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Accumulation and translocation of trace elements and macronutrients in different plant species across five study sites

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ABSTRACT

The present study aims to analyze the capacity of plant species (52 individuals) for accumulation and translocation of trace elements (Fe, Cd, Cr, Cu, Al, Ni, and Pb) and the macronutrients (N, P, K, Ca, Mg, Mn, and Zn), in five different study sites. Fixed area sampling approach tests were used to determine the plant community and density. For trace elements and macronutrient analysis, the soil and plant samples were collected and were quantified with the help of Inductively Coupled Plasma (ICP) – Atomic Emission Spectroscopy and Oxygen/Hydrogen836 (OH836). The findings revealed that the levels of bioaccumulation capacity, translocation capability of each plant component, and overall concentration in each tissue are generally species-specific. The bio-concentration data revealed substantial amounts of elements and macronutrients among the research locations, demonstrating that element and nutrient levels often decrease in order: Root > Leaves > Stem is the order of importance. Translocation factor profiles were independent of individual tissue species and life forms. Based on the resulting translocation factors of plant communities, study site 5 (S5) was observed to be enriched with trace elements, whereas study site 1 (S1) had the highest levels of macronutrients. This study demonstrates that plant richness is an important of trace elements and macronutrients and helps understanding the ecology of soil in the study area. The potential of plant species to accumulate in their morpho-anatomical shapes is also demonstrated in this study, which supports the prevailing ecological considerations.

1. Introduction

Plant population ecology and demography provide insights into the interactions of the species in a particular environment. Understanding population interaction with the environment can give us a sense of where they fit into the ecosystem in the context of environmental ecology (Lowe et al., 2017). The evolutionary changes take place at the population level based on their interaction with the surrounding biotic and abiotic components (Gómez-Llano et al., 2021). The population research might also aid in observing evolutionary mutation in a particular species across a variety of ecological settings. The genetic heterogeneity in these plant populations is a result of mutation, gene flow, and natural selection (Bessega et al., 2019; Fernando et al., 2015). The rate of plant population varies with the availability of various factors such as water, micro-nutrients, and macro-nutrients and even traces metals (Barletta et al., 2019). It also depends on the soil type prevailing in the site.

Minerals are necessary for a plant's regular growth, development, fruiting, and blooming. Aside from C, H, O, and twelve more elements are thought to be necessary for plant development and other activities (Zouari et al., 2020). Trace metals are naturally present in soil texture. They are essential for plant growth, development, and reproduction, as the roots absorb the metal and mobilise it as metal ions, which the vascular tissue transports to the appropriate organelles (Boutté and Jaillais, 2020). The constant supply of the nutrients is ensured via the translocation process which involves the transfer of soluble nutrients throughout the plant via xylem and phloem (Zhang and Turgeon, 2018). This might be due to the constant use of fertilizers in order to meet the needs of the growing population over the last few decades (Zhuang et al., 2020). The non-biodegradable nature of trace elements, which causes them to collect over time, makes them potentially dangerous to the environment. They continue to biomagnify once they have gained entry into the environment, causing havoc with the trophic levels of the particular location (Bonanno et al., 2018; Radić et al., 2018). These

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processes are linked with a decline in soil structure, a resultant loss of soil water storage and quality, which ultimately results in the desertification of the land (Garcia-Franco et al., 2018). Though the toxic metals have an effect on the environment as a whole, the direct and foremost effect is upon the soil. Humans and their activities are encroaching upon arid environments and altering the natural land cover (Fu, 2003). Erosion, salinity, and soil degradation are some of the processes that lead to the loss of land cover. Land degradation prevention is one of the worldwide ultimatums, since it is a growing environmental disruption all over the world (Prăvălie, 2021).

The present study is aimed to open up the knowledge about the plants prevailing naturally in the semi-arid regions, like, where the study was conducted. It further sheds light upon the ability of these plants to translocate and accumulate trace elements and macro-nutrients from the soil to its own various parts, deeply focusing upon the stem, root, and leaves; thus establishing the relationship between concentrations of trace elements and macronutrients in plant species and surrounding environment. Despite a few studies have been carried out about nutrient translocation and accumulation capacities of plant community to date, it has not been showed the plant species have similar translocation capacities of trace elements and nutrients. The research will further extend to work upon the variations in the study sites' environment and will be quoted in the next works.

2. Materials and methods

2.1. Site description

The experimental study site selected was a site within the Bharathidasan university campus (BDU), Tiruchirappalli, Tamil Nadu, India. The study site is situated in the southern plateau of the Eastern Ghats (TN uplands) within the campus of Bharathidasan University in the Indian central south-eastern district Tiruchirappalli. Tiruchirappalli district is situated at the geographical central point of the state. The average rainfall is around 700–730 mm/a. The temperature maximum is up to 37.2 °C and the minimum is up to 20.6 °C (Arul Pragasan and Parthasarathy, 2010; Goldar and Banerjee, 2004). The environmental experiment landscape has been divided into 5 different study sites: study site 1 (10.682261 N, 78.744381 E), study site 2 (10.683147 N, 78.744360 E), study site 3 (10.682860 N, 78.742667 E), study site 4 (10.683114 N, 78.744928 E) and study site 5 (10.682039 N, 78.744699 E) (Fig. 1).

2.2. Sampling

A total of five sites were chosen randomly for estimating the plant community population, trace elements and macronutrient content of soil, root, stem, and leaf, thus establishing the relation of plant communities with soil. BDU campus comprised of two or three canopy layers and was dominated by shrub and herb-like species.

For assessing the plant community and density, fixed site sampling method experiments (transects and quadrats) were carried out and plant community relationship with soil was established in the year 2020. For transect method, the thread length taken was 100 cm, properly measured and the plant samples coming under or in contact with the length of the thread were noted. The quadrat method was carried out by encircling an area of 100 cm^2 measured properly. The individuals coming inside that labeled area were counted and noted. Each sampling at five study sites was directly encountered to record the presence (1) or absence (0) of individuals in the data matrix across the mentioned five sites.

2.3. Trace elements and macronutrients analysis

To analyze the content of selected trace elements (ppm), in different study sites, soil samples were assessed. Composite soil samples (300 gm) were collected within a depth of 15–20 cm. The collected mineral soil samples were handled according to Peli et al. (2021) with modifications wherever required. Before sieving (0.149 mm) the samples were air-dried. The sieved subsamples (10.0 g) were ground with agate mortar and microwave-digested with 10 ml of HCl-HNO_3 mixture in a 3:1 proportion. The mixture was allowed to settle and precipitate for 24 h and then centrifuged in an ultracentrifuge at 3250 rpm for 2 min. The supernatant was collected and transferred to another dark container for further experimentations (Peli et al., 2021). Analysis were done using by a inductively coupled plasma optical emission spectrometry (ICP-OEC, Perkin Elmer optima) for the determination of Al, Cu, Cr, Fe, Pb, Ni, and Cd. Likewise for P, K, Ca, Mg, Mn, and Zn, ICP- Atomic Emission Spectroscopy (ARCOS, Simultaneous ICP spectrometer) were used. For nitrogen (N), a series elemental analyzer (OH836 Analyzer) was used. The blank sample served as reference material for quality assurance of the trace elements.

