



Application of Definite Indices For Assessment of Some Heavy Metals Pollutants in surrounding Soils of Metal Recycling Companies in Sulaimani Governorate

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Article info	Abstract
Original: 30 October 2019 Revised: 27 January 2020 Accepted: 30 January 2020 Published online: 20 June 2020	This study was conducted to apply some indices assessment methods for heavy metal pollution in the soil as well as to study the variation in physicochemical characteristics of the soil samples taken from different sites around scrap metal recycling companies in the township of Bazian behind Bibijak village, Sulaimani Governorate.
Key Words: Physicochemical parameters; Heavy metals; Pollution Indices; Scrap recycling companies; Soil; Sulaimani Governorate	Physicochemical parameters results indicated relatively high variation along with the ranges of the specified distances from the companies, directions, and depths as well as between the companies even though the two companies are adjacent to each other. Additionally, correlation analysis approved the significant effect (at $p \leq 0.05$) of some soil physicochemical properties on the concentrations of the investigated heavy metals in the studied soils. In general, the concentration of all the investigated metals were mostly higher in surface soils (D1) samples rather than the subsoil (D2) samples at all the distances ranges and directions of the sampling sites. The spatial occurrence of the studied metals followed the order of; Fe > Mn > Ni > Cr > V > Co, and this may be in a sequence that agrees with the trend of main scrap metals components. Results of the simple Geoaccumulation index (I _{geo}) for Fe, Co, Cr, Mn, Ni, and V indicated that the soil qualities were generally in unpolluted status, but limited sampling sites fell in class one which characterized by uncontaminated to moderately polluted. On the contrary, the comparative integrated pollution load indices (PLI) and Nemerow Pollution Index (PI _{Nemerow}) showed that most of the studied sampling sites around the scrap metal recycling companies were slightly polluted according to PLI, but they were in warning limit (precaution domain) according to PI _{Nemerow} in consequence of the industrial activity of Sulaimani Steel and Super Steel at all the four main directions, and all distances ranges.

INTRODUCTION

Scrap recycling is the core of a powerful industry and even the minimum step that can play a significant role in environmental protection. Scrap recycling has become progressively important to industry and society to meet the goals of efficient management of limited resources, increased the level of metal consumption, control of potentially toxic metals in the environment, cost reduction as well as economic development and social enhancement. Scrap metal recycling include processing and recovery of scrap metal from end of life usage (durability) in order to be used again as a raw material in the production of new products instead of tossing them away and mining for new ores, because scrap metal can be recycled frequently with little degradation of its properties[1 and 2].

However, scrap metal recycling in developing countries can lead to soil heavy metal pollution, degrading of natural habitats, and detrimental effects on human health. Numerous studies have found that accumulation of heavy metals in soil may occur as a result of either natural processes such as weathering of metals and pedogenic processes or anthropogenic activities such as; emissions from the rapid scrap recycling, expanding industrial areas, agriculture fields application of fertilizers and pesticides, burning of fossil fuels, vehicle emissions, mine tailings atmospheric deposition and etc.[3 and 4]. The Researchers[5 and 6] have pointed out that heavy metals differ from other organic pollutants because it is likely to remain in the soil system for an extended period owing to their ability to resist degradation and destroying once they accumulate in the soil. Also, the authors [7] referred that heavy metals exhibit toxic effects and cause severe problems to the environment and human health as they are long persistent in the environment and not easily removed, degraded, oxidized, or converted to less harmful components through chemical or biological processes. Uptake of heavy metals by plants and succeeding accumulation along the food chain is a potential threat to animal and human health. According to a study by [8], to evaluate the effects of the released heavy metals of Fe, Cu, Mn, Ni, Zn, As, Pb, Co from steel factories and their impact on pigments and total protein contents in five plant species (*Olea europaea* L., *Eucalyptus amygdalina*, *Nerium oleander* L., *Dodonaeaviscosa*, and *Phragmitesaustralis*) in Erbil City. Their results indicated a negative correlation between the concentration of the investigated heavy metals and the pigments as well as with the total protein contents in all plant species. Furthermore, the accumulation rates of the studied metals were varied with the plant species. Pollution indices are regarded as the most effective assessment, comprehensive evaluation and most frequently used method to the real valuation and comprehensive estimation of soil pollution with heavy metals and geochemical valuation of the soil quality[4 and 9]. Consequently, pollution indices are a powerful tool for analyzing, processing, and transferring raw environmental information to decision-makers, technicians, managers, and the public[10]. Additionally, the indices can support to conclude whether the accumulation of heavy metals in soil is attributed to the anthropogenic activities (human activity monitoring) or due to the natural processes[11 and 12]. According to[9], some of the most useful indices that can be applied for assessing the degree of soil heavy metal pollution and geochemical valuation of the soil quality may include: Geo accumulation Index (Igeo); Enrichment Factor (EF); Single Pollution Index (PI); Sum of Pollution Index (PIsum); Nemerow Pollution Index (PINemerow); Potential Ecological Risk (RI); Contamination Severity Index (CSI) and Modified Contamination Factor (mCdeg).

Over the past two decades, the industrial activity in Sulaimani Governorate, and particularly in Kani Shaitan and Bazian townships has increased intensely. Although the industrial sector included many strategic industries such as; several cement plants, oil production, four scrap metal recycling companies, etc., the industrial activities were poorly regulated and were not by the strategy of sustainable development. Moreover, there were almost limited studies and information about the environmental status of the region. Therefore, this research aimed to study the impacts of the scrap metal recycling companies of Sulaimani Steel and Super Steel in the township of Bazian, Sulaimani Governorate on some physicochemical properties and to estimate the degree of heavy metal pollution in surrounding soils.

MATERIALS AND METHODS

Study area and geological nature

The scrap metal recycling companies of Sulaimani Steel and Super Steel are located in the township of Bazian behind Bibijak village, and the two companies are adjacent to each other in terms of location. Bazian township (35.5915° N, 45.1409° E) situated about 20 km far from west of Sulaimani city center and extends up to 35 km along the street from Sulaimani to Kirkuk city and surrounded by mountains from all sides at an altitude of 860 meters above sea level. Both companies were initiated to establish in 2013 and started to produce in 2015, and they produce construction rebar in all measurements from a wide range of stainless-steel scrap of various sizes, grades, types and different sources of Kurdistan region and Iraq as a whole. The average daily productions were 150 and 600 tones for Super Steel and Sulaimani Steel companies respectively.

As referred by [13], the geological time scale of Bazian region has deposited during Mesozoic and Cenozoic eras timeline, while the rock structure of Bazian region is composed of limestone, dolomitic limestone, marly limestone, dolostone, gypsum, marl, claystone, sandstone, mudstone, and conglomerates.

Soil sampling

Based on the principles of the approved research plan and accessibility, eighteen (18) sampling sites were selected around the two scrap metal recycling companies of Sulaimani Steel and Super Steel in all the four main directions of north, east, south, and west at four ranges of the specified distances far away from the companies which they were 50, 100, 250 and 500 m in each direction. Additionally, control samples at a distance of 1000 m were taken whenever the sampling process was probable to collect.

Soil sampling, collection, and handling were conducted according to the standard guideline for soil sampling. Composite soil samples were randomly collected from the selected sites of the surface (0-20) and subsurface (20-40 cm) depths in summer/2018 (from July until September) around the scrap metal recycling companies. The GPS coordinates (latitude and longitude) were also recorded for each sample site (Table 1 and Figure 1). Once the soils samples were air-dried at room temperature for a few days, then they have been gently crushed and sieved using 2 mm stainless-steel sieve. Finally, the samples were stored for subsequent analyses at room temperature. Regarding metal and organic carbon analysis, 50 g of the prepared 2-mm soils were extra pulverized to pass through a 0.50 mm sieve.

Hygroscopic moisture was determined according to [14] in about 10-g of the air-dried soil for each soil samples gravimetrically after 24 hours of oven-drying the soil at 105 °C to constant weight.

Analytical methods and laboratory soil analysis

Hydrogen ion concentration (pH-value): The pH was measured on a 1:2.5 ratio soil: distilled water suspension according to [14] using a portable pH-meter (model WTW 330i/ Germany).

ECe-Value at 25 °C: EC of 1:2.5 ratio soil: distilled water suspension was measured as described by [14] using a portable EC-meter (model WTW 330i/ Germany).

Organic matter (OM) content: Organic carbon (OC) content in soil samples were first determined according to Walkley-Black method (wet oxidation method) as described by [15], then the content of organic matter (OM) was calculated as follows;

% Organic matter = % organic carbon x 1.724 (factor)

Percent of equivalent calcium carbonate (ECaCO₃ %): ECaCO₃ percent were determined in soil samples by the acid-neutralization method according to [15].

Water-soluble ion species, including Ca²⁺, Mg²⁺, K⁺, Na⁺, Cl⁻, HCO₃⁻, CO₃²⁻ were determined according to the methods described by [15] on a 1:2.5 ratio soil: distilled water suspension after filtration the suspensions through an ashless Whatman 42 filter paper.

Particle size distribution (texture): Particle size fractionation and analysis were carried out by international pipette method as recommended by [16].

