

The Study of Peri-Urban Soil Contamination in the Kenitra Region, Morocco – Characterization and Assessment Using a Statistical Approach

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ABSTRACT

The peri-urban solid waste in the Kenitra region is experiencing a significant change in terms of quantity and quality. High concentrations of both inorganic and organic materials are present in these wastes, posing a significant threat of pollution. This research sought to analyze the extent of soil contamination by heavy metals, providing valuable insights to prompt proactive interventions and propose alternative solutions for sustainable waste management. The objective of this work was to study peri-urban soil contamination in the Kenitra region-Morocco. For that purpose, several soil contamination indicators were analyzed, namely: nitrogenous, fertilizer and heavy metals concentration, soil pH, etc. The analyzed soil samples were taken from water from the different points at the levels of the studied region. The analysis shows that the studied soils are polluted with Zn, Mg, Cu, Ni, Cr, Cd, Pb, and other chemical elements. The results obtained suggest a correlation between soil pollution and the concentrations of the measured heavy metals. Furthermore, the analysis shows that heavy metals, contamination is particularly related to the presence of lead, cadmium, and zinc. The zinc contamination in the soil is about 390 mg/kg for a standard of between 0.2 and 2 mg/kg. Lead concentrations are 53 mg/kg for a standard of 0.3 mg/kg. On the basis of Moroccan standards, the soil is contaminated by lead, cadmium, and zinc.

Keywords: soil properties, statistical, contamination, Kenitra-Morocco.

INTRODUCTION

The essential medium for plant growth is soil, a dynamic natural system rich in minerals and organic matter. Its physical, chemical and biological properties facilitate the supply of nutrients in optimal quantity and the quality required for balanced plant development. In many sub-Saharan African countries, soils are often poorly fertilized and the nutrients exported are inadequately

replenished. As a result, yields remain modest and land productivity is in decline. The global problem of heavy metal contamination is recognized, and plants obtain trace elements primarily from their growth media (soil, air, nutrient solutions), with uptake by roots or leaves. The bioavailability of elements to plants is influenced by various factors, including the physico-chemical properties of soils, climatic conditions, plant genotype, species and agronomic practices. To evaluate the

quality, preservation, and maintenance of the basin, in this study it was proposed to quantify the contents of metallic trace elements (Cd, Cr, Cu, Ni, Pb, Zn) in the surface sediments, and to evaluate the level of metallic contamination/pollution based on the cratering of the soil of the region and the calculation of the contamination index. The concentration of most of these contaminants sometimes reaches the levels that are toxic for aquatic life in both soil and sediment. The importance of environmental risk assessment is linked to the potential transfer of pollutants in soils in peri-urban areas. The conducted research is part of this theme as well as proposes characterization and assessment of the soil quality using statistical methodology for the interpretation and study of the obtained laboratory results (Ceci et al., 2019; Garau et al., 2022). Evaluating trace metal pollution and pinpointing its sources relies on straightforward principles involving the measurement of concentrations, computation of indices, and subsequent comparison with established standards (Jiang et al., 2018), which vary according to the nature of the element, its toxicity, and the receiving environment. In both basic and applied research, the normalization of metal levels is typically done using a reference material that may not be directly connected to the local environment. Indices, such as the accumulation index, serve as a common method for this standardization (Masas et al., 2013; Wang et al., 2022). Another way is to present the relative enrichment of a trace metal element compared to an immobile element not affected by anthropogenic activities (Al, Th, Ti, Sc) such as the enrichment factor and the metal pollution index (Hasan et al., 2018). Alternative methods compare measured concentrations to specific regulatory thresholds (TEC – threshold effect concentration, PEC – probable effect concentration). These thresholds are considered representative of an acceptable level of protection for the biota associated with the sediment, and any concentration above the threshold is considered unacceptable (Kulkarni et al., 2018; Ziyaadini et al., 2017). For a long time, humans have shown little concern for their natural environment. Today, the situation is dramatic, particularly for soil and aquatic ecosystems. The contaminants that reach these environments still constitute a major environmental issue. Pollution by heavy metals is a current problem that concerns all regions concerned with maintaining their soil and water heritage at a high level of quality. This concern affects

the Gharb region, which is a major economic pole in Morocco, due to its surface and underground water reserves as well as the quality of its fertile soil (Barakat et al., 2021; Tenzon, 2019). This region has several wet depressions. The Kénitra region is one of these main depressions. The region of the city of Kénitra is an active environment, in the protection zone. In the past, this region was a natural lake where various types of migratory birds found a favorable environment for their rest and reproduction. Discharges of raw sewage effluent (domestic and industrial) as well as agricultural leaching have turned the soil into a real outlet (Babaranti et al., 2019; Huang et al., 2019). The risks of contamination of the groundwater and soil in the region and the transfer of pollutants to the ecosystem. From this perspective, the authors were interested in evaluating the degree of metallic pollution of the sediments of this site. In this work, peri-urban soil contamination in the Kenitra region-Morocco was studied by carrying out soil characterization and soil quality assessment. The results were interpreted and analyzed with a statistical approach using SPSS software.

MATERIALS AND METHODS

Study area

Kenitra's climate is characterized by semi-arid and mesothermal, mainly influenced by its position on the Atlantic Ocean, while the winds are mainly from the western to the northwestern direction, originating from the sea. The length of the coastline of Kenitra is 20 km. The city is located about 50 km north of Rabat, the capital of Morocco, between the meridians 6° 30' and 6° 45' West and the parallels 34° 15' and 34° 20', with an area of 672 km² and an elevation of 26 m (El Azzouzi et al., 2019). The average total rainfall per year is 718.6 mm, with 0.4 and 135.09 mm as minimum and maximum recorded in July and in December, respectively. The average low, high, and daily average temperatures recorded annually are 12.8, 22.4, and 17.6°C, while the annual potential evaporation shows a range between 865.7 mm and 912 mm (Hakkou et al., 2018).

