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DYNAMIC INTERCHANGE BETWEEN FLORISTIC COMPOSITION AND INDUSTRIAL POLLUTION: AN ECOLOGICAL PERSPECTIVE

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Abstract

The distribution of plants over the earth's surface is not even or random but follows a particular geographical pattern. The variation in the floristic composition of plants can be attributed to various environmental factors. The current study was conducted in Sialkot, Pakistan, a prominent industrial hub of the country, to assess the impact of industrial pollution on floristic composition. Vegetation was sampled using standard quantitative ecological techniques. A total of 150 quadrats were established across three sites based on pollution gradient. The soil samples from each quadrat were examined using standard laboratory techniques to assess various physicochemical parameters and the concentration of heavy metals. The collected data were analyzed using PCORD and CANOCO software. Our findings indicate that this region exhibits a diverse range of plants from twenty-eight phytogeographic regions, highlighting its rich biodiversity. The most dominant phytogeographic elements were Cosmopolitan (13.3%), followed by Tropical (10.7%) in contrast, the least dominant ones were Western Himalayan, Sub-cosmopolitan, Sino-Japanese, sub-Himalayan, Indo-Chinese, etc., each represented by one member. Poaceae was the dominant family represented by 19 species (13%), followed by Asteraceae 18 (13%). We observed that floristic diversity decreased as we moved from a less polluted area to a more polluted area. In addition, local residents of the region dispose of cow dung and other household waste along the study region. This adds organic matter and heavy pollutants, coupled with industrial waste, to the environment and has a crucial impact on the distribution of phytogeographic elements in this region. Therefore, we believe industrial pollution has a remarkable role in the distribution of phytogeographic elements. It is suggested that Irano-Turanian and Tropical elements distributed in our study should be protected because of their narrow geographic range.

Key words*:* Phytogeography, Floristic regions, Phytodiversity, Industrial pollution, Cosmopolitan and Tropical.

Introduction

Phytogeography is the study of plant spatial interactions in the present and past. (Wickens, 2008), focusing on explaining the range of plants in terms of origin, dispersal, and evolution (Tekleva *et al*., 2021). Plants and geographical units are dispersed in a particular pattern on the surface of the earth as a result of numerous environmental variables (Zeb *e al*., 2021), such as habitat characteristics, hydrology, topography, soil types, and climate change (Badshah *et al*., 2010; Manan *et al*., 2020; Pearson & Dawson, 2003). Environmental factors are the main drivers that govern species distribution directly if their values change beyond the eco-physiological tolerance level of the species of an area (Thammanu *et al*., 2021; Wittlinger & Petrikovičová, 2021). It is necessary to understand the extent to which these factors play a role in the floristic composition of an area. Industrial pollution is one of the most critical factors in determining the vegetation of an area. It is argued that changes in the environmental conditions may cause the extinction of some species in the subtropical region, which will significantly affect the diversity and, hence the ecosystem (Deb *et al*., 2018). To conserve biodiversity, one should better understand an area's phytogeographic distribution and floristic inventory of vegetation (Harris *et al*., 2012; Jehangir *et al*., 2024; Qian, 2001; Zandebasiri *et al*., 2024). The impact of natural vegetation in geographic locales extends significantly beyond the influences of climate, geology, and soil typologies as it increasingly grapples with the pervasive effects of anthropogenic activities, notably environmental pollution (Chernen'kova, 2014; Ejaz *et al*., 2024). This pollution, arising from diverse sources such as industrial emissions, waste disposal practices, and the release of effluents, catalyzes profound and rapid transformations within natural ecosystems (Bayouli *et al*., 2021). These transformations are characterized by marked changes in ecosystem structure, functionality, and species composition, thereby establishing pollution as a dominant and disruptive force within the natural environment (Haq *et al*., 2020). The detrimental impacts of pollution are particularly evident in industrial activities, where the improper disposal of waste materials, especially those associated with mineral extraction processes, triggers a cascade of environmental repercussions. As elucidated by (Banerjee *et al*., 2019), industrial pollution exerts a direct and far-reaching impact on natural vegetation, precipitating rapid alterations in the ecological balance. This scenario accentuates the critical need for developing, implementing, and rigorous enforcement of environmental regulations and pollution control mechanisms, emphasizing international collaboration and compliance (Ahriz *et al*., 2010).

Our study area Sialkot, Pakistan, has reported that with increasing industrialization, certain plant species disappear altogether from an ecosystem and are replaced by others (Naeem *et al.*, 2021; Treshow, 1980). The rapid industrialization of Sialkot city over the past 20 years has made it particularly vulnerable to environmental pollution (Khalid *et al.*, 2021a). The city is well-known throughout the world for its ceramics, leather goods, sports equipment, processed foods, and surgical instruments. One estimate list 92 tanning factories, 244 leather clothing and product manufacturing facilities, over 900 leather sportswear manufacturing facilities, 57 rice husking facilities, and 14 flour mills (Qadir *et al.*, 2008). There is no adequate handling of waste from cities and industries. Solid waste and effluents are discharged directly or indirectly into open fields, canals, ponds, and natural streams without prior treatment (Naeem *et al.*, 2021). Researchers have studied the influence of industrial pollution on the vegetation of this area. Heavy metal pollution in the soil of Sialkot industrial zone is considered responsible for a negative impact on the growth of various plants (Jadoon & Malik, 2019; Khalid *et al.*, 2021b; Malik *et al.*, 2010a; Nazer *et al.*, 2006; Qadir & Malik, 2009; Ullah *et al.*, 2009). However, no literature is available on the phytogeography and floristic composition of the Sialkot region and the phytogeography and floristic composition of the Sialkot region. It was hypothesized that phytogeographical elements represent specific environmental conditions, but the changing environment has a significant role in reshaping the characteristic vegetation. This study aimed to achieve the following objectives: firstly, to offer a comprehensive global understanding of the examined region in terms of phytogeography, secondly, to explore the relationship between soil nutrients and various phytogeographic elements; and finally, to assess the impact of industrial pollution on the floristic composition of the area under consideration.

Material and Methods

An extensive study was conducted in Sialkot, Pakistan. It is situated in between the latitudes of 32.240°N and 32.370°N and the longitudes of 73.590°E and 75.020°E (Fig. 1). The city is located at a height of 244 meters above sea level. It has a population density of 4.5 million people (Anon., 2023). The climate in this area is known for its humid summers, winters and an average yearly rainfall of approximately 1,000 mm (Junaid *et al.*, 2016). Most of the rain falls during the monsoon season leading to the formation of deposits, on the flat plains. (Qadir & Malik, 2009). The alluvial soils here are of recent quaternary origin, predominantly composed of loamy and silty loam soils (Malik *et al.*, 2010b).

This city is well-known for manufacturing sports goods, leather garments, and surgical instruments. (Qadir *et al.*, 2008a). The ecological integrity of this city is deteriorating over time, primarily due to untreated industrial waste, particularly from the leather industry (Abbas *et al.*, 2008). The waste that these industries release includes both organic and inorganic materials, toxic substances like heavy metals, synthetic oils, resins, biotoxins, and disinfectants (Garai, 2014; Maqbool *et al.*, 2018; Rabelo *et al.*, 2018; Tariq *et al.*, 2010) (Dixit *et al.*, 2015; Islam *et al.*, 2014; Jerry *et al.*, 2011). This region has been found to contain high concentrations of heavy metals like chromium, lead, cadmium, mercury, copper, zinc, nickel, and arsenic, according to many researchers (Jadoon & Malik, 2019; Khalid *et al.*, 2021b; Lokhande *et al.*, 2011; Malik *et al.*, 2010b; Qadir & Malik, 2009; Qadir *et al.*, 2008a). Due to its increasingly severe pollution burden, the region needs to be thoroughly studied regarding its phytogeographical composition.