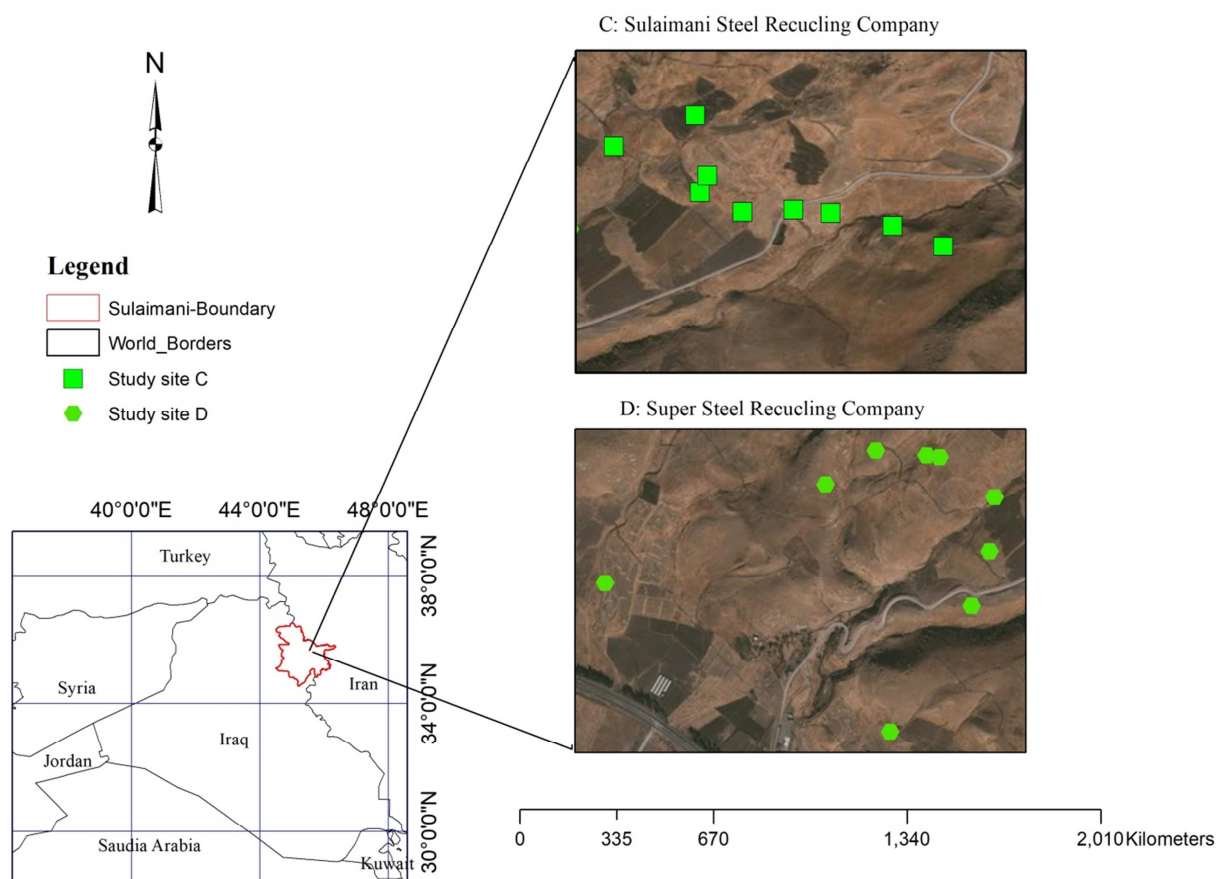


Figure 1: Sites for surface soil sampling around the two scrap metal recycling companies of Sulaimani Steel and Super Steel in Bazian townships, Sulaimani Governorate (Source: Google map).

Total heavy metals content analysis of Fe, Mn, Ni, Cr, V, and Co: The total content of the intended six heavy metals were measured in the aqua regia extractions according to the procedure recommended by the [19]. Determination of the metals was carried out by atomic emission spectroscopy using inductively coupled plasma-optical emission spectroscopy ICP-OES (model PerkinElmer, precisely Optima 2100/USA). Duplicate measuring was conducted in each digestion solution of the soil sample, and the average values for each metal were taken out,

Additionally, it should be mentioned that oven-dry weight has been used whenever the soil mass was required for calculating the results of the soil parameter.

Water-soluble ion species, including Ca^{2+} , Mg^{2+} , K^+ , Na^+ , Cl^- , HCO_3^- , CO_3^{2-} were determined according to the methods described by [15] on a 1:2.5 ratio soil: distilled water suspension after filtration the suspensions through an ashless Whatman 42 filter paper.

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Table 1: GPS coordinates, elevations, direction and the ranges of the specified distances of the sampling sites around the scrape recycling companies.

Sulaimani Steel Recycling Company				
Site numbers	Direction & Distances	GPS Coordinates		Elevations (m)
		Latitude	Longitude	
C1	N 50	N 35.61840°	E 045.14087°	975
C2	N 117	N 35.61883°	E 045.14106°	981
C3	N 250	N 35.62040°	E 045.14075°	993
C4	300 NW Sulaimani Steel	N 35.61960°	E 045.13863°	970
Combined site	250 NE Super Steel			
C5	E 50	N 35.61790°	E 045.14198°	972
C6	E 110	N 35.61795°	E 045.14330°	971
C7	E 250	N 35.61787°	E 045.14426°	969
C8	E 500	N 35.61753°	E 045.14587°	983
C9	E Control 700	N 35.61700°	E 045.14719°	1010
Super Steel Recycling Company				
D1	S 75	N 35.61745°	E 045.13750°	945
D2	S 125	N 35.61596°	E 045.13733°	947
D3	S 250	N 35.61446°	E 045.13672°	927
D4	S 700	N 35.61097°	E 045.13396°	872
D5	W 50	N 35.61855°	E 045.13564°	954
D6	W 100	N 35.61860°	E 045.13519°	951
D7	W 250	N 35.61873°	E 045.13348°	945
D8	W 500	N 35.61780°	E 045.13177°	932
D9	W Control 1000	N 35.61508°	E 045.12431°	841

Note:1- where C stand for Sulaimani Steel and; D for Super Steel.

2- the missing directions or sites by each company can be attributed to the presence of construction, hindrances or any other stumbling block.

Indices assessment of soil heavy metals pollution

A-Single indices:

A-1. Geo-accumulation index (I_{geo}) = $\log_2 Ci / (Cig * 1.5)$(1)

where Ci is the measured concentration of the studied metal in the surface soil

Cig is the geochemical background concentration or reference value of the metal, and

1.5 is constant that is used for lithologic variations of the heavy metal.

Calculation of soil pollution indices need the evaluated level of the geochemical background (GB). This term was presented to discriminate natural concentrations of heavy metals in the soil from unusual concentrations [18].

The authors [19] have classified the geo-accumulation index into seven intensity classes and they are as follow: $I_{geo} \leq 0$ named as class 0 or unpolluted; $0 < I_{geo} \leq 1$ called class 1 or unpolluted to moderately polluted; $1 < I_{geo} \leq 2$, termed class 2 or moderately polluted; $2 < I_{geo} \leq 3$ named class 3 or moderately to strongly polluted; $3 < I_{geo} \leq 4$ is termed as class 4 or strongly polluted; $4 < I_{geo} \leq 5$ is considered as class 5 or strongly to very polluted, and finally $I_{geo} > 5$ is regarded as class 6 or very polluted.

A-2. Contamination factors (CF) = Cm / Cb(2)

where, Cm is the concentration of the metal in surface soils, and

Cb is the geochemical background concentration of the target heavy metal.

In this study, the results of contamination factors (CF) have been used to calculate the integrated index of pollution load indices (PLI) and Nemerow Pollution Index (PINemerow). According to [20 and 21], CF was categorized into four classes, and they are as follow: $CF < 1$ denotes to low contamination; $1 < CF < 3$ refers to moderate contamination; $3 > CF < 6$ indicates considerable contamination and $CF > 6$ shows very high contamination.

B- integrated indices

B-1. Pollution Load Indices (PLI) = (CF1 x CF2 x CF3 x..... x CFn) 1/n.....(3)

Where CF stand for the contamination factor; and n is the number of the studied metals.

PLI offers simple but comparative valuation for assessing a soil quality, whenever the PLI value is more than one (> 1); the soil is regarded as polluted soil, but when PLI value is less than or equal to one (≤ 1), this illustrates that the soil is not polluted [22 and 23].

B-2. Nemerow Pollution Index (PINemerow)

$$PI_{Nemerow} = \sqrt{\frac{(\frac{1}{m}\sum_{i=1}^m P_i)^2 + P_{i\ max}^2}{m}} \dots\dots\dots (4)$$

Where m = the number of studied heavy metals

Pi = single pollution index of particular heavy metal,

Pi max= maximum value of single pollution index of all heavy metals,

Nemerow Pollution Index (PINemerow) provides the assessment of the wide-ranging level of soil pollution because it takes into account the concentration of all of the intended heavy metals [24 and 25].

As indicated by [26 and 27], soil pollution in regard with heavy metals and its quality was classified into five categories from Nemerow, and they are as follow; PI Nemerow<0.7, clean (safety domain); 0.7<= PI Nemerow<1.0, warning limit (precaution domain) ;1.0<=PI Nemerow<2.0, slightly polluted domain ; 2.0<=PI Nemerow<3.0, moderately polluted domain ; and PI Nemerow >3.0, heavy (seriously) polluted domain.

Statistical analysis

Based on the physicochemical parameters and the concentration of heavy metals as well as the calculated indices for the collected soil samples around scrap metal recycling companies, we applied XLSTAT Extension Version 2016.02.28451 for calculation correlation coefficients (at P ≤ 0.05) between the soil parameter and heavy metals content were calculated to test the correlation.

RESULTS AND DISCUSSION

A-Physicochemical characteristics of the studied soils

Physicochemical characteristics of soil play a substantial role in retention–release processes of soil heavy metal content, and subsequently, they influence the plant uptake of heavy metals or leaching them to groundwater [28]. Because of given that, the depicted physicochemical parameters in Tables (2 and 3) were analyzed for the obtained soil samples around scrap metal recycling companies.

In general, a wide variation in the results of the analyzed physicochemical analysis was observed for the studied samples at the two depths. This might be because scrap metal recycling is a complex industrial activity and encompasses a wide range of metals, processes (such as; raw scrap pretreatment, melting, refining, forming and finishing), chemical compound and emitted pollutants that may influence the environment of surrounding soil and its physicochemical parameters. On the contrary, physicochemical parameters of soil such as pH, organic matter, particle size distribution, bulk density, porosity are recognized to influence the interactions and dynamics of the heavy metals within the soil matrix [29].

The results showed that the soils had a slight alkali pH (7.61-8.34), with wide-ranging electrical conductivity, organic matter, and calcium carbonate content which they varied between 159-1210µS cm⁻¹, (6.5-123.7 g Kg⁻¹) and (42.2-461.9 g Kg⁻¹) respectively.

The concentration of CO₃⁻², HCO₃⁻¹, Cl⁻¹, Ca⁺² and Mg⁺² ions were ranged between not detected (ND); 1.20-2.85; 0.44-4.65; 0.5-2.5 and 0.1-1.5 millimoles per liter (mmoles L⁻¹) respectively, while the concentrations of Na⁺¹ and K⁺¹ were in the range of 2.33-40.78 and 0.78-11.4 microgram per milliliter (µg mL⁻¹), Table (2 and 3).

Table 2: Basic physicochemical properties of topsoil, D1(0-20 cm) and subsoil, D2 (20-40 cm) for the studied sites.

