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Tree Bark as a Bioindicator of Atmospheric Contamination by Heavy Metals according to Vehicular Traffic Intensity in El Tambo, Huancayo, Peru

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Tree bark as a bioindicator of atmospheric contamination by heavy metals according to vehicular traffic intensity in El Tambo, Huancayo, Peru

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Abstract. Tree bark is a good atmospheric heavy metals contamination bioindicator. This study aims to determine heavy metals in tree bark in El Tambo, Huancayo, Peru. Salix babylonica, Populus nigra, Senna multiglandulosa, and Schinus molle bark samples were taken in 2021 and analyzed through Inductively Coupled Plasma Optical Emission Spectroscopy. Results show heavy metals concentrations (mg.kg-1) of Zn (195.92 ± 125.97) > Pb (24.45 ± 15.57) > Cu (23.39 ± 11.01) > Cr (2.43 ± 1.13) > Cd (1.77 ± 3.06) > Ni (1.01 ± 0.70). The highest contamination levels were by Zn, Pb, and Cu, and the lowest by Cr, Cd, and Ni. The average concentration due to vehicular traffic intensity was Zn > Cu > Pb > Cr > Cd > Ni. Cr reveals higher concentration at high traffic levels; Cu, Ni, Pb, and Zn at moderate, and Cd at low levels. Schinus molle showed the highest concentration of Ni, Populus nigra of Cr, and Salix babylonica of Zn and Cd. The lowest concentrations of all metals were found in Senna multiglandulosa. This and Salix babylonica are bioindicators of Pb, Cr, Cd, Cu, Ni, and Zn, the first report for the world on bark in Fabaceae and Salicaceae species.

Keywords: Bark, Indicator organisms, Heavy metals, Traffic, Air pollution.

1 Introduction

Air pollution in large cities comes from various sources, with vehicles being the main source of emissions and associated with vehicular traffic intensity. The latter, in turn, concerns the flow of light or heavy vehicles, the type of fuel, the age of the vehicles, their maintenance, the state of the vehicles, and their speed [1]. Intense vehicular traffic produces heavy metals that accumulate in the atmosphere [2]. Pollutants emitted by vehicles include heavy metals that are potentially toxic to health, such as lead, cadmium, and zinc, among others. In addition, heavy metal pollution is potentially a persistent problem worldwide in increasing order [3,4]. Weather conditions and local sources play an essential role in the concentrations of particulate matter in the air that are important carriers of metals [5].

Detecting trace metals deposition, accumulation, and distribution in ecosystems can be done through biomonitoring. This method employs various tree organs or parts [6] to detect in the atmosphere trace metal elements [7]. Besides, lichens have proven to be excellent biomonitoring organisms due to their homogeneous geographic distribution, slow growth, great capacity to accumulate elements, and easy sampling compared to other biomonitors [8]. The use of plant bioindicators has many advantages. The most significant are low cost, long-term sampling, and high availability [9]. The use of phytoindicators is increasingly being used to assess the quality of an ecosystem due to their sensitivity to chemical variations in the composition of the environment and the accumulation of pollutants. Additionally, atmospheric trace metal concentrations have been successfully monitored utilizing several vegetation types [6, 10, 11].

Tree bark is a tool to measure the consequence of heavy metal pollution and monitor air quality [12]. Moreover, it allows identifying and mapping organic and inorganic pollutants and accumulating atmospheric particles due to its absorbent surface and deeply grooved structure [13]. The use of tree bark as a biomonitoring technique was established to estimate the levels of atmospheric contamination by heavy metals in urban areas [14, 15]. Additionally, tree bark retains higher trace metal concentrations than air and rainwater [6, 16] .

The inorganic content of heavy metals in the atmosphere measured in tree bark is a surface deposit that should not be considered a simple cumulative material but rather an excellent source of information that points to recent geotechnical and anthropogenic pressures [14].

