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Metal Contamination and Human Health Risk Assessment of Soils from Parks and Playgrounds of an Industrialized Town (Galati, Romania)

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Abstract: The aim of the present study was to evaluate the contamination state of the surface soil from 10 parks and playgrounds from Galati, Romania, and the health hazard. The soil samples, collected in each site from the playing ground and from the edge of the park, were analyzed by using combined Wavelength- (WDXRF) and Energy-Dispersive (EDXRF) X-ray fluorescence techniques. A total number of 27 chemical elements (Ag, Al, As, Ba, Ca, Cd, Cr, Co, Cu, Fe, Hg, K, Mg, Mn, Na, Ni, P, Pb, Rb, Sb, Sc, Sn, Sr, Ti, V, Zn and Zr) were quantified in the urban soils, and the results were compared to the normal and alert values from Romanian legislation for toxic trace elements, as well as with European and world average values of element concentrations. The mineralogical analyses were performed by Scanning Electron Microscopy with Energy Dispersive X-ray Analysis (SEM-EDX) and Attenuated Total Reflectance-Fourier Transform Infrared technique (ATR-FTIR). To assess the soil contamination and the impact on human health of the presence of potential toxic elements and heavy metals in the soil, a series of pollution and health risk indices were used. All the results indicated an unpolluted to moderate polluted soil. The soil samples collected from the edge of the parks presented higher values for the specific pollutants that originated from heavy traffic, such as Cu, Cr, Zn and Pb. The non-carcinogenic risk to children was assessed using the estimate daily intakes (EDI), afferent to the pathways that pollutants can enter the human body, such as ingestion, dermal contact and inhalation. Using the obtained values for EDI, the hazard quotient and hazard index were determined, which strengthen the formerly issued presumption that soil pollution is moderate and, by itself, does not present any threat to the children's health.

Keywords: soil; playgrounds; parks; heavy metals; XRF; FTIR; SEM-EDX

1. Introduction

In association with uncontrolled urban development, the quality of all environmental constituents is negatively affected. Soil, is that environmental part that represents the link between humans and the potentially toxic elements, usually represented by heavy metals. Heavy metals are defined as any metals with a density greater than 5 g cm^{-3}, and there are currently sixty known chemical elements in this category. In soils, the concentration of heavy metals varies, generally due to two types of sources: natural and anthropogenic [Suciu et al. 2008; Tong et al. 2020].

The natural sources of heavy metals in soil are related to the mineralogical composition of the bedrock, causing the soil to inherit elements specific to the soil-forming material of each region. In

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rural areas, these natural sources account for the majority of heavy metal concentrations because the soil is largely undisturbed, and human activities are generally limited to agriculture [Gagiu et al. 2015; Rodriguez-Oroz et al. 2018; Zglobicki et al. 2021].

Urban soils differ significantly from natural soils due to the strong influence of intense anthropogenic activities, which typically emit high amounts of pollutants. Some urban soils are completely transformed and serve as foundations for human settlements, while others undergo minimal changes and are used for plant foundations. A small proportion of urban soils remain unmodified, typically found in woods or old parks with minimal anthropogenic activity. The concentration of heavy metals in urban soils is influenced by two types of factors: the geogenic abundance and anthropogenic activities, including industrial and vehicular emissions, as well as household activities [Lacatusu et al. 2008; Ungureanu et al. 2017].

In urban environments, anthropogenic sources of heavy metals are grouped by human activities and can be classified into the following categories: industrial activities, the production of electric and/or thermal power, vehicular emissions, atmospheric depositions, and domestic waste. Due to the immobility, non-degradability, and persistence of heavy metals, they tend to accumulate in the upper soil layers, reaching concentrations that can be harmful to humans, particularly children under the age of 7, if exposure is frequent. Besides their negative impact on human health, heavy metals can disrupt the ecological balance of the environment, leading to changes in the chemical and physical properties of the soil. The level of soil pollution depends on the concentration of present heavy metals, as well as their bioavailability and solubility [Massas et al. 2010; Faciu et al. 2012; Gagiu et al.2015; Gurbunov et al. 2015; Apostoae, 2016; Sapcanin et al. 2017; Rodriguez-Oroz et al. 2018; Tong et al. 2020; Zglobicki et al. 2021; Pikula and Stepien, 2021].

Bioavailability refers to the extent to which an element is available for absorption by both plants and humans. In soil, several physical and biogeochemical factors influence the mobility and solubility of heavy metals. The most important factors include pH, temperature, clay content, redox potential, geochemical specificity of the element, origin of the pollutant, granulometry and mineralogy of the sample, organic carbon content, and mode of retention. When the pH value is above 5.5, solubility is limited; however, at lower pH values, most metals in the soil become highly soluble. Highly soluble toxic elements are less available to humans because they tend to accumulate at lower depths in the soil [Verla et al. 2020; Miguel et al. 2021].

In urban environments, humans, especially children, have close contact with dust and soil. Due to their smaller body size and developing systems, children are the most exposed and vulnerable category. They are in direct contact with the soil surface and can be directly exposed to potentially toxic elements through intentional or unintentional ingestion. Soil or dust can enter their bodies through three pathways: inhalation, ingestion, dermal contact or vaporization (only for mercury) [Massas et al. 2010; Sapcanin et al. 2017; Schiavo et al., 2023; Sahachian et al., 2019; Battsengel et al., 2020].

In urban environments, parks and playgrounds are the main places where children come into contact with high quantities of dust, soil, and sand. Green infrastructure has a direct positive impact on physical and mental health by encouraging social cohesion. Additionally, it provides environmental benefits such as reducing temperature and urban noise by 26%, regulating environmental humidity, and decreasing pollution through the absorption of carbon dioxide. Regarding their aesthetic role in a city, green spaces help mitigate urban rigidity and increase the value of nearby land [Apostoae et al. 2013; Apostoae and Iancu, 2014; Air quality plan, 2018].

As part of green infrastructure, parks and playgrounds have a positive impact on child development and help adults relax by releasing accumulated stress. A park is a green space, with a minimum surface area of 1 hectare, featuring specific types of vegetation and various areas for cultural, social, and recreational purposes. In temperate climates, where apartment blocks are the primary residences for most city inhabitants, parks and playgrounds become the main outdoor spaces where people, especially children, spend a significant amount of their free time. Activities in these areas allow children to explore, develop creativity, play, and engage in various sports, which can help lower obesity rates and contribute to their overall development, providing social, health,

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and psychological benefits [Richmond et al. 2018]. During these activities, besides the risk of injury, children face the risks of ingesting (geophagia), inhaling, or, rarely, absorbing soil or dust through the skin. This is because small children tend to play very close to the soil surface, exposing them to the negative effects of pollutants [Faciu et al. 2012; Apostoae et al. 2013; Air quality plan for Galati, 2018; Verla et al.2020; Tong et al.2020; Kumar et al. 2020; Zglobicki et al.2021].

In a city, these types of pollutants are usually emitted by industries, thermal and electric plants, exhaust gases, particles from tires and asphalt, demolitions, and waste incineration etc. [Faciu et al., 2021], but the main sources of airborne heavy metal emissions in parks and playgrounds are inputs from industry and traffic, which can introduce high concentrations of lead (Pb) into the environment. Additionally, treated wood structures in play areas can be sources of substances based on chromium (Cr), copper (Cu), and arsenic (As) (commonly known as CCA). The green areas are often treated with weed killers and insecticides, which can also contribute to pollution [Gagiu et al.2015; Sapcanin et al. 2017; Rodriguez-Oroz et al. 2018]. The level of soil pollution in parks and playgrounds depends on several factors. One key factor is the capacity of heavy metals to gradually accumulate in the soil, meaning that older parks tend to have higher amounts of pollutants in the topsoil. Another important factor is the presence of vegetation, which can protect the park or playground from toxic emissions; in the absence of vegetation, pollutants can be re-suspended. Additional factors include the distance from pollution sources, as well as the topography and architectural design of the area [Massas et al. 2010; Gagiu et al.2015; Zglobicki et al.2021].

Soil plays an important role in urban environments, notably by preventing floods, improving air quality, and supporting plants, vegetables, and animals. The presence of pollutants can impair these functions and negatively impact human health through ingestion or consumption of food grown in contaminated soil. Additionally, heavy metals deposited on the soil surface or pavements can become re-suspended into the atmosphere, where they are inhaled, contributing to the early development of respiratory diseases [Garcia-Rico et al. 2020; Herbon et al. 2021]. Furthermore, the negative effects of heavy metals on humans can include geotoxicity, carcinogenesis, hepatotoxicity, renal toxicity, neurotoxicity, and apoptosis [Verla et al. 2019].

The heavy metals commonly found in urban environments are specific to their sources. For example, zinc (Zn), lead (Pb), and copper (Cu) typically originate from vehicular traffic, while copper (Cu), antimony (Sb), cadmium (Cd), and zinc (Zn) are often associated with industrial sources. Heavy metals pose a severe threat to children's health and can affect adults as well. The most common heavy metals include cadmium (Cd), cobalt (Co), copper (Cu), manganese (Mn), nickel (Ni), lead (Pb), tin (Sn), and zinc (Zn), as well as metalloids such as arsenic (As) etc. [Massas et al. 2010; Gredilla et al. 2017; Laha et al. 2023; Li R. et al. 2020; Herbon et al. 2021].

Copper (Cu), manganese (Mn), and zinc (Zn) are essential for human health and normal development at low concentrations. However, lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg) are extremely toxic even at very low concentrations.

Numerous studies have shown a link between the presence of these toxic metals in the environment and various types of cancers and respiratory disorders [Ng et al. 2003; Suciu et al. 2008; Faciu et al. 2012; Tong et al. 2020]. When heavy metal concentrations reach high levels, they can cause metal poisoning, leading to various diseases over the long term. Over the past 30 years, the infant mortality rate has shown a continuous decline. For instance, from 1990 to 2007, Romania had the highest infant mortality rate in the EU. Until 1990, respiratory diseases were the leading cause of death among children aged 0-4 years. However, starting from the year 2000, this pattern shifted, with perinatal diseases becoming the primary cause of death, relegating respiratory diseases to the second position. According to the health reports, during the period from 2012 to 2016 (excluding 2014 and 2015), the average percentage of deaths due to respiratory disorders among children under 19 years old was 25.33%. This marks a significant decline compared to 1990, when deaths due to respiratory disorders accounted for 48.15 % of deaths in this age group. By 2016, respiratory disorders remained the leading cause of death among children aged 0-19 years, representing 22 % of total deaths, while tumors accounted for 6% [Daina et al. 2015; Duma et al. 2016; Pop et al. 2020]. In 2018, in Galati,

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respiratory disorders accounted for 6.52% of the total number of deaths, while different types of tumors accounted for 18.67% [Statistical yearbook of Galati, 2018].

Literature reveals some important studies regarding soil pollution in parks and playgrounds [Elom et al. 2013; Javed et al. 2019; Garcia-Rico et al. 2020; Laha et al. 2023], but in Romania there are very few investigations on this subject [Apostoae et al. 2013; Posta et al. 2015].

Few studies have examined the pollution with heavy metals in the soil of Galați city. The available data mainly focus on the impact of industrial activities on the soil quality in the surrounding areas [Ene et al. 2010; 2023; 2024 a,b]. Although it is an important environmental issue, little attention has been paid to soil quality inside Galati city, particularly in parks and playgrounds, where the soil quality directly affects the health of inhabitants. This study aims to assess the quality of soils in urban and highly frequented playgrounds and parks where children in Galati municipality spend significant amounts of time. The findings will characterize the level of pollution with heavy metals in these areas and provide crucial insights to protect young lives from exposure to heavy metals.

2. Materials and Methods

2.1. Description of the Studied Area

The studied area is Galati municipality, located in the east of Romania, at the southern extremity of the Moldavia Plateau, at a latitude of 45°27' North and a longitude of 28°02' East. It has a total surface area of 243.6 km². The climate is temperate continental, with a mean annual temperature of 10.5 °C and predominant (>50%) North and North-West winds. Galati city hosts the largest port on the maritime Danube, situated 130 km from the Black Sea shore and 250 km from Romania's capital, Bucharest.

Galati has a total surface area of 24,363.37 hectares, of which, in 2013, 3.53% was designated as green spaces. By 2019, the amount of green space per inhabitant in Galati was reported to be 30.44 m², surpassing the national and European legal recommendations of 26 m² per inhabitant. According to the last census in 2019, Galati has a population of 305,386, making it the 8th largest city in Romania [Statistical yearbook of Galati, 2018; Air quality plan for Galati, 2018].

Regarding the soil pollution, are studies that sustain that in an urban environment the order is, from low to high, botanical garden<suburbs farmland<traffic area<industrial area [Apostoae, 2016]. The sources of soil pollution in Galati municipality are diverse and strongly linked to human activities. The key economic sectors in Galati city include agriculture, food processing, shipbuilding, metallurgy, and industrial equipment production. In urban areas, the primary industries are related to food processing, shipbuilding, metallurgy, and industrial equipment production [Faciu et al. 2012]. The number of vehicles in Galati nearly doubled over a ten-year period. In 2018, the total number of vehicles was 153,841, comprising 0.82 % buses and minibuses, 97.73% personal vehicles and taxis, and 1.45% mopeds and motorcycles [Statistical yearbook of Galati, 2018; Air quality plan for Galati, 2018].

2.2. Soil Sampling and Analysis

This research was conducted in ten parks and playgrounds located in various areas of Galati city. These locations were chosen based on their proximity to major roads with heavy traffic or important industrial activities and are popular among families with children.

The sample sites, presented in detail in Figure 1, were chosen to evaluate whether the anthropogenic activities occurring around and within parks and playgrounds negatively impact soil quality, thereby affecting children's and overall human health.

A total of twenty topsoil samples were collected from playgrounds and parks. For each location, the first sample was taken near the edges of the park (ES), close to the most major adjacent road, and the second sample was taken from areas where children frequently play near recreational equipment (PS). One sample point was selected using different criteria, serving as a control area, as it is located in a very remote place, far from intense traffic and industrial activities.

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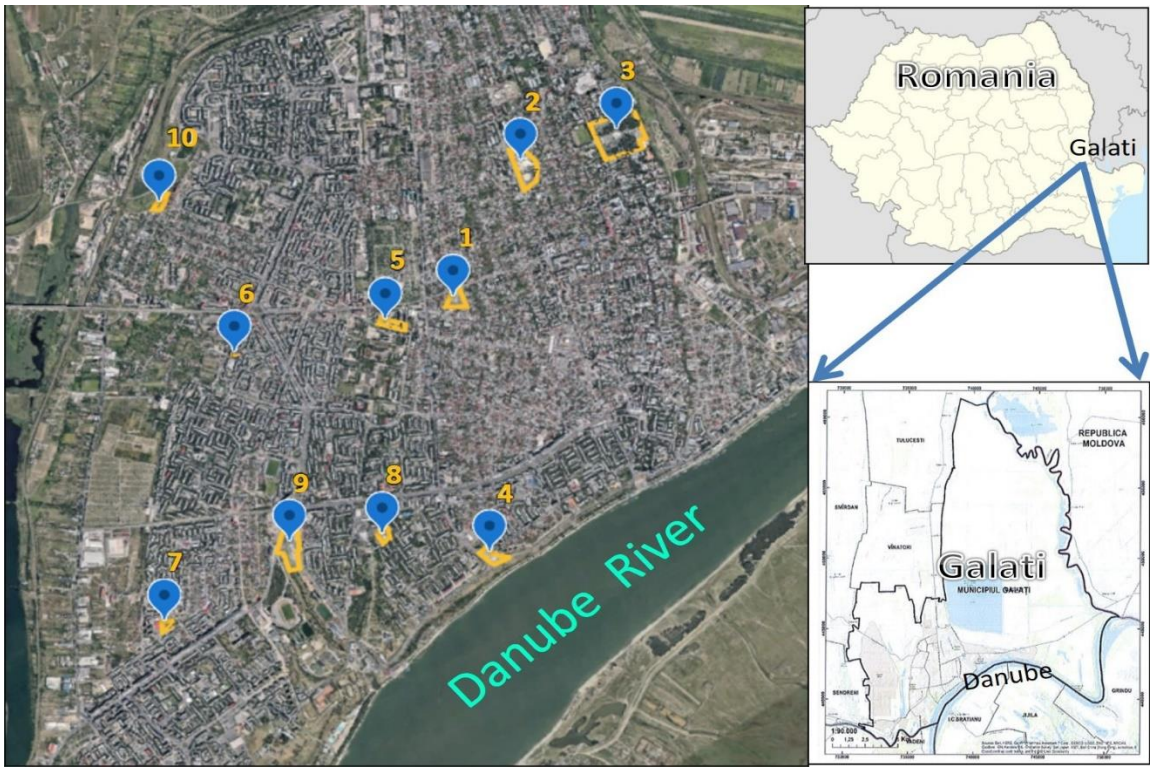

Sample ID	Location	Latitude (N)	Longitude (E)
1	Liberty Park	45°26′27″	28°02′16″
2	Rizer Park	45°26′57″	28°02′38″
3	Public Garden	45°27′04″	28°03′08″
4	Viva Park	45°25′26″	28°02′32″
5	IFR Park	45°26′21″	28°01′57″
6	Siderurgists Park	45°26′14″	28°01′08″
7	Micro 17 Park	45°25′07″	28°00′43″
8	Children City Park	45°25′32″	28°02′56″
9	Closca Park	45°25′31″	28°01′27″
10	ANL 13 Park	45°26′55″	28°00′50″

Figure 1. Sample locations and geographical coordinates.

