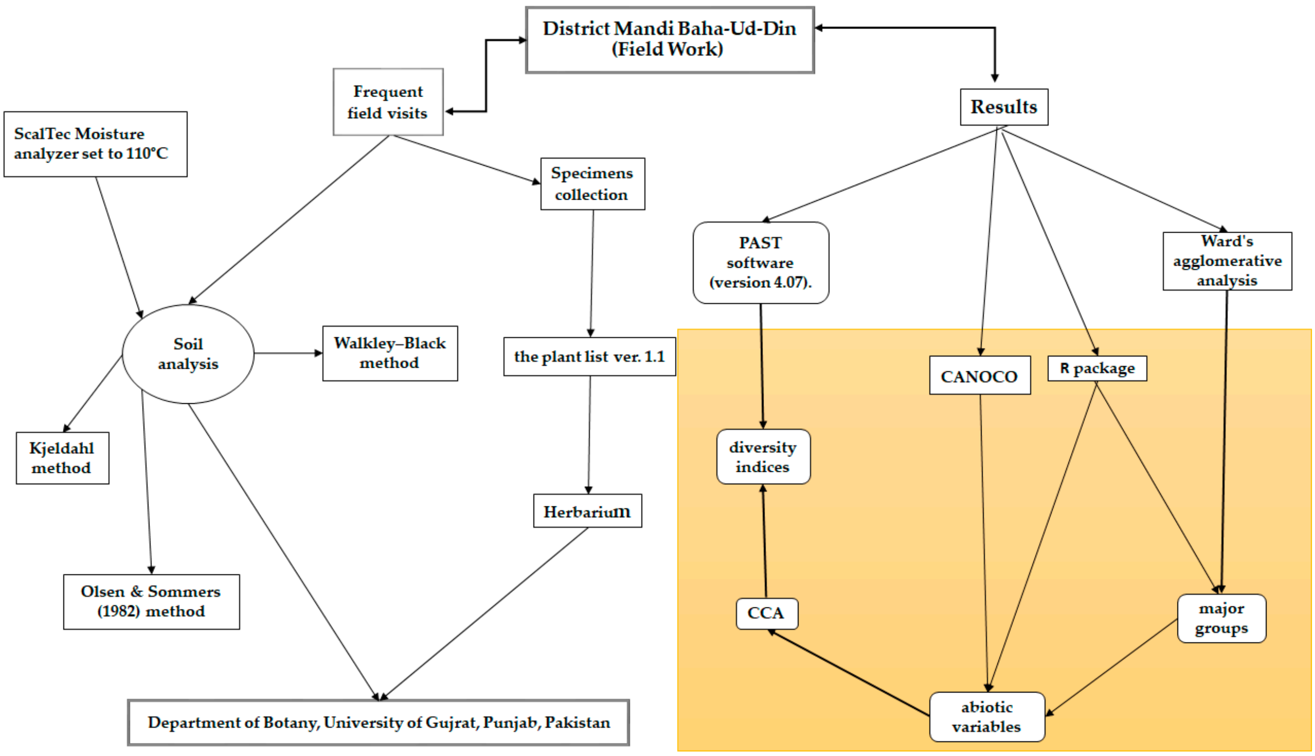

Figure 2. Flow-sheet diagram showing the overall working layout in this study.

3. Results

3.1. Diversity and Ecological Traits

As a whole, 43 invasive alien species from 37 genera and 18 families were recorded from the district Mandi Bahuddin. The leading family was Poaceae with ten species (23.25%) followed by Leguuminosae with six species (13.95%), Compositae with five species (11.62%), Amaranthaceae with three species (6.97%), and Convolvulaceae, Euphorbiaceae, Malvaceae, Polygonaceae, and Scrophulariaceae with two species each (4.65%), while the remaining families had a single species in each. Out of these, 52.13% of species were herbs, 23.25% were grasses, shrubs were 9.30%, and trees were also 9.30% (Figure 3).