In large cities worldwide, air pollutant emissions are generated by vehicular traffic [17]. The sources of toxic elements such as Zn, Cd, Cu, Pb, Ni, and Cr are emissions released by vehicles on the surface and street dust from the ground [18, 19]. On the other hand, traffic-related metal emissions come from vehicle exhaust pipe emissions from burning fuels, lubricating oils, and engine wear. These, in turn, depend on oil and fuel compositions. Gasoline-fuelled vehicles have been associated with the highest emissions of Cu and Ni.

The city of Huancayo in Peru shows a major air quality problem due to particulate matter (PM) as the primary source of contamination. In 2017, PM_{10} and $PM_{2.5}$ were much higher than the annual Peruvian air quality regulation standard. Furthermore, even $PM_{2.5}$ is a much higher value than those registered in other Peruvian cities. The vehicle fleet is the most critical source of emission as it causes a greater risk to the health of the inhabitants [20]. The estimated concentrations of air pollutants by vehicles with gasoline- and diesel-fuelled engines exceed the Environmental Quality Standards (EQS) for Peru, especially carbon monoxide [21].

Sauce llorón or weeping willow (*Salix babylonica*) belongs to the Salicaceae family. It has high biomass productivity, high transpiration rates, and great potential for accumulation and tolerance to Pb, providing valuable and scientific information for phytoremediation research in places with trees under Pb stress [22].

Álamo or black poplar (*Populus nigra*) is a deciduous perennial tree species of the Salicaceae family. It is characterized by its rapid growth, extensive root system, high biomass production, high resistance to water and nutrient scarcity, to storms and cold, and it has a high tolerance and potential for the accumulation of metals [23, 24]. It accumulates metals through its root system and foliage and translocates and stores high Cd contents in the leaves and bark [25, 26].

Molle or Peruvian or American pepper (*Schinus molle*) belongs to the Anacardiaceae family. This species has been utilized in San Luis de Potosí, Mexico, to evaluate the environmental impact of different land uses (agricultural, rural, urban residential, commercial, and mining). For this, the concentrations of Al, As, Co, Cu, Cd, Pb, Ti, V, and Zn were analyzed in leaflets [27].

In the Mantaro Valley in the Andean region of Peru, the *Millhua tanquish* shrub or glandular senna (*Senna multiglandulosa*) is an adapted species [28] that belongs to the Fabaceae family appreciated and valued as fuel and ornamental in the main green areas of the city of Huancayo [29–31].

Plants with an exceptional ability to accumulate metals in the plant kingdom are called hyperaccumulators [32]. Its discovery worldwide has been slow due to the lack of systematic screening of plant species in various world regions [33]. In 2017, a global database of plants that hyper accumulate metals and metalloids included the species *Senna obtusifolia* [34].

According to the Agency for Toxic Substances and Disease Registry (ATSDR), Pb is found in small amounts in the earth's crust and throughout the environment. Lead is produced through human activities such as burning fossil fuels. Cadmium is naturally found on the earth's crust. It adheres firmly to the organic matter in which it remains immobile in the soil and can be incorporated by plants. Chromium is present in the environment in various forms. Copper is found naturally throughout the environment. It can enter the environment from landfills, domestic wastewater, the combustion of waste and fossil fuels, wood and phosphate fertilizers production, and natural sources such as dust in the air, ground, volcanoes, decaying vegetation, and forest fires. Zinc is one of the most common elements in nature [35].

Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) is an appropriate technique to determine metal elements [36]. These authors state that this methodology is very promising for environmental studies since various elements can be measured, and is highly sensitive to detecting heavy metals.

Studies that use biomonitors to measure environmental pollutants in Peru are very scarce. The district of El Tambo at 3,260 m a.s.l. is densely populated, where the main source of heavy metal contaminants is vehicular traffic. The major contaminant elements found are Al, Ca, Fe, K, and Na, as well as trace elements such as As, Ba, Cd, Ce, Co, Cr, Cu, La, Mn, Ni, Pb, Sb, Sc, Sr, U, V, and Zn [37].