The soil samples were manually collected using a stainless-steel spade, which was cleaned after each operation to avoid cross-contamination between samples. Since the interaction between metal contaminants and children occurs primarily on the top layer of the soil, only surface soil was collected. The sampling sites had no vegetation cover, and the sampling depth was 0-0.05 meters. Each sample weighed between 1.5 and 2 kg, and the locations were recorded using a Garmin GPS (Global Positioning System) device.

The soil samples were transported in labeled plastic zip-lock bags to the laboratory for analysis. In the lab, the air-dried soil was ground using porcelain mortar and pestle, then sieved through a 200 μm sieve to improve sample homogeneity and achieve a uniform particle size distribution. All rocks, vegetation, and other debris were removed. The remaining material was stored for future determinations of soil physicochemical properties.

2.3. Analytical Procedures

The soil samples were analyzed in order to obtain physical and chemical properties, as well as the total content of potential toxic elements. All the analyses were at Dunarea de Jos University of Galati and Valahia University of Targoviste, Romania.

The analytical samples were subjected to pH measurements and electrical conductivity in soil-water according to a standard method with a 1:2.5 soil/water suspension using a Hanna HI 98195

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pH/ORP & EC/TDS/NaCl/Resistivity with an HI9828-0 calibration standard solution. These analyses were conducted at the Molecular Spectroscopy, Multiparameter Analysis, and Experimental Data Processing Laboratory of the INPOLDE research center, Dunarea de Jos University of Galati.

X-ray fluorescence spectrometry (XRF) was used for the determination of element content in soils, by employing both energy dispersive (EDXRF) and wavelength dispersive (WDXRF) techniques. It is a powerful analytical method employed for the qualitative and quantitative analysis of the chemical composition of materials. XRF is widely used in environmental monitoring, geology, life sciences, materials science, archaeology, and many other fields [Weindorf, 2020]. The method is based on the interaction between X-rays and the atoms of a sample, which leads to the emission of characteristic secondary (or fluorescent) X-rays. This allows for the identification and quantification of chemical elements.

Sample analyses were performed using the EDXRF at Dunarea de Jos University of Galati with a portable INNOV-X Systems ALPHA SERIES 8000 spectrometer, specifically calibrated for the analysis of soil samples [Innov-X-MANUAL], equipped with an X-ray tube featuring an Ag anode and a Be window, and a silica PIN diode for radiation detection. The device performs analyses using the fundamental parameters method. The most notable limitations include poor detection of light elements ($Z< 11$) and surface sensitivity, as the penetration depth is only a few microns, which may not always represent the bulk composition. Additionally, the matrix effect is observed, where the presence of other chemical elements in the sample can affect the detection accuracy due to absorption and enhancement effects [Marguí, 2022]. For EDXRF analysis, the fine and homogenized soil samples were encapsulated using special capsules, and irradiated for 120 seconds.

In order to obtain a complete set of concentration values, multi-element analysis of soil samples was also performed using the Rigaku (Japan) Supermini 200 WDXRF spectrometer at the Institute of Multidisciplinary Research for Science and Technology of Valahia University of Targoviste. The system is equipped with three position crystal changers: LiF (200) for heavy elements (Ti-U), PET and RX 25 for light elements (O-Mg and Al-Sc) and a X–ray tube, 50 kV, 4 mA, 200W, Pd anode. Detection limit is found to be between 1 ppm and 10 ppb and the precision of the analysis is 0.1-0.5%. For this analysis, samples were prepared by mixing 2 g of fine ground (200 μm) soil sample with 2 g of binder (Fluxana Boreox, $C_{12}H_{22}O_{11}$). The pellets used for WDXRF analysis were prepared from the sample-binder mixture using the TestChem LPR-250 laboratory press. The obtained pellets (32 mm diameter) were analyzed in vacuum atmosphere. The ZSX software was used for spectra recording and data processing. Spectrum interpretation was performed using the calibration curve method, based on Certified Reference Materials (CRMs) with similar matrix (soil, sediment).

The study of soil morphology and qualitative analysis was conducted in the Electron Microscopy Laboratory at Dunarea de Jos University of Galati using a Scanning Electron Microscope coupled with Energy Dispersive X-ray Analysis (SEM-EDX) system [Ene et al. 2024a]. Morphological analyses were performed on FEI Quanta 200 SEM microscope (Thermo Fischer Scientific, Massachusetts, USA). Secondary electron signals were detected to provide high-resolution images about the texture, shape and size of soil particles, at different magnifications. Prior imaging, the specimen preparation is very important step. The powders with discontinuous grading were mounted on metal support using a carbon double-adhesive tape. To avoid charging effects on electron images, a metal thin layer coating was necessary to ensure the electrical conductivity of the samples (SPI Supplies sputtering equipment, West Chester, USA). An ultra-thin window Ametek EDX detector (silicon crystal) (Gatan, California, USA) along with SEM apparatus was used for the elemental composition measuring. The semi-quantitative assay was performed using the ZAF algorithm (corrections for Z – atomic number; A – absorption; F – fluorescence) and controlled by GENESIS software. The following settings were used for the analysis: an accelerating voltage (EHT) of 15 kV, a working distance (WD) ranging between 8.9-10.3 mm, and a probe current of less than 100 nA. The EDX system utilized a Silicon Drift Detector (SDD). All samples were analyzed in high vacuum (HiVac) mode with a chamber pressure of 60 Pa, at magnifications ranging from 250x to 500x. An accelerating voltage of 25 kV has been set to maximize the quality of the microstructural results. SEM-EDX was used in five scanning fields,

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randomly selected on the surface, for mineral characterization. After the elemental compounds' identification, they were spatial mapped using the EDX analyser.

Soil characterization in terms of organic and inorganic compounds was carried out using Attenuated Total Reflectance Fourier Transform Infrared Spectroscopy (ATR-FTIR), which is the second most widely used method for studying soil organic matter, including its constituents, water content, and mineral and artificial soil components [Volkov et al, 2021]. It was used a BRUKER TENSOR 27 FTIR spectrometer coupled with a diamond ATR device, at the INPOLDE research centre from Dunarea de Jos University of Galati. Soil samples were air dried and sieved at 200 μm, then pressed in a thin layer directly onto the ATR crystal. This simple and non-destructive method of analysis offers significant advantages; however, a potential drawback lies in the possibility of imperfect contact between the soil and the ATR crystal. This imperfection can lead to a loss of sensitivity and precision in the final results [Volkov et al, 2021]. Each sample was measured with 32 scans between 4000 and 400 cm^{-1}, with a spectral resolution of 4 cm^{-1}. The spectra were corrected for H_2O and CO_2 using OriginPro 2016 software (version 9.3.226) [Ene et al. 2024a; Sion et al., 2020].

2.4. Pollution Indices of Soil Contamination and Potential Human Health Risk Assessment

Because is important to assess soil pollution and the level that heavy metal concentrations from soil can affect the human health a descriptive analysis was performed with Microsoft Excel. The analysis was focused on statistical parameters that will characterize the heavy metal content from soil and if the concentrations will influence the health state of the inhabitants [Apostoae, 2016].

To estimate the soil heavy metal contamination, pollution indices were considered, such as integrated pollution index (*IPI*), geo-accumulation index (*Igeo*) and enrichment coefficient (EC) equations, presented in Table 1.

To assess the potential toxic effect on the children that are playing in that given area, were considered four paths of direct contact with the contaminants from soil: ingestion (found to be the principal exposure pathway to human health), dermal contact, inhalation and volatilization (only for mercury) in other words to establish the relationship between the contaminant, pathway and receptor. To assess the non-carcinogenic risk to heavy metal exposure from soil collected from parks were calculated the estimated daily intakes (EDI) for Sr, Rb, Cu, Pb, As, Ni, Zn, Zr, V, Cd, Ag and Hg according to USEPA standards as seen in Tables 1 and 2 [Zhang et al.,2023; Rodriguez et al. 2005; Laha et al. 2023].

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Table 1. Pollution indices of soil contamination and potential human health risk assessment factors.

Indices	Information	Equation	Pollution classification	References
IPI	Soil contamination also can be described using the integrated pollution index (IPI), that is defined as the ratio between the measured concentration of heavy metals and the reference values from national legislations that are expressing normality for Romanian soils.	$IPI = \frac{C_i}{NV}$	If IPI value is < 1 the level of pollution is low, if 1<IPI<2 is an average level of pollution and if IPI>2 is considered to be a high level of pollution.	[Gagiu et al. 2015]
Igeo	The geo-accumulation index (*Igeo*) is indicating the potential anthropogenic input of heavy metals into soils. C_i is the measured concentration of heavy metals in soil; NV is the normal value and 1.5 is the background matrix correction factor due to lithogenic effects.	$I_{geo} = log_2 \frac{C_i}{1.5\ NV}$	If the results are smaller or equal to 0 there is an unpolluted soil; 0-1 the soil is unpolluted to moderate pollution soil; 1-2 the soil is moderate polluted; 3-4 the soil is moderate to strongly polluted; 4-5 the soil is strongly polluted; > 5 the soil is very strongly polluted.	[Apostoae et al., 2013; Apostoae and Iancu 2014; Laha et al. 2023]
EC	Enrichment coefficient (EC) is a factor that is used to compare the heavy metal concentration from soil (C_i) with the element composition from the earth's crust (C_{crust}), establishing the level of anthropogenic input.	$EC = \frac{C_i}{C_{crust}}$	EC <1 there is no or is an insignificant enrichment but if the value is > 1 are considered to be enrichments from different sources.	[Javed et al. 2019; Laha et al. 2023]
EDI ingestion EDI inhalation	The exposure of the children that are playing in playgrounds and parks to the heavy metals found in soil and dust can occur via three ways: direct ingestion, inhalation and dermal contact.	$EDI_{ingestion} = \frac{C \times IngR \times EF \times ED}{Bw \times AT} \times 10^{-6}$ $EDI_{inhalation} = \frac{C \times InhR \times EF \times ED}{PEF \times Bw \times AT}$	If the values of HQ and HI are smaller than 1, there is no risk presented, but if the values are higher than 1 there are present non-carcinogenic health risks.	[Rodriguez et al. 2005; Javed et al. 2019; Battsengel et al. 2020; Zgłobicki et al. 2021; Schiavo et al. 2023]

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EDI dermal	$EDI_{ingestion}$, $EDI_{inhalation}$, EDI_{dermal} and $EDI_{vaporization}$ (mg kg^{-1} day^{-1}) are the *estimate daily intakes* via ingestion, inhalation, dermal and vaporization pathways. These factors are assessing the non-carcinogenic risk of daily exposure of children to polluted soils from parks.	$EDI_{dermal} = \frac{C \times SA \times SAF \times ABS \times EF \times ED}{Bw \times AT} \times 10^{-6}$
EDI vaporization		$EDI_{vaporization} = \frac{C \times IngR \times EF \times ED}{VF \times Bw \times AT}$
HQ ing	Hazard quotient (HQ) was calculated in order to establish the potential risks that are subjected children if they are in contact with the polluted soil. HQ is an estimation of a non-carcinogenic risk due to the exposure to pollutants found in soils with respect to their estimated daily intake (RfD)(mg kg^{-1} day^{-1}).	$HQ_{ing} = \frac{EDI_{ing}}{RfD}$
HQ inhal		$HQ_{inhal} = \frac{EDI_{inhal}}{RfD}$
HQ dermal		$HQ_{dermal} = \frac{EDI_{dermal}}{RfD}$
HQ vaporization		$HQ_{vaporization} = \frac{EDI_{vaporization}}{RfD}$
HI	Hazard index (HI) was calculated as a sum of the entire hazard quotient.	$HI = HQ_{ing} + HQ_{inhal} + HQ_{dermal} + HQ_{vaporization*}$

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Table 2. The definition and unit of measurement for the used parameters.

Parameter	Definition	Unit	Children	References
IngR	Soil ingestion rate depending on age	[mg/day]	200	[Schiavo et al., 2023, Sahakyan et al., 2019, Battsengel et al., 2020]
EF	Exposure frequency	[days/year]	350 days	[Schiavo et al., 2023, Sahakyan et al., 2019, Battsengel et al., 2020]
ED	Exposure duration	[year]	6	[Schiavo et al., 2023, Sahakyan et al., 2019, Battsengel et al., 2020]
Bw	Average body weight	[kg]	15	[Schiavo et al., 2023, Sahakyan et al., 2019, Battsengel et al., 2020]
AT	Average time	[days]	ED X 365	[Schiavo et al., 2023, Sahakyan et al., 2019, Battsengel et al., 2020]
InhR	Inhalation rate	[m^3/day]	7.6	[Schiavo et al., 2023 ,Sahakyan et al., 2019, Battsengel et al., 2020]
PEF	Particle emission factor	[m^3/kg]	$1.36x10^9$	[Schiavo et al., 2023, Sahakyan et al., 2019, Battsengel et al., 2020]
SA	Skin area exposed to the pollutant	[cm^2/day]	2800	[Sahakyan et al., 2019, Battsengel et al., 2020]
SAF	Skin adherence factor	[mg/cm]	0.2	[Schiavo et al., 2023, Sahakyan et al., 2019, Battsengel et al., 2020]
ABS	Dermal absorption factor	none	0.001 (for all the metals)	[Schiavo et al., 2023 , Battsengel et al., 2020]
VF	Volatilization factor	[mg^3/kg]	32675.6	[Schiavo et al., 2023 , Battsengel et al., 2020]
C	Concentration of the element	[mg/kg]		

The potential risks to children's health were evaluated by calculate the hazard quotient (HQ) that represents the non-carcinogenic risk due to the exposure to the heavy metals from soil with reference to EDI and the reference dose (RfD) [Javed et al. 2019; Battsengel et al. 2020; Zgłobicki et al. 2021]. RfD (mg kg^{-1} day^{-1}), found in Table 3, is considered to be the maximum daily dose from a specific heavy metal from a specific pathway that will not affect the health of a sensitive adult or child body, through a lifetime [Laha et al. 2023; Reference dose (RfD); Schiavo et al. 2023; Wcisło, 2021].

Table 3. Toxicants risk reference doses (RfDs).

Elements		RfD [mg/kg day]			
		Pathways			
		Ingestion	Dermal	Inhalation	Inhalation of Hg vapor
1	Cu	$4 \times 10^{-2(a)}$	$4\times10^{-2(a)}$	$1.2\times10^{-2(a)}$	–
2	Pb	$3.5\times10^{-3(a)}$	$3.25\times10^{-3(a)}$	$5.25\times10^{-3(a)}$	–
3	As	$3\times10^{-4(a)}$	$3.01\times10^{-4(a)}$	$1.23\times10^{-4(a)}$	–
4	Ni	$2 \times 10^{-2(a)}$	$2.06\times10^{-2(a)}$	$5.4\times10^{-3(a)}$	–

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5	Zn	3×10^{-1}[a]	3×10^{-1}[a]	6×10^{-2}[a]	–
6	Cd	1×10^{-3}[a]	1×10^{-3}[a]	5×10^{-5}[a]	–
7	Hg	3×10^{-4}[a]	8.57×10^{-5}[a]	2.1×10^{-5}[a]	8.75×10^{-5}[b]

(a) [Li et al., 2020]; (b) [Fang et al., 2011].

With respect to HQ, was determined hazard index (HI) for 5 heavy metals (Cu, Pb, As, Ni, Zn, Cd and Hg), by using the equation presented in Table 1 and the explained parameters presented in Tables 2 and 3.

In the case of hazard index, the permitted value is 1 and if this value is exceeded that metal can be harmful for human health.

3. Results

3.1. XRF Soil Analysis

In Tables 4, 5 and 6 and Figure 2 there are presented the heavy metal concentrations from soils collected from 10 parks, from playground (PS) and from the edge of the park (ES), and the physical-chemical identified parameters. X-ray fluorescence (XRF) was the method with what in total where registered in total a number of 26 chemical elements: Ag, Al, As, Ba, Ca, Cd, Cr, Co, Cu, Fe, Hg, K, Mg, Mn, Na, Ni, P, Pb, Rb, Sb, Sc, Sr, Ti, V, Zn and Zr. The wide variations between the obtained concentrations at different locations can indicate a possible contamination from anthropogenic activities.

