LEONARDO TULLIO
(ORGANIZADOR)

PAUTA AMBIENTAL BRASILEIRA E A PROMOÇÃO DA SUSTENTABILIDADE

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Pauta ambiental brasileira e a promoção da sustentabilidade

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APRESENTAÇÃO

A obra “Pauta ambiental brasileira e a promoção da sustentabilidade” aborda uma apresentação de 11 capítulos envolvendo pesquisas que englobam educação, projetos e manejo sustentável no cenário ambiental.

Pesquisar sobre variáveis que pressupõem a sustentabilidade no meio, é assunto com ênfase no cenário nacional e mundial. Esclarecer relações entre ação humana e ambiente é o foco principal desta obra. Os autores trazem aspectos da sociedade em contribuição para um mundo mais sustentável.

O cenário das mudanças climáticas são preocupantes e exigem pesquisas que vão além, que definam estratégias de conservação, manejo e educação social. Pois a remediação de um problema nem sempre é uma tarefa fácil, mas tendo a percepção da realidade em que vivemos podemos traçar metas e rumos para novos caminhos.

Educação ambiental faz parte é se torna cada vez mais evidente como resultado primordial para a conscientização dos problemas ambientais e a promoção de virtudes que proponham a sustentabilidade do meio.

Na leitura dos capítulos, serão discutidos esses aspectos por pesquisadores preocupados em demostrar possibilidades para uma abordagem mais técnica e ao mesmo tempo refletiva sobre o tema ambiental.

Sustentabilidade é possível agirmos já?

A resposta para essa pergunta iremos descobrir a seguir. Boa leitura.

Leonardo Tullio

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ABSTRACT: In the present study, an urban and industrial area were evaluated through a biomonitoring study employing the *Tillandsia purpurea* and *T. latifolia* species as a biomonitor. Plants were collected from a non-contaminated area and transplanted and exposed for three months into study areas to determine metal accumulation. Sixteen elements (Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Ni, Pb, Rb, Sb, V, and Zn) were measured using ICP-MS analysis. Datasets were assessed by one-way ANOVA, exposed-to-baseline (EB) ratio, and principal component analysis. Results showed significant differences among study areas for most elements, but no differences were found between species. According to EB ratios, As, Cd, Cr, Cu, Fe, Ni, Pb, Sb, V, and Zn showed EB ratios > 1.75 for both *Tillandsia* species around the industrial area, indicating influence from the Smelter plant. Ba, Sb, and Zn showed EB ratios >.1.75 in the urban area for both plants, indicating the releasing of

pollutants from vehicular sources. PCA showed that most elements are derived from vehicular sources, industrial activities, and dust resuspension.
KEYWORDS: Metals, pollution, biomonitoring, *Tillandsia genus*, two polluted areas.

RESUMO: No presente estudo, uma área urbana e industrial foi avaliada através de um estudo de biomonitoramento utilizando as espécies *Tillandsia purpurea* e *T. latifolia* como biomonitor. As plantas foram coletadas de uma área não contaminada e transplantadas e expostas por três meses nas áreas de estudo para determinar o acúmulo de metal. Dezesseis elementos (Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Ni, Pb, Rb, Sb, V e Zn) foram medidos usando análise ICP-MS. Os conjuntos de dados foram avaliados por ANOVA de uma via, razão exposição-base (EB) e análise de componentes principais. Os resultados mostraram diferenças significativas entre as áreas de estudo para a maioria dos elementos, mas não foram encontradas diferenças entre as espécies. De acordo com as razões de EB, As, Cd, Cr, Cu, Fe, Ni, Pb, Sb, V e Zn apresentaram razões de EB > 1,75 para ambas as espécies de *Tillandsia* ao redor da área industrial, indicando influência da planta de fundição. Ba, Sb e Zn apresentaram razões de EB > 0,1,75 na área urbana para ambas as plantas, indicando a liberação de poluentes de fontes veiculares. A PCA mostrou que a maioria dos elementos são derivados de fontes veiculares, atividades industriais e ressuspensão de poeira.
PALAVRAS-CHAVE: Metais · Poluição · Biomonitoramento · *Gênero Tillandsia* · Duas áreas poluídas.