Sites Numbers	Directions & Distances (m)	Depth (cm)	pH 1:2.5 soil: water susp.(25 °C)	Electrical Conductivity ($\mu\text{S cm}^{-1}$)	Anions (mmoles L^{-1})			Cations (mmoles L^{-1}) ($\mu\text{g mL}^{-1}$)			
					CO_3^{-2}	HCO_3^{-1}	Cl^{-1}	Ca^{+2}	Mg^{+2}	Na^{+1}	K^{+1}
Sulaimani Steel Recycling Company											
C1	N50	D1	8.13	284	ND	1.9	1.92	1.05	0.6	7.38	2.85
		D2	8.10	168	ND	2.0	1.10	0.63	0.9	5.05	1.81
C2	N117	D1	8.06	292	ND	2.0	1.35	1.13	0.9	5.83	6.00
		D2	8.10	234	ND	1.7	1.43	1	1.5	8.16	4.14
C3	N250	D1	7.99	284	ND	2.0	0.44	0.85	1.25	4.27	6.00
		D2	8.09	205	ND	1.75	1.10	1.1	1.15	3.88	2.30
C4 Combined site	300 NW to Sul. Steel and 250 NE to Super Steel	D1	7.65	253	ND	1.85	1.10	0.55	0.9	3.88	4.40
		D2	7.93	215	ND	2.2	2.00	0.85	0.1	6.21	2.60
C5	E50	D1	7.80	503	ND	1.80	3.07	1.8	0.7	9.32	5.70
		D2	7.97	254	ND	1.55	1.47	0.85	0.4	4.66	2.07
C6	E110	D1	8.05	264	ND	1.7	0.98	0.85	0.35	4.27	1.55
		D2	8.13	159	ND	1.85	1.10	0.50	0.30	3.50	0.78
C7	E250	D1	8.03	189	ND	1.8	0.77	0.55	1.25	3.88	1.04
		D2	7.94	306	ND	2.05	1.43	0.9	1.33	3.88	3.40
C8	E500	D1	7.80	409	ND	2.2	2.25	1.5	1.18	3.50	6.50
		D2	7.93	325	ND	1.6	1.51	1.25	0.7	3.11	3.40
C9	E Control700	D1	7.67	400	ND	2.4	1.55	1.9	0.85	3.11	8.55
		D2	8.10	167	ND	1.7	1.35	0.9	0.4	2.72	2.60
Super Steel Recycling Company											
D1	S75	D1	7.88	1210	ND	1.40	4.46	2.5	1.05	40.78	4.14
		D2	7.95	922	ND	1.20	3.81	2.0	1.05	33.40	2.60
D2	S125	D1	7.79	353	ND	2.35	0.61	1.45	1.25	4.27	6.70
		D2	8.13	200	ND	1.65	1.76	0.9	0.4	3.50	1.55
D3	S250	D1	7.97	219	ND	1.55	1.92	0.95	0.75	2.72	2.60
		D2	8.12	186	ND	1.80	1.67	0.9	0.85	2.72	1.30
D4	S700	D1	8.01	230	ND	1.55	2.00	0.9	0.5	3.88	3.90
		D2	8.09	173	ND	1.40	0.69	0.65	1.1	3.88	2.30
D5	W50	D1	7.71	440	ND	2.15	2.00	1.8	1.35	6.21	6.50
		D2	8.04	188	ND	1.55	1.51	0.7	0.8	3.50	0.78
D6	W100	D1	7.61	506	ND	2.85	4.00	2.3	0.8	4.66	11.40
		D2	8.21	203	ND	1.75	1.02	1.05	0.55	2.33	2.85
D7	W250	D1	7.92	255	ND	1.75	2.08	1.0	0.8	3.11	2.33
		D2	8.19	162	ND	1.60	1.43	0.85	0.65	3.11	0.78
D8	W500	D1	8.04	234	ND	1.70	1.18	1.0	1.15	2.72	2.85
		D2	8.34	167	ND	1.70	1.59	0.95	0.4	3.11	1.55
D9	W Control 1000	D1	7.90	291	ND	1.85	1.18	1.1	0.8	3.50	4.14
		D2	8.03	185	ND	1.50	1.26	0.75	1.1	3.88	1.81

Note:1- where C stand for Sulaimani steel and; D for Super steel; 2- the missing directions or sites by each company can be attributed to the presence of construction, hindrances or any other stumbling block.

As a matter of fact, the trends of electrical conductivity (EC) and potassium ion were totally alike, and they had a systematic trend, because their values lowered with depth (in D2) by all the sample sites except with C7/E250 site, and this might be attributed mainly to the accumulation of scrap residue on soil surface or application of inorganic chemical fertilizers in some case. A similar trend to EC and K^{+} ion was also occurred for organic matter content by 77.8% of the sample sites. In contrast, calcium carbon contents were increased mainly with depth (in D2) by 66.7% of the sampling sites; this might be attributed to the

calcareous nature of the soils in the Sulaimani region [30]. However, the ions of CO_3^{-2} , HCO_3^1 , Cl^1 , Ca^{+2} , Mg^{+2} , and Na^+ were not repeated in regular or systematic trend with depth along with the sampling sites.

Table 3: Basic physicochemical properties for the studied sites in topsoil, D1(0-20 cm) and subsoil, D2 (20-40 cm).

<i>Sulaimani Steel Recycling Company</i>								
Sites Number	Directions & Distances (m)	Depth	Organic Matter g Kg^{-1}	Calcium Carbonate g Kg^{-1}	Particles Size Distributions g Kg^{-1}			
					Sand	Silt	Clay	Texture
C1	N50	D1	11.6	452.6	110.1	447.7	442.2	SiC
		D2	6.5	462.6	115.3	453.2	431.5	SiC
C2	N117	D1	22.8	342.6	216.0	404.8	379.2	CL
		D2	23.3	281.1	254.3	373.5	372.2	CL
C3	N250	D1	31.3	202.6	67.9	331.1	601.0	C
		D2	16.8	253.5	67.5	460.2	472.3	SiC
C4 Combined site	300 NW Sulaimani Steel 250 NE Super Steel	D1	30.5	274.3	74.8	427.8	497.4	SiC
		D2	26.8	269.0	95.3	359.2	545.5	C
C5	E50	D1	37.3	270.0	126.1	362.0	511.9	C
		D2	20.3	181.6	42.2	311.3	646.5	C
C6	E110	D1	10.1	316.5	98.6	334.9	566.5	C
		D2	10.6	426.9	158.0	357	485.0	C
C7	E250	D1	7.6	393.7	158.0	392.1	449.9	C
		D2	19.5	213.7	73.4	322.8	603.8	C
C8	E500	D1	43	75.6	48.4	299.9	651.7	C
		D2	34.1	91.5	49.9	239.8	710.3	C
C9	E Control700	D1	66.2	150.4	106.7	344.2	549.1	C
		D2	22.2	499.3	245.8	398.7	355.5	CL
<i>Super Steel Recycling Company</i>								
D1	S75	D1	26.2	266.1	123.2	332.3	544.5	C
		D2	27.3	236.6	98.5	336.5	565.0	C
D2	S125	D1	38.6	424.3	240.0	369.7	390.3	CL
		D2	31.3	449.4	326.3	327.4	346.3	CL
D3	S250	D1	36.8	619.3	336.6	457.1	206.3	L
		D2	32.3	582.2	379.9	424.6	195.5	L
D4	S700	D1	18.5	243.6	205.0	447.9	347.1	CL
		D2	11.5	345.2	159.9	481.9	358.2	SiCL
D5	W50	D1	54.9	284.4	120.7	388.9	490.4	C
		D2	31.5	287.4	120.4	323.0	556.6	C
D6	W100	D1	123.7	361.3	165.0	425.3	409.7	SiC
		D2	34.7	639.3	461.9	351.6	186.5	L
D7	W250	D1	49.5	355.4	255.2	392.7	352.1	CL
		D2	29.9	425.4	263.1	407.9	329.0	CL
D8	W500	D1	52.6	298.3	180.3	427.3	392.4	SiCL
		D2	28.4	649.0	455.1	362.2	182.7	L
D9	W Control 1000	D1	28.2	299.8	162.7	328.2	509.1	C
		D2	21.3	302.3	117.5	810.5	72	Si

Note: 1- where C stand for Sulaimani steel and; D for Super steel; 2- the missing directions or sites by each company can be attributed to the presence of construction, hindrances or any other stumbling block.

The particle size distribution as revealed in Table (3) put the predominant frequency of the textural class for the analyzed samples in the following order: clay (44.44%) > clay loam (22.22%)> silty clay (13.88%) > Loam (5.50%) > silt clay loam (5.5%) > silty (2.7%). Moreover, the percentages of the particles clay, silt, and sand were in the ranges of 72.0-710.3; 239.8-810.5 and 42.20-461.9 g Kg^{-1} respectively, in consequence, the sorption capacity for cations in the soil will decrease as far as the following trend; clay < silt < sand will be dominant in the soil matrix.

Besides, Tables 2 and 3 display that the maximum levels of eleven physicochemical parameters out of the fourteen analyzed parameters appeared in soil sampling sites that located mostly within 75 to 100 m

distances range around Super Steel recycling company rather than Sulaimani steel recycling company. This might be attributed to the differences in ranges of industrial activities and emission control system between the two companies as well as to the impacts of prevailing wind direction.

Table (4A and 4B) presents the values of correlation coefficient that have been calculated to examine the significance of correlation among physicochemical parameters themselves as well as between the physicochemical parameters and the studied heavy metals.

In general, the finding indicated a limited significant relation among physicochemical parameters themselves. For instance, significant negative relations was found between pH and each of EC, HCO_3^- , Cl^- , Ca^{+2} , K^+ , OM and clay, ($r = -0.45, -0.54, -0.38, -0.58, -0.76, -0.61$ and $-0.51, p \leq 0.05$) respectively, while significant positive correlation was appeared between pH and CaCO_3 ($r = 0.55, p \leq 0.05$). Besides, K^+ exhibited significant positive correlation with each of EC, HCO_3^- , Cl^- , Ca^{+2} and OM ($r = 0.38, 0.73, 0.34, 0.68$ and $0.74, p \leq 0.05$). Incredibly, some other significant correlations were found among the physicochemical parameters in consequence of positive or negative interaction effects between the correlated parameters.

Table 4A: Correlation matrix (Pearson) values between and among physicochemical parameters and heavy metals.