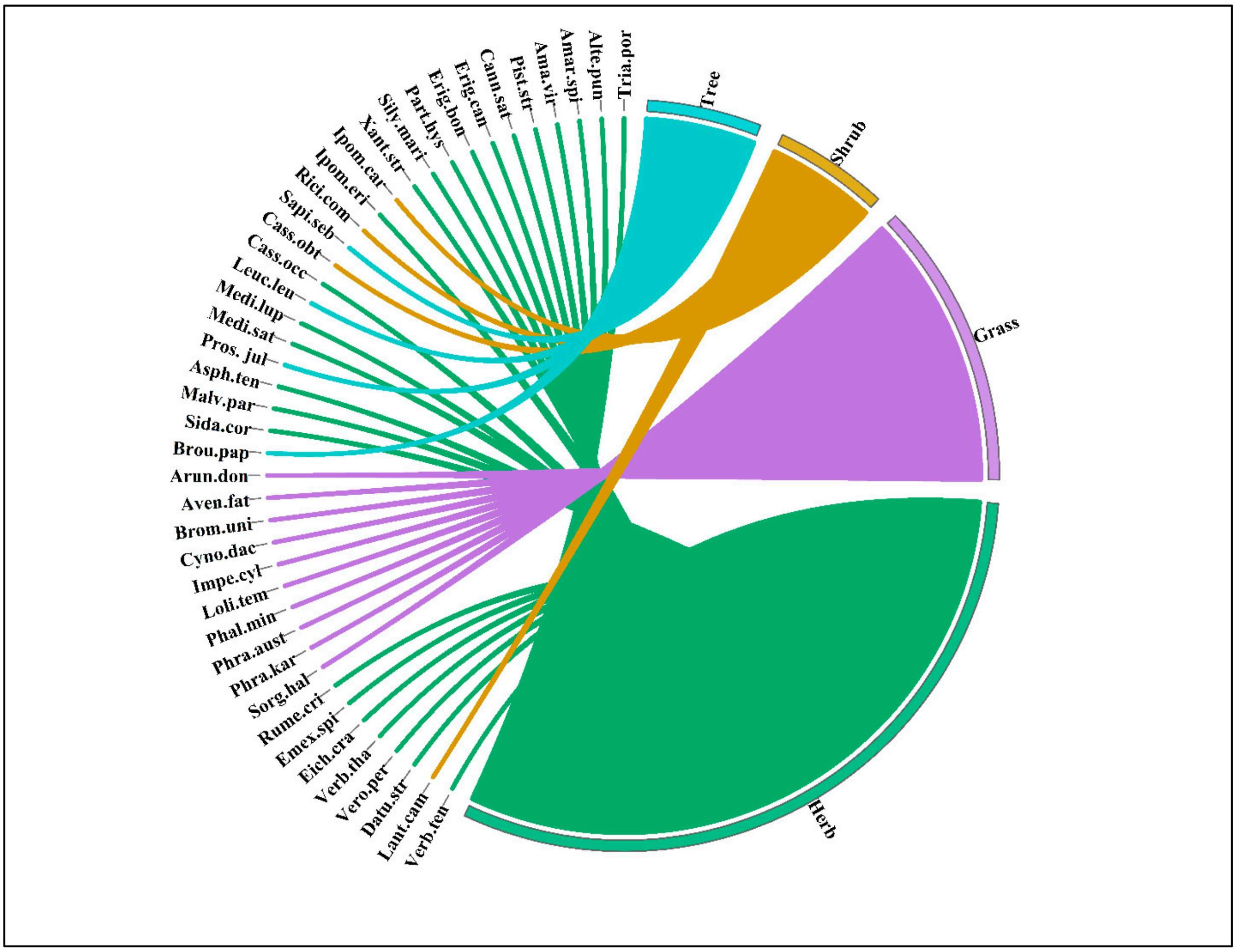

Figure 3. Chord diagram showing the habit-wise classification of invasive alien species in district Mandi Bahauddin.

The results of the life form classification showed that the leading life form was Therophyte (48.83%), followed by Chamaephyte with 16.27% of species, Nanophanerophyte and Megaphanerophyte with 11.62 of species each, Geophyte with 6.97% of species, and Hemicryptophyte with 4.65% of species. The dominant leaf size spectra of invasive alien plants were microphylls (41.86%) followed by mesophylls (27.90%), leptophylls (13.95%), nanophylls (11.62%), and macrophylls (4.65%) (Figure 4) (Table 1).