In geological terms, the sedimentary cycle of the Tertiary era concludes in the Pliocene. This period is marked by deposits exhibiting regressive characteristics, notably observed at outcrops along the basin periphery. To the East, there are

yellow sands; to the North, lumachelles and conglomerates; and in the Southeast, sands and shell sandstones. At the end of the Pliocene, the sea in the Rharb only occupies a gulf that keeps shrinking (Najy et al., 2018). The first Quaternary marine transgressions only concerned a narrow strip of 20 km at most, parallel to the present coast. These pulsations left sediments of marine origin, which are dated at the outcrop in a few privileged points of the Mamora and which are accompanied by ancient dune strips appearing in the form of sands, often sandstone. All these formations in the coastal zone and part of the Mamora can reach 200 m in thickness and constitute an aquifer of primary importance. The Miocene upper marine strata exhibit distinctive grey-blue marls transitioning seamlessly into the subsequent Pliocene period (El Harech et al., 2020). The connections between the Miocene and Pliocene stages remain somewhat ambiguous, as lagoon-continental deposits during this transitional phase may be easily mistaken for analogous Pliocene formations. Upstream of this zone, sediments of continental origin accumulated during the same period, alternately coarse (pebbles and gravels) and fine (silts and clays) depending on the rainfall of the periods and the violence of the erosion. The Villafranchian is made up of ancient pebble and gravel outwash in the north and east of the plain, which can be up to 250 m thick. The Amirian is formed of clayey and silty sediments with limestone pouts up to 50 m thick. In the Tenssiftian, there is a new episode of gravels in more or less clayey sands up to 60 m thick. The Soltanian is characterized by

red and yellow silty facies with some gravel levels at the base up to 50 m thick. In the Rharbian, one can find deposits that cover the whole of the low plain and which are either more or less sandy silts or black clay soils (Lotfi et al., 2019). In various regions, a slender veneer of red silts bears witness to the pervasive presence of the Quaternary era. The agricultural soil layer is distinguished by the prevalence of soils extending with a composition of clay and sand. In the present work, a field study was carried out by investigating X sites, selected according to the proximity of motorways, main sources of pollution, and population density. The geographical location is presented in Figure 1.

Sampling and pre-treatment

Twenty sampling sites were selected for this study, located throughout the study region. These stations were chosen according to their accessibility and closeness to the polluting discharges. The surface sediment samples were taken during a campaign, onboard a boat, and using a hand bucket, taking the precautions mentioned below recommended by the National Institute for Agronomic Research. These samples are collected in plastic bags and stirred until a homogeneous mixture of the studied station is obtained. The core sediments were collected downstream of station 7 (Figure 1) by manual coring using a 2.5 m long, 15 mm diameter corer. The coring cannot exceed a depth of 40 cm, beyond which core was no longer possible with the equipment at authors' disposal (Weber et al., 2021). The samples were

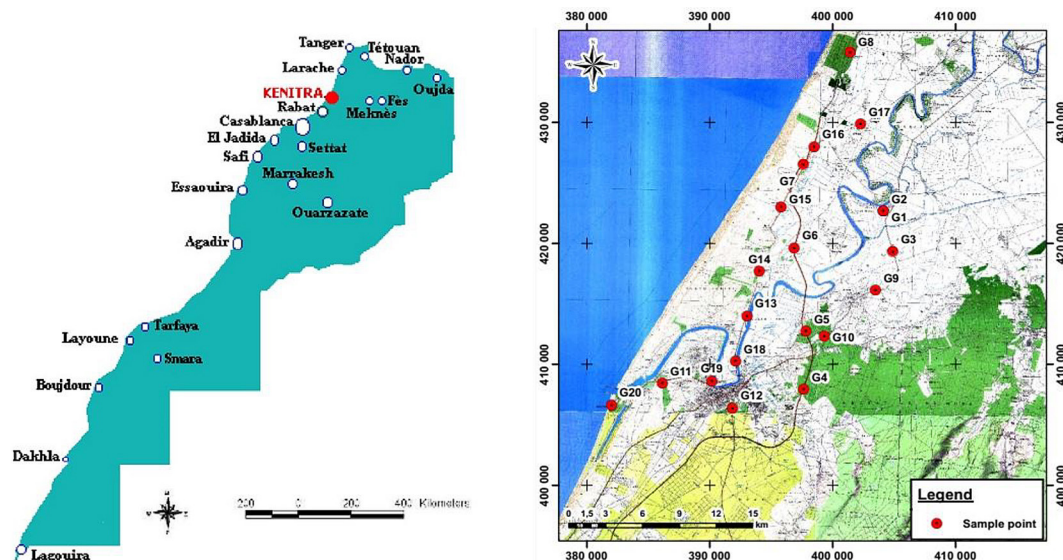


Figure 1. Location of the study area and sampling sites

stored in a portable cooler at 4°C from the time they were taken to the laboratory. In the laboratory, stones and plant debris were removed using a 2 mm diameter sieve. The wet sediment was sieved on a 63 µm diameter sieve and the samples were dehydrated in an oven at 90°C, followed by preservation in sanitary, airtight plastic bags labeled with codes for subsequent physico-chemical analysis. Each soil sample was meticulously pulverized using a laboratory porcelain mortar and pestle, sieved to 0.2 mm, and then placed in labeled plastic containers. The pre-processing of the soil samples adhered to established international standards (Fan et al., 2020).