Variables	pH	EC	HCO_3^-	Cl^-	Ca^{+2}	Mg^{+2}	Na^+	K^+	OM	CaCO_3
pH	1	-0.45	-0.54*	-0.38*	-0.58*	-0.29	-0.14	-0.76*	-0.61*	0.55*
EC	-0.45*	1	-0.07	0.80*	0.84*	0.25	0.92*	0.38*	0.24	-0.33*
HCO_3^-	-0.54*	-0.07	1	0.01	0.28	0.10	-0.34*	0.73*	0.61*	-0.09
Cl^-	-0.38*	0.80*	0.01	1	0.79*	-0.05	0.71*	0.34*	0.45*	-0.15
Ca^{+2}	-0.58*	0.84*	0.28	0.79*	1	0.22	0.62*	0.68*	0.61*	-0.28
Mg^{+2}	-0.29	0.25	0.10	-0.05	0.22	1	0.17	0.32	0.10	-0.32
Na^+	-0.14	0.92*	-0.34*	0.71*	0.62*	0.17	1	0.05	-0.06	-0.19
K^+	-0.76*	0.38*	0.73*	0.34*	0.68*	0.32	0.05	1	0.74*	-0.36*
OM	-0.61*	0.24	0.61*	0.45*	0.61*	0.10	-0.06	0.74*	1	-0.10
CaCO_3	0.55*	-0.33*	-0.09	-0.15	-0.28	-0.32	-0.19	-0.36*	-0.10	1
Sand	0.51*	-0.28	-0.13	-0.09	-0.14	-0.24	-0.19	-0.22	0.07	0.84*
Silt	0.12	-0.25	-0.12	-0.13	-0.23	0.16	-0.14	-0.13	-0.08	0.23
Clay	-0.46*	0.36*	0.17	0.14	0.24	0.08	0.23	0.24	0.00	-0.77*
Fe	-0.17	0.16	0.12	0.06	0.13	0.41*	0.14	0.33	-0.07	-0.58*
Co	-0.15	-0.01	-0.06	-0.13	-0.13	0.21	-0.01	0.09	-0.28	-0.62*
Cr	-0.09	-0.03	-0.08	-0.14	-0.14	0.21	-0.03	0.10	-0.28	-0.53*
Mn	-0.51*	0.44*	0.18	0.26	0.37*	0.44*	0.32	0.41*	0.08	-0.89*
Ni	0.03	-0.12	-0.13	-0.21	-0.23	0.18	-0.08	0.01	-0.33*	-0.37*
V	-0.49*	0.30	0.11	0.14	0.21	0.24	0.19	0.25	-0.05	-0.94*

Note: Values in bold are different from 0 with a significance level $\alpha=0.05$

* Significant at $p \leq 0.05$

About the effect of the specified distances from the companies and direction, the physicochemical parameters differed from one another in their appearing patterns, moreover no uniform or regular direction was generally perceived about the results. This could be ascribed to many reasons, such as; heterogeneity nature of soil matrix, the influences of topographic forms (aspects) and surface micro-aspect on pedogenic processes, erosion and infiltration rate, prevailing wind direction, disturbance of soil profile during the establishment of the companies, agricultural activity in surrounding fields of the companies, narrowed range or near circles distances of sample sites, especially the first two ranges, daily practicing of some recycling process at the nearby areas to the recycling companies, etc.

Table 4B: Correlation matrix (Pearson) values between and among physicochemical parameters and heavy metals.

Variables	Sand	Silt	Clay	Fe	Co	Cr	Mn	Ni	V
pH	0.51	0.12	-0.46*	-0.17	-0.15	-0.09	-0.51*	0.03	-0.49*
EC	-0.28	-0.25	0.36*	0.16	-0.01	-0.03	0.44*	-0.12	0.30
HCO ₃ ⁻	-0.13	-0.12	0.17	0.12	-0.06	-0.08	0.18	-0.13	0.11
Cl ⁻	-0.09	-0.13	0.14	0.06	-0.13	-0.14	0.26	-0.21	0.14
Ca ⁺²	-0.14	-0.23	0.24	0.13	-0.13	-0.14	0.37*	-0.23	0.21
Mg ⁺²	-0.24	0.16	0.08	0.41	0.21	0.21	0.44*	0.18	0.24
Na ⁺	-0.19	-0.14	0.23	0.14	-0.01	-0.03	0.32	-0.08	0.19
K ⁺	-0.22	-0.13	0.24	0.33	0.09	0.10	0.41*	0.01	0.25
OM	0.07	-0.08	0.00	-0.07	-0.28	-0.28	0.08	-0.33	-0.05
CaCO ₃	0.84*	0.23	-0.77*	-0.58*	-0.62*	-0.53*	-0.89*	-0.37	-0.94*
Sand	1	0.07	-0.79*	-0.39*	-0.58*	-0.46*	-0.76*	-0.34	-0.91*
Silt	0.07	1	-0.67*	-0.16	-0.02	0.01	-0.30	0.11	-0.25
Clay	-0.79*	-0.678	1	0.39*	0.45*	0.34*	0.75*	0.19	0.83*
Fe	-0.39*	-0.16	0.39*	1	0.43*	0.45*	0.78*	0.30	0.56*
Co	-0.58*	-0.02	0.45*	0.43*	1	0.98*	0.50*	0.95	0.60*
Cr	-0.46*	0.01	0.34*	0.45*	0.98*	1	0.43*	0.97	0.48*
Mn	-0.76*	-0.30	0.75*	0.78*	0.50*	0.43*	1	0.24	0.90*
Ni	-0.34*	0.11	0.19	0.30	0.95*	0.97*	0.24	1	0.32
V	-0.91*	-0.25	0.83*	0.56*	0.60*	0.48*	0.90*	0.32	1

Note: Values in bold are different from 0 with a significance level $\alpha=0.05$

* Significant at $p \leq 0.05$

B-Total heavy metals concentration in soils regarding depth and the ranges of the specified distances from the companies.

The total concentrations of the studied six metals in the soil samples are shown in Table (5); knowing that the concentration of Fe is in gram per kilogram (g kg^{-1}), but the concentration of Co, Cr, Mn, Ni, and V are in milligram per kilogram (mg kg^{-1}). Our results showed a considerable variation in the determined ranges of Fe, Co, Cr, Mn, Ni, and V in the soils of the different sites and they ranged as follow: 16.81-105.26 g kg^{-1} for Fe, but the other metals were 15.57-86.65 for Co; 80.04-713.85 for Cr; 291.51-1444.2 for Mn; 74.67-1118.8 for Ni and 40.36-174.74 for V mg kg^{-1} with a mean values of 44.818 g kg^{-1} (Fe), 38.904 (Co), 258.229 (Cr), 822.242 (Mn), 309.037(Ni) and 109.027 (V) mg kg^{-1} .

In a similar study by [31].for assessing the soil heavy metal pollution in the surrounding soil of Erbil Steel scrap recycling company, lower concentration was found for the alike investigated metals by the study as compared to the current study, and the metals usually ranged as follow: 4.75-15.87 g kg^{-1} for Fe, while for the other metals were 4.00-74.00; 56.00-378.00; 1.27-220.4; 8.00-85.20; 8.00-17.67 and 1.43-10.17 mg kg^{-1} for Cr, Pb, Zn, Mn, and Ni respectively. The causes of low concentration for the metals contents in the surrounding soil of Erbil Steel scrap recycling company can be due to the differences in number of the scrap recycling company, pollution control system equipment and production capacity of the recycling companies, method of determination the heavy metals, type of the soil parent materials, etc.

Based on the average values of the metals, the spatial distribution or occurrence of the studied metals was in the following order $\text{Fe} > \text{Mn} > \text{Ni} > \text{Cr} > \text{V} > \text{Co}$, and this may be in a sequence that agrees with or follows the trend of major scrap metals components. Similar trend of spatial distribution was obtained by [32] for the alike or recurring metals in both studies through an assessment study of heavy metal soil contamination in a Steel Factory and its surrounding soil in Erbil City, and their sequences was as follow; $\text{Fe} > \text{Al} > \text{Zn} > \text{Mn} > \text{Ti} > \text{Pb} > \text{Cu} > \text{Ni} > \text{Cr} > \text{V} > \text{Co} > \text{As} \geq \text{Mo} > \text{Cd}$. Our findings regarding the occurrence of higher heavy metal concentrations in surrounding soil of steel company in comparison with other sites were also in good agreement with the findings of [33] who studied the concentrations the metals of Pb, Cd, Cu and Zn by steel company and some related area in Erbil.

Table 5: Heavy metal concentrations in topsoil and subsoil of the studied sites around the scrap recycling companies.

Sulaimani Steel Scrap Recycling Company								
Sites Numbers	Directions & distances (m)	Depth	Heavy Metal concentrations					
			g kg ⁻¹			mg kg ⁻¹		
			Fe	Co	Cr	Mn	Ni	V
C1	N50	d1	42.40	36.63	225.44	710.19	303.85	111.83
		d2	39.94	37.59	222.43	659.07	283.05	105.99
C2	N117	d1	105.26	37.74	319.90	1146.20	301.32	109.04
		d2	99.26	36.86	241.87	1142.70	288.50	108.87
C3	N250	d1	49.82	55.58	416.03	984.26	569.62	120.86
		d2	46.79	54.99	386.93	986.02	526.62	128.42
C4 Combined site	300 NW to Sul. Steel and 250 NE to Super Steel	d1	41.14	41.18	259.27	897.91	273.80	121.91
		d2	42.50	42.36	257.09	975.18	258.22	132.84
C5	E50	d1	45.97	38.32	225.57	951.18	247.87	128.19
		d2	45.11	39.56	227.08	955.89	198.07	139.28
C6	E110	d1	41.66	40.93	253.97	792.56	295.35	121.19
		d2	35.59	37.66	234.12	657.44	325.84	105.45
C7	E250	d1	45.18	53.68	376.86	815.25	541.70	107.71
		d2	56.99	51.74	356.66	1161.00	447.70	140.96
C8	E500	d1	68.92	54.65	357.87	1444.20	372.60	174.74
		d2	54.02	46.14	304.97	1063.70	306.15	152.56
C9	E Control700	d1	43.42	39.49	232.78	1005.80	248.36	136.65
		d2	31.75	27.84	163.27	573.52	179.94	87.72
Super Steel Scrap Recycling Company								
D1	S75	d1	51.14	35.62	233.67	1117.40	205.39	124.56
		d2	42.28	35.50	215.11	1049.10	203.33	125.66
D2	S125	d1	34.92	26.75	162.44	718.65	137.51	91.35
		d2	30.42	24.44	156.46	588.20	133.99	86.15
D3	S250	d1	20.01	17.58	107.53	390.11	98.44	56.54
		d2	17.97	16.45	104.48	316.71	95.17	52.74
D4	S700	d1	56.59	86.65	713.85	767.34	1118.80	112.11
		d2	35.81	70.21	516.81	642.49	874.80	100.94
D5	W50	d1	49.06	36.92	240.10	1026.10	244.60	118.19
		d2	46.84	37.85	247.69	924.34	253.01	115.74
D6	W100	d1	39.19	28.73	176.90	792.58	164.54	91.85
		d2	16.81	18.49	107.41	316.38	111.81	40.36
D7	W250	d1	38.98	28.96	169.20	771.50	141.53	103.45
		d2	34.96	28.28	154.56	665.08	139.34	96.57
D8	W500	d1	43.81	31.92	186.99	813.82	161.49	114.37
		d2	17.36	15.57	80.04	291.51	74.67	46.55
D9	W Control 1000	d1	35.48	32.02	199.34	690.28	197.61	108.36
		d2	33.67	31.26	184.13	705.85	225.35	108.23
Minimum values			16.81	15.57	80.04	291.51	74.67	40.36
Maximum values			105.26	86.65	713.85	1444.2	1118.8	174.74
Average Values			44.818	38.904	258.229	822.243	309.037	109.027

Note:1- where C stand for Sulaimani steel and; D for Super steel; 2- the missing directions or sites by each company can be attributed to the presence of construction, hindrances or any other stumbling block.

