ANNALS OF “DUNAREA DE JOS” UNIVERSITY OF GALATI
MATHEMATICS, PHYSICS, THEORETICAL MECHANICS
FASCICLE II, YEAR XVII (XLVIII) 2025, No. 1
DOI: https://doi.org/10.35219/ann-ugal-math-phys-mec.2025.1.04

Assessment of heavy metal soil pollution adjacent to the streets of Galati city

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Abstract
The objective of this study was to assess the level of soil pollution in the vicinity of streets from Galati city, with different ages, traffic densities, and permitted speeds. Samples were collected from the surface (0–10 cm), at a distance of 2–5 m from the edge of the streets, in duplicates. The immediate roadside area was avoided to eliminate the risk of accidental contamination. After determining the heavy metal concentrations, the degree of soil contamination was assessed using the following indices: the contamination factor (Cf), the pollution load index (PLI), the geoaccumulation index (Igeo), the enrichment factor (EF), and the metal pollution index (MPI).

Keywords: traffic, heavy metals, soil, XRF.

1. INTRODUCTION

With the rapid development of road communication networks over the past century, road traffic has become one of the most serious environmental problems in many cities and the primary source of urban soil pollution. The dispersion of these contaminants is influenced by weather conditions and can settle in surrounding areas, such as urban and agricultural soils, as well as in water bodies.

Among all possible pollutants originating from road traffic, metals and polycyclic aromatic hydrocarbons (PAHs) are the most dangerous. While organic compounds can be transformed or degraded naturally in the environment, metals are non-degradable and tend to accumulate in soils over time, posing long-term risks to ecosystems and human health.

Roadside soils have become a key sampling point for assessing anthropogenic metal concentrations. Several studies conducted over the years by different authors have demonstrated road traffic-induced soil pollution, showing that these soils contain high levels of metals [1–5]. Studies have demonstrated the negative effects associated with increasing traffic density and vehicle speed, and the type of asphalt also playing an important role. However, other studies have not indicated significant differences in the content of toxic elements in soil and plants between areas with heavy and light traffic, suggesting that the distribution of elements along streets and highways is influenced by multiple factors.

Generally, the accumulation of hazardous elements in soils tends to be higher along highways, decreasing with distance from the road [6].

In the specific case of pollution caused by road traffic, the following sources can be mentioned: metals from fuel (As, Cd, Cr, Hg, Mn, Ni, Pb, Se, and Zn), motor oil (Cd, Cr, Ni, Zn, and W), tire wear (Cd, Co, Cu, Cr, Pb, Ni, Se, and Zn), brake wear (Ag, As, Cd, Cu, Cr, Ni, Pb, Sb, and Zn), vehicle exhaust catalysts (Pt, Pd, and Rh), road asphalt erosion, road construction and maintenance, as well as materials used for traffic safety.

Over the past 25 years, numerous new metals have been incorporated into automotive technologies and are now introduced into the environment as a result of vehicle movement. These include Sb in brake pads as a replacement for asbestos and Mn in fuel as a substitute for Pb. These metal emissions accumulate in the environment over time, and even when vehicle emissions stop, their concentrations tend to persist for long periods [5,7].

Globally, Romania ranks 52nd in traffic density, with a traffic index of 108.90, while in Europe, Romania ranks 18th.

Regarding transportation modes in Romania, the top two positions are equally occupied by cars and walking, each with a share of 30 %. These are followed, in descending order, by buses, the subway, bicycles, remote work, trams, and motorcycles.

Comparing Romania's five largest cities (Bucharest, Iasi, Cluj-Napoca, Brasov, Timisoara), the traffic index varies from 143.56 in Bucharest, where traffic is the most congested, to 78.37 in Timisoara, which has the lowest index and ranks first in terms of traffic sustainability. In Timisoara, the time spent in traffic is the shortest, with an average of 22 minutes [8].

Understanding the quality of soil along streets frequented by vehicles in urban environments is essential in any country. One of the targeted aspects in these cases is contamination with heavy metals. Heavy metal contamination is a topic of interest within the scientific community due to their toxic effects on the entire biosphere. Heavy metals emitted from vehicles remain suspended for a time and then deposit along the streets. The quality of soil near streets is important because pedestrians or residents in the area can easily come into contact with it or the existing dust. Groundwater can also be considered a secondary source where heavy metals can accumulate. Heavy metals pose serious issues for human health and the proper development of plants and animals [9].

2. EXPERIMENTAL

The analyses were conducted at the Faculty of Science and Environment, "Dunărea de Jos" University of Galati. The working protocol, the stages of soil sample preparation for XRF analysis, along with the characteristics of the equipment used are presented in other studies [10–13]. The XRF method is widely used due to its cost efficiency, short sample processing protocol (minimizing human error), as well as its speed, sensitivity, accuracy and, most importantly, its multielemental capability.

