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*Research Article*

# Assessment of Potential Soil Contamination by Heavy Metals in Some Areas of Nile Delta, Egypt

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**Abstract:**
Pollutants have a detrimental effect on crop quality, endangering both human health and food security in recent decades. In order to design a remediation approach that stabilizes heavy metals in contaminated soil and reduce the high concentration levels of heavy metals in the soil, an accurate estimation of the concentrations of heavy metals in Egypt's northwest Nile Delta is necessary. A geo-accumulation index (I-geo), contamination factor (CF), Pollution Load Index (PLI), and Modified Degree of Contamination (mCd) supported by GIS were used to analyse 50 surface soil samples for five heavy metals (As, Cu, Ni, Pb, and Zn) to assess the level of soil contamination in the study area. The results demonstrate that there were notable differences in the amounts of As, Cu, Ni, Pb, and Zn in the various soil samples. There was a range of -6.60 to 0.67 for I-geo (As), -10.06 to -0.55 for I-geo (Cu), -6.68 to 1.42 for Ni, -6.68 to 1.47 for Pb, and -4.70 to -1.02 for Zn. As a result, I-geo ratings varied from severely to uncontaminated. As, Cu, Ni, Pb, and Zn had CF values of 0.15 to 2.401, 00.00 to 1.02, 0.01 to 4.02, 0.01 to 4.16, and 0.05 to 0.73, respectively. As a result, the CF categories in the research region vary from low contamination to very high contamination. Based on the PLI index, the study areas were categorized as moderately and unpolluted. It was found that 76.70 % of the study region was unpolluted. However, approximately 23.30%of the research area was comprised of the class with moderate contamination .According to the mCd values, the majority of the study area (57.90%) was categorized as slightly polluted, while around 42.10% of the research area was moderately contaminated. The current data show that the content of heavy metals in the soil increased because of inadequate management in the study area. The results of the spatial distribution maps of pollutants and their concentrations could serve as a foundation for the development of heavy metal mitigation plans. Mapping soil pollution can assist decision-makers develop effective heavy metal mitigation plans. The study advises implementing measures to reduce hazardous human behaviors that contribute to environmental contamination.Farm management legislation. Future study will focus on measures to minimize and mitigate the effects of soil pollution.

## 1. Introduction

Soil is crucial to food safety, since it controls the potential composition of food and feed at the base of the food chain (Tóth et al., 2016). Numerous contaminants are introduced into agricultural soils, which lower soil quality and accelerate soil degradation (Kamal et al., 2023). Natural resources are under additional stress because of the increased demand for food and agricultural goods, which necessitates the expansion and improvement of agricultural land use (Santa-Cordero et al., 2016; Abd-Elmabod et al., 2019). Five million locations worldwide have soil contamination from heavy metals or metalloids that are now present in higher concentrations than are acceptable (Li et al., 2019). The hazards that potentially hazardous metal pollution poses to human health and the environment make it a serious global concern (Boumaza et al., 2023). According to El-Zeiny and El-Hamid (2022), soil contamination is a severe issue that endangers the ecosystem in the majority of nations, particularly those in the third world. The biological world, human health, and the sustainable development of social resources all greatly benefit from the study of soil heavy metal pollution (Wang et al., 2017). Unless it forms a compound with a unique cofactor, the metal is physiologically inactive (Knany et al., 2022). Excessive levels of heavy metals (HMs) in soil are first absorbed and enriched by plants and animals, and subsequently enter the human body through the food chain, which has a major negative impact on crop productivity and quality as well as human health (Sawut et al., 2018). The higher levels of heavy metals in the soils in the middle Nile Delta are having a negative effect on Egypt's crop and soil quality (Shokr et al., 2022a). The Nile Delta has long been recognized for its agricultural pursuits and is one of the most heavily populated regions in the world (Khater et al., 2015). Wastewater is used for irrigation in this region; the water from the Nile is combined with effluent from industry and agriculture from Egypt's El Gharbia main drain (Kitchenr) (Abowaly et al., 2021). Most often, uncontrolled activity results in the deposition of several hazardous substances into the soil, which ultimately degrades the soil and endangers human health. Pesticides, agricultural practices, particularly land usage, and inorganic and petrochemical fertilizers for organic matter (bio-solids, animal dung, and organic fertilizers) are the main anthropogenic agents responsible for the deposition of soil-bearing solids) (Nagajyoti et al., 2010). Soil quality has also been significantly impacted by human activity (Wang et al., 2017). Regular environmental monitoring and reduced fertilization rates are required to reduce the contamination hazards in Egyptian soils (Said et al., 2019). Being aware of the causes of contamination and comprehending the geographical distribution of heavy metals are the first stages in properly managing soil pollution (El-Zeiny et al., 2022). Thus, geographic information system (GIS) facilitate the mapping of soil characteristics' geographical distribution (El Nahry and Mohamed, 2011; Mohamed et al., 2015; Abuzaid et al., 2022). GIS is a valuable tool for mapping heavy metal concentrations and identifying locations that need immediate care. It allows for a thorough investigation of pollution levels and severity (Hendawy et al., 2025). Spatial data can be studied and the location of the unsampled data can be anticipated using a technique known as geostatistical analysis (Hammam et al., 2020). There are numerous geostatistical analysis methods, such as inverse distance weighting (IDW) and Kriging. Numerous techniques, such as the index approach, quotient method, fuzzy comprehensive assessment, geoaccumulation index, prospective ecological risk index, and pollutant load index, are used to evaluate soil ecological risk (Khan et al., 2021; Abuzaid, et al., 2020; Boumaza et al., 2024). The current study intends to analyze soil contamination with a number of selected heavy metals (As, Cu, Ni, Pb, and Zn) by mapping their spatial distribution in the Northwest Nile Delta, Egypt and Contamination levels were defined using the Geo-Accumulation Index (I-Geo), Contamination Factor (CF), Pollution Load Index (PLI), and Modified Degree of Contamination (mCd) indices.

## 2. Methodology

### 2.1. Study area

The study region is situated in Egypt, northwest of the Nile Delta. As illustrated in (Figure 1), it is bounded by the latitudes 30°56' to 31°13'N and the longitudes 29°54'30" to 30°10'30"E with an area of 387.21 km$^2$ The region has a Mediterranean climate, with hot, dry summers and little precipitation in the winter. In the dry season, the average temperature is 22 °C, with mean temperatures ranging from 25 to 30 °C. The average temperature difference between summer and winter is 6 °C (Climatological Normal for Egypt, 2011). Thermic and Torric, respectively, are the definitions of the soil temperature and moisture regimes in the examined area, according to the keys to soil taxonomy (USDA, 2010). According to Said (1993), the research region is composed of Pleistocene sediments, which are separated into the following geological sectors: young terraces from the Pleistocene covered by marine deposits, sand and gravels, sand dunes, and sand accumulations. The main climatic conditions and parent materials that affected the morphological and physicochemical properties of the soils were significantly linked to soil formation in the research area (Dengiz et al. 2011).

