Iraqi National Journal of Earth Science

www.earth.mosuljournals.com

Heavy and Toxic Metals in Soils of Selected Areas in Erbil City, Iraq

Chia H. Abdoulqadir [1,2*], Farhad A. Mohammad [2]

[1] *Department of Earth Sciences and Petroleum, College of Science, University of Salahaddin-Erbil, Erbil, Iraq.*

[2] *Petroleum Technology Department, Erbil Technology College, Erbil Polytechnic University, Erbil, Iraq.*

Article information

Received: 07- Nov -2023

Revised: 12- May -2024

Accepted: 08- Aug -2024

Available online: 01- Jul – 2025

Keywords:
Heavy Metals
Toxic Elements
Soil Pollution
Environmental Contamination
Erbil, Iraq

Correspondence:
Name: Chia H. Abdoulqadir
Email:
chia.abdoulqadir@epu.edu.iq

ABSTRACT

The presence of heavy metals in soils and sediments can potentially pose a toxic threat to ecosystems, and possibly impacts the human health through the food chain. The soils present in the study area) Erbil City (, both natural and imported, will be subjected to anthropogenic input and the influence of waste generated in these locations, thereby resulting in potential environmental and health concerns. Erbil City, the administrative center of the Kurdistan region of Iraq is situated in northern Iraq. This heavily populated urban city exhibits a high level of activities with regards to the presence of manufacturing plants, medical institutions, automobiles, industrial infrastructures, industrial emissions, vehicle cleaning establishments, and accumulation of waste containers. The study aims to elucidate the specific areas where the input of heavy metal pollutants from human activities are expected to significantly contribute in a localized pollution. A comprehensive analysis is conducted to a total of sixty-five soil samples collected from various locations within the busiest urban areas of Erbil City. The primary objective of this study is to investigate the potential presence of heavy and toxic metals, thereby assessing the extent of contamination in the region. To achieve this, a thorough examination is carried out for twenty-five different elements of the collected soil samples. When comparing to international standards, it is observed that the overall pollution levels do not exceed the permissible pollution concentration levels, except for certain specific localities.

DOI: 10.33899/earth.2024.144447.1172, ©Authors, 2025, College of Science, University of Mosul.

العناصر الثقيلة والسامة في ترب مناطق مختارة من مدينة أربيل، العراق

جيا حسين عبدالقادر [1،2] * ، فرهاد احمد محمد [2]

[1]قسم علوم الأرض والنفط، كلية العلوم، جامعة الصلاح الدين- اربيل، اربيل، العراق.

[2]قسم التكنلوجيا النفط، كلية التكنلوجيا- اربيل، جامعة اربيل التقنية، اربيل، العراق.

معلومات الارشفة

تاريخ الاستلام: 07- نوفمبر -2023

تاريخ المراجعة: 12- مايو -2024

تاريخ القبـول: 08- أغسطس-2024

تاريخ النشر الالكتروني: 01- يوليو -2025

الكلمات المفتاحية:

عناصر ثقيلة

العناصر السامة

تلوث التربة

التلوث البيئي

أربيل، العراق

المراسلة:

الاسم: جيا حسين عبدالقادر

Email: chia.abdoulqadir@epu.edu.iq

الملخص

يمكن أن يشكل وجود العناصر الثقيلة في التربة والرواسب تهديدًا سامًا للنظم البيئية، وربما يؤثر على صحة الإنسان من خلال السلسلة الغذائية. خضعت التربة الموجودة في منطقة الدراسة (مدينة أربيل)، سواءً الطبيعية أو الدخيلة، للمدخلات البشرية وتأثير النفايات المتولدة في هذه المواقع، مما يؤدي إلى مخاوف بيئية وصحية محتملة. تقع مدينة أربيل، المركز الإداري لإقليم كردستان العراق، في المنطقة الشمالية من البلاد. تُظهر هذه المنطقة الحضرية المكتظة بالسكان مستوىً عالياً من الأنشطة فيما يتعلق بوجود المصانع والمؤسسات الطبية والسيارات والبنى التحتية الصناعية والانبعاثات الصناعية ومؤسسات تنظيف المركبات وتراكم حاويات النفايات. تهدف هذه الدراسة إلى توضيح المناطق المحددة التي من المتوقع أن تساهم فيها الملوثات المعدنية الثقيلة الناتجة عن الأنشطة البشرية بشكل كبير في التلوث الموضعي. تم إجراء تحليل شامل على ما مجموعه خمسة وستون عينة من التربة تم جمعها من مواقع مختلفة داخل المناطق الحضرية الأكثر ازدحاما في مدينة أربيل. الهدف الأساس من هذه الدراسة هو دراسة احتمال وجود معادن ثقيلة وسامة، وبالتالي تقييم مدى التلوث في المنطقة. ولتحقيق ذلك، تم إجراء فحص شامل لخمسة وعشرين عنصراً مختلفاً لعينات التربة المجمعة. وعند المقارنة بالمعايير الدولية، يمكن ملاحظة أن مستويات التلوث الإجمالية لم تتجاوز مستويات تركيز التلوث المسموحة، باستثناء مناطق محددة.

