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Research Article: Evaluating Soil Contamination Risks Using a Novel Combined Pollution Quality Index (CPQI) in Sulaymaniyah, Iraq

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Abstract

Soil is a great reservoir of nutrients and pollutants, and as such plays an important role in health and socio-ecological sustainability. Contaminants from agriculture, urbanization and industrial activities enter the soil which increases soil pollution and impose a big risk on human health. Soil samples from two different locations (Kostay Cham and Kani Goma) in Sulaymaniyah city were examined. The areas are two agricultural farms irrigated by water from stream and by wastewater respectively. Six different points were selected at two study areas at surface and at 60 cm depth for each point. While two water samples were collected at each site (pH, electric conductivity EC, DO, BOD_5, TDS, TSS, salinity, turbidity, total alkalinity and hardness, with heavy metals Pb, Cd, Cu, Ni, Fe, and Zn) in Qilyasan stream water and wastewater determined. This study introduces a novel Combined Pollution Quality Index (CPQI) that integrates six weighted Indices- Nutrient Index, Salinity Index, Organic Matter Index, Sodium Adsorption Ratio (SAR) Index, Heavy Metal Risk Index, and Pollution Quality Index (PQI). Analytic Hierarchy Process (AHP) used to find weight values for each index. Chemical, physical and biological tests were carried for all soil samples such as; heavy metals, organic matter, nutrients, PH, TDS, EC. The results showed that the heavy metal concentration in all samples (surface and 60 cm depth) are within the allowable range. Generally higher levels of most heavy metals observed at 60 cm depth compared to surface samples. CPQI (combined pollution quality index) derived from all indices together to realize pollution index for each location, consequently all the CPQI values founded are below 1**,** meaning they fall under "Low Pollution" for all selected sites condition according to the limitations values, the highest value taken by the first location 60 cm deep result about 0.49 and lowest value 0.34 for the first location surface sample. this result is due to the high probability of absorption by plant roots and vegetables.

1. Introduction

Water security is one of the current issues that requires attention due to the growing demand for water. Farmers face challenges when it comes to groundwater availability, they now resort to irrigating crops with wastewater. Different human activities such as traffic, agriculture, domestic undertakings, mining, and even industrial processes like steel and iron, chemical, and the smelting industries, contribute to increasing the concentration of metals in the environment (Nath, et al., 2005); (Dheri, et al., 2007). Similarly, Industrial activities and processes pose danger as it emits a plethora of contaminants such as heavy metals and metalloids. Residents in areas where long-term wastewater irrigation is practiced suffer the most as they are exposed to food contaminated with high levels of heavy metals, (Ukom, et al., 2019); (Gupta, et al., 2019). Because of the pollutants and contaminating, soil nurture plays a vital part in overall health and socio-ecological stability. Misguided agricultural practices continue to contribute to soil being heavily contaminated with sewage and civilization waste, which is composed predominantly of metals from urban and industrial soils. The detrimental impact of accumulating metals in soil from industrialized agricultural activities on human health is undeniably grave. Irrigating land with wastewater for extended periods of time tends to raise the concentration of heavy metals in soil (Abbasi, et al., 2023). Overall, irrigation with wastewater enriches the soil with the following macro and micronutrients (Ganjegunte, et al., 2018), nitrogen (N), phosphorus (P), potassium (K), zinc (Zn), iron (Fe), manganese (Mn), and copper (Cu) due to its composition. Organic matter in wastewater is reported to be high and wastewater could serve as an organic matter sustainable supply (Ofori, et al., 2021). Among all compartments of the environment, soils are subject to the heaviest accumulation of some metals (Mazurek, et al., 2017). The amount of heavy metals deposited in the soils is controlled predominantly by the clay content, physical and chemical properties of the soil, and the structure of the soils (Kabata-Pendias, 2011). The presence of oxygen in soils permits heavy metals mobility; however, different distributions of heavy metals in a soil profile are possible (Akan, et al., 2013). Besides, human activity, when compared to natural processes, is more responsible for the primary accumulation of metals in soils. Domestic wastes, traffic emissions, and industrial and agricultural activities are some of the most important sources of anthropogenic inputs (Jia, et al., 2018); (Kumar V, et al., 2019).

(Alnaimy, et al., 2021) commented that the amounts of heavy metals in soils, as well as in fresh water irrigated fields and long-term wastewater irrigated soils, had significant differences. In a throw deep dug well south of Buran (Al-Jaboobi, et al., 2014) found that P, K, S as well as Zn, Cu, Fe, Mn, and Ni concentrations are quite significant compared to the values, phosphate shallow wells containing cadmium, while other elements like copper, manganese, nickel, chromium, iron, and lead are in relative higher concentration. This result presented in. (Latosinska, et al., 2021) for heavy metals concentration within municipal waste SS (sewage sludge) and suggests these materials can contain significant quantities of some metals that should be handled with caution. Among the many contaminants, SS is known for them having concentration of zinc higher than the allowable limit. (Su, et al., 2014) said that anthropologies industrial waste is a source of toxic polluting metals of arsenic, and lead along with cadmium contaminants from cadavers which are hazardous to soils and primary reason of increasing their concentrations obtained from the environments by human activities. (Baltas, et al., 2020); (Eziz, et al., 2018) documented evidence in which heavy metals adhere to the food chain through vegetation and present prospective dangers to the greater ecosystem including human beings. Even so, increases in salinity levels are pollution in soil and has emerged as a challenging problem and an essential constraint in the cultivation of crops worldwide (Wahid, et al., 2007). Similarly, an important contributor to soil pollution is the extensive employment of agricultural pesticides. Pesticides contain high concentration of chemical toxic substances that lead to loss of soil and induce drought conditions. Some are laced with arsenic which leads to the pollution of agricultural crops. The use of chemical pesticides in excess amounts results in crops absorbing and later storing these pesticides in their tissues, roots, and leaves, thereby poisoning other animals and humans that ingest them directly (Suaad, 2021). The aim of the study is to analyze soil pollution from two different locations in Sulaymaniyah city , northern of Iraq, in terms of the content of heavy metal accumulation in soil by calculating a number of pollution indices; Igeo accumulation index (Igeo), the potential environmental risk index (PERI), the risk assessment (RI), pollution quality index (PQI), nutrient pollution index (NPI), salinity index (SI), sodium adsorption ratio (SAR), the organic matter index (O.M.I). In addition, Combined pollution quality index (CPQI) is found to assess the overall pollution level of the soil. Finding CPQI considered as a novel work as it combines six indices using AHP for finding the weights of each index.

2.Material and Method

2.1 Study Area

The study conducted in Sulaymaniyah city, Kurdistan Region, Northern of Iraq and Southern of Kurdistan, Sulaymaniyah center is approximately 830 meters above sea level (Zakaria, et al., 2013). Sulaymaniyah province covers an area of more than 12 $*10^8$ m^2 in Iraq Kurdistan (Altemimi, et al., 2023).The population of Sulaymaniyah city estimated as 847,000 people (Population Stat, 2025). The climate is characterized by rainy winter with significant amount of snow and cooler summer. Two agricultural locations were selected in the city. The first location is close to Kostay Cham area near Darwaza City, with coordination of 35° 33' 10" N, and 45° 22' 18" E and approximate area of 1,500 m^2. The second location is in Kani Goma with coordinates of 35° 31' 45.5" N and 45° 23' 00.6" E and an area equal to 8000 m^2. Fig 1 (A-B) and Fig 2 (A-B) shows the two locations of the study area and sampling points. From each site three different points were selected for taking samples at two different depths. One from the surface and the second from 60 cm depth.

2.2 Sampling

2.2.1 Water Sampling

Water sample collection and wastewater treatment is an integral procedure towards evaluation of water quality, safeguard of the environment, and public health institutions. Accurate techniques of sampling, like grab sampling which allows instantaneous analysis, are utilized for rigorous and valid results. Such analyses identify and quantify heavy metal, nutrient pollution, and other forms of pollution. Two water samples were taken from different sources in the study area. Source 1 represented Qilyasan stream water which used for irrigating first location which was pomegranate small farm and source 2 represented wastewater to irrigate turnip area. The water samples were collected using grab sampling method, in polyethylene bottles at two different agricultural sites, kept cool by preserving in ice, and transferred to the laboratory. Two water samples were collected at each site on the same date. pH and electric conductivity EC, DO, BOD_5, TDS, TSS, salinity, turbidity, Total alkalinity and hardness, with heavy metals (Pb, Cd, Cu, Ni, Fe, and Zn) in Qilyasan stream water and wastewater samples were directly determined.

2.2.2 Soil Sampling

Soil sampling is a process used to obtain soil samples from specific locations and depths using random, grid, or systematic sampling . The collected soil is tested for chemical, physical, and biological properties contain of (heavy metals, TDS, nutrients, EC, organic matter, Ph) .From each location three different points selected at two depths (60 cm and surface). In conclusion twelve soil samples were extracted using auger.

2.3 Soil Pollution Indices: In order to assess the degree of contamination in the soil of the study area, a number of soil pollution indices were calculated. In this study 8 indices measured as in below:

A. Heavy Metal Indices

Heavy metals in elevated concentrations are typically found in soils located beneath or adjacent to landfills, as well as in agricultural areas irrigated with contaminated water. The toxicity and mobility of these metals in the soil are influenced not only by their total concentration but also by their particular chemical forms, bonding states, individual metal characteristics, environmental conditions, soil properties, and the presence of organic matter (Osu & Okoro J, 2011). To assess the risk of heavy metal contamination 4 pollution indices were found as in below:

(1) *The Geo-Accumulation Index (Igeo):* It is one of the methods that used for assessing how soil is polluted with heavy metals. It is widely used in many studies as an indication to estimate the severity of the contamination in the area. It is utilized to evaluate environmental risks for specific regions (Haris, et al., 2017) , (Kamani, et al., 2018). It is calculated according to Eq.(1), (Wedepohl, 1995).

$$I_{geo} = Log_2 \left(\frac{Cn}{1.5 \ x \ Bn}\right) \quad (1)$$

Where: Cn represents the heavy metal concentration value in the studied soil samples, and Bn represents the element's background value. The constant value of 1.5 as a correction factor is used for possible changes in the background data due to lithological differences (Barbieri, et al., 2015).Table (1) shows the (Igeo) classification values in the soil based on (Muller.G, 1969); (Salman, et al., 2019).