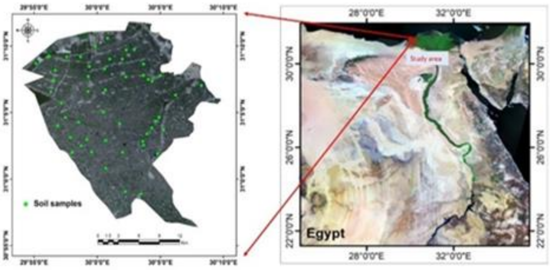



**Figure 1.** Location of the investigated area and distribution of soil samples.

### 2.2. Fieldwork and Lab. analysis

Fifty soil samples were gathered using a plastic hand trowel at a depth of less than 30 cm below the soil's surface (Figure1). Three subsamples were properly blended to create a composite sample that was representative. They were then stored in plastic sample bags at a temperature of around 4°C after being air-dried and crushed to pass through a 2 mm sieve. According to (USDA, 2014), the soil samples were analyzed at Tanta University Faculty of Agriculture in a soil, water, and plant laboratory that complies with ISO/IEC 17025 (2017) and is accredited. Soil Reaction (pH) was determined in the soil paste (1:2.5) using pH –meter. The Electrical Conductivity (EC) was determined in Water Extract of Soil (Soil Water Extract) using conductivity meter. Particle size distribution of the soil samples was described according to the pipette method by (USDA, 2014). Organic matter was determined by the modified Walkley and Black method .Cation Exchange Capacity (CEC) was calculated using equation according to (Ersahin et al., 2006). CEC=4.97+0.53*Clay% Using three milliliters of hydrofluoric acid and seven milliliters of strong nitric acid, the soil samples were broken down (Page 1982). Using the Prodiy plus model of inductively coupled plasma mass spectrometry (ICP-MS), the amounts of As, Cu, Ni, Pb, and Zn were determined.

### 2.3. Contamination Indices

#### *2.3.1. Geo-Accumulation Index (I-Geo)*

The I-Geo formula utilized the following formula to express contamination: I-geo compares observed levels of trace elements with background values.

$$I_{geo} = log_2 \frac{C_n}{1.5B_n} \quad (1)$$

Where:

Cn is the concentration of heavy metals as determined by soil sample measurements, and Bn is the geochemical background concentration as found in the average upper crust (Wedepohl, 1995).

Since soil is a component of the Earth's crust and has a comparable chemical composition to the crust, the primary focus in this case is the relationship between the concentration obtained and the concentration of elements in the crust (Rahman et al., 2012). To lessen the effect of any background value variations that might be brought on by variations in rocky sediment, the constant 1.5 was added to equation (1) (Guan et al., 2014). Muller (1979) asserts that there are seven distinct Igeo levels (Table S1).

#### *2.3.2. Contamination Factor (CF)*

The total concentration of each measured metal was divided by the background value to determine the contamination factor (CF) for each heavy metal in the study. To compute CF, the following formula was utilized. (Harikumar and Jisha, 2010)

$$C_f = \frac{C_{metal}}{C_{background}} \quad (2)$$

Where:

Cm is the measured total concentration of heavy metals. Cb is each metal's the background value. As stated by Håkanson (1980), there are four different levels (Table S2)

*2.3.3 Modified Degree of Contamination (mCd)*

Because it considers the combined impacts of the contaminants at a study site, the modified degree of contamination (mCd) index has an advantage over single element indices (Brady et al., 2015; Vu et al., 2017). Equation is used to compute the modified degree of contamination ($mC_d$). (Table S3) lists the terms used to classify the mCd.

$$mC_d = \frac{\sum_{i=1}^{n} C_f}{n} \quad (3)$$

*2.3.4 Pollution Load Index (PLI)*

PLI shows how much of a pollutant is present in the environment (Seshan et al., 2010). Equation was used to determine the index.

$$PLI = \left(C_f^1 * C_f^2 * C_f^3 * \dots \dots * C_f^n\right)^{\frac{1}{n}} \quad (4)$$

Where:

CF is the contamination factor and n is the number of target heavy metals**.** The classification of PLI for assessing pollution levels in soil (Chon et al., 1996), was shown in (Table S4)

### 2.4. Geostatistical analysis

Geographically referenced data can be modelled using statistical theory and techniques with the help of the ArcGIS Spatial Analyst 10.4 extension. The intervening values for five heavy metals were extracted from the data using ArcGIS Spatial Analysis's interpolation algorithms. Data that have been measured near the predicted point were used in an interpolation method known as the inverse distance weighting (IDW) (Jalhoum et al., 2022; Shokr et al., 2022b; El-Aziz et al., 2024; Hendawy et al., 2024, Einar et al., 2025). The points closest to the forecast site are assigned a higher weight, which varies with distance. The expected values of the distant values are more affected by the values measured nearer to the forecast site. One advantage of IDW for mapping the regional distribution of heavy metals is its effectiveness (El Behairy et al., 2022).

