EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2023, 24(2), 38–44
https://doi.org/10.12912/27197050/157037
ISSN 2719-7050, License CC-BY 4.0

Received: 2022.11.15
Accepted: 2022.12.08
Published: 2023.01.01

Assessment of Heavy Metal Contamination Using Pollution Index, Geo-Accumulation Index, and Potential Ecological Risk Index in Agricultural Soil – A Case Study in the Coastal Area of Doukkala (Morocco)

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ABSTRACT

Studies assessing the environmental risks related to metal pollution in agricultural soils are lacking in the coastal area of Doukkala, with is one of Morocco's most agricultural regions. To overcome the shortcomings of such studies, trace element (As, Cd, Pb, and Zn) analyses were carried out at four sampling points in agricultural surface soils, a total of sixty-six surface soil samples were raised with an auger at a depth of (0–20 cm) from the study area. This study examined the classification and levels of heavy metals in agricultural soil and applied the pollution score and ecological risk index to the Doukkala coastal area (Morocco). This study used pollution indicators, a geo-accumulation index, and potential ecological risk indices to examine the distribution and quantity of heavy metals in agricultural soils in the coastal region of Doukkala (Morocco). This study provides significant information for policymakers and environmental specialists to quantify soil contamination in the coastal area of Doukkala (Morocco).

Keywords: heavy metals; pollution index; potential ecological risks; agricultural soil; doukkala; Morocco.

INTRODUCTION

The health of humans, plants, and animals and also the quality of the environment, are threatened by metallic pollution, which is a serious ecological problem. Heavy metals are found in the Earth's crust together with other metals and metalloids; however, they cannot be destroyed or degraded because of their persistent nature. Environmental heavy metals and metalloids can be influence and taint the food chains and may be harmful to peoples and other species in high amounts (Lenntech, 2004; Nagajyoti et al., 2010). Owing to the increased use of fungicides, pesticides, and artificial fertilizers, modern agricultural practices have resulted in agricultural pollution, which has negatively affected the environment and ecosystem (Malik et al., 2017). In addition, a significant source of heavy metals in agricultural systems is the land application of livestock manure, organic waste manure, industrial wastes, and wastewater (Tóth et al., 2016; Balkhair and Ashraf., 2016; Srivastava et al., 2017; Woldetsadik et al., 2017; Sharma et al., 2017). Several experimental and quantitative methods have been developed to evaluate the hazards associated with the concentration of trace metals in soil, which serves as the first receiver of these metals in the agricultural systems, (Kouchou et al., 2020). The present study builds on earlier work done in the same field of study a few years ago (Mohcine et al., 2016, Mdiker, 2017; Moustaghfer, 2017; El Adnani, 2021). In this search, 66 agricultural ground samples (0–20 cm) have been collected from the coastal region of El Jadida.

The highest total metal concentrations found in agricultural soil near the coast were measured in chronologically to examine their distribution, potential ecological risks, and relationship with agronomic and industrial activities, as the origins of total metal concentrations could come from either human activity or natural sources to properly comprehend the status and the causes of ecological risks. The aims of this study were to (1) measure the levels of toxic metals in the surface soil, such as arsenic (As), cadmium (Cd), lead (Pb), and zinc (Zn); (2) analyze the level of contamination using the Soil Pollution Index (PI) and Geo-accumulation Index (Igeo); and (3) evaluate the Potential Ecological Risk Index (PERI). The results of this research provide a reference for heavy metal contamination and ecological hazards in agricultural soils of the coastal region of Doukkala.

MATERIALS AND METHODS

Study area

Western Morocco also has coastline. The Oued Oum-Errabia in the northeast, Gantour Plateau in the south, the Rehamna Massif in the east, and the Atlantic Ocean in the west are its external boundaries. This area, which is part of the Moroccan Meseta, is composed of tabular sedimentary layers from the Tertiary, Secondary, and Quaternary epochs that lie on a folded primary basement (El Achheb 2002).

The study area was a part of the Sahel. Located between El Jadida and Oualidia. It is limited to the north by the plateau of El Jadida, west by the Atlantic Ocean, south by the Sahel of Safi, and east by the Doukkala Plain. It extends over a length of approximately 85 km and a width of approximately 8 km.