Table (1): Classifications *(Igeo) Index.*

Igeo Values	**Pollution Range**
Igeo ≤0	Unpolluted
0 < Igeo < 1	Unpolluted to moderately polluted
1 < Igeo < 2	Moderately pollution
2 < Igeo < 3	Moderately to highly pollution
3 < Igeo < 4	Highly polluted
4 < Igeo < 5	Highly to extremely polluted
Igeo ≥ 5	Extremely polluted

(2) *Contamination Factor (Cf) Index:* it is a simple and powerful indicator to reveal the degree of contamination in soil of every individual heavy metal. It is found by dividing the value of the heavy metal element concentration by the background value as in Eq. (2): Where: (Cn) is the concentration of the heavy metal in the soil, and (Bn) is the background value of the element (Mason, 1982)

$$Cf = \frac{Cn}{Bn} \quad (2)$$

The ranges of *Cf* are shown in Table (2) (Hakanson, 1980).

Table (2): The categories of contamination factors.

Pollution Range	***Cf* Value**
Low contamination	*Cf* < 1
Moderate contamination	1≤ *Cf* <3
Considerable contamination	3≤ *Cf* ≤6
Very high contamination	*Cf* >6

(3) Pollution Quality Index (PQI): it is the overall effect of the heavy metals together in soil. It is found by the square root of the products of *Cf* values of each heavy metal as shown in Eq.(3) (Abbas, 2024)

$$PQI=(Cf1 \times Cf2 \times Cfn\ldots)^{\frac{1}{n}} \quad (3)$$

Where n is the number of metals and *Cf* represents the contamination factor (Angulo, 1996) classified the pollution load index into three categories as shown in table (3)

Table (3): Classifications of pollution load index.

Pollution Range	*PQI* Value
No pollution	$PQI < 1$
Moderate Pollution	$PQI = 1$
Pollution	$PQI > 1$

(4) Potential Ecological Risk Index (RI): it measures the potential ecological risk that may produce by heavy metals. This index is proposed by (Hakanson, 1980) as shown in Eq.(4)

$$RI=\sum Er=\sum Tr\times\frac{Ci}{Cb} \qquad (4)$$

Where *Er* represents the Ecological Risk Index of heavy metal, Tr is the toxic-response feature for each given hazardous metal (*Cr = 2, Cd = 30, Zn = Mn =1, Ni = Pb = Cu = Co =5,* and *As =10*), (Hakanson, 1980) , (Wang, et al., 2018) . (Hakanson, 1980) classified Er to five categories and the RI for the four categories as shown in table (4).

Table (4): Classifications of the *RI* index.

Risk Index Category	*RI* Range
Ecological risk	$RI <150$
Moderate ecological risk	$150\leq RI <300$
Considerable ecological risk	$300\leq RI <600$
Very high ecological risk	$RI \geq 600$

B. Nutrient Pollution Index (NPI):

Soil is a major source of nutrients, the main nutrients are NO_3, PO_4, SO_4, K. This index is used to assess the potential impact nutrient pollution will have on soil health and the surrounding environment. NPI calculated Eq (5) :

$$NPI=\sum\left(\frac{Ci}{Bi}\right) \qquad (5)$$

Where *Ci* is the concentration of nutrients PO_4, NO_3, *K* and SO_4, and *Bi* is background value of nutrients mentioned in table (5) (EPA, 2012)

Table (5): Background value of nutrients.

Nutrient	NO_3	PO_4	SO_4	K
Value	5-10	5-10	10-20	100-200
Avg. Value	7.5	7.5	15	150

is generally calculated using the concentrations of nutrients in the soil and comparing them to established background levels or thresholds. Classification of nutrient pollution index is shown in table (6) (EPA, 2012)

C. Salinity Index (SI)

It is the amount of dissolved salt in soil. Saline soils have high salinity levels that impede water availability to plants, degrade soil structure, and are toxic as a result of specific ions (e.g., sodium [Na^+], chloride [Cl^-], etc.). Damage occurs when the concentration is high. The Salinity Index provides a quantification of the severity of the problem, and it is used as a basis to devise management practices to mitigate the problem. Defined in Eq. (6): (This equation has been created by the authors of the article to find salinity index at the most accurate way).

Table (6): Classification of nutrient pollution index

Pollution Range	*NPI value*
Low pollution	$NPI < 1$
Moderate pollution	$1\leq NPI <2$
High pollution	$2\leq NPI \leq 3$
Very high pollution	$NPI >3$

$$SI=\frac{Ci}{Bi} \qquad (6)$$

Where; *Ci* is concentration of *EC* and *Bi* is background value. Electrical conductivity of the soil saturation extract (EC) is the standard measure of salinity. (Staff, 1954) described values as below:

Table (7): Classification of *SI* based on *EC*.

Category	SI Range
No salinity	< 2
Low salinity	2 – 4
Medium salinity	4 – 8
High salinity	8 – 16
Very high salinity	> 16

D. Organic Mater Index (OMI)

Is a measurement used to estimate the amount of proportion of organic matter present in soil. organic matter in soils made up of plant and animal detritus, cells and tissues of soil microbes, and substances that microbes secrete. It is an essential component of soil health, affecting its physical & chemical properties, and confer regulatory ecosystem services. It is calculated as in Eq. (7):

$$OMI=\frac{O.M}{B_{OM}} \qquad (7)$$

Where: O.M. is organic matter concentration, and B_{OM} is the background value of organic matter. Table (8) shows *OMI* classification.

Table (8): Classification of Organic Matter Index.

Category	OMI Range
Very low	< 1
Low	1 - 2
Moderate	2 - 4
High organic	4 - 6
Very high	> 6

E. Sodium Adsorption Ratio Index (SAR)

It is a critical chemical index used to evaluate the Na^+ hazard in soil. It finds the relative concentration of sodium ions compared to calcium (Ca^{2+}) and magnesium (Mg^{2+}), which influence soil structure and permeability. SAR can be determined following formula shown in Eq.(8), (Suarez, et al., 2008). Table (9) shows the classification of SAR.

$$SAR = \frac{[Na^+]}{\sqrt{\frac{[Ca^+]+[Mg^+]}{2}}} \quad (8)$$

Table (9): classification of *SAR*.

Category	SAR
Low sodality	< 3
Moderate sodality	3 - 9
High sodality	≥ 13

F. Combined Pollution Quality Index (*CPQI*)

It is a comprehensive metric used to assess the overall pollution level of soil by integrating multiple contamination indicators into a single value. It examines soil health, assessing factors such as heavy metal concentrations, pesticide residues, organic matter content, and soil erosion as shown in Eq.(9)

$$CPQI = \sum_{i=1}^{6} (w_i \; x \, N_i) \quad (9)$$

Where:

w_i is weight of the pollution parameter

N_i is normalized value of the pollution parameter

Table (10): Classification of *CPQI*.

Category	CPQI
Low pollution	< 1
Moderate pollution	< 3
High pollution	< 6
Very high pollution	≥ 6

2.4 Analytical Hierarchy Process (AHP)

To find weight values of each index, AHP method used, which is a decision-making method used to rank alternatives they are considering based on pairwise comparisons which is developed by saaty in 1980. The weight and the effect of the parameters are placed based on expert, knowledge and research information. The weights of the six types of indices are measured (PQI, RI, NPI, SI, O.M.I, SAR). Table (11) represents the random index value

Table (11): Random Index Value.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

The scale of pairwise comparisons are from 1 to 9 (Table 12) based on the importance between scales. Table.16 shows the normalized pairwise comparison matrix of the six criteria. The consistency ratio (CR) is calculated as below (Saaty, 1980):

$$CI = \frac{\lambda max - n}{(n-1)} \quad (10)$$

$$CR = \frac{CI}{RI} \quad (11)$$

Where n is the number of the criteria

CI is consistency index

RI is random index value (Table 11) the RI value for n=6 is 1.24

λ max is largest Eigen value

Table 12. Scale for pairwise comparisons (Saaty, 1990).

Intensity of Importance	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extreme importance
9	Extreme importance

3.Result and Discussion

3.1 First and Second Site Comparison

As a result of first and second location of the study, regarding the results of water tests, Qilyasan water turns out to be cleaner and more favorable than wastewater that used to irrigate second location because most of the test parameters are passed the limitations. As for the test of soil from both locations, determined that all the heavy metals are within the limitations, but they differ while finding (Igeo, Cf, PQI, and RI). Regarding nutrients values second location surface samples has the highest value =0.874 compared to first location. For organic matter all OMI values in first location are < 0.25%, far below the threshold (<1%). No significant difference between surface and 60 cm (both avg. 0. 21%) while second location is higher than first location, surface (0.23%) and 60 cm (0. 24%), but still below the threshold.

3.2 Wastewater

3.2.2. Qilyasan Water Test

Qilyasan water test results, as shown in table.13 pH, TDS, EC, SO_4, Fe, pb, Co, DO, Turbidity, TSS, Salinity, Cd, Hardness are within safe limits. There is possible contamination by NO_3 that exceed the limit by the result of 31.3 mg/l and background value about

15 mg/l. There is significant risk of algal blooms of phosphate concentration which the result is about 4.1 mg/l and limitation 0.4 mg/l. About total alkalinity there is higher ion concentration 210.2 mg/l comparing to limitation 200 mg/l.

