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Assessment of Pollution by Heavy Metals at Landforms of Selected Areas in the Nile Valley and Desert Fringes

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Abstract

The high concentricity of heavy metals is noxious to soils, plants, and humans. The aim of this study is to investigate the distribution of heavy metals (Fe, Mn, Zn, Cu, Pb, Ni, Cd, and Cr) in the landforms of the El-Saff area, Egypt. Satellite images were used to produce the landform map, digital elevation model (DEM), and field data. Collected soil samples were analyzed, the obtained data were used to create the spatial distribution layers of heavy metals. Data indicated that the main landforms in the study area are the flood plain, piedmont, and valleys which covered 19.57, 45.43, and 8.27 % of the study area respectively. The data also showed that the concentrations of Mn, Pb, Cu, and Ni were high in the flood plain while Zn and Cd concentrations were higher in the desert fringes (*i.e.*, piedmont and valleys). The assessment of heavy metals reveals that most of the elements are under the critical levels in the studied landforms. The higher contaminations are associated with cultivated areas irrigated by sewage water.

Keywords: Desert fringes, heavy metals, landforms, Nile valley, and spatial analysis.

1. Introduction

Heavy metals in the agroecosystems trigger several chain reactions that alter the quality of soil, water, and the atmosphere. This is mirrored in the alterations in the structure of living organisms that inhabit them [1]. In recent years, pollution became a global issue the emergence of heavy metals contaminants above natural loads it has a growing issue. That has direct implications for human health and environmental degradation [2]. The accumulations of heavy metals in soils threaten the crops, atmosphere, and aquatic environments [3]. The link between deterioration of human health and pollution has been verified in recent environmental assessments [4]. Heavy metals can move into the food through soil or water. Pollutants are deposited in soil as a result of a variety of human activities then risky compounds are absorbed by cultivated plants, causing some issues at various stages in the food chain. So, the soil is a leaching layer for trace elements [5]. Humans and other animals are poisoned by excessive heavy metal deposition in soils. Pollutants can be prevented from being taken up by plants by using optimal soil and crop management [6]. When heavy metals enter live organisms, they generate extremely stable bio-toxic compounds because they are mixed with enzymes, proteins, and DNA molecules, which impair their correct functioning and prevent them from participating in bioreactions, resulting in mutagenic, carcinogenic, and genotoxic consequences [7]. Through 2015, pollution-related illnesses were responsible for 16% of all fatalities globally. The pollution-related disease is caused more than one out of every four deaths in the most seriously impacted countries. This has emerged because of population growth, rising urbanization, changing lifestyle, industrial expansion, natural resource discovery and exploitation, and extension of modern agricultural practices [8]. In Egypt, the speedy

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urbanization and industrialization have led to increased disposal of heavy metals [9]. All inputs that contain excessive quantities of chemicals or biological materials into soils are considered pollution sources for agricultural soils. Another source of soil contamination is irrigation with low water quality [10]. Egypt's primary sources of soil contamination include that: During the intensive Egyptian farming system, fertilizers and insecticides were misused. Also, household wastewater is discharged to drains in rural regions, where it is utilized for agricultural irrigation. likewise, industrial effluents are discharged into irrigation watercourse. Furthermore, polluted wet and dry atmospherically deposits might be counted as a source of soil contamination in Egypt [11] adapted from [12]. Heavy metals emitted by smelters, waste incinerators, industrial effluent, sludge, or municipal compost pesticides and fertilizers can pollute large regions of land [13]. The industrial complex created liquid wastes that elevated Fe, Zn, and Mn levels in the Nile River by three times their usual levels at Helwan [14]. Some international researchers began to use the Geographic Information Systems (GIS) to detect likely pollution sources and undertake ecological risk assessments to better understand the distribution of heavy metals in the soil, with impressive results [15] and [16]. GIS is one of the most effective techniques for investigating environmental geochemistry [17]. The spatial analysis technique might be used to map heavy metals concentration levels and identify potential hotspots in soils [18]. The interpretation of spatial trends in multivariate is the key problem for researchers [19]. By using a spatial analysis technique, the pollution level and immediate action to remediate the soil could be assessed [20]. For assessing the impact of heavy metals on soil and defining contaminated zones, spatial distribution is critical [21].

The main objective of this work is to use Remote sensing data and Geographical Information Systems (GIS) to assess and compare the distribution of the heavy metals in the soils of the flood plain and desert fringes located in El-Saff area, Giza governorate, Egypt.