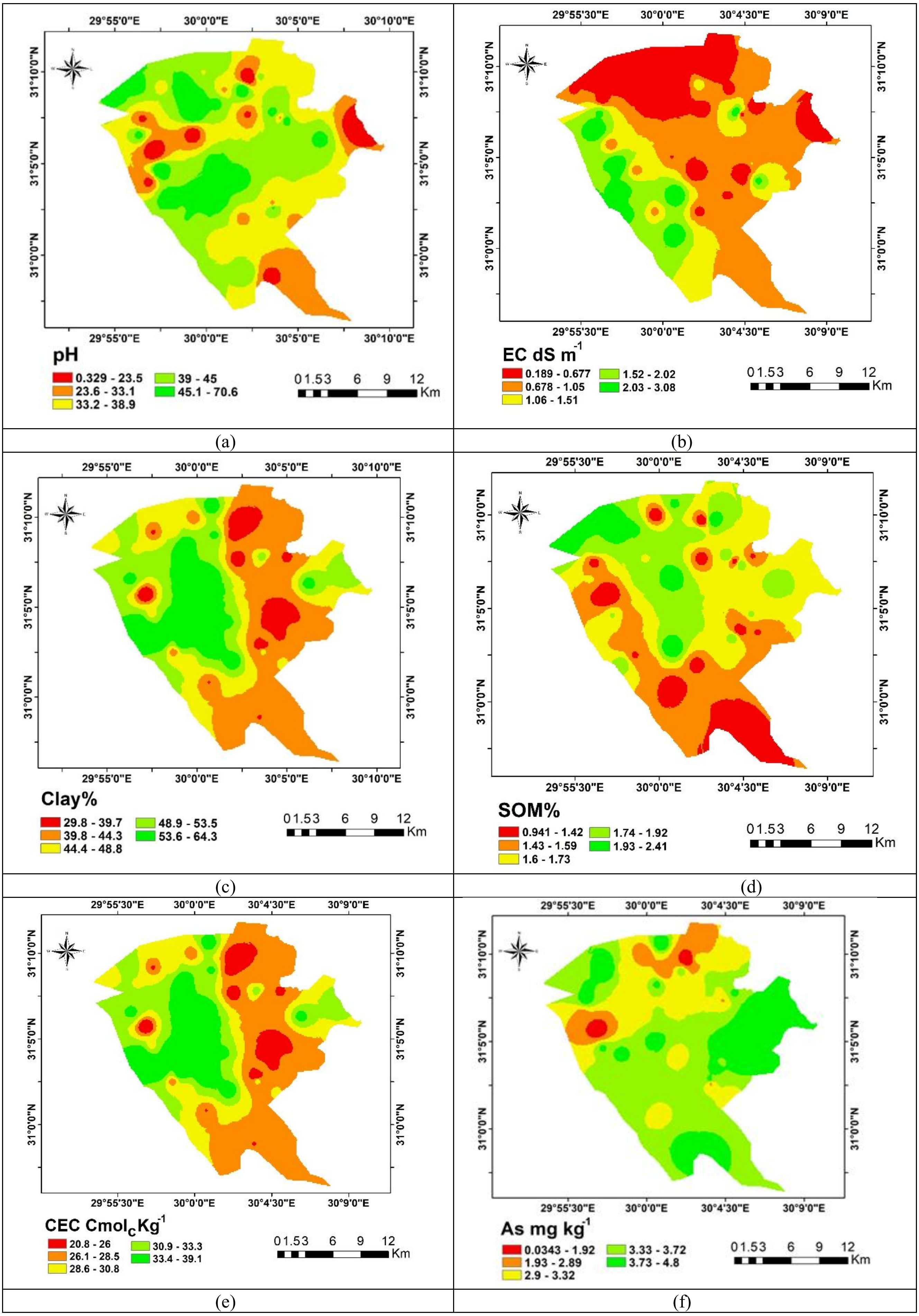
## 3. Results

### 3.1. Specific characteristics of the soil and concentrations of heavy metals

The pH levels had a mean of 7.52 and ranged from 7.00 to 8.30. With a mean of 1.03 dS $m^{-1}$, the EC values in the studied region ranged, from 0.18 to 3.13 dS $m^{-1}$ (Table 1). The soil's clay content ranged from 29.78 to 64.40%, with an average of 47.40%. The SOM% had a mean value of 1.66% and ranged from 0.94 to 2.40%. The CEC ranged from 20.75 to 39.10, with a mean of 30.09 Cmolec $kg^{-1}$ (Table1). The concentration of total As ranged between 0.030 and 4.803 mg $kg^{-1}$ with an mean value of 3.387 mg $kg^{-1}$. The ranged Cu mg $kg^{-1}$ is 00.02 ± 14.62 with a mean value of 3.95. The total Ni content we found was 00.27±74.90 mg $kg^{-1}$, with a mean value of 27.41 mg $kg^{-1}$ (Table 1). A mean of 38.99 mg $kg^{-1}$ of Pb is present in the whole content with a range between 0.24 and 70.75 mg $kg^{-1}$. The value of the total Zn concentrations is 3.00 ± 38.19 mg $kg^{-1}$ with a mean value of 14.46 mg $kg^{-1}$ as Showed in (Table 1, and Figure 2).