A comprehensive comparison of the area was ensured by randomly selecting a total of 150 stations. For the sampling of vegetation, quadrat quantitative ecological methods were employed at three distinct sites, categorized based on pollution gradients as Less Polluted Zones (LPZ), Highly Polluted Zones (HPZ), and Moderately Polluted Zones (MPZ) (Fig. 1). Employing quadrat ecological methods as outlined by (Khan *et al.*, 2013) the sizes for sampling were designated as follows: trees were allocated a quadrat size of 20m x 20m, shrubs a size of 4m x 4m, and herbs a smaller size of 1m x 1m. Vegetation samples were collected from each quadrat. Various phytosociological variables, including cover, density, frequency, and important value index, were recorded for each plant species following the methods provided by (Jehangir *et al.*, 2024; Khan *et al.*, 2017). For trees, Cover was measured at the stem's basal area using Diameter at Basal Height.

BA= <pi>r2

where BA is Basal Area, r is a radius, and <pi>= 3.14

Plants were gathered, placed in blotting sheets, pressed using a plant presser, labeled, and transported to the lab for identification. Plants were treated with the combination of ethyl alcohol and mercuric chloride prior to being displayed on 11.5x 17.5-inch standard herbarium sheets. Plants were identified with the help of the Pakistan e-flora and other resources.

Soil sampling: Soil samples were collected from every quadrat following protocols given by (Ravindranath & Ostwald, 2007). The samples were stored in an airtight polythene bag that had been appropriately labeled. Various extensive analyses were conducted to assess the characteristics of the soil, including pH levels, total dissolved solids (TDS), organic matter content, temperature, electrical conductivity, moisture levels, saturation levels, phosphorous and potassium content, as well as concentrations of heavy metals.

The measurement of TDS, EC, and pH was carried out using TDS, EC meters, and a pH meter (Russel RL060P). A combination of soil and condensed water prepared with a ratio of 1 part soil to 9 parts water was stirred for a duration of 60 seconds every 10 minutes intervals over a 30-minute period before the measurements of pH, EC, and TDS were taken. For the measurement of organic matter, the Loss on Ignition (LOI) method was employed. We started by drying each soil sample at a temperature of 105°C until it reached a weight. Subsequent incineration in a muffle furnace at 360°C for two hours led to the combustion of organic matter. The residue, upon cooling, was weighed, and the organic matter content was calculated based on the weight loss. Phosphorus levels in the soil were determined using either the Bray-1 process for soils with a pH less than 7.0 or the Olsen way for soils with a pH above 7.0. Both methods involved the soil being mixed with the respective reagent, the supernatant being filtered, and the phosphorus concentration being measured using a spectrophotometer based on the color intensity of the solution. The potassium levels in the soil were evaluated by extracting potassium using an ammonium acetate solution, followed by the filtration of the resulting solution. The potassium concentration was then measured using flame photometry.

Floristic data collection: Phytogeographic information was obtained from several books and published research papers i.e., (Abd-El-Ghani *et al*., 2015; Al-Sherif *et al*., 2013; Anwar *et al*., 2019; Khan *et al*., 2020; Moradi *et al*., 2010; Nadaf *et al*., 2011; Ravanbakhsh *et al*., 2013; Razavi & Hasan, 2009; Stavrou *et al*., 2008; Ullah *et al*., 2015). The distribution range of different phytogeographic elements present around the world can be seen in (Table 1).

Data analysis: The statistical analysis of the data collected from all sampling sites was meticulously organized using Microsoft Excel 2010. For basic statistical evaluations, IBM SPSS version 25 was employed. To investigate the presence and absence of species, Two-way Cluster Analysis (TWCA) was conducted using PC-ORD version 5, a software tailored for analyzing geographical components, following the methodology of (Lep, 2003). Additionally, Canonical Correspondence Analysis (CCA) was carried out with CANOCO version 4.5, as per (Ter-Braak & Barendregt, 1986) to explore the relationships between species distribution and environmental gradients. R version (4.2.2) software was utilized to classify phytogeographic elements zone-wise, enhancing the comprehensiveness of the ecological assessment.

Results

The overall data analysis showed 150 plant species which were divided into various floristic elements. The maximum percentage of elements, 13.3% (20 species), belong to Cosmopolitan. The next maximum percentage was that of Tropical plants 10.7% (16 species), followed by pluriregional elements (10%), Irano-Turanian (8.7%), and Pantropical (6.7%), Eurasia (6%), and so on. The least representation was that of Western Himalayan, Sub-cosmopolitan, Pakistan, Sino-Japanese, sub-Himalayan, Indo-Chinese, etc. (Table 2) displays the occurrence rates of Phytogeographic elements in the study area, while (Table 3) provides a list of recorded species and their respective families.

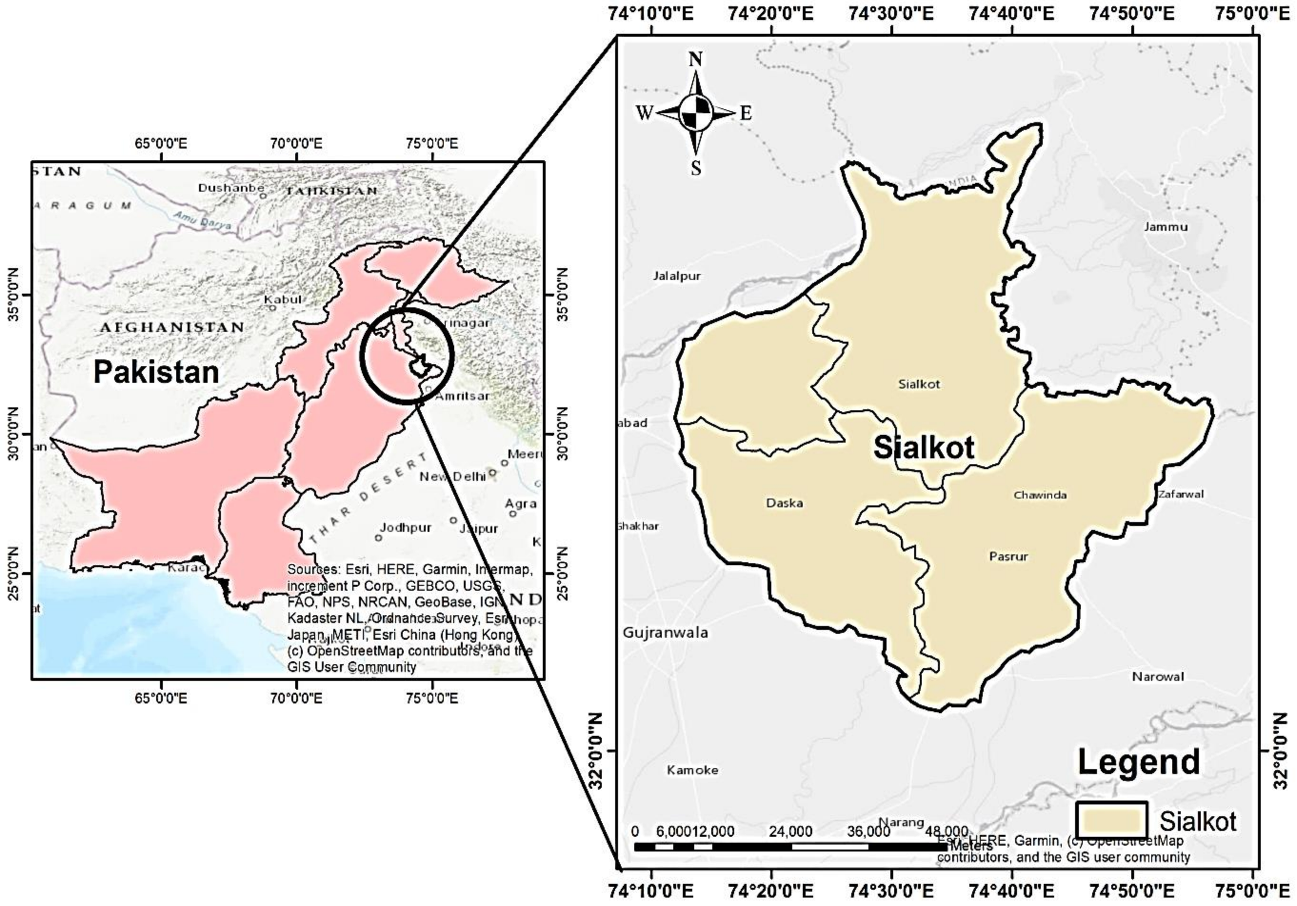


Fig. 1. Map illustrating the study area in Sialkot, Pakistan.