In this study, using the XRF method, six major elements (K, Ca, Ti, V, Mn, and Fe) and nine minor elements (Cr, Ni, Cu, Zn, As, Rb, Sr, Sc, and Pb) were identified. Additionally, elements such as Sb, Sn, Cd, Ag, Se, Hg, and Co were detected, but their concentrations were below the instrument's detection limit (LOD). All samples were analyzed three times, and the averages were calculated using the Microsoft Excel, *AVERAGE* function.

Duplicate samples were collected from various locations in Galai city, including areas near different roads: DN26 (Metro area), Arcasilor, Henri Coanda, Domneasca, Tecuci and Balcescu. Additionally, a control sample was collected from a park located at least 0.5 km away from any road or more than 1 km from any industrial site.

New roads were considered those with age between 2–5 years, medium-aged roads between 10–15 years, and old roads those older than 30 years. Low speed was defined as 20–50 km/h, medium speed as 50–80 km/h, and high speed as over 100 km/h. According to this classification, the sample sites were categorized as new for Tecuci and medium-age for Arcasilor, but both fell within the low-speed and low-frequency of cars category. Old roads with high speed limits and high traffic frequencies were DN26, Balcescu, Domneasca and Henri Coanda. *Figure 1* summarizes the characteristics of the sampling locations and an image generated using Google Earth [14].

Sample location	Depth (cm)	Latitude(N)	Longitude (E)
Tecuci 1	0-10	45°26’21.0”	28°02’02.8”
Tecuci 2	0-10	45°26’23.7”	28°01’51.1”
Arcașilor 1	0-10	45°28’25.7”	28°01’42.4”
Arcașilor 2	0-10	45°28’25.3”	28°01’42.5”
DN26 (1)	0-10	45°29’06”	28°01’52”
DN26 (2)	0-10	45°29’08”	28°02’00”
Balcescu 1	0-10	45°26’16.0”	28°03’09.2”
Balcescu 2	0-10	45°26’19.6”	28°03’08.6”
Domneasca 1	0-10	45°26’55.3”	28°03’10.2”
Domneasca 2	0-10	45°26’55.2”	28°03’10.3”
Henri Coanda 1	0-10	45°27’18.4”	28°01’30.7”
Henri Coanda 2	0-10	45°27’18.9”	28°01’31.2”
Control sample 1	0-10	45°27’28.8”	28°01’25.9”
Control sample 2	0-10	45°27’29.5”	28°01’27.6”

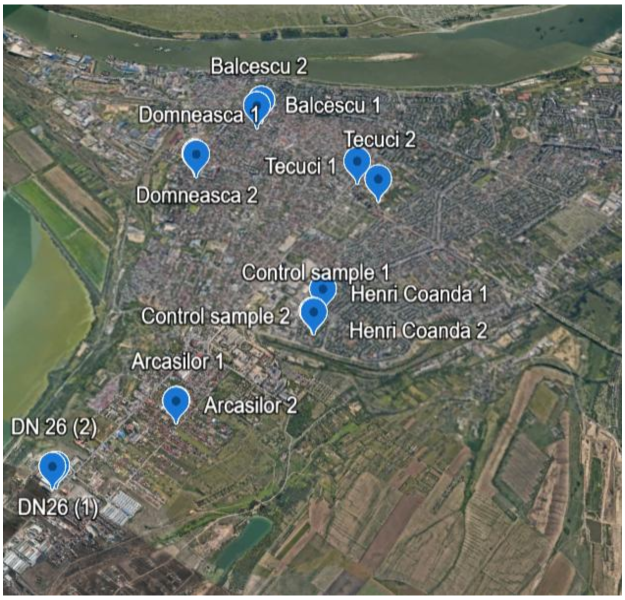

Figure 1. Coordinates, depth and satellite imagine of the sampling locations [14]

To determine the degree of heavy metal contamination in soils, the following were calculated: the *contamination factor (Cf), the pollution load index (PLI), the geo-accumulation index (Igeo), the enrichment factor (EF),* and *the metal pollution index (MPI)*. These indices depend on the assessment of heavy metal contamination in the study area compared to reference concentrations from legislation or baseline levels identified in various studies. The normal, alert, and intervention values for sensitive areas were recorded according to Order 756/03.11.1997 [15]. Only the sensitive values were presented, as soil quality can directly impact human health, given the presence of gardens, parks, and residential areas along the streets.