3.2.3 Wastewater Test

The result of sewage water tests in table 14 shows that, pH, TDS, Salinity, Sulphate are within the limits, Co, Ca are in borderline limits. Nitrate (63.3 mg/l vs. 15 mg/l background limit) severe pollution risk**,** Phosphate (23.5 mg/l vs. 0.4 mg/l background limit) is extreme eutrophication risk**,** Lead (0.09 mg/l vs. 0.05 mg/l) which is toxic to humans & wildlife. DO (2.5 mg/l vs. >5 mg/l) in low oxygen conditions. Turbidity (231.1 Ftu vs. 25 Ftu) & TSS (222.1 mg/l vs. 40 mg/l) consist heavy pollution.EC (883 µS/cm vs. 700 µS/cm), Hardness (553.4 mg/l vs. 300 mg/l) and alkalinity (355.6 mg/l vs. 200 mg/l) indicate high dissolved ions and minerals. Overall The water is highly polluted, with critical risks from nutrients (nitrate, phosphate), heavy metals (pd, Ca), and low oxygen as shown in table.2, these results regards to the contaminants in wastewater include The byproducts of various industrial processes, including those from the paper and pulp sectors as well as food and beverage production, generate significant amounts of dark brown wastewater. This wastewater is characterized by an unpleasant odor and a high pH level. (Pratap, et al., 2021)

3.3 Heavy Metals

The heavy metals considered of concern in the investigation are Fe, Pb, Cd, Zn and Cu, Mn, Cr and Ni. To assess the environmental pollution of the soil, the concentrations of above heavy metals were determined and compared to allowable limit of each heavy metal based on (EPA, 2012),(Cadmium (Cd) = 1 mg/Kg, Chromium (Cr) =250 mg/Kg, Copper (Cu) = 100 mg/Kg, Lead(Pb) = 80 mg/Kg, Manganese (Mn) = 3000 mg/Kg Nickle (Ni) =100 mg/Kg, Zinc (Zn) = 200 mg/Kg, Iron (Fe) = 50,000 mg/Kg). As shown in Fig. (3)- (A_1 to H_2), All samples (surface and 60 cm) have Fe concentrations well below the allowable limit. The highest Fe concentration is 745.59 mg/kg (D 60cm), which is significantly lower than the allowable limit so concern for Fe contamination. Zn, Cu, Mn, Cr, Ni, Cd from all the samples within the allowable range. Pb in all samples not detected which means Pb concentrations are below detectable levels. As a result of both locations, heavy metals may not be as high as it is predicted, the use of contaminated water for irrigation can lead to heavy metals entering the food chain (Wogu & Okaka, 2011) also long-term application of untreated wastewater results in the accumulation of heavy metals in soils in long period .That leads to not appear heavy metal contamination in large amount because of absorbing by plant root.

3.4 Soil Indices

3.4.1 Geo accumulation (Igeo)

The Geo-Accumulation Index results as shown in Fig (4) - (I_1 to N_2)**,** values of first location are ≤ 0 or very low**,** meaning no significant pollution is detected for any metal at any point. The most negative values which is Fe around -6 it is a very low contamination compared to the background values mentioned in table (1). All points of Fe at first location are highly negative which are ≤ -4.35**.** Zn ranges are between -3.60 to -2.33**,** Cu 4.37 to -2.38, Mn -4.68 to -4.17**,** Cd -5.79 to -0.93 all values ≤ 0, but Point A surface has the lowest contamination. Cr -6.06 to -1.69, Ni -2.81 to -0.25 and Pb is not detected. The area is clean and unpolluted with respect to the analyzed heavy metals. No significant anthropogenic contamination is detected. The extremely low Igeo values shows that the metal concentrations are either naturally low or below detectable limits. Regarding second location points, (D surface, D 60 cm, E surface, E 60 cm, F surface, F 60 cm), all metals at all points are unpolluted (Igeo ≤ 0). Regarding these results plant uptake could be one of the reasons why metals appear at very low concentrations in the soil. Plants can absorb metals from the soil through their roots, which may lead to lower detectable levels in soil samples. This depends on the type of plants (some are hyper accumulators, bioavailability of metals (pH, organic matter, soil texture affect absorption). Duration of plant growth (long-term cultivation may deplete metals). Also it may be naturally low background levels, leaching metals washed away by rain/irrigation, especially in sandy soils.

3.4.2 Contamination Factor (Cf)

CF values of lead (Pb) is not detected at points A, B and C in the first location (A surface, A 60 cm, B surface, B 60 cm, C surface, C 60 cm). For cadmium (Cd), contamination was moderate to considerable for most samples with particular reference to 60cm depth (Point A: 0.433, Point C: 0.786). For nickel (Ni), it was observed a moderate contamination for the most samples, but the highest value was recorded in Point A 60 cm (1.261). In general, chromium (Cr) was in the low contamination range, except Point C surface (0.462) which is still lower than moderate. Iron (Fe), Zinc (Zn), Copper (Cu), and Manganese (Mn) are typically at low contamination levels (CF < 1) for all samples. In the second area, several positions (D surface, D 60 cm, E Surface, E 60 cm, F Surface, F 60 cm) as the first location Pb is not found. Nickel (Ni) pollution is moderate in Point D 60 cm (1.121), Point F surface (0.697) and Point E 60 cm (0.352). Chromium (Cr) contamination is moderate at Point F 60 cm (0.765) and Point D 60 cm (0.371) and Point D surface (0.288) as Cd at E 60 cm (0.162) and E surface (0.314). Iron (Fe), Zinc (Zn) and Copper (Cu) and Manganese (Mn) are generally at low levels of contamination (CF < 1). As shown by graph in Fig (5)- (O_1 to T_2). As results of contamination factor it helps to identify polluted locations. and allows contamination comparison in different regions.

3.4.3Pollution Quality Index (PQI)

PQI from different sites could provide soil quality assessment. Pollution quality index for the first location comparing to limitation values, all PQI values as shown in Fig (6) -(U_1-U_2), are far below 1, indicating no pollution at both depths. Surface points (especially Point A) are slightly cleaner than at 60 cm. Similar to the first location, all PQI values are <1 (no pollution). Point D (60 cm) has the highest PQI (0.2497) but still falls under "no pollution." Surface values are generally lower (cleaner) than at 60 cm, except for Point F (surface PQI > depth PQI). All averages are far below 1, confirming no pollution risk. Second location is slightly cleaner (lower PQI) on average. First location has higher average PQI than the second (0.17 vs. 0.153 at 60 cm). Surface averages are nearly identical (0.13–0.14).

3.4.4 Nutrient Pollution Index NPI

As nutrient index including NO_3**,** PO_4**,** SO_4**,** K, which can lead soil contamination, crop toxicity and eutrophication, results as shown in Fig. (7)- (V_1-V_2), at first location All points (A, B, C) show significantly higher NPI values at 60 cm compared to the surface. For average values NPI concentrations are times higher at 60 cm (avg. 0.784) than at the surface (avg. 0.389). Unlike the first location, NPI values at second location are high at the surface (avg. 0.874) compared to 60 cm (avg. 0.635). Point D has the highest NPI at 60 cm = 5.24, and lowest value of point F surface= 3.83**.**

3.4.5 Potential Risk Index (RI)

As a result of risk index, every measurement for risk index at first location (surface and 60 cm) falls under low ecological risk (RI < 150). The highest RI (30.124 at Point C, 60 cm) and point A (surface) the lowest RI (2.485). Second location shows lower average RI than the first, indicating better conditions**.** AS shown in Fig. (8) (W_1-W_2).

3.4.6 Salinity Index (SI)

Salinity as a critical indicator, can degrade the quality of soil, harm ecosystem and reduce crop yields, for salinity index results, for first location all SI values are <2, indicating that there are no salinity issues across all points and depths. The highest value is 0.7375 (Point A surface), still far below the low salinity threshold. Higher average SI at 60 cm (0.64) compared to surface (0.6). Point C shows the largest drop from 60 cm (0.6575) to surface (0.455). All SI values are < 2 in second location, confirming no salinity concerns at any point or depth. Highest value 0.65 (Point F, 60 cm). Slightly higher average SI at 60 cm (0.62) compared to surface (0.52), similar to the first location. Point F shows significant drop from 60 cm (0.65) to surface (0.385), as shown in Fig. (9)- (X_1-X_2).

3.4.7 Organic Matter Index

Organic matter evaluation explains either level of organic matter in soil is healthy, moderate or polluted. According to the results, Fig. (10)- (Y_1-Y_2) shows that all OMI values in first location are < 0.25%, far below the threshold (<1%). No significant difference between surface and 60 cm (both avg. 0. 21%). Point C consistently has the highest OMI (0.2422% at 60 cm, 0.2311% surface). For the second area there is minimal variation between surface (0.23%) and 60 cm (0. 24%).Point F has the highest OMI at both depths (0.26% at 60 cm, 0.251% surface). Every OMI value is < 0.26%, well below the "Very Low" threshold (<1%). While the highest value is 0.26% (Point F, 60 cm).

3.4.8 Sodium Adsorption Ratio SAR

SAR, for the both 60 cm and surface measurements fall under moderate sodicity which concentrations are between 3–9. The average concentration is very similar (6.83 at 60 cm vs. 6.91 on the surface). Point A has the highest Ci (8.5–8.6), and point B & C have lower Ci (5.8–6.3), indicating slightly better conditions but still in the moderate sodicity range. At second area, point E (60 cm) has the highest concentration (10.187), nearing High Sodicity, which could indicate sodium accumulation at depth. Point F has the lowest concentration (5.1), similar to points B & C from the first location. Point D remains in moderate sodicity at both depths (6.1 and 6.7). About average values, at 60 cm 7.35 which is higher than the first location's 6.83, high SAR leads toxicity and reduce permeability about results on average surface was 6.09 slightly lower than the first location's 6.91 as shown in Fig. (11)- (Z1-Z2).

3.4.9 Combined Pollution Index CPQI

The result of founded CPQI for each location, described by establishing each index at location with the ratio of weight suggested**.** All the CPQI values founded are below 1**,** meaning they fall under "Low Pollution" condition according to the limitations values, the highest value taken by the first location 60 cm deep result about 0.49578. As values of CPQI shown in Fig. (12)- (CPQ_1-$CPQI_2$)

3.4.10 Analytical hierarchy process (AHP)

As a result of AHP, calculated consistency ratio, found as % 0.91 which is <%10 which is acceptable value, which means that the criteria evaluation was correct. Weights of each index assigned based on the toxicity and importance of the parameter. PQI value which is putted on 0.25 weight is the highest value between indices because are toxic even at low concentrations and can accumulate in the environment, leading to severe consequences. Human health including Direct ingestion inhalation of dust particles and food chain transfer (consuming crops grown in polluted soil). Also health risks neurological damage by and cancer by, kidney & bone damage by and cardiovascular & reproductive issues. On the other hand, effects on plants by reducing growth, yellowing leaves and cell death and effects on ecosystem by Loss of beneficial bacteria & fungi, leading to poor soil fertility. For risk index (RI) weight suggested to take 0.2 of all the weights because it assesses human health risks (cancer, organ damage). Slightly lower than PQI because it focuses only on health, not overall pollution. As for NPI weight value suggested 0.2 because it is critical for agriculture but secondary to direct pollution and health risks. Salinity index (SI) in between high value and low value of weight = 0.15, which measures salt stress, which worsens metal toxicity. Moderately important, especially in arid and coastal regions. Organic matter index (O.M.I) and Sodium adsorption ratio (SAR) are in lower weight =0.1 because O.M.I it's an indirect factor and least critical unless in highly saline areas. As a results of the weights of index types using the pairwise comparison matrix (as shown in table.15) of the six types of indices, comparing each index with each to found the actual weight of indices the weight of W1 which is pollution quality index (PQI) has the largest amount which is equal to %25 as shows in table (17).