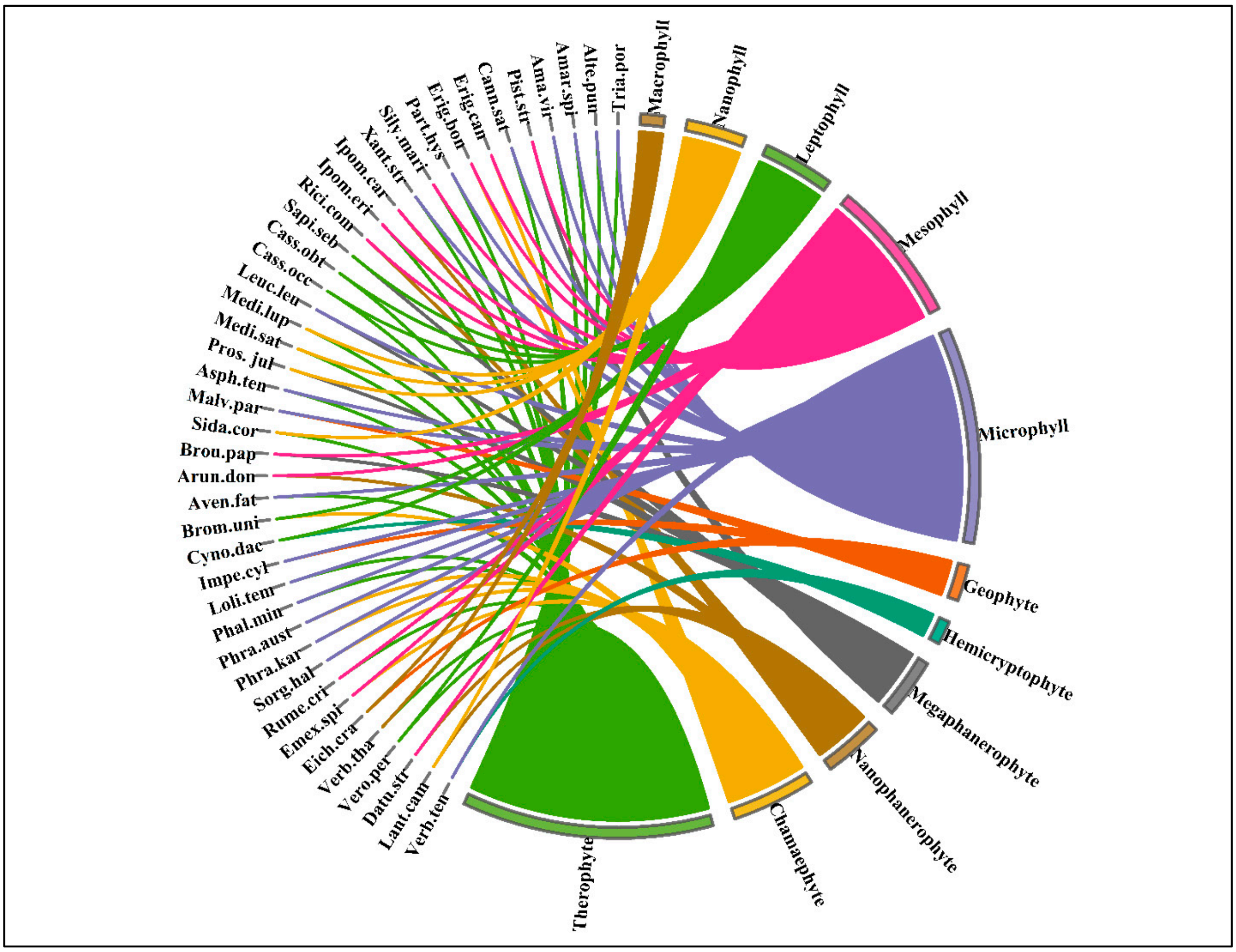

Figure 4. Chord diagram showing the ecological traits of invasive alien plants recorded from district Mandi Bahauddin.

Table 1. Invasive alien species list native range and habits recorded from district Mandi Bahauddin Punjab, Pakistan.

Family	Species	Species Codes	Native Range	Status
Aizoaceae	*Trianthema portulacastrum* L.	Tria.por	Tropical America	Herb
Amaranthaceae	*Alternanthera pungens* Kunth	Alte.pun	Tropical America	Herb
	Amaranthus spinosus L.	Amar.spi	Tropical America	Herb
	Amaranthus viridis L.	Amar.vir	South America	Herb
Araceae	*Pistia stratiotes* L.	Pist.str	South America	Herb
Cannabaceae	*Cannabis sativa* L.	Cann.sat	Central Asia	Herb
Compositae	*Erigeron canadensis* L.	Erig.can	North-Central America	Herb
	Erigeron bonariensis L.	Erig.bon	North-Central America	Herb
	Parthenium hysterophorus L.	Part.hys	North-Central America	Herb
	Silybum marianum(L.) Gaertn.	Sily.mar	China	Herb
	Xanthium strumarium L.	Xant.str	North America	Herb

Table 1. *Cont.*

Family	Species	Species Codes	Native Range	Status
Convolvulaceae	*Ipomoea carnea* Jacq.	Ipom.car	Tropical America	Shrub
	Ipomoea eriocarpa R. Br.	Ipom.eri	Tropical Africa	Herb
Euphorbiaceae	*Ricinus communis* L.	Rici.com	Africa	Shrub
	Sapium sebiferum (L.) Roxb	Sapi.seb	Japan, China	Tree
Leguminosae	*Cassia obtusifolia* L.	Cass.obt	Australia	Shrub
	Cassia occidentalis L.	Cass.occ	South America	Herb
	Leucaena leucocephala (tant.) De wit.	Leuc.leu	Mexico, Central America	Tree
	Medicago lupulina L.	Medi.lup	Eurasia	Herb
	Medicago sativa L.	Medi.sat	North Africa	Herb
	Prosopis juliflora (Sw.) DC.	Pros.jul	North and South America	Tree
Liliaceae	*Asphodelus tenuifolius* Cavan. L.	Asph.ten	Mediterranean	Herb
Malvaceea	*Malva parviflora* L.	Malv.par	Europe	Herb
	Sida cordata Blumea	Sida.cor	India	Herb
Moraceae	*Broussonetia papyrifera* (L.) L'Herit. ex Ven	Brou.pap	South-East Asia	Tree
Poaceea	*Arundo donax* L.	Arun.don	Africa	Grass
	Avena fatua L.	Aven.fat	Eurasia	Grass
	Bromus unioloides Kunth	Brom.uni	Africa	Grass
	Cynodon dactylon (L.) Pers.	Cyno.dac	Australia	Grass
	Imperata cylindrica (L.) Raeuschel.	Impe.cyl	Europe	Grass
	Lolium temulentum L.	Loli.tem	Mediterranean	Grass
	Phalaris minor Retz.	Phal.min	Europe	Grass
	Phragmites australis (Cay.) Trin. ex Steud.	Phra.aus	Australia	Grass
	Phragmitis karka (Retz.) Trin. ex Steud	Phra.kar	Africa	Grass
	Sorghum halepense (L.) Pers.	Sorg.hal	Americas	Grass
Polygonaceae	*Rumex crispus* L.	Rume.cri	Europe	Herb
	Emex spinosus (L.) Campd.	Emex.spi	Mediterranean	Herb
Pontederiaceae	*Eichhornia crassipes* (Mart.) Solms.	Echh.cra	Africa	Herb
Scrophulariaceae	*Verbascum thapsus* L.	Verb.tha	Eurasia	Herb
	Veronica persica Poir.	Vero.per	Europe	Herb
Solanaceea	*Datura stramonium* L.	Datu.str	North-Central America	Herb
Verbenaceae	*Lantana camara* L.	Lant.cam	Americas	Shrub
Verbinaceea	*Verbena tenuisecta* Briq	Verb.ten	South America	Herb