DOI: 10.33899/earth.2024.144447.1172, ©Authors, 2025, College of Science, University of Mosul.

Introduction

Heavy metals are those having a density of more than 5.6 g/cm^3 (Ali et al., 2019). The term "trace metals" is widely used to refer to heavy metals found in extremely low concentrations in the environment (Kumar et al., 2017). Non-essential metals with uncertain biological activities include Hg, Pb, and Cd, while essential metals (micronutrients) such as As, Cr, Cu, Ni, and Zn are required by select species. Excessive levels of micronutrients can be hazardous, even though they are essential for some kinds of life (Ali et al., 2019).

For long periods of time, metals can be stored in particulate matter (sediment porewater) before being released back into the dissolved phase and surrounding water (Wuana and Okieimen, 2011). Partitioning behavior causes heavy metals to concentrate in sediments to levels many times greater than those in surrounding waters (González-Macas et al., 2006). Heavy metals in sediments can be analyzed to reveal pollution sources even if they are not present or only present in trace amounts in the water column.

The geochemical study of urban soils is very important in geology and environmental domains. This study examines and identifies the locations which might have contributed to soil pollution of the area.

When it comes to the movement of pollutants, sediments play an important role and can reveal important details about their location and history (Sahuquillo et al., 2003). Sediment is a mixture of inorganic and organic particles, as well as detritus as stated by Mohajane and Manjoro (2022). It has varying particle sizes (gravel, sand, silt, and clay), and its physical, chemical, and biological properties are not uniform. Because of their high adsorption capacity and wide specific surface area, fine-grained sediments like clay and silt contain notably higher amounts of heavy metals. The content of heavy metals in sediment is significantly affected by the grain size of the sediment.

Heavy metals and hazardous components in soils are the subject of many researches around the world. Because of the prevalence of human-caused contamination, these studies frequently target metropolitan and industrial zones. Few studies have been conducted to assess the levels of heavy metals and hazardous components in the soil.

Mohammed et al. (2013) investigated heavy metal pollution in six different sites within Erbil City by analyzing 27 soil samples. Their results revealed higher concentrations of Fe, K, Al, Na, P, Li, Be, B, Sc, V, Cr, Ga, As, Se, Rb, Sr, Y, Zr, Mo, Sn, Cd, Cs, Ba, La, Ce, Th, and U compared to local background levels, but still below than their values in international pollutant standards. But Ni, Cu, and Zn exceeded pollutant levels and were considered non-toxic under current oxidizing environmental conditions. Industrial and Citadel areas had shown critical levels of Co, Mn, and Pb, while Ni, Cu, Co, and Mn were critical in the Citadel soils. Ca concentrations were higher than in its value international standards, while Mg levels were lower. Erbil Citadel soils exhibited pollutant levels of P. The current study indicates that the overall heavy metals have been increased specifically at the industrial zones, where Zn, Cu, Ag, Be, and Ni concentrations are significantly greater. See table (4) below for the contamination index study.

Al-Dulaimi and Al-Mallah (2024) have conducted a thorough study on various heavy metals from soil deposited on tree leaves of Eucalyptus in Erbil City. The study included collection and analyzing 30 soil samples from various sites including green areas, industrial areas, residential neighborhood and streets. The study mainly focused on the health risk associated with the studied metals and concluded that except for vanadium, all other studied metals were exceeding the reference values. The total cancer risk by some elements was below the permissible level of such as Ni, Pb, Co and Cd. It has been concluded that the most common routes of exposure to heavy metals, both carcinogenic and non-carcinogenic, were ingestion followed by cutaneous and inhalation pathways.