Peru has very little scientific knowledge about the bioaccumulation of heavy metal traces in the bark of the species *Salix babylonica, Populus nigra, Senna multiglandulosa,* and *Schinus molle* as a consequence of atmospheric contamination. Hence, it is necessary to contribute to the knowledge of the environmental state of El Tambo District, Huancayo Province, Junín Region of Peru, considering the environmental importance and the absence of quantitative records.

Accordingly, the aim of this study is to evaluate the bark of the species *Salix babylonica, Populus nigra, Senna multiglandulosa,* and *Schinus molle* as bioindicators of atmospheric contamination by traces of heavy metals determined by the intensity of vehicular traffic in the main urban areas with ornamental trees in the District of El Tambo, Huancayo, Peru.

2 Materials and methods

2.1 Study area, vehicular traffic intensity, and species

This study was carried out in the district of El Tambo, province of Huancayo, Junín Region, Peru (Figure 1). It has a population of 166,359 inhabitants [38] and is located at 3,260 m a.s.l. It is densely populated, where the main source of pollution is vehicular traffic comprised of vehicles such as massive transport, rural pickups (5% and 20%), motorcycles (3%), public transport buses (4% to 5%), collective cars, independent taxis, company taxis, school service vehicles, loading, and unloading vehicles and interprovincial buses (4 to 6%), for a total of 11,135 vehicles [39, 40]. There are about 49 vehicles per thousand inhabitants [41] .

The climate of the study area is temperate, with a maximum temperature of 15°C in December and a minimum of 1°C in July. It is characterized by its short and cloudy summers, and the rest of the year is dry (MINAM, 2022). It had a maximum rainfall of 121 mm.

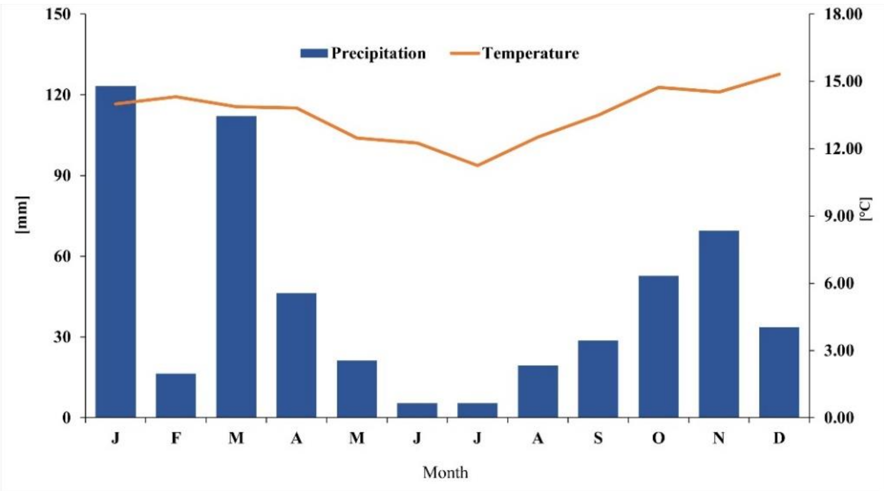

Figure 1. Climatogram of the District of El Tambo, Huancayo, year 2021

The district of El Tambo has high vehicular traffic congestion that causes air pollution due to city expansion. In addition, suburban development and low maintenance of roads and paths are observed benefitting middle to upper-class car users [42]. The intensity of the vehicular traffic considered in this study (Table 1) was the one occurring solely on main roads where automotive vehicles circulate [20, 37, 43].

Table 1. Intensity of vehicle traffic

Location	Scale
a. Intihuatana, Ciudad Universitaria, Caminito de Huancayo, Parque Infantil	High

b. Parque Industrial y Parque El Triangulo	Moderate
c. Parque de los Sombreros y Umuto	Low

Bark samples were taken from trees located near streets with different levels of traffic intensity. The trees sampled belong to the species *Populus nigra* (Pni), *Salix babylonica* (Sba), *Schinus molle* (Smo), and *Senna multiglandulosa* (Smu) (Figure 2), as these are the most predominant species established as ornamental plants in the main streets and avenues of the District of El Tambo [1].