1 | INTRODUCTION

Atmospheric emissions and posterior deposition of different trace elements into the environment released from anthropogenic activities have substantially increased (De La Cruz et al., 2019). The presence or release of toxic elements into the atmosphere is of great concern due to that these elements are very stable, are easily dispersed a lot in the environment, non-degradable, and are toxic even at low concentrations (Matin et al., 2016). Industrial activities and traffic from urban areas (vehicular exhaust and road dust) are the main responsible for releasing potentially toxic elements in different sizes, states (solid and/or liquid), and forms into the atmosphere (De La Cruz et al., 2020). Since the deposition and inhalation of these trace elements may produce negative impacts on the health of humans and the ecosystem arises the need and importance to monitor the contamination state.

Monitoring studies may contribute with relevant information, which may be used to implement strategies of prevention and preservation of the environment. However, monitoring studies usually need to use expensive equipment, qualified staff, and many times the high cost of maintenance. Recently, biomonitoring studies (inexpensive alternative method) using epiphytic species of several *Tillandsia* species have been successfully applied to determine the anthropogenic sources of trace metals present in the atmosphere (De La Cruz et al., 2018; Goix et al., 2013; Pinto et al., 2006). Epiphytic plants have the habit of obtaining nutrients, minerals, and moisture from the atmosphere via wet and dry deposition. Their morphology and physiology characteristics related to this type of nutrition (e.g. trichomes) make these species candidates key for biomonitoring studies (Sanchez-Chardi, 2016). Likewise, these species are well distributed in South, Central, and North America (Fontoura et al., 2012; Hesse, 2012)to answer the questions: (i. The genus *Tillandsia latifolia* is native to Peru and Ecuador. It has thick light green leaves which are covered totally by trichomes with growth slow and size between feet (Rundel and Dillon, 1998). *Tillandsia purpurea* are endemic species from Peru and Chile (Rundel and Dillon, 1998). It grows on rock, sand, and xerophytic vegetation with stemless to long-caulescent species (Rundel and Dillon, 1998).

Among Tillandsias species more widely used and reported in the scientific literature as bio-accumulators of metals in different areas of study (urban, agricultural, and industrial) are the *Tillandsia capillaris* (e.g. Abril and Bucher, 2009; Bedregal et al., 2012, 2009; Goix et al., 2013; Rodriguez et al., 2011; Schreck et al., 2016; Wannaz et al., 2013), and *Tillandsia usneoides* (Ferreira, 2014; Figueiredo et al., 2007; Santos et al., 2017; Schreck et al., 2020; Techato et al., 2014; Vianna et al., 2011)Brazil. Five consecutive transplantation experiments (8 weeks each which were carried out mainly in Brazil and Argentina, respectively. Although, other Tillandia species understudied were also reported in the literature. For example, *Tillandsia permutata* (Wannaz et al., 2006), *Tillandsia recurvata* (Chaparro et al., 2015; Sanchez-Chardi, 2016), *Tillandsia albida* (Kováčik et al., 2012), *Tillandsia bulbosa* and *Tillandsia caput-medusae* (Brighigna et al., 2002), and *Tillandsia retorta* (Wannaz and Pignata, 2006).

In Perú, biomonitoring studies using *Tillandsia* species are scarce. Until now, only two works were reported, both assessed metals using *T. capillaris* in Lima city (Bedregal et al., 2009) and Huancayo city (De La Cruz et al., 2020). Therefore, the main purposes of this study were: (i) to quantify sixteen trace element accumulation in the *T. latifolia* and *T. purpurea* transplanted and exposed during three months in an industrial and urban area from the Peruvian city of Lurigancho-Chosica; (ii) evaluate the pollution levels through EB-ratio to determine its possible sources of contamination.

2 | MATERIALS AND METHODS

2.1 Site description

Lurigancho-Chosica is located in the valley of the Rímac River, Lima Province in Peru (12.0097° S, 76.9054° W) at 861 m a.s.l. Climatic is tropical with an average annual temperature and rainfall of 26 °C and 2437 mm, respectively. Lurigancho-Chosica hosts Jicamarca and Cajamarquilla zones, where one of the principal zinc refineries named “Cajamarquilla” is located. Cajamarquilla is the largest zinc smelter in Latin America and the sixth largest globally. Sulfuric acid, copper cement, silver concentrate, and cadmium sticks are other products produced (Nexa, 2017).

The urban area covers an area of 236.47 km^2 and 204,814 inhabitants estimated in 2017 (INEI, 2007). Vehicular traffic (passenger cars, buses, trucks, motorcycles, etc.) is intense in this area due to that is used as a commercial connection between the mountains and the coast Peruvian. Likewise, the vehicular fleet is powered mainly by gasoline, petroleum derivates, and natural gas (GNV) (MTC, 2018).