Table 4. Physical-chemical parameters determined for 10 parks from Galati city, Romania.

Location/ Parameter		pH (units)	Conductivity (µS/cm)	Resistivity (MΩcm)	Salinity (PSU)	Total Dissolved Solids (ppm)	Oxidation Reduction Potential (mV)
1	**PS**	6.96	1000	0.001	0.49	500	1.8
	ES	7.14	765	0.0013	0.37	383	7.1
2	**PS**	7.37	870	0.0011	0.43	435	19.3
	ES	7.52	777	0.0013	0.38	389	18.9
3	**PS**	7.24	444	0.0022	0.21	222	10.6
	ES	7.48	396	0.0025	0.19	198	8.4
4	**PS**	7.14	492	0.002	0.24	246	6.3
	ES	7.21	1318	0.0008	0.65	659	9.2
5	**PS**	7.61	1349	0.0007	0.67	675	9
	ES	7.54	941	0.0011	0.46	471	8.9
6	**PS**	7.53	991	0.001	0.49	496	22.5
	ES	7.21	573	0.0017	0.28	287	2.4
7	**PS**	7.33	260.5	0.0039	0.12	130.5	8
	ES	7.15	221.5	0.0046	0.11	110.5	9.05
8	**PS**	6.49	725.33	0.0014	0.35	363	7.57
	ES	6.85	224.50	0.0045	0.11	112.50	6.15
9	**PS**	7.27	181	0.0056	0.09	90.50	4.50
	ES	7.34	232.5	0.0043	0.11	116.5	9.05
10	**PS**	6.67	501.5	0.002	0.24	250.5	8.05
	ES	7.22	234	0.0043	0.11	117	7.4

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Table 5. Possible toxic elements concentrations (mg kg^{-1}) found in 10 parks from Galati city, Romania.

Site	Element concentration (mg kg^{-1})																	
	Sr	Rb	Cu	Pb	As	Co	Cr	Ni	Mn	Zn	Sc	Zr	Hg	V	Sb	Ba	Cd	Ag
1 PS	84	73	33	22	5.6	2.4	72	51	724	113.3	<LOD	327	0.9	85	0.51	330	0.15	3.5
1 ES	76	87	56	108	5.7	2.5	65	25	660	383.6	<LOD	343	0.9	92	0.51	521	0.14	3.6
2 PS	88	69	50	37	5.0	3.5	60	48	704	164.8	52	301	1	82	0.5	434	0.07	3.3
2 ES	135	68	36	29	6.0	3.7	58	22	640	129.4	<LOD	298	0.9	83	0.51	386	0.1	2.8
3 PS	116	51	28	24	6.3	2.3	66	48	787	142.5	<LOD	260	1.1	61	0.48	316	0.12	3.4
3 ES	81	69	25	40	6.4	3.3	67	31	742	161.9	<LOD	287	0.9	82	0.49	374	0.12	3.7
4 PS	68	87	31	16	4.0	3.4	76	41	803	123.3	<LOD	245	1	106	0.48	512	0.09	3.4
4 ES	75	88	36	23	4.5	3.0	75	42	731	124.4	<LOD	287	1	104	0.49	447	0.13	3.6
5 PS	74	82	34	29	6.9	2.6	64	39	729	136.9	<LOD	334	1.2	93	0.49	515	0.15	3.3
5 ES	118	72	33	32	6.3	2.4	62	48	736	127.5	<LOD	317	1.1	79	0.5	349	0.16	3.2
6 PS	107	70	55	72	8.0	3.8	55	30	716	212.8	<LOD	289	1.1	70	0.51	370	0.17	3.5
6 ES	111	76	35	92	8.4	3.9	50	57	753	221	<LOD	305	0.9	81	0.51	431	0.23	3.4
7 PS	67	86	42	16	5.0	2.5	78	43	837	119.6	<LOD	307	1	93	0.52	482	0.1	3.3
7 ES	64	86	30	21	5.3	2.8	73	42	777	129.7	31	317	1.1	90	0.53	477	0.14	3.3
8 PS	113	69	45	27	5.2	2.7	68	23	691	117.1	<LOD	320	0.9	79	0.5	407	0.16	3.5
8 ES	80	76	28	29	6.0	2.8	64	34	761	105	<LOD	309	1	80	0.51	378	0.08	3.4
9 PS	133	70	39	25	4.5	2.5	59	41	743	137.9	48	304	0.8	82	0.52	399	0.14	3.2
9 ES	124	70	49	29	4.8	2.7	59	28	687	118.6	<LOD	308	1	73	0.51	344	0.13	3.4
10 PS	81	70	35	35	4.3	2.2	49	39	810	155.6	<LOD	338	1.1	79	0.53	399	0.25	3.4
10 ES	86	72	40	23	4.5	3.1	71	25	773	139.4	<LOD	361	1	89	0.54	402	0.1	3.4
Mean	94.05	74.55	38.00	36.45	5.64	2.91	64.55	37.85	740.20	153.22	43.67	307.85	1.00	84.15	0.51	413.65	0.14	3.38
Minimum	64.00	51.00	25.00	16.00	4.00	2.20	49.00	22.00	640.00	105.00	31.00	245.00	0.80	61.00	0.48	316.00	0.07	2.80
Maximum	135.00	88.00	56.00	108.00	8.40	3.90	78.00	57.00	837.00	383.60	52.00	361.00	1.20	106.00	0.54	521.00	0.25	3.70
STD	23.06	9.18	8.95	24.86	1.19	0.53	8.23	10.14	50.01	62.11	11.15	27.11	0.10	10.59	0.02	62.27	0.05	0.19
CV	24.52	12.31	23.55	68.22	21.04	18.16	12.75	26.80	6.76	40.54	25.54	8.81	10.04	12.58	3.21	15.05	33.04	5.56
NV	-	-	20	20	5	15	30	20	900	100	-	-	0.1	50	5	200	1	2
SAT	-	-	100	50	15	30	50	75	1500	300	-	-	1	100	12.5	400	3	10
SIT	-	-	200	100	25	50	100	150	2500	600	-	-	2	200	20	1000	5	20
EUROPE soil (mean)[1]	130	86.8	17.3	32.6	11.6	10.4	94.8	37.3	810	68.1	9.1	251	0.061	68.1	1.04	400	0.28	0.304
World soil[2]	250	-	30	35	6	20	70	50	850	90	-	-	0.1	110	1	500	0.30	1
Agricultural area[3]	-	-	27.72	10.92	-	7.64	169.25	39.75	262.16	83.53	-	-	-	-	-	-	0.14	-
Industrial area[4]	117.6	82.53	23.13	29.40	8.55	11.08	92.11	37.99	749.5	102.26	10.29	300.63	6.62	62.25	0.95	355.6	0.33	-
Urban study[5]	45.00	68.36	36.60	30.10	11.44	-	78.04	58.24	563.11	91.54	-	-	-	86.34	-	-	-	-

PS – playground sample; ES – edge sample; STD –standard deviation; CV– coefficient of variation; LOD – limit of detection; NV–normal value; SAT–Sensible alert threshold; SIT–Sensible intervention threshold [Order no. 756/03.11.1997]; [1][Salminen et al. 2005]; [2][Adriano et al. 2001]; [3][Ene et al., 2024 a]; [4][Ene et al., 2024 b]; [5][Sion et al., 2023].

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Table 6. Major element concentrations (g kg^{-1}) found in 10 parks from Galati city, Romania.

Site	Element concentration (g kg^{-1})							
	Mg	Na	P	Al	Ti	Fe	Ca	K
1 PS	8.20	11.14	0.75	67.10	3.80	22.36	38.20	17.75
1 ES	6.74	10.00	1.57	66.73	3.40	19.32	24.52	17.81
2 PS	7.47	11.13	1.02	69.63	3.62	21.72	42.32	17.38
2 ES	10.10	10.76	1.03	67.04	3.45	21.17	59.09	17.85
3 PS	4.60	11.12	1.34	82.64	3.38	18.69	35.05	15.25
3 ES	7.18	11.46	3.01	69.01	3.47	21.84	37.22	18.54
4 PS	5.73	11.60	1.41	55.80	3.65	24.26	13.99	20.39
4 ES	5.84	11.58	0.78	55.21	3.45	25.07	15.49	18.56
5 PS	7.36	11.38	1.11	73.09	3.93	23.70	21.95	18.83
5 ES	6.31	11.44	0.32	71.21	3.54	22.20	36.14	18.35
6 PS	6.65	11.68	2.21	75.28	3.58	21.88	43.64	19.87
6 ES	9.46	11.10	2.23	69.57	3.37	22.18	49.29	18.11
7 PS	5.11	12.38	0.03	60.80	3.70	24.61	15.89	19.05
7 ES	5.30	11.70	0.40	67.83	3.72	24.83	17.92	19.93
8 PS	4.39	12.27	0.38	71.55	3.63	21.24	41.23	17.62
8 ES	4.05	12.49	0.28	72.18	3.59	24.02	31.28	18.19
9 PS	3.54	12.49	0.57	74.11	3.64	21.69	44.11	17.90
9 ES	4.12	12.34	0.17	74.03	3.30	21.23	42.39	16.51
10 PS	0.765	12.73	1.01	78.82	3.81	22.77	11.78	9.13
10 ES	1.53	12.90	0.73	76.81	3.57	21.65	25.11	18.47
Mean	5.72	11.68	1.02	69.92	3.58	22.32	32.33	17.78
Minimum	0.77	10.00	0.033	55.21	3.30	18.69	11.78	9.13
Maximum	10.10	12.90	3.01	82.64	3.93	25.07	59.09	20.39
STD	2.35	0.74	0.772	6.89	0.16	17.08	13.32	2.34
CV	0.41	0.06	0.76	0.10	0.05	0.08	0.41	0.13
EUROPE soil (mean)[1]	11.8	11.5	1.5	105	6.09	38	35.4	20.2
Agricultural area[2]	-	6.85	-	44.10	4.56	39.42	-	-
Industrial area[3]	2.7	6.88	-	44.68	3.84	31.89	29.26	16.8
Urban study[4]	-	-	-	-	4.14	19.24	27.37	17.95

PS – playground sample; ES – edge sample; STD –standard deviation; CV– coefficient of variation; [1][Salminen et al. 2005]; [2][Ene et al., 2024 a]; [3][Ene et al., 2024 b]; [4][Sion et al., 2023].

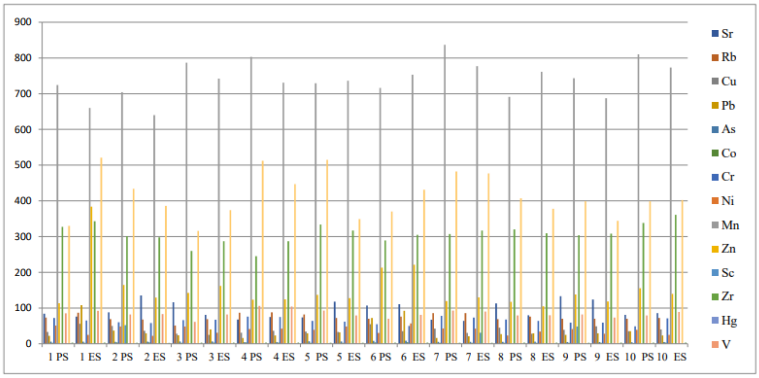

Figure 2. The elemental concentrations (mg kg^{-1}) found in 10 parks from Galati city, Romania.

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Standard deviations, coefficient of variation, means, medians, maximum and minimum values were performed using Microsoft Excel 2019. In Table 5, are also presented the values for normal legal value (NLV), sensible alert threshold (SAT) the sensitive intervention threshold (SIT) according to the Romanian normative "Regulations regarding environmental pollution assessment" [Order no. 756/03.11.1997]. For parks and playgrounds the soil is considered to be for sensitive use, for the reason that children directly exposed to pollutants from soil can develop specific diseases or allergies. In order to investigate if the soils from the parks from Galati are enriched with heavy metals, also were presented the values of soil contaminants from Europe and world, but also from Galati city (Tables 5 and 6) [Adriano et al. 2001; Salminen et al. 2005; Ene et al. 2024 a, b].

The pH of the soil ranged from 6.49-7.61 units, with an average of 7.16 for the playground samples and 7.27 for the edge of park samples. The value of pH is important for the reason that the heavy metal mobility and retention is strongly dependent on lower values. Compared to [Ene et al. 2010], were the pH values ranged from 8.37-8.84, the pH values from this study are lower, and the amount of Fe presented a deficit. The lower value for Fe was also observed in other studies regarding urban soils from playgrounds [De Miguel et al. 2012]. The electrical conductivity of the park soil samples varied between 181 and 1349 μS cm^{-1}, with an average of 681.43 μS cm^{-1} for the playground samples and for the edge of the park the average was 568.25 μS cm^{-1}.

Tin (Sn) is a trace element essential for animal nutrition but has no known benefit in plant development. Under neutral pH conditions, it is immobile in soil. It is the 49th most abundant element in the Earth's crust, with a reported concentration of 2.5 mg kg^{-1} [Adriano et al. 2001]. In our study it was reported only at the 9 ES location, with a 7.2 mg kg^{-1}.

Antimony (Sb) is a potentially toxic element that is non-essential for plants, but at high concentrations, it can cause leaf chlorosis and necrosis. Due to the continuously increasing Sb concentrations released into the environment from various activities, such as mining, smelting, and burning fossil fuels, human health is also at risk. In high concentrations, it can interfere with developmental processes, immunity, reproductive systems, and may even contribute to the development of cancers. According to Tang et al. (2023), the accepted limit is 36 mg kg^{-1}, and what exceeds this limit becomes a problem for plants and organisms [Tang et al., 2023]. In our study, Sb had an average value of 0.51 mg kg^{-1}, with a minimum of 0.48 mg kg^{-1} found at PS 3 and PS 4, and a maximum of 0.54 mg kg^{-1} at ES 10. All values were below the normal limit of 5 mg kg^{-1} [Order no. 756/03.11.1997].

Zirconium (Zr) is the 20th most common element in the Earth's crust, with a naturally high abundance of 400 mg kg^{-1}. Its mobility in soil depends on pH and organic matter content. Typically, it is immobile and has no known biological functions in plants or animals. However, at high concentrations, it can cause phytotoxicity in plants and interfere with enzyme activity [Shahid et al., 2012]. In our case, the average Zr value was 307.85 mg kg^{-1}, with a maximum of 361 mg kg^{-1} found at ES 10, and a minimum of 245 mg kg^{-1} at PS 4. These values are comparable to those obtained in the industrial area [Ene et al. 2024 b].

Phosphorus (P) is an essential element for all life forms, and after N is the most important for crops purpose. Because usually forms strongly bounds with Ca, Fe and Al remains only a small part of P available for plants [Khan et al., 2018]. In this study, a minimum value of 0.033 g kg^{-1} was obtained at location 7 PS, and a maximum value of 3.01 g kg^{-1} at 3 ES. Compared to the European mean value of 1.5 g kg^{-1}, the average phosphorus value obtained in this study was lower.

Strontium (Sr) is an element that can be released into the environment, particularly after nuclear accidents. It is dangerous and important to study and monitor due to its long half-life of 28.8 years and its tendency to accumulate in bone tissue, especially in children [Jung et al., 2017]. In this study, the average Sr value was 94.05 mg kg^{-1}, which is lower than the European average for soil (130 mg kg^{-1}), the world average (250 mg kg^{-1}) and the industrial soil value of 117.6 mg kg^{-1}. However, for urban soils, where the average is 45 mg kg^{-1}, this study presented a higher value.

Chromium (Cr) presented a minimum value of 49 mg kg^{-1} and a maximum of 78 mg kg^{-1} for the playground samples (PS) and for the edge of the park (ES) it range from 50-75 mg kg^{-1}. Since the normal value (NV) for Cr is 30 mg/kg, all the measured values exceeded this limit (Figure 3).

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Compared to the European soil values for Cr, the concentrations obtained in this study are lower by approximately 20 mg kg^{-1}. However, they are slightly higher than the world average, by about 8 mg kg^{-1}. Comparing the obtained Cr values, they are lower than those reported in the literature for agricultural, industrial, and urban soils from Galati, Romania [Ene et al., 2024 a, b; Sion et al. 2023].

