Evaluation of Possible Ecological Risk and Heavy Metal Pollution Level in the Soil of the Kanker District, Chhattisgarh, India

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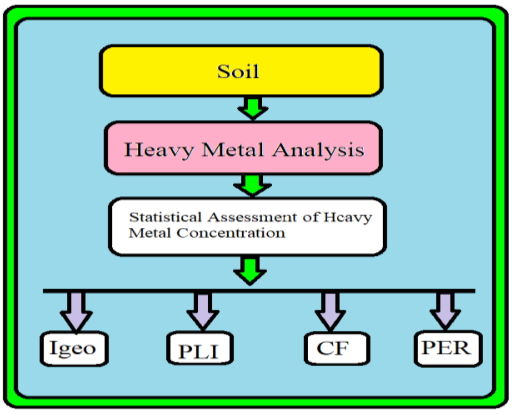
Abstract

Anthropogenic activities affect the soil's composition and structural characteristics and will lead to changes in the soil's properties. In several parts of the world, soils are exposed to mechanical treatment, the application of pesticides, the disposal of garbage, and industrial contamination. Pollution by heavy metals is an immense concern that directly affects human well-being because of our modern lifestyle. This study examined the effects of six toxic elements: Chromium (Cr), Nickel (Ni), Arsenic (As), Cadmium (Cd), and Lead (Pb) in 10 different Kanker, Chhattisgarh, India, and sampling locations. Their contamination levels were examined using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and an Atomic Absorption Spectrometer. In various soil sampling locations, the average concentrations of Cr, Pb, Cd, Ni, Cu, and As were reported to be 0.25, 2.49, 0.13, 0.86, 0.35, and 0.94 mg/kg. The overall contamination condition, possible sources, and source distribution of all six toxic elements in the soil research area were evaluated through various techniques, including the geo-accumulation value (Igeo), potential ecological index (RI), pollution load index (PLI), and contamination factor. All metals were determined to have low contamination factors and potential ecological risk values, although a geoaccumulation index assessment found that Cr, Pb, and Ni had a significant potential to acceptably pollute the study region.

Keywords: Heavy metals, Risk assessment,Geo-accumulation index



Graphical Abstract

1. Introduction

The soil is an essential element for all living things. It is regarded as the fundamental constituent of life, specifically for plants. Since we all regularly utilize these natural resources, water and air,the condition of these resources causes a significant issue for most of the population. Metals are naturally occurring metal complexes with a density of more than 5g/cm3; relative to other metals, they have a density that is at least five times that of water. Essential heavy metals like Mn, Fe, Ni, and Zn are usually required by living things for their growth, progress, and physiological functionality, while undesirable substantial metals like Cd, Pb, Hg, and As are not needed by living things for any physiological growth. They are among the most determinant toxins in soil and water (Singh et al.,2018) Due to our increasing dependency on the agricultural industry, soil degradation is directly related to both economic and environmental sustainability. By accumulating through the food chain, heavy metals deposited in agrarian soils can harm the biochemical pathways of the soil and even threaten human health. (Niu et al., 2018)

Understanding the sources of soil contaminants, such as heavy metals, has become crucial for the local authorities to minimize the cost and concern for soil remediation. (Huang et al., 2018) Anthropogenic impacts, such as automobile traffic, rapid industrialization, drainage, and further mining operations, are largely responsible for the rapidly growing contaminants in urban soils. Hence, toxic metals can spread to soils and aggregate in plants, animals, and water bodies. They can then enter the bodies of humans via a wide range of food chains, representing a serious threat to human health (Adimalla 2019).

Through correlating the results with local geological reference standards, numerous investigations have evaluated the consequences of harmful metal pollution of soils on the health of humans and the environment (Niu et al., 2018). Nowadays, many countries, including Germany, the Netherlands, the UK, Japan, and the USA, have evaluated the contamination level ofheavy metalsin soil, groundwater, and the ecosystem using governmental rules and regulations (Manmat et al., 2019). Different techniques, such as the contamination factor (Cif), geo-accumulation index (Igeo), pollution load index (PLI), enrichment factor (EF), and many others, are more often used to examine the occurrence of extremely hazardous elements in soil (Proshad et al., 2017).The aim of this research was (1) to assess the concentration of toxic metals (Cd, Pb, Cu, Cr, As, and Ni) in the agricultural soil of the Kanker district. (2) To evaluate the quantity of toxicity level in soil dependent on Igeo, PLI, and C_f. (Cai et al.,2021).