The *contamination factor (Cf)* reflects anthropogenic enrichment with heavy metals and it was determined using Hakanson’s equation (1):

$$Cf = \frac{c_{sample}}{c_{background}} \tag{1}$$

where: c_{sample} represents the concentration of elements in the sample, while $c_{background}$ refers to the reference concentrations from legislation or baseline levels. The *contamination factor* is classified into the following categories: <1 no pollution, 1–3 moderate pollution, 3–6 considerable pollution, ≥ 6 high pollution [16].

The *pollution load index (PLI)* was developed by Tomlinson et al. (1980) (equation (2)) to compare pollution levels in different locations or within the same location over time. The determination of PLI involves calculating the concentration factor, obtained by dividing the measured concentration of an element by the background concentration of that same element [10,12,17]:

$$PLI = \sqrt[n]{C_{f1} \times C_{f2} \times C_{f3} \times \ldots \times C_{fn}} \tag{2}$$

where: n is the number of elements. *PLI* is divided into four levels: unpolluted ($PLI \leq 1$), from unpolluted to moderate ($1 < PLI \leq 2$), moderately polluted ($2 < PLI \leq 3$), heavily polluted ($PLI > 3$) [12,18].

The *geoaccumulation index (Igeo)* was calculated to determine the concentration of heavy metals in soils for the purpose of assessing the degree of contamination, thereby estimating soil quality. This index provides a simple method to quantify the extent of soil pollution with heavy metals, describing the pollution levels of trace elements in the soil [19]. It has been utilized to evaluate the pollution level of a single trace element in the soil. The equation has been used since the late 1960s, specifically since 1969, when it was published by Müller for estimating sediment quality, although it has also been successfully applied to soil. The equation proposed by Müller is as follows (3):

$$I_{geo} = log_2 \left[\frac{c_{sample}}{1.5 \times c_{background}}\right] \tag{3}$$

where: c_{sample} represents the concentration of elements in the sample, and $c_{background}$ refers to the reference concentrations from the legislation or background levels. The constant *1.5* aids in analyzing the natural fluctuations of the given content for an element in the environment and helps to detect slight anthropogenic influences or potential variations in background values due to lithogenic effects [18]. The contamination level classifications of soils are as follows: 0-1 unpolluted soil, 1–2 moderate contamination, 2–3 moderate to strong contamination, 3–4 maximum contamination, 4–5 high to very high contamination, and 5 very high contamination [5, 16, 20, 21].

The *enrichment factor (EF)* was calculated using equation (4) to determine anthropogenic metal inputs in soils, following Dantu’s methodology. Iron (Fe) was used for geochemical normalization with a reference value of 38,000 mg/kg, according to Salminen:

$$EF = \frac{(C/C_{Fe})_{sample}}{(C/C_{Fe})_{background}} \tag{4}$$

where: EF is the enrichment factor of an element, $(C_i/C_{Fe})_{sample}$ is the ratio between the concentration of the element and that of Fe in the analyzed sample, while $(C_i/C_{Fe})_{background}$ is the same ratio, but calculated using background values. According to the obtained enrichment factor values, soil is classified into six categories, ranging from no enrichment (<1) and minor enrichment (<3) to moderate (3–5), moderate to severe (5–10), severe (10–25), very severe (25–50), and extremely severe enrichment (>50) [17, 21].

The *metal pollution index (MPI)* was calculated using Usero’s equation (5) to estimate the metal load for each location, where *C* represents the concentration of an element in the sample [17].

$$MPI = (C_1 \times C_2 \times C_3 \ldots \times C_n)^{1/n} \tag{5}$$

In the cases of soil pollution, ecological engineering recommends the use of plants and animals to improve environmental quality. Ecological engineering involves designing sustainable ecosystems, integrating human and natural systems for their mutual benefit [22]. One example is the purification of polluted runoff using natural processes in helophyte plant filters. Transitioning from conventional asphalt to porous asphalt also has a significant positive effect on the quality of highway runoff. Helophyte filters can be effective in the long term if combined with improvements to ecological values along highways, particularly in areas where conventional asphalt is used [6].

Large trees can also be used to filter air and reduce summer temperatures, but they require sufficient space for their roots and an adequate water supply. When planting, trenches must be dug, considering that a tree 25 m tall needs at least 25 m in root depth, while one 18 m tall requires at least 15 m in depth, often restricted by pavement or soil over-compaction.

Besides their positive environmental effects, trees can also be used in studies on the accumulation of traffic-emitted metals, and those with strong accumulation properties could be planted on a larger scale. In addition to leaves (*Prunus laurocerasus* successfully collects platinum), tree bark exposed to traffic conditions also accumulates deposited elements [23].