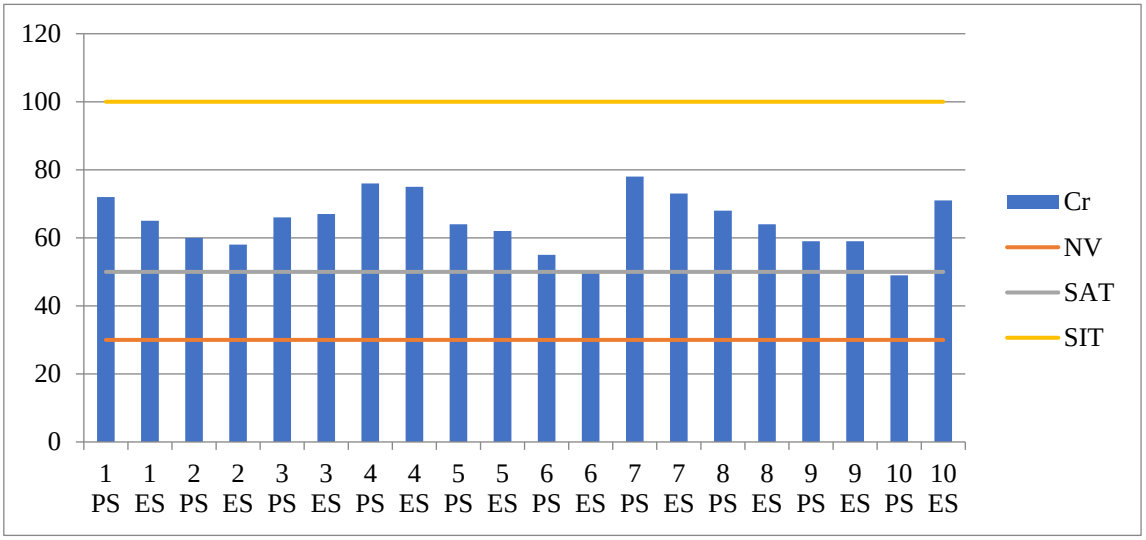

Figure 3. Cr concentrations (mg kg^{-1}) compared to the NV, SAT and SIT.

The Cr values, compared to those found in agricultural and industrial soils from Galați, Romania, reported in the literature [Ene et al., 2024a, b], are lower. Chromium concentrations in the agriculturally influenced soil are 104.7 mg kg^{-1} higher, while industrial soils contain 27.56 mg kg^{-1} more Cr. These values are also higher than those reported in previous studies by Ene et al. (2010; 2012) from Galați (81.72 mg kg^{-1}). The locations where were found the highest values where 4 and 7. Cr (III and VI) is associated high incidence of cancer formation and in case of direct contact, can cause dermatitis. It can be found in the composition of different alloys, bricks, glass, ceramic pigments and detergents, additive-enriched gasoline as well in fungicide and insecticides [Faciu (Chirila) et al. 2012; Apostoae et al. 2013; Javed et al. 2019].

Nickel presented a minimum value of 23 mg kg^{-1} and a maximum of 51 mg kg^{-1} for the PS and a for ES a minimum of 22 mg kg^{-1} and maximum of 57 mg kg^{-1}. These values are over the NV (20 mg kg^{-1}) but they don't reach SAT (75 mg kg^{-1}). Ni was found for the locations 1 (with the maximum value for PS) and 6 (with the maximum value for ES). The average values ranged between 35.5-40.3 mg kg^{-1} for PS and ES, and are comparable to the values obtained in other studies from Galati [Ene et al., 2024a, b], but lower than those reported by [Sion et al. 2023] in their urban study. The average values ranged between 35.5-40.3 mg kg^{-1} for PS and ES, and are comparable to Galati values obtained in other studies [Ene et al., 2024 a, b]. The average values compared to the average from Europe are higher but smaller than the average value from the world. Ni is not a very toxic pollutant, but it causes for at least 30 % from population allergies and for high concentrations can cause respiratory problems and even cancer. Ni can be found in fertilizers, alloys, batteries, fungicides etc. [Faciu (Chirila) et al. 2012; Apostoae et al. 2013].

Copper element presented a minimum value of 28 mg kg^{-1} and a maximum of 55 mg kg^{-1} for PS and for ES the minimum value is 25 mg kg^{-1} and the maximum 56 mg kg^{-1}. According to Romanian legislation the NV is 20 mg kg^{-1}, and in all locations the obtained concentrations where higher but the SAT value (100 mg kg^{-1}) was not over passed (Figure 4). The mean value for PS was 39.3 mg kg^{-1} and for ES 36.8 mg kg^{-1}, which were higher than those found in Galati for soils affected by industrial and agricultural activities [Ene et al., 2024a, b], but within the same range when compared to the Cu value of 36.60 mg kg^{-1} reported by [Sion et al. 2023].

The mean value for PS was 39.3 mg kg^{-1} and for ES 36.8 mg kg^{-1} that where higher than the ones found in Galati for soil affected by industrial and agricultural activities [Ene et al., 2024 a, b].

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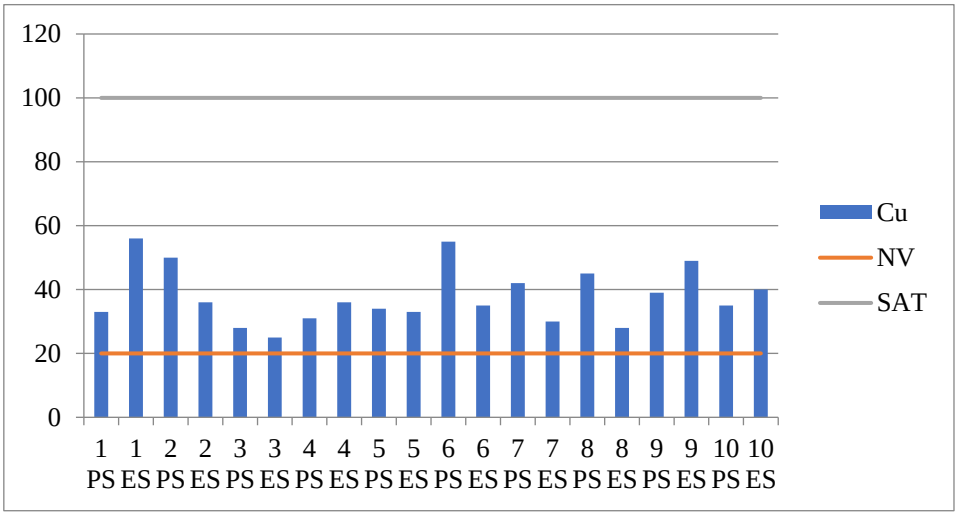

Figure 4. Cu concentrations (mg kg^{-1}) compared to the NV.

Compared to the European and world average value, the mean values found in the present study were higher. In this case, the maximum concentrations of Cu, were found on the 1st location. Cu sources near to an intense circulated road are the cars and other electric vehicles [Malizia et al. 2012]. Cu in high concentrations can cause anemia for children and can accumulate in the liver of adults leading to necrosis. Cu can be found in pipes, printed circuits, materials used for buildings in general, braking devices and radiators, [Faciu (Chirila) et al. 2012; Apostoae et al. 2013].

Zinc had a minimum value of 113.3 mg kg^{-1} and a maximum of 212.8 mg kg^{-1} for PS, and for the ES the minimum value was 105 mg kg^{-1} and the maximum 383.6 mg kg^{-1}. The maximum values are exceeding the NV for Zn equal to 100 mg kg^{-1} and in one case even the SAT value (300 mg kg^{-1}) for location 1 at the edge of the park (Figure 5).

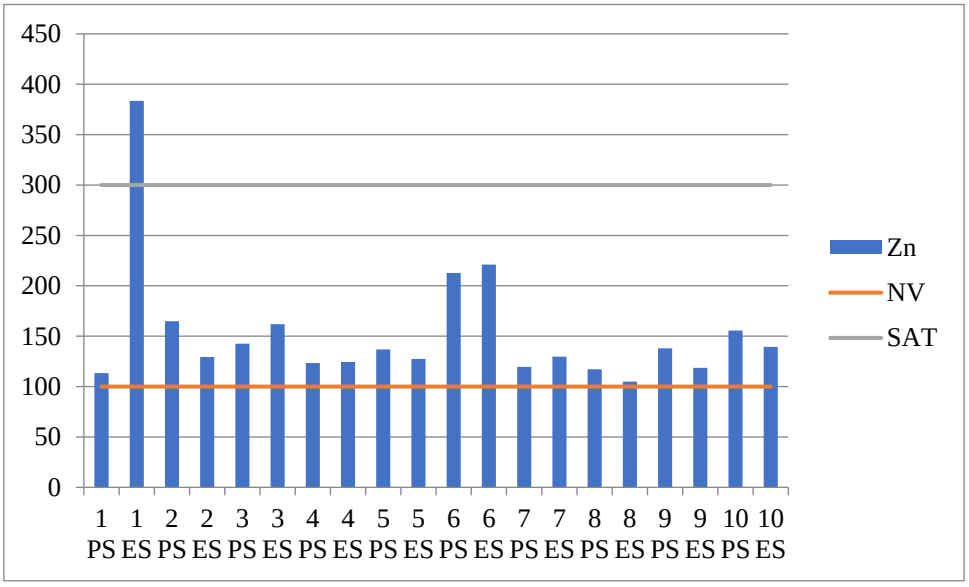

Figure 5. Zn concentrations (mg kg^{-1}) compared to the NV.

The average values 142.38 mg kg^{-1} for PS and 164.05 mg kg^{-1} for ES exceed the world and European average values. Comparing the average values obtained for Zn with the ones found in Galati for agricultural and industrial influenced soil, it can be concluded that in our case the Zn concentrations are higher [Ene et al., 2024 a, b; Sion et al. 2023]. The highest concentration of Zn (383.6 mg kg^{-1}) is found on the first location of the study. Zn can be found in oils, pneumatics and old car pieces, alloys, composition of brass and bronze. In normal concentration Zn is essential for the

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development of children but high concentrations can interfere with the calcium uptake [Faciu (Chirila) et al. 2012; Malizia et al. 2012].

For Arsenic, the minimum values for PS and ES where 4 mg kg^{-1} and 4.8 mg kg^{-1} and the maximum values, for the same locations, were 8 mg kg^{-1} and 8.4 mg kg^{-1}. The average values were higher than the other data reported in the literature, as presented in Table 5, except for the urban study by [Sion et al. 2023], where As had a concentration of 11.44 mg kg^{-1}.

In dermal contact can cause skin diseases, and high concentrations can lead to different types of cancer. It can be found in alloys and electronic components, as well in fertilizers, pesticide, herbicides or fire proof wood products [Faciu (Chirila) et al. 2012; Apostoae, 2016; Hiller et al. 2018].

Lead presented for PS a minimum concentration of 16 mg kg^{-1} and a maximum of 72 mg kg^{-1} and for the ES the values for minimum concentration was 21 mg kg^{-1} and for maximum 108 mg kg^{-1}. The maximum values are corresponding to the location 6 (PS) and 1 (ES). The average values of Pb exceed the NV, the European value and only the location ES is higher than the world value, as can be observed in Figure 6. Compared to the values found in Galati for Pb in this study, lower values were reported in other papers, with a difference of 25.53 and 7.05 mg kg^{-1} [Ene et al., 2024 a, b]. As a conclusion, in locations closer to the traffic, the concentrations of Pb are higher than those from inside the park.

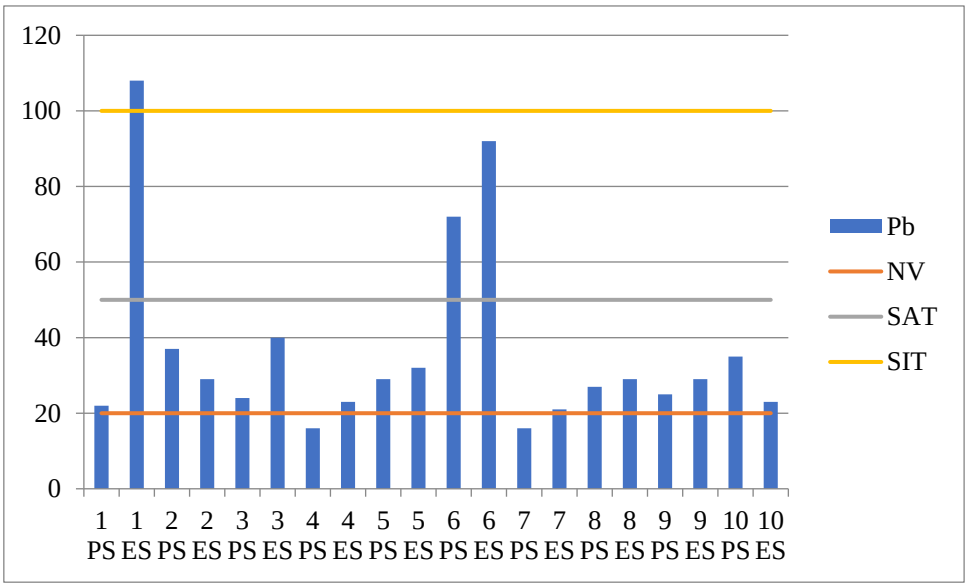

Figure 6. Pb concentrations (mg kg^{-1}) compared to the NV, SAT and SIT.

In the last 300 years de lead concentrations increased over 1000 times, especially in the time interval 1950-2000, mainly due to the lead fuels [Posta et al. 2015]. In the past, the main source of lead has been due to use of it as anti-detonating agent in fuels. At the end of 1998, with the Directive 98/70/EC European Union prohibits the use of leaded petrol [Maliza et al. 2012]. In Romania, the lead gasoline was forbidden from 2005.

In our days the maximum admitted Pb concentration in gasoline is 0.005g/l. But the high concentrations found in soil are reflecting the long use of Pb as additive in gasoline [Apostoae et al. 2013].

High levels of Pb in blood, especially for children smaller than 7 years, were associated with negative effects on intelligence and behavior. The most important sources of lead are: lead based paint, gasoline, soil/dust, industry, food and water [Button et al. 2008; Ottesen et al. 2008; Javed et al. 2019]. It is a well-known fact that high concentrations of Pb in soil can produce a disaster, such from Zamfara state where over 400 children reported dead in 2010 due to an illegal gold mining [Verla et al. 2019].

In USA, some studies revealed that lead affects the health of children under 7 years, from different sources such as: lead base paint (houses build before 1979, 12 million of children), old water

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pipes (before 1970), petrol (5.6 million of children) and dust-soil (5.9-11.7 million of children). In Romania, a study from WHO, presented that between years 1999-2000, children with age 1 to 9 had over 10 μg dl^{-1} geometric mean of lead in blood. But in 1980 the level of lead in blood was found to be between 18.2-18.9 μg dl^{-1} in Bulgaria, Hungary and Romania compared to Germany that had 7.4 μg dl^{-1}. This concentration is associated with a toxicity that involves a lower intelligence quotient (IQ), usually being reduced by 1-3 points. In addition, concentrations of 5.0 μg dl^{-1} may affect the neurobehavioral performances of children. Children are more exposed to lead toxicity due to the intake of lead per unit of body and young children often place dirty hands or toys in their mouths and inhale dust from the place where are playing [Button et al. 2008; WHO].

Mercury (Hg), a potential toxic element classified as a heavy metal, has an atomic weight of 200.59, an atomic number of 80, and a density of 13.534 g/cm^3. Hg is typically categorized into three chemical species: elemental mercury (Hg^0), inorganic mercury, primarily in the form of mercuric chloride ($HgCl_2$), and organic mercury, primarily methylmercury (MeHg), with a toxicity greater than of other organic Hg compounds [Khan et al., 2019; Counter and Buchanan, 2004].

It is a naturally occurring element, commonly found in the environment as a result of the Earth's crust degassing, releasing nearly 10,000 tons annually. Human activities have doubled its concentration, and emissions are predicted to increase by 5% each year [Khan et al., 2019]. The Earth's upper crust contains approximately 0.05 ppm of Hg, the middle crust has about 0.0079 ppm, and the lower crust contains 0.014 ppm [Beckers and Rinklebe, 2017].

Elemental Hg vapor is present in the atmosphere, where it can be retained and transported over long distances. It has a residence time of 0.5 to 1.5 years, while other oxidized species have much shorter lifetimes, lasting only hours or days, leading to rapid deposition and localized impacts. In soil, water, and sediments, mercury is primarily found in its inorganic form, Hg (II), while in biota, the dominant form is (mono)methylmercury (MeHg; CH^3Hg^+) [Fthenakis et al, 1995; Nakazawa et al, 2016].

Natural sources of Hg include volcanic activity, weathering of mercury-containing ores, vegetation fires, and evaporation from soils and water, particularly from ocean water, which contributes approximately 2.68×10^6 tons of Hg per year [Li and Tse, 2015; Fthenakis et al, 1995; Sahakyan et al, 2019].

Anthropogenic sources are responsible for two-thirds of the total release of Hg. The primary human-related sources include coal combustion, municipal solid waste incineration, various thermochemical conversion processes, pharmaceutical industries, medical compounds, dentistry, scientific instruments, the paint and paper industry, ceramic and cement production, pesticides, antiseptics, artisanal small-scale gold mining where Hg is used in refining gold and silver, mercury mining, and the chlor-alkali industry [Li and Tse, 2015; Lonati et al, 2013; Sahakyan et al, 2019; Khan et al., 2019; Nakazawa et al, 2016; Jiang et al, 2021].