Al-Sheraefy et al. (2023) study was on selected areas of Mosul’s City soil especially at the right bank of the city. It revealed that the anthropogenic input has a crucial role in the increase of Cd, As, Ni, Cr, Zn, and Pb when compared to average crust concentration reference. The main human activities highlighted by these researchers are the military wastes of missiles, bombs, remnants and ammunition. Along with the gases and fumes released by burning garbage, automobile exhaust, power plants, liquid waste in cities and industries, sewage water, fertilizers, and pesticides.

Al Obaidy and Al Mashhadi (2013) investigated soil samples collected from three different land use types in Baghdad urban areas. The analysis of the samples revealed higher concentrations of Cd, Cr, Cu, Fe, Ni, Pb, and Zn in the industrial area, while residential areas exhibited higher levels of Mn. The concentrations of Cd, Ni, and Pb exceeded the worldwide means of unpolluted soil. The industrial area, both in roadside and open areas, displayed elevated values of Cd, Ni, and Pb, indicating the most polluted soil type in Baghdad. The Combined Pollution Index (CPI) for Cd, Ni, and Pb ranged from 0.98 to 2.15, with a mean of 1.28 for all urban soil samples, with the highest values observed in the industrial area. This suggests multi-element contamination and highlights the need for remediation measures. Additionally, the study recorded significant to extremely high values of enrichment factors, confirming the significant contribution of anthropogenic pollution to the soil contamination in Baghdad.

Salah and Noori (2013) aimed to assess the concentrations and contamination levels of heavy metals in urban soils. Twenty soil samples were collected from Fallujah City, and the concentrations of Cu, Zn, Ni, Pb, Fe, Mn, Cd, Co, and Cr were determined. The mean concentrations of these metals were within the following ranges: 235.77 μg/g for Fe, 24.09 μg/g for Mn, 11.59 μg/g for Cr, 8.96 μg/g for Ni, 5.50 μg/g for Zn, 3.82 μg/g for Pb, 3.43 μg/g for Co, 2.01 μg/g for Cu, and 0.64 μg/g for Cd. Soil quality guidelines were applied to assess metal contamination, revealing that the mean concentrations of Cu, Zn, Ni, Pb, Fe, Mn, Co, and Cr were within acceptable limits, while Cd exceeded the USEPA guideline. Spatial distribution patterns indicated similar sources for these metals. Metal contamination in the soils was further evaluated using enrichment factor (EF), pollution load index (PLI), integrated pollution load index (IPLI), and Geo-accumulation index (I_{geo}). Results showed that the urban soils in Fallujah City exhibited extremely high enrichment with Cd and Co, very high enrichment with Ni and Cr, and significant enrichment with Pb, Cu, and Zn. According to the IPLI values, the heavy metal pollution in the urban soils of Fallujah was low. The I_{geo} assessment indicated that the soils were uncontaminated to slightly contaminated by Cd, with industrial and anthropogenic activities being potential sources.

Khudhur et al. (2018) presented a comprehensive evaluation of soil contamination resulting from a steel factory in Erbil City. The study revealed that the highest metal concentrations, except for Al, were found in the vicinity of the Erbil Steel Company (E.S.C.). The dominant heavy metals in the soil followed the trend of Fe, Al, Zn, Mn, Ti, Pb, Cu, Ni, Cr, V, Co, As, Mo, and Cd. Notably, the concentration of Ni exceeded the limits set by the World Health Organization (WHO) in all sampled sites. Various contamination indices, such as index of Geo-accumulation (I_{geo}), enrichment factor (EF), contamination factor (CF), degree of contamination (C_{deg}), pollution load index (PLI), element contamination index (ECI), and the overall metal contamination index (MCI), were employed to assess soil pollution. Comparisons with local soil backgrounds from Erbil City indicated moderate contamination in Sahdawa, Shamamal, and Sardasht areas, primarily with As, Co, Cr, Mn, Mo, Ni, Ti, V, and Zn. However, Sahdawa exhibited a significant contamination by Pb. Sites 2-8 displayed a substantial degree of contamination ($16 \leq C_{deg} < 32$). The PLI values, except for Sardasht, indicated a decline in site quality (PLI > 1), highlighting the impact of the steel factory. Factor analysis identified three factors: metals originating from E.S.C. activities, a lithogenic factor, and the sampling date.