2.2 Sampling method

Plants of *T. latifolia* and *T. purpurea* were collected from tree trunks of a non-contaminated area located in San Mateo District, Huarochiri Province, Peru (11º45´31´´ S - 76º18´00´´W). This area is characterized by low air pollutant emissions and represents the initial condition (baseline site) of these species. The specimens collected were placed in paper bags and transported to the laboratory. In the laboratory, plants were cleaned manually of debris and strange materials. After that, were acclimated for 7 days in an ambient free of contamination before transplantation.

Bags (nylon net) containing ~20 g *T. latifolia* and *T. purpurea* by separate were prepared according to Bermudez et al., (2009) and transplanted simultaneously to two areas: urban area (Figure 1) and industrial area (Figure 2) with different atmospheric pollution. In total 78 samples (39 samples of each plant) were prepared. Three samples randomly selected of each species were not transplanted to obtain values of not-exposed (*baseline* values - T_0) species which were preserved until analysis. In each area, thirty-six (eighteen samples of *T. latifolia* and *T. purpurea*) samples were exposed for 3 months during the dry season from 01/04/2019 to 10/07/2019. Samples were tied up on tree trunks using small plastic cable ties considering 1.5 m of height (to avoid soil influence) and a distance minimum of 100 meters among samples at each monitoring area. During the transplantation period, 2 samples were lost, with 70 samples remaining being re-sampled and transported to the laboratory for analysis. In the laboratory, the samples were carefully cleaned with short washing of bi-distilled water as recommended by the international harmonized approach to biomonitoring trace element atmospheric deposition (Smodiš and Bleise, 2002). Then, exposed and not exposed samples were oven-dried at 50 ºC until constant weight reached (48-72 h), milled, homogenized, sieved through a 2.0 mm mesh, and stored in polyethylene 50 mL tubes.

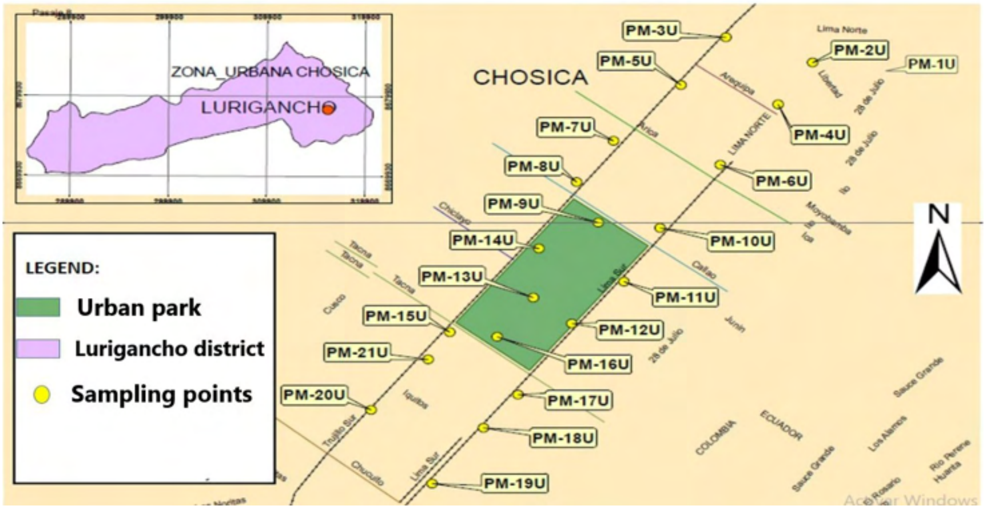

Fig. 1 Location of the sampling sites in the Urban area. Map prepared with Arc GIS 10.0 software analysis.

