A New Ecological Risk Assessment Method of Heavy Metals in Sediments and Soil

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Abstract The aim of this work was to derive a new modified equation to assess the potential ecological risk (E_r) of heavy metals in riverine sediments and soils. The new equation calculates the ecological risk (E_r) in terms of the geoaccumulation index (I_{geo}). Six new equations were derived to assess the E_r of Cd, Cr, Cu, Ni, Pb and Zn. The E_r of heavy metals in sediments of the Euphrates, Iraq and the Tietê River, Brazil was assessed using the new equation. The E_r was also assessed for the heavy metals in soils of Fallujah, Iraq and Tarkwa, Ghana. Results of application of the new equation were compared with those resulted from common equation (Hakanson's equation). Results of the comparison give credibility to use the new equation for ecological risk assessment. The effect of the reference value and concentration of heavy metal on E_r value was investigated.

Keywords Metal · Pollution · Ecological risk · Soil · Sediment

1 Introduction

Recently, the heavy metal pollution has attracted global concern as serious environmental issue because of its toxicity, bioaccumulation, abundance and persistence [1–3]. The primary sources of heavy metals accumulation in sediments of the aquatic environment are chemical leaching of bedrocks, water drainage basins and runoff from banks [4]. The anthropogenic activities such as mining operations, disposal of industrial wastes and application of pesticides are also heavy metals pollution sources in sediments of the aquatic systems [5]. The polluted sediments, in turn, can act as source of heavy metals conveying them into the water and degrading water quality [6, 7]. Sediments polluted by heavy metals can reflect the water quality of aquatic systems [8]. The main sources of heavy metals accumulation in soils and especially in urban soil are industrial activities, coal and fuel combustion, vehicles emissions,

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mining operations, fertilizers and pesticides use, municipal solid waste disposal, and other wastes [1, 9]. Heavy metals in sediments and soils can be spread and accumulated in plants and taken by human through consumption. The heavy metals cumulate in greasy tissues and then affect the functions of nerves, endocrine, and immune systems, normal cellular metabolism [10–12]. The ecological risk assessment is tool to some extent specifies the probability of an adverse effect to an organism or ecosystem due to exposure to environmental stressors, such as, chemical or biological pollution [13]. Different methods were developed to calculate the ecological risk of heavy metal, like potential ecological risk index $\left(E_r^I\right)$ [14] and index of geoaccumulation $\left(I_{geo}\right)$ [15]. After the pioneer work of Hakanson's [14], several authors have proposed modified methods that take into consideration the chemical fractions and bioavailability of heavy metals to assess the ecological risk. These modified methods include the risk assessment code (RAC) proposed by Perin et al. [16], the multiparameter evaluation index (MPE) suggested by Thurston and Spengler [17] and the modified ecological risk (MRI) introduced by Kulikowska et al. [18]. I_{geo} and E_r^I are widely employed as a quantitative measure of the potential risk of heavy metals in sediments and soils. These two indices $\left(I_{geo} \text{ and } E_r^I\right)$ have been extensively employed to assess E_r^I of heavy metals pollution in sediments of aquatic systems, [3, 18–24]. Both indices have been also used to evaluate the ecological risk in polluted soils by heavy metals [25–28]. This work aims to: (1) finding relationship between E_r^I and I_{geo}, (2) applying the new relation in different cases study and (3) comparing the results of application of the new modified and Hakanson methods.

2 Methodology of Ecological Risk Assessment

Two methods were widely employed as a quantitative measure of the potential ecological risk level of heavy metals in sediments and soils. These two methods are I_{geo} and E_r^I. I_{geo} is determined using the following equation [15]:

$$I_{geo} = \log_2\left(C_s^i / K C_r^i\right) \tag{1}$$

$$I_{geo} = \log_2\left(C_s^i / 1.5 C_r^i\right) \tag{2}$$

where C_s^i refers to the concentration of heavy metal i in the sample and C_r^i is the reference value of heavy metal i. K is a constant in view of the reference value fluctuation. The factor 1.5 is introduced as a value of K constant to include the possible variation of the reference values due to lithogenic effect. Muller [15] classified the I_{geo} values as follows: (0) practically unpolluted ($I_{geo} \leq 0$), (1) unpolluted to moderately polluted ($0 < I_{geo} \leq 1$), (2) moderately polluted ($1 < I_{geo} \leq 2$), (3) moderately to heavily polluted ($2 < I_{geo} \leq 3$), (4) heavily polluted ($3 < I_{geo} \leq 4$), (5) heavily to extremely polluted ($4 < I_{geo} \leq 5$), (6) extremely polluted ($5 < I_{geo}$).

The E_r^I was suggested by Hakanson [14] and used to assess the ecological risk of heavy metal in sediments and soils. The E_r^I is calculated using the following equations:

$$E_r^i = T_f^i \times C_f^i \tag{3}$$

$$C_f^i = C_s^i / C_r^i \tag{4}$$

$$E_r^i = T_f^i \left(C_s^i / C_r^i \right) \tag{5}$$

where E_r^i is the potential ecological risk factor of metal i, T_f^i is the toxic response factor of metal i. The values of heavy metals are 30, 2, 5, 5, 5, and 1 for Cd, Cr, Cu, Ni, Pb and Zn, respectively. C_s^i is the metal i concentration in a sediment or soil sample, and C_r^i is the reference value of metal i. E_r^i results are classified as follows: low potential ecological risk ($E_r^i < 40$), moderate potential ecological risk ($40 \le E_r^i < 80$), considerable potential ecological risk ($80 \le E_r^i < 160$), high potential ecological risk ($160 \le E_r^i < 320$), and very high ecological risk ($320 \le E_r^i$).

2.1 New Modified Equation for Assessment of E_r^i

Based on the methods mentioned above, the E_r^i depends on the concentration and the toxicity response factor of heavy metal. In Eqs. (2) and (5) C_s^i / C_r^i are common in both equations. In term of this common limit, new modified equation to assess the ecological risk was derived as follow:

Since $C_f^i = C_s^i / C_r^i$, (2) becomes

$$I_{geo} = \log_2\left(\frac{2}{3} \times c_{f^i}\right) \tag{6}$$

Rewriting Eq. (3)

$$C_{f^i} = \frac{E_r^i}{T_f^i} \tag{7}$$

Combination of (6) and (7), we obtain

$$I_{geo} = \log_2\left(\frac{2}{3} \times \frac{E_r^i}{T_f^i}\right) \tag{8}$$

According to the logarithmic rules, we rewrite (8)

$$I_{geo} = \log_2 \frac{2}{3} + \log_2 \frac{E_r^i}{T_f^i} \quad (9)$$

$$I_{geo} = 1 - 1.58 + \log_2 E_r^i - \log_2 T_f^i \quad (10)$$

Then

$$\log_2 E_r^i = I_{geo} + \log_2 T_f^i + 0.58 \quad (11)$$

Substitution value of T_f^i for each metal, we obtain the following equations:

$$\log_2 E_r^{cd} = 5.486 + I_{geo} \quad (12)$$

$$\log_2 E_r^{cr} = 1.58 + I_{geo} \quad (13)$$

$$\log_2 E_r^{cu} = 2.901 + I_{geo} \quad (14)$$

$$\log_2 E_r^{Ni} = 2.901 + I_{geo} \quad (15)$$

$$\log_2 E_r^{Pb} = 2.901 + I_{geo} \quad (16)$$

$$\log_2 E_r^{Zn} = 0.58 + I_{geo} \quad (17)$$

Using of the equations mentioned above, we can calculate Er for *Cd, Cr, Cu, Ni, Pb* and *Zn* in term of I_{geo}. The difference between our new modified method and the classical Hakanson's method is in calculation of pollution index C_f^i. In our method, we used the I_{geo} to estimate the pollution index because it takes the possible variation of reference values due to the lithogenic source into consideration.