Physico-chemical soil analysis

To ensure the accuracy of soil and plant sample analyses, quality assurance measures included the utilization of blanks, duplicate sample analyses, control solutions, and standard reference materials sourced from the Bureau Inter-Professional des Analyses. Employing chemicals of analytical reagent-grade purity, and utilizing deionized water for solution preparation, upheld stringent standards. The Anne method was employed for the carbon determination process (Rajaram et al., 2020). A combination of potassium dichromate and sulfuric acid is used to oxidize organic carbon. The excess dichromate was titrated with a solution of Mohr's salt. The organic matter was determined by loss on ignition at 550°C (Raya-Moreno et al., 2017). Calcium carbonate was determined by calcimetry. The limestone content was calculated as a function of the volume of CO₂ released by the action of HCl (50%) on the sediment (Li et al., 2020). Total phosphorus was determined after mineralization with a solution of K₂S₂O₈ (100 g/L) and concentrated sulfuric acid, and the phosphorus released was determined by the colorimetric method (Aboubakar et al., 2023). Digestion of the sediments was carried out using a microwave oven by mixing strong acids: HF-HNO₃-HClO₄ in the proportions (4-5-1) mL (Tauqeer et al., 2022). The solutions obtained were analyzed by high-performance Inductively Coupled Plasma Mass Spectrometer (ICP-MS) type VG plasma. The artificial standards were analyzed at the same time as the samples, to check the quality of the analyses for validation.

All tests were carried out in accordance with internationally recognized standards. The various analyses included pH (H₂O), electrical

conductivity measured with a conductivity glass electrode at a ratio of 1:5 (10 g fine fraction to 50 ml distilled water), determination of organic carbon (OC), total nitrogen (N) and assessment of soil texture. The pH of the soil in an aqueous extract with a soil/water ratio of 1:5 (volume weight) was measured using a pH meter (Hanna Instrument) according to NF ISO 10390 (Rue et al., 2019). The sulfochromic oxidation method according to NF ISO 14235 was used to determine organic carbon (Clivot et al., 2019). Total nitrogen (N) was determined by using the modified Kjeldahl method (NF ISO 11261) (Allani et al., 2019). The soil particle size distribution (Pipet method) was assessed by categorizing particles into five size classes: clays (0 to 2 µm), fine silts (2 to 20 µm), coarse silts (20 to 50 µm), fine sands (50 to 200 µm), and coarse sands (200 to 2000 µm) following the guidelines of NF X31-107 (Caria et al., 2023). Surface soil samples were collected from 0–20 cm depth and, after air drying, sieved through a 2 mm mesh. Analyses were carried out specifically on the fine fraction of soil particles with a diameter of less than 2 mm. Soil texture, which represents the dimensions of the elementary particles that make up the soil, was examined by particle size analysis.

Humidity

The water content in soil is expressed in percent and it is water content by weight. The measurement is carried out by drying conventionally by evaporation of water from a soil mass in an oven, which corresponds to water which evaporates at a temperature above 100°C.

$$w = mw/ms \times 100 = (mh - ms)/ms \times 100 \quad (1)$$

where: w – expression of water content in %, mw – mass of evaporated water, ms – mass of dry material, mh – mass of wet material

Total nitrogen

Total soil nitrogen includes organic nitrogen and mineral nitrogen, the latter representing only 4 to 5% of total nitrogen, so organic nitrogen and total nitrogen can be confused. Its determination was carried out by the Kjeldahl method which consists of hot mineralization of organic matter with concentrated sulfuric acid H₂SO₄ in the presence of CuSO₄ and K₂SO₄ catalysts. The ammoniacal nitrogen (NH₄⁺) produced is trapped, after distillation in the first 4% boric acid solution. The

total nitrogen was measured after titrating the boric acid solution that has trapped the ammonium (NH₄⁺) with sulfuric acid H₂SO₄ (0.05 N). Organic nitrogen (% N) is determined by using the Kjeldahl method where the nitrogen of the organic compounds is transformed into ammoniacal nitrogen by boiling concentrated sulfuric acid, which acts as an oxidant and destroys the organic matter.

Carbon and hydrogen are released as carbon dioxide and water. The nitrogen transformed into ammonia is fixed by sulfuric acid in the state of ammonium sulfate. Then the ammonia is distilled in a solution of boric acid. Titrate with a 0.02 N sulfuric acid solution.

Contamination index

The evaluation of pollution using the simple identification of the metal content in sediments is not a very significant approach. Boust et al. (Yang et al., 2022) and Belamie et al. (Ouali et al., 2018) use the contamination factor Fm (measured content/reference content with Fm > 1) and the contamination index Im: Several authors express the metallic contamination by the contamination factor Fm (measured level/reference level with Fm > 1) and by the contamination index Im.

$$Im = \frac{1}{n} \sum Fm \quad (2)$$

where: n – refer to the number of elements analyzed.

These authors indicate the onset of contamination when Im exceeds 2 (Im > 2).

Analysis of statistics

Statistical analysis of the data was performed using Microsoft Excel 2016 (Microsoft Corp.) and IBM SPSS Statistics 21 (SPSS Inc.) (Banerjee et al., 2018). The mean values and standard deviations were determined. Pearson correlation coefficients were performed. Analyses of variance (ANOVA) were also performed to determine statistically significant differences between soil parameters and heavy metal concentrations between soil parameters and heavy metal concentrations in soils.