4. Conclusion

The study proposes a novel (Combined Pollution Quality Index, CPQI) in Sulaymaniyah city for two specific locations as Kostay Cham for the first location and Kani Goma for the second location. Taking 12 samples is introduced to integrate six weighted indices, nutrient index, salinity index, organic matter index, sodium adsorption ratio (SAR) index, heavy metal risk index and pollution quality index (PQI). AHP was employed to estimate the weight of each index. Soil, as a large basin, is crucial for retention of both nutrients and pollutants, the core of long term human health and environmental sustainability. As inputs of heavy metals from agriculture, urban and industrial activities increase, many soils are becoming heavy metal contaminated and have potential harm to human health .The eating of vegetables that have been cultivated in soils with pollutants may also cause toxicity in humans. Soil and water properties of all samples were tested at the laboratory by standard methods as the quality of water using for irrigation has the main influence on soil contamination level. The outcomes suggested that the levels of heavy metals (in surface and a depth of 60 cm) were all acceptable. On the other hand, higher amounts of some heavy metals such as chromium (Cr), cadmium (Cd), copper (Cu) and iron (Fe) were generally detected in 60 cm depth in contrast with surface samples .For the pollutant indices, different fluctuations were found in the six pollutants. Integrated as CPQI, the index well represented the pollution profile of each site. The maximum CPQI value, was obtained for the first depth (60 cm) and at the first location. This value is below the critical value and indicates that pollution according to the proposed index is acceptable, this result is due to the high probability of absorption by plant roots and vegetables .

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تقييم مخاطر تلوث التربة باستخدام مؤشر جودة التلوثفي السليمانية، العراق

المستخلص

التربة هي خزان كبير للعناصر الغذائية والملوثات، وبالتالي تلعب دورًا مهمًا في الصحة والاستدامة الاجتماعية والبيئية. تدخل الملوثات من الزراعة والتحضر والأنشطة الصناعية إلى التربة مما يزيد من تلوث التربة ويفرض خطرًا كبيرًا على صحة الإنسان. تم فحص عينات التربة من موقعين مختلفين (كوستي تشام وكاني كوما) في مدينة السليمانية. المناطق عبارة عن مزرعتين زراعيتين تروى بمياه من مجرى مائي ومياه الصرف الصحي على التوالي. تم اختيار ست نقاط مختلفة في منطقتين للدراسة على السطح وعلى عمق ٦٠ سم لكل نقطة. بينما تم جمع عينتين من المياه في كل موقع (الرقم الهيدروجيني والتوصيل الكهربائي EC و DO و BOD5 و TDS و TSS والملوحة والعكارة والقلوية الكلية والصلابة، مع تحديد المعادن الثقيلة Pb و Cd و Cu و Ni و Fe و (Znفي مياه مجرى نهر قليسان ومياه الصرف الصحي. تقدم هذه الدراسة مؤشر جودة التلوث المركب ((CPQI) الجديد الذي يدمج ستة مؤشرات مرجحة - مؤشر المغذيات، ومؤشر الملوحة، ومؤشر المادة العضوية، ومؤشر نسبة امتزاز الصوديوم (SAR)، ومؤشر مخاطر المعادن الثقيلة، ومؤشر جودة التلوث (PQI) تم استخدام عملية التسلسل الهرمي التحليلي (AHP) لإيجاد قيم الوزن لكل مؤشر. تم إجراء اختبارات كيميائية وفيزيائية وبيولوجية لجميع عينات التربة مثل؛ المعادن الثقيلة، والمواد العضوية، والمغذيات، ودرجة الحموضة (PH)، والمواد الصلبة الذائبة (TDS)، والتوصيل الكهربائي

(EC).أظهرت النتائج أن تركيز المعادن الثقيلة في جميع العينات (السطح وعمق ٦٠ سم) يقع ضمن النطاق المسموح به. بشكل عام، لوحظت مستويات أعلى لمعظم المعادن الثقيلة على عمق ٦٠ سم مقارنة بالعينات السطحية. تم استخلاص مؤشر جودة التلوث المركب (CPQI) من جميع المؤشرات معًا لتحقيق مؤشر التلوث لكل موقع، وبالتالي فإن جميع قيم CPQI التي تم التوصل إليها أقل من ١، مما يعني أنها تندرج تحت "التلوث المنخفض" لجميع المواقع المختارة وفقًا لقيم القيود، حيث كانت أعلى قيمة تم أخذها بواسطة الموقع الأول بعمق ٦٠ سم حوالي ٠,٤٩ وأدنى قيمة ٠,٣٤ لعينة سطح الموقع الأول. ترجع هذه النتيجة إلى الاحتمالية العالية لامتصاص جذور النباتات والخضروات.

الكلمات المفتاحية:
تلوث التربة؛ المعادن الثقيلة؛ مؤشر التلوث

Fig 1-A: The (Kostay Cham)study site sampling points

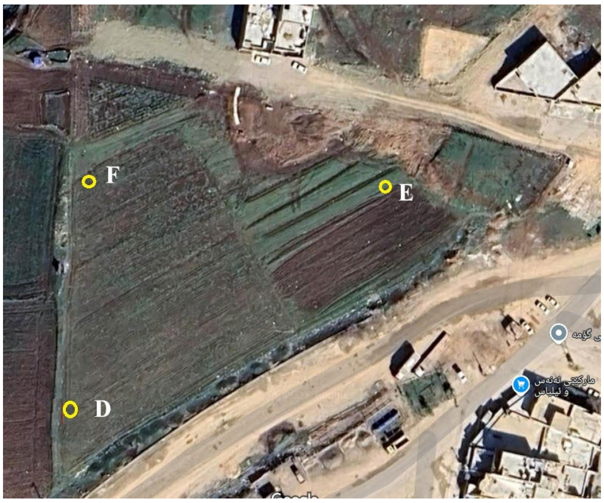
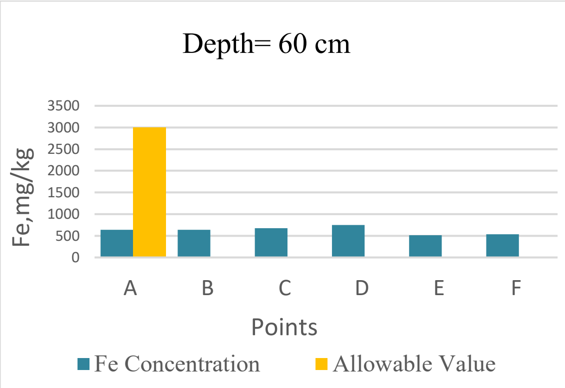
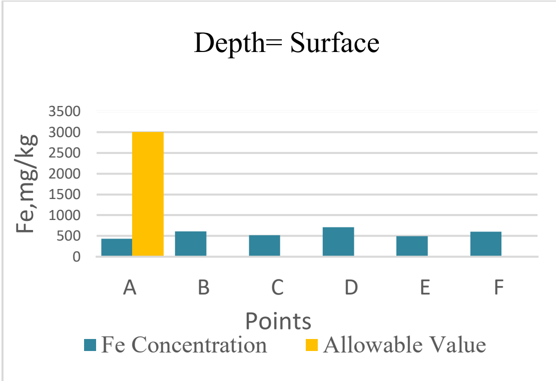


Fig 1-B: The (Kani Goma) study site sampling points



(A1)



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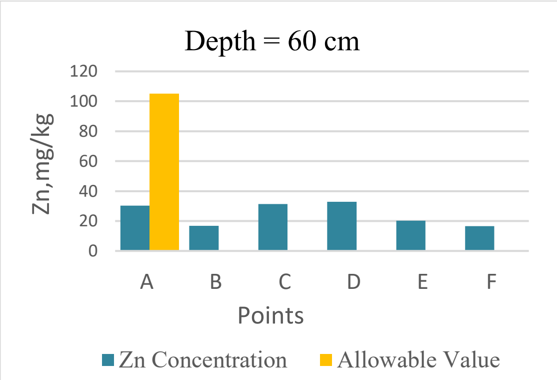

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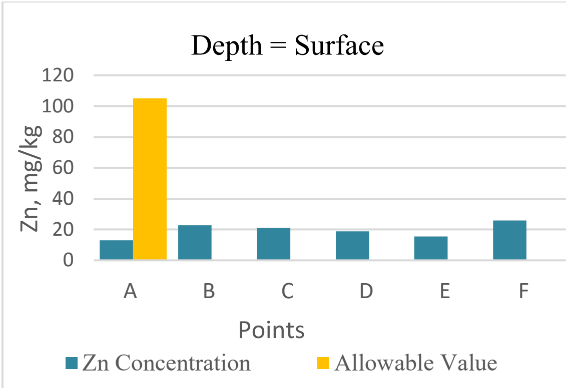

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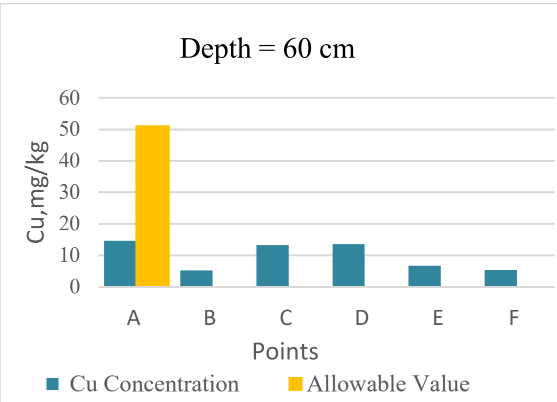

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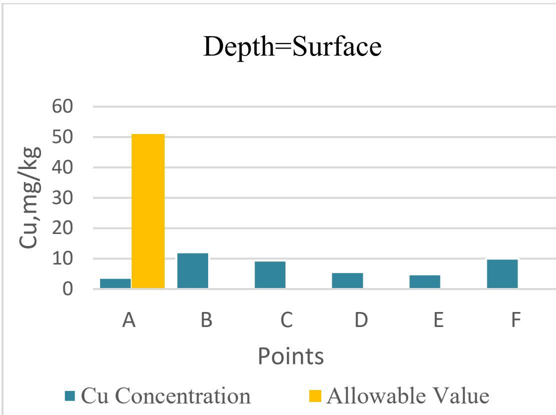