Al-Hamzawi and Al-Gharabi (2019) focused on investigating the levels of lead (Pb), cadmium (Cd), copper (Cu), and zinc (Zn) in soil samples collected from residential, industrial, and agricultural areas of Al-Diwaniyah Governorate in southern Iraq. Atomic absorption spectroscopy (AAS) was employed as an effective technique to analyze the heavy metal concentrations and then assess the degree of pollution. The results indicated that the mean concentrations of Pb, Cd, Cu, and Zn in the soil samples were 31.75 mg/l, 1.804 mg/l, 18.51 mg/l, and 29.82 mg/l, respectively. The study found that heavy metal concentrations were higher in the industrial regions compared to other locations. Furthermore, the mean values of Pb and Cd exceeded acceptable limits indicating varying degrees of pollution with heavy metals in the studied soils.

Al-khafaji and Jaafar (2023) worked on collected soil samples from Al-Zubair City using the technology of ICP-MS as it is used for this study too. Heavy metals such as (Zn, Pb, Cd, Ni, Fe, Co, Cr, Cu and Mn) were measured to evaluate the pollution level in the soil. They used several pollution indices like geo-accumulation index, pollution index, and enrichment factor. Fe, Zn and Co were amongst the most affecting heavy metals on polluting the study area. And as indicated by the study, industrial emissions of oil refineries, vehicle emissions and oil exploration processes are the major factors attributed as anthropogenic sources of pollution.

Al-Khafaji and Jalal (2020) also studied heavy metals but in Basrah. The concentration of the studied heavy metals were determined in 16 soil samples in the urbanized area of the city using inductively coupled plasma-mass spectrometry technique to evaluate the pollution potential by other indices of pollution such as mean values PI and I_{geo}. The authors found that the sources of pollution are mainly from industrial emissions and vehicle exhausts. The main heavy metals which exceeded the normal range were nickel and chromium.

Khudhur and Khudhur (2015) studied and assessed soil pollution of Erbil City's industrial area using AA 500 atomic absorption spectrometer to analyze heavy metals. The results showed that the ranges of Ni, Zn and Pb were between 0.399±0.061 and 0.982±0.048 ppm; 1.439±0.006 and 3.078±0.003 ppm and 1.26±0.069 and 17.472±0.058 ppm, respectively. The concentrations of Cr and Cd were below the detection limit and Cu level differed from 11.407 ± 0.434 to 0.073 ± 0.003 ppm, The Cu was not detected in certain sites.

Al-Rubaiee and Al-Owaidi (2022) aimed to assess the contamination level of heavy metals in Hilla City considering the impact of urban expansion and population growth. The concentrations of heavy metals (Cr, Mn, Ni, Cu, Zn, As, Zr, and Pb) were determined in industrial and residential soils. The mean concentrations and enrichment factors varied among the metals in both areas. In industrial soils, the mean enrichment factors were higher for Pb (11.44), Ni (6.45), and Zn (5.60), while in residential soils, the mean enrichment factors were higher for Ni (11.40), As (5.39), and Pb (3.6). The I_{geo} values indicated that Mn, Pb, and Ni were the most abundant heavy elements in the industrial area, while Mn, Ni, and as were predominant in the residential area. The Integrated Pollution Load Index confirmed high contamination levels in both industrial and residential areas. Anthropogenic sources were identified as the main contributors to heavy metal pollution in the study area.

Aim of study

The assessment of the levels of contamination by studied elements is carried out using the geo-accumulation index (I_{geo}), correlation coefficient, R-mode factor analysis, and contamination factor (CF) to identify the potential sources of the heavy metals causing soil pollution in Erbil City. The study aims also to identify locations with potential soil pollution and to compare chemical compositions of collected samples with each other, with previous studies, and with international standards, and then proposing solutions to address soil pollution problems.

Geomorphology of the Study Area

The baseline state of the research area's social and environmental conditions was established using a strategic method. This required acquiring information about the environmental parameters by fieldwork (observation, on-site measurements, and sample collection), as well as laboratory examination of the samples that were obtained. The next section provides a physical description of the research area.

Relief and Drainage

In this area, most of the streams run in a south-westerly direction. The tiny tributaries enter the main river in a tree-like arrangement, which is the typical drainage pattern in this research region. The area's drainage system is typically identified by the accumulation of several tiny bodies of water and streams that are dry for extended periods of time. The buildings in the study region influence the normal trellis drainage pattern.

Material And Methodology

To make all the objectives achievable, different methods are used based on our baseline. All of them are successful. The utilized methods are:

Study area

Preliminary research was done prior to the fieldwork exercise starting. The initial research included a desk examination of earlier work. The area's various satellite imageries were then obtained. To have a better knowledge of the application of remote sensing and ARC GIS for geological mapping, literature on the subject issue is also obtained and analyzed. The study was conducted in accordance with the (Table 1) below.