**Table1.** Properties of soil and concentrations of heavy metals in the research area (n=50).

| Sample | pH 1:2.5 | EC | Clay | OM | CEC | As | Cu | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|---|
| **Units** | **-** | **dS m$^{-1}$** | **%** | | **Cmolc kg$^{-1}$** | **mg kg$^{-1}$** | | | | |
| 1 | 7.01 | 0.35 | 51.60 | 1.71 | 32.32 | 3.82 | 0.12 | 34.47 | 7.87 | 4.60 |
| 2 | 8.06 | 2.27 | 41.60 | 1.40 | 27.02 | 3.82 | 4.26 | 4.12 | 34.96 | 30.40 |
| 3 | 7.10 | 0.83 | 56.02 | 1.89 | 34.66 | 4.80 | 2.20 | 61.52 | 48.38 | 14.20 |
| 4 | 7.25 | 0.92 | 43.35 | 1.86 | 27.95 | 3.89 | 14.00 | 0.81 | 38.10 | 26.60 |
| 5 | 7.85 | 0.87 | 45.23 | 1.55 | 28.94 | 2.91 | 5.34 | 27.56 | 30.24 | 24.00 |
| 6 | 7.05 | 0.75 | 39.63 | 1.14 | 25.98 | 3.95 | 0.08 | 56.38 | 19.36 | 10.38 |
| 7 | 7.21 | 1.22 | 41.49 | 1.53 | 26.96 | 3.92 | 2.00 | 6.98 | 44.76 | 22.00 |
| 8 | 8.01 | 2.59 | 39.58 | 1.22 | 25.95 | 3.07 | 6.34 | 23.45 | 33.87 | 3.46 |
| 9 | 7.02 | 0.50 | 40.68 | 1.66 | 26.53 | 3.53 | 0.80 | 17.27 | 41.20 | 13.50 |
| 10 | 7.60 | 0.87 | 45.27 | 1.50 | 28.96 | 3.56 | 8.24 | 1.00 | 42.34 | 5.90 |
| 11 | 8.30 | 1.66 | 41.36 | 1.37 | 26.89 | 3.40 | 3.82 | 10.07 | 42.94 | 20.60 |
| 12 | 7.76 | 0.25 | 38.65 | 1.40 | 25.45 | 3.82 | 0.02 | 46.09 | 33.27 | 4.50 |
| 13 | 7.00 | 3.13 | 41.39 | 1.29 | 26.91 | 3.24 | 4.90 | 18.30 | 31.45 | 16.90 |
| 14 | 7.88 | 0.19 | 31.97 | 1.19 | 21.92 | 3.66 | 3.04 | 24.48 | 35.08 | 9.24 |
| 15 | 7.02 | 0.55 | 58.69 | 1.32 | 36.07 | 3.40 | 0.06 | 63.58 | 30.24 | 32.00 |
| 16 | 7.05 | 3.04 | 62.55 | 2.33 | 38.12 | 3.33 | 14.62 | 50.20 | 47.17 | 16.20 |
| 17 | 8.20 | 1.54 | 58.37 | 1.58 | 35.91 | 3.43 | 6.32 | 0.27 | 70.75 | 18.00 |
| 18 | 8.02 | 2.44 | 64.41 | 1.53 | 39.11 | 3.50 | 1.00 | 74.90 | 51.41 | 3.00 |
| 19 | 7.01 | 1.23 | 52.85 | 1.89 | 32.98 | 3.40 | 0.92 | 6.98 | 49.59 | 4.40 |
| 20 | 7.13 | 0.67 | 58.42 | 1.78 | 35.93 | 4.12 | 4.30 | 43.00 | 49.59 | 7.48 |
| 21 | 7.73 | 0.80 | 58.15 | 1.47 | 35.79 | 4.05 | 0.74 | 47.11 | 39.92 | 26.00 |
| 22 | 7.11 | 2.92 | 46.94 | 1.75 | 29.85 | 3.85 | 0.42 | 39.91 | 61.08 | 13.64 |
| 23 | 7.01 | 0.46 | 39.73 | 1.91 | 26.03 | 2.81 | 0.10 | 57.40 | 50.80 | 20.00 |
| 24 | 7.82 | 0.49 | 34.99 | 1.27 | 23.51 | 3.01 | 0.06 | 47.11 | 21.18 | 8.42 |
| 25 | 7.13 | 0.81 | 61.66 | 2.22 | 37.65 | 3.37 | 9.02 | 0.27 | 36.90 | 3.68 |
| 26 | 7.01 | 0.99 | 56.37 | 1.85 | 34.84 | 3.07 | 0.20 | 19.33 | 10.90 | 22.80 |
| 27 | 7.88 | 0.72 | 30.75 | 0.94 | 21.27 | 0.03 | 12.28 | 3.16 | 0.59 | 10.40 |
| 28 | 7.01 | 1.39 | 37.42 | 1.88 | 24.80 | 3.66 | 7.04 | 28.59 | 58.06 | 5.02 |
| 29 | 7.62 | 0.29 | 51.21 | 1.81 | 32.11 | 3.92 | 3.48 | 18.30 | 47.78 | 38.20 |
| 30 | 7.38 | 0.45 | 57.49 | 1.70 | 35.44 | 3.01 | 0.02 | 0.27 | 59.27 | 3.28 |
| 31 | 7.70 | 0.37 | 34.21 | 1.53 | 23.10 | 3.72 | 5.36 | 41.97 | 42.94 | 20.40 |
| 32 | 7.88 | 0.47 | 31.80 | 1.73 | 21.82 | 3.89 | 3.04 | 26.53 | 30.85 | 14.62 |
| 33 | 7.17 | 0.23 | 54.55 | 1.80 | 33.88 | 2.94 | 0.10 | 5.95 | 51.41 | 3.50 |
| 34 | 7.02 | 0.21 | 55.74 | 1.80 | 34.51 | 2.29 | 8.24 | 22.42 | 32.06 | 20.40 |
| 35 | 7.32 | 0.33 | 60.55 | 1.88 | 37.06 | 3.11 | 0.26 | 13.16 | 53.82 | 5.88 |
| 36 | 7.34 | 0.36 | 29.79 | 1.19 | 20.76 | 0.03 | 7.22 | 6.15 | 0.248 | 3.66 |
| 37 | 7.02 | 0.33 | 59.04 | 1.97 | 36.26 | 4.41 | 1.48 | 34.77 | 42.94 | 14.24 |
| 38 | 7.57 | 0.29 | 40.67 | 1.22 | 26.52 | 2.19 | 7.38 | 3.90 | 38.71 | 21.20 |
| 39 | 7.00 | 0.31 | 46.55 | 1.99 | 29.64 | 3.11 | 2.00 | 52.26 | 53.82 | 18.00 |
| 40 | 7.83 | 0.43 | 39.06 | 2.25 | 25.67 | 4.80 | 0.46 | 13.16 | 36.29 | 3.72 |
| 41 | 8.03 | 0.35 | 52.68 | 1.97 | 32.89 | 3.43 | 0.04 | 18.30 | 52.01 | 6.12 |
| 42 | 8.04 | 2.16 | 53.33 | 1.32 | 33.24 | 4.15 | 10.24 | 23.45 | 19.97 | 12.28 |
| 43 | 8.30 | 3.05 | 55.76 | 1.60 | 34.52 | 2.62 | 1.28 | 32.71 | 47.78 | 5.08 |
| 44 | 8.04 | 1.98 | 63.45 | 1.66 | 38.60 | 3.30 | 8.42 | 41.97 | 18.76 | 30.00 |
| 45 | 8.24 | 2.35 | 48.91 | 1.91 | 30.89 | 3.69 | 2.00 | 48.14 | 41.13 | 24.00 |
| 46 | 7.57 | 0.65 | 46.44 | 2.41 | 29.58 | 3.63 | 0.08 | 13.16 | 49.59 | 10.00 |
| 47 | 8.06 | 0.34 | 47.90 | 1.81 | 30.36 | 3.79 | 12.64 | 37.85 | 38.71 | 31.00 |
| 48 | 7.41 | 0.88 | 46.80 | 1.60 | 29.77 | 2.81 | 0.34 | 58.43 | 45.96 | 3.78 |
| 49 | 7.60 | 0.44 | 38.27 | 2.20 | 25.25 | 3.24 | 9.42 | 43.00 | 41.13 | 8.74 |
| 50 | 7.80 | 1.07 | 37.02 | 1.78 | 24.59 | 4.64 | 2.00 | 0.30 | 42.34 | 28.00 |
| **Minimum** | **7.00** | **0.18** | **29.78** | **0.94** | **20.75** | **0.03** | **0.02** | **0.27** | **0.24** | **3.00** |
| **Maximum** | **8.30** | **3.13** | **64.40** | **2.40** | **39.10** | **4.80** | **14.62** | **74.90** | **70.75** | **38.19** |
| **Mean** | **7.52** | **1.03** | **47.40** | **1.66** | **30.09** | **3.39** | **3.95** | **27.41** | **38.99** | **14.46** |
| **STD.** | **0.43** | **0.87** | **9.71** | **0.32** | **5.14** | **0.89** | **4.16** | **20.50** | **14.82** | **9.56** |


pH
0.329 - 23.5
23.6 - 33.1
33.2 - 38.9
39 - 45
45.1 - 70.6
0 1.5 3 6 9 12 Km
(a)
EC dS m-1
0.189 - 0.677
0.678 - 1.05
1.06 - 1.51
1.52 - 2.02
2.03 - 3.08
0 1.5 3 6 9 12 Km
(b)
Clay%
29.8 - 39.7
39.8 - 44.3
44.4 - 48.8
48.9 - 53.5
53.6 - 64.3
0 1.5 3 6 9 12 Km
(c)
SOM%
0.941 - 1.42
1.43 - 1.59
1.6 - 1.73
1.74 - 1.92
1.93 - 2.41
0 1.5 3 6 9 12 Km
(d)
CEC Cmolc Kg-1
20.8 - 26
26.1 - 28.5
28.6 - 30.8
30.9 - 33.3
33.4 - 39.1
0 1.5 3 6 9 12 Km
(e)
As mg kg-1
0.0343 - 1.92
1.93 - 2.89
2.9 - 3.32
3.33 - 3.72
3.73 - 4.8
0 1.5 3 6 9 12 Km
(f)