2. **Materials and methods**

2.1. Study area

The study area is located in El-Saff district, Giza Governorate east of River Nile (Figure 1). It occupies 356.74 Km2 and extends between latitudes 29°46’6.96’’ and 29°31’15.6’’north and longitudes 31°17’32.28’’ & 31°20’23.64’’ east. It represents the Nile sediments' former farmed area as well as their outskirts of the newly reclaimed land for agricultural land use. According to the Egyptian Meteorological Authority, [22]. the main annual temperature reaches its maximum (27.3 C°) in June - August interval, while the minimum attains 12.7 C° in January. The precipitation is not equally distributed through the rainy seasons. The amount of annual rainfall is very low, mostly falls in winter, as it reaches 26.7 mm/year. The rainfall mostly falls in November-March intervals. Geologically, the area belongs to the lower to middle Eocene formations of shale with siltstone, sandstone and subordinate limestone layers [23]. The area has two main sources of irrigation *i.e.*, (1) the Nile River and (2) new El-Saff canal which is supplied with sewage water from Arab Abu-Saed treatment plant. The area is characterized by a large number of brick factories and dense road network where burnet fuel and automobile exhaust increases.

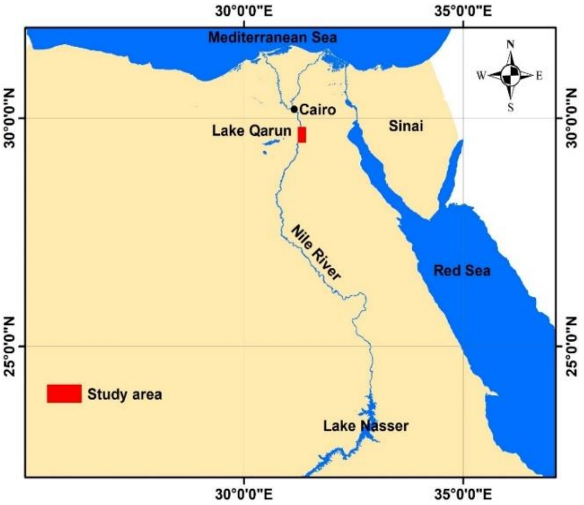

Figure 1: Location of the study area.

2.2. Landform mapping

In this study satellite data were used to delineate the main landforms in the investigated area [24]. The Landsat 8 and Shuttle Radar Topography Mission (SRTM) images were obtained from US Geological Survey website. The Landsat-8 image (path /176 - row /040) acquired during 2018 was processed using ENVI 5.2 software [25], specifications of this data are illustrated (Table 1). The image was projected to the UTM system and WGS 1984 datum. The digital elevation model (DEM) was extracted from the SRTM data. The DEM was combined with Landsat 8 image to delineate the preliminary landforms over the area following the methodology detailed by Zinck and Valenzuela, [26].

Table 1. The spectral characteristics of Landsat-8

Bands	Wavelength (μm)	Spatial Resolution (m)
Band 1-Coastal aerosol	0.43–0.45	30
Band 2-Blue	0.45–0.51	30
Band 3-Green	0.53–0.59	30
Band 4-Red	0.64–0.67	30
Band 5-Near infrared (NIR)	0.85–0.88	30
Band 6-Short-wave infrared (SWIR 1)	1.57–1.65	30
Band 7-Short-wave infrared (SWIR 2)	2.11–2.29	30
Band 8-Panchromatic	0.50–0.68	15
Band 9-Cirrus	1.36–1.38	30
Band 10-Thermal infrared (TIRS) 1	10.60–11.19	100*(30)
Band 11-Thermal infrared (TIRS) 2	11.50–12.51	100*(30)

2.3. Fieldwork and lab analysis

Fieldwork was carried out to collect soil samples from different landform units and verify the accuracy of the preliminary landform map. Sum of 28 soil profiles of which flood plain 9, piedmont 12, and valley 7 were studied selected in the field (Figure 2), morphologically described according to the guidelines outlined by FAO, [27]. Based on the morphological variations a total of 76 disturbed soil samples were collected and prepared to determine the soil texture, CaCO3 %, exchangeable sodium percent (ESP), and organic matter (OM) in the soil following the methods detailed by Soil Survey Staff, [28]. The available content of heavy metals; Fe, Mn, Zn, Cr, Cu, Cd, Ni, and Pb were chemically extracted from soils by DTPA according to [29] and determined by Inductively Coupled Plasma (ICP-OSE).