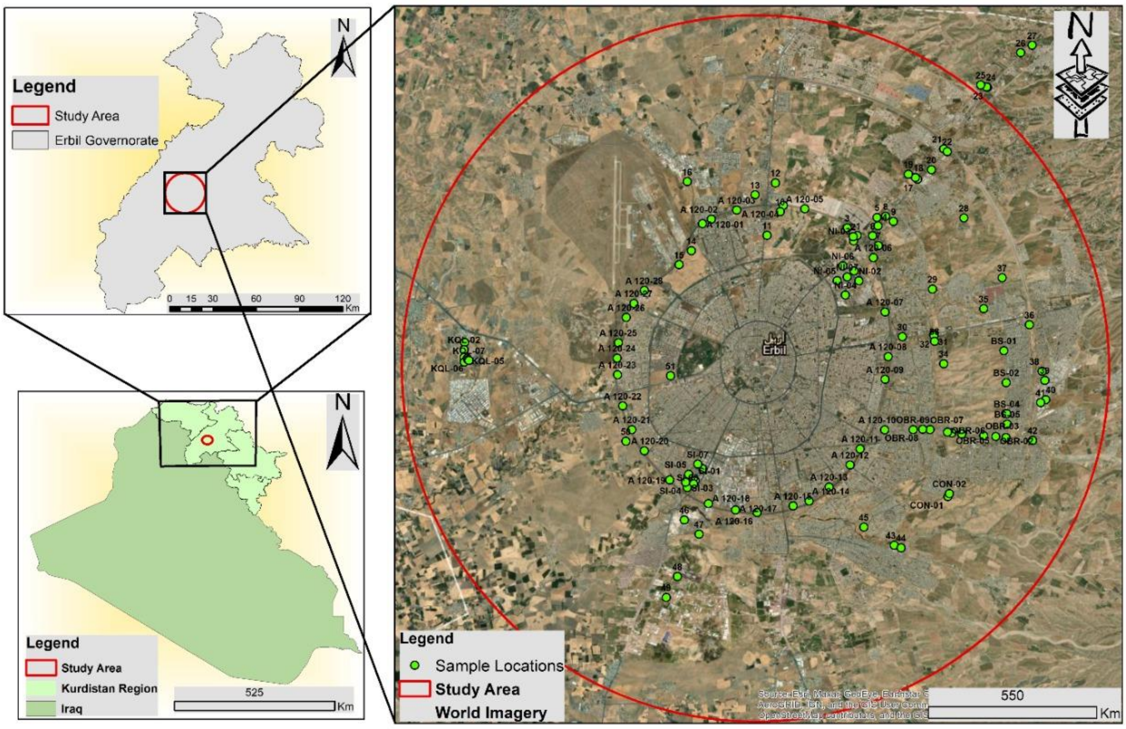

Fig. 1. Study area and sample's locations.

Table 1: Summary of sample codes and locations

Sample code	Northing	Easting
A 120-01	36 14 16	43 59 06.4
A 120-02	36 14 22	43 59 20.5
A 120-03	36 14 34	44 00 00.3
A 120-04	36 14 40.4	44 01 13.3
A 120-05	36 14 36.4	44 01 47.3
A 120-06	36 13 35.1	44 03 36
A 120-07	36 12 25.7	44 03 55
A 120-08	36 11 28.7	44 04 00.6
A 120-09	36 10 59.7	44 03 56.3
A 120-10	36 09 55.4	44 03 56.3
A 120-11	30 09 30.6	44 03 18
A 120-12	36 09 10.1	44 03 02.4
A 120-13	36 08 41.7	44 02 30
A 120-14	36 08 23.4	44 01 58.6
A 120-15	36 08 17	44 01 33.7
A 120-16	36 08 08.2	44 00 37
A 120-17	36 08 11	44 00 03
A 120-18	36 08 19	43 59 20.3
A 120-19	36 08 48.5	43 58 19.2
A 120-20	36 09 25.4	43 57 39
A 120-21	36 09 52.3	43 57 19
A 120-22	36 10 22.3	43 57 04
A 120-23	36 11 02.2	43 56 55.5
A 120-24	36 11 23.4	43 56 54.6
A 120-25	36 11 43	43 56 56.3
A 120-26	36 12 15.4	43 57 08
A 120-27	36 12 33.4	43 57 20
A 120-28	36 12 50	43 57 36.1
NI-01	36 13 17.7	44 03 05.7
NI-02	36 13 05.1	44 03 13.3
NI-03	36 13 56	44 03 04.7
NI-04	36 12 47	44 02 52.4
NI-05	36 13 05	44 02 39.4
NI-06	36 13 10	44 02 42.2
NI-07	36 13 55	44 02 57.8
SI-01	36 08 48	43 58 59
SI-02	36 08 44	43 58 57
SI-03	36 08 39	43 58 47
SI-04	36 08 46	43 58 44
SI-05	36 08 56	43 58 49
SI-06	36 08 12	43 57 55
SI-07	36 08 24	43 57 40

