The Study of Heavy Metal Contamination in Industrial Soils of Aurangabad Using GIS Techniques

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Abstract: The main objective of the present study is to assess the level of contamination, source identification, and health risk assessment of heavy metals in the industrial soils of Aurangabad. A total of 15 Soil samples were collected with a sampling density of 3–5 composite soil samples from 0–10 cm surface soil, analyzed heavy metals (Ni, Pb, Cd, Zn, Cr, Mn, Fe, and Cu) using atomic absorption spectroscopy. The geographical information system (GIS) technology like Kriging and inverse distance weighted interpolation (IDW) was used for the preparation of spatial distribution maps. A significant spatial relationship was found for Ni, Cd, Zn, Pb, and Cu in the soils using a GIS-based analysis, suggesting that these metal contaminants in the industrial area had common sources. Assess the risks of contamination for heavy metals in the soil were assessed based on a geo-accumulation index (Igeo) and contamination factor (CF). According to the Igeo and CF, most of the samples vary between 0 to 1, unpolluted to moderately polluted except Cd values. Most of the measured heavy metals showed the highest availability in top soils collected from around the steel and metal industries of the Waluj MIDC area. Also, based on the outcomes of the health risk assessment, particular attention should be paid to Ni, Pb, Cd, Zn, Cr and Cu in the industrial soils of Aurangabad. This study is socially beneficial for prevailing human health hazards in such industrially populated regions.

Keywords: Geo-accumulation index, GIS, Heavy metals, Pollution, Soil

1. Introduction

Soil contamination is now a global problem, owing primarily to intensive industrialization, urbanization, and transportation (Nazzal et al., 2015; Wieczorek et al., 2020). Soil pollution by potentially heavy metals represents one of the major problems for the sustainable development of urban areas. The amounts of heavy metals in soil are harmful to human health and they enter the human body, affecting directly or indirectly by ingestion and inhalation. The heavy metal concentrations of groundwater (Deshpande et al., 2013) and soils (Bikkad et al., 2008) have been studied in Aurangabad. According to Maharashtra pollution control boards (MPCB-2020) suggests that different Action plans for the Responsible Stake Holders were studied. Many kinds of research on the fate and transport of heavy metals in soil, as well as the remediation of polluted soils, have all been solving this issue extensively (Ma et al., 2015, Hou et al., 2016). For regional soil quality assessment, a growing number of researchers have used integrated geographical information systems (GIS) and multivariate analysis in recent years (Ali et al., 2016; Huang et al., 2015, Hou et al., 2017, Lin et al., 2016; Mihailovic et al., 2015, Moore et al., 2016; Zhou et al., 2016). This can be attributed in part to the use of specialized software that can handle enormous spatial data sets in GIS. GIS and GIS-based geo- statistics have proven to be effective tools. (Hooker & Nathanail, 2006).

Consequently, attempts to carry out a detailed survey of Aurangabad's urban soils using a systematic sampling technique have been limited. Furthermore, only a few studies have used a GIS-based technique to analyze heavy metal contamination in an urban environment, and there has not been a GIS-based investigation of soil quality in Aurangabad.

The main objective of the present study is to assess the heavy metal contamination of the topsoil based on a geo-accumulation index (Igeo), contamination factor (CF), correlation matrix and, to assess the possible sources and hotspots of heavy metal contamination in industrial soil samples in the study area using GIS techniques. The spatial distribution maps deciphering different zones of heavy metal concentration in the soil were generated in the GIS environment.

2. Materials and methods

2.1 The study area and sampling sites

The study area belongs to the City of Aurangabad coordinates 19° 53' 47"N, 75° 23' 54"E (Figure 1). In Aurangabad, the geological formations from the Deccan basaltic flow of the upper cretaceous to the lower Eocene age. The lava flows are overlain by thin alluvial deposits. The basaltic flows represent Deccan trap-rocks, which are two distinct units. The uppermost is vesicular basalt and amygdaloidal basalt. The bottom-most is massive basalt. The soil of the study area, mainly from an igneous rock, is a black and calcareous type having different depths (Deshpande, 2012). Aurangabad consists of three industrial areas, namely Waluj- Chikhalthana- Shendra Industrial Zone. For smaller-scale site-specific soil contamination investigations, sample locations are often chosen based on professional judgment, to determine the soil contamination within the 15 number sampling locations. As shown in figure 1, the three major MIDC (Maharashtra industrial development corporation) areas, Aurangabad have been selected for soil sampling sites, collecting multiple sub-samples to render composite samples are chosen randomly at the depth of 0-10 cm using a stainless-steel spatula. At each sampling location, composite samples are typically obtained from several sub-sampling points and combined (Li et al., 2004). Because the distribution of heavy metals in the soil is extremely varied from the micro to mesoscale, this technique is widely used.