Sample collection and preparation

This study was based on the identification and quantification of tpollution. These four trace elements (arsenic, cadmium, lead, and zinc) were inspected in sixty-six soil samples from the study area. The sampling was divided into four stations: Oualidia, Oulad Ghanem, Sidi Abed, and Jorf Lasfar. None of the sampling sites regions differed significantly in terms of the plant community, crop management, and agricultural practices. In general, the chosen plots were intended for market gardening. To complete this work, sixty-six topsoil samples were taken from the surface horizons (0–20 cm) using an iron auger. The samples were then transported to the laboratory and placed in clean polyethylene bags before being mixed and dispersed by hand. They were then licensed to airdried at room temperature prior to being sieved to 2 mm, which is the most reactive particle size fraction of the soil.

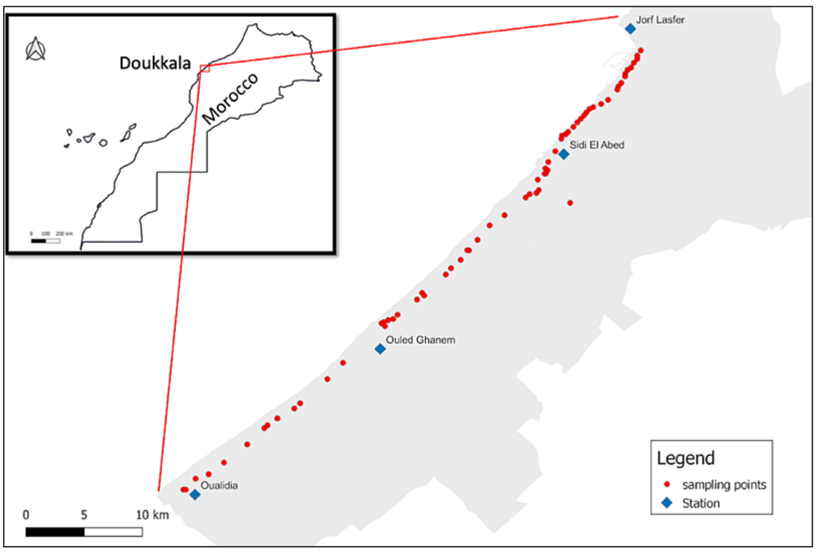

Fig.1. Map of the study area and sampling points

Metallic trace elements (As, Cd, Pb, and Zn) were determined by inductively coupled plasma atomic emission spectroscopy (ICP–AES) and controlled usign ICP-Expert Sequential software.

Assessment of heavy metal pollution

Many indices have been used to determine the degree of contamination of soils with trace metals. These indices were determined by using the commonly used geochemical background of the upper crust. This study focuses on the soil Pollution Index (PI), the Geo-accumulation Index (Igeo), and the Potential Ecological Risk Index (PERI).

Pollution index (PI)

The PI explains how the environmental limitation average value, which is employed to analyze a specific contamination project, and the measured value relate to one another. This approach is straightforward and suitable for many types of pollution evaluations (Jiang, et al., 2020). The following formula was used to perform the calculations (Eq. 1):

$$IP = \frac{(As/40 + Cd/3 + Pb/100 + Zn/300)}{4} \quad (1)$$

Sayadi (2015) divided the Pollution Index into seven classes. The standard classifications of the pollution index are presented in Table 1:

Table 1. Classification of pollution index Sayadi (2015)

PI	Pollution levels
0	Unpolluted
1	Unpolluted-moderate
2	Moderate pollution
3	Moderate-high pollution
4	High pollution
5	High-Very high pollution
6	Very high pollution

Geo-accumulation index (Igeo)

Igeo was presented by Muller (1969) to determine the level of metallic pollution in the sediments. This was calculated with the use to the following equation (Eq. 2):

$$I_{geo} = log_2\left(\frac{C_n}{1{,}5*B_n}\right) \quad (2)$$

where: C_n – the checked concentration of a metal (n) in the soil; B_n is the level of metal (n) in the geochemical background; 1.5 – the matrix correction factor of the geochemical background related to lithology.

The following table presents the classification of polluted soils according to Igeo (Muller 1969).