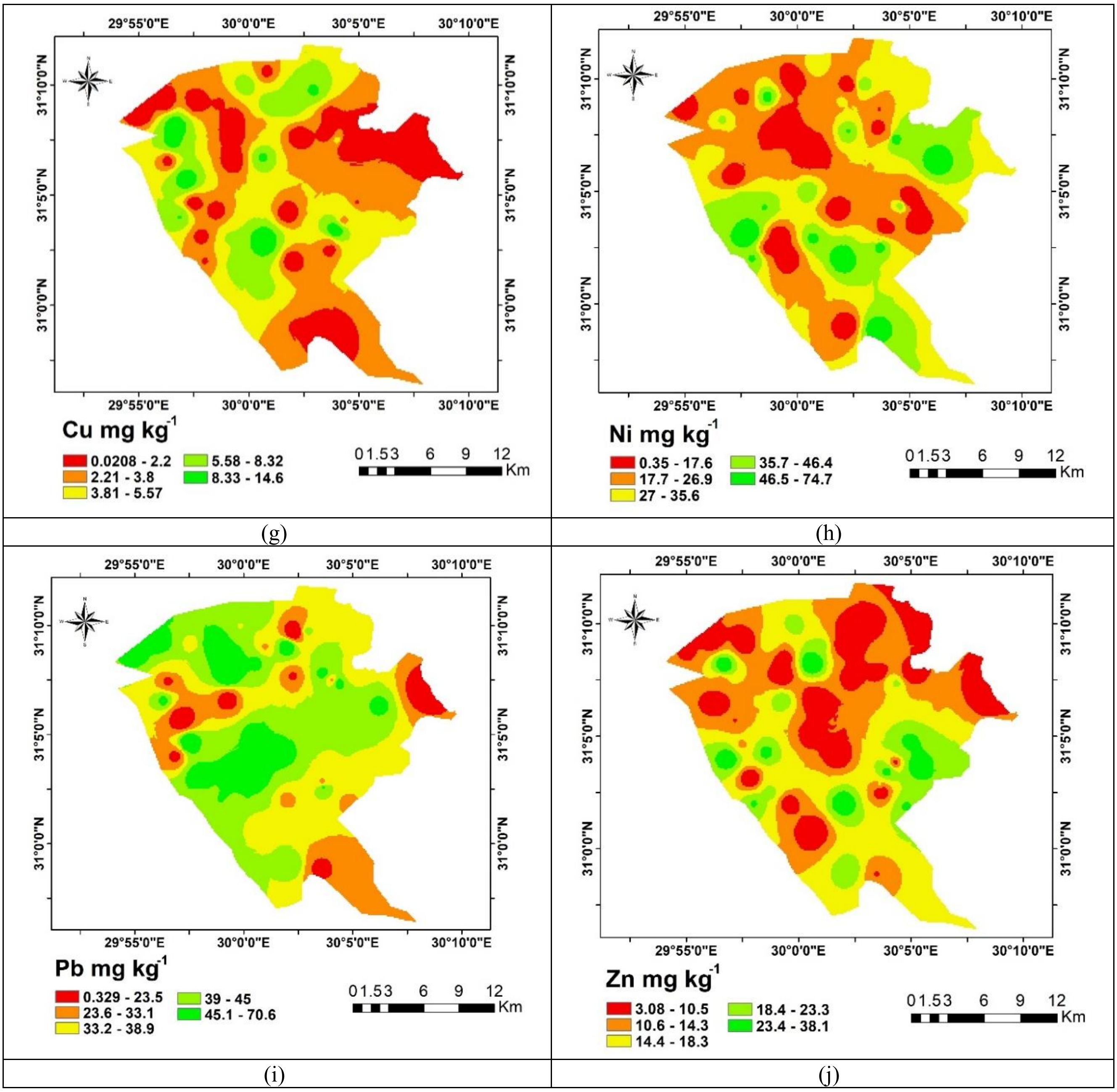



**Figure2**. Spatial distribution maps of total heavy metal concentrations and selected soil characteristics.

## 3.2. Comparison between current study and other previous studies

The average levels of current metal concentrations in the research region were compared in (Table1) to those of Nile delta, Egypt, Wedepohl, recommended values, and the acceptable concentrations set by the Department of Environmental Affairs (DEA) (Abu Khatita etal., 2020; Guda et al., 2020; Abowaly et al., 2022; Ibrahim and Selim, 2022; Wedepohl, 1995; DEA, 2013). The average concentration of As was higher than the recommended concentrations by Wedepohl (1995) and lower than the other values displayed in the (Table 2) While, Cu concentrations were lower than all concentration mentioned in (Table 2) The Ni value exceeded Wedepohl's recommended concentrations (Table 2) and was lower than values derived from several regions of the Nile delta. The Pb concentration exceeded the values reported by Ibrahim and Selim (2022), Abu Khatita et al. (2020), as well as the recommended limits established by Wedepohl (1995) and the DEA (2013) (Table 2). On the other hand, The Zn concentrations were lower than all concentrations in (Table 2).

**Table 2.** Comparing the current study's HM concentrations to background levels and HMs from other regions.

| | As | Cu | Ni | Pb | Zn |
|---|---|---|---|---|---|
| **Present study** | 3.387 | 3.95 | 27.41 | 38.99 | 14.46 |
| **Middle Nile Delta, Egypt** (Abu Khatita et al., 2020) | 5.9 | 61.8 | 70.6 | 30.7 | 14.3 |
| **Southeast Nile delta, Egypt** (Guda et al., 2020) | 7.98 | 252.40 | - | 69.58 | 184.00 |
| **North Nile Delta, Egypt** (Abowaly et al., 2022) | - | 44.02 | 61.45 | 63.12 | 122.66 |
| **Eastern Nile Delta, Egypt** (Ibrahim and Selim, 2022) | - | 9.85 | 27.25 | 28.31 | 100.01 |
| **Background values** (Wedepohl, 1995) | 2 | 14.3 | 18.6 | 17 | 52 |
| **Recommended concentration based on** (DEA, 2013) | 5.8 | 16 | 91 | 20 | 240 |

### 3.3. Soil contamination statues within study area

The findings show that the levels of As, Cu, Ni, Pb, and Zn in the different soil samples varied significantly, as shown in (Table 3) I-geo (As) varied from -6.60 to 0.67, I-geo (Cu) from -10.06 to -0.55, I-geo (Ni) from -6.68 to 1.42, I-geo (Pb) from -6.68 to 1.47, and I-geo (Zn) from -4.70 to- 1.02. I-geo classifications ranged from uncontaminated to highly to contaminated as a result. The CF values for As, Cu, Ni, Pb, and Zn were, respectively, 0.15 to 2.401, 00.00 to 1.02, 0.01 to 4.02, 0.01 to 4.16, and 0.05 to 0.73. Consequently, the research area's CF classifications range from low contamination to very high contamination.

The study areas were classified as unpolluted, moderately polluted, and moderately-heavily polluted based on values ranging from 0.18 to 1.79 on the $MC_d$ index (Table 4 and Figure 3). According to the Pollution Load Index (PLI), which has values ranging from 0.00 to 1.23, the research region is classified as either unpolluted or moderately polluted. (Table 4, and Figures 4) illustrate that the study areas were classified as unpolluted and moderately polluted based on the PLI index. The majority of the research area (76.70%) was found to be unpolluted. But the class with moderate pollution made up around 23.30% of the study area (Figure 4). As shown by the mCd values (Figure 5), roughly 42.10% of the study area was moderately contaminated, while the bulk of the study area (57.90%) was classified as slightly polluted.