2.4. Spatial analysis

In this regard, spatial distribution is necessary to assess the effects of heavy metals in soil and to map the contamination zones. The use of inverse distance weight (IDW) model commonly used spatial interpolation of heavy metal distribution patterns [30]. Spatial interpolation is usually used for creating incessant information for the data collected from discrete sites (*i.e.*, soil samples). The IDW's interpolation can create heavy metal distribution maps for large area and evaluate the probability of heavy metal concentrations exceeding their guidance levels [31]. The IDW model in Arc-GIS 10.3 software has been used to interpolate the heavy metals (*i.e.*, Cd, Cr, Fe, Zn, Pb, Cu, Ni, and Mn) in the soils of different landforms. The levels of heavy metals were assessed based on the limits proposed by Ewers [32].

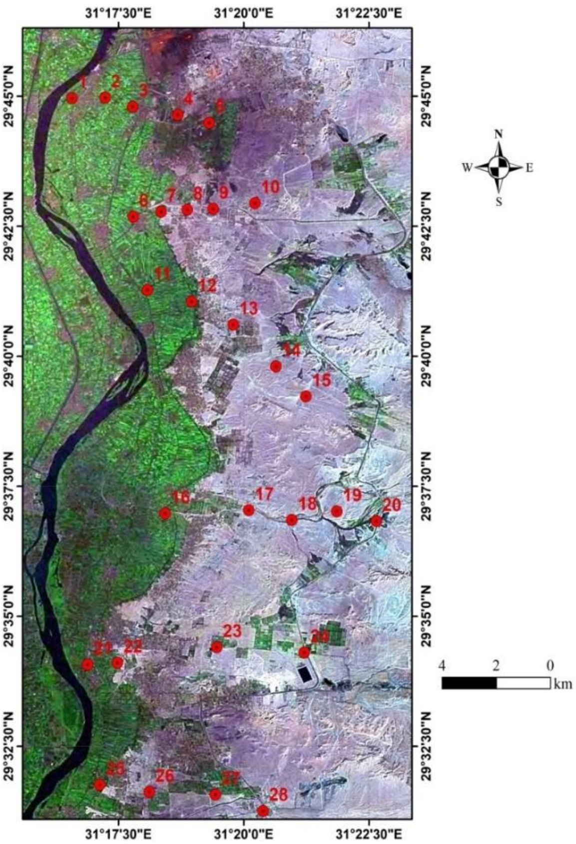

Figure 2: Location of the investigated soil profiles over landsat-8 image acquired in 2021

3. **Results and discussion**

3.1. Landforms and soils

The main landforms of the study area are presented in Figure 3. The area includes four main landforms *i.e.*, flood plain, piedmont, valley, and plateau were identified. The obtained data could be detailed as follows:

The flood plain: this landform is in the general flat area closed to the Nile stream and formed from alluvial deposits of silt and clay during the sequential flooding periods. This landform was represented by 9 soil profiles (*i.e.*, 1, 2, 3, 6, 11, 12, 16, 21 and 25). Data show that the soils in the flood plain landform are characterized by moderate soil depth (60 to 100 cm), clay to clay loam texture, and moderate content of calcium carbonate (3.04 to 18.68%). The exchangeable sodium percent (ESP) is in general low except profile No. 1 (ESP= 44.99) and profile No. 11 (ESP= 15.25). Organic matter content (OM %) is rather low as it changes from 0.34 to 1.51 % due to the arid climate. Cultivation is the main land use in this landform, where the traditional crops *i.e.,* wheat, barley, maize, and vegetables are dominant. Some areas suffer from land degradation by water logging and alkalinity.

The piedmont: this landform is undulating area formed closed to the foot of highland and plateaus. Twelve soil profiles represent this landform (*i.e.*, 4, 5, 10, 13, 14, 15, 19, 23, 24, 26, 27 and 28). The soil depth is moderate as it differs from 60 to 100 cm; soil texture is sandy to sandy clay loam. Calcium carbonate content ranges between 3.05 and 16.08%. The ESP as a whole is low as it changes from 1.57 to 7.86. Organic matter content is very low (> 0.50 %) in the soils of piedmont landform except some cultivated areas scattered over this landform as the OM may increase to be 1.21%. In general, the piedmont is barren land interspersed with burnt clay bricks industry and scattered patches of newly reclaimed areas. The main limitations of agriculture extension in piedmont are soil texture, fertility, and drainage.