KQL-01	36 11 41.4	43 52 54.4
KQL-02	36 11 32	43 52 53.5
KQL-03	36 11 22	43 52 53.7
KQL-04	36 11 16	43 52 54.2
KQL-05	36 11 21	43 52 59
KQL-06	36 11 19	43 52 59.5
KQL-07	36 11 18.3	43 53 01.4
BS-01	36 11 37.8	44 07 02.7
BS-02	36 10 57	44 07 06.5
BS-03	36 10 17.2	44 07 06
BS-04	36 10 17.2	44 07 08
BS-05	36 10 04	44 07 09
OBR-01	36 09 47	44 07 07
OBR-02	36 09 48	44 06 51
OBR-03	36 09 49	44 06 32
OBR-04	36 09 51	44 05 57.6
OBR-05	36 09 52	44 05 42
OBR-06	36 09 53	44 05 35
OBR-07	36 09 56	44 05 07.7
OBR-08	36 09 56.5	44 04 56
OBR-09	36 09 56	44 04 41
CON-01	36 08 31	44 05 36.7
CON-02	36 08 34.6	44 05 38.8

Samples analysis

The concentrations of 25 trace elements (Ag, Al, Be, Ca, Cd, Co, Cu, Cr, As, B, Ba, K, Mg, Mn, Pb, Sb, Se, Mo, Na, Ni, Th, Ti, V, Zn) in the soil samples are measured utilizing inductively coupled plasma- mass Spectrometry (ICP-MS) SHIMADZU ICPE-9820 at Atmosphere labs in Erbil. The samples collected from each site are manually homogenized and weighed to 0.5 g utilizing a microbalance capable of weighing 100 g. To prepare the samples for analysis, they are digested with a mineral acids' digestion reagent (HNO3 65% HCL 36% and HF 40%) because ICP-MS requires aqueous and homogeneous solution. It is a recent development in analytical chemistry using microwave technique in extracting heavy metals from contaminated soil (Sastre, 2002). The resulting digested samples are then treated with the operation method of appropriately adding (6 milliliters of HNO3, 2 ml of HCL, and 2 ml of HF) through high pressure microwave digesters (BIOBASE) and microwave oven, which will significantly reduce time, effort, and solvent wastage.

Results And Discussion

The soil study is made using the geochemical approach, which resulted in 18 detectable elements are (Ag, As, B, Ba, Be, Cd, Co, Cr, Mo, Ni, Pb, Sb, Se, Th, Ti, U, V, and Zn) as shown in the (Table 2). Some not detected trace elements are (Ga, Bi, In, and Sr) because they are below the detection limits of ICP-MS capacity.

Table 2: Summary of Averages per metal in all locations in Erbil City (ppm).

No.	Elements	Mean	Std. Error	Std. Deviation
1	Ag	0.86	0.018	0.145
2	As	4.17	0.117	0.945
3	B	8.95	0.367	2.965
4	Ba	50.93	4.882	39.363
5	Be	58.231	4.607	37.148
6	Cd	0.777	0.077	0.624
7	Co	7.145	0.379	3.057
8	Cr	4.117	0.343	2.771
9	Mo	2.61	0.095	0.768
10	Ni	29.867	10.4	83.846
11	Pb	1.668	0.055	0.444
12	Sb	0.244	0.006	0.049
13	Se	0.733	0.067	0.545
14	Th	2.289	0.0835	0.673
15	Ti	180	25.047	201.94
16	U	0.345	0.01	0.079
17	V	124.15	4.958	39.972
18	Zn	74.625	2.169	17.49

Correlation Coefficient

The provided table 3 presents correlation coefficients pertaining to 18 distinct elements observed in 65 soil samples, thereby providing valuable insights into the interrelationships existing among these elements. The correlation coefficients, as elucidated by Pearson's correlation analysis, indicate the magnitude and direction of linear relationships between variables, specifically, the concentrations of elements in soil samples. The coefficients in question span a range from -1, which signifies a perfect negative correlation, to 1, which signifies a perfect positive correlation (Kumar, Bhargava and Choudhury, 2016; Sedgwick, 2012). A value of 0 indicates the absence of a linear correlation. The significance levels, represented by the values 0.01 and 0.05, indicate the likelihood of observing these correlations solely due to random chance.