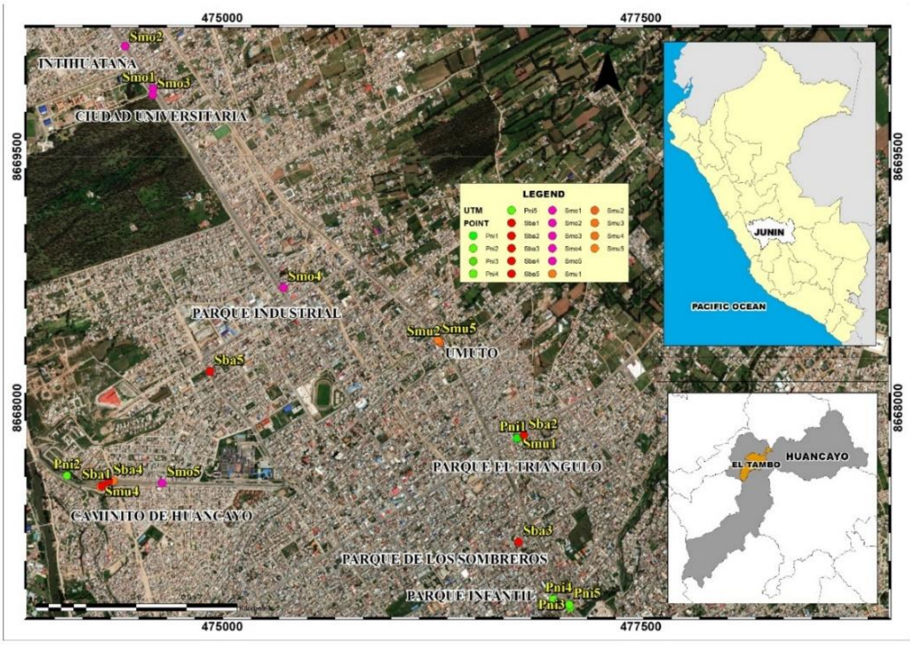

Figure 2. Study area map of the District of El Tambo, Huancayo, Peru, with the location of the sampling points. Pni (green dots): *Populus nigra,* Sba (red dots): *Salix babylonica*, Smo (pink dots): *Schinus molle*, Smu (orange dots): *Senna multiglandulosa*.

Source: elaborated by the authors.

2.2 Sampling and bark preparation

During the first quarter of 2021, bark samples were collected from 20 trees of the species Populus nigra, Salix babylonica, Schinus molle, and Senna multiglandulosa. Five bark samples were collected for each species at the height of 1.5 m from the soil surface. The amount of bark collected was 100 g and stored in a cooler container at 4 °C ± 0.1 for 24 h. The impurities of the outer bark were cleaned, removing very mature cells with the help of a brush, a paintbrush, and a fine thread brush. Next, it was ground manually in a porcelain mortar, homogenizing the bark particles and obtaining 50 g of sample. These samples were dried in an Inucell oven at 60°C ± 0.1 for 90 h until constant weight, and the final anhydrous moisture content was determined. The bark was then ground with a Pulviressette mill to a particle diameter of 50 microns. Finally, 5 g of bark from each sampled tree were weighed and sent to the laboratory for further analyses.

2.3 Laboratory analyses

Please Digestion was carried out using a weighed sample of 0.5 g of dry bark, to which a mixture of nitric acid 65% p.a. (EMSUR® Reag. Ph Eur,ISO), and hydrochloric acid (EMSURE® ACS,ISO, Reag. Ph. Eur. ISO) were added. Digestion initiated at a temperature of 85 °C for 4 h. It was then cooled and filtered through a Whatman® quantitative filter paper, ashless, Grade 40, into a 50 mL volumetric flask. The digested solution was read in an Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES) (Agilent, Model 700). Results were processed with the ICP-EXPERT program series version 4.1.0 b 443, registering heavy metal concentration values in mg kg-1. The readings of each metal concentration were fitted to the calibration curves with a value of r = 1 (Tabla 2). The standardized EPA 200.7 method "Determination of Metals and Trace Elements in Water and Wastes by Inductively Coupled Plasma-Atomic Emission Spectrometry" was used (U.S. EPA, 1994).