RESULTS AND DISCUSSION

The soil characteristics

The pH and electrical conductivity of soil

Average pH values vary from 7.4 to 8.5 in cultivated soils. Heavy metals are generally more mobile in soils, affecting bioavailability and transport. When the soil pH is pronounced, enhanced mobility and bioavailability of heavy metals have been observed. This makes heavy metals more mobile and bioavailable, increasing their uptake by plants and thus their risk to human health. Therefore, the threat to human health is of concern (Davison et al., 2021; Dixit et al., 2019). The pH of the sediments in the Kenitra region is slightly alkaline (Figure 2a). This basic character reflects the nature of the sediments, which are dominated by calcareous and clayey soils. The pH fluctuations do not exceed one unit during

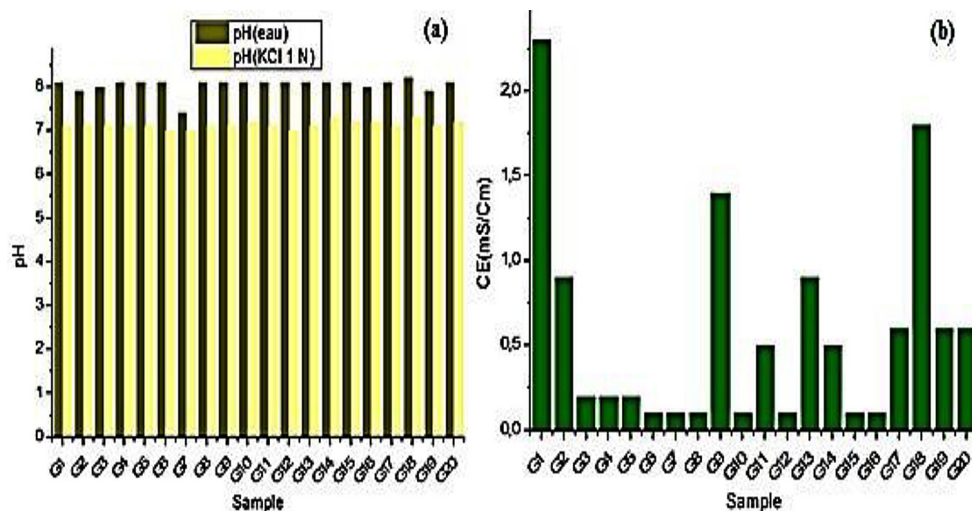


Figure 2. (a) Soils pH and (b) electrical conductivity in the Kenitra area

the sampling campaigns for the majority of the stations, which reflects the buffering capacity of these sediments. Soil pH is an important parameter in the control of the chemical behavior of metals and other important processes in the soil. As it can be seen in Figure 2a, the pH of the soils in the Kenitra area is very variable, ranging from 6.68 to 8. Most of the soils have values above 7. Soil alkalinity is due to the occurrence of carbonate in the soil.

The conductivity of the sediments in the Kenitra region averages between 2.5 and 0.2 mS/cm (Figure 2b). It increases from station G1 to station 18. This increase could be since the sediments are rich in monovalent and divalent ions which would come from various domestic and industrial discharges.

Phosphorus pentoxide (P₂O₅) and Potassium oxide (K₂O)

The analysis results of phosphorus pentoxide in the studied sediments show that these sediments are loaded with this element. The highest content was recorded at station 17 (Figure 3a). This result can be explained by the proximity of this station to agricultural land which receives leached water from land rich in phosphate fertilizers (Y. Wang et al., 2021). Indeed, most of the phosphorus is associated with the fine particles that constitute the predominant fraction of the sediments studied (X. Wang et al., 2021). On the other hand, the decantation of autochthonous particles rich in phosphorus (phytoplankton and zooplankton) contributes to the enrichment of the sediment in this element. Originally, the soils would be considered

to be normally or well supplied with exchangeable K₂O, since a normal content is about 0.2 g/kg. The soils of points 1, 9, 13, and 18 receiving wastewater have exchangeable K₂O contents that increase on average by 0.5 g/kg compared to their original value (Figure 3b) (Crusciol et al., 2020).

Nitrogen, calcium carbonate and humidity

The nitrogen (N) content decreases significantly with depth (Figure 4a). These values provide data on the homogenization ability of the product, allowing the degree of development of the organic matter to be assessed, i.e. its ability to degrade more or less quickly in the soil (Blankinship et al., 2018).

The obtained average carbonate contents vary from 1 to 4% (Figure 4b). These carbonates are abundant in the coarse fraction (site 2) which is accompanied by a low percentage of organic matter (Brankovits et al., 2021). Calcareous soil is soil containing free CaCO₃ in sufficient quantity to present a visible effervescence under the action of cold diluted HCl. CaCO₃ is often accompanied by MgCO₃. The carbonate (CaCO₃) content is high and can be attributed to the nature of the environment; the Neogene continental sedimentation cover of the basin is directly underlain by a carbonate formation.

Granulometric analysis

A homogeneous distribution with a sandy texture is reflected in the particle size analysis of the studied samples. Figure 5 illustrates the texture distribution of all the samples studied.