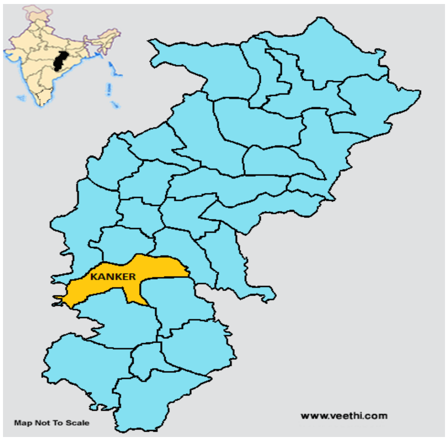


Fig.1 Study area(Kanker District of Chhattisgarh)

2. Sample collection and analysis

In the southern region of Chhattisgarh, India, in the Kanker district (Figure 1), ten different locations were selected for this assessment. The Kanker District is located between north latitudes 80.48–81.48 and longitudes 20.6-20.24. The district's total area is 5285.01 kilometers. 748,941 people are living here. Red soil dominates the area's topography. In November and December, soil samples were taken for analysis. Before being pulverized and homogenized to determine the amount of toxic metals, samples were stored in a cold environment and then dried in the ambient temperature of the air for a couple of weeks. After being sieved through a 2 mm wire mesh and pulverized with a marble pestle and mortar, the soils were sealed in an airtight polyethylene bag and stored refrigerated until analysis.

Dry homogenized samples were weighed in a Teflon digestion vessel between 0.1 and 0.2 g. For microwave digestion of the samples, 5 mL of ultra-pure, highly concentrated nitric acid (HNO_3) and 2 mL of ultra-pure HCl, highly concentrated hydrofluoric acid (HF), were utilized. The microwave was used to complete the sample digestion process. The processing of the samples took 20 minutes. Samples were taken out of the microwave after at least 30 minutes of cooling. If there is any residue in the solution after digestion, 1 ml of HNO3 is added and repeat the procedure till a clear solution is obtained. Then, after removing the Teflon vessel from the microwave, pour the solution into the Teflon beaker and then fill the vessel with distilled water (about 3 ml). A hotplate is used to heat the Teflon container to a temperature between 60° and 70°C until it is dry. Distilled water was used to clean the beaker. The solution is then filtered using filter paper (125 mm in diameter, 100 circles) before being diluted with water to the desired level (either 30 or 50 ml) for the analysis.

ICP (TELEDYNE LEEMAN LABS) and AAS (Electronic Cooperation of India Limited)are used for the determination of the concentration of heavy metals (As, Cr, Ni, Pb, Cd, Cu). The blank reagent was monitored throughout the analysis for the correct analytical results. Ensured reference material was utilized for quality control and quality confirmation.

3. Pollution assessment methods

3.1Contamination factor (Cif)

The contamination factor is the proportion of the amount of metals within the soil samples to the baseline values.

Contamination factor (Ci_f) $= C_{\text{heavy metal}} / C_{\text{background value}}$

The levels of contamination can be categorized into six groups, ranging from 1 to 6, depending on the intensity of the contamination: extremely high degree ($Cif \geq 6$), significant level ($3 \leq Cif < 6$), moderate level ($1 \leq Cif < 3$) and minimal extent ($Cif < 1$).

3.2Geo-accumulation index (Igeo)

Igeo is considered a significant methodology for determining the level of pollution from hazardous elements. Using the geo-accumulation index (Igeo) proposed by Muller, the contamination levels of heavy metals in urban soils and agricultural soils are assessed (1969). Since the middle of the 1960s, the method has been widely used in European follow-metal examinations (Wei et al., 2010). This approach is currently used extensively to evaluate soil defilers. The main aim of choosing the geo-accumulation index (Igeo) is to determine the degree of heavy metal pollution in soil samples(Cai et al., 2020;Proshad et al.,2019; Mamat et al., 2019;). By using the parameters mentioned below, the Igeovalue can be evaluated.

$\mathrm{Igeo} = \log_2 (C_n/1{:}5B_n)$

In which Cn is the concentration of every element determined within the soil sample (mg/kg), and Bn is the mean of background value of each metal determined in soil (mg/kg)(Kabta,Pendias & Mukherjee2007;Li et al.2014).

3.3The pollution load index (PLI)

According to Suresh et al., the PLI is calculated using a systematic approach for evaluating the quality of soil for the six metals. The formula mentioned can be used to determine the PLI (Proshad et al., 2019).