Over the past decades, growing awareness of mercury's harmful effects has led to various regulatory measures. One significant initiative is the Minamata Convention on Mercury, held in Geneva, Switzerland, on January 19, 2013. This convention required the development of strategies to identify and assess Hg-contaminated sites to protect human health and the environment from the adverse effects of mercury [Jiang et al, 2021; https://www.unep.org/resources/report/minamata-convention-mercury].

Mercury holds a unique and significant place among environmental pollutants, as its severe health effects have been clearly demonstrated in several tragic poisoning incidents. Notably, in Japan in 1953, an epidemic of mercury poisoning occurred in villages around Minamata Bay due to the consumption of contaminated fish. A similar incident took place along the Agano River in Niigata, Japan, between 1964 and 1965, and in rural Iraq from 1971 to 1972, where mercury-based fungicide-treated grain led to widespread poisoning [Fthenakis et al, 1995]. Fish consumption is considered the primary pathway for exposure to methylmercury (MeHg). According to the United States Environmental Protection Agency (USEPA), mercury ranks among the top three most potent toxic agents that can occur naturally or be introduced through various human activities. The World Health Organization (WHO) designates mercury as one of the ten most dangerous substances to public

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health. In conclusion, mercury can exist in toxic forms as organic, inorganic, and metallic compounds, each with distinct properties related to solubility, volatility, mobility, toxicity, and bioavailability. Due to its high volatility, elemental mercury from soil can enter the atmosphere, posing significant environmental threats. Mercury is a highly mobile pollutant, toxic to humans and wildlife even at extremely low concentrations [Khan et al., 2019; Fthenakis et al, 1995; Jiang et al, 2021; Lonati et al, 2013].

For PS (Figure 7), the minimum concentration of Hg was 0.8 mg kg^{-1} (observed at locations 9), while the maximum concentration was 1.2 mg/kg (observed at locations 5). Hg presented for ES a minimum concentration of 0.9 mg kg^{-1} for location 6 and a maximum of 1.1 mg kg^{-1} for location 5 and 7. All Hg values exceeded the normal value (NV) specified in Romanian legislation, and at PS locations 2, 3, 4, 5, 6, 7, and 10, as well as ES locations 4, 5, 7, 8, 9, and 10, the SIT limit was also exceeded.

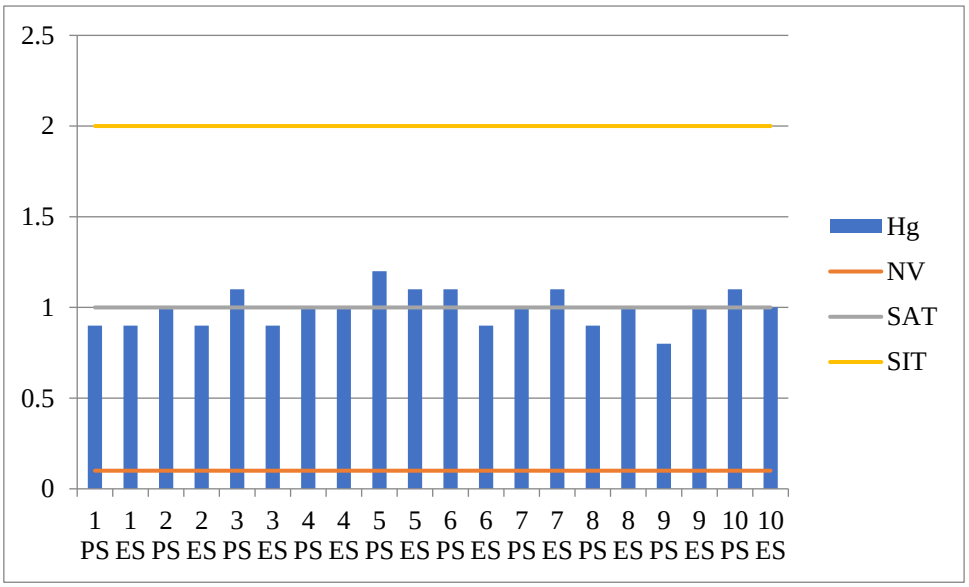

Figure 7. Hg concentrations (mg kg^{-1}) compared to the NV, SAT and SIT.

3.2. Results of Pollution Indices of Soil Contamination and Potential Human Health Risk Assessment

Coefficient of Variation

The values of the coefficient of variation (CV), presented in Tables 5 and 6, regarding the heavy metal concentrations are found to be within (0.09-0.29), usually with higher values obtained for the edge of the parks. A high CV value can suggest an anthropogenic input [Apostoae and Iancu, 2014; Apostoae et al. 2013]. In particularly, for ES, the values of CV for Ni (0.65), Cu (0.50), Zn (0.86) and Pb (0.73) are indicating a supplementary contribution due to the traffic secondary effects. Based on the CV values, the soil can be divided into soils that are affected by anthropogenic activity and soils that are not affected by anthropogenic activity.

Correlation Coefficients

The Pearson correlation coefficients, presented in Table 7, indicate a significant strong association (>0.50) between Rb-Ba-V; Cu-Pb-Co-Zn-Sc; Pb-As-Co-Zn-Sc; As-Zn-Sc-Hg; Co-Zn-Sc; Ni-Sc-V; Mn-Sc; Zr-Sc-Hg-Ba-Ag; Hg-Sb-Cd and Ba-Cd for the playground samples. Regarding the edge of the park samples Rb-Cr-V-Ba; Cu-Zn-Zr; Pb-As-Zn-Ba-Cd; As-Co-Ni-Cd; Cr-V; Ni-Mn-Cd; Mn-Hg; Zn-Ba; Zr-Sb and Sb-Ba. The correlations among the metals suggest a common source [Apostoae and Iancu, 2014] or similar behavior in environment.

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Table 7. Pearson's correlation matrix for the heavy metal concentrations in soils divided by the a) playground sample (PS) and b) edge sample (ES).

a)

	Sr	Rb	Cu	Pb	As	Co	Cr	Ni	Mn	Zn	Sc	Zr	Hg	V	Sb	Ba	Cd	Ag
Sr	1																	
Rb	-0.72	1.00																
Cu	0.20	0.03	1.00															
Pb	0.27	-0.26	0.71	1.00														
As	0.18	-0.26	0.32	0.67	1.00													
Co	-0.07	0.21	0.65	0.58	0.27	1.00												
Cr	-0.39	0.45	-0.32	-0.68	-0.20	-0.06	1.00											
Ni	-0.27	-0.08	-0.48	-0.42	-0.21	-0.25	0.22	1.00										
Mn	-0.44	0.26	-0.49	-0.43	-0.41	-0.36	0.26	0.32	1.00									
Zn	0.24	-0.30	0.62	0.94	0.56	0.59	-0.72	-0.22	-0.24	1.00								
Sc	-1.00	-1.00	1.00	1.00	1.00	1.00	1.00	1.00	-1.00	1.00	1.00							
Zr	-0.11	0.12	0.15	0.07	0.04	-0.44	-0.34	-0.15	-0.28	-0.10	-1.00	1.00						
Hg	-0.43	0.00	-0.10	0.34	0.53	0.10	-0.25	-0.01	0.21	0.42	1.00	-0.01	1.00					
V	-0.70	0.93	-0.20	-0.50	-0.48	0.13	0.53	0.09	0.26	-0.49		0.00	-0.11	1.00				
Sb	0.06	0.10	0.34	0.20	-0.20	-0.27	-0.41	-0.09	0.13	0.15	-1.00	0.63	-0.29	-0.09	1.00			
Ba	-0.62	0.84	0.00	-0.28	-0.27	0.24	0.32	-0.15	0.24	-0.22	1.00	-0.01	0.22	0.83	-0.17	1.00		
Cd	0.14	-0.19	-0.06	0.35	0.12	-0.39	-0.64	-0.40	0.01	0.22	-1.00	0.58	0.20	-0.32	0.54	-0.31	1.00	
Ag	-0.02	-0.20	0.09	0.33	0.33	0.17	0.05	-0.35	-0.25	0.11	1.00	-0.03	0.11	-0.27	-0.14	-0.45	0.34	1

b)

	Sr	Rb	Cu	Pb	As	Co	Cr	Ni	Mn	Zn	Sc	Zr	Hg	V	Sb	Ba	Cd	Ag
Sr	1.00																	
Rb	-0.70	1.00																
Cu	0.16	0.23	1.00															
Pb	-0.02	0.28	0.49	1.00														
As	0.30	-0.23	-0.30	0.57	1.00													
Co	0.31	-0.33	-0.32	0.12	0.52	1.00												

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Cr	-0.76	0.50	-0.13	-0.48	-0.75	-0.44	1.00											
Ni	-0.03	0.25	-0.39	0.16	0.56	0.13	-0.22	1.00										
Mn	-0.52	0.13	-0.60	-0.30	0.05	-0.02	0.35	0.53	1.00									
Zn	-0.21	0.41	0.62	0.92	0.27	-0.09	-0.17	-0.10	-0.38	1.00								
Sc											1.00							
Zr	-0.19	0.11	0.51	0.22	-0.27	-0.35	0.16	-0.30	0.11	0.38		1.00						
Hg	-0.18	0.20	-0.23	-0.60	-0.40	-0.62	0.44	0.32	0.50	-0.52		0.17	1.00					
V	-0.63	0.77	0.08	0.01	-0.41	-0.05	0.70	0.02	0.09	0.22		0.07	0.03	1.00				
Sb	-0.13	0.02	0.19	-0.11	-0.25	-0.01	0.12	-0.22	0.28	-0.02		0.77	0.27	-0.03	1.00			
Ba	-0.61	0.86	0.35	0.54	-0.04	-0.06	0.32	0.05	-0.05	0.70		0.30	-0.16	0.70	0.21	1.00		
Cd	0.19	0.18	0.09	0.59	0.66	0.26	-0.51	0.78	0.12	0.36		-0.10	-0.08	-0.08	-0.14	0.23	1.00	
Ag	-0.67	0.41	0.10	0.30	-0.10	-0.26	0.37	0.11	0.34	0.35		0.02	-0.13	0.32	-0.28	0.30	0.11	1

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The Integrated Pollution Index (IPI)

The results for the integrated pollution index presented in Table 8, enclosed into the high level of pollution the locations 1 ES, 2 PS, 5 PS, 6 PS and 6 ES, the rest of locations presenting an average level of pollution. The obtained values for IPI ranged between 12 and 0.07, with an average of PS equal to 1.93 and for ES equal to 1.94. The average value ordered descending the locations from the most polluted to the least polluted place: 6>1>5>7>4>10>2=3>8>9 [Gagiu et al. 2015].

The Geo-Accumulation Index (Igeo)

As shown in Table 9, the Igeo values estimated the pollution of the soil as moderate polluted for the majority of the samples and elements. The values ranged from -3.84 to 3.58 for all the locations and heavy metals. The maximum value for Igeo is found for Hg in the 5 PS location, at the playground area of the park, closed to a road with an intense vehicular traffic.

Table 8. The integrated pollution index (IPI) values.

Element	1		2		3		4		5		6		7		8		9		10	
	PS	ES	PS	ES	PS	ES	PS	ES	PS	ES	PS	ES	PS	ES	PS	ES	PS	ES	PS	ES
Cu	1.65	2.80	2.50	1.80	1.40	1.25	1.55	1.80	1.70	1.65	2.75	1.75	2.10	1.50	2.25	1.40	1.95	2.45	1.75	2.00
Pb	1.10	5.40	1.85	1.45	1.20	2.00	0.80	1.15	1.45	1.60	3.60	4.60	0.80	1.05	1.35	1.45	1.25	1.45	1.75	1.15
As	1.12	1.14	1.00	1.20	1.26	1.28	0.80	0.90	1.38	1.26	1.60	1.68	1.00	1.06	1.04	1.20	0.90	0.96	0.86	0.90
Co	0.16	0.17	0.23	0.25	0.15	0.22	0.23	0.20	0.17	0.16	0.25	0.26	0.17	0.19	0.18	0.19	0.17	0.18	0.15	0.21
Cr	2.40	2.17	2.00	1.93	2.20	2.23	2.53	2.50	2.13	2.07	1.83	1.67	2.60	2.43	2.27	2.13	1.97	1.97	1.63	2.37
Ni	2.55	2.17	2.00	1.10	2.40	1.55	2.05	2.10	1.95	2.40	1.50	2.85	2.15	2.10	1.15	1.70	2.05	1.40	1.95	1.25
Mn	0.80	0.73	0.78	0.71	0.87	0.82	0.89	0.81	0.81	0.82	0.80	0.84	0.93	0.86	0.77	0.85	0.83	0.76	0.90	0.86
Zn	1.13	3.84	1.65	1.29	1.43	1.62	1.23	1.24	1.37	1.28	2.13	2.21	1.20	1.30	1.17	1.05	1.38	1.19	1.56	1.39
Hg	9.00	9.00	10.00	9.00	11.00	9.00	10.00	10.00	12.00	11.00	11.00	9.00	10.00	11.00	9.00	10.00	8.00	10.00	11.00	10.00
V	1.70	1.84	1.64	1.66	1.22	1.64	2.12	2.08	1.86	1.58	1.40	1.62	1.86	1.80	1.58	1.60	1.64	1.46	1.58	1.78
Sb	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.10	0.10	0.10	0.10	0.11	0.11
Ba	1.65	2.61	2.17	1.93	1.58	1.87	2.56	2.24	2.58	1.75	1.85	2.16	2.41	2.39	2.04	1.89	2.00	1.72	2.00	2.01
Cd	0.15	0.14	0.07	0.10	0.12	0.12	0.09	0.13	0.15	0.16	0.17	0.23	0.10	0.14	0.16	0.08	0.14	0.13	0.25	0.10
Ag	1.75	1.80	1.65	1.40	1.70	1.85	1.70	1.80	1.65	1.60	1.75	1.70	1.65	1.65	1.75	1.70	1.60	1.70	1.70	1.70

Table 9. The geo-accumulation index (Igeo) values.

Element	1		2		3		4		5		6		7		8		9		10	
	PS	ES	PS	ES	PS	ES	PS	ES	PS	ES	PS	ES	PS	ES	PS	ES	PS	ES	PS	ES
Cu	0.72	1.49	1.32	0.85	0.49	0.32	0.63	0.85	0.77	0.72	1.46	0.81	1.07	0.58	1.17	0.49	0.96	1.29	0.81	1.00
Pb	0.14	2.43	0.89	0.54	0.26	1.00	-0.32	0.20	0.54	0.68	1.85	2.20	-0.32	0.07	0.43	0.54	0.32	0.54	0.81	0.20
As	0.16	0.19	0.00	0.26	0.33	0.36	-.032	-0.15	0.46	0.33	0.68	0.75	0.00	0.08	0.06	0.26	-0.15	-0.06	-0.22	-0.15
Co	-2.64	-2.58	-2.10	-2.02	-2.71	-2.18	-2.14	-2.32	-2.53	-2.64	-1.98	-1.94	-2.58	-2.42	-2.47	-2.42	-2.58	-2.47	-2.77	-2.27
Cr	1.26	1.12	1.00	0.95	1.14	1.16	1.34	1.32	1.09	1.05	0.87	0.74	1.38	1.28	1.18	1.09	0.98	0.98	0.71	1.24
Ni	1.35	0.32	1.26	0.14	1.26	0.63	1.04	1.07	0.96	1.26	0.58	1.51	1.10	1.07	0.20	0.77	1.04	0.49	0.96	0.32
Mn	-0.31	-0.45	-0.35	-0.49	-0.19	-0.28	-0.16	-0.30	-0.30	-0.29	-0.33	-0.26	-0.10	-0.21	-0.38	-0.24	-0.28	-0.39	-0.15	-0.22
Zn	0.18	1.94	0.72	0.37	0.51	0.70	0.30	0.31	0.45	0.35	1.09	1.14	0.26	0.38	0.23	0.07	0.46	0.25	0.64	0.48
Hg	3.17	3.17	3.32	3.17	3.46	3.17	3.32	3.32	3.58	3.46	3.46	3.17	3.32	3.46	3.17	3.32	3.00	3.32	3.46	3.32
V	0.77	0.88	0.71	0.73	0.29	0.71	1.08	1.06	0.90	0.66	0.49	0.70	0.90	0.85	0.66	0.68	0.71	0.55	0.66	0.83
Sb	-3.29	-3.29	-3.32	-3.29	-3.38	-3.35	-3.38	-3.35	-3.35	-3.32	-3.29	-3.29	-3.27	-3.24	-3.23	-3.29	-3.27	-3.29	-3.24	-3.21
Ba	0.72	1.38	1.12	0.95	0.66	0.90	1.36	1.16	1.36	0.80	0.89	1.11	1.27	1.25	1.03	0.92	1.00	0.78	1.00	1.01
Cd	-2.74	-2.84	-3.84	-3.32	-3.06	-3.06	-3.47	-2.94	-2.74	-2.64	-2.56	-2.12	-3.32	-2.84	-2.64	-3.64	-2.84	-2.94	-2.00	-3.32
Ag	0.81	0.85	0.72	0.49	0.77	0.89	0.77	0.85	0.72	0.68	0.81	0.77	0.72	0.72	0.81	0.77	0.68	0.77	0.77	0.77

At this location, the value is 3.58, result that indicates that soil is moderate to strongly pollute with Hg. The average for all the positive values per location the values indicated in order location 6 > 4 > 1 > 10 > 5 > 7 > 9 > 2 > 3 > 8. The average for all the positive values for heavy metals on the

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playground samples was in the order: Hg > Cr > Ba > Ni > Cu > V > Pb > Zn > As and for the edge of the park near to the important roads is: Hg > Cr > Ba > Cu = Pb > Ni = V > Zn > As. The *Igeo* value indicated that the playground samples where moderate polluted with Cr and Ba and Hg that presented a moderate to strongly pollution case. While for Co, Mn, Sb and Cd had only negative values, concluding that practically the park soil was unpolluted with those metals. Based on the obtained values for the mean value of *Igeo*, the pollution is moderate [Apostoae et al. 2013; Apostoae and Iancu, 2014; Laha et al. 2023].