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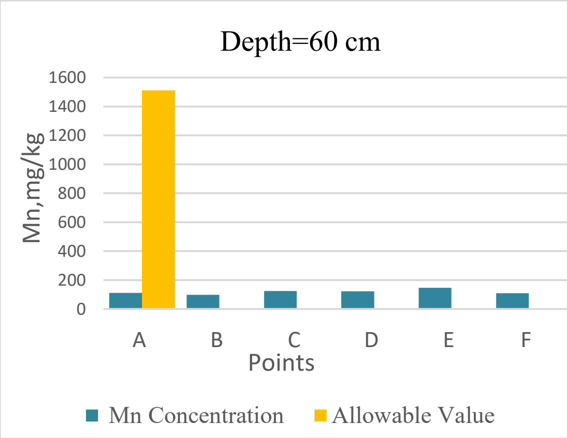

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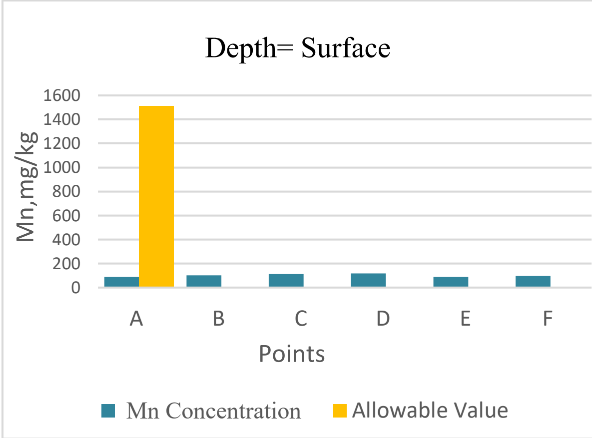

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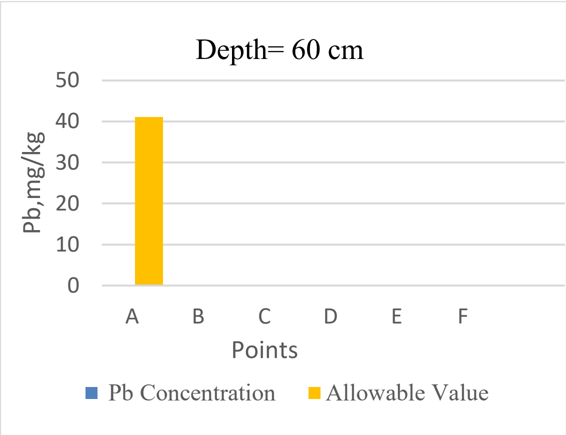

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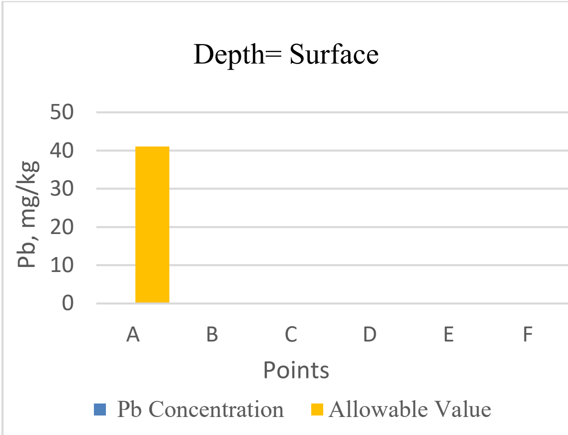

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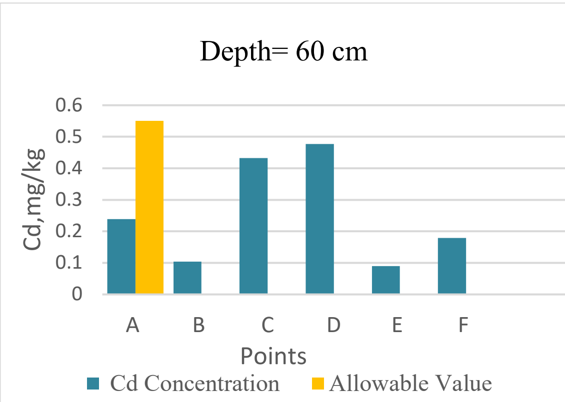

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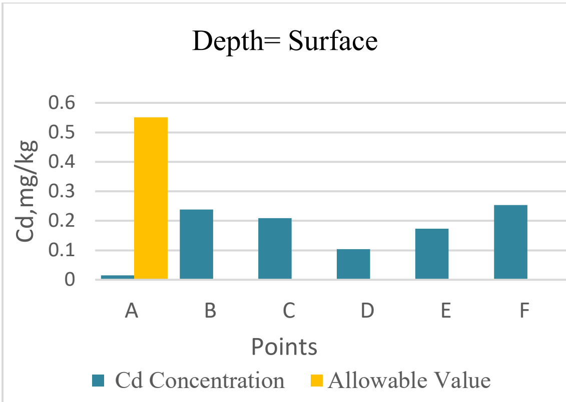
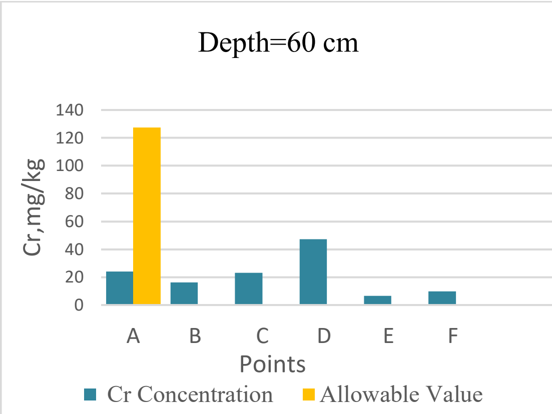
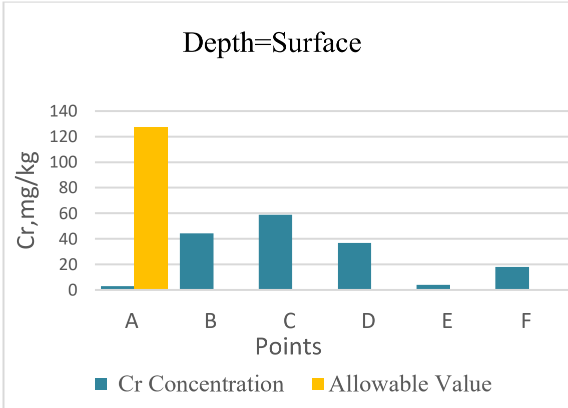


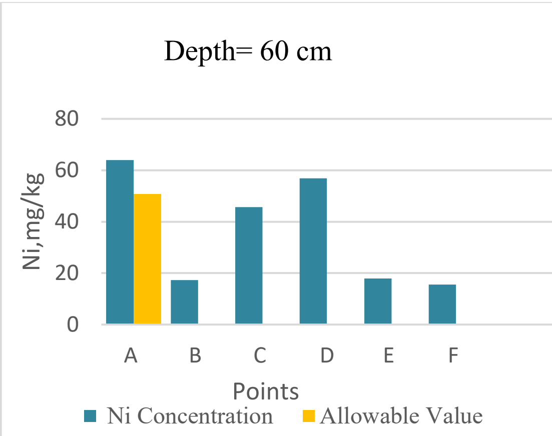
(F2)



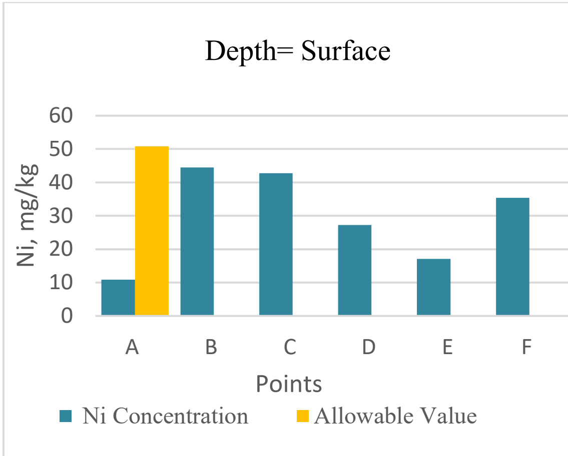
(G_1)



(G_2)

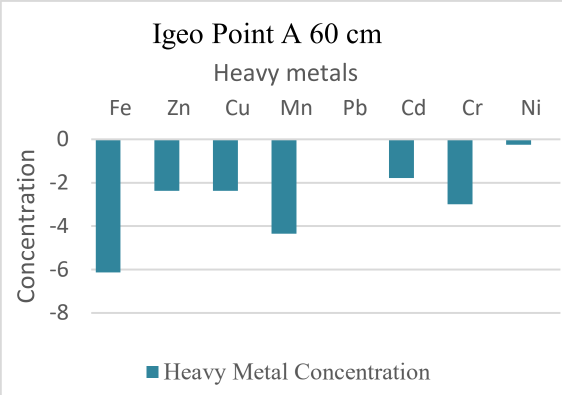


(H_1)

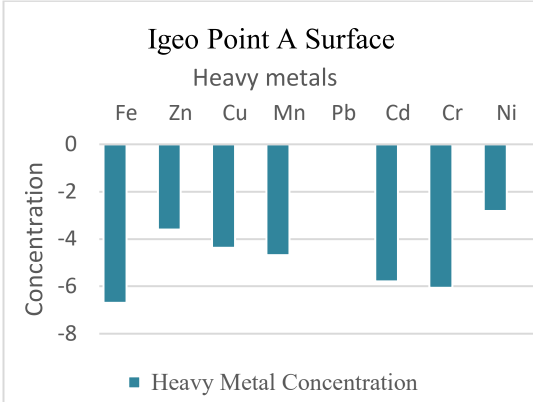


(H_2)

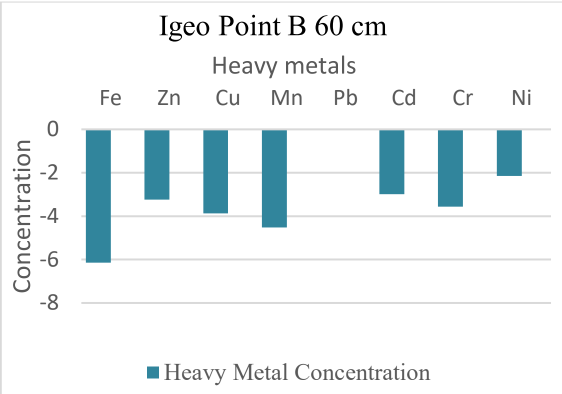
Fig. (2) -(A_1 to H_2): The concentration of heavy metals (Fe, Zn, Cu, Mn, Pb, Cd, Cr, Ni) for surface and 60 cm depth points respectively.