3. RESULTS AND DISCUSSION

Characterization of Sampling Points: Tecuci and Arcasilor

Samples were collected from the locations shown in *Figure 1.* The Tecuci Street is classified as a new location with low density and low traffic speed. Therefore, intense pollution associated with vehicular traffic should not be present. However, lead (Pb) and chromium (Cr) exceeded the normal values stipulated by legislation at both locations.

Other elements exceeding normal values only at the second location included arsenic (As), with a concentration of 14.82 mg kg^{-1} (normal value: 5 mg kg^{-1}) and a contamination factor of 2.96 (moderate pollution), nickel (Ni) with 47.70 mg kg^{-1} (normal value: 20 mg kg^{-1}) and a contamination factor (Cf) of 2.39 (moderate pollution), and vanadium (V) with 110.51 mg kg^{-1} (normal value: 50 mg kg^{-1}), also classified with a moderate Cf value.

For lead, concentrations exceeded normal values at the first location but did not reach the alert threshold for sensitive areas (50 mg kg^{-1}). Chromium exceeded the normal values stipulated by legislation but remained below the alert threshold (100 mg kg^{-1}). It also exhibited significant pollution based on its *contamination factor* (3.13), further confirmed by a *geoaccumulation index* value of 1.06 (moderate contamination) at the first location, presented in equations 1, 3.

Despite these findings, the *pollution load index* (equation 2) for the first area recorded the lowest value at 1.16. *Figure 2* illustrates the element concentrations (mg kg^{-1}) identified at the two sampling zones at the Tecuci and Arcasilor locations.

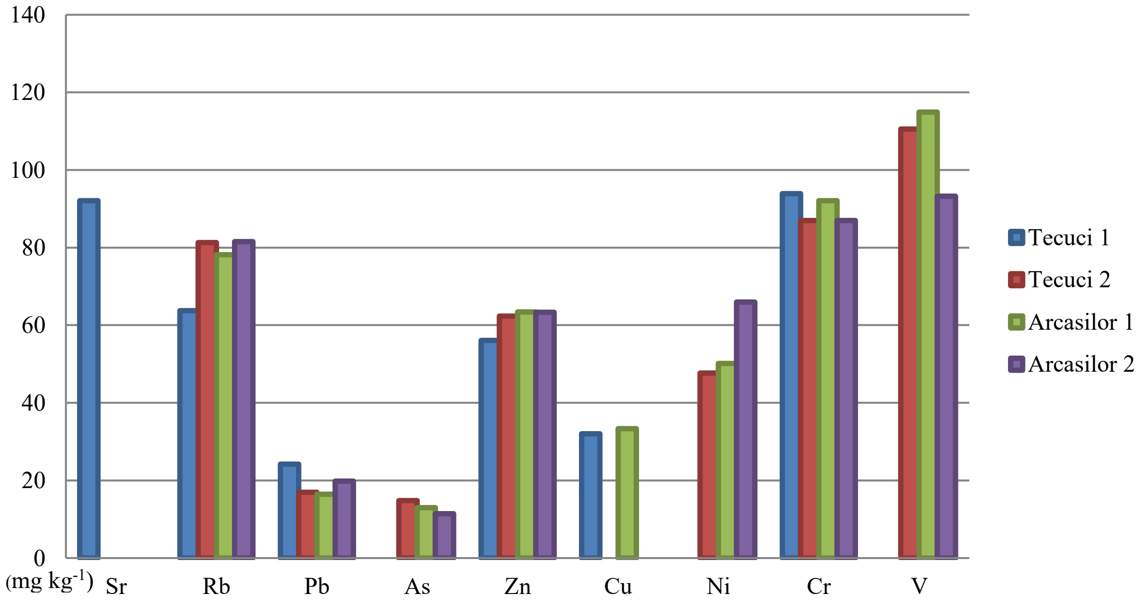

Figure 2. Element concentrations (mg kg^{-1}) identified at Tecuci and Arcasilor Streets

For the Arcasilor area, elements such as chromium (Cr), arsenic (As), nickel (Ni), and vanadium (V) exceeded the normal values specified in the legislation.

Chromium exceeded normal legislative values but did not reach the alert threshold (100 mg kg^{-1}). At the first location, higher values of 92.09 mg kg^{-1} were recorded. Based on *Cf* values, it belongs to the moderate pollution category, ranging between 2.90 and 2.97.

Arsenic also exceeded normal values but remained below the alert threshold (15 mg kg^{-1}). At the first location, concentrations reached 12.98 mg kg^{-1}. *Cf* values ranged between 2.96 and 2.87, indicating moderate pollution.