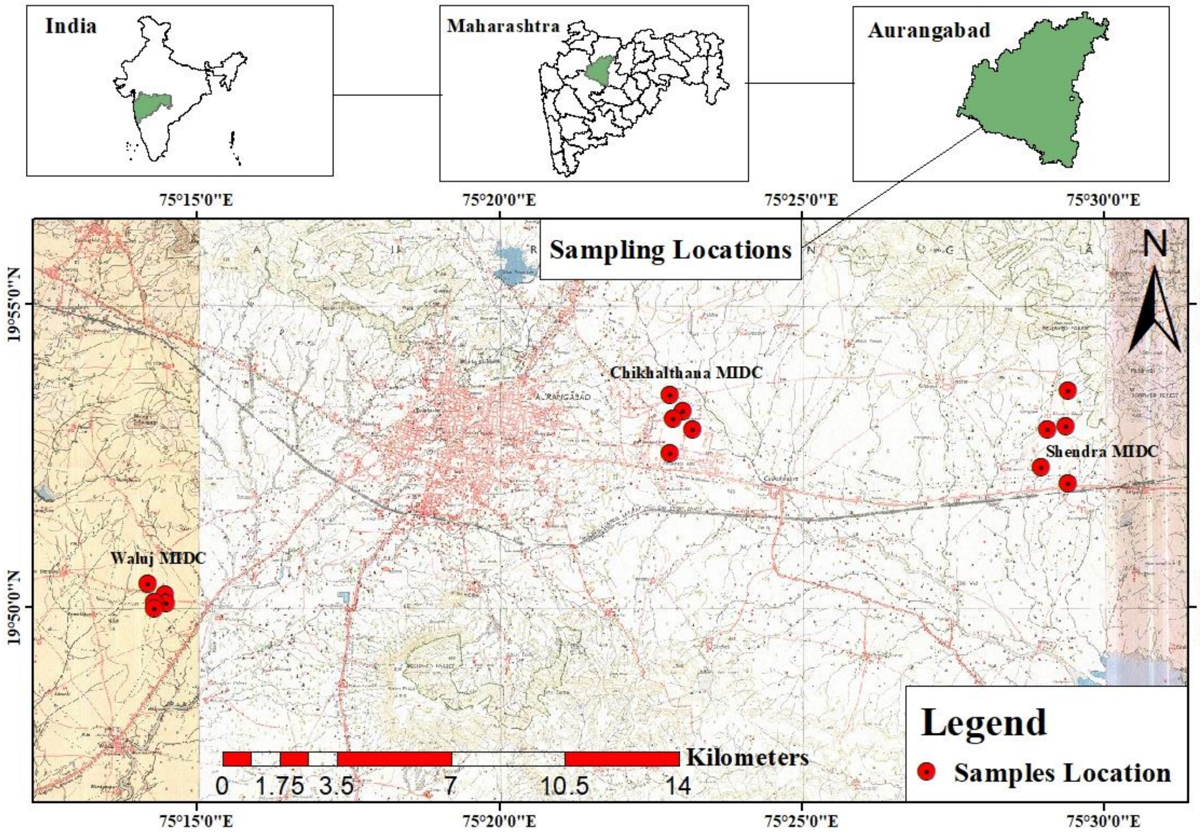

Figure 1. Location map of the study area and sample location

2.2 Heavy metal analysis

The soil samples were analyzed for heavy metal concentrations using a strong acid digestion method (Siaka et. al, 1998). Approximately 1 gm of the soil samples were weighed and placed into pre-cleaned 250 ml Beakers separately. Concentrated hydrochloric acid (HCl) and concentrated nitric acid (HNO3) acid were added in a ratio of 3:1. The mixtures were heated until they were completely transparent. After cooling, the resultant solution was filtered using Whatman filter paper no. 42 and into a 50 ml dilute to 50 ml volumetric flask and diluted to mark volume using double distilled water. Metal concentrations of the solutions were measured using an Atomic Absorption Spectrometer (Chemito Analyst Instrument 300).

2.3 Geo-accumulation Index

The geo-accumulation Index (Table 1), a quantitative measure of the degree of pollution in soil, the method assesses the degree of metal pollution in terms of seven enrichment classes based on the increasing numerical values of the index.

This index is calculated by following equation (1)

$$I_{geo} = log_2\left(\frac{C_n}{1.5\times B_n}\right) \text{------- (1)}$$

Where Cn is the concentration of a given element in the soil and Bn is the average background value described by Stoffers et al. (1986). The constant 1.5 factor is used because of to minimize the effect of possible variations in the background values due to lithogenic effects. The following descriptive classification is known for the index of geo-accumulation by (Salomons and Forstner, 1984).