Table 1. The distribution range of different phytogeographic elements is present around the world.

Phyto-geographic elements	Distribution range
American	This floristic kingdom covers the whole of North and South America.
Asiatic	A taxon that presents only in the Asian countries like Pakistan, India, China, Nepal, Bhutan, Bangladesh, etc.
Australian	This floristic kingdom includes the plants of the whole Australian continent, which is characterized by plant species, e.g., eucalyptus.
Cosmopolitan	A taxon is considered to have cosmopolitan distribution if it can be found in all or most of the world's ecosystems.
Cultivated	The species are cultivated in various regions of the world, including their endemic ones.
East Asia	This region, also known as the Sino-Japanese Region, the East Asian Region, or the Temperate Eastern Region, is in East Asia's temperate zone.
Eurasia	Comprising the whole of Europe and Asia
Holarctic	The temperate to Arctic regions of Eurasia and North America are included in the Holarctic.
Indo-Asia	The Indian subcontinent, as well as nearby sections of East and Southeast Asia, mainly the tropical and subtropical regions, make up this region.
Indo-Chinese	It is located in Southeast Asia and south of China, bounded on the west by the Indian Ocean and on the east by the Pacific Ocean.
Indo-Malaysian	It includes the Malay Peninsula and western Indonesian areas (Sundaland), as well as the Philippines, eastern Indonesian regions, and New Guinea.
Irano-Turanian	Western Asia, which includes Anatolia, Mesopotamia, and Irano-Armenia and extends up to the Tien-Shan mountains, is at the heart of Irano-Turanian variety.
Mediterranean	Europe, Africa, and Asia are all included in the Mediterranean basin.
Neotropical	It covers the Americas' tropical terrestrial ecoregions as well as the whole temperate zone of South America.
Pakistan	Plants indigenous to Pakistan are included.
Palaeotropical	This kingdom covers the majority of Africa, Southwest Asia, South Asia, Southeast Asia, and the southern and central parts of China. This floral kingdom is further subdivided into floral provinces or regions, such as the West African rainforest region, Madagascar region, Iran-Turanian region, East Asian region, and so on.
Pantropical	It is distributed throughout the tropical regions of the Earth.
Pluri-regional	In this paper, elements present in more than two floristic regions are considered pluriregional.
Saharo-Arabian	The Sahara Desert, Sinai Peninsula, Arabian Peninsula (as defined by geography), Southern Palestine, and Lower Mesopotamia are all part of the area.
Sino-Japanese	East Asian Area, Temperate Eastern Region, and East Asian Region are all part of the Sino-Japanese region.
Sub-cosmopolitan	Subcosmopolitan elements are present throughout the world except in the new world.
Tropical	The Tropical are the region of Earth surrounding the Equator.
Western Himalaya	It is mostly located in the disputed Kashmir area of the northern Indian subcontinent, which includes parts managed by India and Pakistan, as well as the northwestern section of India's Himachal Pradesh state.

The results of the two-way cluster analysis demonstrate the presence or absence of phytogeographic elements. The presence of various components is represented by black dots, while the absence is represented by white dots, as shown in (Fig. 2). The dendrogram shows six sub-clusters, each with a different color. The first group, represented by purple, has Cosmopolitan, Pantropical, and tropical as the most dominant floristic elements. The rare floristic elements belong to the Mediterranean, Australian, and American floristic subkingdoms. The second sub-cluster, abounded by Irano-Turanian, cosmopolitan, and Tropical elements, is represented by greenish-yellow color in the dendrogram. This group is the largest one in terms of vegetation and floristic elements. The rare elements in this group are East Asiatic, Eurasian, and Himalayan. The third group, which is shown in dark blue color, is bounded by Irano-Turanian, Cosmopolitan, and Tropical floristic elements. The rare elements of this group again are Asiatic, Indo-Asiatic, and Saharo-Arabian. Irano-Turanian and Cosmopolitan elements mostly dominate the fourth and fifth groups. The fourth group is shown in organ color, while the fifth group is given in light green color. The last group is represented by purplish color, which Irano-Turanian and Cosmopolitan elements dominate.

Evaluation of soil parameters: Soil samples from the study area were analyzed for various parameters, including pH, temperature (°C), electrical conductivity (EC, µs/cm), total dissolved solids (TDS, mg/l), organic matter (OM, %), phosphorus (P, mg/kg), and potassium (K, mg/kg) (Table 3). Considerable variation in pH were detected across the sampled sites, with the values ranging from 6.55 to 9.20. In terms of EC, a range from 1.10 to 9.20 µS/cm was recorded. Organic substances were found, exhibiting measurements from 0.050 to 0.990. Total Dissolved Solids (TDS) showed a variation from 51 to 757 mg/kg. Meanwhile, the levels of Phosphorus (P) and Potassium (K) fluctuated between 2.50 to 11.6 mg/kg and 243 to 744 mg/kg, respectively.

The CCA analysis shows a significant effect (p>0.002) of various soil and environmental effects on phytogeographic element distribution in the area, as shown in (Fig. 3). In the first axis of the CCA plot, it is observed that Tropical, subtropical, and Irano-Turanian elements are the predominant ones under the strong pressure of pollution, anthropogenic factors, and potassium distribution in the soil. The second axis of the plot shows tropical, pantropical, Irano-Turanian, and cosmopolitan to be the most dominant elements under a strong influence of electrical conductivity (EC), pH, Phosphorus, and Organic matter distribution in the soil. In the third axis, the most dominant elements are tropical and Irano-Turanian under the influence of latitude and longitude. The fourth axis shows that Irano-Turanian, tropical, pantropical, and Eurasian elements are abundant. Overall, there is an entry of a few Cosmopolitan, Eurasian, Australian, and Saharo-Arabian elements in the first axis. The rare elements are East Asian, Australian, and Neotropical on the second axis. On the third axis, one can see a few Holarctic elements and Sub-Himalayan and Mediterranean elements as rare ones. There are a few Indo- Chinese and some other rare elements (Fig. 3). Monte Carlo tests of CCA analysis can be seen in (Table 4).

Table 2. The percentage and frequency of all the floristic elements observed in the study area.