3.2. Principal Component Analysis

PCA was applied in order to further outline the species distribution and abundance patterns of the invasive alien species. The analysis was done on the plant data set to find significant connections among the species with sampling locations of various habitats. The first principal component (PC1) of the PCA, based on the species importance value index, accounted for 13.5% of explained variations, with grassland and arable land habitats clearly differentiating from the forest, riverine, and scrubland habitats (Figure 5). The second component (PC2), which was primarily influenced by forest habitat, riverine, and scrubland habitat accounted for 9.1% of the explained variation. The grassland habitats show the highest value in PC1 while the forest habitat shows the highest value in PC2.

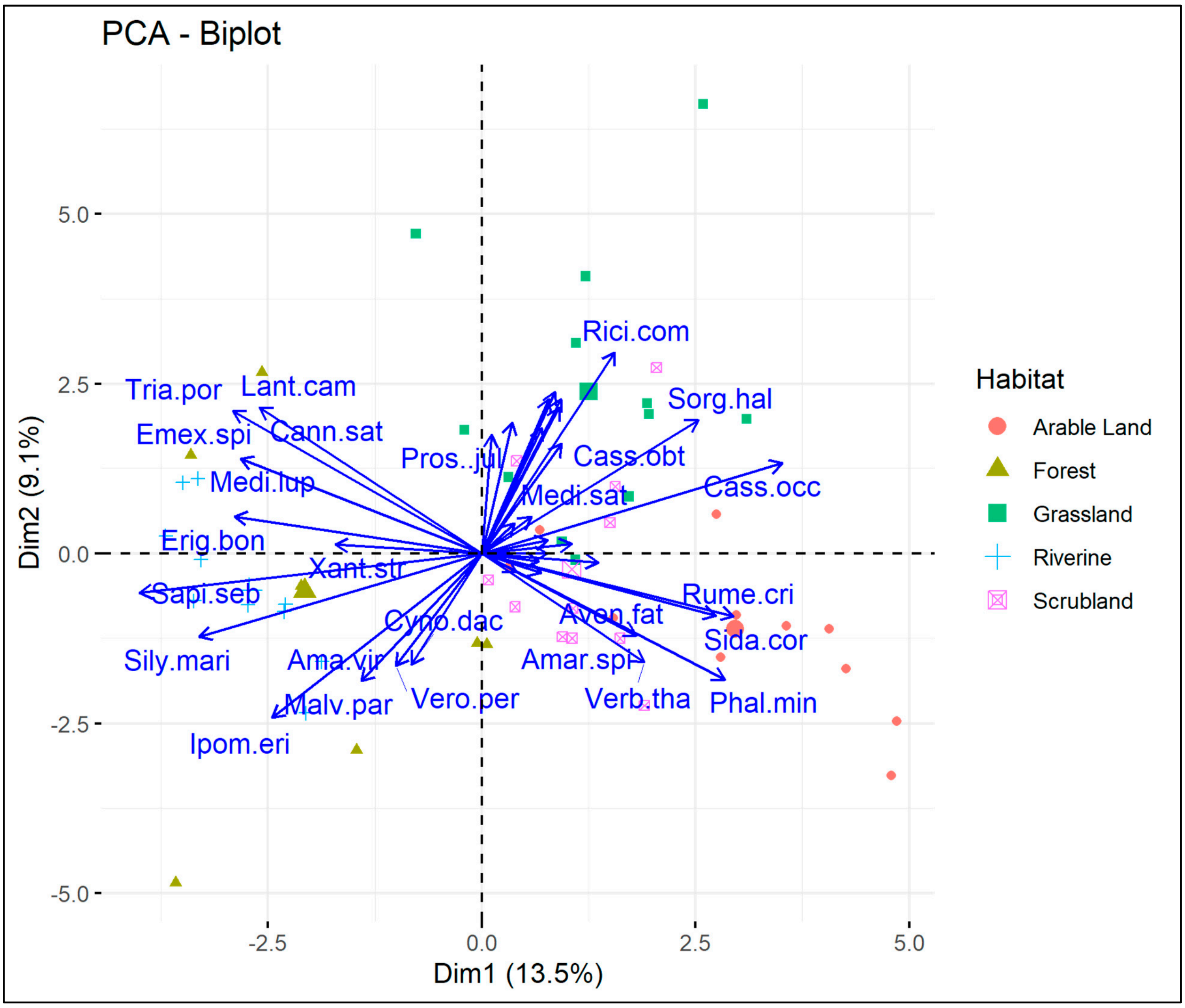

Figure 5. Principal component analysis based on importance value index of sampling sites in different habitats. The grassland and arable land habitats are similar in species composition while the riverine and scrubland habitats are more similar to forest habitat.