**Table 3.** Statistical evaluation of the research area's individual HMs contamination indicators (CF, Igeo)

| | CF | | | | | Igeo | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **sample** | **As** | **Cu** | **Ni** | **Pb** | **Zn** | **As** | **Cu** | **Ni** | **Pb** | **Zn** |
| 1 | 1.91 | 0.01 | 1.85 | 0.46 | 0.09 | 0.35 | -7.48 | 0.31 | -1.70 | -4.08 |
| 2 | 1.91 | 0.30 | 0.22 | 2.06 | 0.58 | 0.35 | -2.33 | -2.76 | 0.46 | -1.36 |
| 3 | 2.40 | 0.15 | 3.31 | 2.85 | 0.27 | 0.68 | -3.29 | 1.14 | 0.92 | -2.46 |
| 4 | 1.95 | 0.98 | 0.04 | 2.24 | 0.51 | 0.38 | -0.62 | -5.10 | 0.58 | -1.55 |
| 5 | 1.46 | 0.37 | 1.48 | 1.78 | 0.46 | -0.04 | -2.01 | -0.02 | 0.25 | -1.70 |
| 6 | 1.98 | 0.01 | 3.03 | 1.14 | 0.20 | 0.40 | -8.07 | 1.01 | -0.40 | -2.91 |
| 7 | 1.96 | 0.14 | 0.38 | 2.63 | 0.42 | 0.39 | -3.42 | -2.00 | 0.81 | -1.83 |
| 8 | 1.54 | 0.44 | 1.26 | 1.99 | 0.07 | 0.04 | -1.76 | -0.25 | 0.41 | -4.49 |
| 9 | 1.77 | 0.06 | 0.93 | 2.42 | 0.26 | 0.24 | -4.74 | -0.69 | 0.69 | -2.53 |
| 10 | 1.78 | 0.58 | 0.05 | 2.49 | 0.11 | 0.25 | -1.38 | -4.80 | 0.73 | -3.72 |
| 11 | 1.70 | 0.27 | 0.54 | 2.53 | 0.40 | 0.18 | -2.49 | -1.47 | 0.75 | -1.92 |
| 12 | 1.91 | 0.00 | 2.48 | 1.96 | 0.09 | 0.35 | -10.07 | 0.72 | 0.38 | -4.12 |
| 13 | 1.62 | 0.34 | 0.98 | 1.85 | 0.33 | 0.11 | -2.13 | -0.61 | 0.30 | -2.21 |
| 14 | 1.83 | 0.21 | 1.32 | 2.06 | 0.18 | 0.29 | -2.82 | -0.19 | 0.46 | -3.08 |
| 15 | 1.70 | 0.01 | 3.42 | 1.78 | 0.62 | 0.18 | -8.48 | 1.19 | 0.25 | -1.29 |
| 16 | 1.67 | 1.02 | 2.70 | 2.77 | 0.31 | 0.15 | -0.55 | 0.85 | 0.89 | -2.27 |
| 17 | 1.72 | 0.44 | 0.01 | 4.16 | 0.35 | 0.20 | -1.76 | -6.68 | 1.47 | -2.12 |
| 18 | 1.75 | 0.07 | 4.03 | 3.02 | 0.06 | 0.22 | -4.42 | 1.42 | 1.01 | -4.70 |
| 19 | 1.70 | 0.06 | 0.38 | 2.92 | 0.08 | 0.18 | -4.54 | -2.00 | 0.96 | -4.15 |
| 20 | 2.06 | 0.30 | 2.31 | 2.92 | 0.14 | 0.46 | -2.32 | 0.62 | 0.96 | -3.38 |
| 21 | 2.03 | 0.05 | 2.53 | 2.35 | 0.50 | 0.43 | -4.86 | 0.76 | 0.65 | -1.58 |
| 22 | 1.93 | 0.03 | 2.15 | 3.59 | 0.26 | 0.36 | -5.67 | 0.52 | 1.26 | -2.52 |
| 23 | 1.41 | 0.00 | 3.09 | 2.99 | 0.38 | -0.09 | -7.74 | 1.04 | 0.99 | -1.96 |
| 24 | 1.51 | 0.00 | 2.53 | 1.25 | 0.16 | 0.01 | -8.48 | 0.76 | -0.27 | -3.21 |
| 25 | 1.69 | 0.63 | 0.01 | 2.17 | 0.07 | 0.17 | -1.25 | -6.68 | 0.53 | -4.41 |
| 26 | 1.54 | 0.01 | 1.04 | 0.64 | 0.44 | 0.04 | -6.74 | -0.53 | -1.23 | -1.77 |
| 27 | 0.02 | 0.86 | 0.17 | 0.03 | 0.20 | -6.61 | -0.80 | -3.14 | -5.43 | -2.91 |
| 28 | 1.83 | 0.49 | 1.54 | 3.42 | 0.10 | 0.29 | -1.61 | 0.04 | 1.19 | -3.96 |
| 29 | 1.96 | 0.24 | 0.98 | 2.81 | 0.73 | 0.39 | -2.62 | -0.61 | 0.91 | -1.03 |
| 30 | 1.51 | 0.00 | 0.01 | 3.49 | 0.06 | 0.01 | -10.07 | -6.68 | 1.22 | -4.57 |
| 31 | 1.86 | 0.37 | 2.26 | 2.53 | 0.39 | 0.31 | -2.00 | 0.59 | 0.75 | -1.93 |
| 32 | 1.95 | 0.21 | 1.43 | 1.81 | 0.28 | 0.38 | -2.82 | -0.07 | 0.27 | -2.42 |
| 33 | 1.47 | 0.01 | 0.32 | 3.02 | 0.07 | -0.03 | -7.74 | -2.23 | 1.01 | -4.48 |
| 34 | 1.15 | 0.58 | 1.21 | 1.89 | 0.39 | -0.39 | -1.38 | -0.32 | 0.33 | -1.93 |
| 35 | 1.56 | 0.02 | 0.71 | 3.17 | 0.11 | 0.05 | -6.37 | -1.08 | 1.08 | -3.73 |
| 36 | 0.02 | 0.50 | 0.33 | 0.01 | 0.07 | -6.33 | -1.57 | -2.18 | -6.68 | -4.41 |
| 37 | 2.21 | 0.10 | 1.87 | 2.53 | 0.27 | 0.56 | -3.86 | 0.32 | 0.75 | -2.45 |
| 38 | 1.10 | 0.52 | 0.21 | 2.28 | 0.41 | -0.45 | -1.54 | -2.84 | 0.60 | -1.88 |
| 39 | 1.56 | 0.14 | 2.81 | 3.17 | 0.35 | 0.05 | -3.42 | 0.91 | 1.08 | -2.12 |
| 40 | 2.40 | 0.03 | 0.71 | 2.13 | 0.07 | 0.68 | -5.54 | -1.08 | 0.51 | -4.39 |
| 41 | 1.72 | 0.00 | 0.98 | 3.06 | 0.12 | 0.20 | -9.07 | -0.61 | 1.03 | -3.67 |
| 42 | 2.08 | 0.72 | 1.26 | 1.17 | 0.24 | 0.47 | -1.07 | -0.25 | -0.35 | -2.67 |
| 43 | 1.31 | 0.09 | 1.76 | 2.81 | 0.10 | -0.19 | -4.07 | 0.23 | 0.91 | -3.94 |
| 44 | 1.65 | 0.59 | 2.26 | 1.10 | 0.58 | 0.14 | -1.35 | 0.59 | -0.44 | -1.38 |
| 45 | 1.85 | 0.14 | 2.59 | 2.42 | 0.46 | 0.30 | -3.42 | 0.79 | 0.69 | -1.70 |
| 46 | 1.82 | 0.01 | 0.71 | 2.92 | 0.19 | 0.28 | -8.07 | -1.08 | 0.96 | -2.96 |
| 47 | 1.90 | 0.88 | 2.04 | 2.28 | 0.60 | 0.34 | -0.76 | 0.44 | 0.60 | -1.33 |
| 48 | 1.41 | 0.02 | 3.14 | 2.70 | 0.07 | -0.09 | -5.98 | 1.07 | 0.85 | -4.37 |
| 49 | 1.62 | 0.66 | 2.31 | 2.42 | 0.17 | 0.11 | -1.19 | 0.62 | 0.69 | -3.16 |
| 50 | 2.32 | 0.14 | 0.02 | 2.49 | 0.54 | 0.63 | -3.42 | -6.52 | 0.73 | -1.48 |
| **Minimum** | **0.15** | **0.00** | **0.01** | **0.01** | **0.05** | **-6.60** | **-10.06** | **-6.68** | **-6.68** | **-4.70** |
| **Maximum** | **2.40** | **1.02** | **4.02** | **4.16** | **0.73** | **0.67** | **-0.55** | **1.42** | **1.47** | **-1.02** |
| **Mean** | **1.69** | **0.27** | **1.47** | **2.29** | **0.27** | **-0.05** | **-3.98** | **-0.93** | **0.30** | **-2.80** |
| **STD.** | **0.44** | **0.29** | **1.10** | **0.87** | **0.18** | **1.34** | **2.78** | **2.24** | **1.44** | **1.11** |