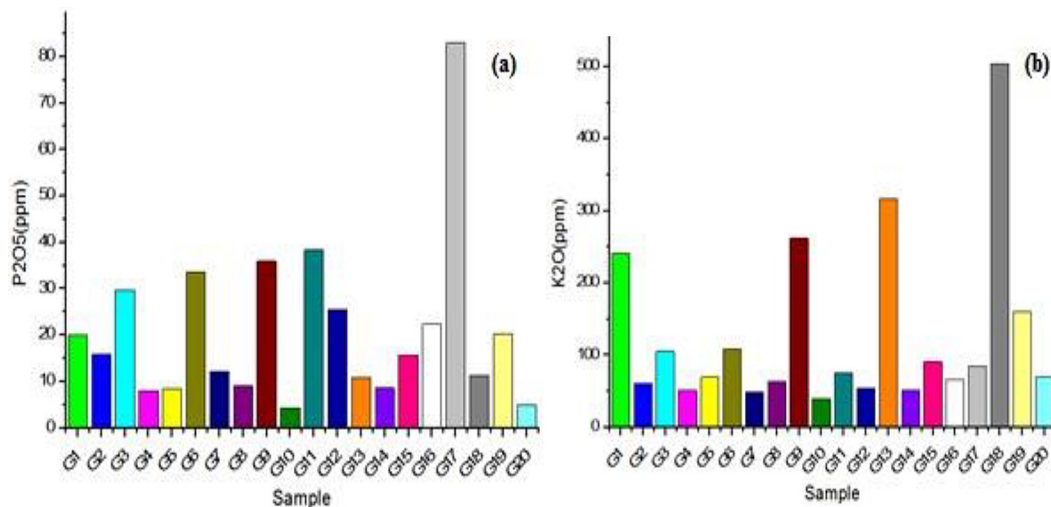


Figure 3. (a) Soils P₂O₅ and (b) K₂O

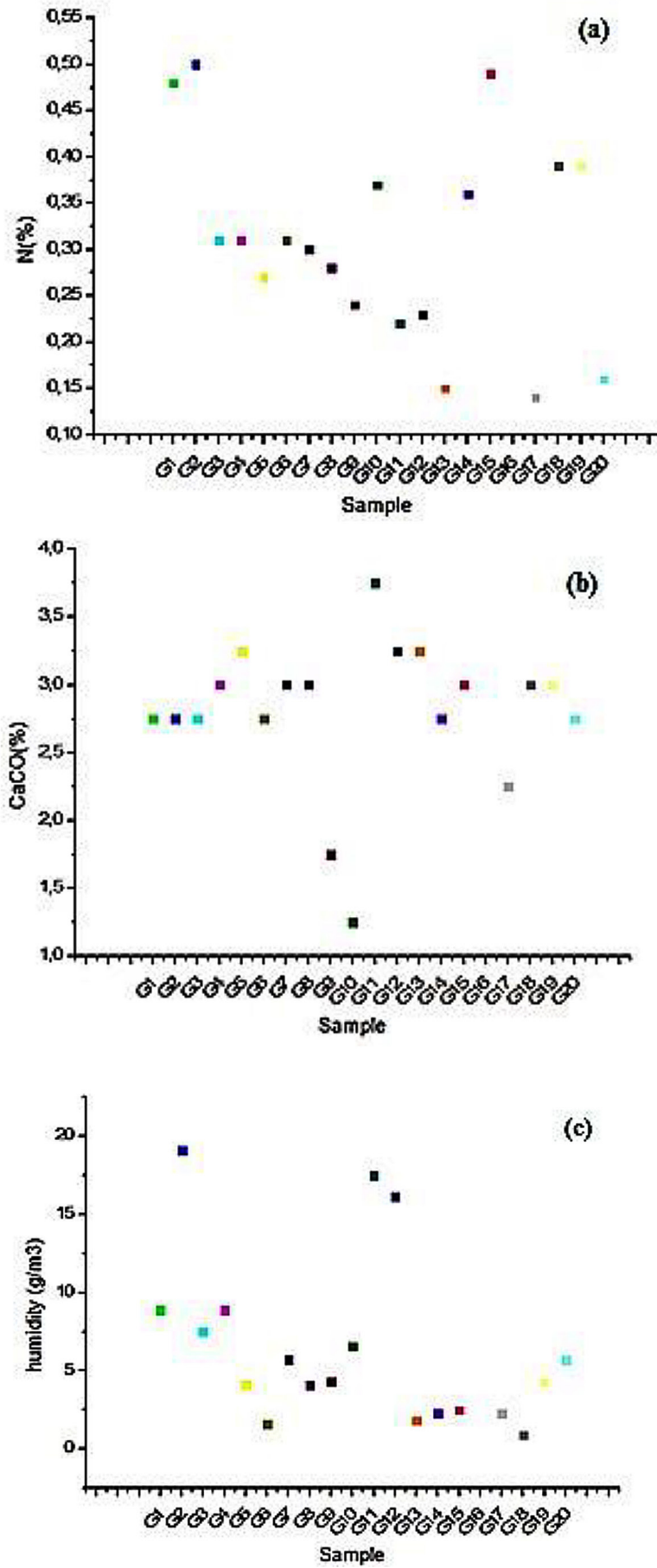


Figure 4. (a) Nitrogen, calcium carbonate (b) and (c) humidity of soils

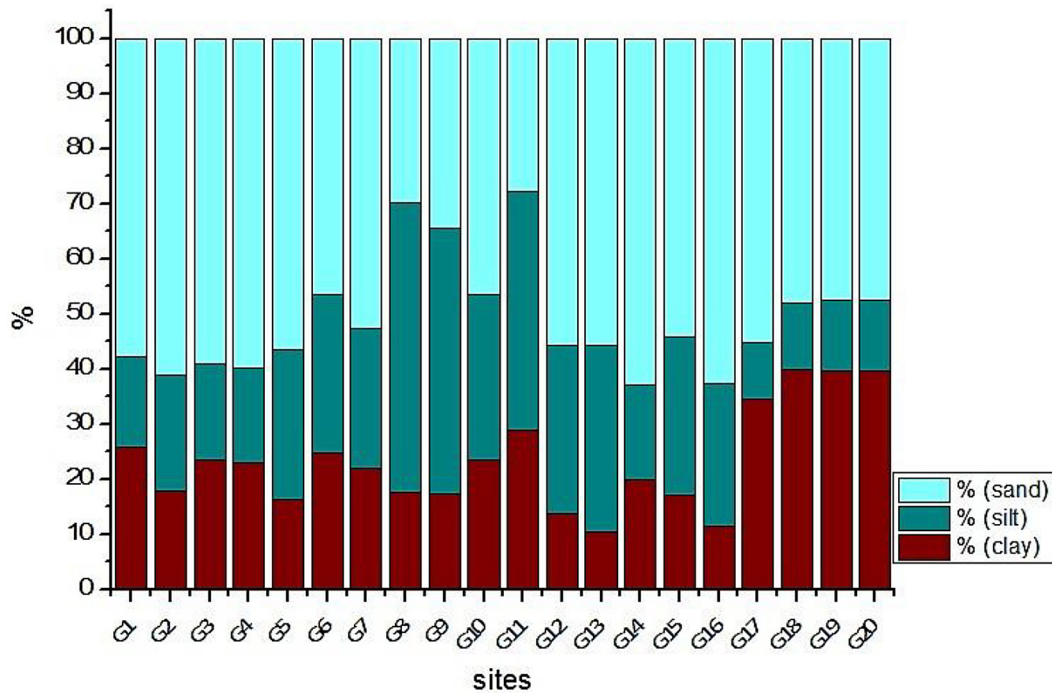


Figure 5. Samples distributed in the textured triangle

The findings reveal a sandy-clay texture for the soil. Various physico-chemical parameters such as pH, organic carbon (OC), and clay content are significant factors affecting soil quality. Additionally, these physico-chemical parameters (pH, OC, and clay content) are recognized as key factors influencing the solubility and mobility of metals in the soil (Ponting et al., 2021; Setälä et al., 2017).

Concentrations of trace metals

The sediments can constitute an internal source of metal contamination through the phenomenon of remobilization, which depends on the metal-sediment bond and the physico-chemical parameters. This shows the release of these metals during this period (Rees, A. B., 2018), which highlights the affinity of these metals with the exchangeable carbonate phase. This shows the potential risk of remobilization of these metals during this period at the slightest change in physico-chemical conditions (basic pH, decomposition of the organic matter, etc.).

The maximum chromium level recorded at station 7 (Table 1) is 149 ppm. The high load of wastewater from the city of Kenitra explains this result. Analyses were performed at levels of the analyzed soils. The copper values found are variable from one campaign to another. The maximum copper content was 80 ppm. As for copper,

the maximum zinc content was recorded at 61.5 ppm; this can be attributed to the pollutant load from the discharge. The important contribution of zinc is the result of the discharge of wastewater from the city of Kénitra, particularly the leaching of uncontrolled domestic waste at the river's edge. Indeed, zinc forms 44 to 47% of batteries, 12 to 13% of ferrous products protected by zinc against corrosion, 11 to 13% of rubbers, 8 to 9% of paper-cardboard, etc (Nzihou, 2020). On the other hand, cultivated soils can contribute to the Zn supply. Indeed, the fertilizers used are responsible for this contribution. The work has shown that nitrogen-phosphate based fertilizers can contain up to 83.3 mg Zn/Kg of fertilizer (Rasulov et al., 2020).