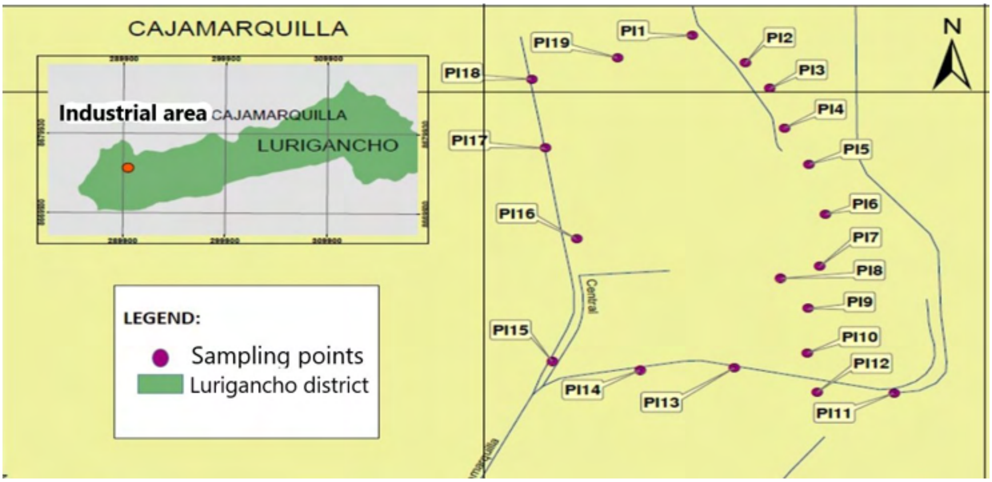

Fig. 2 Location of the sampling sites in the Industrial area. Map prepared with Arc GIS 10.0 software analysis.

2.3 Major and trace elements determination

Triplicate of each sample from 0.250 ± 0.003 g dry weight (DW) was weighted with a digital balance and placed into a Savillex Teflon bottle with 3 mL bi-distilled HNO_3 (65%) and 0.5 mL of H_2O_2. The chemical decomposition was carried out on a hot plate for 4 h at 300 °C. After decomposition, samples were transferred into a 50 mL Falcon tube and diluted to 20 mL using Milli-Q water with 2% HNO_3 and rhodium as an internal standard. Major and trace elements were quantified by an Inductively Coupled Plasma Mass Spectrometry (ICP-MS) Elan DRC II (Perkin Elmer SCIEX, Norwalk, CT, USA). Quality assurance and measurement traceability was ensured by measuring two certified reference materials (CRM): SRM 1515 “Apple leaves” and SRM 1573 “Tomato leaves”, both published by the National Institute of Standards and Technology (NIST). Likewise, triplicate samples of CRM and blank samples were analyzed in parallel to the samples. All certified elements present satisfying recoveries in the range of 80% - 108%.

2.4 Exposed-to Baseline ratios (EB ratios)

Exposed-to baseline (EB) ratios were computed as the ratio of the concentration measurement of exposed samples to the concentration measured in the not-exposed samples (baseline samples -T_0) as suggested by Frati et al., (2005). The values of EB ratios were interpreted through a 5-class scale: severe loss (SL: 0-0.25), loss (L: 0.25-0.75), normal (N: 0.75-1.25), accumulation (A: 1.25-1.75), and severe accumulation (SA: >1.75).

2.5 Statistical analysis

The values obtained were represented as mean ± SD (standard deviation) and the normal distribution was assessed by Kolmogorov-Smirnov. One-way analysis of variance (ANOVA) and subsequent posthoc Tukey test at 95% confidence interval were used to determine the difference between concentrations of trace elements among areas of study and *Tillandsia* species transplanted. Principal component analysis (PCA) with Varimax rotation was applied to identify possible sources of contamination in the studied areas. All treatment and statistics were performed in the CRAN R version 3.2.6 free software (R Team Core, 2019) using the factoextra package (Kassambara and Mundt, 2017).

3 I RESULTS AND DISCUSSION

3.1 Trace and major elements concentration and EB ratios in T. latifolia and T. purpurea

Mean concentration ± standard deviations (SD) and ANOVA results of the elements measured (Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Ni, Pb, Rb, Sb, V, and Zn) in *T. latifolia* and *T. purpurea* transplanted at an urban area and industrial area are shown in Table 1. Besides, elements measured in species not-transplanted (*baseline*) also are reported in Table 1. Levels of most elements measured in transplanted areas (urban and industrial areas) were significantly higher than baseline samples, confirming pollutants accumulation capacity for both Bromeliaceae species. The results showed that the sampling location/transplantation had a clear influence on the concentration levels of the analytes in the exposed plant material.