**Table 4.** Statistical evaluation of the research area's integrated HMs contamination indices (PLI, mCd)

| Sample | PLI | mCd |
|---|---|---|
| 1 | 0.39 | 0.87 |
| 2 | 0.77 | 1.01 |
| 3 | 0.99 | 1.80 |
| 4 | 0.72 | 1.14 |
| 5 | 0.94 | 1.11 |
| 6 | 0.51 | 1.27 |
| 7 | 0.74 | 1.11 |
| 8 | 0.74 | 1.06 |
| 9 | 0.67 | 1.09 |
| 10 | 0.56 | 1.00 |
| 11 | 0.82 | 1.09 |
| 12 | 0.39 | 1.29 |
| 13 | 0.86 | 1.02 |
| 14 | 0.79 | 1.12 |
| 15 | 0.60 | 1.50 |
| 16 | 1.21 | 1.70 |
| 17 | 0.56 | 1.34 |
| 18 | 0.71 | 1.79 |
| 19 | 0.53 | 1.03 |
| 20 | 0.93 | 1.55 |
| 21 | 0.85 | 1.49 |
| 22 | 0.74 | 1.59 |
| 23 | 0.63 | 1.58 |
| 24 | 0.45 | 1.09 |
| 25 | 0.43 | 0.91 |
| 26 | 0.49 | 0.73 |
| 27 | 0.21 | 0.26 |
| 28 | 0.90 | 1.47 |
| 29 | 1.00 | 1.35 |
| 30 | 0.19 | 1.01 |
| 31 | 1.06 | 1.48 |
| 32 | 0.85 | 1.14 |
| 33 | 0.36 | 0.98 |
| 34 | 0.93 | 1.04 |
| 35 | 0.50 | 1.11 |
| 36 | 0.17 | 0.19 |
| 37 | 0.84 | 1.40 |
| 38 | 0.73 | 0.90 |
| 39 | 0.95 | 1.60 |
| 40 | 0.51 | 1.07 |
| 41 | 0.41 | 1.18 |
| 42 | 0.91 | 1.09 |
| 43 | 0.67 | 1.21 |
| 44 | 1.05 | 1.24 |
| 45 | 0.96 | 1.49 |
| 46 | 0.46 | 1.13 |
| 47 | 1.24 | 1.54 |
| 48 | 0.58 | 1.47 |
| 49 | 1.00 | 1.44 |
| 50 | 0.50 | 1.10 |
| **Minimum** | **0.17** | **0.18** |
| **Maximum** | **1.23** | **1.79** |
| **Mean** | **0.69** | **1.20** |
| **STD.** | **0.25** | **0.32** |