The average cadmium content ranged from 2 to 4.6 ppm (Table 1). A load of this element can have an atmospheric, agricultural and/or urban origin. The leaching of fertilized soil can also be a source of cadmium. Indeed, analyses of metal on phosphate and potash fertilizers have revealed their presence (Widi Astuti, 2019). Like the previous element, the analysis of lead in soil sediments shows that the levels vary between 3 and 53 ppm for the sampling campaigns. A particularly high level was found at station 14. This level could be due to vehicle exhaust gases (Chanklinhorn et al., 2022). The lead contamination of the system studied seems to come from the lead used

in fishermen's nets and washed up on the lake bottom, without neglecting the contribution of wastewater discharge (Skrzypczak et al., 2022). The average nickel content in the sediments studied ranged from 748 ppm. The nickel concentrations found are therefore not likely to disturb the ecological balance of the environment studied. The average manganese concentration varies from 474.4 ppm. The high concentrations are recorded during flooding. This is probably due to the leaching of manganese-rich soil. The average variation of manganese in the sediments is very irregular and does not seem to be linked solely to the discharges of the Kenitra agglomeration. The various results obtained for heavy metals indicate that the amount of these metallic elements is high in the areas affected by discharges and agricultural activities.

A comparison of the metal content of the soils studied with the sampling sites highlights the extent of metal pollution caused by domestic discharges and agricultural leaching, other activities (Pal and Maiti, 2018) (mechanics' garages, vehicle surface treatment workshops using paint, petrol distribution stations, textile industry and a concrete pipe manufacturing industry).

Statistic study

The major sources of heavy metal pollution in the general environment are anthropogenic. Several studies indicate that soils polluted with heavy metals, including low concentrations, as a result of human practices such as industrial waste disposal, recycling, public health may be at risk due to mining, smelting, and agricultural practices, including the utilization of sewage sludge, animal manure, agrochemicals, and inorganic fertilizers, which is a worldwide problem (Abdulghani et al., 2018; Arbyn et al., 2020).