In the urban area, the highest concentration values were found for Ba, Ca, Cd, Cr, Fe, K, Mn, Ni, Pb, Rb, and Zn in *T. latifolia*; Al, As, Co, Cu, Mg, Sb, and V in *T. purpurea*. In the industrial area, As, Ba, Ca, Co, Cr, Cu, Fe, K, Mg, Mn, Ni, Rb, and Zn showed highest concentrations in *T. latifolia*, while Al, Cd, Pb, Sb, and V in *T. purpurea* (Table 1). For *T. latifolia*, most elements shown the highest concentration values in industrial areas than the urban area (except Ba, Ca, K, and Rb). The *T. purpurea* showed similar behavior with higher concentration for most elements found in the industrial area than the urban area (except Ba, Ca, K, and Mg). Thus, the highest concentrations of most elements were found in the industrial area than the urban area for *Tillandsia latifolia* and *T. purpurea*, except for Ba and Ca who showed higher concentration values in the urban area. Schreck et al., (2016) who exposed plants of *T. capillaris* found Pb, Sb, Sn, and Zn concentrations in plants of Smelter area higher than those from Downtown Oruro (Bolivia) samples. Likewise, Guéguen et al., (2012)urban, rural and remote forested environments in order to collect coarse airborne particles for subsequent chemical characterization. To identify principal polluting sources, isotopic tracers, such as Sr, Nd and Pb isotopic ratios, have been used. The mass deposition rates (MDRs using passive samplers in urban and industrial environments, reported enrichment of As, Cd, Co, Cr, Fe, Ni, Pb, Sb, V, and Zn in the industrial area, while Ba in the urban area. Barium is considered an indicator of vehicle emissions (Goddard et al., 2019). Lima and Callao cities account for 66% of the cars present in the whole Perú (MTC, 2018), therefore Ba concentration found may be related to this activity. Ca is considered as an indicator of cement production (Canbek et al., 2020), and their presence may be ascribed to release from local construction/demolition activities in form of waste and dust resuspension.

As shown in Table 1, significant differences ($p < 0.05$) among the mean concentrations from baseline samples and transplanting sites were found. Besides was observed significant difference ($p < 0.05$) between baseline accumulation values of *T. latifolia* and *T. caperata* for most elements. Likewise, urban and industrial sites were observed differences. However, no significant differences ($p>0.05$) for most elements (except Co, K, and Rb) were observed between plants in the same area (urban or industrial area). This last result indicates that both species accumulate similarly the pollutants. *T. latifolia* and *T. purpurea* have similar characteristics with thick light green leaves that are covered in trichomes.

The EB ratios calculated according to the scale of Frati et al., (2005) are presented in Table 2 (EB ratio values greater than 1.75 indicates anthropogenic influence). In the industrial area: As, Ba, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Sb, V, and Zn showed EB ratios > 1.75 for *T. purpurea,* while As, Cd, Cr, Cu, Fe, Ni, Pb, Sb, V, and Zn for *T. latifolia*. These results suggested an elevated enrichment of these elements in the vicinities of the Smelter plant in both species. Likewise, Zn who presented higher concentrations in both species of *Tillandsia*s confirms that the Zn smelter has a strong and negative impact on the atmospheric of this area. Schreck et al., (2016) who exposed plants of *T. capillaris* found Pb, Sb, Sn, and Zn in high concentrations around the Smelter plant in Bolivia. Likewise, Basile et al., (2009) reported severe accumulation of Cd and Pb in industrial sites using the moss *Scorpiurum circinatum* from Italy.

In the urban area: Ba, Sb, V (only for *T. purpurea*), and Zn showed EB ratios > 1.75

for both plant species, confirming thus again a similar accumulation capacity of the two *Tillandsias* studied. Ba, Sb, V, Zn, and other elements (e.g., Pb, Ni, and Cd with 1.25 < EB ratio <1.75) are considered toxic (Hoodaji et al., 2012). Liu et al., (2018) used epiphytic mosses to evaluate metal content on emissions from road traffic in a mountain area and concluded that Zn, Cu, Mn, Cr, Cd (background levels), and Pb were released from vehicle-related materials including tires and brakes. Basile et al., (2009) through the moss *Scorpiurum circinatum* determine heavy metals in urban areas from Italy. They found Cd and Pb to the highest concentrations, which were related to anthropogenic origin. Likewise, De Agostini et al., (2020) reported Al, Cr, Cu, V, and Zn at highest concentrations, which were ascribed to industrial emissions. According to EB ratios and the location, we can assume that these elements were released mainly from vehicular sources related particularly to brake and tire wear and historical deposition.

3.2 Principal component analysis

The Tillandsia data set containing the enrichment factor of 18 trace elements from 2 polluted areas (18 variables x 34 samples) for each area were submitted to principal component analysis.