2.2 Application of the New Modified Equations

The E_r^I of heavy metals (Cd, Cr, Cu, Ni, Pb and Zn) in riverine sediments and soils of four cases was assessed using the new modified equation. The selected cases for sediment of the rivers are of Euphrates River, Iraq and the Tietê River, Brazil, respectively [29, 30]. For soils, the cases are of the urban soil in Fallujah City, Iraq [31] and of the agricultural soils in Tarkwa, Ghana [32]. The heavy metals concentrations (Cd, Cr, Cu, Ni, Pb, and Zn) for each case were listed in Appendix 1. The United States Environmental Protection Agency (USEPA) guidelines for these metals are employed as reference value [33]. These reference values (Cr) are 0.6, 25, 16, 16, 40, and 90, for Cd, Cr, Cu, Ni, Pb, and Zn, respectively. The first step in application of the new modified equation is calculation of I_{geo} for each metal and the second step is using one of the equations for each metal.

3 Results and Discussion

New modified equations were mathematically derived for assessing the E_r^I of some heavy metals in sediments and soil are listed in Table 1. These equations are estimated E_r^I in terms of I_{geo}.

The results of application of the new modified equation for assessing of E_r^I are listed in Appendix 2. To detect if there is relationship between the new modified equation and the original Hakanson's equation, the E_r^I values were also calculated for two cases (sediment of Euphrates River, Iraq and soils in Tarkwa, Ghana) using the Hakanson's equation. A regression analysis between $E_{r\,(\text{Modified})}$ index and $E_{r\,(\text{Hakanson})}$ index values was carried out (see Figs. 1 and 2). The result of comparison shows a very significant correlation between the E_r^I values calculated using the new modified equation and those estimated by the Hakanson's equation. A scatterplot between E_r^I values calculated by Hakanson's method and I_{geo} for two cases (sediment of Euphrates River, Iraq and soil of Tarkwa, Ghana) was conducted and listed in Table 2, Appendix 3. The results show significant empirical relations between E_r^I and I_{geo}.

The E_r^I takes into account the metal concentration, reference metal value and toxic response factor of the metal. The toxic response factor is the primary requirement for assessing the E_r^I. The other factor controlling the ecological risk assessment is the selected reference value Cr of the metal. The E_r^I of heavy metals in soil of Fallujah, Iraq was calculated using different reference values. The obtained results show that using different reference values could cause an overestimation or underestimation of the E_r^I. Protano et al. [34] found that the lack of abundance of updated reference metal values could lead to overestimation or underestimation of E_r^I. The accurate

Table 1 The mathematical derived relations and empirical relations for assessing of potential ecological risk index E_r^I of some heavy metals in sediment and soil

Mathematical relations	Empirical relations	
	Sediment of Euphrates river, Iraq	Soil of Tarkwa city, Gahna
$\log_2 E_r^{Cd} = 5.486 + I_{geo}$	$\log_2 E_r^{Cd} = 5.481 + 1.008 I_{geo}$	$\log_2 E_r^{Cd} = 5.477 + 0.992 I_{geo}$
$\log_2 E_r^{Cr} = 1.580 + I_{geo}$	$\log_2 E_r^{Cr} = 1.581 + 1.001 I_{geo}$	$\log_2 E_r^{Cr} = 1.585 + 0.999 I_{geo}$
$\log_2 E_r^{Cu} = 2.901 + I_{geo}$	$\log_2 E_r^{Cu} = 2.917 + 0.999 I_{geo}$	$\log_2 E_r^{Cu} = 2.971 + 1.015 I_{geo}$
$\log_2 E_r^{Ni} = 2.901 + I_{geo}$	$\log_2 E_r^{Ni} = 2.908 + 0.999 I_{geo}$	$\log_2 E_r^{Ni} = 2.900 + 0.996 I_{geo}$
$\log_2 E_r^{Pb} = 2.901 + I_{geo}$	$\log_2 E_r^{Pb} = 2.903 + 0.999 I_{geo}$	$\log_2 E_r^{Pb} = 2.908 + 0.998 I_{geo}$
$\log_2 E_r^{Zn} = 0.580 + I_{geo}$	$\log_2 E_r^{Zn} = 0.584 + 0.998 I_{geo}$	$\log_2 E_r^{Zn} = 0.582 + 0.997 I_{geo}$

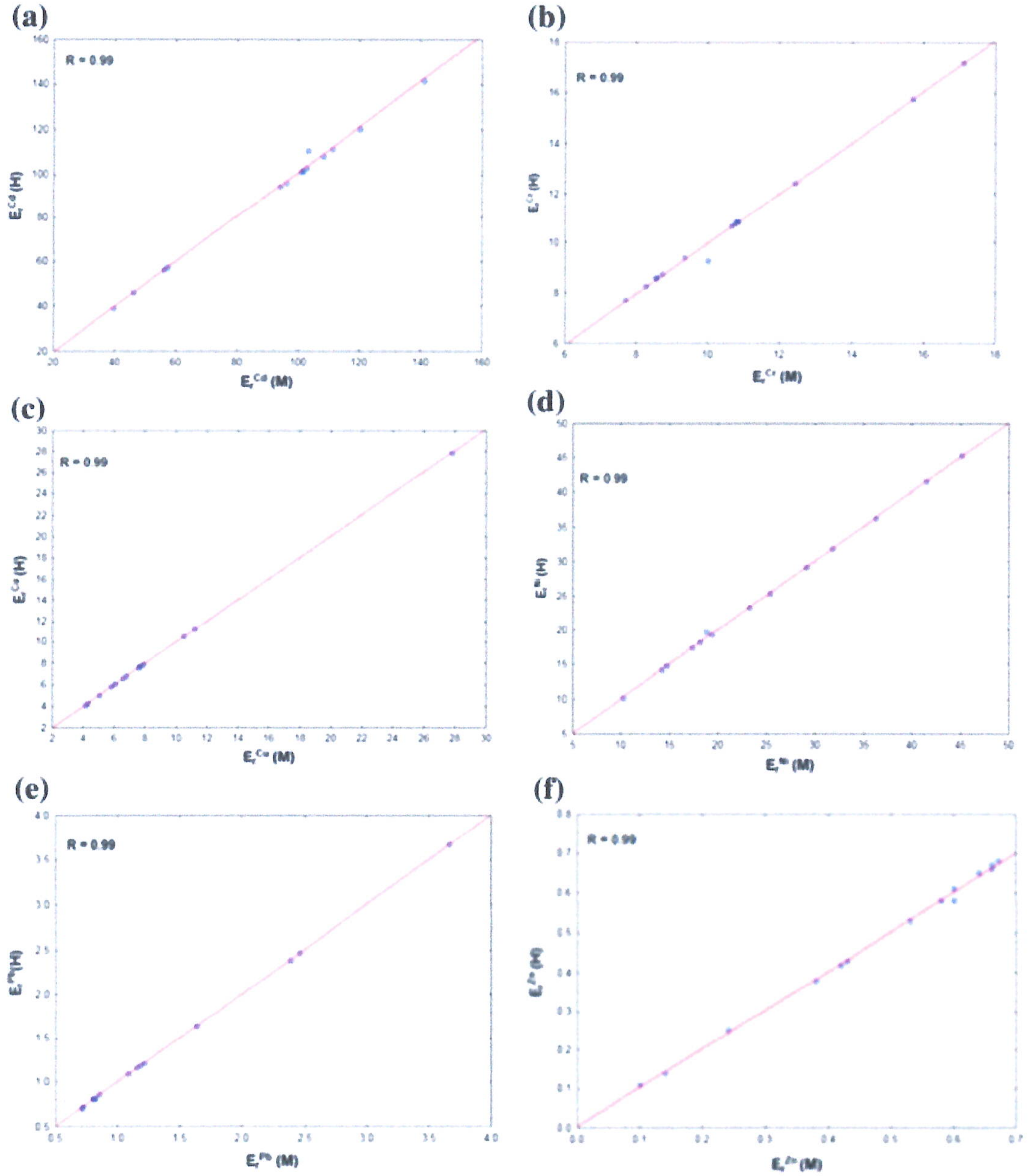


Fig. 1 Scatterplot between the E_r^I values of heavy metals in sediment of Euphrates river, Iraq calculated by Hakanson equation E_r(H) and those calculated by the new modified equation E_r(M)

evaluation of the E_r^I requires regular updating of the reference values periodically at the regional scales, particularly in geologic regions including sensitive ecological habitats [35]. Significant relationships between E_r^I and I_{geo} for Cd, Cr, Cu, Ni, Pb and Zn were recorded for two cases (sediment of Euphrates River, Iraq and soil of Tarkwa City, Gahna), Table 1 and Appendix 3. A significant relation between E_r^I and I_{geo} for Antimony (Sb) was reported in XKS mine, Hunan province in China [36]. The obtained results show significant agreement between the mathematical derived relations and the empirical relations. This agreement and the strong correlation between the E_r^I values calculated by our modified method and those estimated