The valleys: this landform is an elongated depression extending between highlands (*e.g.*, hills, plateaus, or mountains). The soils of the valleys were represented by 7 profiles (*i.e.*, 7, 8, 9, 17, 18, 20, and 22). Valleys are recognized by moderate to deep soils (60 - 150 cm), sandy to sand clay loam texture, moderate content of calcium carbonate (5.27 – 16.36%), and low ESP (3.11 – 12.11). the organic matter content in the valley landform has a wide range as it differs from 0.05 to 1.48 % according to the type of land use. As a whole, the valleys in the area are barren land with few reclaimed areas. The main limitations of agriculture in this landform include soil texture, drainage, soil fertility as well as water scarcity.

3.2. Heavy metals and landforms

By using the data illustrated in Table 2, the spatial distribution of heavy metals in the soils of the study area was done in (Figure 4). The obtained data were compared with the threshold limits suggested by UNEP, [33] and Toth *et al.*, [34]. The results indicate that the concentration of available Fe differs from 3.80 to 158.60 mg kg^{-1}, Fe is highly deficient (< 10 mg kg^{-1}) in sites 15 and 17 (barren land) while considered excess (> 150 mg kg^{-1}) in site 20 (cultivation irrigated with sewage water). Values of available Mn range between 1.12 and 65.00 mg kg^{-1}, Mn is highly deficient (<4 mg kg^{-1}) in sites No. 10, 15, 17, and 19, it is noticed that all of these sites are barren lands. The Mn values are adequate (8 - 80 mg kg^{-1}) in the rest of investigated sites. The available concentration of Zn in the soils is located in the range (0.60 – 55.44 mg kg^{-1}) this indicates that zinc concentration in all sites is located under the allowed limits (0.50 – 200 mg kg^{-1}) in the soils. Regarding to copper (0.10 – 13.00 mg kg^{-1}), it is found that it is highly deficient in all sites. The available concentration of Pb in the investigated soils range between 0.16 and 132.80 mg kg^{-1}, maximum values characterize the old cultivation in sites no. 2 and 16.