The instrumental conditions of the ICP-OES method were Power (kW) = 1.30; Plasma flow (L/min) = 16.5; Auxiliary flow (L/min) = 1.50; Nebulizer flow (L/min) = 0.75; Replica reading time (s) =10, and Instrument Stabilization Delay (s) = 15. The sample introduction parameters were Sampling Delay (s) = 55, Pump Speed (rpm) = 5, and Wash Time (s) = 5.

Table 2. Major and trace element calibration standards

Element (mg kg-1)	Pattern	Concentration (mg L-1)	Intensity	Equation	r2
	1	0	13.0217		
Cd	2	0.2	2020.95	Y = 10435x - 24.392	0.96
	3	2	20848.9		
	1	0	3.13641		
Cr	2	0.5	519.17	Y = 1019x + 6.2257	0.96
	3	5	5101		
	1	0	109.504		
Cu	2	0.2	3538.31	Y = 17784x + 48.886	0.99
	3	2	35623.4		
	1	0	7.23193		
Ni	2	0.2	101.847	Y = 506.36x + 4.0786	0.99
	3	2	1017.15		
	1	0	6.04907		
Pb	2	1	203.649	Y = 217.7x - 3.4727	0.99
	3	10	2174.6		

	1	0	4.49847		
Zn	2	0.5	387.441	Y = 781.74x + 0.7429	0.97
	3	5	3909.87		

2.4 Statistical analyses

The data collected were analyzed using multivariate, inferential, and descriptive statistics. One-way analysis of variance (ANOVA) ($p \leq 0.05$) was performed to test differences in heavy metal accumulation by vehicular traffic intensity and per tree species. The analyzes were performed with the SPSS v25 software.

3 Results and discussion

The general average concentrations of heavy metals in the bark of four tree species are presented in Table 3, showing the following descending order Zn > Pb > Cu > Cr > Cd > Ni. The results indicate the presence of Zn, Pb, and Cu in high concentrations, while Cr, Cd, and Ni are registered in low concentrations.

Table 3. Average concentration of heavy metals in the bark of four ornamental tree species

Element ($mg\ kg^{-1}$)	Mean Standard Deviation ($mg\ kg^{-1}$)
Cd	1.77 ± 3.06
Cr	2.43 ± 1.13*
Cu	23.39 ± 11.01*
Ni	1.01 ± 0.70
Pb	24.45 ± 15.57*
Zn	195.92 ± 125.97*

(*) Shapiro-Wilk test ($p \geq 0.05$)

* Normality test n = 20, Shapiro-Wilk ($p > 0.05$), Lilliefors Significance Correction

The metals quantified are emitted into the atmosphere mainly by the vehicle fleet [44]. Pb and Zn contents correlate with traffic volume [45], and the main cause of Pb, Cd, Cu, and Zn contamination are automobile tires and brakes. These can adversely affect the atmospheric environment and ecosystems [46]. Likewise, the sites with different anthropogenic activities reveal higher concentrations for Pb, Zn, and Cu, while the concentrations of Cd are lower. This could be due to adding these metals in minimal quantities into petrol to increase gasoline octane [2].

Table 4. ANOVA of heavy metal concentration in tree bark according to traffic intensity in the district of El Tambo.