Table 1. Classification of samples in terms of enrichment factor and geo-accumulation

I-geo Value	Class	Qualification of material
< 0	0	Unpolluted
0-1	1	From unpolluted to moderately polluted
1-2	2	Moderately polluted
2-3	3	From moderately polluted to strongly polluted
3-4	4	strongly polluted
4-5	5	From strongly polluted to extremely polluted

>5	6	Extremely polluted

2.4 Contamination Factor (Cf)

The assessment of soil contamination was accomplished using the contamination factor. The CF is the single element index of the environment and all four classes are recognized. In the version suggested by Hakanson (1980), they enable the ratio of the concentration of that heavy metal in the sample to the respective mean values or background concentration of the metal for the natural environment. Mathematically, this factor is given by following equation (2).

$$\boldsymbol{CF} = \frac{Csample}{Cbackground} \text{------- } \mathbf{(2)}$$

The following terminologies are used to describe the contamination factor according (Hakanson (1980):

$CF < 1$ low contamination factor
$1 \leq CF < 3$ moderate contamination factor
$3 \leq CF < 6$ considerable contamination factor
$CF \geq 6$ very high contamination factor

2.5 GIS and spatial analysis

The heavy metal concentrations were used as the input data to study the distribution of metals in the urban soils. A geo-statistics method Kriging and inverse distance weighted (IDW) method was adopted for the interpolation of geographical data for assessed heavy metal (Table 2).

The Spatial distribution maps that were obtained were then overlaid in GIS with other geographical features such as roads. Arc GIS 10.3 was used to conduct the spatial analysis for the current study. GIS was used in this study in the following aspects: (a) to locate the sampling locations in the study area (Figure 1). (b) To generate spatial distribution maps showing polluted areas of heavy metal contamination in soils (Figure 2-9).

Table 2. Using Interpolation Techniques for Various heavy metals

Element	Interpolation Techniques
Nickel (Ni)	IDW method
Lead (Pb)	IDW method
Cadmium (Cd)	IDW method
Zinc (Zn)	IDW method
Chromium (Cr)	Kriging method
Manganese (Mn)	IDW method
Iron (Fe)	IDW method
Copper (Cu)	Kriging method

3. Results and Discussion

3.1. Heavy metal concentrations in soil

Assessment of heavy metal concentrations with Ni, Pb, Cd, Zn, Cr, Mn, Fe, and Cu in the industrial soils of Aurangabad was assessed and their spatial distribution was compared with heavy metal concentration in the earth's crust (Mason & Moore, 1982), (Table 3). The Ni varied from 66.32 - 161.23 ppm, Pb varied from 9.56 - 18.23 ppm, Cd varied from 0.15 -0.80 ppm, Zn 61.20 - 140.30 ppm, Cr 113.10 - 168.08 ppm, Mn varied from 1262.32 -1834.16 ppm, Fe varied from 79500.4000 - 86600.3000 ppm, and Cu varied from 90.02 -134.74 ppm. The heavy metal concentration in the industrial soil is in descending order as Fe>Mn>Cr>Ni>Zn>Cu>Pb>Cd. The obtained results of the studied area of heavy metals were higher than the background values of the volcanic rocks according to Mason & Moore (1982).

Based on these values it is expected that Ni, Cd, Cr, Fe, And Cu are dominated by natural sources whereas Pb and Zn are likely to be affected by Anthropogenic sources (Ramdani et al., 2018). Fe is abundant in natural soils, it has been used as an indicator of lithogenic origin in multivariate statistical analysis results (Kinniburgh et al., 1976). Depending on the location, different heavy metals may be attributed to natural sources. For instance, Li et al. ascribed Cd, Co, and Cr concentrations to natural sources, whereas, Shan et al. ascribed Cu, Ni, and Cr concentrations to natural sources. Facchinelli et al. also made this conclusion for Crand Ni concentrations. It is concluded that multivariate statistical analysis techniques are effective at determining heavy metal lithogenic origins (Hou et al., 2017). The higher amount of Fe and Mn have come from steel, Iron, and poor disposal of spare parts (metallurgical sources). A study by Kubier et al. (2019) reveals that Cd comes into soil due to combustion emissions, sewage sludge, traffic, metal industry and mining, where as Cu and Zn are added from the deterioration of automobile parts (Orosun et al., 2020). Cr is one of the toxic elements found naturally from the process of weathering minerals in the earth's crust or because of industrial waste reaching the soil (Hammam et al., 2022). However, a high concentration of them causes a reduction of plants and affects human health. Waluj Industrial and Chikalthana area mainly contain Pb, Zn, Cd, Cu and Cr are like higher concentrations from an industrial process. Therefore, the source of contamination generated by metal Industries through metal emission.