The data reveals several noteworthy correlations. As an example, silver (Ag) exhibits strong positive associations with various elements, such as arsenic (As), boron (B), cobalt (Co), molybdenum (Mo), lead (Pb), antimony (Sb), thorium (Th), titanium (Ti), uranium (U), and zinc (Zn). The observed strong positive associations exhibit statistical significance at the 0.01 level. Likewise, lead (Pb) exhibits significant positive associations with elements such as arsenic (As), boron (B), cobalt (Co), molybdenum (Mo), antimony (Sb), and thorium (Th).

The data also reveals the presence of moderate positive correlations, as exemplified by the elements beryllium (Be), chromium (Cr), nickel (Ni), and vanadium (V). Chromium exhibits moderate positive correlations with cobalt (Co) and nickel (Ni) as observed in the data.

Moreover, the data exhibits negative correlations with the element barium (Ba) as well as several other elements. However, it is worth noting that these correlations typically exhibit a low magnitude and lack statistical significance (Kumar, Bhargava and Choudhury, 2016).

The presence of strong positive correlations between lead (Pb) and several other elements in the soil indicates the possibility of co-occurrence. The observed phenomenon can be ascribed to either anthropogenic activities or natural processes that exert an influence on the spatial arrangement of elements within the soil. Elements such as molybdenum (Mo) and antimony (Sb) demonstrate significant positive associations with various elements suggesting potential common origins or similar patterns of movement within the soil (Kumar, Bhargava and Choudhury, 2016).

It is imperative to underscore that correlation coefficients do not establish a causal relationship. Although these coefficients indicate correlations between variables, they do not reveal causal relationships. The presence and distribution of elements in soil can be influenced by a variety of factors, including geological formations, land usage, and pollution sources.

Table 3: Correlation coefficients of the distinct 18 elements in 27 soil samples.

No.		Ag	As	B	Ba	Be	Cd	Co	Cr	Mo	Ni	Pb	Sb	Se	Th	Ti	U	V	Zn
1	**Ag**	1	.831**	.530**	-0.228	.318**	0.098	.288*	0.083	.604**	0.152	.323**	.644**	0.044	.434**	.245*	.698**	.398**	.455**
2	**As**		1	.608**	-0.157	.328**	.338**	0.227	.257*	.601**	0.214	.526**	.755**	.331**	.355**	0.157	.605**	.409**	.626**
3	**B**			1	0.176	.872**	.426**	.424**	.408**	.873**	0.129	.478**	.764**	.306*	.558**	0.219	.561**	.728**	.647**
4	**Ba**				1	.249*	0.135	-0.123	0.114	0.006	-0.059	0.033	0.034	0.069	0.214	-0.082	-0.2	0.162	0.046
5	**Be**					1	.370**	.321**	.359**	.738**	0.059	.408**	.634**	.268*	.470**	.320**	.458**	.662**	.396**
6	**Cd**						1	.531**	.616**	.399**	-0.032	.849**	.654**	.795**	.622**	.553**	.485**	.502**	.395**
7	**Co**							1	.525**	.432**	-0.033	.423**	.443**	.305*	.507**	.316*	.462**	.463**	.323**
8	**Cr**								1	.353**	0.014	.465**	.465**	.421**	.527**	0.232	0.134	.582**	.431**

9	**Mo**	1	0.127	.449**	.725**	0.209	.563**	.358**	.603**	.725**	.587**
10	**Ni**		1	0.041	0.108	0.032	-0.072	-0.054	0.056	0.027	0.084
11	**Pb**			1	.788**	.842**	.660**	.610**	.652**	.543**	.319**
12	**Sb**				1	.576**	.707**	.464**	.762**	.730**	.586**
13	**Se**					1	.461**	.421**	.411**	.296*	.261*
14	**Th**						1	.530**	.598**	.761**	.396**
15	**Ti**							1	.517**	.395**	0.106
16	**U**								1	.471**	.362**
17	**V**									1	.451**
18	**Zn**										1

**** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed)**

R-Mode Factor Analysis

The present study employs R-mode factor analysis to investigate the interrelationships among 18 distinct elements within the soil samples under examination. (Table 4) below presents the loading of these elements onto four distinct components. Moreover, this analysis yields eigenvalues, which indicate the magnitude of variance accounted for by each component, as well as the percentage of variance explained by each component and the cumulative variance percentages. These metrics facilitate our comprehension of the fundamental patterns and factors that impact the elemental composition of the soil (MacLeod, 2021).