Table 3, presents the results of PCA after varimax rotation from urban samples, which shows three factors that featured Eigenvalues greater than 1 and explaining the 71.91% of the total variability in the dataset. Factor 1 accounts for 48.68% of the total variance and presents high positive loading for Ba, Ca, Cr, Cu, Mg, Mn, Ni, Sb, V, and Zn. As and Pb show high loading in factor 2, which accounts for 17.00% of the total variance. Factor 3 explains 6.25% of the total variance and was noted positive loadings for Al, Co, and Rb. The communalities of As, Ba, Ca, Co, Cr, Cu, Fe, K, Mg, Mn, Ni, Pb, Sb, V, and Zn in the data set were in the range 0.60 – 0.91 indicating that each element was satisfactorily apportioned to the identified factors. However, Al, Cd, and Rb shower communalities values lower than 60%, suggesting that a substantial fraction of their concentrations of these elements could not be apportioned to factors whose Eigenvalues were *>1*. Factor 1 grouped 10 elements with significant loadings. At first glance, is noted that the main source of these elements might be anthropogenic due to that Ba, Sb, and Zn presented EB ratios values > 1.75 and Cr, Cu, Ni, and V show accumulation (1.25 < EB ratio < 1.75) in the urban area. Therefore, the source may be non-exhaust vehicle emissions (e.g., tire and brake wear), since these elements are commonly found in urban areas. Factor 2 has significant loadings of As and Pb, with the lesser influence of Fe and Rb, indicating an influence of both anthropogenic and natural origin, such as apatite (Fe). Factor 3 showed significant loadings of Al, Co, and Rb suggesting primarily natural origin.

Table 4, shows the results of PCA from industrial samples after varimax rotation showing four factors with Eigenvalues greater than 1, and accounting for 74.57% of the total variation in the data set. Factor 1 explains 39.92% of the total variance and shows high positive loading for Ba, Ca, Cr, Mn, Ni, V, and Zn. Al, As, Fe, and K shown high loading in factor 2 with 18.21% of the total variance. Factor 3 and factor 4 account for 9.86% and 6.57%, respectively. Factor 3 shows positive loading for Al and Rb, while factor 4 only shows positive loading for Sb. Al, As, Ca, Co, Cr, Cu, Fe, K, Mn, Ni, Pb, Rb, Sb, and V in the data set shown commonalities in the range of 0.67 – 0.91, suggesting that each element apportioned satisfactorily the factor identified. Cd and Zn showed communalities lower than 60% indicating that a fraction of their concentration of both elements could not be apportioned to factors with Eigenvalues minor than 1. Factor 1 grouped significant loadings of Ba, Ca, Cr, Mn, Ni, V, and Zn, indicating industrial and vehicular sources. Factor 2 showed a strong influence of Al, As, Fe, and K, suggesting natural and anthropogenic origin (De Paula et al., 2015). Factor 3 and factor 4 showed a strong natural origin influence with a significant loading of Rb. Thus, the source may be road dust due to this element is commonly found in soil.

Lima, Peruvian capital is built on a desert strip separating of Andes Mountains and the Pacific Ocean and is known as the world´s second-largest desert city after only Cairo, Egypt (Tegel, 2019). Thus, Lurigancho-Chosica is bordered by hills composed mainly of dust and dirt, which are dispersed by windblown and sedimented in houses and road travels. Therefore, the presence of elements may be related to dust resuspension and soil particles. Thus, the results of this study confirm that soil particle resuspension, vehicles, and industrial activities are the main sources of emission of potentially toxic elements into the air of Lurigancho-Chosica.