Individuals were collected from the five study sites to access the concentrations of the trace elements and macronutrients in the root, stems, and leaves; with a total of 52 samples. From the collected plant samples debris is carefully removed to prevent contamination by using running tap water. Then, the plant parts were divided into roots, stems, and leaves and stored in a refrigerator at 4 °C for further analysis. The

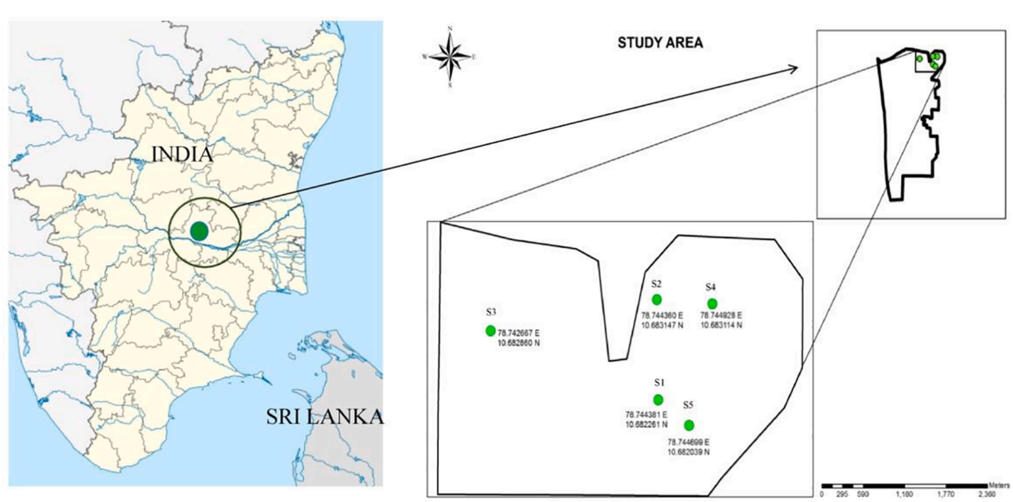

Fig. 1. Location of study site.

cumulative weight of plant samples ranged from 1.0 to 2.0 kg which are the dissected plant organs that were allowed to dry for homogenization. After homogenization, 10.0 g of the powder was taken and to this, a mixture of H_2O_2/HNO_3 was added in the ratio of 2:3. The mixture was kept overnight at 90 °C in a microwave oven for 12 h. The mixtures are centrifuged at 2500 rpm for 2 min and the supernatant collected were subjected to inductively – coupled plasma optical emission spectrometry.

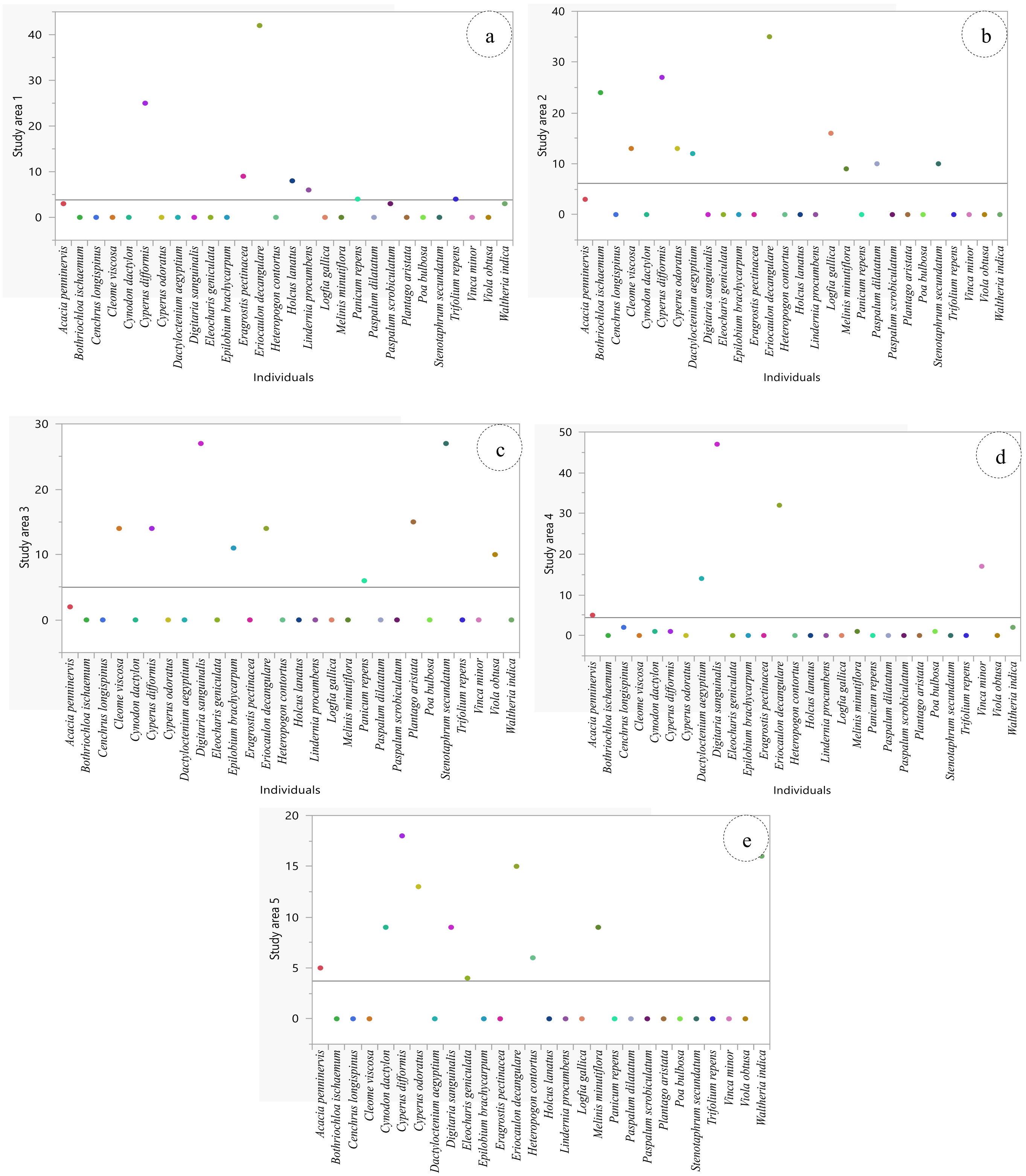

Fig. 2. Distribution of individuals in different study sites. (a) Study site 1 (S1). (b) Study site 2 (S2). (c) Study site 3 (S3). (d) Study site 4 (S4). (e) Study site 5 (S5). The name of the y-axis is the abundance of the individual's species (%).

2.4. Statistical analysis

Statistical analysis was preliminarily conducted by the quadrats and line transects methods for attaining the individual's percentage and density for the data sets. A two-way ANOVA was used to detect the difference in the levels of trace elements and macronutrients between the selected plant species by using JMP software (Bitani et al., 2020). Bio-concentration and translocation factors were calculated. The accumulation of trace elements and macronutrients along with their mobility from soil to plants, and across the plant tissues (root, stem, and leaves). The values of bio-concentrations and translocation factor were based on the following formula,

Bio-concentration factor = $C_{root}/C_{soil}$where C_{root} and C_{soil} are the concentrations of trace elements or macronutrients in the root and soil respectively. Bio-concentration factor express the availability of trace elements and nutrient in soil and root (Zhang et al., 2002).

Translocation factor = C_{leaves}/C_{root}, C_{stem}/C_{root}, $C_{leaves}/C_{stem}$where C_{root}, C_{stem}, and C_{leaves} are the concentration of the trace elements and macronutrients in the root, stem, and leaves of the species. Translocation factor express the mobility of trace elements and nutrients from root, stem and leaves (Deng et al., 2004).

To analyze the distribution of trace elements and micronutrients in the 52 individuals Principal Components Analysis (PCA) and Hierarchical clustering dendrogram analysis (Ward method) were performed on JMP (Bitani et al., 2020). The distribution and functional traits of the five study zones were correlated with matched-pairs *t*-test and Pearson's correlation value of the leaves/root, stem/root, and leaves/stem translocation factors of trace elements and macronutrients in the studied individuals were analyzed (Sanjerehei and Rundel, 2020).