Element (mg kg^{-1})	High	Moderate	Low	P-value 0.05
Cd	0.96 ± 0.88*	2.28 ± 3.28	3.02 ± 5.84	0.514*
Cr	2.57 ± 0.93*	2.55 ± 0.81	1.91 ± 1.99*	0.181
Cu	23.64 ± 9.60*	26.20 ± 9.65*	18.55 ± 16.98*	0.256
Ni	1.02 ± 0.63*	1.12 ± 0.81*	0.85 ± 0.86*	0.244
Pb	23.83 ± 11.25*	26.76 ± 14.00*	22.54 ± 28.51*	0.076
Zn	194.02 ± 93.35*	233.87 ± 119.77*	143.73 ± 209.58	0.569

* Shapiro-Wilk (p > 0.05), Lilliefors Significance Correction. P-value (p > 0.05)

According to the different vehicular traffic intensities, the concentration of heavy metals registered in tree bark (ANOVA, Table 4) did not show significant statistical differences for Cd, Cr, Cu, Ni, Pb, and Zn. On the other hand, the mean concentration value in descending order is Zn > Cu > Pb > Cr > Cd > Ni. In addition, Cr reveals a higher concentration at a high traffic intensity. In turn, Cu, Ni, Pb, and Zn show a higher concentration in a moderate traffic intensity, and Cd shows a higher accumulation when there is low traffic intensity.

It should be mentioned that there are three common sources of metallic elements directly related to the intensity of vehicular traffic, including the wear of the brake disk coating that liberates Pb, Zn, Cr, Ni, and Cd; tire wear generates Pb, Zn, Cu and Cd; and oil leaks produces Pb, Zn, Cu, Ni and Cd [47]. The study revealed that vehicular traffic in the district of El Tambo at peak hours is characterized by having a very high flow on the green areas of main avenues where *S. molle, P. nigra, S. babylonica,* and *S. multiglandulosa* are found.

A study on *Tillandsia capillaris* in the District of El Tambo showed that the average concentration of atmospheric heavy metals pollutants according to the intensity of vehicular traffic showed very low values for Cd, Cr, Cu, and Zn. In contrast, the ones for Ni were very high [37]. However, the contrary was found in the current study, where the concentrations in the bark in mg kg^{-1} (Table 3) show very high values for Cd, Cr, Cu, and Zn and very low values for Ni. This may be because tree bark is probably a better indicator and bioaccumulator when monitoring atmospheric pollutants by heavy metals in urban areas [6, 12, 13, 15, 16].

Table 5. ANOVA of heavy metal concentration in the bark of four ornamental tree species

Element	Tree species			
(mg kg^{-1})	*S. molle*	*P. nigra*	*S. babylonica*	*S. multiglandulosa*

					(p-value = 0.05)
Cd	0.34 ± 0.11*	0.95 ± 0.32*	5.63 ± 4.36*	0.15 ± 0.12*	0.003
Cr	2.51 ± 1.10*	2.80 ± 0.49*	2.49 ± 1.42*	1.93 ± 1.46*	0.701**
Cu	27.90 ± 8.92*	26.28 ± 10.17*	22.59 ± 13.01*	16.79 ± 11.50*	0.416**
Ni	1.52 ± 0.65*	0.89 ± 0.51*	0.99 ± 0.98	0.66 ± 0.41*	0.262
Pb	30.88 ± 14.58*	27.09 ± 9.38*	24.98 ± 23.44*	14.85 ± 11.23	0.435**
Zn	132.09 ± 55.39*	226.36 ± 55.29*	361.24 ± 72.97*	63.99 ± 41.86*	0.000**

(*) Shapiro-Wilk (p ≥ 0.05) (**) and Levene (p ≥ 0.05) tests

According to the ANOVA (Table 5), there are no significant statistical differences ($p > 0.05$) between the four species concerning the concentration of Pb, Cr, Cu, and Zn. However, there are significant statistical differences ($p < 0.05$) in relation to the concentration of Cd and Ni. Also, the average values of heavy metals of each species revealed differences in accumulation. It also shows that the species *Schinus molle* (Molle) has a higher concentration of Ni; *Populus nigra* (black poplar) of Cr; *Salix babylonica* of Zn and Cd; and *Senna multiglandulosa* exhibited lower concentrations of metals such as Cd, Cr, Cu, Ni, Pb, and Zn. The barks of the studied species are confirmed to be good bioaccumulators of metals that come from atmospheric pollution, which, in turn, is related to the intensity of vehicular traffic in the El Tambo district.