It is important to note that the maximum concentration of all the investigate metals were appeared by the surface soil (D1=0-20 cm depth), while all the minimum levels were found by the subsoil samples (D2= 20-40 cm). Indeed, these findings strengthen the confirmations that in current time surface soils particularly

around the scrap metal recycling companies were mostly got heavy metals rather than the subsoil, because surface soils are more exposed to the ongoing processes of recycling as well as deposition of heavy metals from the emissions of the melting furnaces. Additionally, companies are established in recent years and started to produce in 2015. All the minimum levels, as well as three of the maximum levels for the studied metals were found by Super Steel scrap recycling company, and they were by the sites and distances ranges of D6/W100 and D8/W500 for the minimum levels, but all the three maximum levels appeared by D4/S700 (Table 5).

The attained maximum concentrations in surface soils (D1) were approximately in the ranges of 4.33 for V to 14.98, for Ni times higher than the minimum concentrations of the metals in subsoil (D2) samples, accordingly we have regarded the concentrations in subsoil as a reference values (geochemical background concentration) for calculating the pollution indices (Figure 2).

In general, the concentration of all the metals except Co were mostly (72-88%) higher in surface soils (D1) samples rather than the subsoil (D2) samples at all the ranges of the specified distances from the companies and directions of the sampling sites. Regarding Co metal, the concentrations were mostly close to each other in D1 and D2, but for some sampling sites, the concentrations like the other metals were higher in surface soil rather than the subsoil. Hence, heavy metal concentration in surrounding soil of the scrap recycling companies have increased due to the establishment of the scrap metal recycling companies in the region, and this can be supported by the view of the authors [34 and 35], who mentioned that the distribution pattern of heavy metals inside the soil profile could give information about their source.

Regarding the impact of distances rang and direction on the spatial distribution of the studied heavy metals in surrounding soils of the scrap metal recycling companies, no considerable regular pattern was observed (Figures 4A and 4B). In some cases and with the definite direction the concentrations were high at distances range of 100 and 250 m. On the contrary, in other cases the concentrations were high at distances range of 50 and 500 m. The irregular distribution of the elemental concentrations with distances range and directions could be due the effects of many factors such as: parent material and heterogeneity nature of soil matrix, impacts of topographic appearances and surface micro-aspect on pedogenic processes, disturbance of soil profile throughout the establishment of the companies, erosion and infiltration rate, prevailing wind direction, agricultural activity in surrounding fields of the companies, narrow distance range, daily practicing of some recycling process at the nearby areas to the recycling companies, etc.

The correlation analyses between the analyzed metals and the soil physicochemical parameters are shown in Table 4A and 4B. Calcium carbonate and sand particles were significantly negatively correlated with all the studied metals ($r = -0.58, -0.62, -0.53, -0.89, -0.37$ and $-0.94, p < 0.05$) and ($r = -0.39, -0.58, -0.46, -0.76, -0.34,$ and $-0.61, p < 0.05$) for calcium carbonate and sand particles with the metals Fe, Co, Cr, Mn, Ni, and V respectively. In contrast, clay particles were significantly positively correlated with all the investigated metals except Ni which was also positive but not significant ($r = 0.39, 0.45, 0.34, 0.75,$ and $0.83, p < 0.05$) for Fe, Co, Cr, Mn, and V respectively. These correlations indicate that clay particles played a substantial role in adsorbing the metals as a result of their negatively exchangeable sites. However, our findings of the correlation between clay content and the concentration of the total metals were not in agreements with the results of [36], who found a negative correlation between clay content and the total concentration of the metals Zn, Pb, and Cd. Although pH values showed a negative correlation with the total concentration of the metals as a whole except Ni, the correlation was significant only with Mn, and V ($r = -0.51$ and $-0.49, p < 0.05$) respectively.

Similarly, the authors [36] also found negative correlations between pH and their studied metals concentration due to the increasing of carbonate compounds in soil rather than the metal-bearing minerals or particles in soil. Furthermore, some other significant correlations between limited metals and the soil physicochemical parameters appeared. The previous correlation results approve that the correlation analysis is an important statistical tool to show the effect of the soil physicochemical properties on the concentrations of heavy metals in the soils.

Another interesting aspect in the correlation analyses was the correlation among the heavy metal themselves; the metals generally showed a similar trend and designated significant positive correlation with each other's as shown in Table (4B).

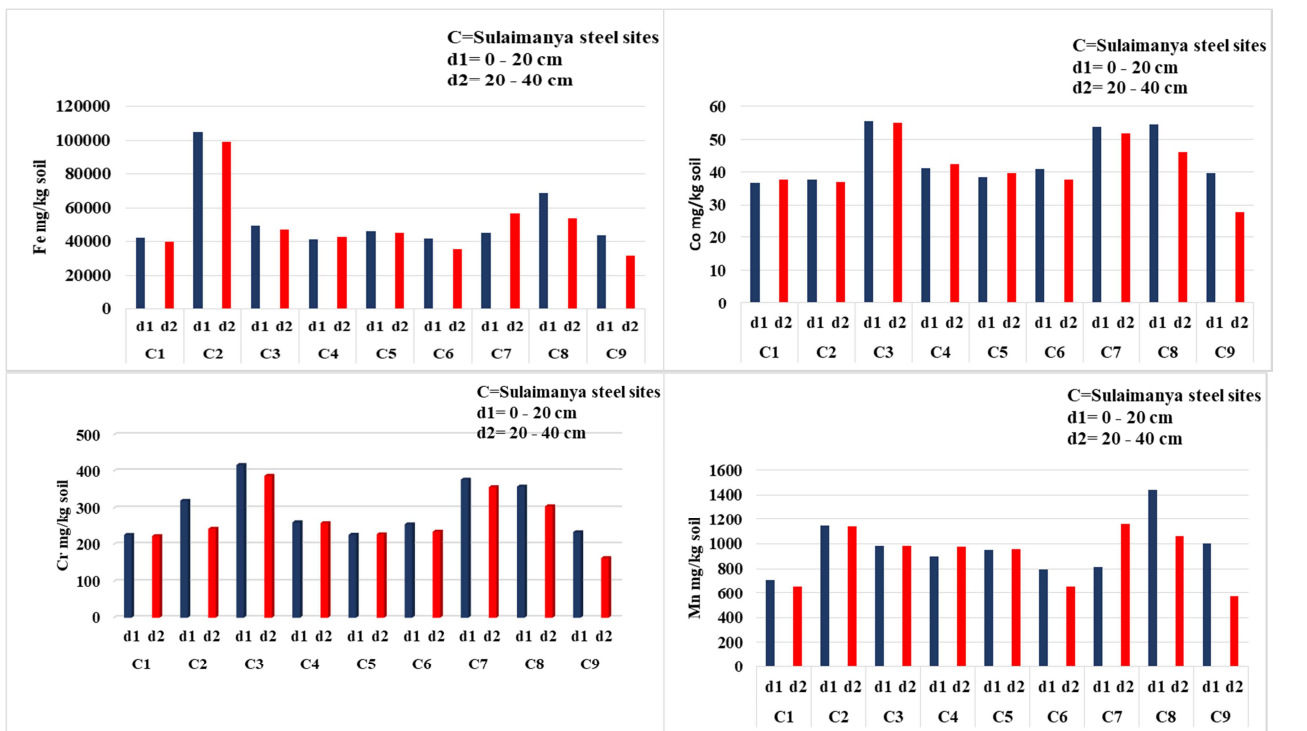
Heavy metals pollution is a threat to our environment when they become a leading source to pollute the soil matrix's of our plant products supply, and particularly with the vegetables[37], therefore the status assessment of soil heavy metal pollution is essential for human health and environmental management by comparing the soil heavy metals content with the adopted national and international standard levels.

Based on current ecological and toxicological data gained by Dutch ecologists, the following designated heavy metals and metalloids from the consequent sequence according to their hazard degree in soils: Se > Tl > Sb > Cd > V > Hg > Ni > Cu > Cr > As > Ba. Consequently, The Dutch maximal permissible addition (MPA) for soils are sub-classed to; a-highly hazardous and the adopted concentration is <1 mg kg⁻¹ for the elements Be, Se, Tl, Sb, Cd; b- moderately hazardous and the addressed levels are in the range of 1to10 mg kg⁻¹ for the elements V, Hg, Ni, Cu, Cr, As, Ba, and c- low hazardous and the defined concentrations is >10 mg kg⁻¹ for the elements Zn, Co, Sn, Ce, Pb, Mo [38]. Based on the previous information, we can conclude that the metals of; V, Ni, and Cr are considered as moderately hazardous metals, but Co is regarded as low hazardous metal, while for Fe and Mn metals the status of their hazardous have not been defined yet.

As stated by[39], MPA is the core or basic idea for standardization of the soil contamination and can be calculated from the following equation;

$$MPA = \frac{1}{4} NOEC \dots \dots \dots (5)$$

Where NOEC represents the maximal concentration that exerting no significant influence (no detected effect concentration) on the growth and reproduction of the investigated organisms. In general, the Dutch ecologists consider the following cases; soil fauna, microbiological processes, and plant response to show the influence of contaminated soils. Moreover, the ecologist also took into account the biological effect of heavy elements transferring into the soil solution and the ground and surface water under natural conditions.