3. Results and discussion

3.1. Vegetation diversity and individual's abundance

Fig. 2 indicates that 52 plant species were recorded in five different study sites. Among the total 24 species were remediated in all five study sites. From all the study sites (1–5), the diversity of plants was recorded along with their vegetation diversity and individual abundance of each species (Table S1). In the study site 1, ten individual species were present, dominated by; *Eriocaulon decangulare* (70%) and *Cyperus difformis* (70%) followed by *Eragrostis pectinacea* (60%), *Holcus lanatus* (60%), and *Launaea procumbens* (50%) respectively. The other species were *Panicum repens* (30%), *Paspalum scrobiculatum* (30%), *Trifolium repens* (20%), *Waltheria indica* (20%), *Acacia penninervis* (20%), were found about 20% – 30%. It was remarkable that for the abundance of the study site 1, *E. decangulare* and *C. difformis* were found majority of the species compared to other species abundance (Fig. 2a). In study site 2, totally 11 species were recorded. Among them, the most abundant plant species are *C. difformis* (70%), and the range of 60% of the species were *E. decangulare*, *Bothriochloa ischaemum*, *Logfia gallica.* The frequency ranges (40% – 30%) corresponds to the *Stenotaphrum secundatum*, *Cleome viscosa*, *Dactyloctenium aegyptium*, *Melinis minutiflora*, *Cyperus odoratus*, *Paspalum dilatatum* (Fig. 2b). According to the study site 3, showed in Fig. 2c, out of 10 plants, the *S. secundatum* (80%), *Plantago aristata* (60%), *C. difformis* (50%), *Epilobium brachycarpum* (50%), *Viola obtusa* (50%), *E. decangulare* (40%), *C. viscosa* (40%), *Digitaria sanguinalis* (30%), *P. repens* (20%), *A. penninervis* (10%) were presented in respective percentage of individual's frequency. In study site 4, the most abundant species were *E. decangulare* (80%), *Vinca minor* (50%), *D. aegyptium* (50%), which was maximum abundance range from 11 individuals and the median abundance ranges of the species are *D. sanguinalis* (30%), *A. penninervis* (30%), *Cenchrus longispinus* (20%). The low level of plants were presented in this site such as, *W. indica* (10%), *C. difformis* (10%), *M. minutiflora* (10%), *Cynodon dactylon* (10%), and *Poa bulbosa* (10%), respectively (Fig. 2d). Study site 5 indicates 10 species, the maximum abundance ranges of the plant species are *C. difformis* (60%), *C. odoratus* (50%), *C. dactylon* (50%), *A. penninervis* (50%). In the mid abundance ranges of the individuals frequencies are *E. decangulare* (40%), *D. sanguinalis* (30%), *Heteropogon contortus* (30%), *M. minutiflora* (20%), *Eleocharis geniculata* (20%) respectively and the lower (10%) level of the plant is *W. indica* (Fig. 2e).

This is in line with the five different study sites, 52 plants have monitored the presence of individuals by using the quadrat technique. These vegetation diversity and species abundance showed, in all study sites, higher frequencies compared to the among the species diversity. From study site 1, the majority of the individuals are, *E. decangulare,*

C. difformis were found most abundance frequencies. In study site 2, *E. decangulare,*

C. difformis, B. ischaemum are present in high ranges of the individuals. *E. decangulare,*

D. sanguinalis, and *S. secundatum* were found highest abundance range in study site 3. Generally most abundant species are, *A. penninervis*, *C. difformis*, and *E. decangulare* were found in all study sites.

Individual number richness and evenness grew and declined in all research site populations as their respective nutrients increased and reduced (Yang et al., 2020a). The individuals-site relationships are shred study with large size of individuals and support other species (Opuni-Frimpong et al., 2021). However, the study site 2 (individuals no – 166), the most density of the plants were present. Followed by study site 3 (individuals no – 140), study site 4 (individuals no – 123), study site 5 (individuals no – 105), and study site 1 (individuals no – 102), respectively (Table S2). The mountain vegetation communities, topographic factors controlling vegetation distribution (Ferrari et al., 2021). The vegetation density is mainly affected by temperature and light and also solar radiation and precipitation (Wu et al., 2021).

3.2. Functional traits and nutritional status of study sites

The five study sites considered for the quadrant sampling indicate differences in the average population (Table 1 and Fig. S1), their correlation with 10 different study sites was recorded by matched-pairs *t*-test. The demographic differences between the research locations were revealed using the matched-pairs *t*-test. The sample distribution and variations in the means of each research location were evident. Individual differences in various studies are represented by the vertical red lines. The p-values of people from the current research location are shown by the shaded sites. Among the 10 different studies, the individuals were monitored by the matched-pairs *t*-test to find their differences and the plant species, distribution, and variation of the traits presented individuals presence and absence. The presence or absence of the individual differed in their distribution traits that influence their survival ability (Bitani et al., 2020). These variations showed a study site geographical association between availability of nutrient-rich soils interaction with a high concentration of growth pattern (Reich and Cornelissen, 2014). The influence of every individual's traits affecting by soil, required nutrients, competition and niche differentiation (Xu et al., 2021). Study site topography is a further potent trigger of trait spatial variations of individuals. At present, the study demonstrated the individual variations from each study site. Previously reported that frugivorous species are present in margins of the gaps in study sites, forests, microenvironment (Mokotjomela et al., 2013). Therefore, the open habitat individuals have more frequency compared to others. The *A. penninervis, C. difformis,* and *E. decangulare,* individuals are present in all the study sites more frequent. This finding demonstrated that soil resource competition might shift to individuals in the neighbourhood that have smaller trait dispersion. Strong resource rivalry, on the other hand, prevents cohabitation among neighbours (Kunstler et al., 2016).

Table 1
Differences of individuals by matched-pairs *t*-test from five different study sites.

	Study site 1	Study site 2	Study site 3	Study site 4	Study site 5	Mean Difference	Std Er.	Upper 99%	Lower 99%	N	Correlation	t-Ratio	DF	Prob > |t|	Prob > t	Prob < t
Study site 2/ Study site 1	3.82	6.14	–	–	–	2.32	1.51	6.51	−1.86	28	0.63	1.53	27	0.13	0.06	0.93
Study site 3/ Study site 1	3.82	–	5	–	–	1.17	2.05	6.86	−4.50	28	0.21	0.57	27	0.57	0.28	0.71
Study site 3/ Study site 2	–	6.14	5	–	–	−1.14	2.12	4.73	−7.01	28	0.21	−0.53	27	0.59	0.70	0.29
Study site 4/ Study site 1	3.82	–	–	4.39	–	0.57	2.18	6.61	−5.47	28	0.34	0.26	27	0.79	0.39	0.60
Study site 4/ Study site 2	–	6.14	–	4.39	–	−1.75	2.45	5.04	−8.54	28	0.20	−0.71	27	0.48	0.75	0.24
Study site 4/ Study site 3	–	–	5	4.39	–	−0.60	1.92	4.71	−5.93	28	0.46	−0.31	27	0.75	0.62	0.37
Study site 5/ Study site 1	3.82	–	–	–	3.71	−0.10	1.47	3.96	−4.18	28	0.52	−0.07	27	0.94	0.52	0.47
Study site 5/ Study site 2	–	6.14	–	–	3.71	−2.42	1.68	2.22	−7.08	28	0.42	−1.44	27	0.15	0.92	0.08
Study site 5/ Study site 3	–	–	5	–	3.71	−1.28	1.76	3.59	−6.17	28	0.15	−0.72	27	0.47	0.76	0.23
Study site 5/ Study site 4	–	–	–	4.39	3.71	−0.67	2.00	4.48	−6.23	28	0.31	−0.33	27	0.73	0.63	0.36

Note: Std Er. – Standard error of the individuals difference. Upper 99% – Upper confidence limit for the difference. Lower 99% – Lower confidence limit for the difference. N – No. of the individuals. t-Ratio – Value of the t-statistic. DF – Degrees of freedom used in the *t* test. Prob > |t| – p-value associated with a two-tailed test. Prob > t – p-value associated with an upper-tailed test. Prob < t – p-value associated with a lower-tailed test.

3.3. Bio-concentration factors for trace elements and nutrients in the study sites

As shown in Table 2, the bio-concentration factor per trace elements and nutrients in the studied species from five different study sites. The level of trace elements in soil showed significant differences in the five study sites. The findings were lower than the published Indian limits for trace element concentrations. In terms of trace element concentrations in soil, Fe concentrations were greater than other trace elements. The mean value of the trace elements, Fe and Al ranged between 8672 ppm and 5875.66 ppm from study site 4 is a higher ratio than other study sites. In Cr, study sites 4 and 2 had the highest enriched bio-concentration factors. In the form of trace elements, Ni is highest range (91.66 ppm) in study site 2. Cu is the high range in study site 2. The mean values of bio-concentration factors of the five study sites are showed significant differences compare to each other. Whereas the nutrient content (N, P, K, Ca, Mg, Mn, Zn) is expressed as mg/g. Nitrogen (N) content in the five different study sites is highest enriched (193 mg/g) in study site 3. In, the form of potassium (K) range from 86 to 92.33 mg/g was present in all the study sites. However, study sites 3 and 2 were enriched fields than others. The nutrient of the Ca range was reached at 55.66 mg/g in study site 4. Phosphorus is maximum (47.66 mg/g) was present in study site 4. Among other nutrients (Mg, Mn, Zn) varies from all the study sites (Table S3).