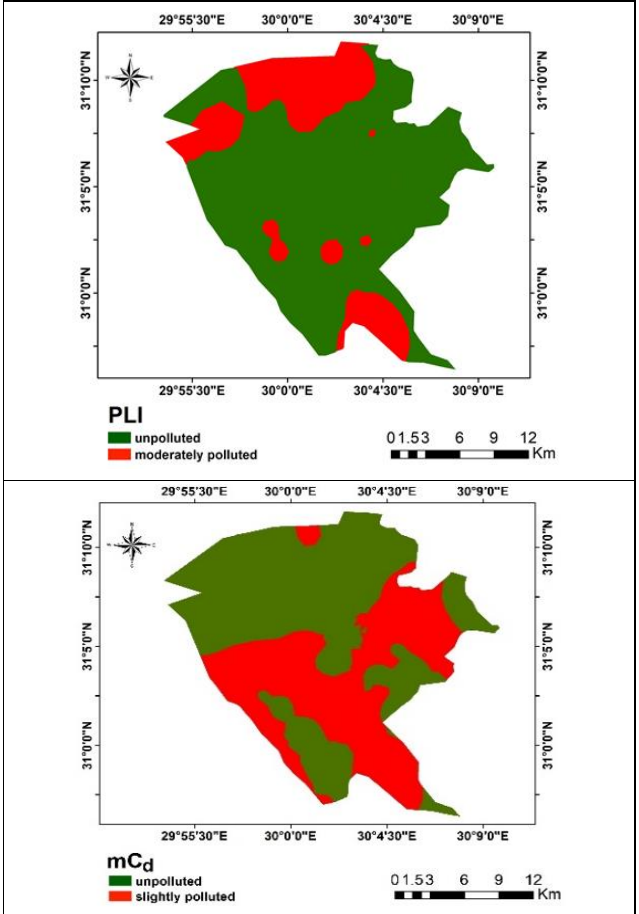



**Figure 3.** Spatial distribution maps of integrated indices

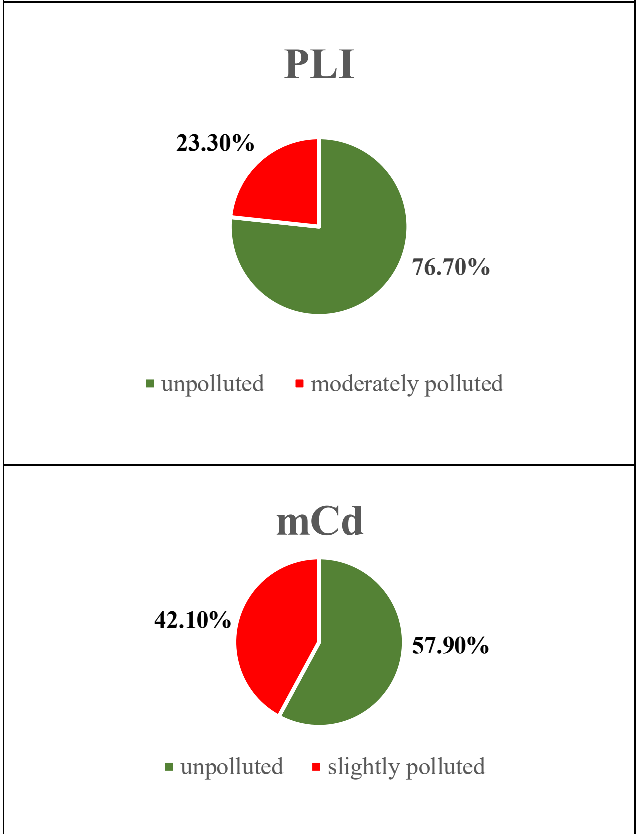



**Figure 4.** areas of integrated indices

## 4. Discussion

### 4.1. Heavy metals and other selected soil parameters in the study area

Although arsenic in soil is often considered to originate from geological origin and to be more common in clayey soils, there is a considerable quantity of anthropogenic arsenic pollution since its emissions into the environment come from more man-made sources than from natural ones (ATSDR, 2000). Copper-containing chemicals are commonly utilised in agriculture, particularly in orchard insecticides (Fishel, 2014). This could be the cause of the higher Cu values discovered in soil samples from Mediterranean locations where these land uses are prevalent (Tóth et al., 2016). Nickel (Ni) in soils originates from both lithogenic sources and anthropogenic inputs, like most other heavy metals, while industrial processes can also contaminate the soil (Cempel, 2006). Although humans and plants both require zinc, excessive amounts of the metal can be harmful (Swartjes, 2011). Therefore, controlling the right amount in agricultural soils is crucial. It may have detrimental consequences right away and lead to problems with the immune and digestive systems, among other things. Furthermore, too much zinc can reduce copper absorption, resulting in symptoms of copper deficiency (Tóth et al.,2016). The food chain is the primary source of lead exposure, however dust and soil ingestion are also potential sources (Abuzaid et al., 2019). Even at relatively low levels, lead (Pb) can damage the brain and neurological processes, particularly in youngsters. As a result, a careful assessment of the Pb danger in topsoil is required (Shokr et al., 2022a). pH is a crucial characteristic since it affects the biological activity in different soil conditions, the activity of enzymes, and the availability of soil nutrients to plant roots (Houben et al., 2013). In certain areas of the research area, the high levels of EC might have been caused by the water table's high salt (Shokr et al., 2022a). SOM is essential for maintaining the proper structure of the soil, increasing the availability of nutrients that boost soil fertility, and maintaining ecosystems' agro-equilibrium (Shokr et al., 2021). The SOM content is comparatively low in the study area because of the detrimental effects of dry and semi-arid climates, which increase the rate at which organic material in the soil decomposes due to high temperatures. Because fine particles have a larger specific surface area than coarse particles, they are the main location where trace elements accumulate (Abuzaid et al., 2021). It has been observed that the concentration of every element in the different soils rises with an increase in clay content. Additionally, a favorable correlation was found between clay and CEC. The positive correlation is caused by clay's exceptional capacity to absorb and transmit cations (Yousif et al., 2024).

### 4.2. Contamination status in the study area

The research area is capable of supporting a substantial population because it is one of Egypt's most populous, fertile, and agriculturally advanced regions (Abowaly et al., 2021). It is also under a lot of stress due to its proximity to the sea and the Nile Delta's high volume of domestic drainage. Industrial zones and residential neighborhoods usually overlap when there is no formal planning. Consequently, a range of human activities, including transportation networks, industrial operations, household waste, sewage sludge effluents from within or close to urban areas, and the application of fertilizer, pesticides, and insecticides in farmlands, release contaminants into the region's soil, water, and air (Abu Khatita, 2011). As a result, many methods for cleaning up soil contaminated by heavy metals have been developed. These commonly employed methods are categorized using labels for chemical, biological, and physical cleanup. When compared to alternative remediation techniques, in situ chemical amendment of soil is a cost-effective remediation technique that stabilizes the heavy metals in contaminated soil (Zhang, 2011). Using adsorption, precipitation, ion exchange, and complication, inorganic supplements are utilized to reduce the mobility and bioavailability of heavy metals (Udeigwe, 2011). To clean up historically heavy metals, it is advised to employ tourmaline, a borosilicate mineral with an extremely complicated chemical makeup. Alkaline soils that have been contaminated are likely to succeed (Wang, 2014). Additionally, with concentrations of water-soluble calcium and magnesium in the soil increased dramatically with increasing amounts of tourmaline applied to the soil. Additionally, tourmaline reduced the mobility of metals in contaminated soil without raising the pH of the soil.

## 5. Conclusions

Soil contamination ranks among the most important issues that worry world decision-makers. Food security and soil fertility are also related to it. Egypt's crop and soil quality are suffering greatly as a result of the high concentration of heavy metals in the Nile Delta's soils.

GIS is an essential tool for storing, retrieving, and modifying enormous amounts of data needed for mapping and calculating degree of soil contamination by heavy metals. To evaluate soil contamination, the most crucial step is to create spatial distribution maps for HMs. 50 surface soil samples were analysed for five heavy metals (As, Cu, Ni, Pb, and Zn) using a geo-accumulation index (I-geo), contamination factor (CF), Pollution

Load Index (PLI), and Modified Degree of Contamination (mCd) supported by GIS to determine the degree of soil contamination in the research area.Consequently, the research region's CF categories range from low contamination to very high contamination. The study areas were classified as moderately and unpolluted according to the PLI index. 76.70% of the research area was found to be unpolluted. However, the class with considerable contamination made up around 23.30 %of the research area. About 42.10% of the research area was classified as moderately contaminated, while the rest of the study region (57.90%) was classified as slightly polluted based on the mCd values.

**Supplementary Materials:** Supplementary data associated with this article can be found in the online version.

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**Conflicts of Interest**: The authors declare that they have no conflict of interest in the publication.

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