$\mathrm{PLI} = (CF1 \times CF2 \times CF3 \times \ldots \times CFn)^{1/n}$

PLI is used to determine the overall toxic level of soils containing heavy metals.

3.4 Potential ecological risk (PER)

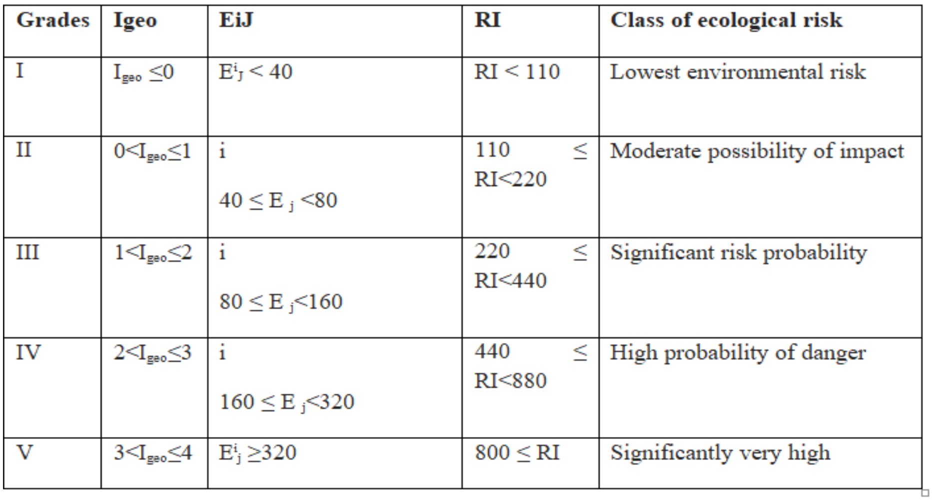
Hankinson's possible ecological risk index methodologies were used to assess the level of ecological as well as biological risks based on the properties of every metal and associated ecological behavior (Kureban et al., 2020). This method evaluates the hazardous level, amount of toxic element,and impact on the environment.

$C^i_f = C^i_D / C^i_R$

$E^i_R = T^i_R \times C^i_f$

Ti is the toxic-response factor of a specific metal (e.g., Chromium = 2 Zinc =1, Cadmium =30, Copper=Lead=5, and Arsenics =10),Ei is the algebraic potential ecological risk factor, C_0 is a reference value, and Ci is the quantity of metals within the soil. RI is determined by combining all of the potential ecological risk variables for significant metal content in soil (Elias et al., 2014).

Table 1.Environmental riskassessment of soil due to the presence of toxic metals is classified based on Pollution Load Index, Potential ecological risk and Geo- accumulation index.



Grades	Igeo	EiJ	RI	Class of ecological risk
I	$I_{geo} \leq 0$	$E^i_J < 40$	RI < 110	Lowest environmental risk
II	$0<I_{geo}\leq 1$	i $40 \leq E_j < 80$	110 ≤ RI<220	Moderate possibility of impact
III	$1<I_{geo}\leq 2$	i $80 \leq E_j < 160$	220 ≤ RI<440	Significant risk probability
IV	$2<I_{geo}\leq 3$	i $160 \leq E_j < 320$	440 ≤ RI<880	High probability of danger
V	$3<I_{geo}\leq 4$	$E^i_j \geq 320$	800 ≤ RI	Significantly very high

4.Result and Discussion

Heavy metal contamination harms soil quality and is harmful to agricultural land. Deteriorated soil is then usually at risk for ecosystem destruction and impact on human beings.The accumulation of toxic elements, their transformation, of their effects on human, animal, and plant health could all influence agricultural output (Proshad et al., 2019).

4.1 Soils HMs

Because soils are initially formed from rocks, it is expected that the kind of rock on which soils are developed will have an impact on the concentration of metals in soils (Adimalla 2019). Due to their oxidation, solubility, and leaching processes, those metals' concentrations might vary (Zhaoyong et al., 2019). The concentrations of the toxic elements (Cr, Pb, Cd, Ni, Cu, and As) found in samples from various sampling sites are listed in Table 2. According to this study, the mean values of Cr, Pb, Cd, Ni, Cu, and As in distinct soil sampling sites were found to be 0.25, 2.49, 0.13, 0.86, and 0.35 mg kg^{-1}, respectively, in the soil samples of Kanker District in Chhattisgarh, India (Table 2). Figure 2 shows the total concentrations of six metals in soil samples (mg/kg) at sampling locations in the Kanker region of Chhattisgarh, India. Our study revealed that the soil quality was overall satisfactory and that the heavy metal content in each of the ten sampling regions under investigation was only slightly high.