The bio-concentration study revealed the general capacity to tolerate significant levels of trace elements and nutrition in five different study site soils. Study site 4 is enriched with trace element content when compared to others. These elements are, at a low-level content when compared to the legal limits. But, our present study demonstrated to the different individuals is present in the different study site and found the maximum concentration of the trace elements to uptake. Generally, the plant's tolerance capability enhance their growth against trace metals and micronutrients (Tibbett et al., 2021). Even, the trace elements accumulated high concentrations to play a vital role in growth and development. However, trace elements and micro-nutrients functions are numerous even though, the compartmentalization of plants tissue allows for reduction and translocation to another part of the plants (Yang and Ye, 2009). In the present study, the bio-concentration factor for trace elements and nutrients studied field whose various patterns showed significant difference. In contrast with previous literature found that levels of elements and nutrition generally decreased root > leaves > stem (Bonanno et al., 2017; Bonanno and Cirelli, 2017; Liu et al., 2016; Punchay et al., 2020; Sankaran and Grusak, 2014).

3.4. Translocation factors of trace elements in the studied individuals

The concentrations of translocation factors of trace elements are calculated using root, stem, and leaves. Across five research locations,

Table 2
Descriptive statistics of the bio-concentration factor per trace elements and nutrients in the studied species from five different study sites.

	RS-Fe	RS -Cd	RS -Cr	RS -Cu	RS -Al	RS -Ni	RS -Pb	RS -N	RS -P	RS -K	RS -Ca	RS -Mg	RS -Mn	RS -Zn
EdS1	0.59	0.42	0.37	0.29	0.29	0.69	0.30	0.56	0.24	0.77	0.15	0.15	0.06	0.02
ApS1	0.70	0.63	0.51	0.27	0.52	0.63	0.49	0.54	0.26	0.88	0.17	0.21	0.05	0.02
CdS1	0.84	0.51	0.37	0.43	1.01	0.60	0.44	0.57	0.20	0.88	0.19	0.18	0.06	0.02
WiS1	0.97	0.45	0.51	0.26	0.81	0.41	0.38	0.63	0.18	0.91	0.19	0.21	0.07	0.01
PrS1	0.76	0.64	0.47	0.32	0.84	0.23	0.37	0.53	0.24	0.78	0.15	0.15	0.08	0.01
HlS1	0.48	0.49	0.28	0.27	0.49	0.32	0.25	0.58	0.20	1.02	0.13	0.18	0.07	0.01
LpS1	0.64	0.40	0.37	0.21	0.54	0.24	0.22	0.56	0.18	0.67	0.17	0.21	0.06	0.02
EpS1	0.84	0.74	0.51	0.29	0.43	0.33	0.30	0.63	0.22	0.74	0.15	0.18	0.06	0.02
PsS1	0.63	0.63	0.36	0.34	0.54	0.35	0.50	0.57	0.24	0.73	0.11	0.18	0.05	0.02
TrS1	0.54	0.47	0.38	0.36	0.55	0.49	0.56	0.68	0.26	0.97	0.13	0.21	0.07	0.02
EdS2	0.56	0.31	0.37	0.27	0.29	0.60	0.44	0.59	0.22	0.89	0.17	0.18	0.06	0.02
ApS2	0.68	0.47	0.46	0.24	0.51	0.56	0.47	0.53	0.20	0.79	0.17	0.18	0.06	0.01
CdS2	0.77	0.37	0.36	0.40	0.96	0.53	0.58	0.51	0.15	0.76	0.17	0.18	0.05	0.01
MmS2	0.51	0.45	0.50	0.24	0.78	0.51	0.55	0.52	0.24	0.76	0.13	0.15	0.05	0.01
SsS2	0.62	0.36	0.32	0.26	0.51	0.43	0.43	0.59	0.26	0.93	0.19	0.21	0.07	0.02
CoS2	0.45	0.37	0.37	0.22	0.47	0.53	0.44	0.53	0.24	0.85	0.15	0.18	0.06	0.02
DaS2	0.53	0.43	0.46	0.24	0.50	0.65	0.49	0.56	0.22	0.89	0.15	0.18	0.06	0.02
CvS2	0.67	0.48	0.51	0.46	0.32	0.60	0.17	0.58	0.24	0.90	0.17	0.18	0.06	0.02
BiS2	0.45	0.36	0.41	0.23	0.32	0.50	0.51	0.58	0.20	0.93	0.15	0.18	0.04	0.02
LgS2	0.51	0.28	0.46	0.15	0.39	0.21	0.44	0.52	0.22	0.89	0.17	0.21	0.04	0.02
PdS2	0.55	0.28	0.28	0.22	0.68	0.23	0.28	0.52	0.24	0.80	0.15	0.15	0.06	0.01
EdS3	0.55	0.39	0.43	0.40	0.33	0.58	0.40	0.52	0.17	0.83	0.18	0.16	0.06	0.01
ApS3	0.68	0.62	0.49	0.30	0.51	0.58	0.49	0.54	0.21	0.74	0.15	0.16	0.06	0.01
CdS3	0.81	0.49	0.39	0.53	1.05	0.52	0.49	0.57	0.24	0.79	0.17	0.19	0.06	0.01
PrS3	0.67	0.54	0.51	0.35	0.81	0.21	0.38	0.51	0.19	0.79	0.17	0.16	0.06	0.01
SsS3	0.68	0.49	0.35	0.37	0.54	0.44	0.29	0.55	0.24	0.81	0.15	0.16	0.06	0.02
CvS3	0.69	0.64	0.59	0.61	0.33	0.62	0.22	0.54	0.19	0.74	0.18	0.16	0.05	0.01
VoS3	0.67	0.48	0.39	0.32	0.49	0.37	0.25	0.56	0.24	0.84	0.15	0.16	0.07	0.02
EbS3	0.72	0.59	0.54	0.21	0.53	0.35	0.35	0.50	0.26	0.75	0.17	0.16	0.06	0.02
PaS3	0.58	0.55	0.35	0.32	0.54	0.43	0.37	0.56	0.19	0.74	0.17	0.14	0.04	0.01
DsS3	0.58	0.47	0.39	0.35	0.24	0.25	0.38	0.51	0.24	0.79	0.15	0.16	0.05	0.02
EdS4	0.55	0.36	0.39	0.33	0.28	0.65	0.38	0.55	0.19	0.88	0.16	0.17	0.07	0.01
ApS4	0.65	0.51	0.49	0.25	0.48	0.63	0.62	0.52	0.23	0.74	0.18	0.14	0.08	0.02
CdS4	0.80	0.43	0.35	0.44	0.98	0.54	0.58	0.58	0.19	0.83	0.14	0.14	0.06	0.02
WiS4	0.85	0.37	0.52	0.27	0.75	0.41	0.41	0.58	0.19	0.90	0.14	0.17	0.06	0.02
MmS4	0.51	0.52	0.50	0.24	0.74	0.52	0.57	0.57	0.25	0.79	0.14	0.17	0.07	0.02
DaS4	0.56	0.49	0.46	0.27	0.49	0.67	0.57	0.54	0.19	0.74	0.16	0.17	0.07	0.01
DsS4	0.58	0.44	0.42	0.23	0.51	0.63	0.41	0.58	0.23	0.83	0.14	0.17	0.06	0.01
CdaS4	0.69	0.48	0.36	0.30	0.32	0.52	0.19	0.52	0.21	0.83	0.14	0.17	0.06	0.02
ClS4	0.53	0.34	0.37	0.15	0.19	0.53	0.43	0.58	0.23	0.79	0.16	0.17	0.06	0.01
VmS4	0.58	0.26	0.39	0.14	0.60	0.46	0.39	0.59	0.21	0.78	0.16	0.14	0.07	0.01
PbS4	0.61	0.49	0.34	0.15	0.65	0.59	0.51	0.53	0.19	0.91	0.14	0.17	0.06	0.02
EdS5	0.59	0.34	0.43	0.37	0.32	0.68	0.41	0.54	0.23	0.87	0.18	0.21	0.07	0.02
ApS5	0.76	0.45	0.59	0.31	0.58	0.66	0.49	0.62	0.21	0.79	0.14	0.15	0.07	0.01
CdS5	0.85	0.37	0.40	0.53	1.18	0.59	0.49	0.59	0.23	0.88	0.21	0.21	0.07	0.02
WiS5	0.95	0.34	0.60	0.31	0.90	0.45	0.39	0.60	0.18	0.85	0.16	0.15	0.08	0.02
MmS5	0.60	0.45	0.56	0.31	0.94	0.58	0.55	0.56	0.21	0.85	0.16	0.18	0.07	0.02
CoS5	0.48	0.40	0.41	0.31	0.56	0.57	0.41	0.58	0.23	0.81	0.14	0.15	0.06	0.02
DsS5	0.68	0.39	0.51	0.27	0.57	0.66	0.35	0.62	0.28	0.93	0.16	0.21	0.07	0.01
CdaS5	0.81	0.43	0.44	0.23	0.38	0.57	0.27	0.56	0.28	0.80	0.14	0.24	0.06	0.02
EgS5	0.62	0.31	0.41	0.26	0.38	0.27	0.33	0.62	0.25	0.90	0.18	0.15	0.06	0.01
HcS5	0.59	0.35	0.50	0.25	0.33	0.37	0.19	0.53	0.23	0.91	0.16	0.24	0.06	0.02