Element	Baseline *T. latifolia* (N=3)	Baseline *T. purpurea* (N=3)	Industrial area *T. latifolia* (LI) (N=17)	Urban area *T. latifolia* (LU) (N=17)	Industrial area *T. purpurea* (PI) (N=17)	Urban area *T. purpurea* (PU) (N=17)	ANOVA p-valueA
Al	2083 ± 182 [c]	2189 ± 223 [d]	1883 ± 82 [a]	1667 ± 46 [b]	1921 ± 94 [a]	1679 ± 69 [b]	**
As	3.69 ± 1.82 [c]	4.06 ± 1.32 [d]	8.26 ± 0.57 [a]	6.41 ± 1.04 [b]	8.24 ± 1.04 [a]	6.85 ± 0.63 [b]	*
Ba	24.81 ± 8.24 [c]	17.58 ± 7.82 [d]	37.86 ± 4.02 [a]	48.67 ± 4.97 [b]	33.43 ± 4.02 [a]	48.55 ± 3.98 [b]	***
Ca	5020 ± 812	4200 ± 982	5451 ± 348 [a]	5801 ± 397 [a]	5132 ± 274 [b]	5768 ± 351 [a]	**
Cd	0.55 ± 0.12 [c]	0.44 ± 0.22 [d]	5.44 ± 0.48 [a]	0.82 ± 0.12 [b]	5.54 ± 0.50 [a]	0.67 ± 0.14 [b]	***
Co	1.66 ± 0.82 [a]	1.55 ± 0.67 [a]	1.76 ± 0.38 [a]	1.65 ± 0.38 [a]	1.73 ± 0.63 [a]	1.72 ± 0.17 [a]	0.12
Cr	2.09 ± 1.11 [b]	1.53 ± 0.98 [c]	4.44 ± 1.10 [a]	2.63 ± 0.39 [b]	4.16 ± 0.90 [a]	2.45 ± 0.72 [b]	**
Cu	16.79 ± 4.27 [c]	14.38 ± 3.85 [d]	34.00 ± 4.56 [a]	18.70 ± 3.17 [b]	30.30 ± 3.84 [a]	20.03 ± 2.59 [b]	***
Fe	1154 ± 375 [c]	1234 ± 263 [d]	2236 ± 162 [a]	1669 ± 41 [b]	2201 ± 142 [a]	1657 ± 59 [b]	*
K	4534 ± 789 [c]	1620 ± 179 [d]	2331 ± 321 [a]	2416 ± 394 [a]	1984 ± 268 [a]	2080 ± 364 [a]	***
Mg	1482 ± 234 [d]	1357 ± 311 [c]	1581 ± 187 [a]	1383 ± 161 [c]	1544 ± 141 [a]	1700 ± 153 [b]	**
Mn	128.6 ± 23.5 [c]	78.7 ± 32.1 [d]	174 ± 20 [a]	119 ± 11 [b]	153 ± 14 [a]	104 ± 6 [b]	***
Ni	1.33 ± 0.45 [b]	0.93 ± 0.37 [c]	2.82 ± 0.47 [a]	1.86 ± 0.37 [b]	2.57 ± 0.60 [a]	1.51 ± 0.23 [b]	*
Pb	8.86 ± 2.13 [c]	9.13 ± 3.11 [c]	34.14 ± 4.13 [a]	13.92 ± 0.90 [b]	34.82 ± 4.52 [a]	13.80 ± 1.26 [b]	***

Rb	7.42 ± 1.67 [a]	6.74 ± 1.95 [a]	6.83 ± 1.03 [a]	7.29 ± 0.77 [a]	6.32 ± 0.86 [a]	6.70 ± 0.61 [a]	0.07
Sb	610 ± 76 [c]	601 ± 89 [c]	2822 ± 295 [a]	1384 ± 80 [b]	3090 ± 275 [a]	1516 ± 93 [b]	***
V	3.03 ± 0.87 [c]	2.87 ± 0.68 [d]	7.74 ± 0.66 [a]	4.78 ± 0.43 [b]	8.60 ± 1.10 [a]	5.37 ± 0.54 [b]	**
Zn	84 ± 23 [c]	60 ± 25 [d]	2981 ± 434 [a]	178 ± 26 [b]	2342 ± 240 [c]	115 ± 11 [d]	***

A Values on each horizontal line followed by the same letter do not differ significantly at $p < 0.05$. * Mean significant at $p < 0.05$. ** Mean significant at $p < 0.01$. *** Mean significant at $p < 0.001$.

Table 1. Mean trace element concentrations ($\mu g\ g^{-1}$ DW) ± standard deviation (SD) quantified in both areas of study and *Tillandsia* species.

Element	LI	LU	PI	PU
Al	0.90	0.80	0.88	0.77
As	**2.24**	*1.74*	**2.03**	*1.69*
Ba	*1.53*	**1.96**	**1.90**	**2.76**
Ca	1.09	1.16	1.22	*1.37*
Cd	**9.89**	1.49	**12.59**	*1.52*
Co	1.06	0.99	1.12	1.11
Cr	**2.12**	*1.26*	**2.72**	*1.60*
Cu	**2.03**	1.11	**2.11**	*1.39*
Fe	**1.94**	*1.45*	**1.78**	*1.34*
K	0.51	0.53	1.22	*1.28*
Mg	1.07	0.93	1.14	*1.25*
Mn	1.35	0.93	**1.94**	*1.32*
Ni	**2.12**	*1.40*	**2.76**	*1.62*
Pb	**3.85**	*1.57*	**3.81**	*1.51*
Rb	0.92	0.98	0.94	0.99
Sb	**4.63**	**2.27**	**5.14**	**2.52**
V	**2.55**	*1.58*	**3.00**	**1.87**
Zn	**35.49**	**2.12**	**38.73**	**1.90**

Normal conditions (0.75-1.25) is indicated by a normal figure, accumulation (1.25-1.75) is highlighted in italic, and severe accumulation in bold (>1.75).