The invasive alien species in the first main component of the PCA biplot indicated that the species were considerably more prevalent in arable land, grassland, and scrubland habitat. The most prominent species in these habitats included *Sorghum halepense*, *Rumex crispus*, *Sida cordata*, *Verbascum thapsus*, *Phalaris minor*, *Avena fatua*, *Amaranthus spinosus*, *Erigeron bonariensis*, *Cassia occidentalis*, *Medicago sativa*, *Asphodelus tenuifolius*, *Prosopis juliflora*, and *Parthenium hysterophorus* (Figure 5). In forest and riverine habitats, the most frequent species were *Lantana camara*, *Cannabis sativa*, *Trianthema portulacastrum*, *Silybum marianum*, *Xanthium strumarium*, *Sapium sebiferum*, *Malva parviflora*, *Broussonetia papyrifera*, *Arundo donax*, *Imperata cylindrical*, *Phragmites australis*, *Eichhornia crassipes*, *Datura stramonium*, *Cynodon dactylon*, *Emex spinosus*, and *Medicago lupulina*.

3.3. Diversity Indices

The diversity indices show significant differences in alien invasive species from different habitat types. The highest dominance index was recorded from scrubland and forest habitat. These two habitats significantly differed from riverine, arable land, and grassland habitats. Similarly, the species evenness also shows significant differences between the habitat types, with the maximum species evenness recorded from scrubland sampling sites (Figure 6). The maximum Shannon and Simpson diversity was also observed in the scrubland habitat proving that the scrubland habitat is more vulnerable to invasive species.

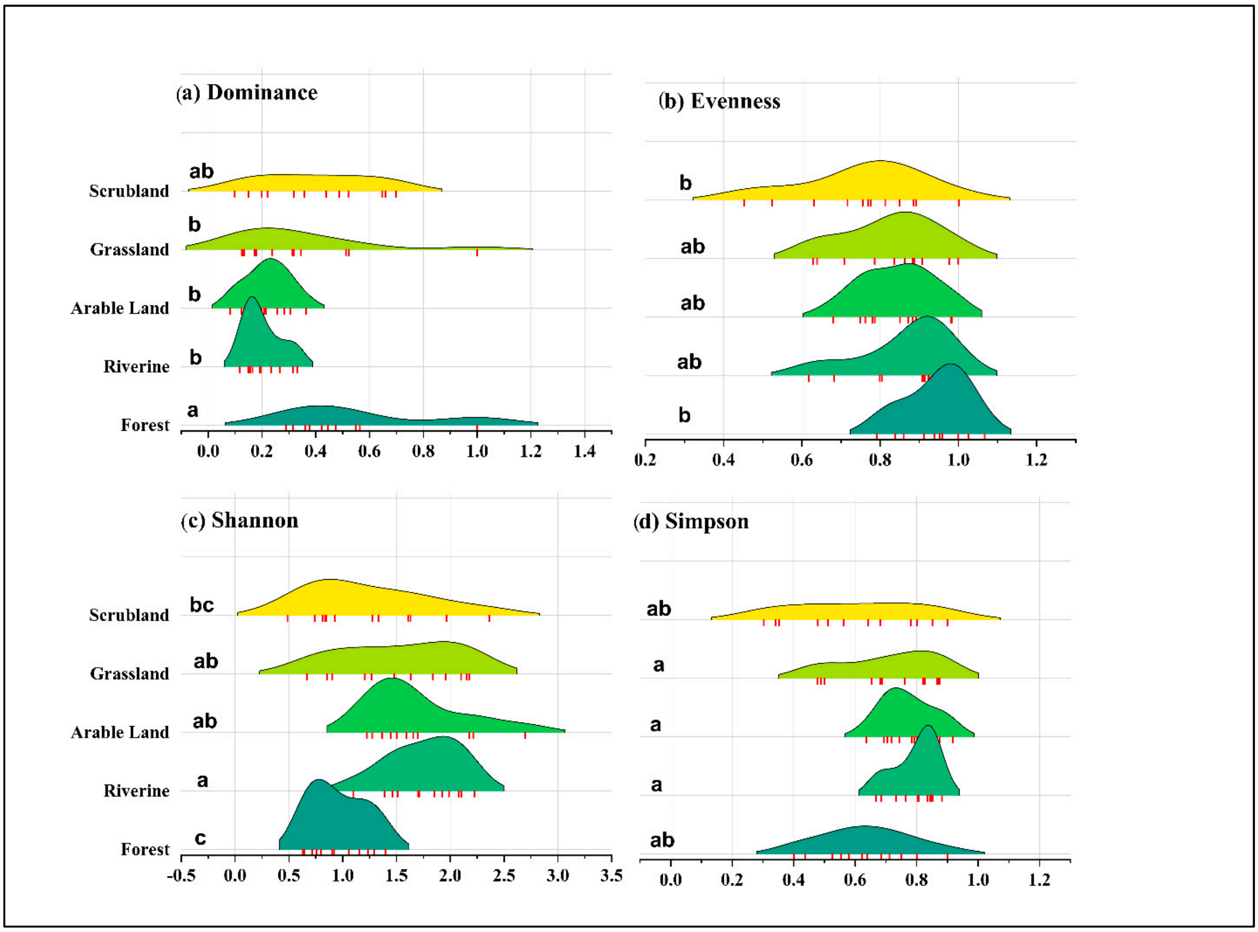

Figure 6. Various diversity indices of invasive alien plants recorded in different habitat types in district Mandi Bahauddin, Punjab, Pakistan. The ridgeline diagram represents the diversity in sampling sites with letters of significant difference between different habitat types from performed Tukey test.