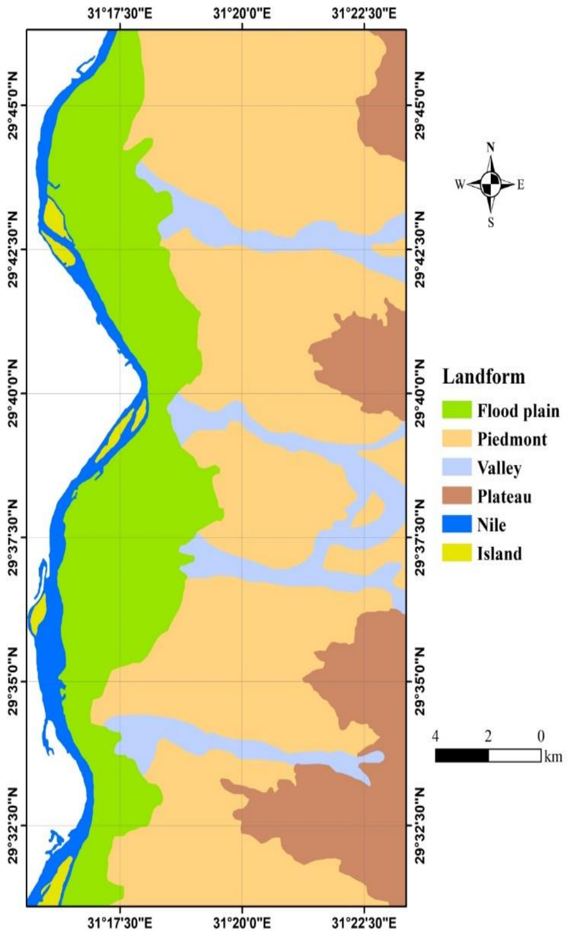

Figure 3: Main landforms of the study area

The threshold limits of Cd (1.00 mg kg^{-1}), Cr (100 mg kg^{-1}), and Ni (50 mg kg^{-1}) indicated that their concentrations in the soils are within safe limits from an ecological perspective statistical parameters of heavy metals in the flood plain, piedmont, and valley landforms are illustrated in Tables 3, 4, and 5. The findings show that the concentrations of Mn, Cu, Pb, Cd, and Ni are increased in the flood plain landform (Figures 5 and 6) as it reaches 58.2, 13.00, 132.80, 0.10 and 2.38 mg kg^{-1} respectively. The high values of Pb, Mn and Ni could be attributed to the dense road network, urbanization and burnt clay bricks industry. Mean values of Fe are almost equal in the different landforms as it reaches 70.58, 62.80 and 78.25 mg kg^{-1} in the flood plain, piedmont and valleys respectively. The concentrations of Zn and Cd are high in the desert fringes (piedmont and valleys) when compared with the flood plain. It worthy to mention that the new cultivation projects in the desert fringes are irrigated with sewage water resulted from Arab Abu-Saed treatment plant.

Table 2: Values of available heavy metals in the studied soils

Site No.	**Landform**	**Concentration of heavy metals (mg kg^{-1})**							
		Fe	**Mn**	**Zn**	**Cu**	**Pb**	**Cd**	**Cr**	**Ni**
1	Flood plain	83.00	58.20	8.80	13.00	10.20	0.06	0.14	1.80
2	Flood plain	98.00	42.12	16.38	12.40	132.80	0.10	0.20	2.38
3	Flood plain	87.20	24.60	7.60	7.40	3.40	0.04	0.08	1.60
4	Piedmont	69.60	24.80	23.80	3.20	1.60	0.02	0.20	0.54
5	Piedmont	32.40	12.20	52.60	0.10	2.60	0.04	0.04	0.20
6	Flood plain	74.40	52.20	3.60	10.00	3.40	0.02	0.08	2.20
7	Valley	66.20	28.80	16.60	7.40	4.40	0.04	0.40	0.90
8	Valley	113.12	31.58	27.54	6.30	4.60	0.04	0.16	0.64
9	Valley	126.90	38.32	55.44	7.34	5.18	0.08	0.30	0.84
10	Piedmont	10.80	4.20	10.20	0.94	2.20	0.01	0.06	0.11
11	Flood plain	52.32	37.60	3.36	6.60	2.70	0.02	0.12	1.00
12	Flood plain	56.20	51.98	5.32	6.52	1.98	0.01	0.08	1.32
13	Piedmont	30.32	26.56	3.48	2.54	1.86	0.01	0.08	0.50
14	Piedmont	80.00	40.62	14.82	3.80	3.54	0.04	0.26	0.92
15	Piedmont	3.80	1.12	0.60	7.00	0.16	0.01	0.02	0.04
16	Flood plain	88.30	31.34	12.26	9.20	97.40	0.02	0.08	1.48
17	Valley	5.56	2.80	0.84	0.88	0.30	0.01	0.02	0.06
18	Valley	25.20	9.00	1.96	2.46	0.66	0.01	0.06	0.40
19	Piedmont	14.80	2.20	1.00	1.00	0.60	0.01	0.02	0.08
20	Valley	158.60	14.28	23.80	6.32	2.40	0.04	0.32	0.80
21	Flood plain	49.80	39.06	4.66	4.40	2.72	0.01	0.08	0.98
22	Valley	52.20	65.00	12.20	6.00	5.20	0.04	0.10	1.18
23	Piedmont	71.36	14.14	8.80	2.00	1.04	0.01	0.32	0.44
24	Piedmont	127.60	21.80	20.40	5.60	2.60	0.04	0.30	1.32
25	Flood plain	46.00	46.94	5.40	4.98	2.60	0.02	0.08	1.00
26	Piedmont	71.68	34.00	14.58	3.94	3.36	0.04	0.24	0.80
27	Piedmont	135.00	47.00	19.40	2.40	2.60	0.04	0.52	1.28
28	Piedmont	106.20	19.68	13.80	4.60	1.68	0.02	0.30	0.58

Table 3: Statistical parameters of heavy metals in the soils of flood plain (9 samples)

Variable	**Fe**	**Mn**	**Zn**	**Cu**	**Pb**	**Cd**	**Cr**	**Ni**
Mean	70.58	42.67	7.49	8.28	28.58	0.04	0.10	1.53
Max	98.00	58.20	16.38	13.00	132.80	0.10	0.20	2.38
Min	46.00	24.60	3.36	4.40	1.98	0.02	0.08	0.98
STDV	18.52	10.17	4.12	2.90	47.05	0.03	0.04	0.49