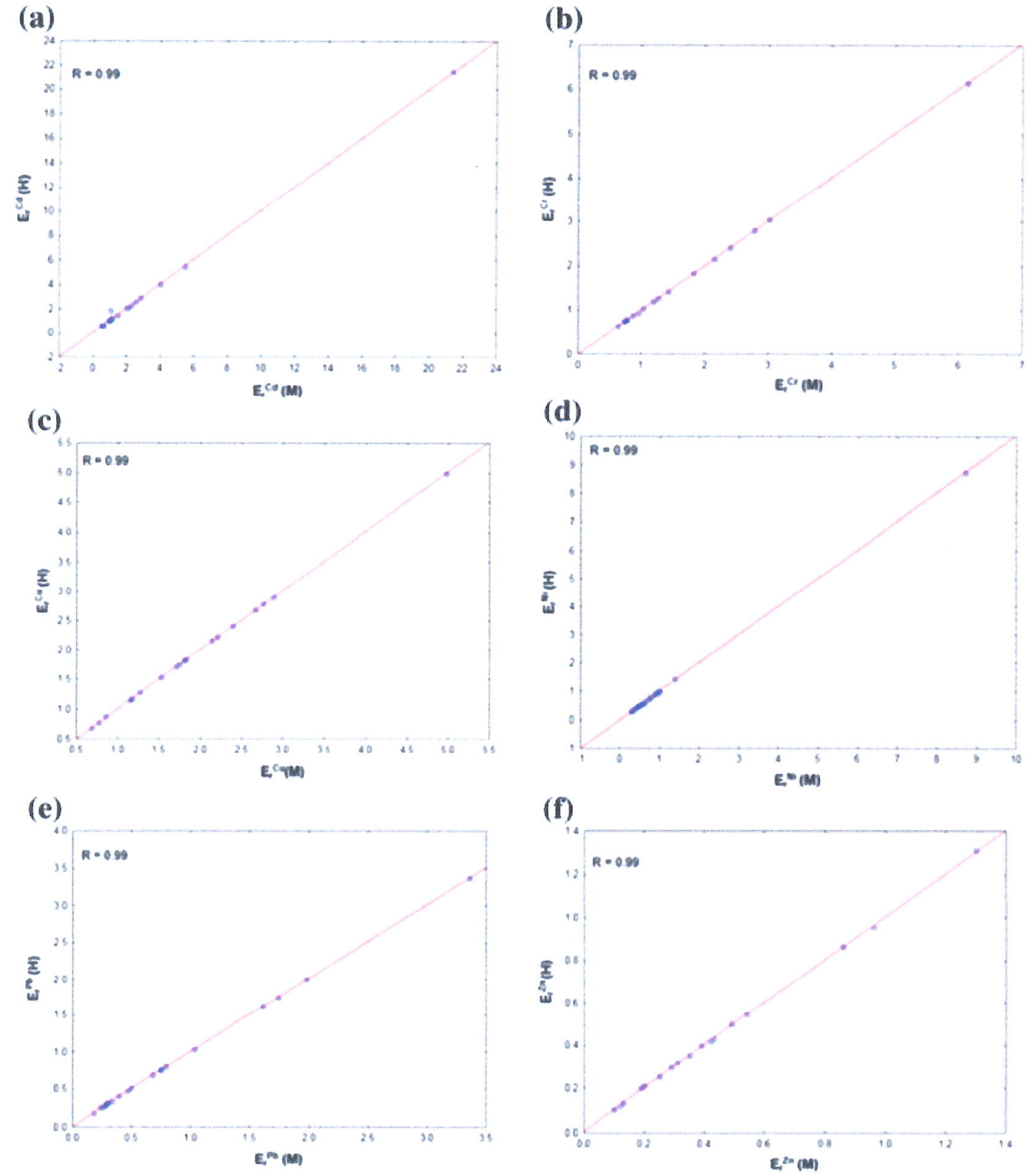


Fig. 2 Scatterplot between E_r^I values of heavy metals in soil of Tarkwa, Ghana calculated by Hakanson equation E_r(H) and those calculated by the new modified equation E_r(M)

by Hakanson's method confirms that our method is a reliable approach for assessing the potential ecological risk levels of heavy metals in sediment and soil.

In terms of the total metal concentration, the new modified method suggests more representative values of E_r^I of heavy metals in sediment and soil because it takes into account effect of the possible variation of the reference values due to the lithological sources. In our method, we do not need to know the toxicity response factor values of Cd, Cr, Cu, Ni, Pb and Zn that represent the basic request to calculate E_r^I according to Hakanson's method.

The relationship between total metal concentration, reference metal value and the toxicity response factor of different metals are considered in Hakanson's and our modified methods. However, the chemical fractions concentrations of metals in sediment and soil are not taken into account in both methods. Comparison of the results of assessment of PERI (Hakanson's method) and MRI for some metals in Daya Bay, South China Sea showed that the MEI and MRI values were higher than E_r^I and RI [22]. They interpreted that in terms of modified index of heavy metal concentration. On contrary, using total metal concentration rather than metal fractions contents may lead to an overestimation of the potential ecological risk (PERI) levels [37, 38]. The current study has theoretical and empirical implications and suggests that our new modified method is reliable technique to quantify the ecological risk levels of heavy metals in terms of geo-accumulation index I_{geo}.

4 Conclusions

From the obtained results, the following conclusions were drawn:

- A new modified equation was derived to assess the E_r^I in soil and sediment polluted by heavy metals in terms of geoaccumulation index I_{geo}.
- The results of application of the new modified equation to assess E_r^I were consistent with the results of application of Hakanson's equation.
- The significant empirical relations between E_r^I nd I_{geo} confirmed the mathematical derived relations and inturn gave them credibility to use as an alternative method of Hakanson's method.

5 Appendices

5.1 *Appendix 1*

Heavy metals concentrations (mg/kg) in sediments of Euphrates river, Iraq

Sampling station	Cd	Cr	Cu	Ni	Pb	Zn
S1	0.78	135.8	36	102.21	6.5	38
S2	1.89	135.6	33.7	145.2	9.8	34.5
S3	2.23	103.6	24.3	58.3	6.9	48
S4	2.03	107.5	21.1	74.7	9.35	38.9
S5	2.17	116.1	16.2	32.8	6.63	22.5
S6	2.04	133.6	89.3	47.2	13.15	60.09

(continued)

(continued)

Sampling station	Cd	Cr	Cu	Ni	Pb	Zn
S7	2.22	155.9	13.8	55.6	9.55	12.7
S8	2.06	107.2	21.9	133.2	6.55	53.06
S9	0.92	197	25.3	116	5.83	60.5
S10	2.41	135	19.5	45.6	5.75	40.5
S11	2.83	109.4	18.7	62.8	19.12	58.5
S12	1.13	96.6	13.3	93.6	19.18	52.5
S13	1.15	117.4	18.6	62	8.73	61.2
S14	1.93	214.7	24.7	81.6	16.02	55

Heavy metals concentrations (mg/kg) in sediments of Tietê river, Brazil

Sampling station	Cd	Cr	Cu	Ni	Pb	Zn
S1	1.12	78.3	15.2	18.4	101.8	52.1
S2	3.2	40.8	7.3	16.6	50.9	38.7
S3	5.1	251.8	33.6	29.6	110.6	201.6
S4	5.6	126.8	202.1	72	67.3	421.3
S5	7.5	132.1	73.1	47.9	92.1	218.6
S6	8.5	137.9	115.6	50.3	67.5	390.9
S7	6.3	88.9	39.0	24.7	36.9	108.7
S8	6.3	151.8	76.4	41.0	63.6	107.1
S9	6.8	272.8	144.2	99.6	64.1	164.1
S10	5.4	241.9	56.5	69.4	53.9	57.9
S11	6.4	343.9	359.7	118.2	44.7	150.2
S12	3.5	388.5	293.9	121.9	25.6	181.3