Nickel exceeded normal values without reaching the alert threshold (75 mg kg^{-1}), leading to moderate pollution, as confirmed by the geoaccumulation index (1.14) and *Cf* values of 2.51 and 3.30, indicating significant contamination. At the first location, lower values of 50.15 mg kg^{-1} were recorded.

Vanadium exceeded the normal legal limits in soil. At the first location, it surpassed the alert threshold (100 mg kg^{-1}) with a value of 114.91 mg kg^{-1}. The second location reached the alert threshold.

PLI ranged between 1.63 and 1.61 at the Arcasilor site, indicating pollution from negligible to moderate.

Regarding the *enrichment factor* (EF), elements with minor enrichment included Pb, Zn, Mn at both locations, and Cu (1). Moderate enrichment (3-5) was observed for As (1 and 2), Ni (1), V (1 and 2), and Cr (1 and 2). Values between 5 and 10 indicate moderate to severe enrichment for Ni (2).

In this case, for both study areas, considered to have a low traffic influence on soil quality, the elements Sr, Rb, and Cr showed high concentrations compared to the overall study values. As and V had the highest concentrations in the study, with arsenic being nearly three times higher than the normal value and vanadium 2.29 times higher.

Vanadium was detected in three out of four studied locations in this group, with its highest recorded concentration (114.91 mg kg^{-1}) at Arcasilor 1, which is 2.3 times higher than the normal legislative limit (50 mg kg^{-1}). It is typically stable in clayey soils and has an affinity for As and Fe. This is also reflected in this study, where these three elements had some of the highest values. Known sources include ash, petroleum and asphalt. It is also used as a corrosion inhibitor, an alloy component in engine parts and springs, in the steel industry, as a catalyst in the glass, in electronic component manufacturing, as a pigment, and in certain pesticides [24].

Regarding lead, three out of four recorded values are below the normal threshold of 20 mg kg^{-1}. Zinc shows low concentrations, nickel registers the lowest value in the entire study, and copper has values close to the study's average of 33.55 mg kg^{-1}.

Tecuci 1 location also exhibited the highest calcium (Ca) concentration (66.033 mg kg^{-1}). Ca is a major metal, and major soil metals play a crucial role in plant metabolism and, in general, they are classified as non-hazardous metals. These nutrients are primary components of parent material and are found in high concentrations in the upper soil horizon, often associated with other metals. Calcium is not linked to any phytotoxicity and helps mitigate surface soil pollution from Cd, Zn, Pb, Ni, and Cu. Additionally, Ca enhances the solubility of Na, K, Fe, Al, and Mg. High concentrations of macroelements promote rapid plant growth and facilitate the absorption of heavy metals from the soil [17].

On the other hand, titanium (Ti) was found at the lowest concentration (3,721.53 mg kg^{-1}), and since it strongly correlates with iron (Fe), the latter also had the lowest concentration (18,932.78 mg kg^{-1}) in the study. Ti is commonly used as a white pigment in various industries and serves as a catalyst in polyethylene production. Even at high concentrations, Ti does not pose environmental concerns. In the human body, titanium tends to accumulate in the lungs and hair over a lifetime, but no adverse effects have been reported [24].

The *metal pollution index* (MPI), presented in equation 5, in ascending order, ranks the locations as follows: Arcașilor 1 (321.97) < Arcașilor 2 (388.87) < Tecuci 2 (389.29) < Tecuci 1 (532.73).

Characterization of Sampling Points: DN26, Balcescu, Domneasca, Henri Coanda, and Control Park

Figure 3 presents the element concentrations (mg kg^{-1}) identified at DN26, Balcescu, Domneasca, and Henri Coanda.

For the *DN26* street only Cr, As, Cu, Ni, and V exceeded normal values. Additionally, Pb, Sr, and Sc were detected, but their concentrations remained within the legally established normal limits.

Chromium (Cr) exceeded normal values but did not reach the alert threshold (100 mg kg^{-1}). The highest recorded concentration at the first location was 85.12 mg kg^{-1}. The *contamination factor* (Cf), presented in equation 1, ranged between 2.84 and 2.16, categorizing the pollution level as moderate.

Arsenic (As) concentrations were above normal values but did not reach the alert threshold (15 mg kg^{-1}). The *contamination factor* (Cf) ranged between 2.23 and 2.05, indicating moderate pollution. The values slightly exceeded the normal limits specified in Romanian legislation.

For both sampling locations, nickel (Ni) surpassed the normal threshold, with a contamination factor (Cf) between 2.84 and 2.16, also indicating moderate pollution.