Table 2. Classification of soils according to the geo-accumulation index (Igeo)

Igeo	Pollution class
<0	Uncontaminated
0–1	Uncontaminated to moderate
1–2	Moderate
2–3	Moderate to strong
3–4	Strong
4–5	Strong to very strong
>5	Very strong

Potential ecological risk index (PERI)

Hakanson introduced the (PERI) to assess the ecological, environmental, and toxicological impacts of heavy metals, (Hakanson, 1980). This approach is frequently used in associated studies (Chen et al., 2022) to represent the effects of pollutants on the environment in a particular context, and to classify quantitatively classify the potential risks of heavy metals. The following equation can be used to determine the possible ecological risk indices of the individual heavy metal elements.

$$E_i^f = C_i^f * T_i^f \quad (3)$$

The formula for calculating the overall index of potential ecological risk for several heavy metals is as follows (Eq. 4):

$$IRE = \sum E_i^f \quad (4)$$

where: Ti is the toxic response factor; Ci (mg/kg) is the measured content of heavy metal; Si (mg/kg) is the reference ratio of heavy metal i.

The standard classification of the potential ecological risk index according to Hakanson (1980), is presented in Table 3.

Table 3. Potential ecological risk index classification

IRE	Risk levels
<150	Low
150–300	Moderate
300–600	Considerate
>600	Very high

RESULTS AND DISCUSSION

Pollution index (PI)

Multi-element contamination has been identified and recognized as the result of an excessive a increase in the toxicity of metals. Multiple authors agree that the ecosystem impacts of trace metal pollution are related to all pollutants, not just to one metal. Therefore, the pollution index (PI) is a typical metal content concentration in soil samples compared to the murmur value (Jung, 1995).

The results of the calculation of the pollution indices for different substrates in our study are shown in Figure 2. The spatial variation of the pollution index in the coastal area of the Doukkala region indicates minimum values observed in the soil of Sidi Abed station (0.47) and the most significant PI values were detected at the Jorf Lasfar station (0.97), and the most likely source of soil pollution in this area is the emissions that fall in the form of dust in a radius near the industrial complex of Jorf Lasfar and the regional highway linking El Jadida to Sidi Abid, where the traffic is the densest. The emissions of metallic micropollutants is an important source of soil pollution by metallic trace elements at the Jorf Lasfar station.

Geo-accumulation index (Igeo)

The studied soils were contaminated with the analyzed metallic trace elements. We found a high contamination by Cd at the different stations studied, moderate to high contamination by arsenic at the station of Jorf Lasfar (2.11), and slight contamination by the same metal at the station of Oualidia (1.08). The values (I-geo) of each element in the soil samples are listed in the following table (4). According to these values, the levels of the metals studied were in the following order: Cd>Ar>Zn>Pb. Note that the contaminated stations are located at the level of the sectors with strong industrial activity and at the level of the sectors with strong agricultural activity.

Potential sources of the heavy metals ecological risks

The index of potential ecological risk is an very important factor for estimating the ecological risk caused by trace metal elements in the studied soils. The obtained results highlight considerable risk levels at the stations of Sidi Abed (387.5), Oulad Ghanem (391.48), and Oualidia (395.73). In contrast, a very high risk has been detected in the Jorf Lasfar area (431.53). This station is located at the level of the sectors with strong industrial activities and at the level of the sectors with strong agricultural activities (Fig. 3).

The distribution of the index of potential ecological risk in the study area probably depends

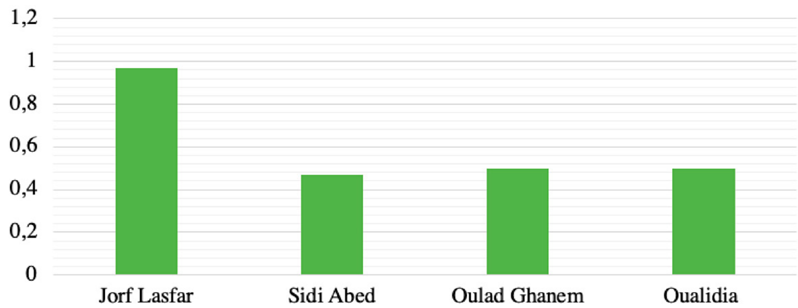

Fig. 2. Soil pollution index (PI) for the studied zones

Table 4. Geo-accumulation indices for the soils of the study sites

Station	Geo-accumulation index (I-geo)			
	As	Cd	Pb	Zn
Jorf Lasfar	2.115	3.001	-0.271	1.345
Sidi Abed	0.082	3.079	-3.157	-1.180
Oulad Ghanem	0.449	3.075	-3.104	-0.404
Oualidia	1.084	3.048	-3.314	-0.117