Heavy metals concentrations (mg/kg) in soil of Fallujah city, Iraq

Sampling station	Cd	Cr	Cu	Ni	Pb	Zn
S1	0.800	21.225	2.050	12.050	4.625	8.925
S2	0.575	12.325	0.925	5.575	3.475	3.800
S3	0.825	14.300	1.325	10.475	4.575	5.175
S4	0.650	16.725	1.050	10.375	3.975	5.350
S5	0.575	14.900	1.425	10.525	3.000	6.950
S6	0.600	9.450	1.450	6.400	3.150	3.225

(continued)

(continued)

Sampling station	Cd	Cr	Cu	Ni	Pb	Zn
S7	0.750	11.600	0.875	8.400	2.675	4.750
S8	0.625	11.300	1.000	7.375	2.900	6.425
S9	0.525	10.725	1.450	7.525	2.625	4.925
S10	0.525	9.400	1.000	6.275	2.750	2.750
S11	0.575	9.350	1.600	7.550	3.550	3.100
S12	0.475	7.900	2.175	7.475	3.300	3.800
S13	0.775	10.100	3.825	11.800	4.350	3.825
S14	0.825	9.975	3.050	12.225	4.750	8.450
S15	0.875	9.425	2.325	11.775	4.050	6.775
S16	0.550	9.450	1.425	7.750	3.725	4.500
S17	0.575	12.25	2.500	10.025	4.400	5.125
S18	0.525	9.550	3.125	10.675	4.700	6.775
S19	0.750	11.675	4.975	8.150	5.300	10.400
S20	0.575	10.275	2.750	6.876	4.600	5.000

Heavy metals concentrations (mg/kg) in soil of Tarkwa city, Ghana

Sampling station	Cd	Cr	Cu	Ni	Pb	Zn
S1	0.038	35	8.9	4.5	6.1	39
S2	0.020	30	9.3	2.6	3.2	12
S3	0.011	13	2.8	1.1	1.5	9.7
S4	0.022	9.9	2.8	1.5	2.3	23
S5	0.020	11	5.5	3.1	2.7	32
S6	0.011	15	2.5	1.6	2.0	11
S7	0.020	27	2.2	1.0	2.1	29
S8	0.021	15	3.7	3.2	2.5	19
S9	0.013	9.6	5.9	1.3	2.4	27
S10	0.030	38	5.8	2.4	8.3	36
S11	0.024	9.2	3.8	1.8	3.8	38
S12	0.011	12	5.6	2.1	4.1	18
S13	0.052	8	4.1	1.3	13	86
S14	0.042	12	6.9	1.9	5.5	78
S15	0.081	23	8.6	3.2	16	49
S16	0.11	16	7.1	3	27	78
S17	0.058	18	7.7	2.9	6	32
S18	0.046	12	4.9	1.9	6.4	45
S19	0.43	77	16	28	14	118

5.2 Appendix 2

Ecological risk index values E_r^I of heavy metals in sediments of Euphrates river, Iraq

Sampling station	E_r^I					
	Cd	Cr	Cu	Ni	Pb	Zn
S1	39.72	10.82	11.19	31.8	0.8	0.42
S2	94.09	10.8	10.48	45.16	1.21	0.38
S3	110.96	8.25	7.55	18.13	0.85	0.53
S4	101.05	8.56	6.56	23.23	1.15	0.43
S5	108	9.99	5.04	10.19	0.82	0.24
S6	101.54	10.64	27.78	14.68	1.63	0.66
S7	103.03	12.42	4.29	17.29	1.18	0.14
S8	102.53	8.54	6.78	41.44	0.81	0.6
S9	45.97	15.7	7.86	36.25	0.72	0.66
S10	119.92	10.75	6.06	14.18	0.71	0.450
S11	140.84	8.71	5.81	18.73	2.39	0.64
S12	56.21	7.7	4.13	29.12	2.46	0.58
S13	57.2	9.35	5.79	19.29	1.08	0.67
S14	96.06	17.11	7.68	25.38	3.66	0.6

Ecological risk index values E_r^I of heavy metals in sediments of Tietê river, Brazil, Iraq

Sampling station	E_r^I					
	Cd	Cr	Cu	Ni	Pb	Zn
S1	59.71	6.24	4.73	4.39	12.66	0.57
S2	159.23	3.25	2.27	5.16	6.33	0.42
S3	253.87	20.07	10.45	9.2	13.67	2.23
S4	278.78	10.1	62.85	22.39	8.36	4.66
S5	373.25	10.52	22.73	14.88	11.46	2.41
S6	423.14	10.98	35.95	15.63	8.39	4.32
S7	313.64	7.08	12.13	8.15	4.59	1.2
S8	313.64	12.1	23.76	12.75	7.91	1.18
S9	338.49	21.73	44.84	30.99	7.97	1.81
S10	268.72	19.27	17.58	21.58	6.7	0.63
S11	318.68	27.39	111.89	36.78	5.56	1.67
S12	174.24	30.95	91.45	37.92	3.18	1.35

Ecological risk index values E_r^I of heavy metals in soil of Fallujah city, Iraq

Sampling station	E_r^I					
	Cd	Cr	Cu	Ni	Pb	Zn
S1	39.8	1.69	0.63	3.75	0.57	0.095
S2	28.6	0.98	0.28	1.73	0.42	0.041
S3	41.06	1.14	0.41	3.25	0.56	0.056
S4	32.37	1.33	0.32	3.22	0.49	0.058
S5	28.6	1.19	0.44	3.27	0.37	0.076
S6	29.85	0.75	0.45	1.98	0.38	0.034
S7	37.34	0.92	0.27	2.61	0.32	0.052
S8	31.12	0.90	0.30	2.29	0.35	0.070
S9	26.13	0.85	0.45	2.33	0.32	0.053
S10	26.13	0.74	0.30	1.95	0.33	0.029
S11	28.6	0.74	0.49	2.34	0.44	0.032
S12	23.62	0.62	0.67	2.32	0.41	0.041
S13	38.61	0.80	1.18	3.66	0.53	0.042
S14	41.06	0.79	0.94	3.80	0.59	0.092
S15	43.59	0.75	0.71	3.66	0.50	0.074
S16	27.39	0.75	0.44	2.40	0.46	0.049
S17	28.6	0.97	0.77	3.11	0.54	0.055
S18	26.13	0.75	0.97	3.31	0.58	0.074
S19	37.34	0.92	1.54	2.53	0.65	0.115
S20	28.6	0.82	0.85	2.13	0.56	0.055

Ecological risk index values E_r^I of heavy metals in soil of Tarkwa city, Ghana

Sampling station	E_r^I					
	Cd	Cr	Cu	Ni	Pb	Zn
S1	1.07	2.78	2.76	1.39	0.75	0.43
S2	0.98	2.39	2.89	0.8	0.39	0.13
S3	0.53	1.03	0.86	0.33	0.18	0.1
S4	1.07	0.78	0.86	0.46	0.28	0.25
S5	0.98	0.87	1.71	0.96	0.33	0.35
S6	0.53	1.19	0.77	0.49	0.24	0.12
S7	0.98	2.15	0.68	0.3	0.26	0.31
S8	1.03	1.19	1.15	0.99	0.3	0.2
S9	0.62	0.76	1.83	0.4	0.29	0.29
S10	1.47	3.02	1.8	0.74	1.03	0.39