The concentration of heavy metals in *S. molle* bark (Table 4) decreased in the following order Zn > Pb > Cu > Cr > Ni > Cd. In addition, [48] indicate that *S. molle* is a good accumulator bioindicator of Cd, Cr, Ni, and Pb, whose Cr concentration is lower and higher in Cd and Pb. At the same time, Ni shows an extremely high concentration compared to what was found in the study. On the other hand, the work of [27] showed higher concentrations of Cd, Cu, Pb, and Zn in the leaflet of *S. molle* in San Luis de Potosí, Mexico. The emission sources come from agricultural soil use systems and rural, commercial and service settlements, indicating the presence of these heavy metals in the bark of *S. molle*. Therefore, it is a good indicator of environmental contamination. The research reveals that the bark of *S. molle* is a good bioindicator of Cd, Cr, Cu, Ni, Pb, and Zn from atmospheric pollution on roads with high, moderate, and low vehicular traffic, and this may be due to the influence of the impact of the land uses to which this species is exposed, such as the use of ornamental trees in main avenues and streets.

The bark of *álamo* or black poplar (*Populus nigra*) revealed heavy metals concentrations in the following order: Zn > Pb > Cu > Cr > Cd > Ni. This species is considered a good bioindicator of atmospheric contamination by heavy metals (mg kg^{-1}) such as Cu (11,360 ± 1.5), Pb (8,627 ± 1.5), Zn (32,308 ± 2.8), and Cd (0.0362 ± 0.02) in Navodari, Romania [49]. Black poplar bark is considered a passive monitor of air pollution by Pb (9.22 ± 0.26 mg kg^{-1}) in Tirupati, India [50]. Also, [51] in Greece found (ppm) Cd (0.137), Cu (0.948), Cr (0.367), and Zn (1.893) in the leaves of this species. In addition, in Turkey, [52] reported concentrations (ug g^{-1}) of Ni (0.484), Pb (0.57), and Zn (0.504). Moreover, [53] registered (ug g^{-1}) Cu (2.27-9.66), Ni (0.84-2.59), and Pb (0.40-0.75) in *P. nigra* leaves. Since there is little information on the transfer of metals from the bark to the leaves, it can be affirmed that the bark of this species is an excellent bioindicator not only of air pollution but also of soil contamination.

The weeping willow (*S. babylonica*) revealed metal concentrations in the following order: Zn > Pb > Cu > Cd > Cr > Ni, being the first record of heavy metals in the bark of this species in El Tambo District, Huancayo Province, Peru. It should be mentioned that, in Ankara, Turkey, [54] studied leaves as bioindicators and bioaccumulators (mg kg^{-1}) of Cd (0.084), Cr (0.024), Cu (0.049), Ni (0.012), Pb (0.008), and Zn (0.014) in different vehicular traffic areas. This species has high biomass productivity and transpiration rates, and its roots are considered excellent Pb phytoextractors [22]. Moreover, it has high resistance to Pb toxicity. On the other hand, this species is preferred for its phytoremediation quality of trace metal contaminated sites due to its easy propagation and cultivation, rapid growth, and deep root system, making it useful to mitigate air pollution in green urban areas. It is an efficient phytoextracting species to accumulate Cd [55]. It can remove heavy metals by natural phytoremediation and induced phytoremediation [56]. However, no study has been carried out on the determination of metals in the bark of these ornamental tree species established in urban areas whose streets have high traffic intensity.

S. multiglandulosa showed significant low concentrations (mg.kg^{1}) for Zn (63.99 ± 41.86) and Cd (0.15 ± 0.12) and was not significant for Cu (16.79 ± 11.50), Pb (14.85 ± 11.23), Cr (1.93 ± 1.46) and Ni (0.66 ± 0.41), compared to S*. molle, P. nigra* and *S. babylonica* and according to the ANOVA (Table 4). This study reveals that the bark of *Millhua tanquish* (*S. multiglandulosa*) is a good indicator and bioaccumulator of traces of heavy metals in ornamental trees established in green areas with different vehicular traffic intensities in Huancayo.