Phyto-geographic Elements	**Frequency**	**Percent**	**Valid percent**	**Cumulative percent**
Cosmopolitan	20	13.3	13.3	13.3
Tropical	16	10.7	10.7	24.0
Pluri-regional	15	10.0	10.0	34.0
Irano-Turanian	13	8.7	8.7	42.7
Pantropical	10	6.7	6.7	49.3
Eurasia	9	6.0	6.0	55.3
Tropical+ subtropical	8	5.3	5.3	60.7
American	6	4.0	4.0	64.7
Neotropical	6	4.0	4.0	68.7
Palaeotropical	6	4.0	4.0	72.7
Irano-Turanian+Sino-Japanese	4	2.7	2.7	75.3
Mediterranian	4	2.7	2.7	78.0
Sino-Japanese	4	2.7	2.7	80.7
Australian	3	2.0	2.0	82.7
East Asia	3	2.0	2.0	84.7
Holoarctic	3	2.0	2.0	86.7
Asiatic	2	1.3	1.3	88.0
Indo-Asia	2	1.3	1.3	89.3
Irano-Turanian+ Saharo-Sindian	2	1.3	1.3	90.7
Irano-Turanian+Sino Japanese	2	1.3	1.3	92.0
Cultivated	1	0.7	0.7	92.7
Indo-Chinese	1	0.7	0.7	93.3
Indo-Malaysian	1	0.7	0.7	94.0
Irano-Turanian+ Euro-Siberian	1	0.7	0.7	94.7
Irano-Turanian+ Himalaya	1	0.7	0.7	95.3
Irano-Turanian+ Mediterranian	1	0.7	0.7	96.0
Mediteranian	1	0.7	0.7	96.7
Pakistan	1	0.7	0.7	97.3
Saharo-Arabian	1	0.7	0.7	98.0
Sub-Himalyan	1	0.7	0.7	98.7
Subcosmopolitan	1	0.7	0.7	99.3
Western Himalaya	1	0.7	0.7	100.0
Total	**150**	**100.0**	**100.0**	

The most dominant family in our study was Poaceae represented by 19 species (13%). The second most dominant family was Compositae represented by 18 members (13%), while Fabaceae has 16 species. The other families had a variable number of species, such as eight species of the family Moraceae, while seven members represented Araceae. The least dominant families are Acanthaceae, Anacardaceae, Aopcynaceae, Cannabaceae, etc., each represented by one species (Fig. 4).

The zone-wise analysis showed that the less polluted zone (LPZ) has 25 distinct phytogeographical elements and has the highest floristic diversity than other zones, the most dominant floristic elements are Cosmopolitan (14%), followed by Tropical (9%), Paleotropical, and pluriregion (8% each), Irano-Turanian (6%) and Eurasia (6%). The other elements of the region were Mediterranean (5%), Neotropical (4%), Sino-Japanese, American, and Holarctic (3% each). Some other elements are Pakistani, Subcosmopolitan, Indo-Asian, and East-Asian, each having around 1% species in the less polluted zone of the studied area. Whereas in the heavily polluted zone (HPZ) 13 phytogeographic elements were recorded and relatively less diverse in terms of floristic elements. The most dominant floristic elements in this region are Cosmopolitan (15%), followed by Irano-Turanian and Tropical (10% each), Eurasia (7%), American, Pluriregional, and Pantropical (6% each). Some other elements of the area are Paleotropical (4%), Mediterranean (4%), and Holoarctic (3%). The rare elements of the area are Saharo-Arabian, Western-Himalayan, and Pakistani (each having 1% species) in the region. In the moderately polluted zone (MPZ), the total recorded phytogeographic elements were 19. The most dominant element of the area is Cosmopolitan and Irano-Turanian (15% each), followed by Tropical (10%), Pluriregional (9%), and Pantropical (8%). Some other area elements include Paleotropical, Pantropical (5% each), Sino-Japanese, American, Australian, Holarctic, and East-Asian (each having 2%). The rarest elements included Indo-Malaysian and Mediterranean (1% each). The comparison analysis of the 3 zones can be seen in (Fig. 5).

Table 3. Displays recorded species, families, and their respective phytogeographic elements.

Families	**Habit**	**Species**	**Phytogeographic elements**
Acanthaceae	Herb	*Justica nilgherrensis*	Asiatic
Amaranthaceae	Herb	*Achyranthes aspera*	Tropical+ subtropical
	Herb	*Amaranthus graecizans*	Neotropical
	Herb	*Amaranthus retroflexus*	Cosmopolitan
	Herb	*Amaranthus spinosus*	Neotropical
	Herb	*Amaranthus viridis*	Cosmopolitan
	Herb	*Chenopodium album*	Cosmopolitan
	Herb	*Dysphania ambrosioides*	American
	Herb	*Salsola Kali*	Cosmopolitan
Anacardiaceae	Tree	*Mangifera indica*	Pantropical
Apiaceae	Herb	*Heracleum sphondylium*	Eurasia
	Herb	*Torilis japonica*	Pluriregional
	Herb	*Trifolium resupinatum*	Mediterranean+Irano-Turanian
	Herb	*Torilis leptophylla*	Irano-Turanian
Apocynaceae	Shrub	*Calotropis procera*	Pluriregional
Araceae	Herb	*Alocasia macrorrhizos*	Tropical+ subtropical
	Herb	*Colocasia esculenta*	Tropical
	Herb	*Colocasia gigantea*	Indo-Asia
	Herb	*Lemna minor*	Pluriregional
	Herb	*Leuccocasia gigantea*	Indo-Asia
	Herb	*Pistia stratiotes*	Pantropical
Asparagaceae	Herb	*Echeandia reflexa*	American
Brassicaceae	Herb	*Brassica compestris*	Irano-Turanian+Sino Japanese
	Herb	*Brassica oleracea*	Cosmopolitan
	Herb	*Coronops didymus*	Cosmopolitan
	Herb	*Goldbachia laevigata*	Irano-Turanian+ Mediterranean
	Herb	*Nastrum officinales*	Irano-Turanian+Sino-Japanese
	Herb	*Sinapis arvensis*	Cosmopolitan
	Herb	*Sisimbrium irio*	Eurasia
Cannabaceae	Shrub	*Cannabis sativa*	Irano-Turanian
Caryophyllaceae	Herb	*Stellaria media*	Eurasia
Commelinaceae	Herb	*Commelina benghalensis*	Tropical
Compositae	Herb	*Ageratum conyzoides*	Neotropical
	Herb	*Artemisia brevifolia*	Irano-Turanian
	Herb	*Artemisia scoparia*	Irano-Turanian
	Herb	*Cichorium intybus*	Irano-Turanian+ Saharo-Sindian
	Herb	*Conyza bonariensisvar*	Saharo-Arabian
	Herb	*Conyza canadensis*	Pluriregional
	Herb	*Echinops latifolius*	East Asia
	Herb	*Eclipta alba*	Neotropical
	Herb	*Erageron canadensis*	Pluriregional
	Herb	*Erigeron bonariensis*	Pantropical
	Herb	*Jurinea heteromalla*	Irano-Turanian+ Himalaya
	Herb	*Parthenium hysterophorus*	Irano-Turanian
	Herb	*Silybum marianum*	Eurasia
	Herb	*Sonchus asper*	Eurasia
	Herb	*Sonchus oleraceous*	Mediterranean
	Herb	*Sylibum marianum*	Irano-Turanian
	Herb	*Taraxacum officinale*	Cosmopolitan
	Herb	*Xanthium strumarium*	Pantropical

Table 3. (Cont'd.).