Note: Bioconcentration factor calculated by C_{root}/C_{soil}. R – Root, S – Soil. Fe – Iron, Cd – Cadmium, Cr – Chromium, Cu – Copper, Al – Aluminium, Ni – Nickel, Pb – Lead; N – Nitrogen, P – Phosphorus, K – Potassium, Ca – Calcium, Mg – Magnesium, Mn – Manganese, Zn – Zinc. Al, Cu, Cr, Fe, Pb, Ni, Cd – Expressed as ppm; N, P, K, Ca, Mg, Mn, Zn – expressed as mg/g.

the trace element distributions among the three compartments (root, stem, and leaves) were significant. Translocation factor levels were considerably varied for each species based on trace element levels from different sections of plants in different research sites. As for the translocation factor of stem/root, the maximum mean value for iron was found in *H. contortus* S5 (0.1 ppm), which also had the highest value for Cu. For Cd, *C. difformis* S1 and S5 gave off the highest value in the range of 0.23 ppm. Al was present in maximum concentration (0.21 ppm) in *C. viscose* S2 and *D. sanguinalis* S3. The highest range for Ni is 0.05 ppm in *D. sanguinalis* S3 and *E. geniculata* S5. Pb is present in *C. viscose* of both study area 2 and study area 3. Following this, the translocation factors of leaves/stem were recorded. The highest mean value for iron was found in *A. penninervis* S4 (0.54 ppm). Cadmium and chromium showed the highest translocation factors in *M. minutiflora* S5, *A. penninervis* S3, and *V. obtuse* S3. The highest value for Cu was recorded in *V. minor* S4 (0.44 ppm) and for Al, they were *A. penninervis* S2, S4, and *M. minutiflora* S4. Ni was found to be present in *C. difformis* S4; while Pb had maximum value in *P. dilatatum* S1.

The sample from among the five study sites with different individual's leaves/root, stem/root, and leaves/stem were presented in Fig. 3. The biplot summary indicated that the PCA dimensions estimated total variations of three different translocation factors among the study site. The PCA two dimensions were nineteen trace element translocation factor traits explained 26.5% of the variation. The variations accounted for 52 plants species for total variability for component 1 and component 2. The PCA analysis figure indicates the relationship between 52 plant species among the seven trace elements directions by arrows with five study sites. The mechanism strategies of trace elements loading into the xylem in regulating the availability of trace elements and nutrients from the root to the stem by vacuolar sequestration in the root system.

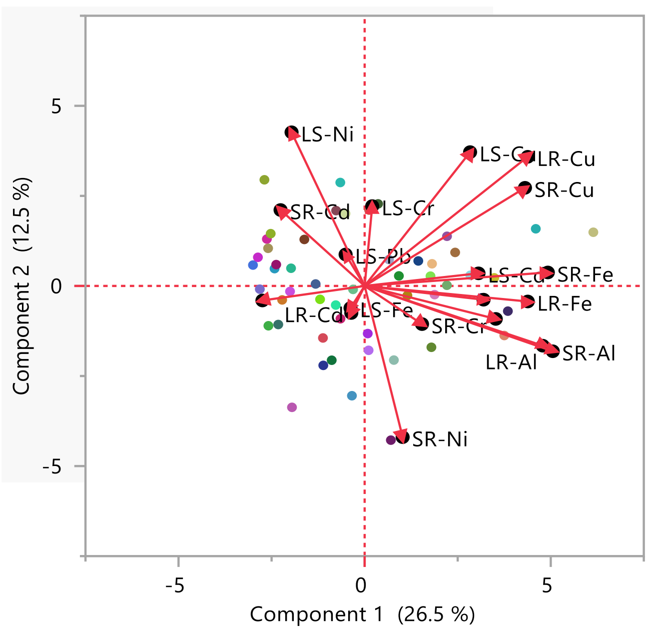

Fig. 3. Principal component analysis – Biplot summary of the leaves/root, stem/root, leaves/stem translocation factor of trace elements in the studied individuals in different study sites of BDU campus. Color indicates different individuals. The distance between 52 individual's plots reflects the degree of dissimilarity of their composition. The direction and length of the vectors represent the strength of associations of individuals. The circle corresponds maximum vector length and indicates Pearson correlation coefficient. R– Root, S– Stem, L– Leaf; Fe– Iron, Cd– Cadmium, Cr– Chromium, Cu– Copper, Al– Aluminium, Ni– Nickel, Pb– Lead.

Two distinct mechanisms are involved in this translocation process (Orłowski et al., 2019; Zhang et al., 2020). The main elements transfer by the phloem and unloading in the xylem. The metal–ligand complexes with Fe, Cu, Cd, and Zn (Merrington et al., 2001; Tibbett et al., 2021). The mobility of trace elements within phloem varies and is also influenced by competition between trace elements and, at high concentrations (Hu et al., 2019). Based on the our present study, the PCA axes were positively correlated with the translocation factor among the 52 individuals,

in leaves /root, LR – Al > LR – Cu > LR – Fe;
in leaves/stem, LS – Cr > LS – Ca > LS – Ni > LS – Pb;
in stem/root, SR – Cu > SR – Cd > SR – Fe > SR – Cr > SR – Al > SR – Ni.

The values of negatively correlated with leaves/root in Cd and leaves/stem in Fe. PCA analysis detailed data were presented for the 52 samples are in Supplementary Table S4. The Pearson's correlations values of the leaves/root, stem/root, leaves/stem translocation factor of trace elements in the studied individuals from different study sites are presented in Supplementary Table S5.

3.5. The distribution of trace elements in the studied individuals

In particular Fig. 4 indicates the translocation factor of leaves/roots by using Hierarchical clustering dendrogram analysis. The studied individuals a significant level of trace elements translocation factors was present in leaves /root, leaves/stem, and stem/root. In particular, the study showed that these individuals are varying from species to species and also study site. Whereas, in leaves /root, *H. contortus* S5 (Fe, Cd, Cu, Al) is the highest range among the trace elements translocation factor followed by *C. dactylon* S5 (Cu), S4 (Al, Pb), *C. viscose* S2 (Al, Pb) and *E. decangulare* S1 (Al), S2 (Cd, Al), S4 (Al). Regarding the study sites are, S5 > S2 > S4 > S1 > S3. In particular of stem/root translocation factor is highest range were found in *H. contortus* S5 (Fe, Cu, Pb). The next level translocation factors accumulated cadmium at high concentrations are *C. dactylon* S1, S5 followed by *C. viscose* S2 (Al, Pb), S3 (Pb). In contrast, the study sites were reached high-level translocation factors as followed, S5 > S3 > S2 > S1 > S4. The level of leaves/stem translocation factor highest level in *A. penninervis* S4 (Fe, Al), S3 (Cr), and S2 (Al), respectively. The translocation factor strategy is consistent in *A. penninervis* > *M. minutiflora* > *V.obtuse* > *C. odoratus.* In study sites are, S4 > S3 > S5 > S2 > S1. Trace elements translocation factors were significantly differed from species to species and also study site. Even though the translocation factor study sites were represented in the same manner as a leaves/root showed S5 > S2 > S4 > S1 > S3, stem/root showed, S5 > S2 > S4 > S1 > S3 and leaves/stem showed S4 > S3 > S5 > S2 > S1.