Finding different concentrations of Zn, Pb, Cu, Cd, Cr, and Ni in the bark of the four tree species studied suggest that they are good accumulators of heavy metals in different urban vehicular traffic intensity areas. In particular, this is due to the various places from which the bark samples were extracted since, in many Latin American cities, the traffic conditions of vehicles are intense due to inappropriate handling by the authorities. Thus, in the Junín region, Huancayo, El Tambo, the conditions are not different from this reality. Considering that the species studied have been established for more than 15 years in the main areas of the district of El Tambo and that in the Junín region, the sale of gasoline with lead was prohibited as of September 1, 2007 [57], it is stated that one of the primary sources for the presence of Pb is related to fuel consumption and the high level of traffic in the district of El Tambo. Moreover, it is probably also due to the bioaccumulation generated by emissions from the DOE RUN metallurgical plant complex of La Oroya, which come from lead circuit operations carried through the air due to favorable weather conditions accumulating in the soil. These particles are suspended by the wind and reach human activities [58]. This result reveals that the atmospheric and environmental contamination by traces of Zn, Pb, Cu, Cd, Cr, and Ni is silent and seriously affects the health of the inhabitants [59]. Therefore, it is necessary to control the contamination sources and perform toxicity tests [60]. Moreover, the results in the five species exceed the lead concentration levels in El Tambo, which are higher than Pb < 0.5 ug m^{-3} for air quality [61].

Pesticides, fertilizers, and other chemical components used in the agricultural farmwork of the district of El Tambo contaminate the soil due to the heavy metals and other toxic elements they contain. Rainwater and surface runoff infiltrates green areas, transporting in solution harmful ions to the soil until they are deposited in aquifers [62] and absorbed by tree roots. Considering that these pollutants do not reach the plants only through the air but also through the soil, these results in relation to Cd and Pb do not exceed the Environmental Quality Standards for residential land or parks [63]. Nevertheless, in relation to Cr, the value is higher. This is probably because this element is found naturally in rocks, animals, plants, and the soil of the district of El Tambo.

The bark of the species *Salix babylonica, Populus nigra, Senna multiglandulosa,* and *Schinus molle* exposed to air pollution in the El Tambo district are natural absorbers [64], providing crucial, precise, and valuable information on the presence of heavy metals such as Zn, Pb, Cu, Cd, Cr, and Ni, evidencing the changes in the conditions through the biomonitoring carried out. In addition, *Senna multiglandulosa* and *Salix babylonica* are considered bioindicators of heavy metals such as Zn, Pb, Cu, Cd, Cr, and Ni, being the first report on bark for the Fabaceae and Salicaceae families for Latin America and the world. Likewise, the species *Schinus molle* can be considered a potential bioindicator of heavy metal traces in urban areas and the Peruvian Andes, where this species has a wide distribution. It is viewed as a component of agroforestry systems. This will allow reducing the levels of soil and air contamination by heavy metals in Andean agricultural systems. With the results found in this study, better handling of the current critical environmental situation through sustainable forest management can be achieved to improve the highly polluted urban environment by different anthropogenic sources. Furthermore, these can also be used to establish an environmental management baseline to improve the life quality of the inhabitants of the district of El Tambo.

4 Conclusions

The bark of *Salix babylonica, Populus nigra, Senna multiglandulosa,* and *Schinus molle* are bioindicators of heavy metals in green areas according to vehicular traffic intensity in the district of El Tambo. The evaluated heavy metals Cd, Cr, Cu, Ni and Pb are principally emitted to the atmosphere by the vehicle traffic and the high concentrations are associated with the use of fossil fuels and tire wear. For Pb, it is probably due to the convection flow of ambient passive air generated by the metallurgical activity of DOE RUN - La Oroya. It is evident that there is little knowledge and there is a need to deepen the Senna multiglandulosa and Salix babylonica species as potential bioaccumulators of heavy metals

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