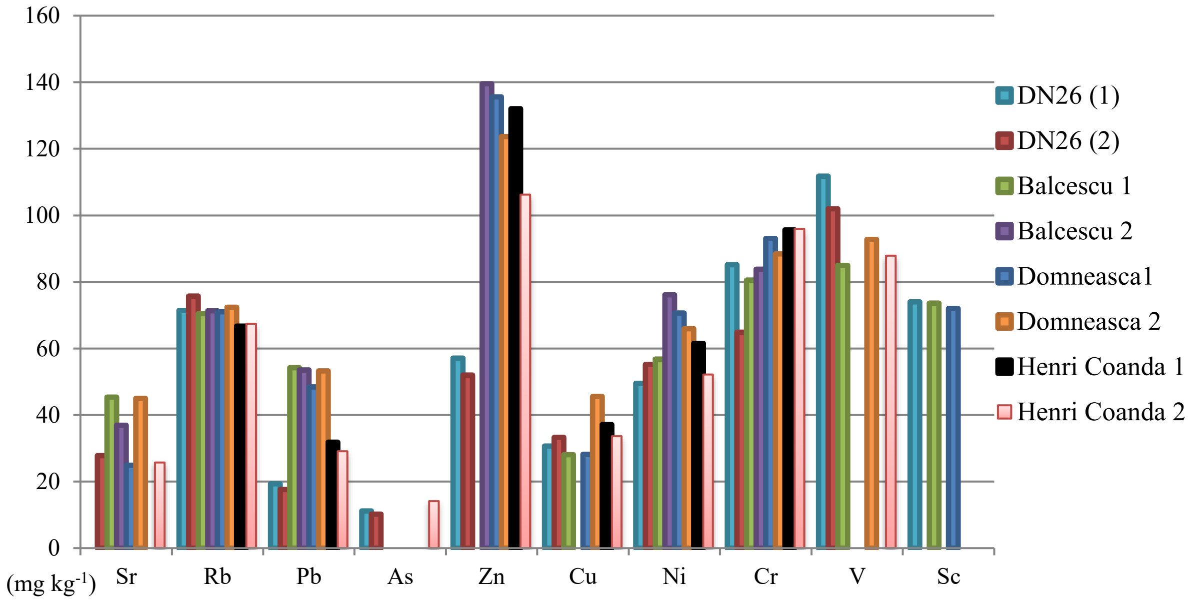

Figure 3. Element concentrations (mg kg^{-1}) identified at DN26, Balcescu, Domneasca, and Henri Coanda

Vanadium (V) exceeded the legally established normal soil values. At the first location, it surpassed the alert threshold (100 mg kg^{-1}), reaching 111.75 mg kg^{-1}. The second location met the alert threshold, with a Cf of 2.04. The *geoaccumulation index,* presented in equation 3, values indicated that the soil was uncontaminated, as they were all below value 1. The *pollution load index* (PLI) (equation 2) ranged between 1.64 and 1.22.

The Balcescu location, characterized by high traffic density and low speed, shows moderate pollution levels for Pb, Ni, Cr, and Zn, with zinc exceeding the intervention threshold at one site. The Zn concentration was 718.97 mg kg^{-1} and was excluded from the graph in *Figure 3* because it was too high, making the graph unclear in the case of the other elements. Additional elements such as Sr, Rb, Cu, V, and Sc were also detected, with *pollution load index* (equation 2) values indicating pollution ranging from nonexistent to moderate. At location Balcescu 1, the *metal pollution index* (equation 5) recorded the highest value of 604.97.

The two sampling locations on Domneasca Street are identified according to the coordinates and the image in *Figure 1*. This location is categorized by old infrastructure, high traffic density, and high speed. The elements Sr and Rb were present at both locations, with concentrations ranging between 24.94–45.02 mg kg^{-1} and 71.05–72.36 mg kg^{-1}, respectively.

In the sample collected from location 2, vanadium was identified with a concentration of 92.77 mg kg^{-1}, exceeding the normal value by 42.77 mg kg^{-1} but remaining below the alert threshold of 100 mg kg^{-1}. Additionally, the elements that exceeded normal values at both locations were Pb, Zn, Cu, Ni, and Cr.

For lead, the concentrations obtained exceeded normal values at all depths. The alert threshold for sensitive areas (50 mg kg^{-1}) was nearly reached at the first location (48.42 mg kg^{-1}), while at the second location it was slightly exceeded (53.23 mg kg^{-1}).

In the case of zinc, the intervention threshold (600 mg kg^{-1}) was not exceeded at either location, but normal values (100 mg kg^{-1}) were exceeded because for the first location the concentration was 135.58 and for the second it was 123.65 mg kg^{-1}.

Copper exceeded the normal values specified in legislation but did not reach the alert threshold (100 mg kg^{-1}). The concentration at the second location is higher than at the first, measuring 45.58 mg kg^{-1}.