(I1)



(I_2)



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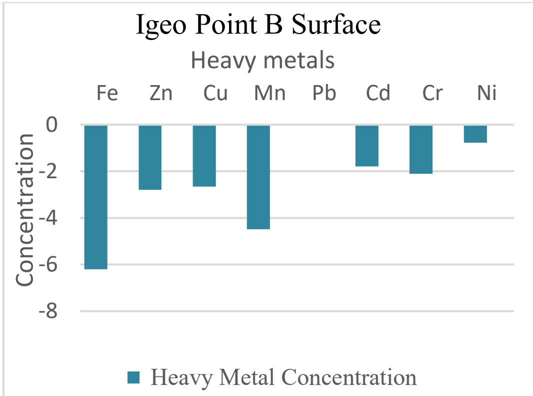

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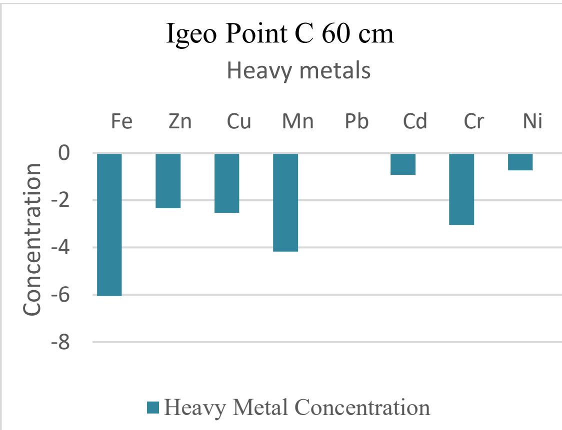

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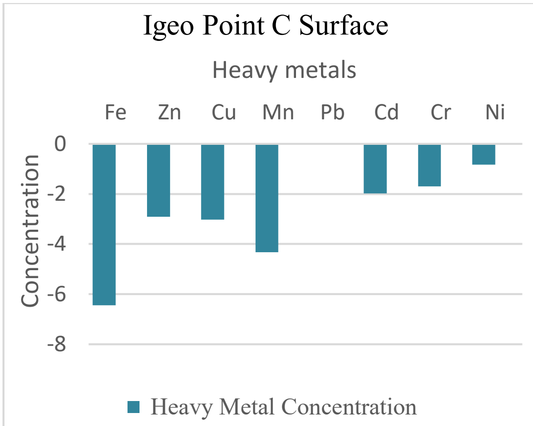

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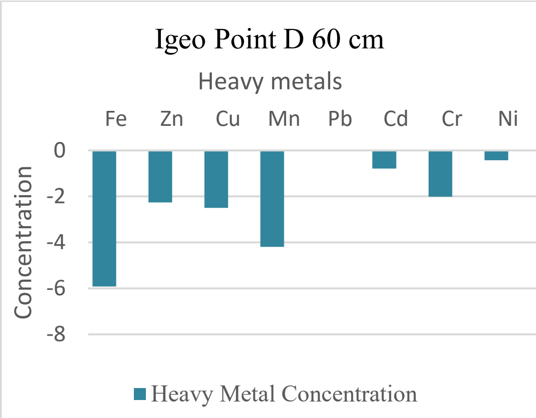
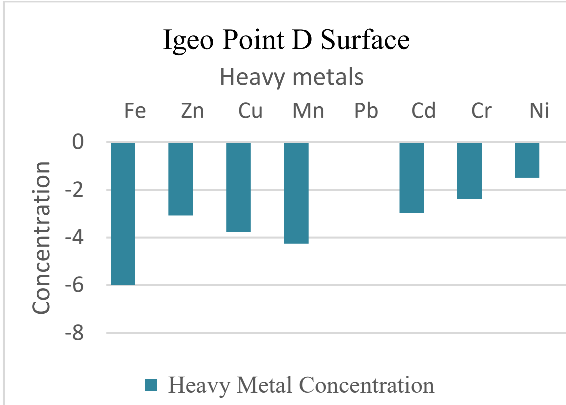


(L1)



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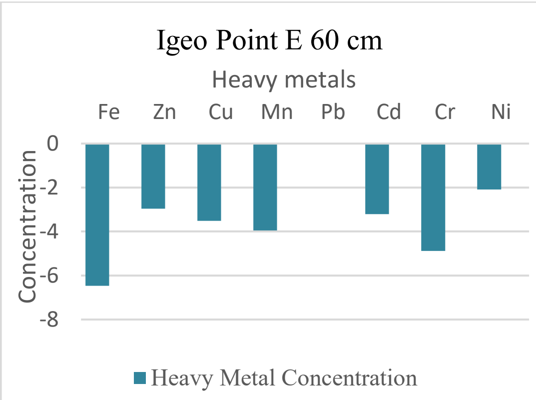
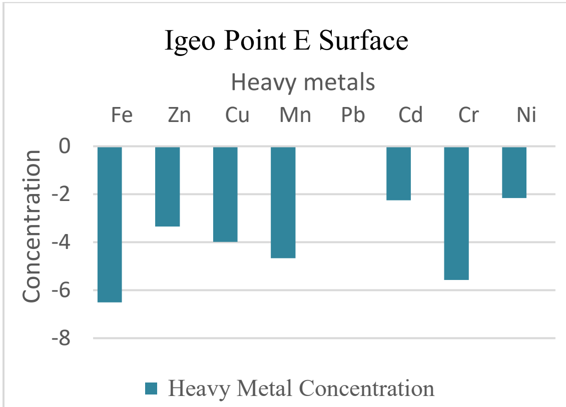
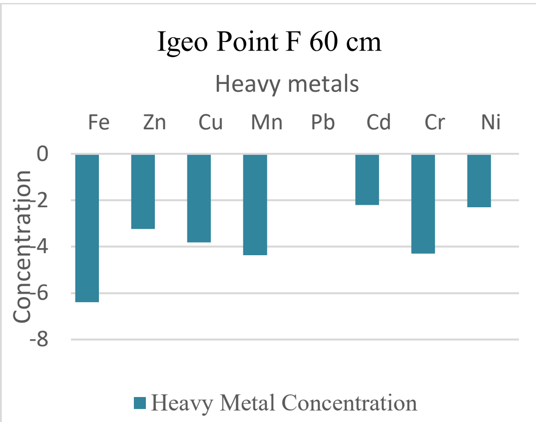


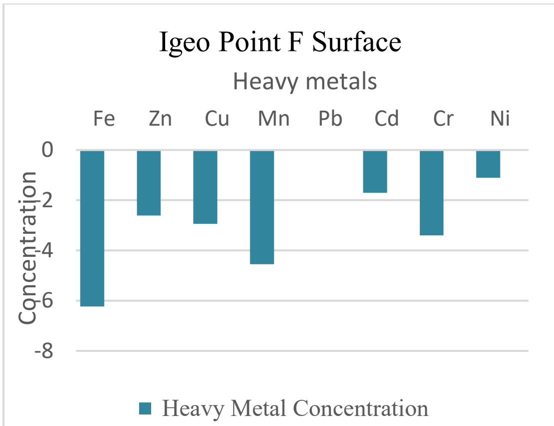
(M1)



(M2)

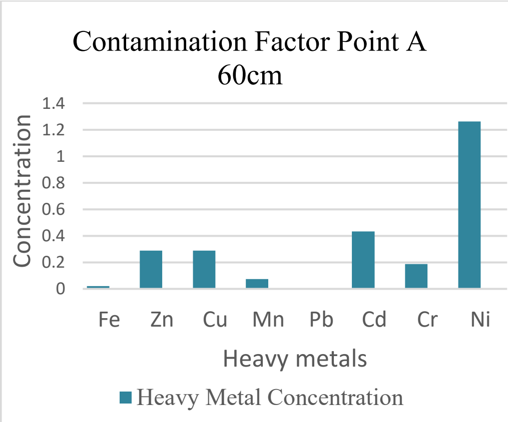


(N1)

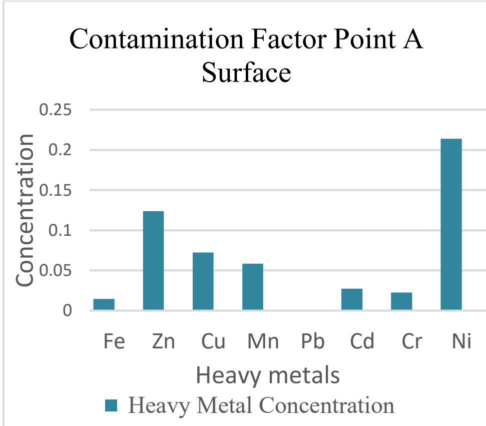


(N2)

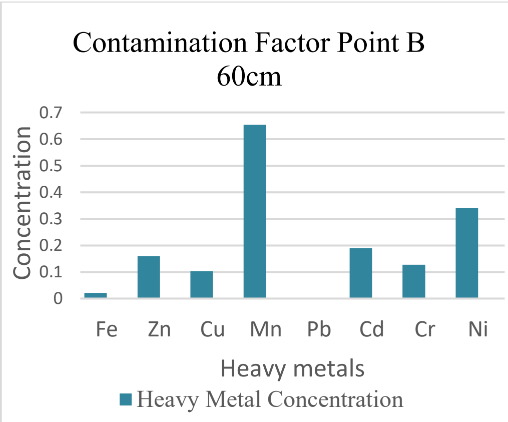
Fig. (3) - (I1 to N2): The concentration of heavy metals (Fe, Zn, Cu, Mn, Pb, Cd, Cr, Ni) for Igeo index in surface and 60 cm depth points respectively.