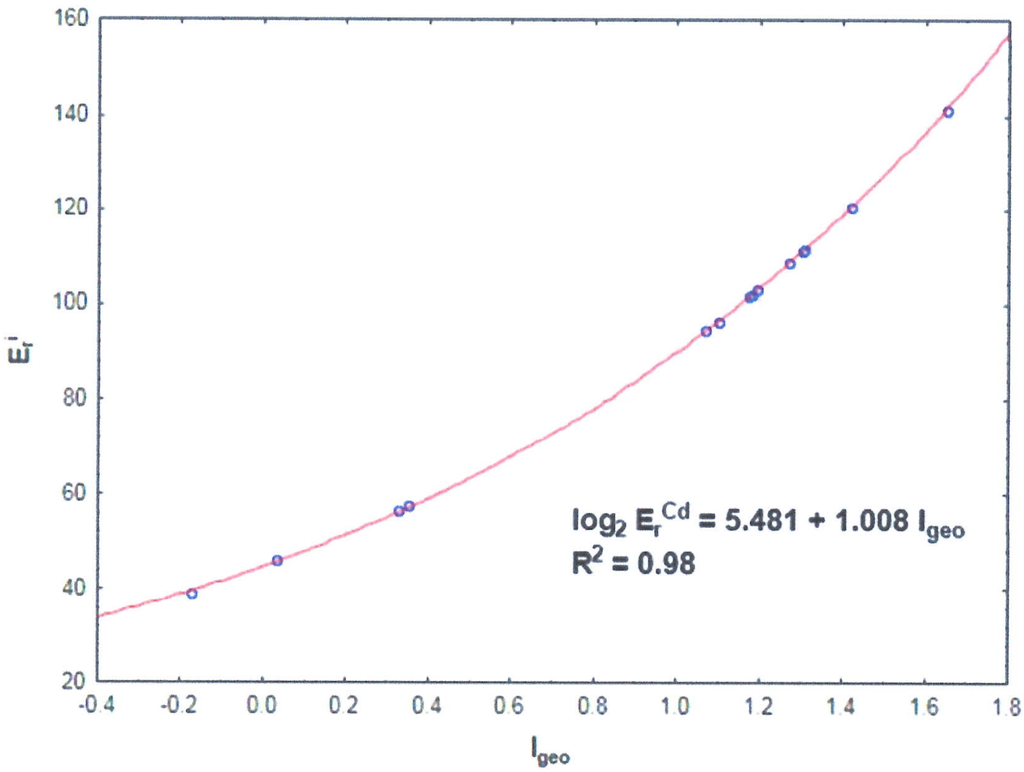
(continued)

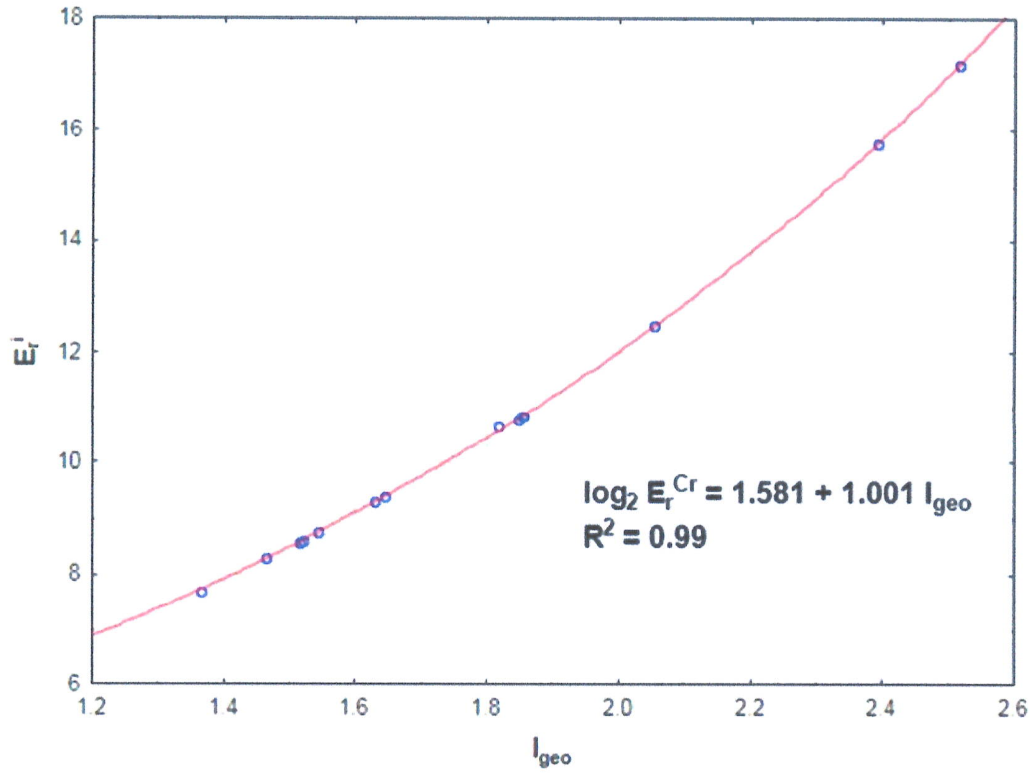
(continued)

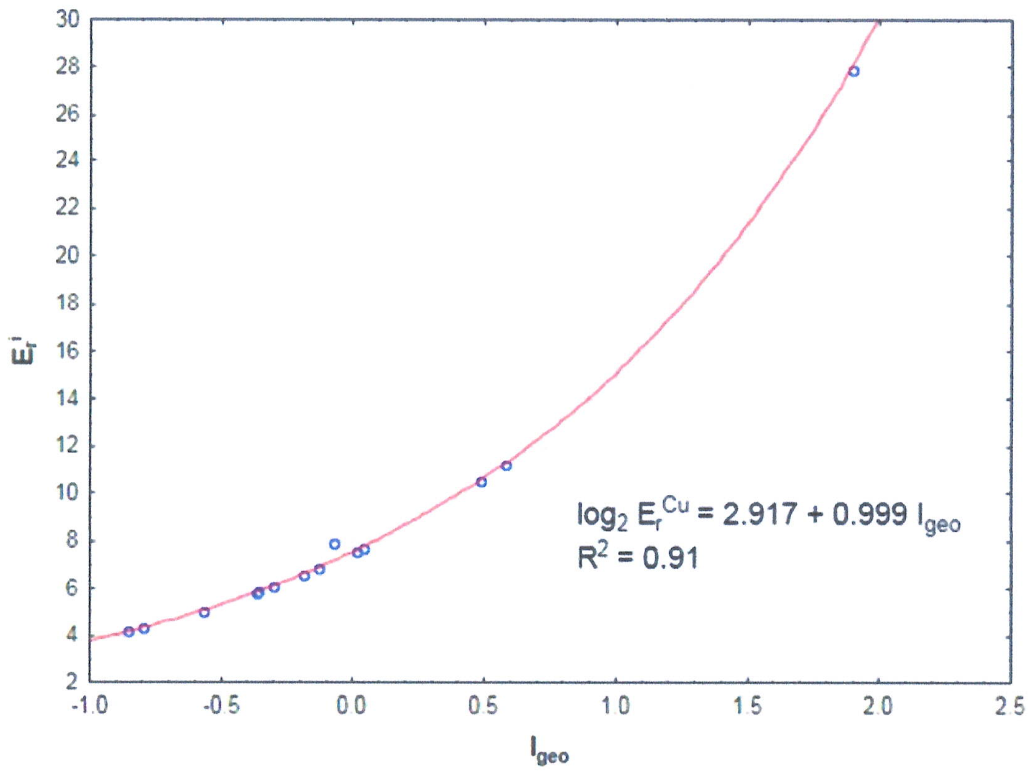
Sampling station	E_r^I					
	Cd	Cr	Cu	Ni	Pb	Zn
S11	1.16	0.73	1.18	0.56	0.47	0.42
S12	0.56	0.95	1.74	0.65	0.5	0.19
S13	2.55	0.63	1.27	0.4	1.61	0.96
S14	2.06	0.95	2.14	0.59	0.68	0.86
S15	4.03	1.83	2.67	0.99	1.98	0.54
S16	5.46	1.27	2.2	0.93	3.36	0.86
S17	2.86	1.43	2.39	0.89	0.74	0.35
S18	2.28	0.95	1.52	0.59	0.79	0.49
S19	21.39	6.13	4.97	8.7	1.74	1.3

5.3 *Appendix 3*

Regression analysis between E_r^i and I_{geo} of Cd, Cr, Cu, Ni, Pb and Zn in sediment of Euphrates River, Iraq.