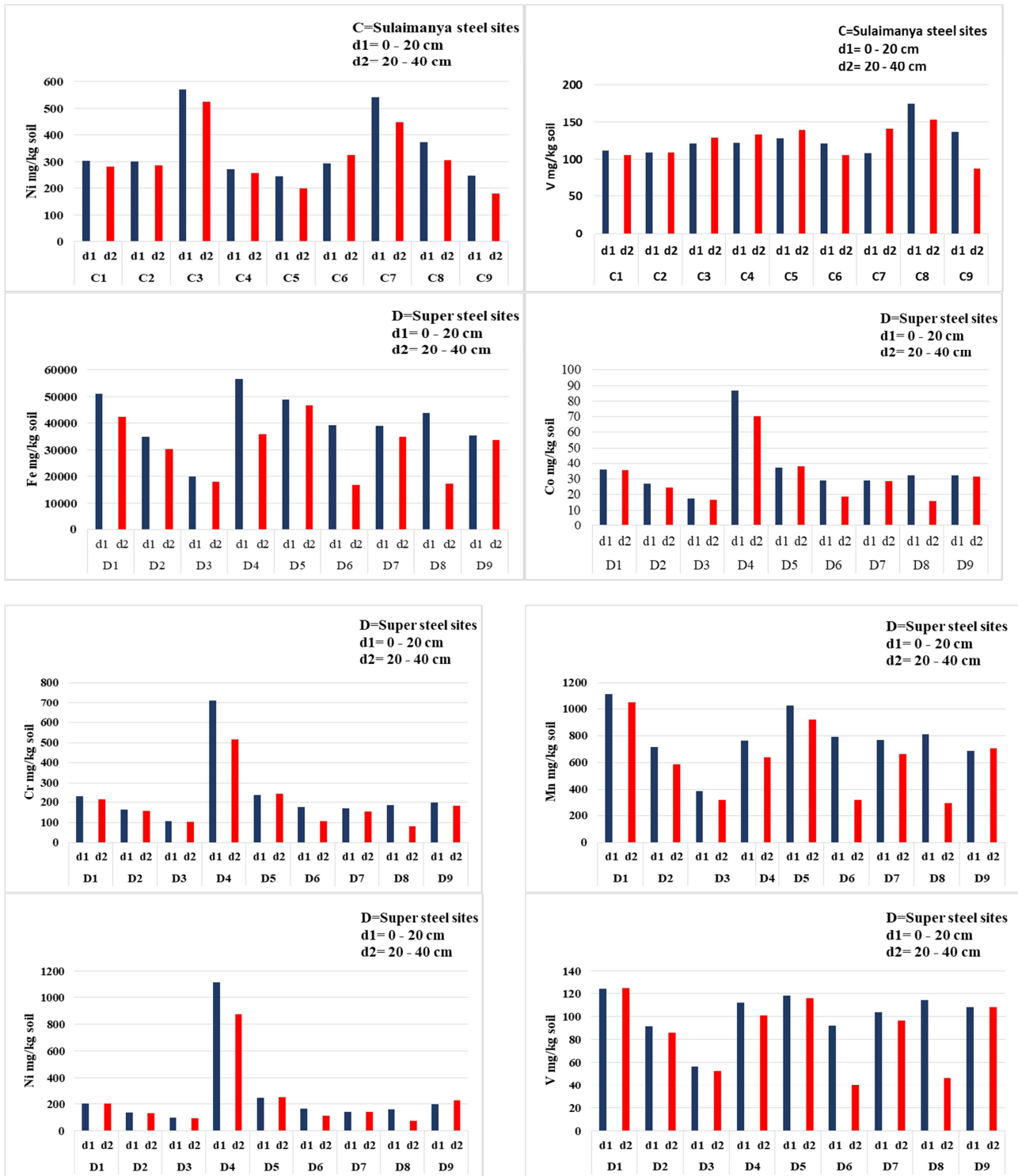


Figure: Heavy metal concentrations in topsoil and subsoil of the studied sites around the scrap recycling Sulaimani Steel and Super Steel companies.

Note, the d1 and d2 letters on the X-axis stand for the depths of sampling, while the capital letters represent the sampling sites around the companies.

C- Indices assessment of soil heavy metals pollution

In this study, assessment of heavy metal pollution was performed by using the quantitative indices into two types of single and integrated indices as mentioned previously. The subsoil concentrations of the samples were used as background or reference values for the soil samples to give a comparative idea about the quality and degree of heavy metal contamination for the surrounding soils of the scrap metal recycling companies.

Table 6 presents values of the Geoaccumulation Index (Igeo) for Fe, Co, Cr, Mn, Ni, and V in surrounding soil of the scrap companies. Igeo was initially described as a simple index by [40] for metal concentrations in the size of the 2-micron portion.

Results of geo-accumulation index (Igeo) revealed that 94 values out of 108 values (87% of the sampling sites) had values less than zero (negative values); indicating that those sampling sites are still not polluted in regarded to the studied metals because they fell in zero class or zero categories (Class 0 = $I_{geo} \leq 0$ is practically uncontaminated) according to [41]. However, for the sampling sites of D8/W500 m and D6/ W 100 m around the Super scrap recycling company; the estimated index of geo-accumulation fell in class one (Class 1 = $0 < I_{geo} < 1$ (uncontaminated to moderately contaminate) which characterized by uncontaminated to moderately contaminated for all the investigated metals except Ni by the sampling site D6/100 [41].

Similar status of uncontaminated to moderately contaminate was also occurred by the sampling sites of D4/S700 m and C9/E control/700m in respect of only one or two metals.

Table 6: Values of the simple index Geo-accumulation (Igeo) for the investigated heavy metals in soils surrounding of the scrap metal recycling companies.

Sulaimani Steel Scrap Recycling Company							
<i>Site Numbers</i>	<i>Directions & Distances (m)</i>	<i>Fe</i>	<i>Co</i>	<i>Cr</i>	<i>Mn</i>	<i>Ni</i>	<i>V</i>
C1	N 50	-0.50	-0.62	-0.57	-0.48	-0.48	-0.51
C2	N 117	-0.50	-0.55	-0.18	-0.58	-0.52	-0.58
C3	N 250	-0.49	-0.57	-0.48	-0.59	-0.47	-0.67
C4	300 NW to Sul. Steel and 250 NE to Super Steel	-0.63	-0.63	-0.57	-0.70	-0.50	-0.71
C5	E 50	-0.56	-0.63	-0.59	-0.59	-0.26	-0.70
C6	E 110	-0.36	-0.46	-0.47	-0.32	-0.73	-0.38
C7	E 250	-0.92	-0.53	-0.51	-1.10	-0.31	-0.97
C8	E 500	-0.23	-0.34	-0.35	-0.14	-0.30	-0.39
C9	E Control 700	-0.13	-0.08	-0.07	0.23	-0.12	0.05
Super Steel Scrap Recycling Company							
D1	S 75	-0.31	-0.58	-0.47	-0.49	-0.57	-0.60
D2	S 125	-0.39	-0.45	-0.53	-0.30	-0.55	-0.50
D3	S 250	-0.43	-0.49	-0.54	-0.28	-0.54	-0.48
D4	S 700	0.08	-0.28	-0.12	-0.33	-0.23	-0.43
D5	W 50	-0.52	-0.62	-0.63	-0.43	-0.63	-0.55
D6	W 100	0.64	0.05	0.13	0.74	-0.03	0.60
D7	W 250	-0.43	-0.55	-0.45	-0.37	-0.56	-0.49
D8	W 500	0.75	0.45	0.64	0.90	0.53	0.71
D9	W Control 1000	-0.51	-0.55	-0.47	-0.62	-0.77	-0.58

Note: 1- where C stand for Sulaimani steel and; D for Super steel; 2- the missing directions or sites by each company can be attributed to the presence of construction, hindrances or any other stumbling block.

Based on the previous results of geo-accumulation index which was calculated on a logarithmic model, we conclude that although the concentrations of all the investigated metals were relatively increased by most of the surface soil samples (D1) around the scrap recycling companies, the surface accumulation rate of the investigated heavy metals has not yet reached the level that causes contamination by the studied sampling sites. This could be ascribed to many reasons such as; applying of a simple index and its weak points which have been mentioned by geo-accumulation index, Igeo as a simple index cannot covers the effects of the whole studied metal in composed form, short working period and production of the companies because it was not long since they were founded or established, incompatibility of the distances range to let sufficient deposition of the emitted pollutants on the surface soil, effectiveness of the emission and pollution control system, etc.

Based on the results of contamination factors (CF) that basically depend on the concentration of each metal in the soil [42]; pollution load indices (PLI) was calculated as an integrated comparative index for assessing the status of soil heavy metal pollution around the scrap metal recycling companies in regard to the investigated metals.

As it can be seen in Table (7), results of pollution load indices which reflect the comprehensive status of heavy metal pollution were varied between 0.91 to 2.37, but most of the PLI values had a slight increase over number one(>1), hence soils were slightly polluted at most of the sampling sites as a result of the industrial activity of the recycling companies according to [43].

Table 7: Values of contamination factors and Pollution Load Index (PLI) for the investigated heavy metals in soils surrounding of the scrap metal recycling companies.

Sulaimani Steel Scrap Recycling Company									
Sites Number	Directions & Distances (m)	Values of contamination factors						Multiplying of Contamination factors (CF)	Pollution Load Index (PLI)
		Fe d1/d2	Co d1/d2	Cr d1/d2	Mn d1/d2	Ni d1/d2	V d1/d2		
C1	N 50	1.06	0.97	1.01	1.08	1.07	1.06	1.27	1.04
C2	N 117	1.06	1.02	1.32	1.00	1.04	1.00	1.48	1.07
C3	N 250	1.06	1.01	1.08	1.00	1.08	0.94	1.17	1.03
C4	300 NW to Sul. Steel and 250 NE to Super Steel	0.97	0.97	1.01	0.92	1.06	0.91	0.84	0.97
C5	E 50	1.02	0.97	0.99	1.00	1.25	0.92	1.13	1.02
C6	E 110	1.17	1.09	1.08	1.21	0.91	1.15	1.74	1.10
C7	E 250	0.79	1.04	1.06	0.70	1.21	0.76	0.56	0.91
C8	E 500	1.28	1.18	1.17	1.36	1.22	1.15	3.37	1.22
C9	E Control 700	1.37	1.42	1.43	1.75	1.38	1.56	10.48	1.48
Super Steel Scrap Recycling Company									
D1	S 75	1.21	1.00	1.09	1.07	1.01	0.99	1.41	1.06
D2	S 125	1.15	1.09	1.04	1.22	1.03	1.06	1.74	1.10
D3	S 250	1.11	1.07	1.03	1.23	1.03	1.07	1.66	1.09
D4	S 700	1.58	1.23	1.38	1.19	1.28	1.11	4.53	1.29
D5	W 50	1.05	0.98	0.97	1.11	0.97	1.02	1.10	1.02
D6	W 100	2.33	1.55	1.65	2.50	1.47	2.28	49.93	1.92
D7	W 250	1.11	1.02	1.09	1.16	1.02	1.07	1.56	1.08
D8	W 500	2.52	2.05	2.34	2.79	2.16	2.46	179.21	2.37
D9	W Control 1000	1.05	1.02	1.08	0.98	0.88	1.00	0.99	1.00

Note:1- where C stand for Sulaimani steel and; D for Super steel; 2- the missing directions or sites by each company can be attributed to the presence of construction, hindrances or any other stumbling block.