At Domneasca Street, nickel exceeded the normal value of 20 mg kg^{-1}. The concentration at the first location is close to the alert threshold of 75 mg kg^{-1}, with a measurement of 70.61 mg kg^{-1}.

For the studied locations, it can be observed that the average concentrations of chromium are above normal values, with the first location nearly reaching the alert threshold of 100 mg kg^{-1}, measuring 93.05 mg kg^{-1}.

Regarding the Cf values (equation 1), they indicate medium pollution for the elements Pb, Zn, Cu, and V, while significant pollution is noted for Ni and Cr at the first site. Nickel shows moderate pollution, with an Igeo value of 1.34. The PLI, presented in equation 2, values were classified between 1.49 and 1.63.

The Henri Coandă location is characterized by high age, density, and speed. For the soil samples collected near Henri Coandă Street, the elements that consistently exceeded normal values were: Cr, Ni, Cu, Zn, As (at two locations), V (at two locations), and Pb.

Although Rb does not have legal limits in Romania, according to Salminen [25], the average concentration in surface soil is 86.8 mg kg^{-1}, which was not exceeded at any location; the average measured was 67.10 mg kg^{-1}. For As, a concentration of 14.13 mg kg^{-1} was identified, which is 9.13 mg kg^{-1} higher than the normal value specified in legislation. Additionally, at the second location, V was present with a concentration of 87.88 mg kg^{-1}, exceeding the normal value by 37.88 mg kg^{-1}.

In this case, for the elements Rb, Pb, Zn, As, Cu, V, and Ni (at the second location), the Cf values range from 1 to 3, classifying the pollution as moderate. Considerable pollution was observed only for Ni at the first location.

Regarding the *Igeo*, presented in equation (3), a moderate pollution was indicated only for Cr and Ni. The *PLI* (equation 2) at the second location was 1.78, corresponding to a level of pollution ranging from nonexistent to moderate, representing the second-highest value identified in this study. This location is characterized by the second-highest *MPI*, presented in equation 5, value of 565.97.

For the selected location with minimal traffic influence, referred to as the control sample, the situation was unusual as it showed significant signs of anthropogenic pollution through the presence of elements Pb, Zn, Cu, and Cr at both sampling sites, exceeding normal values. Elements Sr and Rb were also present at both locations, with concentrations ranging from 45.92 to 59.47 mg kg^{-1} and 63.12 to 72.45 mg kg^{-1}, respectively. Arsenic exceeded the alert threshold of 15 mg kg^{-1} only at the second location, with an average value of 15.30 mg kg^{-1}. Nickel was also found in elevated concentrations of 61.8 mg kg^{-1} compared to the normal value of 20 mg kg^{-1}, and vanadium was detected at 84.20 mg kg^{-1}, surpassing the normal value of 50 mg kg^{-1}.

Thus, the *geoaccumulation index* (equation 3) values indicated moderate pollution for elements Rb, Pb, Zn, Cu, Cr, and V, while arsenic and nickel exhibited considerable pollution, also showing moderate pollution in the geoaccumulation index. The *pollution load index*, presented at equation 2, recorded the third-highest value in the study at 1.77 for the second sampling area and 1.23 for the first area. This location is characterized by the third MPI, presented at equation 5, value of 539.78.

In general, for locations characterized by older infrastructure, high traffic speed, and traffic density, it has been observed that strontium and rubidium approach the average values of this study: 42.56 and 72.61 mg kg^{-1}. Strontium in surface soil is reported with an average of 130 mg kg^{-1} in the study conducted by Salminen [25] on European soil. Thus, in our case, it is three times lower. Rubidium has an average of 86.8 mg kg^{-1}, making it 1.20 times lower in our study. Therefore, the presence of these two elements does not pose a threat to environmental health. Rubidium is generally inherited from the parent material, and high concentrations appear in the presence of clays due to its high affinity. Regarding Sr, it has a strong affinity for Ca and a slightly lower affinity for Mg. Sr is easily absorbed by clays and stabilized by organic matter. The main sources of strontium include fertilizers, limestone, manure, industrial, or common waste [24].

Arsenic was identified only at DN26 1 and 2 (11.14 and 10.27 mg kg^{-1}) and Henri Coanda 2 (14.13 mg kg^{-1}), being absent elsewhere.

Zinc showed values above the normal threshold (100 mg kg^{-1}), except at DN26, where it had the lowest value in the study (52 mg kg^{-1}), and at Balcescu, where the highest concentration was identified (718.98 mg kg^{-1}), which is 7.19 times higher than the normal value. Zinc is widely used in various industries, mainly for corrosion protection, as part of numerous alloys, and as a catalyst for plastics, rubber, pesticides, and lubricants. It is also found in batteries, automotive equipment, pipes, fertilizers, and pesticides [24]. Therefore, the high Zn concentrations detected may result from a combination of sources such as tire wear, batteries, body corrosion, fertilizers, or pesticides.