The median level concentrations of heavy metals in the depth of the agricultural soil (0–30 cm) at the Kenitra site were 93.95; 34.6; 2.780; 284.95; 25.4; 300.38 and 495 mg/kg for Zn, Cu, Cd, Ni, Pb, Cr and Mn, respectively at the study site. It is evident from the findings that the soils have incurred heavy metal contamination, with concentrations exceeding normal levels. A noteworthy majority of soil samples exhibit a considerable ecological risk, particularly influenced by elevated Cd levels. Despite concentrations remaining within acceptable thresholds, the presence of non-essential heavy metals, even at lower levels, raises concerns about the potential harm to both the cultivation of vegetables in these soils and the broader environmental impact (Wang and Li, 2019).

Tables 2 and 3 present the number of heavy metals in agricultural soils as a function of the average concentration in the study site. On the basis of the results of the two-way ANOVA analysis detailed in Table 2, the differences in heavy metal concentrations within the cultivated soils of the different sites showed a high level of significance ($P < 0.001$) for Pb ($F = 29.538$), Cr ($F = 124.330$) and Mn ($F = 168.966$). A significant difference ($P < 0.01$) was also observed for Zn ($F = 11.068$), Cu ($F = 21.225$) and Ni ($F = 20.533$). No significant difference between sites was observed for Cd. With regard to the sampling depths, the mean concentration did not differ significantly for Zn, Cd, Ni, Pb, Cr and Mn, with the exception of Cu where the depth difference was highly significant ($F = 15.729$; $P < 0.001$) where the difference was significant for Zn ($F = 4.596$; $P < 0.05$).

The statistical significance of variations in soil characteristics and heavy metal concentrations was confirmed by the two-way ANOVA test, attributable to the influence of the environment. Heavy metals achieved statistical significance at the 0.05 level because of the site interaction.

Table 1. Characteristics of soils (mean \pm standard deviation) of the cultivated areas in the study site

Metal content	Min	Max	Medium	
	Statistics	Statistics	Statistics	Standard error
Zn	16.0	390.0	93.95	20
Mn	70.0	810.0	495.0	20
Cu	16.0	80.0	34.60	20
Ni	73.0	748.0	284.95	20
Cr	130.3	762.6	300.385	20
Cd	2.0	4.6	2.780	20
Pb	3.0	53.0	25.40	20

Table 2. Two-way ANOVA test results for soil characteristics concentration in soils

Parameter	N		Standard deviation	Variance	Skewness		Kurtosis	
	Statistics (mg/kg)	The mean value of soil properties	Statistics (mg/kg)	Statistics (mg/kg)	Statistics (mg/kg)	Standard error (mg/kg)	Statistics (mg/kg)	Standard error (mg/kg)
OM	20	-	1.0258	1.052	0.615	0.512	-0.766	0.992
P ₂ O ₅	20	-	17.908	320.70	2.351	0.512	7.151	0.992
K ₂ O	20	-	118.27	13988.1	2.154	0.512	4.705	0.992
EC	20	-	0.6233	0.389	1.643	0.512	2.272	0.992
Mg	20	-	1.2866	1.655	0.063	0.512	0.065	0.992
Cl	20	-	0.3703	0.137	2.674	0.512	8.395	0.992
HCO ₃	20	-	0.2911	0.085	1.023	0.512	1.564	0.992
Zn	20	93.95	74.0565	5484.366	3.604	0.512	15.070	0.992
Mn	20	495.0	190.8844	36436.842	-0.442	0.512	0.170	0.992
Cu	20	34.60	14.2880	204.147	1.670	0.512	4.486	0.992
Ni	20	284.95	196.5729	38640.892	1.115	0.512	0.039	0.992
Cr	20	300.385	191.0631	36505.119	1.559	0.512	1.351	0.992
Cd	20	2.780	0.6841	0.468	1.645	0.512	2.050	0.992
Pb	20	25.40	13.7856	190.042	0.554	0.512	-0.420	0.992
Azote	20	-	0.1083	0.012	0.105	0.512	-0.701	0.992
CaCO ₃	20	-	0.5815	0.338	-1.183	0.512	2.488	0.992

The findings are presented at Table 2. For pH and soil texture, a very highly significant difference was observed between sites at the 0.001 level. The organic matter content shows that the sediments studied are fairly high in OM, the majority of which is organic carbon, with an OM/OC ratio varying between 1.2 and 2. This conclusion can be justified by the influence of wastewater loaded with organic matter. Indeed, the fluctuations observed at the stations between the flood period and the low-water period are probably due to the significant leaching of the soil by rainwater and by the return of irrigation water from the agricultural land surrounding the lake, which is rich in organic substances.

Association of soil properties with heavy metals

The correlation matrix between the metals studied and the physicochemical parameters (Table 3) shows that these correlations are above the “significance” threshold. The correlation between the fine fraction (< 63 µm) and most metals is quite good ($r > 0.60$). This result supports previous studies stating that metals preferentially associate with the finest fraction of the sediment (Bayon et al., 2020; Gunalan et al., 2018). Lead, copper and cadmium show an affinity with carbonates (calcite)

and organic carbon ($r > 0.50$). The correlations between zinc, cadmium, chromium, organic carbon and carbonates are very low. This could be explained by the fact that these metals prefer other supports e.g. silicates, iron and manganese oxyhydroxides (Sipos et al., 2021). The good correlation between most of the analyzed metals and pH ($r \geq 0.5$ for Ni, Pb, Cu, Cr) allows noting the influence of this variable on the distribution of metallic elements in sediments. On the basis of the data of this matrix (Table 3), all metals the evolution of which can be considered comparable were grouped in order to minimize the parameters to be monitored in future studies and to adopt a decontamination strategy for this site.