The study revealed a positive correlation between Fe and 3 heavy metals (Mn, Cd, and Ni) based on the observations of the correlation matrix (Table 4). The Pearson correlation coefficient matrix identified that the pairwise linear regression, Fe concentrations positively correlated with Mn and Ni, it mentioned that the natural geogenic source. On the other hand, Fe negative or negligible correlation with Pb, Zn and Cr which replicates the anthropogenic origin (Ali et al., 2016). Cu exhibited a highly significant positive relationship with Pb (0.208), Ni (0.260), and Cr (0.025) indicating the anthropogenic source with geogenic composition. The result suggested that Cu, Pb, and Zn may come from the same source and the local industrial activities contributed greatly to the soil contamination Usually, heavy metals correlate well with the observed similarities in their spatial distributions.

Table 3. Descriptive statistics of metal concentration (ppm) with Background values of volcanic rocks

	Nickel (Ni) (ppm)	**Lead (Pb)** (ppm)	**Cadmium (Cd)** (ppm)	**Zinc (Zn)** (ppm)	**Chromium (Cr)** (ppm)	**Manganese (Mn)** (ppm)	**Iron (Fe)** (ppm)	**Copper (Cu)** (ppm)
Minimum	66.32	9.56	0.15	61.20	113.10	1262.32	79500.4000	90.02
Maximum	161.23	18.23	0.80	140.30	168.08	1834.16	86600.3000	134.74
Mean	103.5187	13.4707	0.3293	93.3060	129.2393	1390.4040	75024.233360	115.7520
Std. Deviation	26.66098	2.97833	0.22195	18.53857	19.77934	174.32496	21178.2629569	9.75255
Background Values (Mason &Moore 1982)	**76**	**7.8**	**0.15**	**86**	**114**	**1280**	**77600**	**110**

Table 4. Pearson correlation coefficient matrix for heavy metals and others properties in the industrial urban soil of Aurangabad

	Nickel (Ni)	**Lead (Pb)**	**Cadmium (Cd)**	**Zinc (Zn)**	**Chromium (Cr)**	**Manganese (Mn)**	**Iron (Fe)**	**Copper (Cu)**
Nickel (Ni)	1							
Lead (Pb)	-0.126	1						
Cadmium (Cd)	-0.055	-0.022	1					
Zinc (Zn)	-0.162	-0.092	-0.044	1				
Chromium (Cr)	-0.146	0.377	-0.444	0.551*	1			
Manganese (Mn)	0.246	-0.312	0.165	-0.234	-0.329	1		
Iron (Fe)	0.344	-0.335	0.055	-0.047	-0.052	0.121	1	
Copper (Cu)	0.260	0.208	0.104	-0.086	0.025	-0.102	0.219	1
*. Correlation is significant at the 0.05 level (2-tailed).								

Table 5. Descriptive Statistics of Igeo Index for Industrial soil

	Minimum	**Maximum**	**Mean**	**Std. Deviation**	**Skewness**
Nickel (Ni)	0.0023	0.0056014	0.0036	0.00095	1.222
Lead (Pb)	0.032	0.0601274	0.04443	0.00982332	0.663
Cadmium (Cd)	1.338	7.134815	2.9372	1.97951	1.412
Zinc (Zn)	0.002	0.00381	0.003	0.000503	1.100
Chromium (Cr)	0.002	0.0026	0.002	0.00031	1.417
Manganese (Mn)	0.0002	0.000225	0.0002	0.0000214	2.028
Iron (Fe)	0.000000003	0.000003	0.000003	0.00000071	-3.607
Copper (Cu)	0.0015	0.002235	0.00192	0.00016174	-0.887

Table 6. Descriptive Statistics of Contamination Factor for Industrial soil

	Minimum	Maximum	Mean	Std. Deviation	Skewness
Nickel (Ni)	0.873	2.122	1.363	0.351	1.222
Lead (Pb)	1.226	2.337	1.727	0.382	0.663
Cadmium (Cd)	1.000	5.333	2.196	1.480	1.412
Zinc (Zn)	0.712	1.631	1.085	0.216	1.100
Chromium (Cr)	0.992	1.474	1.134	0.174	1.417
Manganese (Mn)	0.986	1.433	1.0863	0.136	2.028
Iron (Fe)	0.001	1.116	0.967	0.273	-3.607
Copper (Cu)	0.818	1.225	1.0523	0.089	-0.887