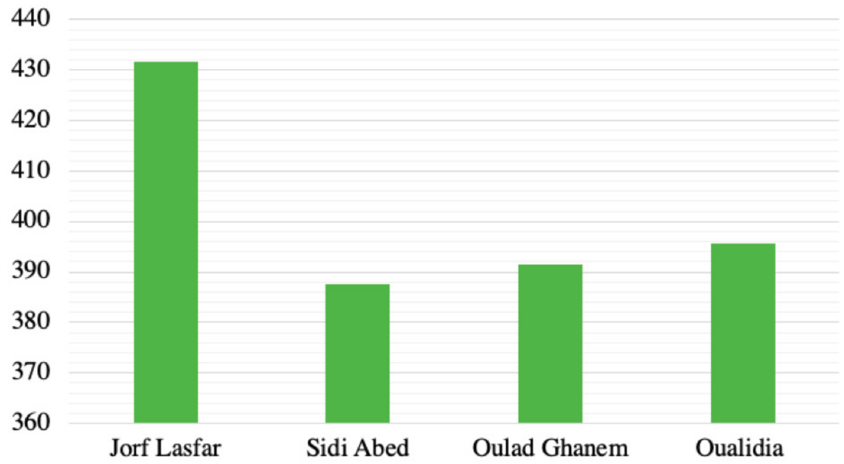

Fig. 3. Potential ecological risk index (IRE) in each station

on several factors characterizing this area; however, it is related to the application of pesticides (herbicides, insecticides, and fungicides) used for agrochemical treatments of vegetable crops and the utilization of fertilizers based on phosphate, which can present very high levels of cadmium. On the other hand, the increase in the content of metallic trace elements by masses of cadmium, lead, and zinc is transported by the flow of water on the surface of soils in rainy weather on roofs and pavements. Roof runoff has two distinct origins: input from atmospheric deposition and metal corrosion.

Approaches to ecological rehabilitation in the future

Due to the high indices of pollution in soils near the industrial zone of Jorf Lasfar in the coastal area of Doukkala, it is important to take seriously efforts to reduce heavy metal contamination in this region. It is crucial to consider land use planning, environmental protection, and soil restoration. First, anthropogenic factors such as factories are responsible for agricultural soil contamination. Inorganic fertilizers, pesticides, industrial waste, wastewater, incineration, open dumps, highways, traffic, and other emission, it can be controlled by optimizing farmland use design. Second, the government must reduce the use of heavy industries, fertilizers, and pesticides in agriculture, as well as to manage the heavy metal contamination (Guan et al., 2018; Briffa et al., 2020). Various soil remediation techniques can be used depending on the type of heavy metals present and the level of risk (Mao et al., 2019; Huang et al., 2019). Specific plants can be grown in places with significant ecological dangers from heavy metals based on the adsorption qualities of the metals. Further biochemical actions are required to remediate contaminated soils (Cong et al., 2021).

CONCLUSIONS

Contamination and accumulation of toxic metals in soil can lead to various environmental, plant, and human health problems. In this study, 66 ground samples were collected from the coastal area of Doukkala (Morocco). To evaluate the toxicity of the heavy metals, the values of arsenic, cadmium, lead, and zinc were employed to determine the indicators of pollution and probable ecological harm. The results showed that the pollution index of the Jorf Lasfar station was significantly higher than that of the other stations. The potential ecological risk index ranged from highlighted considerate risk levels to very high-risk levels, gradually increasing in areas of high industrial activity. The findings of this study advance our understanding of toxic metal enrichment and the risk of soil being used for market gardening, both of which are important issues for human health. In the coastal area of Doukkala. Therefore, it is imperative that the government conducts ecological rehabilitation, including planning for land use, managing pollutants, and restoring soil to reduce heavy metal pollution in farmed soil.

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