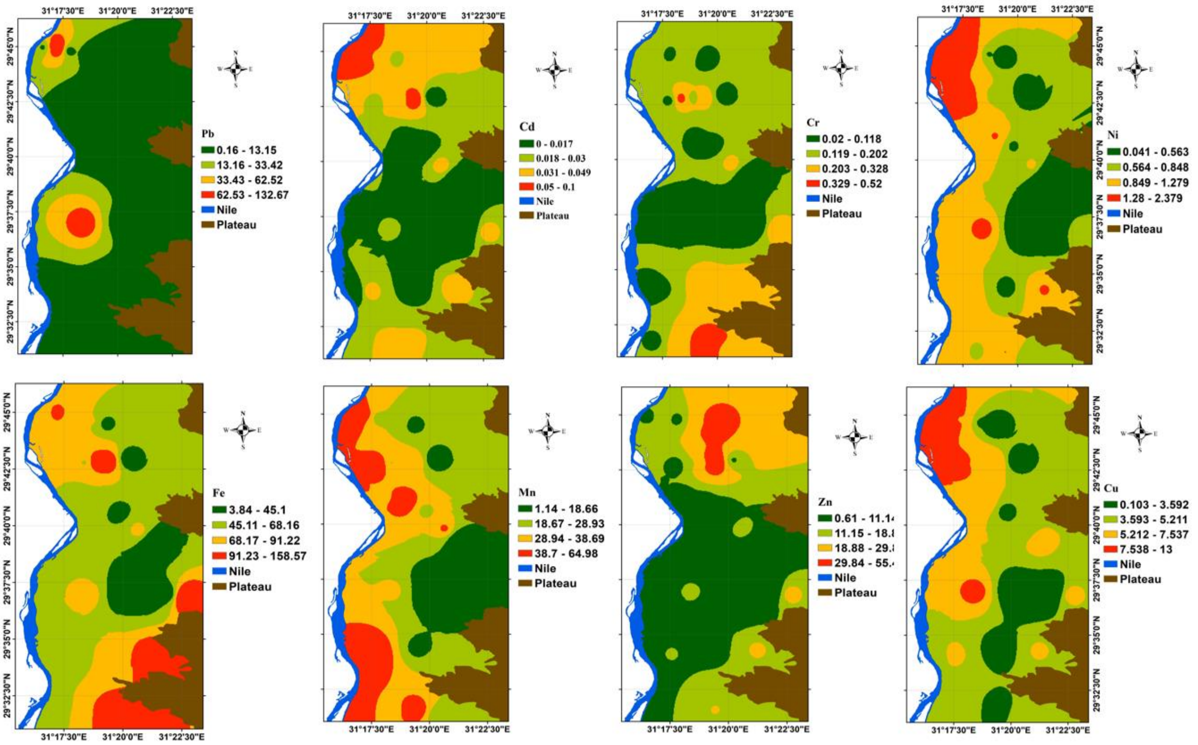

Figure 4: Spatial distribution of heavy metals over the study area (mg kg^{-1}).

Table 4: Statistical parameters of heavy metals in the soils of piedmont (12 samples)

Variable	Fe	Mn	Zn	Cu	Pb	Cd	Cr	Ni
Mean	62.80	20.69	15.29	3.09	1.99	0.03	0.20	0.57
Max	135.00	47.00	52.60	7.00	3.54	0.04	0.52	1.32
Min	3.80	1.12	0.60	0.10	0.16	0.02	0.02	0.04
STDV	43.07	14.24	13.35	1.94	1.00	0.01	0.15	0.42