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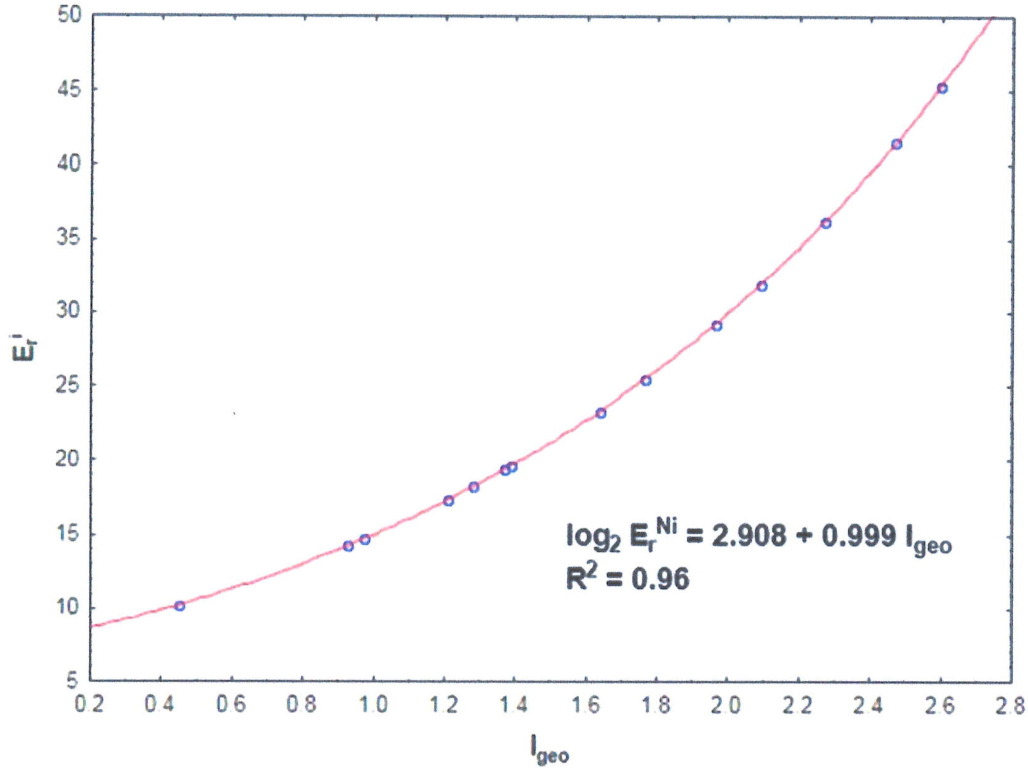
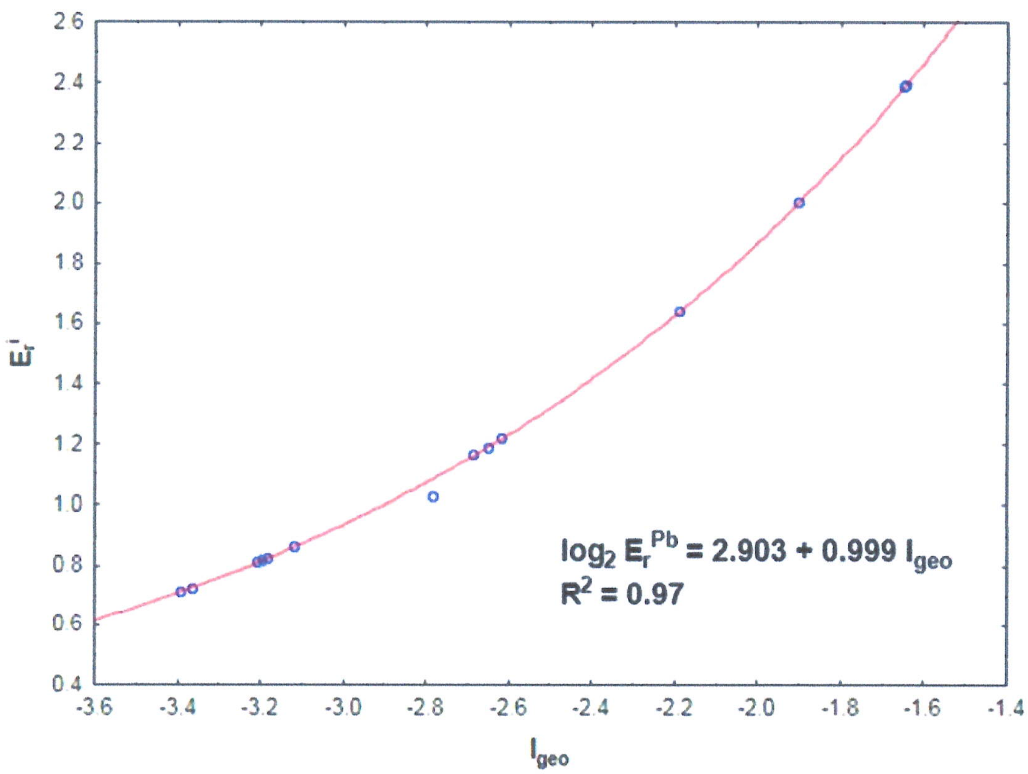
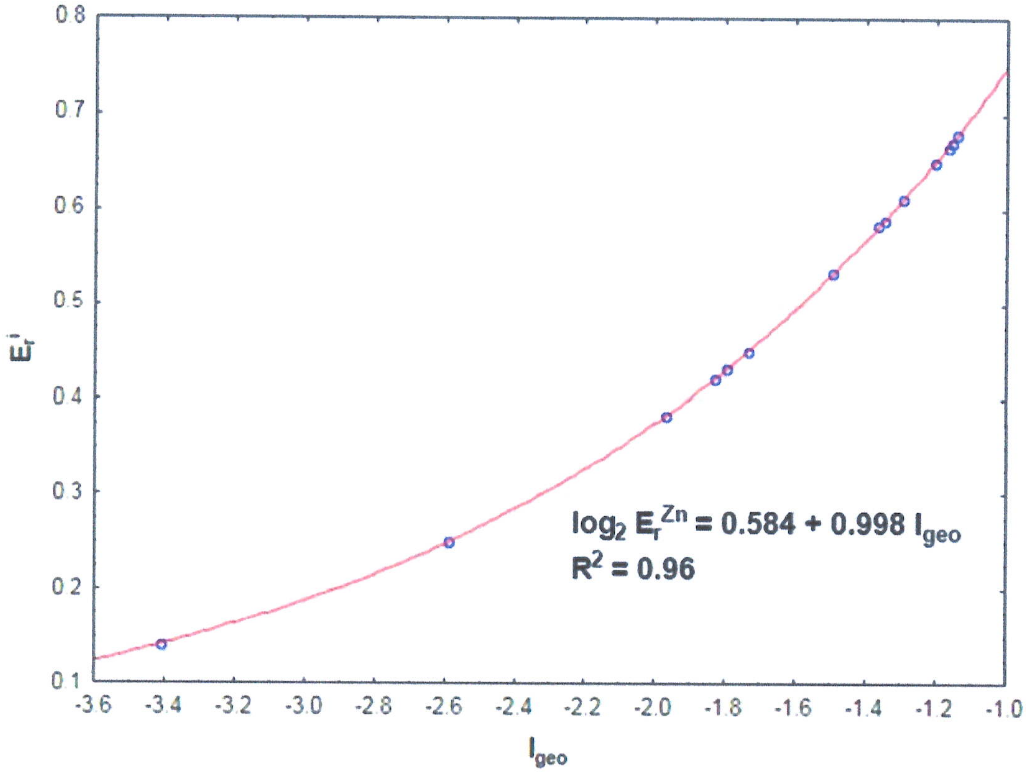
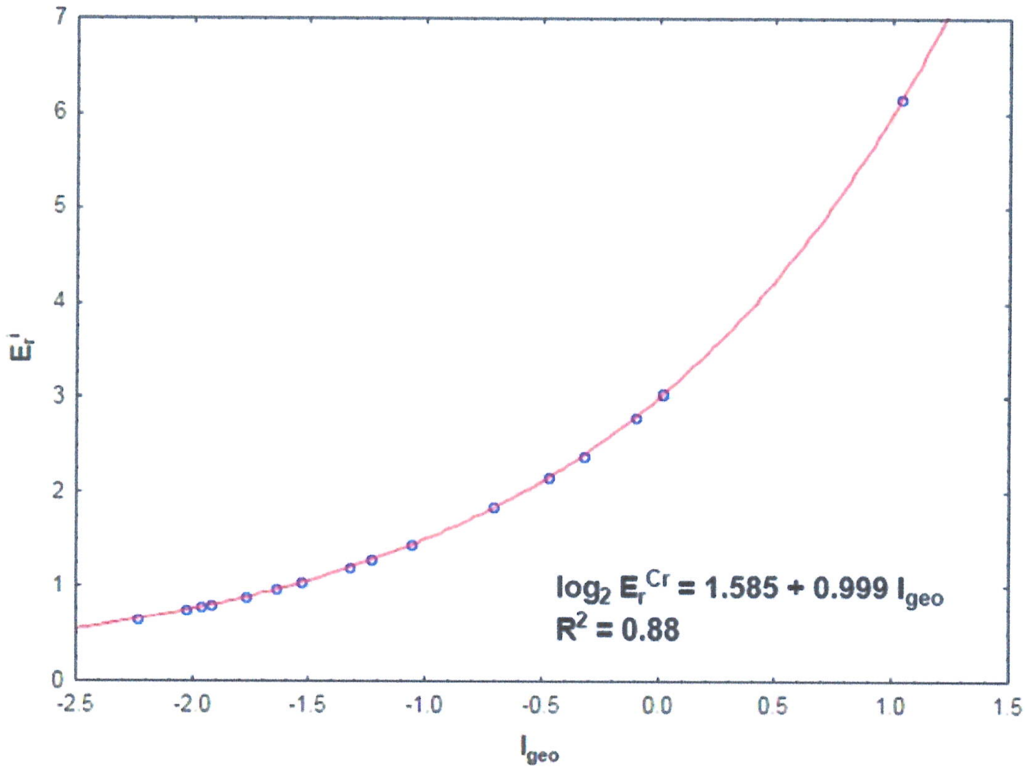