In general, the negative effects of high pH, clay content, active limestone and high CEC on the assimilability of the metals Ni, Zn, Mn and Cu were noted on the one hand and the positive roles of organic matter on the other. In particular, according to statistically significant data, the negative effect of pH and the positive effect of organic matter were distinguished.

Evaluation of the degree of contamination

Analysis of the results obtained in Figure 6 shows that the average contamination indices of the stations studied, except for station 10, are between 3 and 40. These values reflect the high metallic

Table 3. Correlation coefficients between total metal content and other elements

	pH	EC	Zn	Cu	Ni	Cr	Cd	Pb	Clay	Sand
pH	1									
EC	0.043	1								
Zn	0.433*	-0.169	1							
Cu	0.593**	-0.040	0.706**	1						
Ni	0.475**	-0.294	0.612**	0.698**	1					
Cr	0.505**	-0.155	0.757**	0.721**	0.747**	1				
Cd	0.677**	-0.243	0.553**	0.749**	0.674**	0.635**	1			
Pb	0.522**	-0.255	0.764**	0.685**	0.687**	0.696**	0.834**	1		
Clay	0.254	0.007	0.333	0.533**	0.433*	0.412*	0.701**	0.525**	1	
Sand	-0.439*	0.156	-0.381*	-0.576**	-0.490**	-0.611**	-0.745**	-0.538**	-0.719**	1

contamination of the surface sediments of Kenitra sites. Station 10, the Im index of which is 1.8, is little affected by this pollution, given its position far from the discharges and the direction of flow.

Existing literature indicates that sand soil exhibits higher leaching of cadmium and nickel compared to loam soil (Pikuła and Stępień, 2021). By juxtaposing the obtained research results with the findings of other authors, it becomes apparent that heavier leaching of heavy metals into the deeper layers of the soil profile is observed in lighter soils when contrasted with those of medium density (Zhang et al., 2023). The elimination of contaminants from soil is crucial to prevent severe anthropogenic and toxic effects. Soil contamination with heavy metals has harmful consequences for living organisms. The inherent drawbacks of conventional methods, such as high

costs and prolonged efficacy times, impede their viability in the reclamation of contaminated soil (Gautam et al., 2023). Global apprehension surrounds heavy metals due to their widespread occurrence in soil and potent toxicity. The ecological threats posed by these hazardous metals and metalloids hinge on various abiotic factors, such as soil properties and baseline element values. A pioneering integrated risk assessment system has been devised to establish soil quality benchmarks for heavy metals, adaptable across diverse soil types, and equipped to evaluate ecological risks on a multi-regional scale. This cutting-edge framework proves invaluable for conducting ecological risk assessments in intricate, multi-regional soil environments, with its potential applicability extending beyond heavy metals (Guo et al., 2019; Parus et al., 2023; Yang et al., 2023).

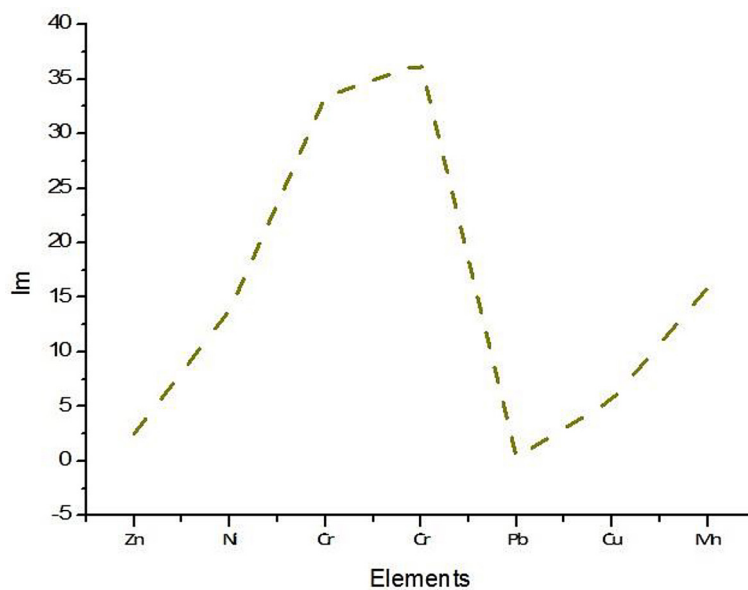


Figure 6. Element contamination index

CONCLUSIONS

The data obtained in this study enabled to assess the metallic content of the sediments of the Kentia site. The physic-chemical analysis of the surface sediments showed that there is significant organic pollution which is felt very clearly in the sediments. It should also be noted that these sediments are essentially formed by fine materials. The study showed that for the lead when the organic matter levels are high, it is the organic matter with the clay that causes its retention in the soil. For zinc, it is the clay that is most involved. However, for Cd, the study showed that its behavior in the soil is governed by pH and manganese. Conversely, when organic matter levels are low, it is the pH and silts that influence the retention of Pb and Cd, while iron and manganese oxides govern the retention of zinc. The concentrations of metals found in the sediments are higher than the concentrations found by some authors in the sediments considered unpolluted. Furthermore, 5 stations far from any disturbance have the lowest concentrations, with a significant difference in values compared to the other stations. The calculation of the contamination index and the contamination factor, which take into account the concentrations of the reference station, confirms metallic contamination of the sediments in the region. The comparison of metal contents in the deep sediments shows a depletion gradient from the sites towards the south for zinc, chromium, and cadmium. Indeed, the enrichment of the first few centimeters in these metals indicates the existence of a recent metal input. This result is only attributed to human activities. Copper and lead do not show such a gradient from the surface to the bottom.

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