The Enrichment Coefficient (EC)

The values for EC, also found as contamination factor, presented in Table 10, are the majority over 1, indicating that the source of heavy metals is external from traffic or industry.

Table 10. The enrichment coefficient (EC) values.

Element	1		2		3		4		5		6		7		8		9		10	
	PS	ES	PS	ES	PS	ES	PS	ES	PS	ES	PS	ES	PS	ES	PS	ES	PS	ES	PS	ES
Cu	1.91	3.24	2.89	2.08	1.62	1.45	1.79	2.08	1.97	1.91	3.18	2.02	2.43	1.73	2.60	1.62	2.25	2.83	2.02	2.31
Pb	0.67	3.31	1.13	0.89	0.74	1.23	0.49	0.71	0.89	0.98	2.21	2.82	0.49	0.64	0.83	0.89	0.77	0.89	1.07	0.71
As	0.48	0.49	0.43	0.52	0.54	0.55	0.34	0.39	0.59	0.54	0.69	0.72	0.43	0.46	0.45	0.52	0.39	0.41	0.37	0.39
Co	0.23	0.24	0.34	0.36	0.22	0.32	0.33	0.29	0.25	0.23	0.37	0.38	0.24	0.27	0.26	0.27	0.24	0.26	0.21	0.30
Cr	0.76	0.69	0.63	0.61	0.70	0.71	0.80	0.79	0.68	0.65	0.58	0.53	0.82	0.77	0.72	0.68	0.62	0.62	0.52	0.75
Ni	1.37	0.67	1.29	0.59	1.29	0.83	1.10	1.13	1.05	1.29	0.80	1.53	1.15	1.13	0.62	0.91	1.10	0.75	1.05	0.67
Mn	0.89	0.81	0.87	0.79	0.97	0.92	0.99	0.90	0.90	0.91	0.88	0.93	1.03	0.96	0.85	0.94	0.92	0.85	1.00	0.95
Zn	1.66	5.63	2.42	1.90	2.09	2.38	1.81	1.83	2.01	1.87	3.12	3.25	1.76	1.90	1.72	1.54	2.02	1.74	2.28	2.05
Hg	14.75	14.75	16.39	14.75	18.03	14.75	16.39	16.39	19.67	18.03	18.03	14.75	16.39	18.03	14.75	16.39	13.11	16.39	18.03	16.39
V	1.25	1.35	1.20	1.22	0.90	1.20	1.56	1.53	1.37	1.16	1.03	1.19	1.37	1.32	1.16	1.17	1.20	1.07	1.16	1.31
Sb	0.49	0.49	0.48	0.49	0.46	0.47	0.47	0.48	0.49	0.49	0.50	0.51	0.48	0.49	0.50	0.49	0.50	0.49	0.51	0.52
Ba	0.83	1.30	1.09	0.97	0.79	0.94	1.28	1.12	1.29	0.87	0.93	1.08	1.21	1.19	1.02	0.95	1.00	0.86	1.00	1.01
Cd	0.54	0.50	0.25	0.36	0.43	0.43	0.32	0.46	0.54	0.57	0.61	0.82	0.36	0.50	0.57	0.29	0.50	0.46	0.89	0.36
Ag	11.51	11.84	10.86	9.21	11.18	12.17	11.18	11.84	10.86	10.53	11.51	11.18	10.86	10.86	11.51	11.18	10.53	11.18	11.18	11.18

For Ag and Hg there were calculated the highest values of EC: 16.31, 11.12 and 2.25 indicating a very high level of pollution. An average of the values of EC indicated that the order of locations is: 6 > 1 = 5 > 10 > 7 > 4 > 3 > 8 > 2 > 9. For locations 1, 4, 7, 8 and 9 the values of EC from the edge of the park are higher than the values from the sample collected from the playground [Javed et al. 2019; Laha et al. 2023].

Potential Health Risk Assessment

The resulting values presented in Tables 11 and 12 for indices that are expressing the risk of carcinogenic effects of the heavy metals that are found in the soil from parks on the health of a 6 years old children, for this study are very low. In conclusion all the investigated places are safe from threat of non-carcinogenic effects.

Table 11. Estimate daily intake for ingestion, dermal contact and inhalation of heavy metals found in 10 parks from Galati, Romania.

Site	Element	Pathways							
		EDI Ingestion E-4		EDI Dermal E-6		EDI Inhalation E-9		EDI Vaporization E-3	
		PS	ES	PS	ES	PS	ES	PS	ES
1	**Sr**	10.74	9.72	3.01	2.72	30.01	27.15	-	-
	Rb	9.33	11.12	2.61	3.11	26.8	31.08	-	-
	Cu	4.22	7.16	1.18	2.00	11.79	20.01	-	-
	Pb	2.81	13.81	0.79	3.87	7.86	38.58	-	-
	As	0.72	0.73	0.20	0.20	2.00	2.04	-	-

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	Ni	6.52	3.20	1.83	0.89	18.22	8.93	-	-
	Zn	14.49	49.04	4.06	13.73	40.48	137.04	-	-
	Zr	41.81	43.85	11.71	12.28	116.82	122.53	-	-
	V	10.87	11.76	3.04	3.29	30.37	32.87	-	-
	Cd	0.019	0.018	0.01	0.01	0.05	0.05	-	-
	Ag	0.45	0.46	0.13	0.13	1.25	1.29	-	-
	Hg	0.12	0.12	0.03	0.03	0.32	0.32	0.35	0.35
2	**Sr**	11.25	17.26	3.15	4.83	31.44	48.23	-	-
	Rb	8.82	8.69	2.47	2.43	24.65	24.29	-	-
	Cu	6.39	4.60	1.79	1.29	17.86	12.86	-	-
	Pb	4.73	3.71	1.32	1.04	13.22	10.36	-	-
	As	0.64	0.77	0.18	0.21	1.79	2.14	-	-
	Ni	6.14	2.81	1.72	0.79	17.15	7.86	-	-
	Zn	21.07	16.54	5.90	4.63	58.87	46.23	-	-
	Zr	38.48	38.10	10.78	10.67	107.53	106.46	-	-
	V	10.48	10.61	2.94	2.97	29.29	29.65	-	-
	Cd	0.009	0.013	0	0	0.03	0.04	-	-
	Ag	0.42	0.36	0.12	0.10	1.18	1.00	-	-
	Hg	0.13	0.12	0.04	0.03	0.36	0.32	0.39	0.35
3	**Sr**	14.83	10.36	4.15	2.90	41.44	28.94	-	-
	Rb	6.52	8.82	1.83	2.47	18.22	24.65	-	-
	Cu	3.58	3.20	1.00	0.89	10.00	8.93	-	-
	Pb	3.07	5.11	0.86	1.43	8.57	14.29	-	-
	As	0.81	0.82	0.23	0.23	2.25	2.29	-	-
	Ni	6.14	3.96	1.72	1.11	17.15	11.07	-	-
	Zn	18.22	20.70	5.10	5.80	50.91	57.84	-	-
	Zr	33.24	36.69	9.31	10.27	92.88	102.53	-	-
	V	7.80	10.48	2.18	2.94	21.79	29.29	-	-
	Cd	0.015	0.015	0	0	0.04	0.04	-	-
	Ag	0.43	0.47	0.12	0.13	1.21	1.32	-	-
	Hg	0.14	0.12	0.04	0.03	0.39	0.32	0.43	0.35
4	**Sr**	8.69	9.59	2.43	2.68	24.29	26.79	-	-
	Rb	11.12	11.25	3.11	3.15	31.08	31.44	-	-
	Cu	3.96	4.60	1.11	1.29	11.07	12.86	-	-
	Pb	2.05	2.94	0.57	0.82	5.72	8.22	-	-
	As	0.51	0.58	0.14	0.16	1.43	1.61	-	-
	Ni	5.24	5.37	1.47	1.50	14.65	15.00	-	-
	Zn	15.76	15.91	4.41	4.45	44.05	44.44	-	-
	Zr	31.32	36.69	8.77	10.27	87.52	102.53	-	-
	V	13.55	13.30	3.79	3.72	37.87	37.15	-	-
	Cd	0.012	0.017	0.00	0.00	0.03	0.05	-	-
	Ag	0.43	0.46	0.12	0.13	1.21	1.29	-	-
	Hg	0.13	0.13	0.04	0.04	0.36	0.36	0.39	0.39
5	**Sr**	9.46	15.09	2.65	4.22	26.44	42.15	-	-
	Rb	10.48	9.21	2.94	2.58	29.29	25.72	-	-
	Cu	4.35	4.22	1.22	1.18	12.15	11.79	-	-
	Pb	3.71	4.09	1.04	1.15	10.36	11.43	-	-
	As	0.88	0.81	0.25	0.23	2.46	2.25	-	-
	Ni	4.99	6.14	1.40	1.72	13.93	17.15	-	-
	Zn	17.50	16.30	4.90	4.56	48.91	45.55	-	-
	Zr	42.70	40.53	11.96	11.35	119.32	113.24	-	-
	V	11.89	10.10	3.33	2.83	33.22	28.22	-	-
	Cd	0.019	0.020	0.01	0.01	0.05	0.06	-	-
	Ag	0.42	0.41	0.12	0.11	1.18	1.14	-	-

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	Hg	0.15	0.14	0.04	0.04	0.43	0.39	0.47	0.43
6	**Sr**	13.68	14.19	3.83	3.97	38.22	39.65	-	-
	Rb	8.95	9.72	2.51	2.72	25.01	27.15	-	-
	Cu	7.03	4.47	1.97	1.25	19.65	12.50	-	-
	Pb	9.21	11.76	2.58	3.29	25.72	32.87	-	-
	As	1.02	1.07	0.29	0.30	2.86	3.00	-	-
	Ni	3.84	7.29	1.07	2.04	10.72	20.36	-	-
	Zn	27.21	28.26	7.62	7.91	76.02	78.95	-	-
	Zr	36.95	39.00	10.35	10.92	103.24	108.96	-	-
	V	8.95	10.36	2.51	2.90	25.01	28.94	-	-
	Cd	0.022	0.029	0.01	0.01	0.06	0.08	-	-
	Ag	0.45	0.43	0.13	0.12	1.25	1.21	-	-
	Hg	0.14	0.12	0.04	0.03	0.39	0.32	0.43	0.35
7	**Sr**	8.57	8.18	2.40	2.29	23.93	22.86	-	-
	Rb	11.00	11.00	3.08	3.08	30.72	30.72	-	-
	Cu	5.37	3.84	1.50	1.07	15.00	10.72	-	-
	Pb	2.05	2.68	0.57	0.75	5.72	7.50	-	-
	As	0.64	0.68	0.18	0.19	1.79	1.89	-	-
	Ni	5.50	5.37	1.54	1.50	15.36	15.00	-	-
	Zn	15.29	16.58	4.28	4.64	42.73	46.33	-	-
	Zr	39.25	40.53	10.99	11.35	109.67	113.24	-	-
	V	11.89	11.51	3.33	3.22	33.22	32.15	-	-
	Cd	0.013	0.018	0.00	0.01	0.04	0.05	-	-
	Ag	0.42	0.42	0.12	0.12	1.18	1.18	-	-
	Hg	0.13	0.14	0.04	0.04	0.36	0.39	0.39	0.43
8	**Sr**	14.45	10.23	4.05	2.86	40.37	28.58	-	-
	Rb	8.82	9.72	2.47	2.72	24.65	27.15	-	-
	Cu	5.75	3.58	1.61	1.00	16.08	10.00	-	-
	Pb	3.45	3.71	0.97	1.04	9.65	10.36	-	-
	As	0.66	0.77	0.19	0.21	1.86	2.14	-	-
	Ni	2.94	4.35	0.82	1.22	8.22	12.15	-	-
	Zn	14.97	13.42	4.19	3.76	41.83	37.51	-	-
	Zr	40.91	39.51	11.46	11.06	114.32	110.39	-	-
	V	10.10	10.23	2.83	2.86	28.22	28.58	-	-
	Cd	0.020	0.010	0.01	0.00	0.06	0.03	-	-
	Ag	0.45	0.43	0.13	0.12	1.25	1.21	-	-
	Hg	0.12	0.13	0.03	0.04	0.32	0.36	0.35	0.39
9	**Sr**	17.00	15.85	4.76	4.44	47.51	44.30	-	-
	Rb	8.95	8.95	2.51	2.51	25.01	25.01	-	-
	Cu	4.99	6.26	1.40	1.75	13.93	17.50	-	-
	Pb	3.20	3.71	0.89	1.04	8.93	10.36	-	-
	As	0.58	0.61	0.16	0.17	1.61	1.71	-	-
	Ni	5.24	3.58	1.47	1.00	14.65	10.00	-	-
	Zn	17.63	15.16	4.94	4.25	49.26	42.37	-	-
	Zr	38.87	39.38	10.88	11.03	108.60	110.03	-	-
	V	10.48	9.33	2.94	2.61	29.29	26.08	-	-
	Cd	0.018	0.017	0.01	0.00	0.05	0.05	-	-
	Ag	0.41	0.43	0.11	0.12	1.14	1.21	-	-
	Hg	0.10	0.13	0.03	0.04	0.29	0.36	0.31	0.39
10	**Sr**	10.36	11.00	2.90	3.08	28.94	30.72	-	-
	Rb	8.95	9.21	2.51	2.58	25.01	25.72	-	-
	Cu	4.47	5.11	1.25	1.43	12.50	14.29	-	-
	Pb	4.47	2.94	1.25	0.82	12.50	8.22	-	-
	As	0.55	0.58	0.15	0.16	1.54	1.61	-	-

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	Ni	4.99	3.20	1.40	0.89	13.93	8.93	-	-
	Zn	19.89	17.82	5.57	4.99	55.59	49.80	-	-
	Zr	43.21	46.16	12.10	12.92	120.75	128.96	-	-
	V	10.10	11.38	2.83	3.19	28.22	31.79	-	-
	Cd	0.032	0.013	0.01	0.00	0.09	0.04	-	-
	Ag	0.43	0.43	0.12	0.12	1.21	1.21	-	-
	Hg	0.14	0.13	0.04	0.04	0.39	0.36	0.43	0.39

Table 12. Hazard quotient for ingestion, dermal contact, inhalation and vaporization, and the hazard index of heavy metals found in 10 parks from Galati, Romania.