Families	Habit	Species	Phytogeographic elements
Convolvulaceae	Herb	*Convolvulus arvensis*	Irano-Turanian+ Sino Japanese
	Herb	*Ipomia purpurea*	Pantropical
	Herb	*Ipomoea carnea*	Tropical
Cyperaceae	Herb	*Cyperus rotundus*	Tropical+ subtropical
Elatinaceae	Herb	*Bergia capensis*	Palaeotropical
Euphorbiaceae	Herb	*Euphorbia helioscopia*	Irano-Turanian
	Shrub	*Riccinus communis*	Cosmopolitan+ Pantropical
	Herb	*Euphorbia hirta*	Pantropical
Fabaceae	Tree	*Acacia homalophylla*	Tropical
	Tree	*Acacia nilotica*	Paleotropical
	Herb	*Cassia occidentalis*	Pluriregional
	Tree	*Dalbergia sisso*	Tropical
	Herb	*Lathyrus pseudocicera*	Mediterranean
	Tree	*Erythrina crista-galli*	Tropical
	Herb	*Indigofera linifolia*	Tropical
	Herb	*Lathyrus aphaca*	Irano-Turanian
	Herb	*Medicago denticulata*	Holoarctic
	Herb	*Medicago minima*	Sino-Japanese
	Herb	*Medicago polymorpha*	Mediterranian
	Tree	*Prosopis juliflora*	Tropical
	Herb	*Rifolium microdon.*	America
	Herb	*Senna occidentalis*	Neotropical
	Herb	*Trifolium alexandrinum*	Asiatic
	Herb	*Vicia sativa*	Eurasia
Juncaceae	Herb	*Juncus acuminatus*	American
	Herb	*Juncus effuses*	Pantropical
Lamiaceae	Herb	*Clinopodium umbrosum*	Eurasia
	Herb	*Mentha spicata*	Cosmopolitan
Malvaceae	Herb	*Abelmoschus moschatus*	Tropical
	Herb	*Abutilon indicum*	Tropical
	Herb	*Malava neglecta*	Irano-Turanian
	Herb	*Malvastrum coromandelianum*	Pantropical
	Herb	*Sida cordata*	Tropical+subtropical
Marsileaceae	Herb	*Marsilea mutica*	Australian
Meliaceae	Tree	*Melia azedarach*	Irano-Turanian+ Sino-Japanese
Moraceae	Tree	*Brossunatia papyrifera*	East Asian
	Tree	*Ficus benghalensis L.*	Irano-Turanian
	Tree	*Ficus carica L.*	Mediterranean
	Tree	*Ficus elastica Roxb.*	Tropical
	Tree	*Ficus virens Aiton.*	Tropical
	Tree	*Ficus religiosa*	Indo-Chinese
	Tree	*Morus alba*	East Asian
	Tree	*Morus nigra*	Irano-Turanian
Myrtaceae	Tree	*Eucalyptus camaldulensis*	Australian
	Tree	*Eucalyptus globulus*	Australian
	Tree	*Syzygium cumini*	Indo-Malaysian
Nyctaginaceae	Herb	*Boerhavia procumbens*	Tropical
Oxalidaceae	Herb	*Oxalis corniculata*	Cosmopolitan
Papaveraceae	Herb	*Argemone mexicana*	Tropical
	Herb	*Fumaria indica*	Irano-Turanian

Table 3. (Cont'd.).

Families	**Habit**	**Species**	**Phytogeographic elements**
Plantaginaceae	Herb	*Campylanthus ramosissimus*	Pakistan
	Herb	*Veronica anagallis-aquatica*	Cosmopolitan
Poaceae	Shrub	*Arundo donax*	Cosmopolitan
	Herb	*Avena sativa*	Pluriregional
	Herb	*Brachiaria reptans*	Tropical
	Tree	*Bromus japonicus*	Pluriregional
	Herb	*Cenchrus biflorus*	Tropical
	Herb	*Cenchrus ciliaris*	Cosmopolitan
	Herb	*Cynodon dactylon*	Cosmopolitan
	Herb	*Cynodon radiatus*	Tropical+subtropical
	Herb	*Desmostachy bippinanta*	Paleotropical
	Herb	*Dicanthium annulatum*	Tropical+ subtropical
	Herb	*Imperata cylindrical*	Pantropical
	Herb	*Koelaria macarantha*	Pluriregional
	Herb	*Paspalum paspalodes*	Tropical+ subtropical
	Herb	*Phragmites karka*	Cosmopolitan
	Shrub	*Saccharum bengalensis*	Pluriregional
	Shrub	*Saccharum spontaneum*	Pluriregional
	Herb	*Setaria pumila*	Pluriregional
	Herb	*Sorghum halepense*	Cultivated
	Herb	*Triticum aestivum*	Cosmopolitan
Polygonaceae	Herb	*Persiaria glabra*	Pantropical
	Herb	*Rumex dentatus*	Irano-Turanian+ Sino-Japanese
	Herb	*Rumex nepalensis*	Mediterranian
Pontederiaceae	Herb	*Eichhornia crassipes*	Neotropical
Primulaceae	Herb	*Anagallis arvensis*	Cosmopolitan
Pteridaceae	Herb	*Adiantum capillus-veneris*	Subcosmopolitan
Ranunculaceae	Herb	*Ranunculus muricatus*	Irano-Turanian+ Sino-Japanese
Rhamnaceae	Tree	*Ziziphus jujuba*	Sino-Janpanese
	Tree	*Ziziphus mauritania*	Paleotropical
	Tree	*Ziziphus nummularia*	Paleotropical
Rosaceae	Herb	*Geum urbanum*	Irano-Turanian+ Euro-Siberian
Rubiaceae	Herb	*Galium aparine*	Holoarctic
Salicaceae	Tree	*Populus alba*	Cosmopolitan
	Tree	*Populus nigra*	Sino-Janpanese
	Tree	*Salix tetrasperma*	Sub-Himalyan
Scrophulariaceae	Herb	*Verbena bonariensis*	American
	Herb	*Verbascum songaricum*	Western Himalaya
	Herb	*Verbascum thapsus*	Eurasia
Solanaceae	Herb	*Datura alba*	Pluriregional
	Herb	*Datura innoxia*	Tropical+ subtropical
	Herb	*Solanum lycopersicum*	American
	Herb	*Solanum nigrum*	Cosmopolitan
	Herb	*Withania somnifera*	Pluriregional
Tamaricaceae	Tree	*Tamarix dioica*	Eurasia
Thymelaeaceae	Herb	*Daphane macronata*	Irano-Turanian
Typhaceae	Herb	*Typha angustifolia*	Holoarctic
Verbenaceae	Shrub	*Lantana camara*	Sino-Japenese
	Herb	*Verbena officinale*	Paleotropical
	Herb	*Verb supina*	Saharo-Sindian + Irano-Turanian