50
45
40
35
30
25
20
15
10
5
E'r
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
Igeo
log2 Er^Ni = 2.908 + 0.999 Igeo
R2 = 0.96


2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
E'r
-3.6
-3.4
-3.2
-3.0
-2.8
-2.6
-2.4
-2.2
-2.0
-1.8
-1.6
-1.4
Igeo
log2 Er^Pb = 2.903 + 0.999 Igeo
R2 = 0.97



Regression analysis between E_r^I and I_{geo} of Cd, Cr, Cu, Ni, Pb and Zn in soil of Tarkwa, Ghana.



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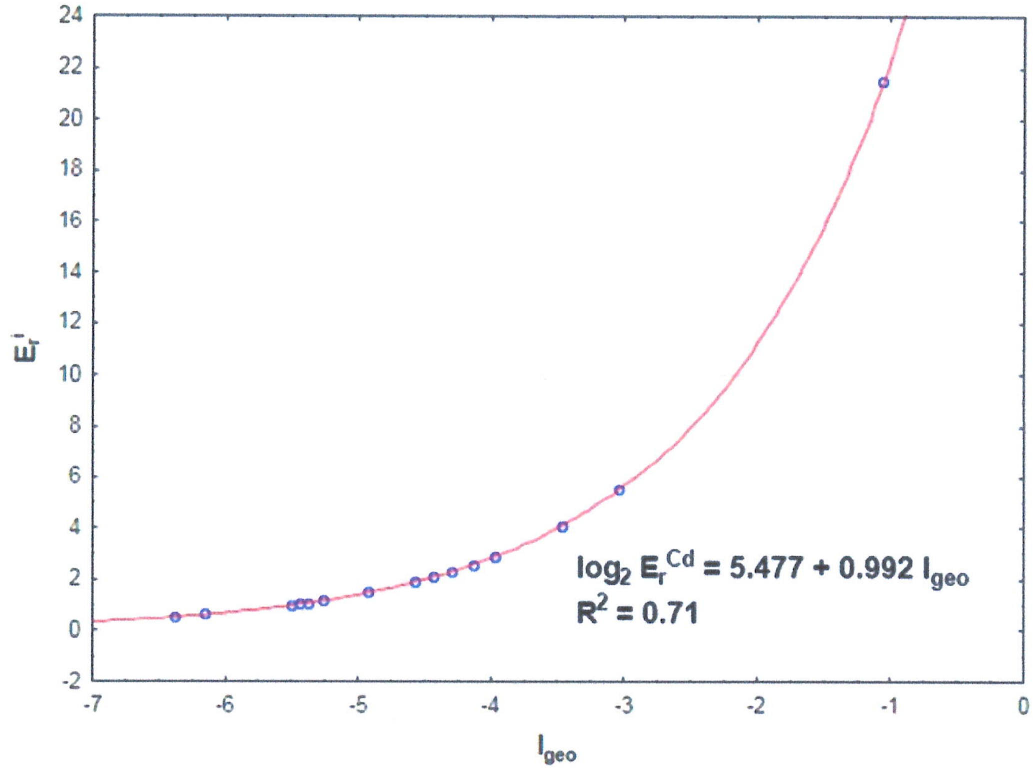
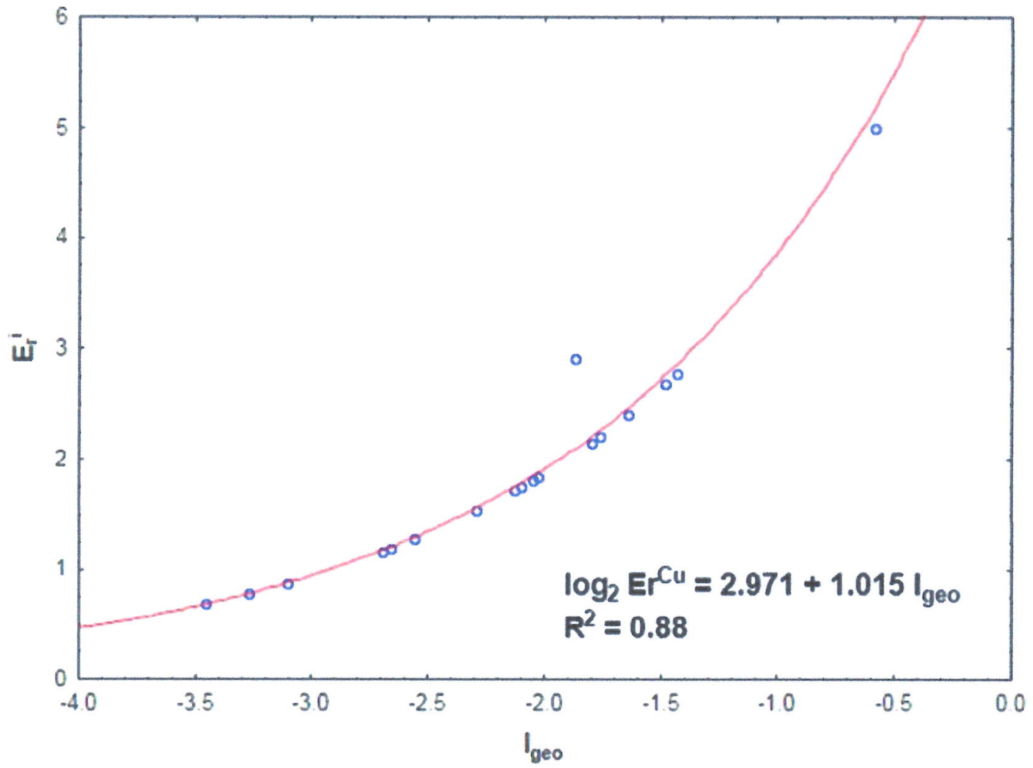
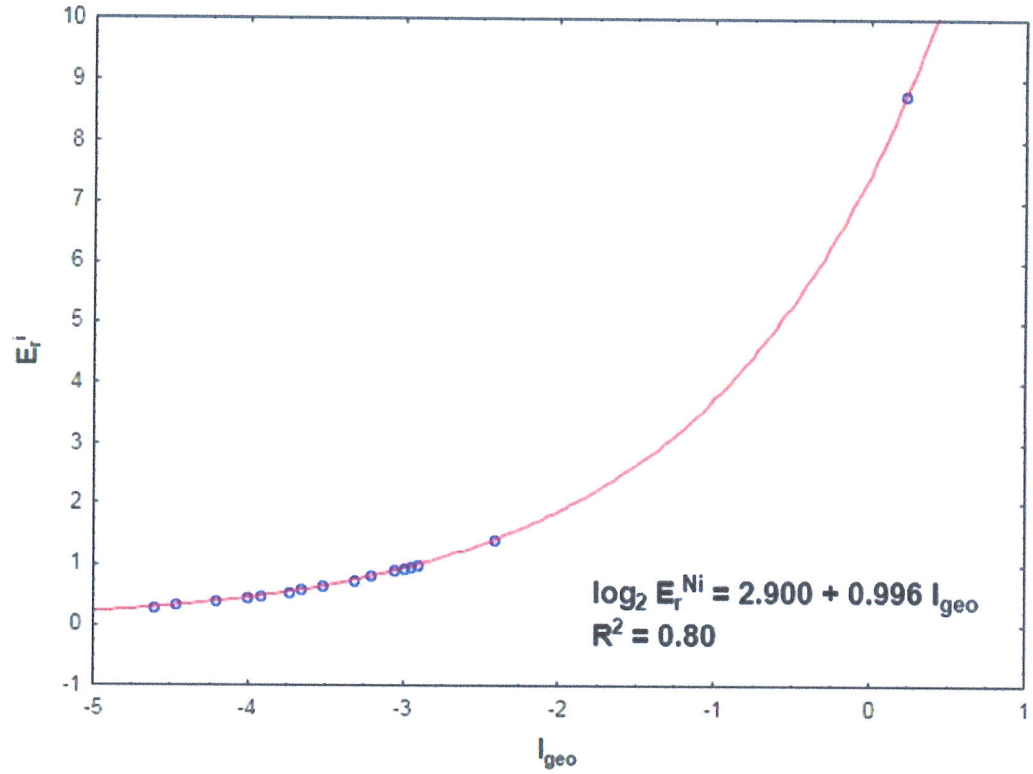
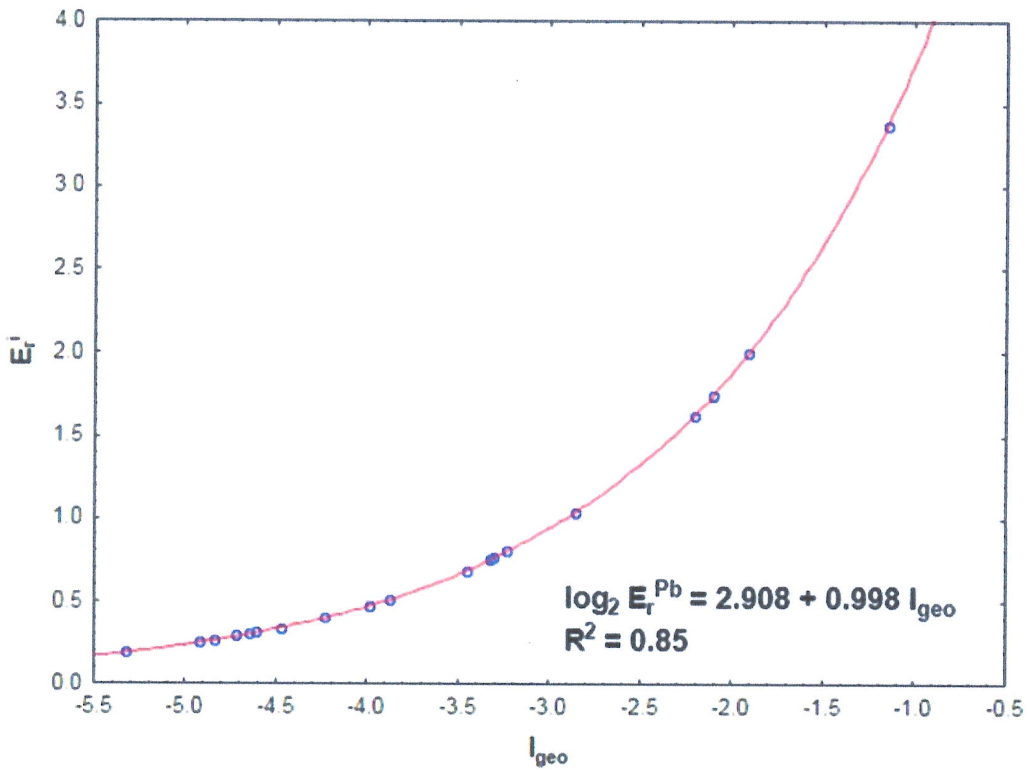