The present studies were more supported to the study site 5 is more and enriched trace elements than others. The trace elements translocation factor was a general pattern in all the individuals whose various study sites showed significantly different levels. In particular, these results indicate that the individuals Fe, Cr, Ni and Pb in soil according to the legal limit (Cicchella et al., 2020; Kabala et al., 2020; Nawrot et al., 2021). The plants have active potential to uptake trace elements from soil and transfer to the other parts of species (Barraza et al., 2021; Pidlisnyuk et al., 2020; Tibbett et al., 2021). The translocation factor of leaves/root varied from stem/root, despite the fact that root, stem, and leaves had a tight relationship. Our findings matched those of a prior study on the *Typha* genus and marsh plants (Bonanno et al., 2018; Carranza-Álvarez et al., 2008).

3.6. Translocation factors of macronutrients in the studied individuals

The PCA indicates (Fig. 5), which the translocation factor of macronutrients from five different sites. The monoplot of PCA showed that the 52 individual's translocation factor of leaves/root, stem/root showed, and leaves/stem of five different study sites. The colours represent each individual's positive and negative correlation to the three parameters studied at the different study site. The range was significantly differing from 1.48 mg/g to 1.44 mg/g in *P. repens* S1 and *A. penninervis* S1, respectively. The highest range for phosphorus was observed in *C. difformis* S2 (2.99 mg/g) and *E. decangulare* (2.13 mg/g). Potassium and calcium were present in the highest levels in *E. pectinacea* S1 (K- 0.95 mg/g), *P. dilatatum* S2, *A. penninervis* S5 (K- 0.9 mg/g), *W. indica* S1 (Ca- 4.2 mg/g), and *A. penninervis* S1 (Ca- 4 mg/g). Magnesium reached its peak in *C. odoratus* (2.6 mg/g) and 2.4 mg/g was present in *M. minutiflora* S2, *P. aristata* S3, *A. penninervis* S4, *C. difformis* S1, and *A. penninervis* S5. *P. dilatatum* S2 and *C. difformis* S1 had a maximum Mn level- 3.75 mg/g. The macronutrient zinc was present in high levels in the following individuals: *A. penninervis* S5 (5 mg/g), *H. lanatus* S1 (3.33 mg/g), *A. penninervis* S2, and S3 (3.33 mg/g). As for stem/root translocation factor, the nitrogen range was around 1.52 mg/g in *P. repens* S1 and 1.48 mg/g in *A. penninervis* S1, S2, and *C. dactylon* S4 respectively. Phosphorus and potassium reached the maximum level in *E. decangulare* S3 (P- 3.38 mg/g), *E. decangulare* S4 (P- 3.11 mg/g), *E. pectinacea* S1 (K- 1.11 mg/g), and *P. aristata* S3 (K- 1.09 mg/g). *C. dactylon* S5 (6.26 mg/g) and *P. scrobilatum* S1 (6.17 mg/g) were recorded to have maximum level of calcium. *E. decangulare* S1, *A. penninervis* S4, *C. dactylon* S4, *A. penninervis* S5, and *C. odoratus* S5 showed the highest range of magnesium, the value being 4.4 mg/g. Mn reached 13.33 mg/g in *A. penninervis* S1, *B. ischaemum* S2, and 12.86 in *C. dactylon* S5. *L. gallica* S2, *C. dactylon* S5, and *H. contortus* S5 held the maximum zinc content (7.14 mg/g). The leaves/stem translocation factor had the following decreasing order: N (*P. repens* S1 – 0.98 mg/g, *A. penninervis* S1 – 0.97 mg/g), P (*C. difformis* S1 – 1.07 mg/g, *P. scrobiculatum* – 0.8 mg/g), K (*C. difformis* S2 – 0.93 mg/g, *W. indica* S5 – 0.91 mg/g), Ca (*W. indica* S1), Mg (*P. aristata* S3 – 0.75 mg/g; *T. repens* S1 – 0.73 mg/g), Mn (Range is 0.5 mg/g – *C. difformis* S1; *H. lanatus* S1; *M. minutiflora* S4; *D. aegyptium* S4; *V. minor* S4), and Zn (1 mg/g –

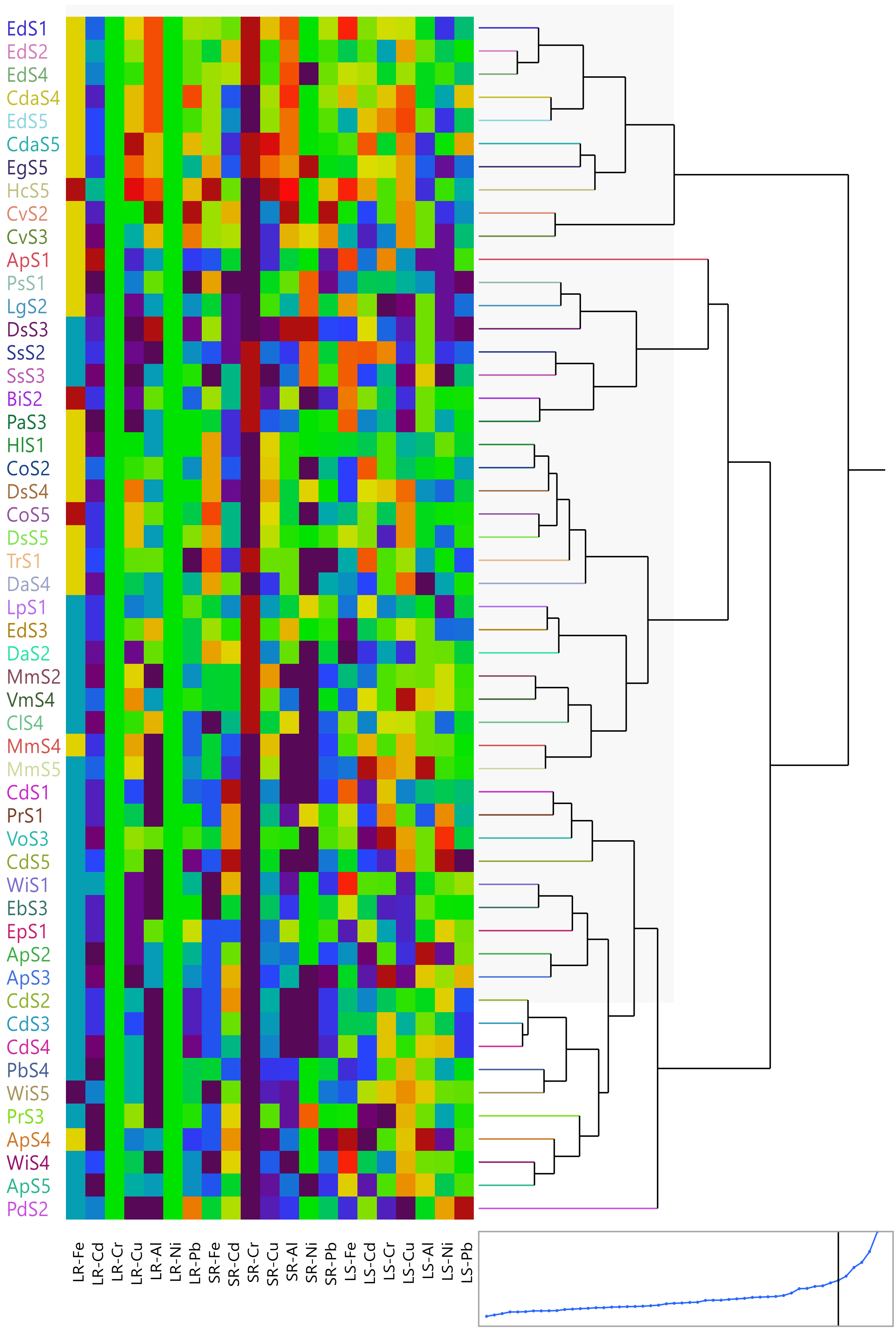

Fig. 4. Hierarchical clustering dendrogram analysis of the leaves/root, stem/root, leaves/stem translocation factor of trace elements in the studied individuals from different study sites, constructed by ward method. Hierarchical clustering indicates the name of the individual's genus, species and study site (e.g. EdS1 – *Eriocaulondecangulare* Study site 1). R – Root, S – Stem, L – Leaf; Fe – Iron, Cd – Cadmium, Cr – Chromium, Cu – Copper, Al – Aluminium, Ni – Nickel, Pb – Lead.