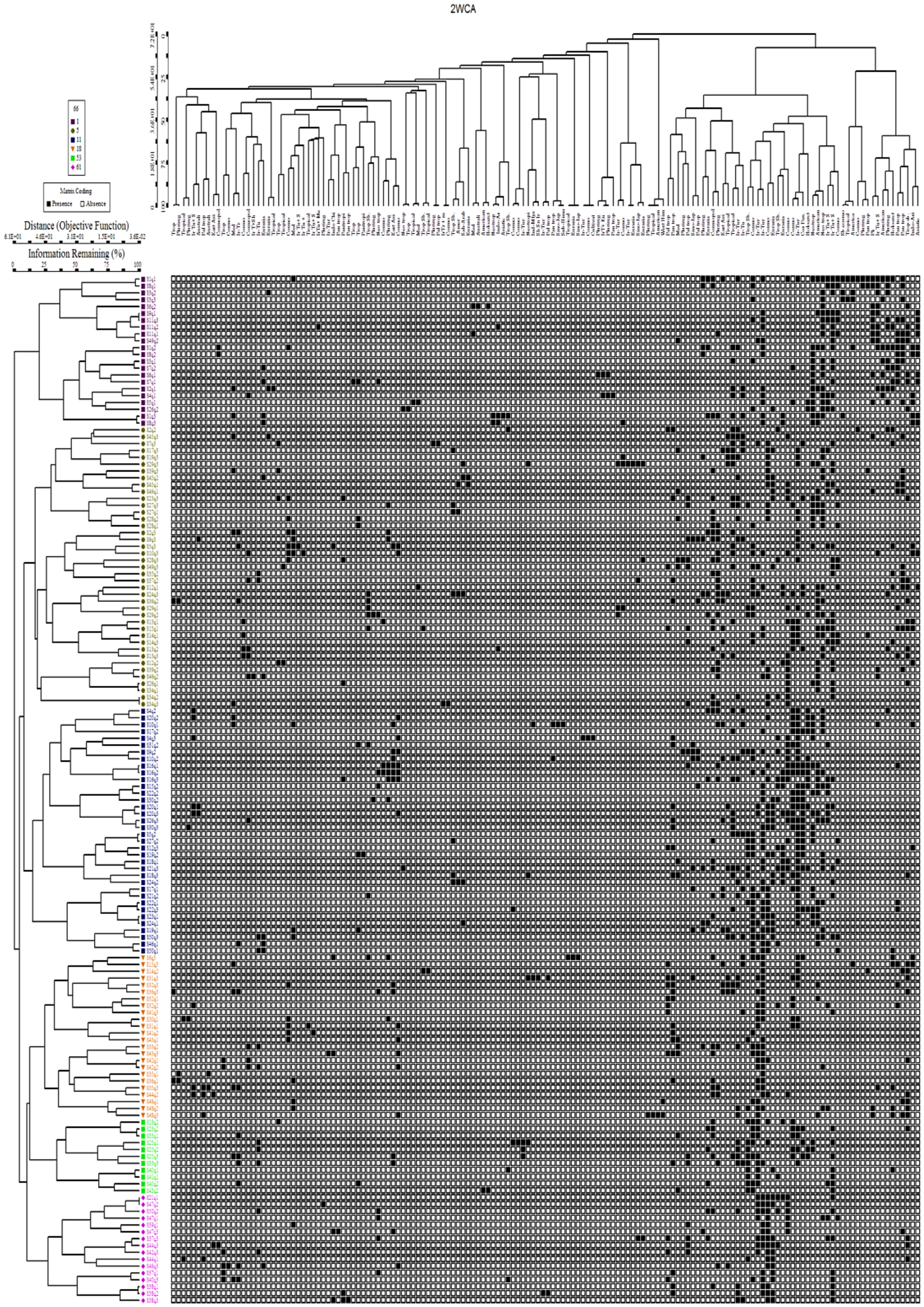


Fig. 2. Two Way Cluster (TWCA) using PCORD software for representation of Phytogeographic elements in the area under study.

Table 3. Summary statistics of soil samples from the study area, detailing the sample size [N = 150 (3x)].

Soil parameters	Mean	St. dev	Minimum	Maximum	Skewness	Kurtosis	Permissible limit
Temperature (°C)	44.1	0.804	2.84	44.1	-12.5	155	26.6
Soil moisture	0.630	0.540	0.630	0.630	-12.5	155	-
TDS (mg/L)	315	152	51	757	0.646	0.314	500
Saturation (%)	34.1	5.40	20.0	58.0	0.953	0.916	-
pH	7.54	0.533	6.55	9.20	0.973	0.80	7
EC (µS/cm)	4.58	3.79	1.10	17.9	1.94	3.46	110
OM (%)	0.39	0.550	0.050	0.990	-0.03	-1.40	0.05
P (mg/kg)	7.06	1.71	2.50	11.6	-0.13	0.206	30
K (mg/kg)	421	78.7	243	744	1.32	0.196	300

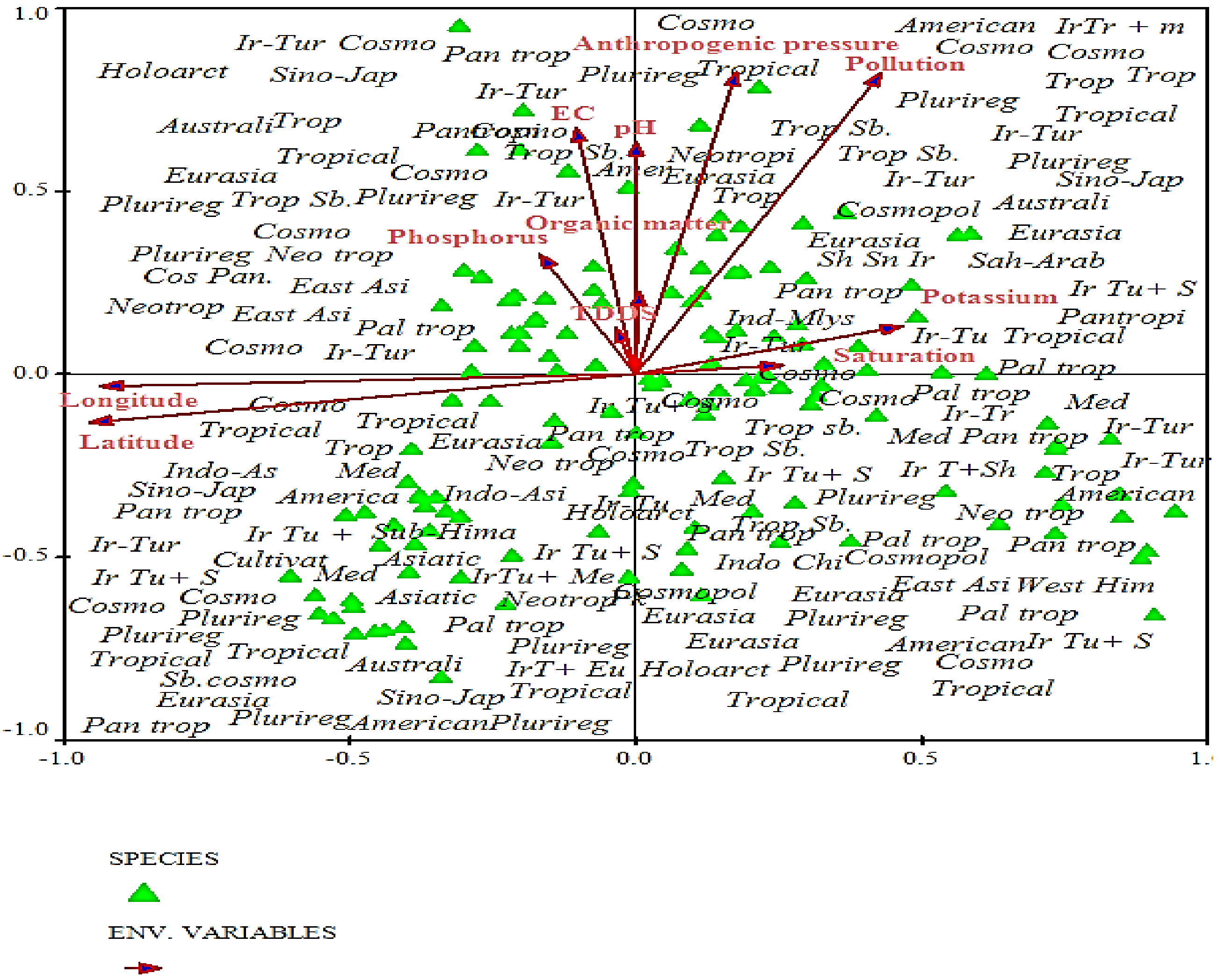


Fig. 3. Canonical Correspondence Analysis (CCA) of Phytogeographic elements across the recorded environmental variables.

Table 4. Monte Carlo tests of phytogeographic elements.

Axes	1	2	3	4	Total inertia
Eigen values	0.318	0.282	0.195	0.144	16.371
Species-environment correlations	0.873	0.824	0.749	0.676	
Cumulative percentage variance of species data	1.9	3.7	4.9	5.0	
Cumulative percentage variance of species-environment relation	19.8	37.3	49.4	58.4	
Sum of all eigen values					16.371
Sum of all canonical eigenvalues					1.608

Summary of Monte Carlo test (499 permutations under reduced model)	
Test of significance of first canonical axis:	Test of significance of all canonical axes:
Eigenvalue = 0.318	Trace = 1.608
F-ratio = 2.733	F-ratio = 1.366
P-value = 0.0020	P-value = 0.0020