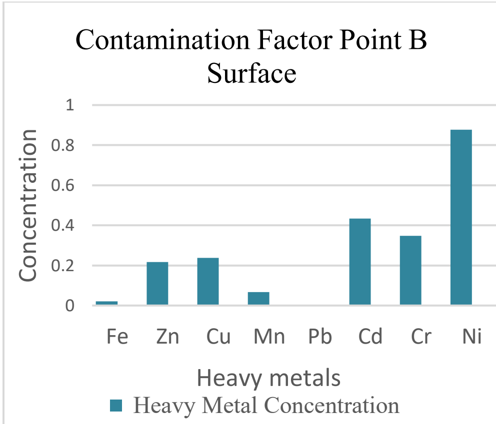
(O_1)



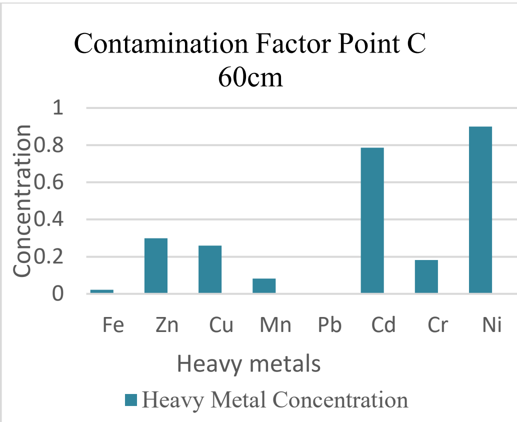
(O_2)



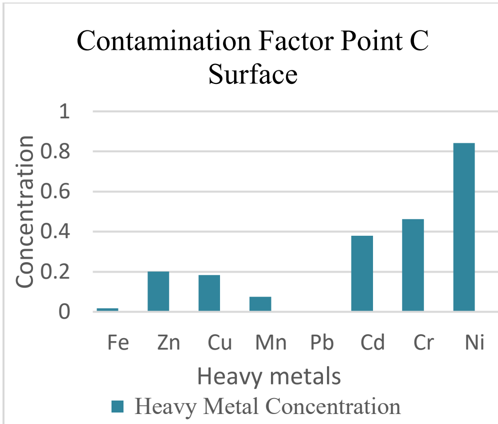
(P_1)



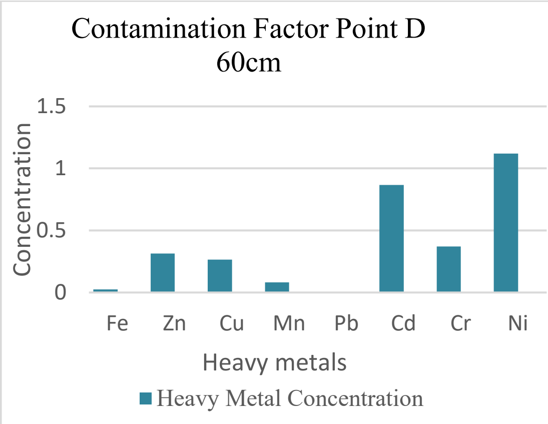
(P_2)



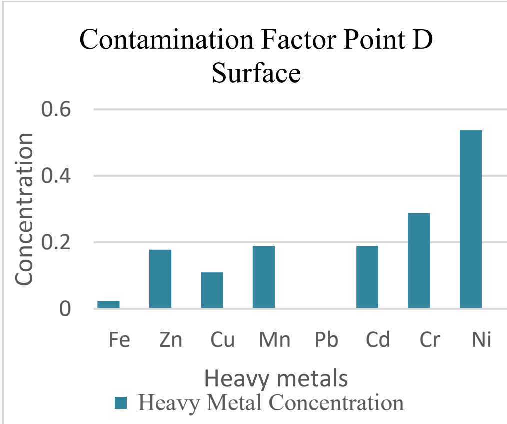
(Q_1)



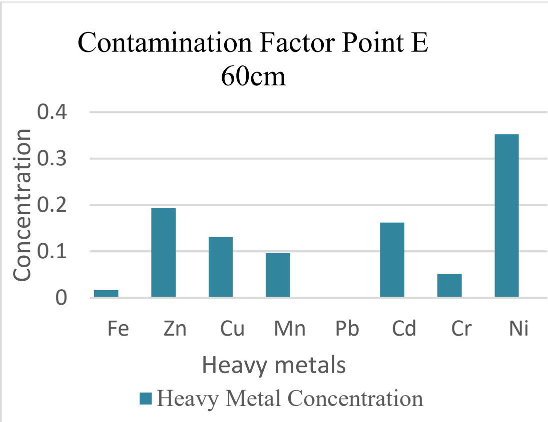
(Q_2)



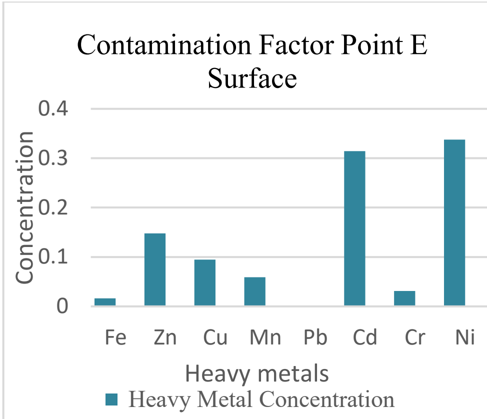
(R$_1$)



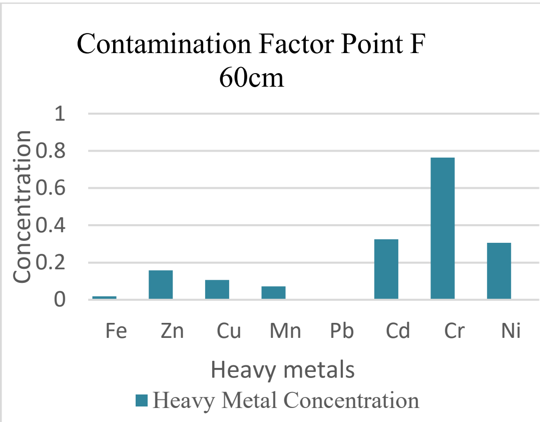
(R$_2$)



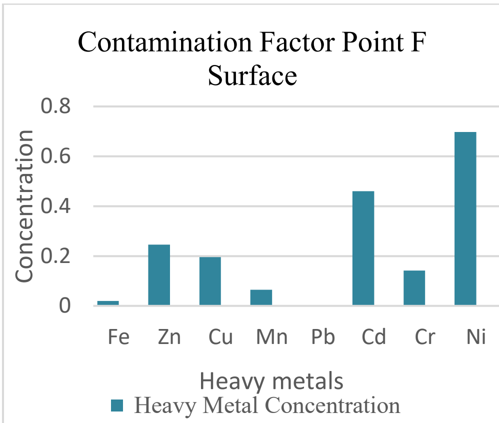
(S$_1$)



(S$_2$)

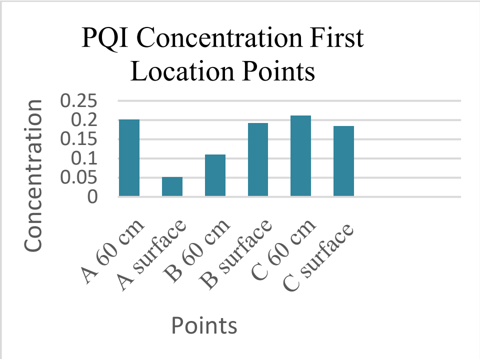


(T$_1$)

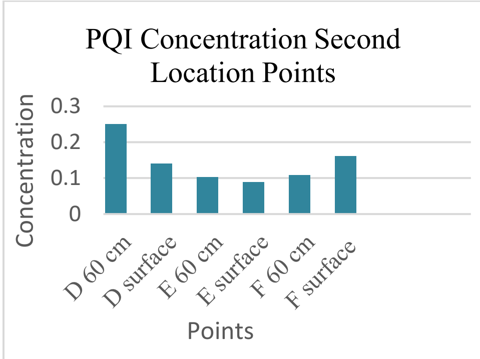


(T$_2$)

Fig. (4) - (O$_1$ to T$_2$): The concentration of heavy metals (Fe, Zn, Cu, Mn, Pb, Cd, Cr, Ni) for contamination factor in surface and 60 cm depth points respectively.

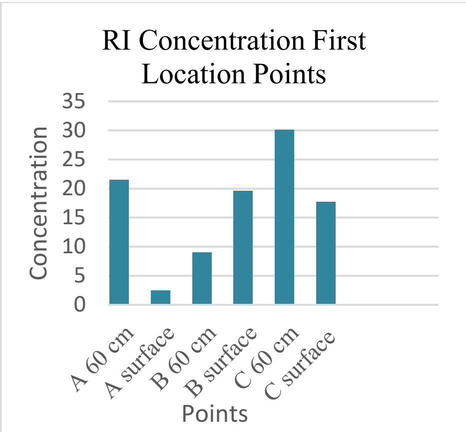


(U1)

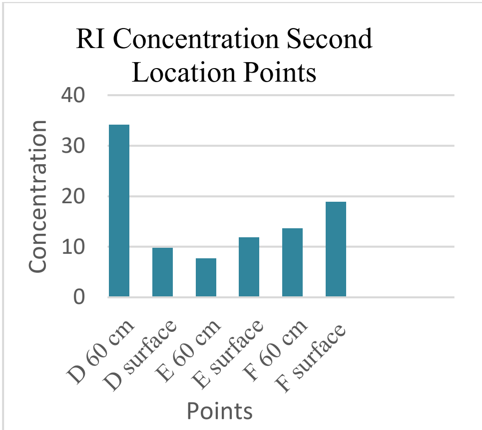


(U2)

Fig. (5) - (U_1-U_2): The concentration of PQI in surface and 60 cm depth points.

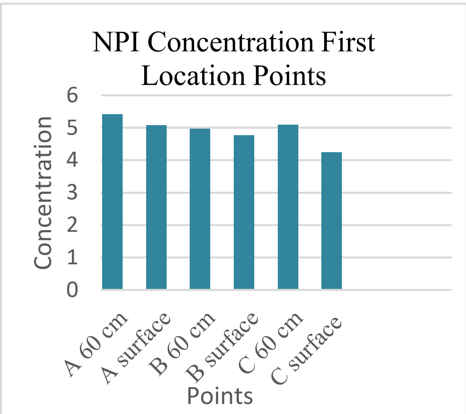


(W_1)

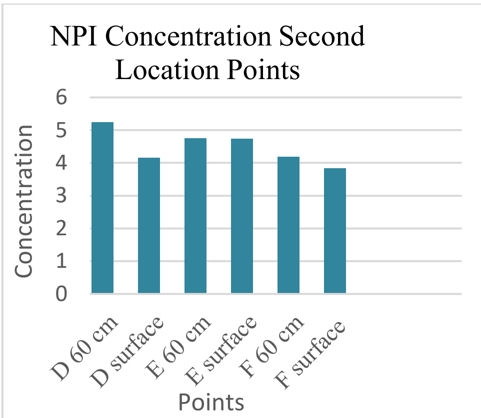


(W_2)

Fig.(6) - (W_1-W_2): The concentration of RI in surface and 60 cm depth points.