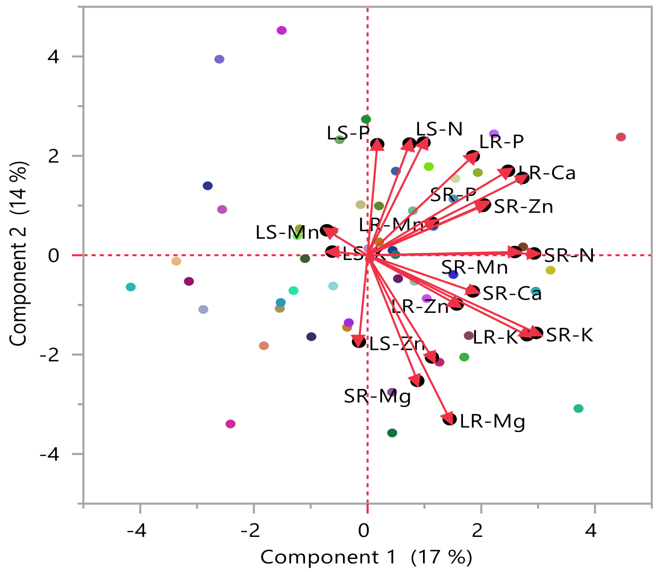

Fig. 5. Principal component analysis – Biplot summary of the leaves/root, stem/root, leaves/stem translocation factor in different study sites of BDU campus. Colors indicate different individuals. The distance between 52 individuals' plots reflects the degree of dissimilarity of individual's composition. The direction and length of the vectors represent the strength of associations of individuals. The circle corresponds maximum vector length and indicates Pearson correlation coefficient. R – Root, S – Stem, L – Leaf; N – Nitrogen, P – Phosphorus, K – Potassium, Ca – Calcium, Mg – Magnesium, Mn – Manganese, Zn – Zinc.

E. pectinacea S1, *C. difformis* S4), respectively.

According to the previous pieces of literature, one species instead of another can resolve the practical problem by replacing other plant species by remediation. The Cattail species of *Typha* found indeed similar nutrient content in all species under the same field conditions (Bonanno and Cirelli, 2017). In our present findings, showed that the the micronutrient translocation factors were analysed among the 52 individuals. The translocation factor of nutrients from leaves/root, stem/root showed, and leaves/stem showed in Supplementary Table S6. The two dimensions PCA were nineteen nutrient translocation factor traits explained with 17% of the variation. The PCA corresponds to components of were showed the strong positive correlation of,

in leaves /root, LR – Mg > LR – P > LR – K > LR – Ca > LR – Zn, > LR – Mn;
in leaves/stem, LS – P > LS – N > LS – Zn > LS – Mn > LS – K;
in stem/root, SR – Mg > SR – K> SR – Ca > SR – P > SR – Zn > SR – Mn > SR – K.

The Pearson's correlations values of the leaves/root, stem/root, leaves/stem translocation factor of trace elements in the studied individuals from different study sites are presented in Table 3. In this condition, the soil and the water can replace the dominant plant community by forming a new species by mono-type species or/multi-type species (Panich-Pat et al., 2004). In the present study was demonstrated that the variety of species differs from each other by different study sites.

3.7. *The distribution of nutrients in the studied individuals*

Fig. 6 showed the nutrition translocation factor of leaves/roots by using Hierarchical clustering dendrogram analysis. Using the spectral range of the Hierarchical cluster, the dendrogram analysis corresponds to the two-way analysis. The amount of root, stems, and leaves in the nutrient translocation factors were substantially differed between the

Table 3
Pearson's correlations values of the leaves/root, stem/root, leaves/stem translocation factor of macronutrients in the studied individuals from different study sites.

	LR-N	LR-P	LR-K	LR-Ca	LR-Mg	LR-Mn	LR-Zn	SR-N	SR-P	SR-K	SR-Ca	SR-Mg	SR-Mn	SR-Zn	LS-N	LS-P	LS-K	LS-Ca	LS-Mg	LS-Mn	LS-Zn
LR-N	1.0000																				
LR-P	0.3617	1.0000																			
LR-K	0.1646	0.0034	1.0000																		
LR-Ca	0.2272	0.1151	0.2270	1.0000																	
LR-Mg	0.0796	−0.0398	0.3456	−0.1676	1.0000																
LR-Mn	0.1932	0.0227	0.2288	0.1874	0.0471	1.0000															
LR-Zn	0.0933	0.1008	0.2115	0.1803	0.1874	0.0171	1.0000														
SR-N	0.7319	0.3161	0.1785	0.1792	0.2596	0.0819	0.1594	1.0000													
SR-P	0.3061	0.8710	0.1260	0.0959	0.0395	−0.1560	0.2006	0.3001	1.0000												
SR-K	0.1577	−0.0124	0.8253	0.2401	0.3087	0.2885	0.1439	0.2548	0.0551	1.0000											
SR-Ca	0.0789	−0.0252	0.1083	0.3405	0.0688	0.0009	0.0702	0.2321	0.0505	0.3438	1.0000										
SR-Mg	0.1521	−0.0089	0.2630	−0.2265	0.8204	0.0181	0.1613	0.1822	0.1135	0.1941	−0.1028	1.0000									
SR-Mn	0.1657	0.0338	0.3589	0.4898	0.0673	0.1397	0.0542	0.2754	0.0685	0.2993	0.2730	−0.0753	1.0000								
SR-Zn	0.2156	0.1925	0.1427	0.2314	−0.1084	0.0203	0.2699	0.1761	0.2312	0.2212	0.2449	−0.1448	0.2526	1.0000							
LS-N	0.6466	0.1695	0.0620	0.1408	−0.1776	0.1781	−0.0322	−0.0417	0.1092	−0.0393	−0.1589	0.0149	−0.0772	0.1328	1.0000						
LS-P	0.1874	0.4861	−0.1987	0.0669	−0.1481	0.3078	−0.1109	0.1139	0.0107	−0.1171	−0.1258	−0.2131	−0.0890	−0.0438	0.1415	1.0000					
LS-K	−0.0184	0.0292	0.1764	−0.0524	0.0359	−0.1368	0.0706	−0.1491	0.1109	−0.4066	−0.4142	0.0810	0.0766	−0.1640	0.1485	−0.1198	1.0000				
LS-Ca	0.1044	0.1091	0.0784	0.7798	−0.2518	0.1741	0.0978	−0.0258	0.0140	−0.0224	−0.2829	−0.2112	0.2961	0.0319	0.1950	0.1918	0.1580	1.0000			
LS-Mg	−0.1150	−0.0493	0.2137	0.0119	0.5146	0.0515	0.0732	0.1352	−0.0773	0.2316	0.2989	−0.0546	0.2280	0.0335	−0.3282	0.0370	−0.0285	−0.1734	1.0000		
LS-Mn	0.0671	−0.0369	−0.0480	−0.1356	0.0055	0.7709	−0.0163	−0.0910	−0.2193	0.0205	−0.1550	0.0786	−0.4813	−0.1634	0.1932	0.3319	−0.1316	−0.0421	−0.1059	1.0000	
LS-Zn	−0.0817	−0.0657	0.1403	−0.0641	0.2309	−0.0026	0.6707	−0.0061	0.0143	0.0123	−0.2108	0.2361	−0.1584	−0.4508	−0.1175	−0.1202	0.1898	0.0568	0.0379	0.0937	1.0000

Note: The correlations are estimated by Row-wise method. R – Root, S – Stem, L – Leaf; N – Nitrogen, P – Phosphorus, K – Potassium, Ca – Calcium, Mg – Magnesium, Mn – Manganese, Zn – Zinc.