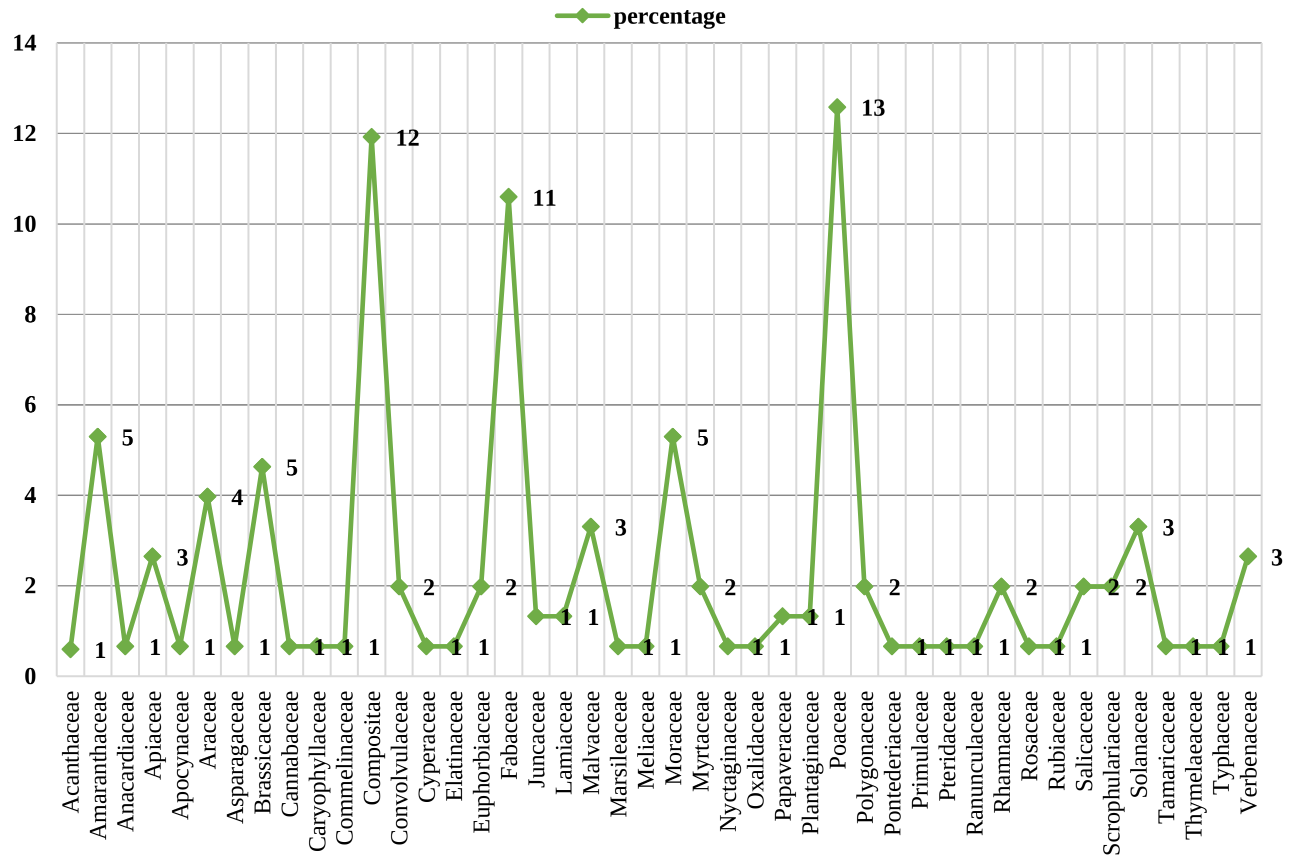
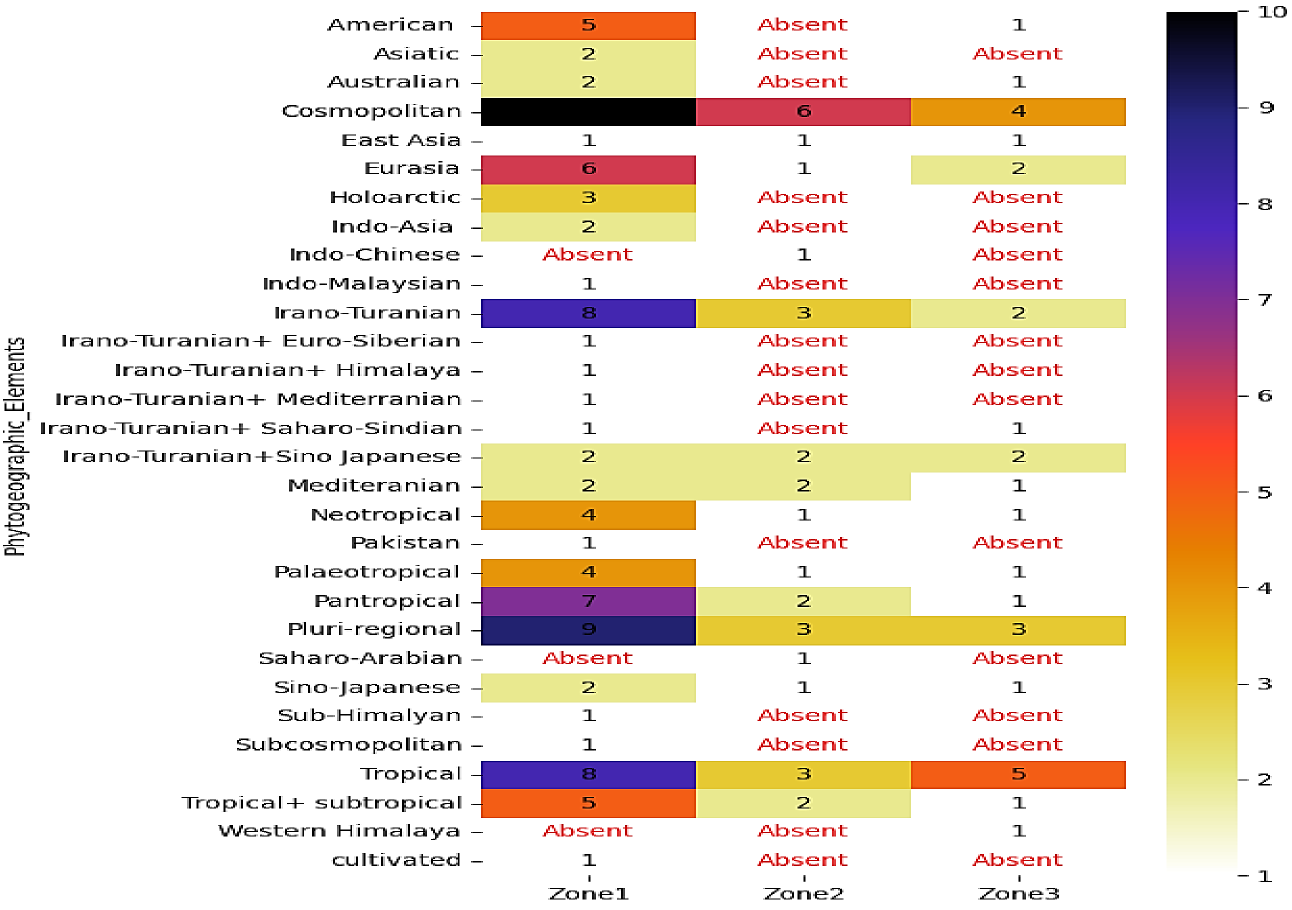


Fig. 4. Pie chart showing percentages of plant families observed in the study area.



Phytogeographic_Elements	Zone1	Zone2	Zone3
American	5	Absent	1
Asiatic	2	Absent	Absent
Australian	2	Absent	1
Cosmopolitan		6	4
East Asia	1	1	1
Eurasia	6	1	2
Holoarctic	3	Absent	Absent
Indo-Asia	2	Absent	Absent
Indo-Chinese	Absent	1	Absent
Indo-Malaysian	1	Absent	Absent
Irano-Turanian	8	3	2
Irano-Turanian+ Euro-Siberian	1	Absent	Absent
Irano-Turanian+ Himalaya	1	Absent	Absent
Irano-Turanian+ Mediterranian	1	Absent	Absent
Irano-Turanian+ Saharo-Sindian	1	Absent	1
Irano-Turanian+Sino Japanese	2	2	2
Mediteranian	2	2	1
Neotropical	4	1	1
Pakistan	1	Absent	Absent
Palaeotropical	4	1	1
Pantropical	7	2	1
Pluri-regional	9	3	3
Saharo-Arabian	Absent	1	Absent
Sino-Japanese	2	1	1
Sub-Himalyan	1	Absent	Absent
Subcosmopolitan	1	Absent	Absent
Tropical	8	3	5
Tropical+ subtropical	5	2	1
Western Himalaya	Absent	Absent	1
cultivated	1	Absent	Absent

Fig. 5. Presence/Absence of various Phytogeographic elements with their frequency in respective zones.