Table 2: Amount of toxicmetals in (mg kg^{-1}) in the soil of Kanker District, Chhattisgarh, India

Sampling sites	Cr	Pb	Cd	Ni	Cu	As
S1	0.184	2.2	0.056	0.86	0.14	0.172
S2	0.274	1.2	0.068	0.934	0.332	1.561
S3	0.178	2.08	0.024	0.53	0.12	0.120
S4	0.362	2.54	0.16	0.888	0.08	nil
S5	0.378	2.92	0.14	0.866	0.084	0.011
S6	0.194	3.86	0.026	1.106	0.75	1.600

S7	0.16	3.18	0.32	0.672	0.614	1.500
S8	0.172	1.89	0.036	0.77	0.18	0.153
S9	0.254	1.78	0.46	0.93	0.56	1.710
S10	0.335	3.26	0.052	1.08	0.64	1.630
Mean	0.25	2.49	0.13	0.86	0.35	0.94

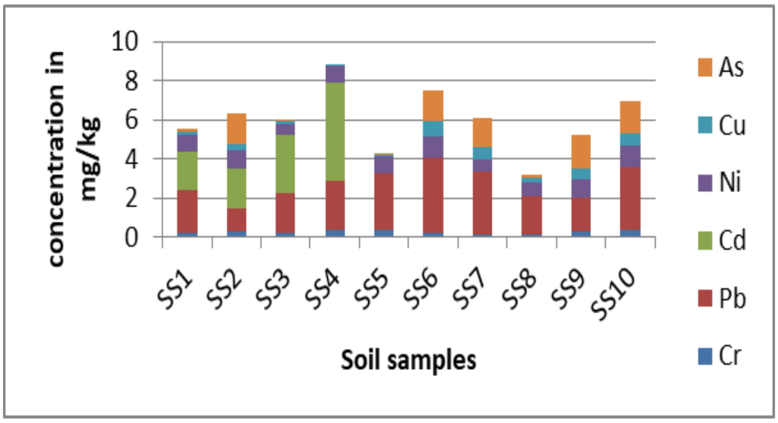


Figure 2: Heavy metal concentration in sampling area

4.2Determination of contamination level of Heavy metals in soils

4.2.1Assessment of Geoaccumulation (Igeo) Index

We used a standard methodology to measure the richness of metal content in soil compared to reference values by calculating the geo-accumulation index shown in Table 3 to learn more about the level of metallic contaminants in the soil close to industrialized areas (Igeo) (Kabir et al.,2011). The calculations of the I-geo of six elements (Figure 3) revealed that, in most of the samples, the ranges of I-geo for Cd, As, Cu, Ni, Cr, and Pb were, respectively, (-9.29--5.03), (-6.04--1.04), (0.08--0.75), (2.83-3.88), (3.42-4.66), and (3.49-5.19), which indicated levels of no pollution to severe pollutants. The average results were Cd (-7.51), As (-1.01), Cu (0.35), Ni (3.50), Cr (3.98), and Pb (4.46), suggesting a level of no pollution to mild pollution. Cd, As, and Cu had a degree of practically unpolluted, while Ni and Cr indicated heavy pollution. The I-geo values for Pd from 4 to 5 indicate that Pb has significantly contaminated the soils.

Table 3: Geo accumulation index values of metals of soil samples

Sampling sites	**Cr**	**Pb**	**Cd**	**Ni**	**Cu**	**As**
S1	3.62	4.36	-8.07	3.52	0.14	-2.28
S2	4.19	3.49	-7.79	3.64	0.33	0.91
S3	3.57	4.28	-9.29	2.82	0.12	-2.80
S4	4.59	4.57	-6.55	3.57	0.08	nil

S5	4.66	4.77	-6.74	3.53	0.08	-6.24
S6	3.69	5.17	-9.17	3.88	0.75	0.94
S7	3.42	4.89	-5.55	3.16	0.61	0.85
S8	3.52	4.14	-8.70	3.36	0.18	-2.45
S9	4.08	4.05	-5.03	3.63	0.56	1.04
S10	4.48	4.93	-8.17	3.85	0.64	0.97