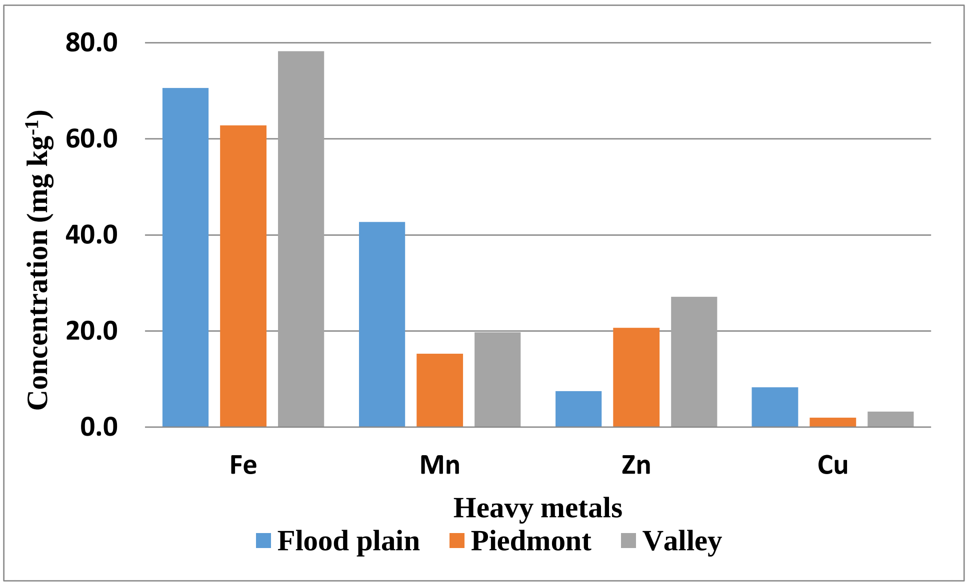

Figure 5: Variation of Fe, Mn, Zn, and Cu (mg kg^{-1}) over the landforms

Table 5: Statistical parameters of heavy metals in the soils of valleys (7 samples)

Variable	Fe	Mn	Zn	Cu	Pb	Cd	Cr	Ni
Mean	78.25	27.11	19.77	5.24	3.25	0.05	0.19	0.69
Max	158.60	65.00	55.44	7.40	5.20	0.08	0.40	1.18
Min	5.56	2.80	0.84	0.88	0.30	0.04	0.02	0.06
STDV	52.05	19.52	17.29	2.35	1.96	0.02	0.14	0.34

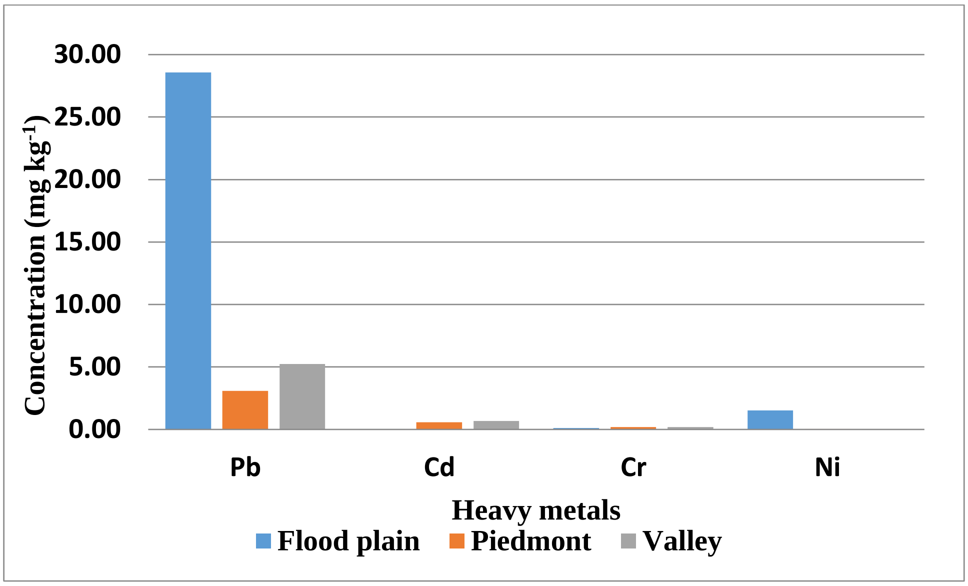

Figure 6: Variation of Pb, Cd, Cr, and Ni (in mg kg^{-1}) over the landforms

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4. **Conclusions**

Recognition of the variations of heavy metals across the landforms is the cornerstone of the optimum land management. This work investigates the spatial distribution of heavy metals along the landforms of flood plain and desert fringes. Heavy metals concentration varies widely between landforms due to the variation in soil characteristics and land use type. The findings of this study indicate high concentration of Pb and Mn in the soils of the flood plain. Concentrations of Zn and Cd are increased in the piedmont and valleys especially in the new cultivated areas irrigated with sewage water. The values of Pb in the flood plain changes widely with STDV (47.05) meanwhile the high concentration is corresponding to the sites adjacent the urban areas. The concentrations of Cd (0.10 – 0.01 mg kg^{-1}), Cr (0.02 – 0.52 mg kg^{-1}) and Ni (0.04 – 2.38 mg kg^{-1}) are in safe limits while Pb (0.16 – 132.80 mg kg^{-1}) exceeds the permissible limits.

5. **References**

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