The sampling sites of C4/300 NW by Sulaimani Steel and the combined site of (250 NE by Super Steel and C7/ E 250) were considered practically as unpolluted soil even though the PLI values of them were a little bit less than one. Because, as far as values of PLI is less than one or equal to one (≤ 1); this designates that the heavy metal loads are close to the background level. But, in the case where the value of PLI index is more than one, the quality of the soil is regarded to be one of the polluted soils by heavy metals.

Besides, the author [31] has found PLI values higher than three regarding assessing of soil heavy metal pollution around Erbil Steel scrap recycling company. Accordingly, the surrounding soil to Erbil Steel scrap recycling company was severely polluted as compared to the soils in our study.

Apart from the previous indices, we introduced and calculated Nemerow Pollution Index ($PI_{Nemerow}$) to assess the overall levels of soil pollution and its quality about the investigated heavy metals [24, 25 and 26]. As referred by [44], Nemerow Pollution Index is the most comprehensive and common method for evaluating the heavy metal pollution, because it is not only reflecting the impacts of the single factor index Pi

alone, but it emphasizes the effect of high concentration level of heavy metals on environmental quality and removes the deficiency of the average value on evaluation grade.

In general, The assessment results which were attained from Nemerow Pollution Index ($PI_{Nemerow}$) ranged between 1.06 to 2.6 (Table 8); and this rang matches a rank or class of soils pollution level that extends from warning limit (precaution domain) to slightly polluted domain. Nevertheless, sixteen (16) sampling sites out of eighteen (88.9%) were categorized by warning limit (precaution domain), but the two rest sampling sites of (D6/W100 and D8/W500 were categorized as a slightly polluted domain [32 and 33].

Based on our findings from the assessing methods of soil heavy metal pollution around the scrap metal recycling companies, it has been detected that soil heavy metal pollution has started to appear with regard to the investigated heavy metals in consequence of the industrial activity of the companies, and this will negatively impact on the region particularly from the nonessential metals which they are toxic to humans, plants, and animals at slight concentrations. Therefore, it is quite clear that anthropogenic activities have a significant contribution to increasing concentrations of heavy metal released into the environment [45].

Table 8: Values of contamination factors and Nemerow Pollution Index ($PI_{Nemerow}$) for the investigated heavy metals in soils surrounding of the scrap metal recycling companies.

<i>Sulaimani Steel Scrap Recycling Company</i>									
<i>Site Numbers</i>	<i>Directions & Distances (m)</i>	<i>Values of contamination factors</i>						<i>Sum of contamination factors</i>	<i>PI_{Nemerow}</i>
		<i>Fe d1/d2</i>	<i>Co d1/d2</i>	<i>Cr d1/d2</i>	<i>Mn d1/d2</i>	<i>Ni d1/d2</i>	<i>V d1/d2</i>		
<i>C1</i>	<i>N 50</i>	<i>1.06</i>	<i>0.97</i>	<i>1.01</i>	<i>1.08</i>	<i>1.07</i>	<i>1.06</i>	<i>6.25</i>	<i>1.06</i>
<i>C2</i>	<i>N 117</i>	<i>1.06</i>	<i>1.02</i>	<i>1.32</i>	<i>1.00</i>	<i>1.04</i>	<i>1.00</i>	<i>6.44</i>	<i>1.20</i>
<i>C3</i>	<i>N 250</i>	<i>1.06</i>	<i>1.01</i>	<i>1.08</i>	<i>1.00</i>	<i>1.08</i>	<i>0.94</i>	<i>6.17</i>	<i>1.05</i>
<i>C4</i>	<i>300 NW to Sul. Steel and 250 NE to Super Steel</i>	<i>0.97</i>	<i>0.97</i>	<i>1.01</i>	<i>0.92</i>	<i>1.06</i>	<i>0.91</i>	<i>5.84</i>	<i>1.02</i>
<i>C5</i>	<i>E 50</i>	<i>1.02</i>	<i>0.97</i>	<i>0.99</i>	<i>1.00</i>	<i>1.25</i>	<i>0.92</i>	<i>6.15</i>	<i>1.14</i>
<i>C6</i>	<i>E 110</i>	<i>1.17</i>	<i>1.09</i>	<i>1.08</i>	<i>1.21</i>	<i>0.91</i>	<i>1.15</i>	<i>6.61</i>	<i>1.16</i>
<i>C7</i>	<i>E 250</i>	<i>0.79</i>	<i>1.04</i>	<i>1.06</i>	<i>0.70</i>	<i>1.21</i>	<i>0.76</i>	<i>5.56</i>	<i>1.08</i>
<i>C8</i>	<i>E 500</i>	<i>1.28</i>	<i>1.18</i>	<i>1.17</i>	<i>1.36</i>	<i>1.22</i>	<i>1.15</i>	<i>7.36</i>	<i>1.30</i>
<i>C9</i>	<i>E Control 700</i>	<i>1.37</i>	<i>1.42</i>	<i>1.43</i>	<i>1.75</i>	<i>1.38</i>	<i>1.56</i>	<i>8.91</i>	<i>1.62</i>
<i>Super Steel Scrap Recycling Company</i>									
<i>D1</i>	<i>S 75</i>	<i>1.21</i>	<i>1.00</i>	<i>1.09</i>	<i>1.07</i>	<i>1.01</i>	<i>0.99</i>	<i>6.37</i>	<i>1.14</i>
<i>D2</i>	<i>S 125</i>	<i>1.15</i>	<i>1.09</i>	<i>1.04</i>	<i>1.22</i>	<i>1.03</i>	<i>1.06</i>	<i>6.59</i>	<i>1.16</i>
<i>D3</i>	<i>S 250</i>	<i>1.11</i>	<i>1.07</i>	<i>1.03</i>	<i>1.23</i>	<i>1.03</i>	<i>1.07</i>	<i>6.54</i>	<i>1.16</i>
<i>D4</i>	<i>S 700</i>	<i>1.58</i>	<i>1.23</i>	<i>1.38</i>	<i>1.19</i>	<i>1.28</i>	<i>1.11</i>	<i>7.77</i>	<i>1.44</i>
<i>D5</i>	<i>W 50</i>	<i>1.05</i>	<i>0.98</i>	<i>0.97</i>	<i>1.11</i>	<i>0.97</i>	<i>1.02</i>	<i>6.1</i>	<i>1.06</i>
<i>D6</i>	<i>W 100</i>	<i>2.33</i>	<i>1.55</i>	<i>1.65</i>	<i>2.50</i>	<i>1.47</i>	<i>2.28</i>	<i>11.78</i>	<i>2.25</i>
<i>D7</i>	<i>W 250</i>	<i>1.11</i>	<i>1.02</i>	<i>1.09</i>	<i>1.16</i>	<i>1.02</i>	<i>1.07</i>	<i>6.47</i>	<i>1.12</i>
<i>D8</i>	<i>W 500</i>	<i>2.52</i>	<i>2.05</i>	<i>2.34</i>	<i>2.79</i>	<i>2.16</i>	<i>2.46</i>	<i>14.32</i>	<i>2.60</i>
<i>D9</i>	<i>W Control 1000</i>	<i>1.05</i>	<i>1.02</i>	<i>1.08</i>	<i>0.98</i>	<i>0.88</i>	<i>1.00</i>	<i>6.01</i>	<i>1.04</i>

Note:1- where C stand for Sulaimani steel and; D for Super steel; 2- the missing directions or sites by each company can be attributed to the presence of construction, hindrances or any other stumbling block.

CONCLUSIONS

In this study, we concluded that among the investigated physicochemical properties clay and sand particles, as well as calcium carbonate contents, play a vital role in the mobility and availability of the examined heavy metals in the soil, and also for plant uptake because the investigated metals correlated significantly (at $p \leq 0.05$) with them. In regards to the studied six heavy metals, it has been concluded that Fe and Mn were the most abundant heavy metals at the studied sites as compared with the other investigated metals. Based on the indices values, we concluded that the studied sites were characterized by a relative gain of heavy metals in surface soils (D1). However, Geoaccumulation index (I_{geo}) because of its mentioned weak points has not yet shown pollution for the sampling sites as a whole.

Additionally, results of pollution load (PLI) and Nemerow pollution indices (PINemerow) were generally confirmed that heavy metal pollution was occurred for the studied soils due to the industrial activities of the established companies. Happening of heavy metal pollution will cause negative impacts whenever the metal levels exceed the established limit for protecting the environment and human health.