3.4. Correlation of Edaphic Factors

Data from various edaphic factors were correlated, and the results showed some significant negative and positive relationships between them. Soil moisture and soil pH showed a positive correlation, whereas pH and soil organic matter showed a negative correlation. The correlation plot between the soil factors is shown in Figure 7.

3.5. Role of Edaphic Factors on the Distribution of Invasive Alien Species

The CCA ordination makes it evident that applicable environmental factors such as pH, moisture, soil saturation, organic matter, N, P, K, and $CaCO_3$ have a significant impact on how species are distributed. Each triangle represents a distinct species of invasive alien plant, with the distance between them showing how similar they are to one another. The species in the first quadrat were under the influence of soil organic matter and potassium, while the species in the second quadrat were influenced by soil moisture, $CaCO_3$, and pH. The distribution of invasive alien species in the third quadrat was impacted by soil nitrogen. The distribution of invasive alien species found in the fourth quadrat of the CCA diagram was controlled by P, soil saturation, and electrical conductance (Figure 8).

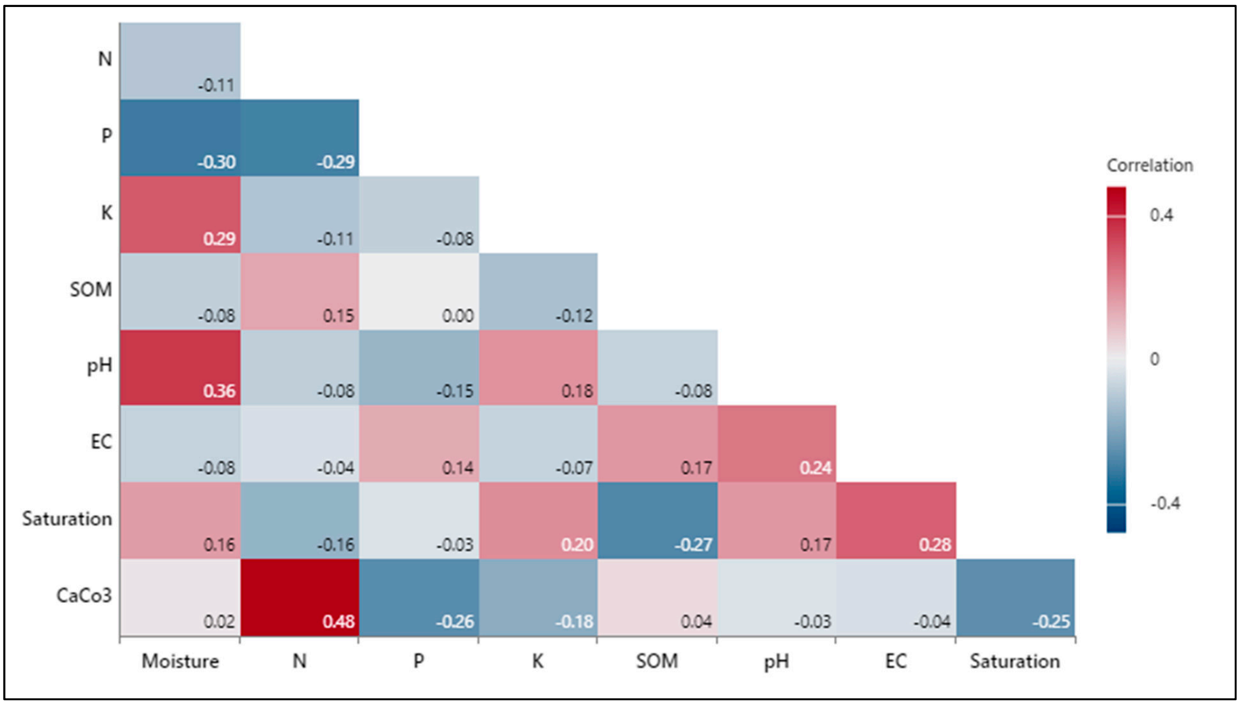

Figure 7. Correlation plot among various edaphic factors.