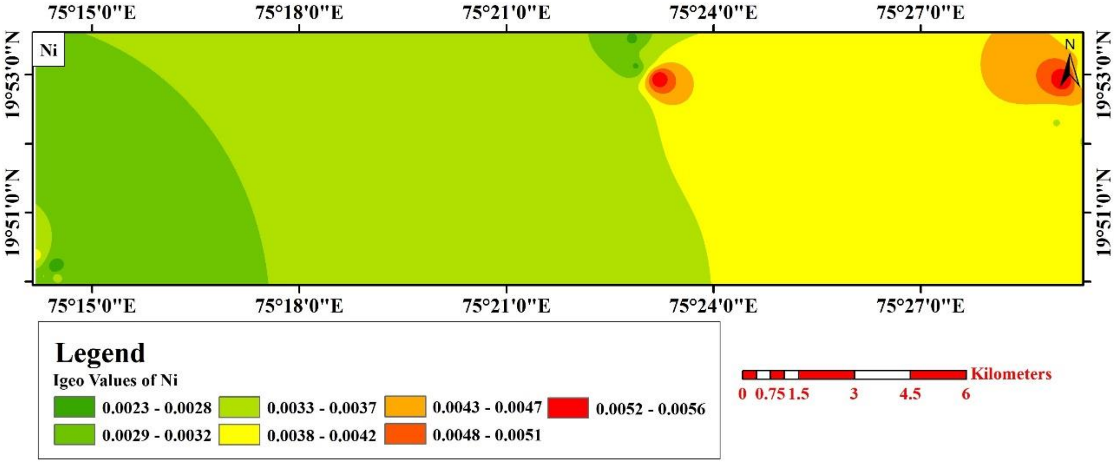

Figure 2a. Spatial distribution map of Ni

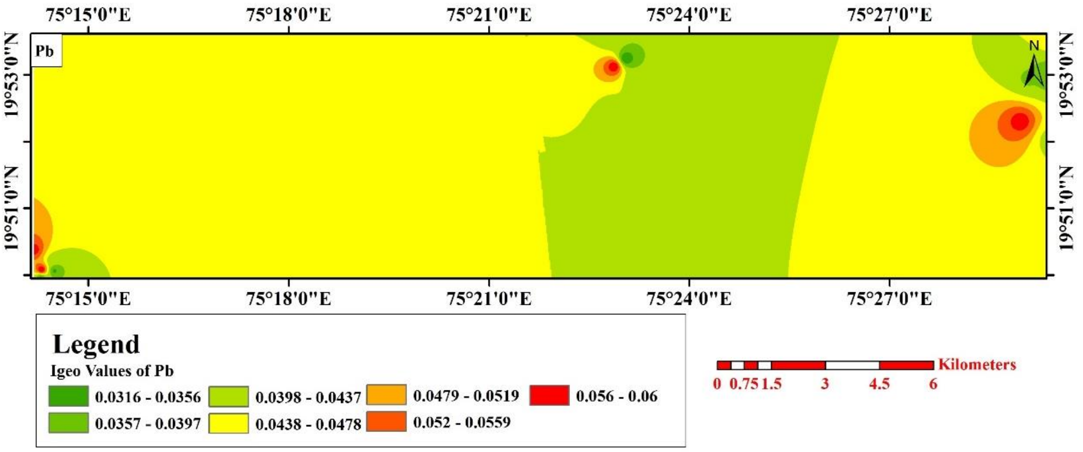

Figure 3. Spatial distribution map of Pb

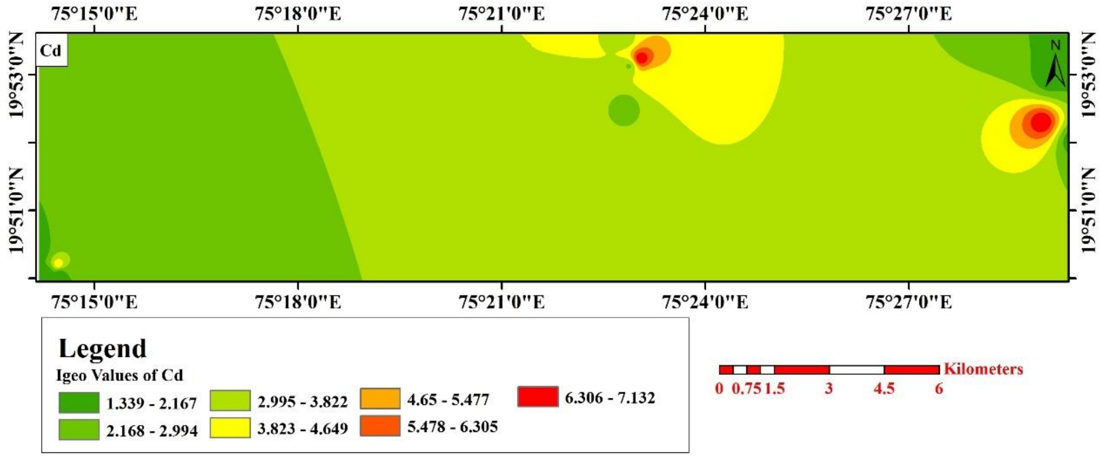

Figure 4. Spatial distribution map of Cd

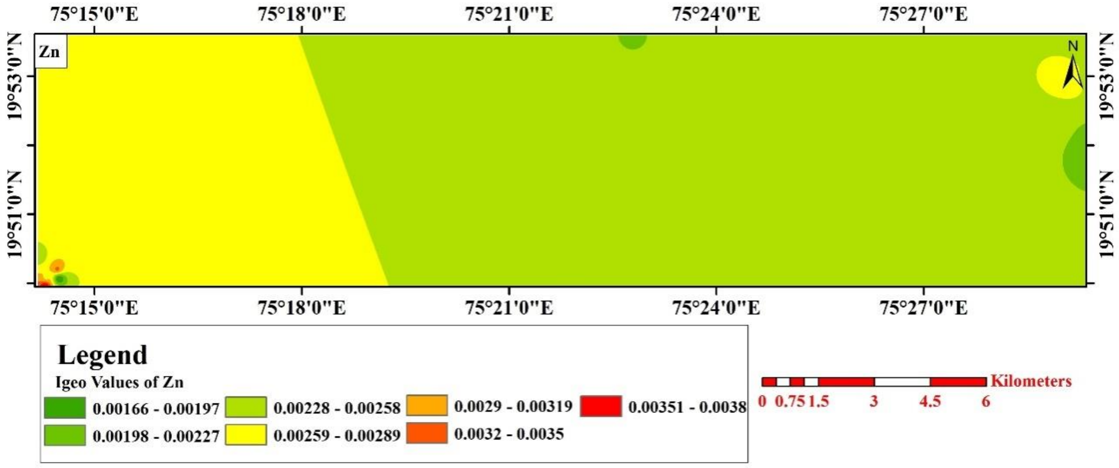

Figure 5. Spatial distribution map of Zn

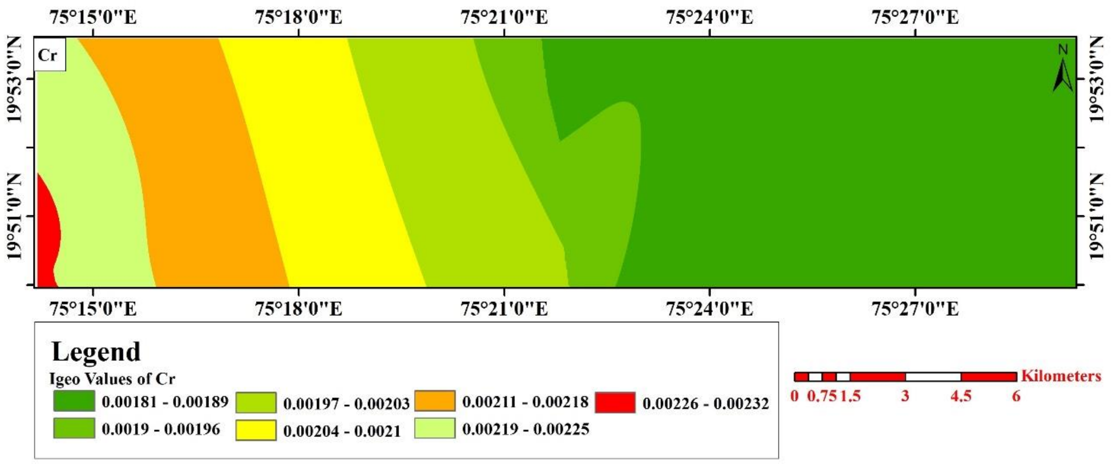

Figure 6. Spatial distribution map of Cr

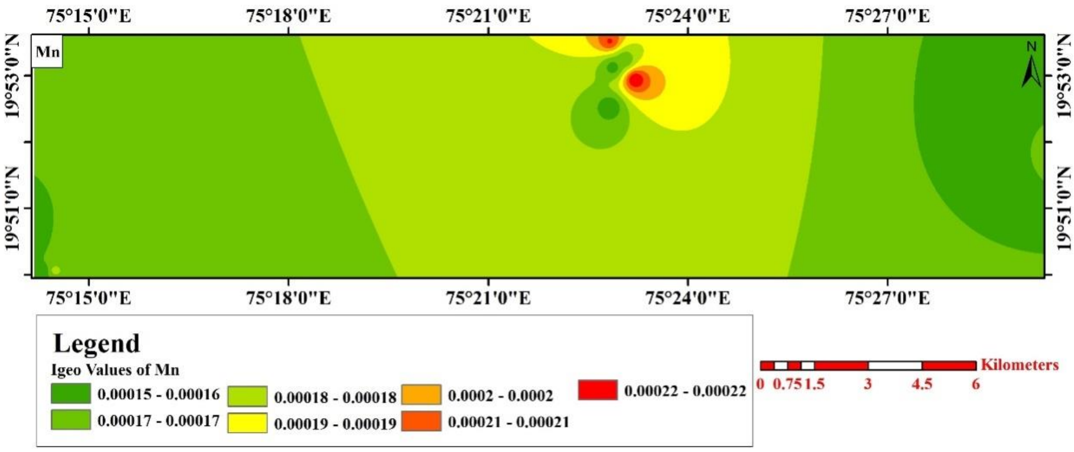

Figure 7. Spatial distribution map of Mn

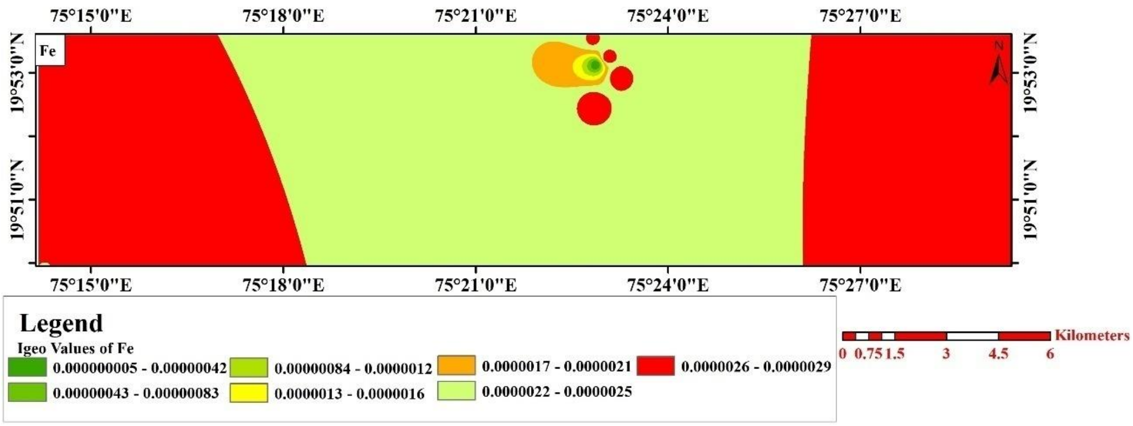

Figure 8. Spatial distribution map of Fe

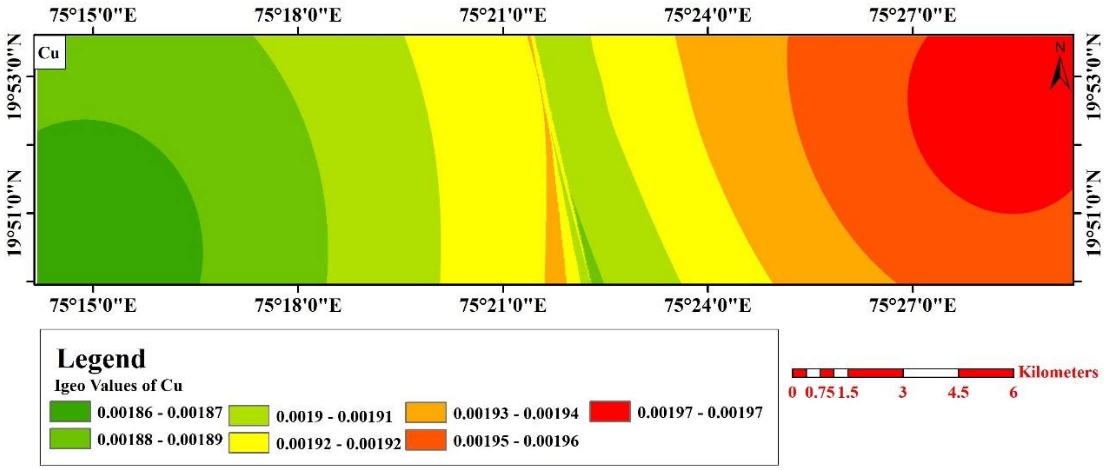

Figure 9. Spatial distribution map of Cu

3.2 Assessment of contamination risk using geo-accumulation index and contamination factor

In the present study, the contamination of soils was assessed based on the I-geo and CF. The I-geo values indicated moderately polluted by Ni, Pb, Cd, Cr, Zn, Mn, Fe, and Cu in the industrial soil. I-geo (Ni) varied from 0.0023 to 0.0056, I-geo (Pb) varied from 0.032 to 0.060, I-geo (Cd) varied from 1.338 to 7.135, and I-geo (Zn) varied from 0.002 to 0.0038, I-geo (Cr) varied from 0.002 to 0.0023, I-geo (Mn) varied from 0.0002 to 0.000225, I-geo (Fe) varied from 0.000000003 to 0.000003, and I-geo (Cu) varied from 0.0015 to 0.0022 (Table 5). The results indicate that there was no significant pollution observed in Ni, Pb, Cr, Zn, Mn, Fe, and Cu. As per the Igeo values (Igeo 1-2 Class 2), the study area belongs to unpolluted to moderately polluted for the assessed Seven heavy metals as shown in Table 5. However, there are some noticeable Igeo values of Cd (Samples I-2,10,11,12,13) indicating an extremely polluted (Igeo >5- Class 6) region.