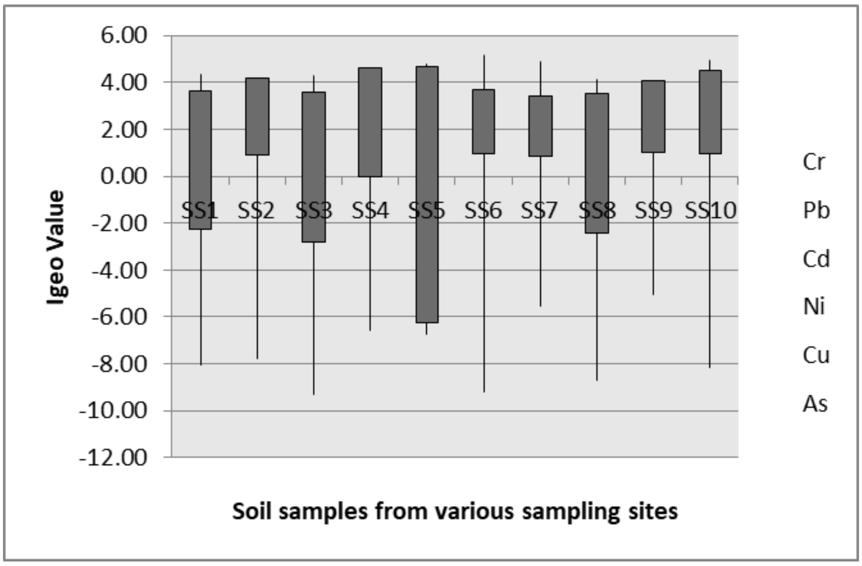


Figure 3: Calculation outcomes of the I-geo of six elements in collected soil samples

4.2.2Assessment of Contamination Factor & Pollution Load Index

The Cif and PLI of metal ions from various sampling sites are shown in Figures 4 and 5.Applying the CF as categorized to interpret the data showed that the soil from various regions is not contaminated with Cr, Pb, Cu, or Ni except Cd and As at a few sites. Soil samples from sites 7 and 9 were found to be contaminated with a considerable degree of cadmium, whereas soils from sites 4 and 5 were found to be medium toxicity with cadmium. However, soils from other sites were having a very low degree of cadmium contamination. Soils from sites 2, 6, 7, 9, and 10 are slightly contaminated in the case of As.

The pollution load index (PLI) zero values are nearly equal to acceptable. If the PLI value is 1, it means that there are no toxicities present, and if it is greater than 1, it means that the soil has toxic metals present in it due to the activities of human beings ((Proshad et al., 2018).For samples collected, the pollution load index values considering 06 toxic metals at distinct locations varied from 0.025 to 0.094, and they were classified into Group 2: 0 PLI 1 which is unpolluted. The soil at Kanker district sites 09 and 03 had PLI values of 0.094 and 0.025, respectively. As a result of the Cd contamination of the evaluated soils, it was discovered that the PLI values of every sampling region were significantly lower than one, indicating no contamination.

4.2.3Assessment of Potential ecological risk of Soil HMs

An assessment of its potential ecological threat was made for each heavy metal, as shown in Table 3. Table 1 also shows the criteria for the ecological hazard index. According to the increasing order of Cd>As>Pb>Ni>Cu>Cr, the estimated values of the potential risk coefficients (Eij) of each heavy metal had values of 40.26, 4.70, 0.89, 0.26, and 0.00, respectively. All of the examined metals, Cu, As, Pb, Cr, and Ni, had EiJ values that were less than 40, and all belonged to the low-risk category shown in Table 4.The Eij value for Cd was value was higher than 40, but below 80, it showed only a slight risk.

The sum of the six constituents of heavy metals is used to determine the ecological hazard index (RI) (Cd, As, Cr, Cu, Pb, and Ni).The following terminology was used to explain the ecological risk index; RI < 150 indicates low ecological danger, 150 < RI < 300 mild ecological threat, 300 < RI< 600 very excessive ecological risk index (Elias et al., 2014). RI is frequently employed to determine the ecological risks of trace detail. All of the samples, as shown in Table 3, had RI values below 150, which means less possibility of environmental threat from

Table 4: RI and PLI of heavy metals in soil samples

Sampling sites	**Cr**	**Pb**	**Cd**	**Ni**	**Cu**	**As**	**RI**	**Pollution degree**
S1	0.00	0.79	16.8	0.26	0.01	0.96	18.82	Low
S2	0.01	0.43	20.4	0.28	0.03	8.67	29.82	Low
S3	0.00	0.74	7.2	0.16	0.01	0.67	8.78	Low
S4	0.01	0.91	48	0.27	0.01	0.00	49.18	Low
S5	0.01	1.04	42	0.26	0.01	0.06	43.38	Low
S6	0.00	1.38	7.8	0.33	0.07	8.89	18.47	Low
S7	0.00	1.14	96	0.20	0.06	8.33	105.73	Low
S8	0.00	0.68	10.8	0.23	0.02	0.85	12.58	Low
S9	0.01	0.64	138	0.28	0.05	9.50	148.47	Low
S10	0.01	1.16	15.6	0.32	0.06	9.06	26.20	Low