Discussion

Phytogeography is the study of the distribution of plants on the Earth's surface. (Razavi & Hasan, 2009). Various ecological factors are responsible for the distribution of plant species in various world regions, and the distribution pattern is peculiar (Zeb *et al.*, 2021). Biotic and abiotic factors influence the distribution of plants on planet Earth. The most important biotic factors are the range of seed dispersal (Smith, 1993), the introduction of invasive species (Bjarnason *et al.*, 2017), the distribution of fungi in the soil and human activities (Pellissier *et al.*, 2013). The range of resources and conditions needed for the survival of a species, is defined by the distribution of micronutrients (Mg, P, S, Na, K, etc.), pH, electrical conductivity, the water content, organic matter in the soil, temperature, and direction of the wind (Zhang *et al.*, 2021: Potts *et al.*, 2020). In the current study, the impact of some of these abiotic factors was evaluated on the distribution of plant species recorded from the area under study. The species found belonged to a variety of phytogeographic groups. The most dominant phytogeographic element recorded from the area was tropically followed by pluriregional, Irano-Turanian, and pantropical floristic elements. The rare elements belonged to Indian, Saharo-Arabian, West Himalayan and Sub-Himalayan phytogeographic elements.

Cosmopolitan was the most dominant phytogeographic element (13.3%) in the study area, which has already been confirmed by (Ullah *et al.*, 2015) for northern Pakistan. The world's tropical and subtropical areas are home to the majority of cosmopolitan species. Floristically, these species are distributed in Africa, Asia, most parts of Northern America, and Europe. This category has a large number of endemic species, which contributes to phytogeographic diversity. (Takhtadzhi͡an *et al.*, 1986). The cosmopolitan species have higher productivity rate, rapid stand-scale expansion, distinct ecophysiological strategies, high phenotypic plasticity, and broader ecological amplitude (Eller *et al.*, 2017). Cosmopolitan elements have been noted in all three zones of the studied area. This implies that cosmopolitan elements are more tolerant of pollution from industrial effluents.

The second dominant element in the current study was tropical (16 elements), which might be due to the region's weather conditions. The region is hot for most of the year, with temperatures ranging above 25˚C for that part of the year. The representative tropical elements include *Dalbergia sissoo*, *Ziziphus* sp., and *Colocasia esculenta*. Most tropical elements have been reported to have a greater capacity to tolerate pollution (Roy *et al.*, 2020). This tolerance to pollution is the major reason for the predominance of tropical elements in the studied area.

Irano-Turanian element (8.7%) in the present study was less than those reported by (Zeb *et al.*, 2021). A study from Kashmir reported 15 texa of Irano-Turanian phytogeographic species (Ali & Qaiser, 1986). The Northern side of Pakistan has more Irano-Turanian elements than Sialkot, which might be due to the unusual weather situation and precipitation in both regions of Pakistan. Pakistan has 04.5 million hectares of Irano-Turanian habitat, Iran has 13.4 million hectares, and Turkey has 21.2 million hectares. It differs from the Mediterranean area by having a higher continentality index, and it differs from the Euro-Siberian region by not having summer rainfall. It also has a greater continentality index, lower winter temperatures, and more winter precipitation than the Saharo-Sindian area. (Zeb *et al.*, 2021). Sialkot has different environmental conditions than the areas where Irano-Turanian elements are usually found. Here, the summers are too hot while the winters are not too cold as the temperature never goes beyond the freezing point. There is less rainfall in the winter but more precipitation in the monsoon season.

The Mediterranean is one of the most diverse regions floristically. It covers the whole Balkan and the Iberian Peninsula. But in Pakistan, Mediterranean elements are not in great numbers. Previous studies have reported only 0.5% of Mediterranean elements in various regions of Pakistan (Ali & Qaiser, 1986). Saharo-Arabian, Indo-Malaysian, Euro-Siberian, sub-Himalayan, and Western Himalayan are all represented by one floristic element each because the regions in Pakistan do not provide a suitable environment for these floristic factors. These are following the results reported by (Ali & Qaiser, 1986).

In this study, the Poaceae family predominates, followed by families such as Asteraceae, Fabaceae, and Moraceae. This finding aligns with studies by (Saarela *et al.*, 2018) and (Majeed *et al.*, 2022), who also reported the dominance of the Poaceae family in similar regions. The prevalence of Poaceae is attributed to its wide ecological adaptability, human disturbances, and perennating capabilities (Manan *et al.*, 2022).

The number of Phyto-geographic elements decreased as we moved from a less polluted area to a more polluted area. The heavily polluted area contained less floristic elements and vegetation cover. Thus, it is evident from the discussion that pollution greatly affects the distribution of phytogeographic elements and the diversity of vegetation. In our case, the pollutants have greatly affected the vegetation diversity which might be that the pollutants trigger excessive amounts of micronutrients and heavy metals in soil which produces stress conditions for the plant species present in the polluted region. Similar results were recorded by (Alsherif *et al.*, 2022) found a loss of species richness in the polluted site as compared to the non-polluted site of study and thus concluded that pollution from heavy metals, sourced by different industries causes not only a change in community structure and species frequency but also the extinction of several species (Alsherif *et al.*, 2022). Several studies by various researchers found that species richness and diversity change along a pollution gradient (Bayouli *et al.*, 2021). Another finding shows a considerable variation in species richness and composition between polluted locations and controlled (less polluted) regions. (Boutin & Carpenter, 2017), which is inconsistent with our study.

In conclusion, our investigation sheds light on the intricate interactions between plant diversity and environmental pollutants from a phytogeographical perspective. Utilizing a broad array of multivariate statistical methods, we have unearthed insights into the ways in which various pollutants affect plant life across different ecological zones. Our findings lay a crucial groundwork for future studies, which should aim to broaden their geographical and methodological horizons. Future research, informed by our recommendations, should prioritize long-term monitoring to understand the temporal effects of pollution, investigate the capabilities of plants for phytoremediation, and examine plant genetic adaptations to polluted habitats (Mahida *et al*., 2023). Employing cutting-edge technology and considering a broader range of environmental factors will refine the accuracy and comprehensiveness of future investigations. Furthermore, it is vital to assess the wider ecological consequences, such as the effects on wildlife and the socio-economic impacts on communities reliant on these ecosystems (Hughes *et al*., 2023). Engaging in collaborative efforts with policymakers, local populations, and the scientific community will ensure that research outcomes are not only academically significant but also have practical applications in environmental management and conservation.

This research paves the way not only for enriching our understanding of ecological interactions in the face of pollution but also for contributing to the development of sustainable environmental practices and policies. Emphasizing the importance of a multidisciplinary approach, our study aims to safeguard and rehabilitate the fragile equilibrium of our planet's ecosystems, highlighting the critical role of phytogeography in environmental research.

Conclusions

Environmental pollution from industries is a main driver of the disturbance of floristic composition in a given area. Our study concluded that effluents from industries largely decreased vegetation diversity because some of the pollutants cause toxicity to plant species. The novelty of this study is we investigate the phytogeographic elements of a floristically diverse pollution gradient. Irano-Turanian and Cosmopolitan elements are generally distributed evenly in the study area with the highest density in the most polluted zone. This shows that Irano-Turanian and Cosmopolitan elements are more tolerant to pollution from industrial effluents and can use certain pollutants to fulfill their nutritional requirements. High levels of pollution due to heavy industries in Sialkot have displaced most of the floristic elements. It is suggested that the rare elements of the region should be protected as pollution has negative effects on these floristic elements.

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