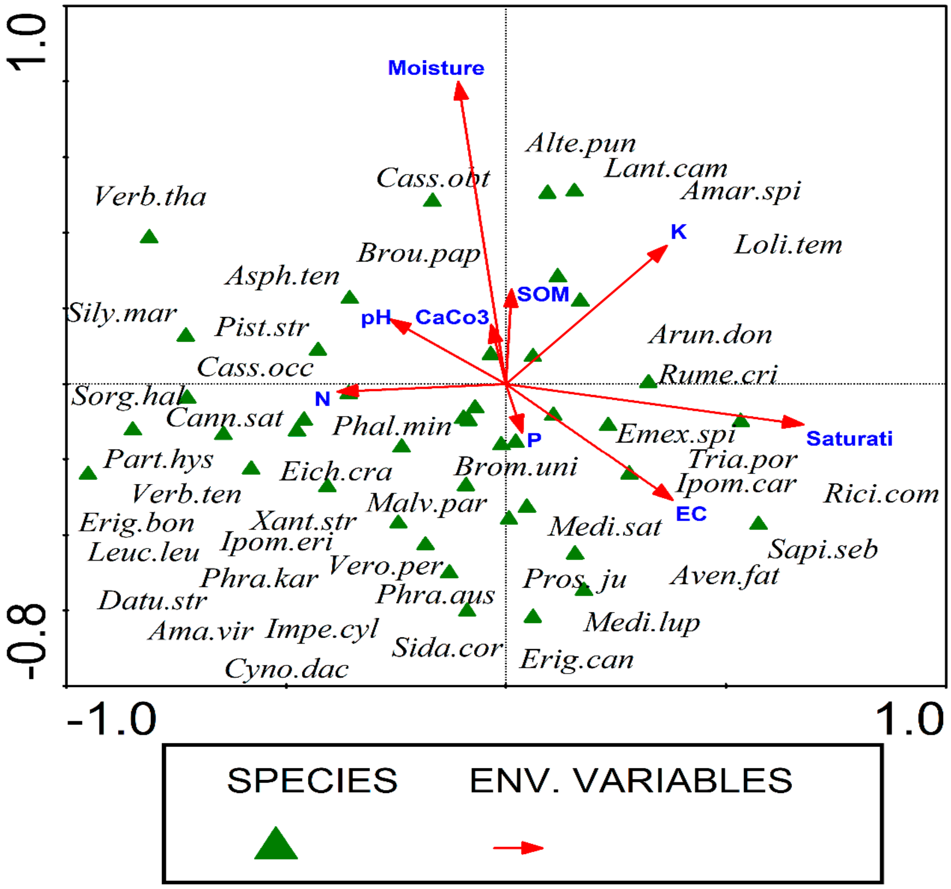

Figure 8. CCA biplot of edaphic factors and invasive alien species in district Mandi Bahauddin, Punjab, Pakistan.

Figure 8 also outlines the species that are sensitive to P, soil saturation, and electrical conductance (EC). These include *Trianthema portulacastrum*, *Emex spinosus*, *Sapium sebiferum*, *Ricinus communis*, *Ipomoea carnea*, *Medicago sativa*, *Prosopis juliflora*, *Avena fatua*, *Bromus unioloides*, and *Erigeron canadensis*. A soil's N concentration also has an impact on the distribution of invasive alien plants; however, the species that are positively associated with their values comprise *Cannabis sativa*, *Sorghum halepense*, *Phalaris minor*, *Parthenium hysterophorus*, *Erigeron bonariensis*, *Leucaena leucocephala*, *Xanthium strumarium*, *Ipomoea eriocarpa*, *Amaranthus viridis*, *Cynodon dactylon*, *Imperata cylindrica*, *Datura stramonium*, *Phragmitis karka*, *Phragmites australis*, *Veronica persica*, and *Sida cordata*. The species impacted by moisture, pH, and $CaCO_3$ include *Verbascum thapsus*, *Cassia obtusifolia*, *Cassia occidentalis*, *Silybum marianum*, *Broussonetia papyrifera*, *Pistia stratiotes*, and *Asphodelus tenuifolius*. The species that were sensitive to K and soil organic matter (SOM) include *Alternanthera pungens*, *Amaranthus spinosus*, *Lantana camara*, *Lolium temulentum*, *Arundo donax*, and *Rumex crispus*.

The first axis identified 5.6 variations, the second, 10.5, and the third and fourth, 13.2–15.7 of the total variation, indicating that N, P, soil saturation, and electrical conductance have a strong relationship with the third and fourth axes and have a significant impact on the diversity patterns of invasive alien species (Table 2).

Table 2. Summary of CCA analysis of invasive alien species in district Mandi Bahauddin.

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.33	0.287	0.158	0.148
Species-environment associations	0.779	0.848	0.666	0.684
Accumulative percentage variance of wild grass species data	5.6	10.5	13.2	15.7
Accumulative percentage variance of species-environment relation	25.5	47.7	59.9	71.4
Total inertia	5.885			
Sum of all eigenvalues	5.885			
Sum of all canonical eigenvalues	1.294			
Monte-Carlo test				
Test of significance of first canonical axis: eigenvalue	0.330			
F-ratio	2.910			
***p*-value**	0.0020			
Test of significance of total canonical axes; Trace	1.294			
F-ratio	1.534			
***p*-value**	0.0020			

4. Discussion

Human pressures from development activities and other biotic components have been shown to influence ecological processes at both the landscape and local patch scale, impacting species composition and habitat attributes on different scales [20]. The habitat type directly selects useful features and eliminates species with traits that are inappropriate for that habitat [33]. Information on the direct physiological adaptations of plants to specific habitats can be learned from the study of functional features. In the current investigation, 43 species from 18 families have been identified. The species identified in this study are similar to those reported by other researchers in other Himalayan locations [17]. Most of the species belonged to the families Poaceae, Leguminosae, Compositae, and Amaranthaceae than any other. The Poaceae family members have a vast ecological amplitude, which contributes to their different habitats. Previous researchers discovered that the aforementioned groups were prevalent in certain other Himalayan regions [34]. The biological spectrum is an important physiognomic characteristic that is frequently used for vegetation study. It shows how plants have adapted to their micro- and macro-climates.