Site	**Element**	**Pathway**								**HI**	
		HQ Ingestion		**HQ Dermal**		**HQ Inhalation**		**HQ Vaporization**			
		PS	**ES**	**PS**	**ES**	**PS**	**ES**	**PS**	**ES**	**PS**	**ES**
1	**Cu**	105.48 E-4	179 E-4	0.30 E-4	0.50 E-4	9.82 E-7	16.67 E-7	-	-	105.78 E-4	179.51 E-4
	Pb	80.37 E-3	394.52 E-3	0.80 E-3	0.96 E-3	4.97 E-6	5.92 E-6	-	-	80.61 E-3	395.72 E-3
	As	23.87 E-2	24.29 E-2	0.07 E-2	0.07 E-2	1.63 E-5	1.66 E-5	-	-	23.93 E-2	24.36 E-2
	Ni	326.03 E-4	159.82 E-4	0.89 E-4	0.43 E-4	3.37 E-6	1.65 E-6	-	-	326.95 E-4	160.27 E-4
	Zn	482.86 E-5	1634.82 E-5	1.35 E-5	4.58 E-5	6.75 E-7	22.84 E-7	-	-	484.28 E-5	1639.63 E-5
	Cd	1.91 E-3	1.79 E-3	5.40 E-6	5.00 E-6	0.11 E-5	0.10 E-5	-	-	1.92 E-3	1.79 E-3
	Hg	3.84 E-2	3.84 E-2	3.76 E-4	3.76 E-4	0.15 E-4	0.15 E-4	4.02 E-5	4.02 E-5	3.87 E-2	3.99 E-2
2	**Cu**	159.82 E-4	115.07 E-4	0.45 E-4	0.32 E-4	14.88 E-7	10.72 E-7	-	-	160.28 E-4	115.40 E-4
	Pb	135.16 E-3	105.94 E-3	0.76 E-3	0.75 E-3	4.70 E-6	4.63 E-6	-	-	135.57 E-3	106.26 E-3
	As	21.31 E-2	25.57 E-2	0.06 E-2	0.07 E-2	1.45 E-5	1.74 E-5	-	-	21.37 E-2	25.64 E-2
	Ni	306.85 E-4	140.64 E-4	0.83 E-4	0.38 E-4	3.18 E-6	1.46 E-6	-	-	307.72 E-4	141.04 E-4
	Zn	702.34 E-5	551.48 E-5	1.97 E-5	1.54 E-5	9.81 E-7	7.70 E-7	-	-	704.41 E-5	553.10 E-5
	Cd	0.89 E-3	1.28 E-3	2.50 E-6	3.60 E-6	0.05 E-5	0.07 E-5	-	-	135.57 E-3	106.26 E-3
	Hg	4.26 E-2	3.84 E-2	4.18 E-4	3.76 E-4	0.17 E-4	0.15 E-4	4.47 E-5	4.02 E-5	4.44 E-2	3.99 E-2
3	**Cu**	89.50 E-4	79.91 E-4	0.25 E-4	0.22 E-4	8.34 E-7	7.44 E-7	-	-	89.76 E-4	80.14 E-4
	Pb	87.67 E-3	146.12 E-3	0.56 E-3	0.76 E-3	3.47 E-6	4.70 E-6	-	-	87.94 E-3	146.56 E-3
	As	26.85 E-2	27.28 E-2	0.07 E-2	0.08 E-2	1.83 E-5	1.86 E-5	-	-	26.93 E-2	27.35 E-2
	Ni	306.85 E-4	198.17 E-4	0.83 E-4	0.54 E-4	3.18 E-6	2.05 E-6	-	-	307.72 E-4	198.73 E-4
	Zn	607.31 E-5	689.98 E-5	1.70 E-5	1.93 E-5	8.48 E-7	9.64 E-7	-	-	609.09 E-5	692.01 E-5
	Cd	1.53 E-3	1.53 E-3	4.30 E-6	4.30 E-6	0.09 E-5	0.09 E-5	-	-	87.94 E-3	146.56 E-3

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	Hg	4.69 E-2	3.84 E-2	4.59 E-4	3.76 E-4	0.19 E-4	0.15 E-4	4.92 E-5	4.02 E-5	4.88 E-2	3.99 E-2
4	**Cu**	99.09 E-4	115.07 E-4	0.28 E-4	0.32 E-4	9.23 E-7	10.72 E-7	-	-	99.37 E-4	115.40 E-4
	Pb	58.45 E-3	84.02 E-3	0.96 E-3	0.97 E-3	5.92 E-6	5.99 E-6	-	-	58.62 E-3	84.27 E-3
	As	17.05 E-2	19.18 E-2	0.05 E-2	0.05 E-2	1.16 E-5	1.31 E-5	-	-	17.10 E-2	19.23 E-2
	Ni	262.10 E-4	268.49 E-4	0.71 E-4	0.73 E-4	2.71 E-6	2.78 E-6	-	-	262.84 E-4	269.25 E-4
	Zn	525.48 E-5	530.17 E-5	1.47 E-5	1.48 E-5	7.34 E-7	7.41 E-7	-	-	527.02 E-5	531.73 E-5
	Cd	1.15 E-3	1.66 E-3	3.20 E-6	4.70 E-6	0.06 E-5	0.09 E-5	-	-	58.62 E-3	84.27 E-3
	Hg	4.26 E-2	4.26 E-2	4.18 E-4	4.18 E-4	0.17 E-4	0.17 E-4	4.47 E-5	4.47 E-5	4.44 E-2	4.44 E-2
5	**Cu**	108.68 E-4	105.48 E-4	0.30 E-4	0.30 E-4	10.12 E-7	9.82 E-7	-	-	108.99 E-4	105.78 E-4
	Pb	105.94 E-3	116.89 E-3	0.90 E-3	0.79 E-3	5.58 E-6	4.90 E-6	-	-	106.26 E-3	117.25 E-3
	As	29.41 E-2	26.85 E-2	0.08 E-2	0.07 E-2	2.00 E-5	1.83 E-5	-	-	29.49 E-2	26.93 E-2
	Ni	249.32 E-4	306.85 E-4	0.68 E-4	0.83 E-4	2.58 E-6	3.18 E-6	-	-	250.02 E-4	307.72 E-4
	Zn	583.44 E-5	543.38 E-5	1.63 E-5	1.52 E-5	8.15 E-7	7.59 E-7	-	-	585.16 E-5	544.98 E-5
	Cd	1.92 E-3	2.05 E-3	5.40 E-6	5.70 E-6	0.10 E-5	0.11 E-5	-	-	106.26 E-3	117.25 E-3
	Hg	5.11 E-2	4.69 E-2	5.01 E-4	4.59 E-4	0.20 E-4	0.19 E-4	5.37 E-5	4.92 E-5	5.32 E-2	4.88 E-2
6	**Cu**	175.80 E-4	111.87 E-4	0.49 E-4	0.31 E-4	16.37 E-7	10.42 E-7	-	-	176.31 E-4	112.20 E-4
	Pb	263.01 E-3	336.07 E-3	0.77 E-3	0.84 E-3	4.76 E-6	5.17 E-6	-	-	263.81 E-3	337.09 E-3
	As	34.09 E-2	35.80 E-2	0.10 E-2	0.10 E-2	2.32 E-5	2.44 E-5	-	-	34.19 E-2	35.90 E-2
	Ni	191.78 E-4	364.38 E-4	0.52 E-4	0.99 E-4	1.98 E-6	3.77 E-6	-	-	192.32 E-4	365.41 E-4
	Zn	906.91 E-5	941.86 E-5	2.54 E-5	2.64 E-5	12.67 E-7	13.16 E-7	-	-	909.58 E-5	944.63 E-5
	Cd	2.17 E-3	2.94 E-3	6.10 E-6	8.20 E-6	0.12 E-5	0.16 E-5	-	-	263.81 E-3	337.09 E-3
	Hg	4.69 E-2	3.84 E-2	4.59 E-4	3.76 E-4	0.19 E-4	0.15 E-4	4.92 E-5	4.02 E-5	4.88 E-2	3.99 E-2
7	**Cu**	134.25 E-4	95.89 E-4	0.38 E-4	0.27 E-4	12.50 E-7	8.93 E-7	-	-	134.63 E-4	96.17 E-4
	Pb	58.45 E-3	76.71 E-3	0.95 E-3	0.95 E-3	5.85 E-6	5.85 E-6	-	-	58.62 E-3	76.95 E-3
	As	21.31 E-2	22.59 E-2	0.06 E-2	0.06 E-2	1.45 E-5	1.54 E-5	-	-	21.37 E-2	22.65 E-2
	Ni	274.89 E-4	268.49 E-4	0.75 E-4	0.73 E-4	2.84 E-6	2.78 E-6	-	-	275.66 E-4	269.25 E-4
	Zn	509.71 E-5	552.75 E-5	1.43 E-5	1.55 E-5	7.12 E-7	7.72 E-7	-	-	511.21 E-5	554.38 E-5

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8	**Cd**	1.28 E-3	1.79 E-3	3.60 E-6	5.50 E-6	0.07 E-5	0.10 E-5	-	-	58.62 E-3	76.95 E-3
	Hg	4.26 E-2	4.69 E-2	4.18 E-4	4.59 E-4	0.17 E-4	0.19 E-4	4.47 E-5	4.92 E-5	4.44 E-2	4.88 E-2
	Cu	143.84 E-4	89.50 E-4	0.40 E-4	0.25 E-4	13.40 E-7	8.34 E-7	-	-	144.25 E-4	89.76 E-4
	Pb	98.63 E-3	105.94 E-3	0.76 E-3	0.84 E-3	4.70 E-6	5.17 E-6	-	-	98.93 E-3	106.26 E-3
	As	22.16 E-2	25.57 E-2	0.06 E-2	0.07 E-2	1.51 E-5	1.74 E-5	-	-	22.22 E-2	25.64 E-2
	Ni	147.03 E-4	217.35 E-4	0.40 E-4	0.59 E-4	1.52 E-6	2.25 E-6	-	-	147.45 E-4	217.96 E-4
	Zn	499.06 E-5	447.49 E-5	1.40 E-5	1.25 E-5	6.97 E-7	6.25 E-7	-	-	500.52 E-5	448.80 E-5
9	**Cd**	2.05 E-3	1.02 E-3	5.70 E-6	2.90 E-6	0.11 E-5	0.06 E-5	-	-	98.93 E-3	106.26 E-3
	Hg	3.84 E-2	4.26 E-2	3.76 E-4	4.18 E-4	0.15 E-4	0.17 E-4	4.02 E-5	4.47 E-5	3.99 E-2	4.44 E-2
	Cu	12.66 E-4	156.62 E-4	0.35 E-4	0.44 E-4	11.61 E-7	14.59 E-7	-	-	125.02 E-4	157.07 E-4
	Pb	91.32 E-3	105.94 E-3	0.77 E-3	0.77 E-3	4.76 E-6	4.76 E-6	-	-	91.60 E-3	106.26 E-3
	As	19.18 E-2	20.46 E-2	0.05 E-2	0.06 E-2	1.31 E-5	1.39 E-5	-	-	19.23 E-2	20.52 E-2
	Ni	262.10 E-4	179.00 E-4	0.71 E-4	0.49 E-4	2.71 E-6	1.85 E-6	-	-	262.84 E-4	179.50 E-4
	Zn	587.70 E-5	505.45 E-5	1.65 E-5	1.42 E-5	8.21 E-7	7.06 E-7	-	-	589.43 E-5	506.93 E-5
10	**Cd**	1.79 E-3	1.66 E-3	5.00 E-6	4.70 E-6	0.10 E-5	0.09 E-5	-	-	91.60 E-3	106.26 E-3
	Hg	3.41 E-2	4.26 E-2	3.34 E-4	4.18 E-4	0.14 E-4	0.17 E-4	3.58 E-5	4.47 E-5	3.55 E-2	4.44 E-2
	Cu	111.87 E-4	127.85 E-4	0.31 E-4	0.36 E-4	10.42 E-7	11.91 E-7	-	-	112.20 E-4	128.22 E-4
	Pb	127.85 E-3	84.02 E-3	0.77 E-3	0.79 E-3	4.76 E-6	4.90 E-6	-	-	128.24 E-3	84.27 E-3
	As	18.33 E-2	19.18 E-2	0.05 E-2	0.05 E-2	1.25 E-5	1.31 E-5	-	-	18.38 E-2	19.23 E-2
	Ni	249.32 E-4	159.82 E-4	0.68 E-4	0.43 E-4	2.58 E-6	1.65 E-6	-	-	250.02 E-4	160.27 E-4
	Zn	663.14 E-5	594.09 E-5	1.86 E-5	1.66 E-5	9.26 E-7	8.30 E-7	-	-	665.08 E-5	595.84 E-5
	Cd	3.20 E-3	1.28 E-3	8.90 E-6	3.60 E-6	0.18 E-5	0.07 E-5	-	-	128.24 E-3	84.27 E-3
	Hg	4.69 E-2	4.26 E-2	4.59 E-4	4.18 E-4	0.19 E-4	0.17 E-4	4.92 E-5	4.47 E-5	4.88 E-2	4.44 E-2

The primary pathway of intake for the studied heavy metals, according to the EDI values, is ingestion, followed by vaporization (only for mercury), dermal contact, and lastly, inhalation. However, nearly all values are below the reference dose (RfD) set by the USEPA, except for mercury at all locations (PS and ES) where the RfD of 8.75×10^{-5} was exceeded, with an average between 38×10^{-5} and 39×10^{-5} (approximately four times higher than the RfD) [Battsengel et al. 2020].

Because the ingestion pathway is demonstrated to be the principal way of exposure to children due to their pica behavior, was calculated HQ_{ingest} and the obtained values were in order: As > Pb >

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Hg > Ni > Cu > Zn > Cd. As seen, As and Pb presented a higher risk than the rest of the metals, but the maximum value for Pb (394E-3) and As (35.80E-2) pose no threat to the children's health, but their concentrations should be under attention.

For HQ_{dermal} the values in order are: As > Hg > Pb > Ni > Cu > Zn > Cd, with maximum values for As (0.10E-2) and Hg (4.16E-6) under the threshold value for the risk as 1.

For $HQ_{inhalation}$ the values indicated the following trend: Hg > As > Ni > Pb > Cu > Cd > Zn. The maximum values for Hg (0.17E-4) and As (2.44E-5) are well below the risk threshold, posing no threat on children's health.

For mercury, the HQ for vaporization ($HQ_{vaporization}$) was also calculated, with values ranging between 4E-5 and 5.1E-5. Based on these values, the locations were ranked from most to least exposed as follows: 5 > 10 = 7 > 3 = 4 = 6 > 2 = 8 > 1 = 9.

If all the HQ values are taken into a comparison, the children were at risk of non-carcinogenic effects firstly through the ingestion and vaporization pathways, followed by dermal contact and inhalation.

The mean values for hazard index, presented in Table 12 are also below the health risk threshold in order: As (24.08E-2) > Pb (13.36E-2) > Hg (4.41E-2) > Ni (2.43E-2) > Cu (1.22E-2) > Zn (0.65E-2) > Cd (0.18E-2).

These results are indicating that the highest non-carcinogenic risk to children's health due to the exposure to heavy metals in the studied parks is from As, Pb and Hg.

As a conclusion, all the HQ and HI values where under 1, suggesting that the exposure of the children to the heavy metals found in soil will not affect their health, but all other sources of heavy metals such as food intake or exposure to dust and aerosol from other urban places, have not been included in this study. All the sources of heavy metals must be connected due to the cumulative character of the pollutants and the serious adverse effects on the body, so the non-carcinogenic risk associated with the exposure to the playground soil cannot be neglected [Javed et al. 2019].

3.3. ATR-FTIR Analysis

The ATR-FTIR spectra exhibited a consistent pattern across all studied soil samples, with slight variations in intensity, as shown in Figure 8.