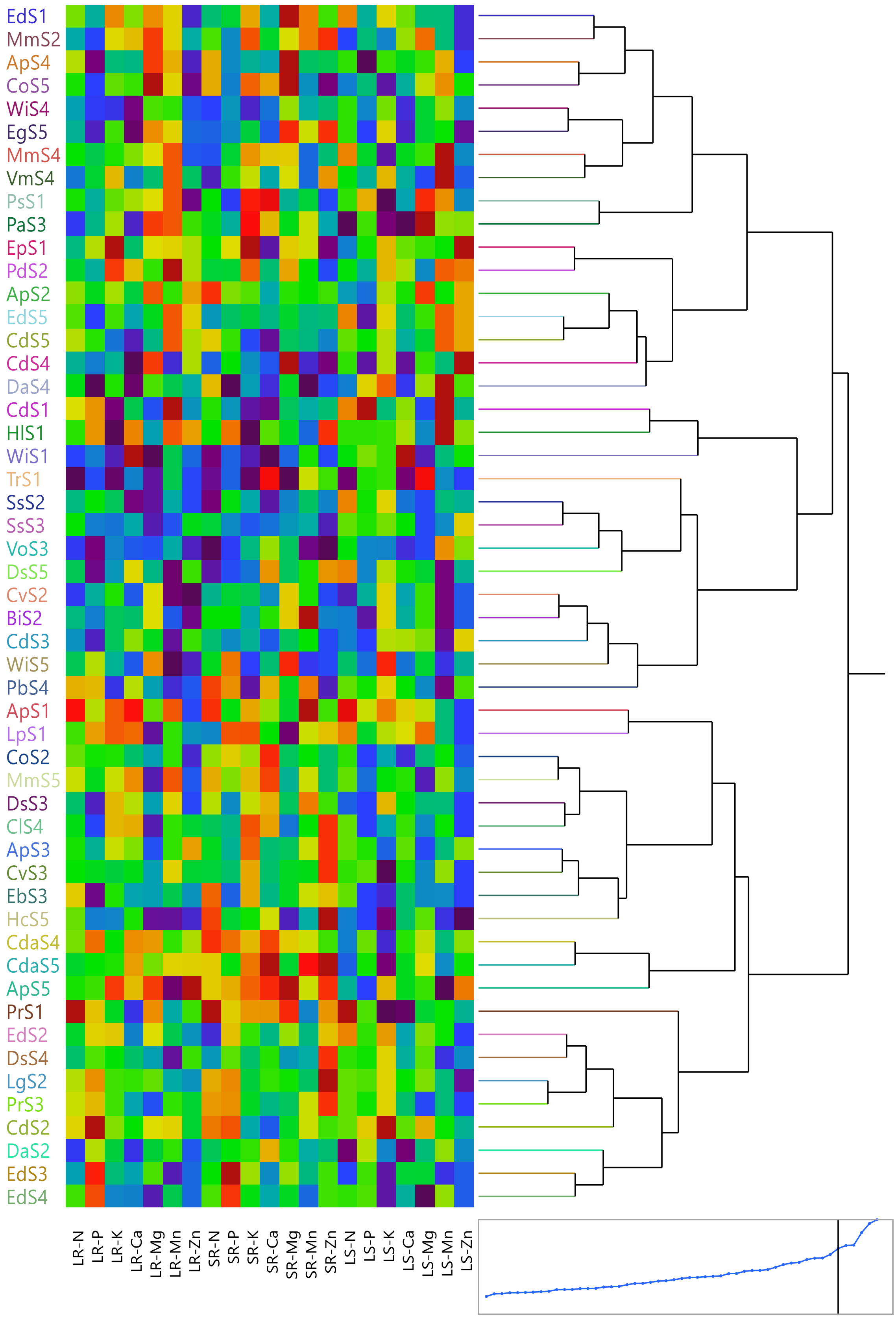

Fig. 6. Hierarchical clustering dendrogram analysis analysis of the leaves/root, stem/root, leaves/stem translocation factor in different study site from BDU campus, constructed by ward method. Hierarchical clustering indicates the name of the individual's genus, species and study site (e.g. EdS1 – *Eriocaulondecangulare* Study site 1). R – Root, S – Stem, L – Leaf; N – Nitrogen, P – Phosphorus, K – Potassium, Ca – Calcium, Mg – Magnesium, Mn – Manganese, Zn – Zinc.

study sites. This present study demonstrated that the N, P, K, Ca, Mg, Mn, and Zn accumulated and translocations of each nutrient to the all parts of plants. In leaves/root, *A. penninervis* S1 (N, Ca), S2 (Zn), S3 (Zn), S5 (Zn) are the highest range compared to the other 52 individuals followed by *C. difformis* S1 (Mn), S2 (P) and S4 (Mg), respectively. In the correlation of the study, the site where enriched nutrient translocation factor is S1 > S2 > S3 > S5 > S4. Whereas, stem/root translocation factor is highly enriched in *A. penninervis* S1 (N, Mn), S2 (N), and S4 (Mg) followed by *C. dactylon* S4 (N), S5 (Ca, Mn, Zn) and *E. decangulare* S3 (P), S4 (P), S1 (Mg), respectively. In the translocation form in study sites were S4 > S5 > S1 > S2 > S1. Regarding leaves/stem, high levels of nutrients were present in *C. difformis* S1 (P, N, Mn), S2 (K) and S4 (N) followed by *M. minutiflora* S4 (N, Mn). Study sites were enriched as the following pattern, S1 > S4 > S5 > S2 > S3.

Internal macronutrient accumulation appeared to be varied and depended on each section of the persons in different study sites. The current study found that nutrient transfer from the root has the maximum mobility, followed by stem and leaves. This is consistent with the general trend of bulk nutrient production and accumulation in the soil (Bonanno et al., 2017; Li et al., 2020; Mufarrege et al., 2021). Nitrogen, potassium, and phosphorus were at the highest levels indicating that all the individuals who had all the nutrients required for proper growth and development had them in the highest levels (Tong et al., 2021; Yang et al., 2020b). In the present study, we observed that S4 plant species were enriched with nitrogen when compared to other study sites.

Mn and Zn which play a vital role in plant metabolism were highest in *A. penninervis* S1 (P, N, Mn), S2 (K), and S4 (N) followed by *M. minutiflora* S4 (N, Mn). These results significantly correlate with the previous report (Piwowarczyk et al., 2021). The large quantities of macronutrients found in the plant body, especially in the stem and leaves, might imply a role in growth, development, and photosynthesis (Annabi et al., 2019; Hawkesford et al., 2012). Overall, levels of macronutrients significantly differed amongst each plant species in the 52 recorded individuals.

4. Conclusion

The present study shows the bioaccumulation potential of trace elements and macronutrients and the total level of translocation factors in different plant tissues such as leaves, stem, and root, proving their mobility. This study found indeed dissimilar trace elements and nutrient concentrations in all study sites among the different individual plant species. Moreover, five different study sites given have dissimilar bioconcentrations and translocations factors. Besides, collecting the five study sites, mixed species in the variations of bio-concentrations and translocations factor were showed differences in all study sites. The species as indicators of ecological value to increase the diversity richness of environmental conditions. This study showed an eco-friendly method for monitoring and assessment of environmental factors. The accumulation and distribution of these trace elements and macronutrients may reflect a specific growth pattern in the species. Furthermore the number of studies carried out in this area is very limited. This study might provide a basic data analysis on the diversity of species and the edaphic characteristics. Further studies on the morpho-anatomical pattern of trace elements and macronutrients can pave way for the localization and mobility to be found on studied individuals.

CRediT authorship contribution statement

Darshini Subramanian: Investigation, Methodology, Writing – review & editing. **Raju Subha:** Investigation, Methodology, Data curation, Writing – review & editing. **Arul Kumar Murugesan:** Conceptualization, Validation, Formal analysis, Investigation, Methodology, Resources, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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