24
22
20
18
16
14
12
10
8
6
4
2
0
-2
Er^i
-7
-6
-5
-4
-3
-2
-1
0
Igeo
log2 Er^Cd = 5.477 + 0.992 Igeo
R2 = 0.71



6
5
4
3
2
1
0
Er^i
-4.0
-3.5
-3.0
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
Igeo
log2 Er^Cu = 2.971 + 1.015 Igeo
R2 = 0.88





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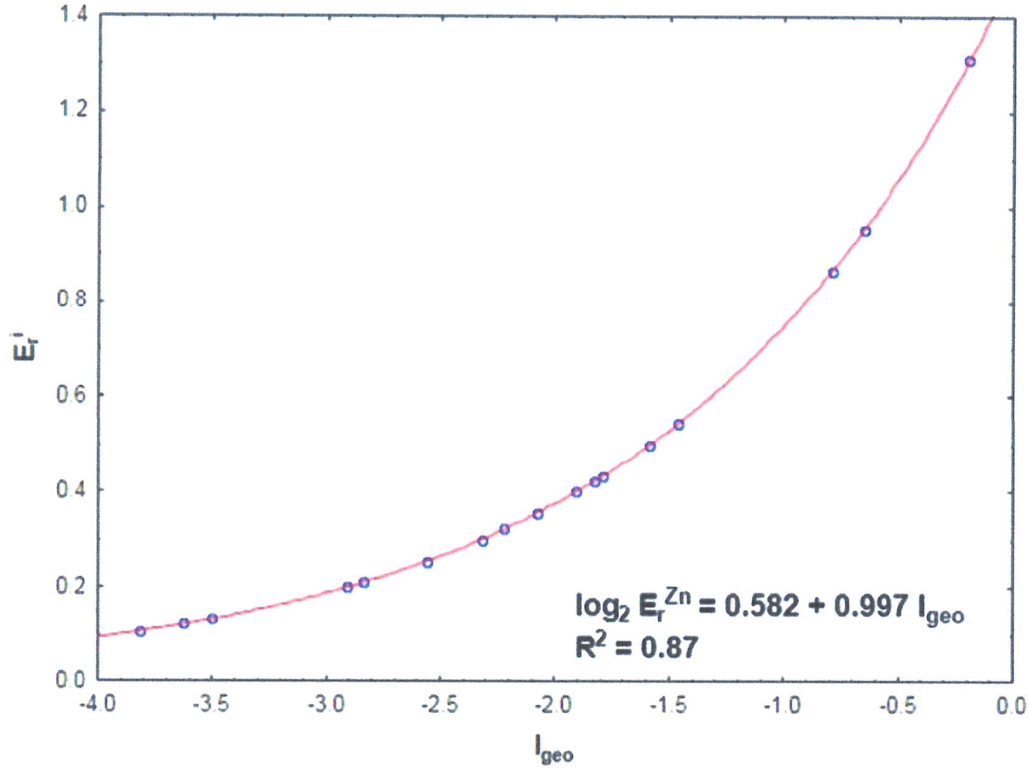

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