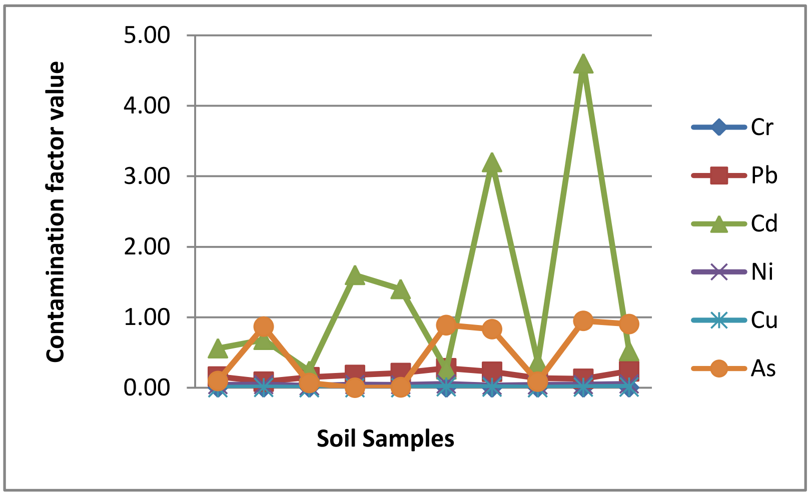


Figure 4: Contamination value of toxic metals in collected soil samples

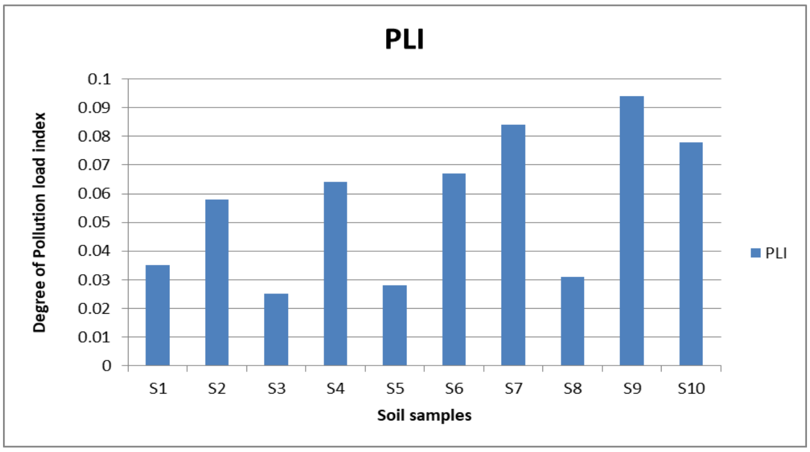


Figure 5: Degree of Pollution load index of all collected samples

5.Conclusion

Many methods were utilized in this study to examine the level of heavy metal pollution in agricultural soil, including the geo-accumulation index, contamination factor, pollution load index, and ecological risk index. According to the research, heavy metals most likely have an industrial origin. All of the metals were found to be less contaminated than what the literature had indicated, measured using Igeo values, the soil contamination status in this study was classified as moderately to extremely contaminated. The majority of the samples showed the most severe Cd, Ni, and Pb contamination. The samples were not significantly contaminated regarding As, Cu, and Cr. Applying the CF as categorized to interpret the data showed that the soil from various regions is not contaminated with Cr, Pb, Cu, or Ni except Cd and As at a few sites. PLI findings indicated minimal heavy metal contamination.These findings revealed that agricultural soils in the Kanker district were free of heavy metal pollution and suitable for use in farming.

The potential ecological coefficients (Eij) Cd for all the samples were 40.26, indicating a minimal potential ecological danger from the HMs. The RI values for all the samples were lower than 150. Moreover, more research should be conducted on the depth profile of GBCs in HMs to assess the quantities, origins, and effects of pollution in this area throughout time.

Further efforts should be made to identify soil contamination in connection with various industrial operations and farming practices, provided that there are sometimes no specific regulations governing soil pollution in emerging economies. This may also enable us to establish appropriate soil-regulating guidelines for maintaining a healthy and balanced environment.

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