Therophytes, hemicryptophytes, and geophytes were the most prevalent life form classes, which shows how plants have adapted to changing environmental conditions, particularly the climate. The conclusions of the current investigation are supported by the findings of [35]. Therophytes, which predominate in the research area and are typically connected to unfavorable dry climatic conditions, are an adopted strategy for survival and are a sign of significant human disturbances. The current findings support [36], who claimed that therophytes dominated their study area.

As a result of the construction of transportation corridors, invasive alien species were unintentionally introduced into the region, opening up new prospects for their dissemination. The majority of invasive plants were recorded from scrubland and forest habitats, showing that these habitats have been altered by human activity. The results are comparable to Naz et al. [37] who reported similar invasive species from the Potohar region of Pakistan. By creating other distributed habitats and building linear corridors, unintentionally introducing alien species into the sub-urban area opens up new pathways for the spread of alien plants. In general, organisms with wide realized niches are more likely to evade these filters and, following a disturbance, invade other environments. As a result, the disturbances aid in the invasion of non-native species [38], especially given that they are becoming more frequent and intense on both a local and a global level as a result of anthropogenic factors such as changing temperature and land usage. The most common invasive species in the study area include *Prosopis juliflora*, *Leucaena leucocephala*, *Xanthium strumarium*, *Phragmitis karka*, *Broussonetia papyrifera*, *Lantana camara*, and *Arundo donax*. These species have also been reported as foreign invaders in subtropical regions by other researchers [16,30,35].

The gradient of environmental stress in the study region had a considerable effect on plant invasion patterns, and the soil properties had a significant impact on the distribution of invasive plants in different habitat types. The findings of this investigation showed that different habitat types had significantly varying soil physicochemical properties due to climatic conditions, geography, microbial activities, weathering processes, and plant cover [31,36]. Edaphic properties of various habitats change throughout time and space. The quality of soil varies across short distances depending on the vegetation types, landscape patterns, and parent rock. A great variety of soil types and their chemical, physical, and biological features can result from the bioclimatic conditions in the Himalayan terrain changing swiftly and over short distances [36]. We discovered that edaphic characteristics, such as soil texture and chemistry, emerged as important predictors of plant composition in addition to climatic parameters like temperature and precipitation. Other studies have suggested similar connections between soil edaphic characteristics and plant species composition, which can be explained by the fact that local edaphic characteristics influence the resource availability of water and nutrients in various soil types, selecting plant communities with a variety of ecological functions [39,40].

Alien plant species become invasive, whether accidentally or deliberately [40], and become accustomed to environments [41] outside of their natural range where they invade and compete with local plants at a fast rate of growth [2]. Alien plant species are diversified all around the world in different geographical locations [41]. Invasive plants [7] are most common in terrestrial ecosystems [35]. Although Pakistan has long had exotic plants introduced in the region, thorough research on invasive species, particularly in the subtropical region [42], is still lacking. As a result, there are no data sets or a database for invasive alien plants available with complete information in Pakistan. This study focused on documenting invasive alien plants in the Lesser Himalayan region of Pakistan [25]. This investigation of invasive plant species will establish the foundation for future investigations into the preservation of native and unaltered forest plants in Pakistan's subtropical regions.

The majority of invasive plant species in the subtropical regions of Pakistan are from the Asteraceae and Poaceae families. The same invasive plant families [43] dominated the Indian Himalayan Himachal Pradesh area [44]. Studies in Europe and China observed patterns that are comparable to the dominant family in invasive flora [5,45], but our findings demonstrate that the families Euphorbiaceae and Fabaceae also made an equal contribution to the Poaceae (seven plant species each).

This study suggests that the majority (almost 51%) of the invasive plants of subtropical regions [46] in Pakistan belong to Continental America as suggested and Chandra was in agreement with 59% of recorded plants being perennials and 60% being herbs. While 11 species of ornamental plants were intentionally introduced in the area and these results are justified, 41 plant species recorded were unintentionally introduced to the area. The escape of these plant species brings a lot of serious consequences for the area and leads to serious threats to biodiversity. It was found that most invasive alien plant species are abundant in subtropical regions of Pakistan, as compared to higher regions, suggesting that these species are capable of flourishing at low altitudes so species diversity decreases from low to higher altitudes [47].

5. Conclusions

The current study sheds light on the extent of invasive alien plant species in the Lesser Himalayan (low altitude) zone of Pakistan. Overall, 43 invasive alien species from 37 genera and 18 families were documented from the district Mandi Bahuddin. The prominent family was Poaceae with ten species (23.25%) followed by Leguuminosae with six species (13.95%), Compositae with five species (11.62%), and Amaranthaceae with three species (6.97%). PCA was used to find significant connections among the species with sampling locations of various habitats. The maximum Shannon and Simpson diversity of invasive plants was observed in the scrubland habitat proving that the scrubland habitat is more vulnerable to invasive species. Introduced species cause adverse effects on the local plant species, habitat, and ecosystem functioning, which causes an imbalance and loss in genetic diversity. Invasive alien plants use the resources of native plants resulting in the extinction of species and huge economic losses. It is recommended, and hoped, that the listing and collection of invasive alien plant species in this subtropical region of Pakistan will have a great impact and help fill the study gap, leading future scientists to study the alien invasive flora of the region. Analysis will provide maximum help for management policies on invasive species.

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