Regarding copper, Domneasca 2 showed the highest value in the study (45.58 mg kg^{-1}), while Balcescu 1 had the lowest (28.13 mg kg^{-1}). The maximum value is 2.28 times higher than the normal value in soil, which is 20 mg kg^{-1}. In the automotive industry, Cu has been partially replaced by Al, while copper wires and cables are being replaced by fiber optics. Copper is also used in pesticides and fertilizers [24].

Vanadium exhibited values around the average of 99.75 mg kg^{-1}.

Scandium occasionally appeared, with an average of 73.23 mg kg^{-1}, a maximum of 74.02 mg kg^{-1}, and a minimum of 72.03 mg kg^{-1}. Scandium is eight times higher than the average reported by Salminen [25] for surface soil, which is 9.1 mg kg^{-1}. It can result from the combustion of materials such as coal, oil, or peat. It is primarily used in fluorescent materials or fertilizers, with concentrations ranging from 7 to 36 mg kg^{-1}. Scandium tends to accumulate in clay soils and shows lower concentrations in sandy soils. Regarding its health effects, scandium accumulates more in marine organisms than in terrestrial ones, with high concentrations found in bones, the heart, and muscles. Scandium is hazardous to human health when inhaled or ingested, causing lung, liver, and cell membrane disorders [24]. Strontium and scandium, which were absent from soil samples collected from newer locations, share a common source: fertilizers used for landscaping green spaces.

Iron exhibited the highest concentration in this study in samples collected from Arcasilor 2 (23,309.55 mg kg^{-1}). It is one of the most important constituents of the lithosphere, making up 5% of the Earth's crust. It plays a crucial role in the behavior of trace elements in the environment, influencing the well-being of plants, animals, and humans.

Nickel showed the highest concentration in this study at Balcescu 2 (76.10 mg kg^{-1}), exceeding the normal soil value by 3.81 times. According to legislation, the normal value is 20 mg kg^{-1}.

The highest chromium concentrations were identified at Henri Coanda 2 (95.94 mg kg^{-1}) and Henri Coanda 1 (95.61 mg kg^{-1}), which are 3.2 times higher than the normal legislative values (30 mg kg^{-1}).

The highest concentration of manganese was identified in the sample collected from DN26 (1) (704.85 mg kg^{-1}).

In the oldest studied locations with the highest traffic intensity and speed, it was expected that Pb would show the highest concentrations. On Domneasca 1 and 2, the concentrations were 48.42 mg kg^{-1} and 53.23 mg kg^{-1}, while on Balcescu 1 and 2, the concentrations were 54.25 mg kg^{-1} and 53.51 mg kg^{-1}, with a maximum of 54.25 mg kg^{-1}. This value is 2.71 times higher than the normal threshold established by legislation (20 mg kg^{-1}).

The metal pollution index (MPI), presented at equation 5, increases in the following order: DN26 (2), DN26 (1), Henri Coanda 2, Parc Control 2, Domneasca 1, Balcescu 1, Domneasca 2, Parc Control 1, Henri Coanda 1, and Balcescu 2, with values ranging from 264.80 to 604.97.

4. CONCLUSIONS

A clear correlation can be observed between the concentrations of Zn, Pb, and Ni and the age of the location, traffic density, and speed limits. Pb concentrations are highest in areas with the highest speed limits, while Cu levels are elevated in locations with older infrastructure, high traffic density, and high speeds.

Lead appears in high concentrations, indicating long-term contamination from fuel emissions, brake wear, oil residues, tire and asphalt erosion. The European Union banned lead in gasoline through Directive 98/70/EC at the end of 1998, with Romania implementing this regulation in 2005. Currently, the maximum allowable Pb concentration in diesel fuel is 0.005 gL^{-1}. Today, a manganese-based compound is used as an additive instead of lead. Since the enforcement of Emergency Ordinance 80/13.09.2018, Romania has allowed the use of methylcyclopentadienyl tricarbonyl manganese (MMT) as a fuel additive, with a maximum concentration of 2 mg MnL^{-1}. Fortunately, the *enrichment factor*, presented at equation 4, only shows values corresponding to minor enrichment, with a decreasing trend: Arcasilor 2 < Control sample 1 < Tecuci 1 = Control sample 2 < Henri Conda 1 = IFR2 < Balcescu 1 = Balcescu 2 < Domneasca 1 = Domneasca 2 = DN26 (2) < DN26 (1).

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