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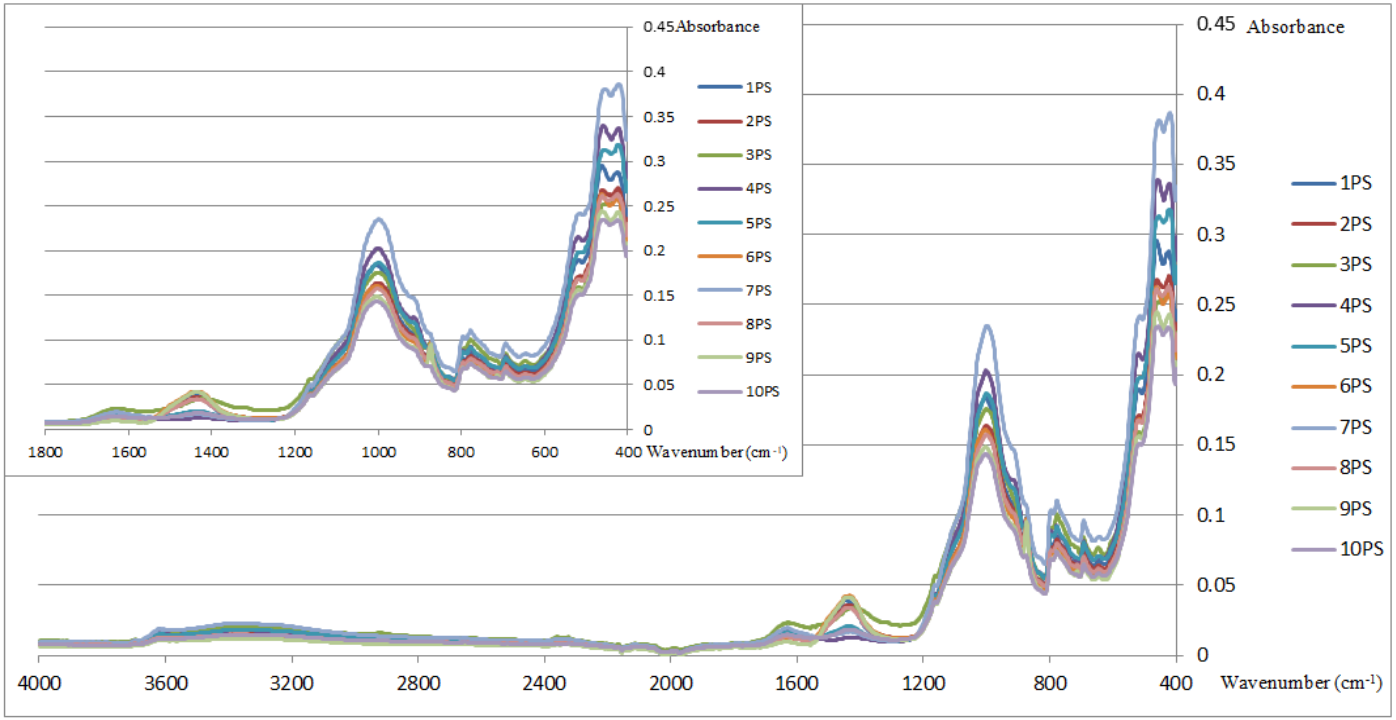

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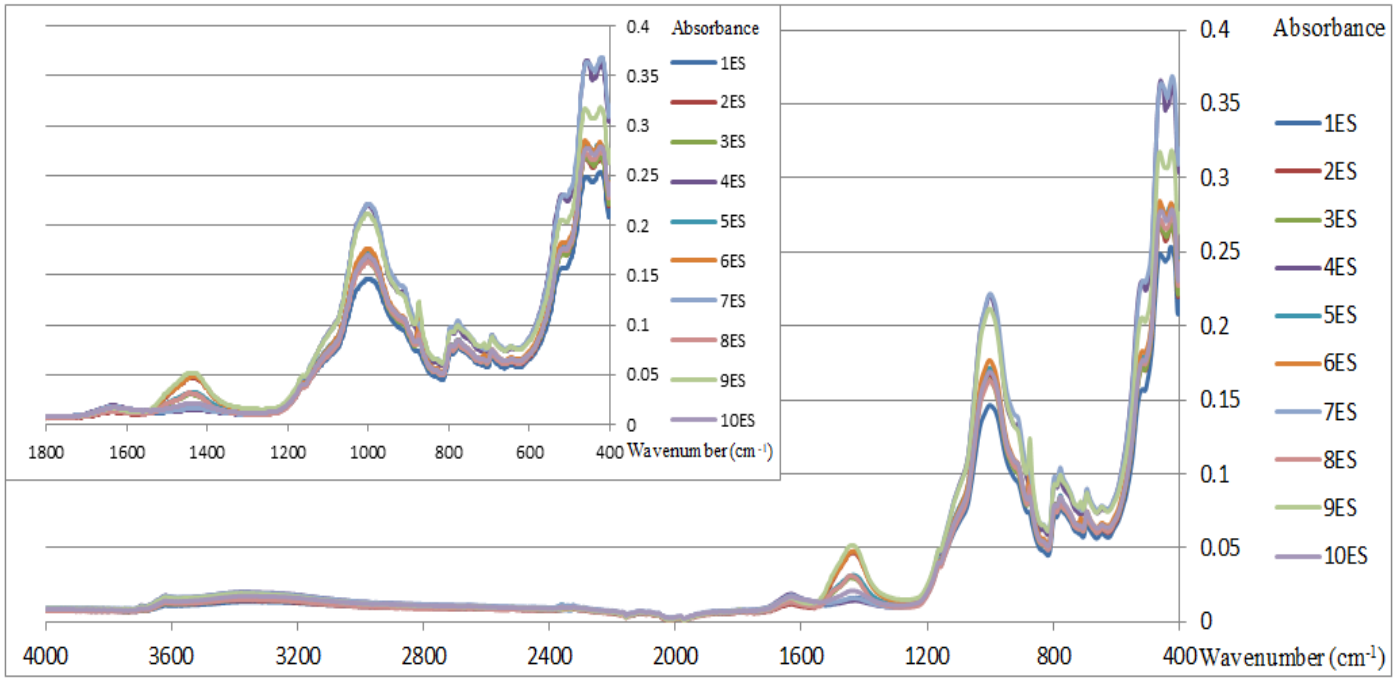

Figure 8. Soil sample playground (PS) and edges of the park (ES) ATR-FTIR spectra in the 4000-400 cm^{-1} and 1800-400 cm^{-1} regions.

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The results revealed specific absorption bands that can be attributed to characteristic functional groups associated with clay and non-clay minerals [Ene et al. 2024a]. In the spectral fingerprint domain, peaks in the 1600-400 cm^{-1} range are observed, which are associated with clay minerals such as montmorillonite ($(Na, Ca)_{0.33}(Al,Mg)_2(Si_4O_{10})(OH)_2NH_2O$) and kaolinite ($Al_2Si_2O_5(OH)_4$) as well as non-clay minerals such as quartz (SiO_2), feldspars ($KAlSi_3O_8$), albite ($NaAlSi_3O_8$), dolomite ($CaMg(CO_3)_2$), gypsum ($CaSO_4)2H_2O$) and calcite ($CaCO_3$). These results are similar to those obtained by [Ene et al. 2024a] on soils collected from agricultural area around Galati steel enterprise, highlighting the mineralogical footprint of the region.

3.4. SEM-EDX Analysis Regarding Microstructure and Variability of Elements in the Playgrounds' Soil

The morpho-structure of soils picked-up from two different areas within a park (near and far from the play area) and different urban parks is analyzed by SEM-EDX technique. Figure 9 highlights the SEM micrographs taken at 5,000x magnification, in five different sections randomly chosen in six samples from different locations. Generally, the fine powders show a compact surface with irregular shaped and different size particles, and low porosity.

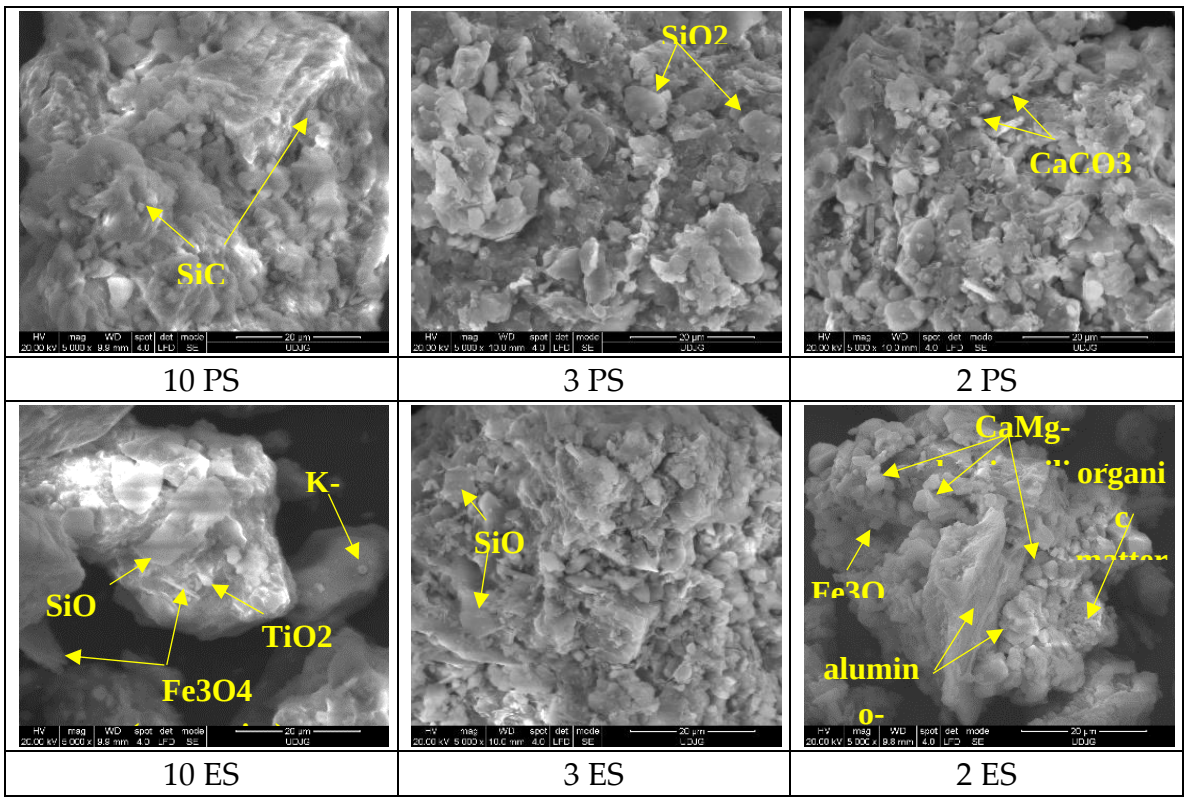

Figure 9. SEM imagistic results of soil samples collected from three areas from different city parks.

SEM images indicate the presence of both light and heavy elements in the studied soils, being recognizable through gray shades, from darkest to brightest. Therefore, different compounds, such as clay minerals, calcite, silica, and many oxides are highlighted by specific geometry: spherical shaped and rod-like particles, well-defined edges or rounded flat microstructures. In addition, the semi-quantitative and qualitative EDX results support the imagistic results.

By calculating the mean of element percentages from five randomly scanned areas, we are estimating the elemental concentration and mineralogical diversity for each studied sample. Table 13 comprises data for 24 macro, micro and trace elements, with the atomic number ranging between C and Sr, which confirms the presence of minerals, organic matter, and some heavy metals (Ni, Co, Hg, Pb, Sr, As) in the urban park soils.

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Table 13. Semi-quantitative EDX results of park soils from different locations of Galati.

Element	Average concentration (wt. %)					
	2		3		10	
	ES	PS	ES	PS	ES	PS
C	19.57	25.28	25.30	46.83	33.19	34.76
N	1.21	1.25	1.24	1.91	0.82	1.44
O	27.01	29.90	31.52	26.22	29.85	33.34
Na	0.28	0.34	0.24	0.18	0.22	0.38
Mg	0.76	1.00	0.77	0.68	1.25	0.89
Al	4.03	4.90	4.48	2.40	4.57	3.88
Si	14.00	12.68	14.63	6.68	10.99	11.32
P	0.00	0.00	0.00	0.03	0.05	0.03
S	0.16	0.19	0.20	0.28	0.06	0.12
K	1.64	1.94	1.92	0.87	2.12	1.38
Ca	8.23	4.12	3.08	2.17	0.90	1.84
Ti	0.57	0.41	0.38	0.17	0.32	0.45
Mn	0.44	0.29	0.27	0.22	0.36	0.25
Fe	3.78	3.45	2.91	1.95	5.55	3.32
Co	0.39	0.27	0.36	0.21	0.41	0.28
Ni	0.59	0.36	0.36	0.24	0.43	0.35
Cu	0.85	0.56	0.63	0.36	0.91	0.35
Zn	0.56	0.50	0.45	0.32	0.73	0.44
Hg	3.52	2.62	2.18	1.37	2.38	1.96
As	0.52	0.40	0.05	0.31	0.20	0.15
Pb	3.39	2.82	3.11	1.94	2.86	1.90
Se	1.87	0.00	0.00	0.00	0.00	0.00
Rb	4.23	3.78	3.61	2.67	1.47	0.53
Sr	2.39	2.95	2.15	2.01	0.42	0.66

Among the 24 identified elements, O (33.34 wt. % at 2 ES sample) and Si (14.63 wt. % at 3 PS sample) represent the major elements in all types of soil. Exception is the Carbon, whose values can be due on the one hand to the carbon tape used for soil fixation during analysis, and on the other hand to the presence of carbonate minerals (calcite - $CaCO_3$) and CO_2 or carbon footprint effect. Silicon is the most abundant microelement in the ecosystem [Ene et al. 2024 a]. Si-based compounds can be recognized from SEM images in both crystalline (as silicate matrices, clay and nonclay-like minerals) and amorphous phases. Other slightly inorganic elements are homogeneously distributed in all locations. Also, alkali metals are important in soil composition. K, Na, Mg and Ca are typical the higher accumulated elements in the soil [Asylbaev and Khabirov, 2016]. However, an alarming presence of toxic elements as Hg (maximum of 3.52 wt. % at 10 PS sample), Pb (maximum of 3.39 wt. % at 10 PS sample) and Rb (maximum of 4.23 wt. % at 10 PS sample) in all studied park's soil was marked. The other important heavy metals are minors (below 1 wt. %). This fact could be explained by soil position near the industry and can be attributed to the anthropogenic activities.

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Figure 10 shows the major and minor chemical elements distribution in playground's soils through quantitative EDX analysis from Table 13. EDX spectrum revealed the presence of the K-lines of C, N, O, Na, Mg, Al, Si, P, S, K, Ca, Ti, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr and the L-lines of Fe, Pb and Hg.

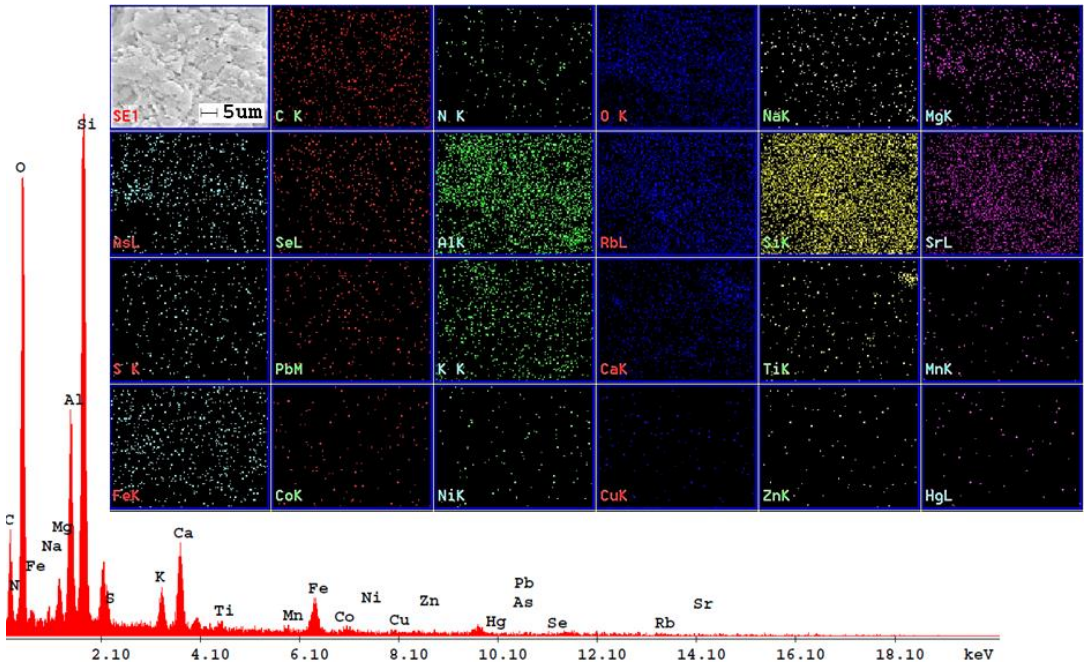

Figure 10. EDX spectrum and the soil elemental distribution map of the 2 ES sample.

4. Conclusions

As a consequence of limited spaces, the major parks in urban areas are located usually near major traffic routes or near the industrial areas. The soil from parks will accumulate all the emitted pollutants and will become a secondary source of heavy metals for the most closed receptors, the children.

In this study, a total of 20 surface soils were collected from 10 different parks from Galati city, Romania, from the playground area (PS) and from the edge of the parks (ES) near to the street with the most intense traffic.

The first study on heavy metals occurrence and assessment of the non-carcinogenic risk to children's health due to the exposure to pollutants in 10 important parks from Galati (Romania) has found no significant problems regarding the actual state of the soils and their potential impact on children's health. The main pathway that can influence the children's health is the ingestion of the contaminated material, while inhalation and dermal contact were less important.

The presence of the heavy metals in parks and playgrounds are regulated as sensitive area in Romanian law, which is important for children who are the most frequently in direct contact with the surface soil. The average concentrations of heavy metals that have been found over the normal values were: Cu, Pb, As, Cr, Ni, Zn, Hg, V, Ba, Ag.

High concentrations of Zn, Cu, Pb and Cr, that are known to be typically urban contaminants, were usual found in soils from locations affected by traffic or different type of industry, but only the concentrations of one element cannot indicate an exact source.

Zn is also found in tires particles and in motor oils, Cu is found in many parts of the car that after corrosion will accumulate in the road dust and then transported in the vicinities. In our case, for all these elements, the maximum concentrations were reached at the edge of the parks, indicating that intense traffic has a strongly contribution to the soil pollution. Additionally, from the Pearson's correlation matrix results exactly the same conclusion. For the safety of the children, all these heavy

metals should be under long term observation because they constitute an important source of pollution for children.

Beside the heavy traffic, other factors than can influence the heavy metals accumulation in soil from parks could also include the age of the parks. Knowing the accumulative nature of heavy metals, the older the park, the more contaminated it is. Moreover, the maintenance works from parks, including the use of pesticides and insecticides, and all the urbanization, modernization and rehabilitation processes usually generate a large amount of dust and debris containing different types of pollutants. Last, but not least the pollution that originates from the industrial activities is present in our case for the first location that exhibits maximum values for Cu, Pb, Zn and Ba.

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