Table 2. EB ratios calculated for 18 elements measured in the samples transplanted in the urban and industrial areas using plants of T. latifolia and T. purpurea exposed for three months.

Element	PC1	PC2	PC3	Communalities
Al	-0.498	0.238	*0.526*	0.50
As	0.147	**0.843**	0.281	0.81
Ba	**0.958**	-0.001	-0.074	0.93
Ca	**0.864**	-0.125	-0.142	0.78
Cd	0.374	0.423	0.317	0.42
Co	*0.683*	0.052	*0.585*	0.60
Cr	**0.767**	0.025	0.336	0.70
Cu	**0.840**	0.357	-0.259	0.90
Fe	*0.694*	0.424	-0.024	0.66
K	*0.669*	-0.330	-0.034	0.87
Mg	**0.899**	-0.151	-0.019	0.83
Mn	**0.931**	-0.193	-0.082	0.91
Ni	**0.747**	0.453	-0.012	0.76
Pb	0.026	**0.775**	-0.352	0.73
Rb	0.315	0.499	*0.517*	0.52
Sb	**0.763**	0.110	-0.077	0.60
V	**0.797**	0.187	0.333	0.78
Zn	**0.738**	*0.620*	-0.017	0.65
Eigenvalues	8.759	3.061	1.125	
% of total variance	48.658	17.009	6.249	
% of cumulative variance	48.658	65.667	71.91	

Principal component analysis (PCA) with Varimax rotation, Kaiser-Meyer-Olkin (KMO) with an eigenvalue > 1 was considered.

Table 3. Principal component analysis result for urban samples. Elements with correlation values greater than 0.7 (are considered to be significant) are listed in **bold**; higher than 0.5 and lower than 0.7 *in italics*.

Element	PC1	PC2	PC3	PC4	Communalities
Al	0.176	**0.708**	*0.521*	-0.021	0.71
As	-0.164	**0.733**	-0.077	0.422	0.75
Ba	**0.879**	0.001	0.085	-0.098	0.79
Ca	**0.804**	-0.290	0.067	0.277	0.82
Cd	0.358	0.049	-0.603	0.081	0.50
Co	*0.648*	0.260	0.088	-0.413	0.67
Cr	**0.877**	0.059	0.208	-0.202	0.86
Cu	*0.535*	0.495	-0.399	0.154	0.71
Fe	-0.003	**0.840**	0.264	-0.187	0.81
K	0.444	**0.701**	-0.008	-0.073	0.91
Mg	*0.678*	0.216	0.303	0.344	0.72
Mn	**0.893**	-0.313	0.077	0.047	0.90
Ni	**0.888**	-0.051	0.076	-0.077	0.80
Pb	0.360	*0.661*	-0.324	-0.216	0.73
Rb	0.257	-0.033	*0.605*	*0.524*	0.71
Sb	*0.505*	0.024	-0.570	0.376	0.72
V	**0.886**	-0.028	-0.009	-0.202	0.83
Zn	**0.738**	0.229	-0.155	0.069	0.51
Eigenvalues	7.186	3.278	1.77	1.18	
% of total variance	39.924	18.211	9.867	6.571	
% of cumulative variance	39.924	58.135	68.002	74.573	

Principal component analysis (PCA) with Varimax rotation, Kaiser-Meyer-Olkin (KMO) with an eigenvalue > 1 was considered.

Table 4. Principal component analysis result for industrial samples. Elements with correlation values greater than 0.7 (are considered to be significant) are listed in **bold**; higher than 0.5 and lower than 0.7 in *italics*.

4 I CONCLUSIONS

The present study represents the first report about the level of pollution of airborne trace elements in urban and industrial areas from Lurigancho-Chosica, Lima-Peru, using two *Tillandsia* species. *T. latifolia* and *T. purpurea* used as a biomonitor. Both *Tillandsia* species behaved as effective biomonitors to evaluate air quality in urban and industrial areas. The results showed the impact of anthropogenic sources in the industrial area related to As, Ba, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Sb, V, and Zn whose elements presented EB ratios > 1.75 which were related to smelter plant, being the Zn the element with the highest value. Ba, Sb, and Zn were found at elevated concentrations and more enriched in the urban area for both species, relating these elements to the releasing of pollutants from vehicular traffic. Likewise, Ca may be influenced by the cement dispersion. PCA analysis showed consistent segregation of the elements studied. Most elements were related to vehicle emission, industrial activities, and dust resuspension (natural origin).

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