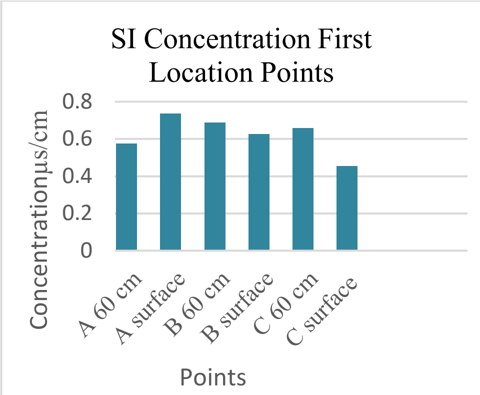


(V_1)

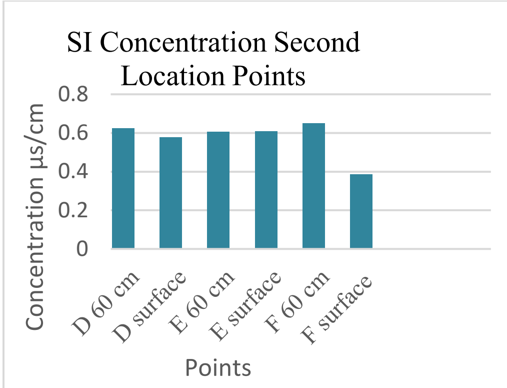


(V_2

Fig. (7) - (V_1-V_2): The concentration of NPI in surface and 60 cm depth poin

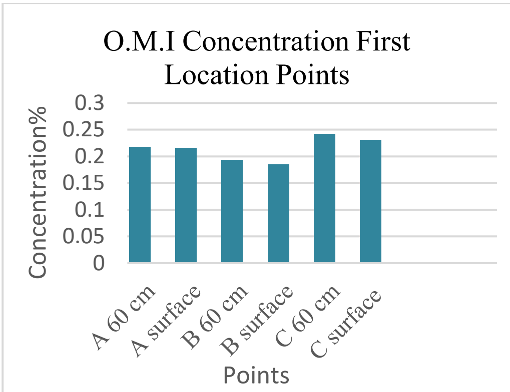


(X1)

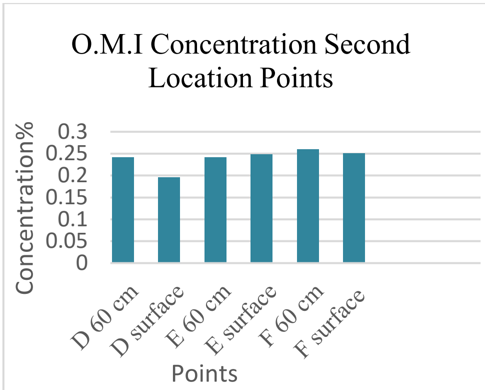


(X2)

Fig. (8) - (X_1-X_2): The concentration of SI in surface and 60 cm depth points.

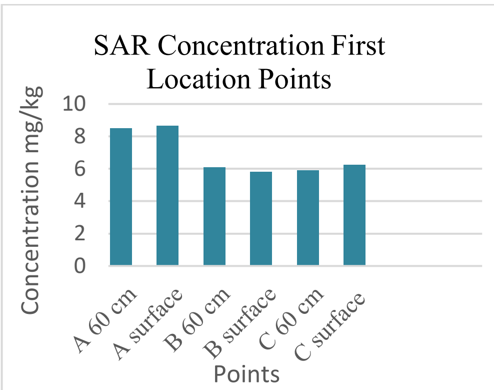


(Y1)

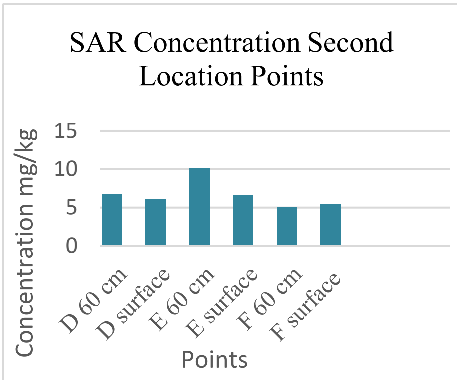


(Y2)

Fig. (9) - (Y_1-Y_2): The concentration of O.M.I in surface and 60 cm depth points.

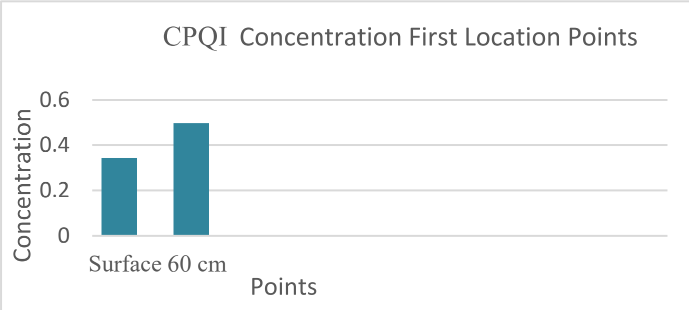


(Z1)

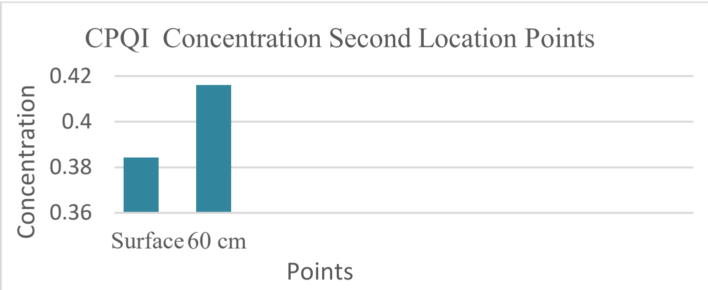


(Z2)

Fig. (10) - (Z_1-Z_2): The concentration of SAR in surface and 60 cm depth points.



(CPQI1)



(CPQI2)

Fig. (11) - (CPQ1-CPQI2): The concentration of CPQI in surface and 60 cm depth points

Table (13): Qilyasan water stream test results for 18 parameters.

No	Parameters	Unit	Result	Background Value	Reference
1	pH	--	8.18	6.5-8.5	(Iraq, 1967)
2	TDS	mg/l	354.9	2500	(Government, 2024)
3	EC	µS/cm	546.1	<700	(Ayers & Westcot, 1985)
4	Total alkalinity as caco3	mg/l	210.2	<200	(Rhoades, et al., 1992)
5	Total hardness as caco3	mg/l	255.1	<300	(EPA, 2012)
6	Sulphate	mg/l	77.3	<200	(Iraq, 1967)
7	Nitrate	mg/l	31.1	<15	(Iraq, 1967)
8	Phosphate	mg/l	4.1	<0.4	(Iraq, 1967)
9	Cod	mg/l	9.2	<100	(Government, 2024)
10	Bod5	mg/l	6.4	<5	(Iraq, 1967)
11	Iron	mg/l	0.1	0.3	(Iraq, 1967)
12	Lead	mg/l	<0.006	<0.05	(Iraq, 1967)
13	Cupper	mg/l	0.009	<0.05	(Iraq, 1967)
14	Cadmium	mg/l	<0.006	<0.005	(Iraq, 1967)
15	Do	mg/l	7.2	<5	(Iraq, 1967)
16	Turbidity	Ftu	11.	<25	(Government, 2024)
17	Tss	mg/l	9.1	<40	(Government, 2024)
18	Salinity	ppt	0.27	0.45	(WHO, 2006)

Table (14) : Sewage water test results for 18 parameters.

No	Parameters	Unit	Result	Background Value	Reference
1	pH	--	8.15	6.5-8.5	(Iraq, 1967)
2	TDS	mg/l	572.0	2500	(Government, 2024)
3	EC	µS/cm	883.0	<700	(Ayers & Westcot, 1985)
4	Total alkalinity as caco3	mg/l	355.6	<200	(Rhoades, et al., 1992)
5	Total hardness as caco3	mg/l	553.4	<300	(EPA, 2012)
6	Sulphate	mg/l	184.3	200	(Iraq, 1967)
7	Nitrate	mg/l	63.3	<15	(Iraq, 1967)
8	Phosphate	mg/l	23.5	<0.4	(Iraq, 1967)
9	Cod	mg/l		<100	(Government, 2024)
10	Bod5	mg/l		<5	(Iraq, 1967)
11	Iron	mg/l	0.4	<0.3	(Iraq, 1967)
12	Lead	mg/l	0.09	<0.05	(Iraq, 1967)
13	Cupper	mg/l	0.05	<0.05	(Iraq, 1967)
14	Cadmium	mg/l	0.005	<0.005	(Iraq, 1967)
15	Do	mg/l	2.5	>5	(Iraq, 1967)
16	Turbidity	Ftu	231.1	<25	(Government, 2024)
17	Tss	mg/l	222.1	<40	(Government, 2024)
18	Salinity	Ppt	0.44	<0.45	(WHO, 2006)

	W1 (PQI)	W2 (RI)	W3 (NPI)	W4 (SI)	W5 (O.M.I)	W6 (SAR)
W1 (PQI)	1	1	1	2	3	3
W2 (RI)	1	1	1	2	2	2
W3 (NPI)	1	1	1	2	2	2
W4 (SI)	0.5	0.5	0.5	1	2	2
W5 (O.M.I)	0.3	0.5	0.5	0.5	1	1
W6 (SAR)	0.3	0.5	0.5	0.5	1	1

Table (15): The Pairwise Comparison Matrix of the Six Criteria

Table (16): The Normalized Pairwise Comparison Matrix of the Six Criteria

Criteria	W1	W2	W3	W4	W5	W6
W1	0.24	0.22	0.22	0.25	0.27	0.27
W2	0.24	0.22	0.22	0.25	0.18	0.18
W3	0.24	0.22	0.22	0.25	0.18	0.18
W4	0.12	0.11	0.11	0.13	0.18	0.18
W5	0.07	0.11	0.11	0.06	0.09	0.09
W6	0.07	0.11	0.11	0.06	0.09	0.09
Sum	1	1	1	1	1	1

Table (17): The Weight of the Six Criteria.

Criteria	W
W1	0.2473
W2	0.2169
W3	0.2169
W4	0.1388
W5	0.0899
W6	0.0899
Sum	1