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REFERENCES

- [1] Martchek, K.J. *"The Importance of Recycling to the Environmental Profile of Metal Products"*.<https://onlinelibrary.wiley.com/doi/abs/10.1002/9781118788073.ch2>. (2000).
- [2] Olatunji, A.S., Kolawole, T.O., Oloruntola, M., and Günter, C. *"Evaluation of Pollution of Soils and Particulate Matter Around Metal Recycling Factories in Southwestern Nigeria"*. J Health Pollution Vol. 17, pp. 20–30. (2018).
- [3] Lehmann, J. and Joseph, S. eds. *"Biochar for environmental management: science, technology and implementation"*. Routledge. Abingdon, Oxon OX14 4RN and New York, NY 10017. (2015).
- [4] Kowalska, J., Mazurek, R., Michal, G., and Zaleski, T. *"Pollution indices as useful tools for the comprehensive evaluation of the degree of soil contamination—A review"*. Environmental Geochemistry and Health. Vol. 40, Issue 6, pp. 2395–2420. (2018).
- [5] Olaniran, A.O., Balgobind, A. and Pillay, B. *"Bioavailability of heavy metals in soil: impact on microbial biodegradation of organic compounds and possible improvement strategies"*. International journal of molecular sciences, Vol. 14, No. 5, pp. 10197-10228. (2013).
- [6] Ali, H., Khan, E. and Sajad, M.A. *"Phytoremediation of heavy metals-concepts and applications"*. Chemosphere, Vol. 91, No. 7, pp.869-881. (2013).
- [7] Sharifuzzaman, S.M., Rahman, H., Ashekuzzaman, S.M., Islam, M.M., Chowdhury, S.R., and Hossain, M.S. *"Chapter 2 Heavy Metals Accumulation in Coastal Sediments"*. DOI: 10.1007/978-4-431-55759-3_2. Springer Japan. <https://www.researchgate.net/publication/301246679>. (2016).
- [8] Salih, Z., and Aziz, F. *"Heavy Metals Accumulation in Leaves of Five Plant Species as a Bioindicator of Steel Factory Pollution and their Effects on Pigment Content"*. Pol. J. Environ. Stud. Vol. 28, No. 6, 4351-4358. DOI: 10.15244/pjoes/99304. (2019).
- [9] Weissmannova, H.D., and Pavlovsky, J. *"Indices of soil contamination by heavy metals – methodology of calculation for pollution assessment (minireview)"*. Environ Monit Assess Vol. 189, pp. 616. <https://doi.org/10.1007/s10661-017-6340-5>. (2017).
- [10] Caeiro, S., Costa, M.H., Ramos, T.B. *"Assessing Heavy Metal Contamination in Sado Estuary Sediment: An Index Analysis Approach"*. Ecological Indicators, Vol. 5, pp. 151–169. (2005).
- [11] Brady, J. P., Ayoko, G.A., Martens, W. N., and Goonetilleke, A. *"Temporal trends and bioavailability assessment of heavy metals in the sediments of Deception Bay, Queensland, Australia"*. Marine Pollution Bulletin, Vol. 89, No. 1, pp. 464–472. (2014).
- [12] Pan, L., Ma, J., Wang, X., and Hou, H. *"Heavy metals in soils from a typical county in Shanxi Province, China: levels, sources and spatial distribution"*. Chemosphere, Vol. 148(Supplement C), pp. 248–254. <https://doi.org/10.1016/j.chemosphere.2015.12.049>. (2016).
- [13] Sissakian, V. *"Neotectonic movement in Darbandi Bazian area, southwest of Sulaimaniyah City, NE Iraq"*. Iraqi Bull. of Geol. and Mining. Vol. 6, No. 2, pp. 57- 69. (2010).
- [14] Gupta, P.K. *Soil, plant, water and fertilizer analysis*. Fourth Edition. Agrobios, India. (2004).

- [15] Estefan, G., Sommer, R., and Ryan, J. "*Methods of Soil, Plant, and Water Analysis: A manual for the West*". Asia and North Africa region ICARDA (International Center for Agricultural Research in the Dry Areas). Third Edition. (2013).
- [16] Black, C.A., Evans, D.D., White, J.L., Ensminger, L.E., Clark, F.E., and Dinauer, R.C. "*Methods of Soil analysis. Part 1 & Part 2. Chemical and Microbiological Properties*". American Society of Agronomy, Publisher Madison, Wisconsin, USA. (1965).
- [17] ISO (International Organization for Standardization). "*Soil quality extraction of trace elements soluble in aqua regia*", ISO 11466:1995(E). ISO, Geneva. Cited from Pueyo, M., Sastre, J., Hernandez, E., Vidal, M., Lopez-Sanchez, J. F., and Rauret, G. "*Prediction of Trace Element Mobility in Contaminated Soils by Sequential Extraction*". J. Environmental Quality Vol. 32, pp. 2054-2066. (2003).
- [18] Reimann, C., and Garret, R. G. "Geochemical background: Concept and reality". Science of the Total Environment. Vol. 350, pp. 12-27. (2005).
- [19] Forstner, U., Ahlf, W., and Calmano, W. "*Sediment quality objectives and criteria development in Germany*" Water Sci. Technol., No. 28, pp. 307. (1993). **Cited in;** Gupta, S., Jena, V., Matic, N., Kapralova, V., and Solanki, J.S. "*Assessment of geo-accumulation index of heavy metal and source of contamination by multivariate factor analysis*". International Journal of Hazardous Materials; Vol. 2, No. 2, pp. 18-22. (2014).
- [20] Tomlinson, D.L.; Wilson, J.G.; Harris, C.R.; Jeffrey, D.W. "*Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index*". Helgoländer Meeresuntersuchungen, Vol. 33, pp. 566-575. (1980).
- [21] Hakanson, L. "*An ecological risk index for aquatic pollution control: A sediment ecological approach*". Water Res. Vol. 14, pp. 975-1001. (1980).
- [22] Chakravarty, I. M., and Patgiri, A. D. "Metal Pollution Assessment in Sediments of the Dikrong River", N.E. India. J Hum Ecol, Vol. 27, No. 1, pp. 63-67. (2009).
- [23] Mohamed, T.A., Mohamed, M.A-K., Rabeiy, R., and Ghandour, M.A. "*Application of pollution indices for evaluation of heavy metals in soil close to phosphate fertilizer plant, Assiut, Egypt*" Assiut University Bulletin for Environmental Researches Vol. 17 No. 1. (2014).
- [24] Kowalska, J., Mazurek, R., Gasiorek, M., Setlak, M., Zaleski, T., and Waroszewski, J. "*Soil pollution indices conditioned by medieval metallurgical activity: A case study from Krakow (Poland)*". Environmental Pollution, Vol. 218, pp. 1023-1036. (2016).
- [25] Guan, Y., Shao, Ch, Ju, M., "*Heavy metal contamination assessment and partition for industrial and mining gathering areas*". Int. J. Environ. Res. Public Health 11, 7286e7303. (2014).
- [26] Cheng, J. L., Shi, Z., and Zhu, Y.W. "*Assessment and Mapping of Environmental Quality in Agricultural Soils of Zhejiang Province, China*". Journal of Environmental Sciences, Vol. 19, pp. 50-54. (2007).
- [27] Zhong, L., Liu, L., and Yang, J. "*Assessment of heavy metals contamination of paddy soil in Xiangyin county, China*" 2010 19th World Congress of Soil Science, Soil Solutions for a Changing World 17 1 - 6 August 2010, Brisbane, Australia. Published on DVD (2010).
- [28] Hooda, P.S. "*Trace Elements in Soils*". A John Wiley and Sons, Ltd., Publication. United Kingdom. (2010).
- [29] Chibuzor, O.J., Nwakonobi, T.U., and Itodo, I.N. "*Influence of Physicochemical Characteristics of Soils on Heavy Metal Contamination in Makurdi, Benue State*". IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT) e-ISSN: 2319-2402, p- ISSN: 2319-2399. Vol. 11, Issue 5 Ver. II, pp. 84-92. (2017).
- [30] Majid, S.N., and Kassim, J.K. "*Mineralogical and Chemical Characterization of Settleable Dustfall in Sulaimani City, Kurdistan Region, Iraq*" Soil Science. Vol. 183, No. 2. (2018).
- [31] Ahmed I.T., and Muna M. Abd-Alhameed, M.M. "*Spatial Distribution of Heavy Metals in Surface Soil Horizons Surrounding Erbil Steel Company (ESC) Areas*". ZJPAS. Vol. 31, No. 3, pp. 32-38. DOI: <http://dx.doi.org/10.21271/ZJPAS.31.3.5>. (2019).

- [32] Khudhur, N.S., Khudhur, S.M. , and Ahmad, I.N. "An Assessment of Heavy Metal Soil Contamination in a Steel Factory and the Surrounding Area in Erbil City". Jordan Journal of Earth and Environmental Sciences. Vol. 9, No. 1, pp. 1-11. (2018).
- [33] Khudhur, N. S., Khudhur, S.M., and Hama-Ameen, N.O. "A Study on Soil Bacterial Population in Steel Company and Some Related Area in Erbil City in Relation to Heavy Metal Pollution". journal of Salahaddin University-Erbil ZJPAS, Vol. 28, No. 5, pp. 101-116. (2016).
- [34] Chen, H., Teng, Y., Lu, S., Wang, Y., and Wang, J. "Contamination features and health risk of soil heavy metals in China". Science of the Total Environment, Vol. 512–513, pp. 143–153. (2015).
- [35] Solek-Podwika, K., Ciarkowska, K., and Kaleta, D. "Assessment of the risk of pollution by sulfur compounds and heavy metals in soils located in the proximity of a disused for 20 years sulfur mine (SE Poland)". Journal of Environmental Management, Vol. 180, pp. 450–458. (2016).
- [36] Dawaki, U.M., Dikko, A.U. Noma, S.S., and Aliyu, U. "Heavy Metals and Physicochemical Properties of Soils in Kano Urban Agricultural Lands". Nigerian Journal of Basic and Applied Science, Vol. 21, No. 3, pp. 239-246. (2013).
- [37] Chauhan, G., and Chauhan, U. K. "Human health risk assessment of heavy metals via dietary intake of vegetables grown in wastewater irrigated area of Rewa, India," International Journal of Scientific Research and Publications, Vol. 4, No. 9, pp. 1–9. (2014).
- [38] Vodyanitskii, Yu. N. "Standards for the contents of heavy metals in soils of some states". Annals of agrarian science pp. 14257-14263. (2016).
- [39] Crommentuijn, T., Polder, M.D., Van de Plassche, E.J. "Maximum Permissible Concentrations and Negligible Concentrations for Metals, Taking Background Concentrations into Account" (RIVM Report 601501001), Bilthoven, Netherlands, (1997).
- [40] Müller G. "Schwermetalle in den sedimenten des RheinseVeränderungenseit 1971". Umschau Vol. 79, pp. 778-783. (1979).
- [41] Simeon, E.O. and Friday, K. "Index models assessment of heavy metal pollution in soils within selected abattoirs in Port Harcourt, Rivers State, Nigeria". Singapore Journal of Scientific Research, Vol. 7, pp. 9-15. (2017).
- [42] Liu, W.H., Zhao, J.Z., Ouyang, Z.Y., et al., "Impacts of Sewage Irrigation on Heavy Metal Distribution and Contamination in Beijing, China". Environment International, Vol. 31, pp. 805–812. (2005).
- [43] Cabrera, F., Clemente, L., Barrientos, D.E., et al.,. "Heavy Metal Pollution of Soils Affected by the Guadamar Toxic Flood". The Science of the Total Environment, Vol. 242, No. 1–3, pp. 117–129. (1999).
- [44] Liu, Y., Yu, H., Sun, Y., Chen, J. "Novel assessment method of heavy metal pollution in surface water: A case study of Yangping River in Lingbao City, China". Environ. Eng. Res. Vol. 22, No. 1, pp. 31-39. (2017).
- [45] Selvi, A., Rajasekar, A., Theerthagiri, J., Ananthaselvam, A., Sathishkumar, K., Madhavan, J. and Rahman, P.K.S.M. "Integrated Remediation Processes Toward Heavy Metal Removal/Recovery From Various Environments-A Review". Frontiers in Environmental Science; Vol. 7, Article 66. (2019).