Similarly, CF values of soil samples of the studied area are less than 1 which indicates a low contamination factor for Ni, Pb, Cr, Zn, Mn, Fe, and Cu (Table 6). The CF values of Cd is in $1 \leq CF < 3$ means moderate contamination factor but soil samples(I2,11,12) show the highest CF in between 3-5 ($3 \leq CF < 6$ considerable contamination factor) present in the studied area it indicating high anthropogenic activity in the study area.

The results of Igeo and CF values of Waluj industrial soil samples show maximum values as then the Chikalthana and Shendra industrial areas. Industrial activity or anthropogenic sources like metal plating, automotive, fossil fuel combustion, and other waste is the main source of contamination of heavy metals Ni, Pb, Zn, Cd, and Cr in soil. Although the Igeo values are shown the maximum amount of Fe, Mn, and Cu heavy metals, hence it is indicating that the Shendra MIDC soil samples are less contaminated or the source of geogenic origin. This result indicates that the studied soil samples are unpolluted to moderately polluted with assessed heavy metal.

3.3 Spatial analysis using GIS

The spatial distributions of I-geo for heavy metals (Ni, Pb, Cd, Cr, Zn, Mn, Fe, and Cu) in the study area using GIS methods are illustrated in (Figure 2-9). The I-geo for heavy metals was first interpolated with the Kriging and IDW method. In general, a spatial distribution map was built up to determine the highly affected areas as well as the pollution source and several hot spots of high metal concentrations correlated to one other more than two faraway points. The lotus pond green colour represents the minimum Igeo values of soils related to the heavy metals analyzed, while the Igeo maximum values of soils are represented by the Mars Red colour. Based on the Igeo values the results shown in the spatial distribution map on the western parts of the area have the highest level of contamination while the eastern parts are clear of toxic levels of both essential trace constituents and toxic heavy elements.

This result may indicate that further monitoring of these heavy metals is required and the prevention of additional enrichment of these elements in soils requires regular protection measures.

4. Conclusion

The current study highlights the assessment of soil contamination by heavy metals in the Aurangabad industrial area. This study demonstrated the effective use of the Spatial distribution maps for predicting the hot-spot areas and assessing the potential sources of pollutants of heavy metals in the study area. Furthermore, the geo-accumulation index and contamination factor provided unconventional results in classifying the study area in significant correlation, reflecting the impacts of anthropogenic especially industrial activities.

The contamination of the soils of the study area was assessed based on the geo-accumulation index obtained for assessed heavy metals indicated unpolluted to moderately polluted. Significant contamination factors observed in the study area indicated very low contamination except for Cd. This indicates, that there were many hotspots contaminated with Cd, Cu, Pb, Fe, Mn and Cr, suggesting human causes such as long periods of industrial activities in the study area are responsible for the heavy metal pollutants.

The soil in the study area could be considered Partially or moderately polluted by heavy metals because mean values were greater than the corresponding background values of volcanic rocks. The increased levels of heavy metals in the study area are a major concern for the suitability of land management practices. Fe, Mn, and Zn concentrations are mainly inherited from parent materials, and Ni, Pb, Cr, Cd, and Zn could be affected by both geogenic and anthropogenic sources including the steel and metal industries, automotive, municipal, or industrial waste, sewage discharge, aerial pollution, etc.

The results emphasize that investigation of heavy metals might be better used for establishing environmental quality to identify the pollution source and to minimize or reduce soil contamination in the study area. Hence, this study is socially beneficial for prevailing human health hazards in such industrially populated regions.

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Conflict of interest

All authors declare no conflicts of interest in this paper.

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