Component (1) exhibits robust positive loadings for elements such as silver (Ag), boron (B), molybdenum (Mo), and vanadium (V). This implies that these elements exhibit similarities in terms of their origin or geological affiliations. This observation aligns with the notion that particular Geological formation, which generally belongs to Bakhtyari Formation and Recent deposits, can contribute to the simultaneous presence of distinct elements in soil samples. Samples taken from industrial areas and a landfill have higher concentration than those in the local background.

Component (2) demonstrates noteworthy factor loadings for the elements lead (Pb), cadmium (Cd), and selenium (Se). The elements exhibit a positive correlation suggesting the presence of shared pollution sources. Lead and cadmium are frequently linked to emissions from industrial and vehicular sources, resulting in their simultaneous presence in the soil.

Component (3) emphasizes the significance of chromium (Cr), Vanadium (V), Zinc and cobalt (Co) as pivotal elements. According to the factor analysis in table (2) below, component (3) is a geochemical factor related to elements that are frequently found in particular geological contexts and are impacted by human activity. High loadings of vanadium (V), cadmium (Cd), zinc (Zn), cobalt (Co), chromium (Cr), and zinc (Zn) indicate a geochemical signature suggestive of specific mineral resources and sources of environmental contamination (Qiu et al., 2021, John et al., 2023). The interpretation derived from the component analysis results is supported by these references, which offer in-depth information about the geological occurrences, environmental relevance, and anthropogenic influences of the materials associated with component (3).

The high factor loadings observed in this study indicate a potential geological connection or similar geochemical characteristics between Cr, V, Zn and Co in the soil. The observed correlations among these elements can be attributed to geological factors, such as formation homogeneity and minerals percentages.

Component (4) exhibits significant factor loadings for the elements barium (Ba), nickel (Ni) and, to a lesser degree, zinc (Zn). The elements in question may exhibit unique associations or origins in contrast to those found in the remaining components. Additional research could be conducted to examine the geological and environmental factors that contribute to this observed pattern. The enrichment of Zn and Ni in particular, may be attributed to the extensive anthropogenic input from industrial activities such as mining and smelting which can create organic complexes with carbonates and bicarbonates (Fletcher and Sposito, 1989).

Eigenvalues offer valuable insights into the relative significance of individual components in elucidating the variability present within a given data set. The first component exhibits the highest eigenvalue with 8.424 suggesting its importance in elucidating the variability observed in the elemental composition of the soil samples. Component (2) with 2.194, component (3) with 1.667 and component (4) has 1.137. The cumulative percentage of

variance, representing the combined contributions of all components, indicates that the first two components collectively account for approximately 59% (46.802% plus 12.191) of the total variance (Akbarpour et al., 2013; Hinkle et al., 1995).

Table 4: R-mode factor analysis of the studied soil samples.

No.	Element	Component (1)	Component (2)	Component (3)	Component (4)
1	**Ag**	0.688	0.088	-0.081	0.574
2	**As**	0.582	0.254	0.093	0.414
3	**B**	0.892	0.157	0.24	-0.095
4	**Ba**	0.183	0.048	-0.039	-0.852
5	**Be**	0.812	0.183	0.102	-0.28
6	**Cd**	0.187	0.81	0.451	-0.084
7	**Co**	0.294	0.258	0.649	0.294
8	**Cr**	0.209	0.291	0.827	-0.133
9	**Mo**	0.878	0.152	0.188	0.102
10	**Ni**	0.057	0.011	-0.067	0.006
11	**Pb**	0.304	0.895	0.181	0.058
12	**Sb**	0.706	0.564	0.192	0.141
13	**Se**	0.02	0.872	0.234	-0.092
14	**Th**	0.57	0.532	0.289	-0.029
15	**Ti**	0.256	0.695	-0.073	0.157
16	**U**	0.599	0.532	-0.08	0.45
17	**V**	0.733	0.284	0.368	-0.109
18	**Zn**	0.545	0.06	0.471	0.098
	Eigenvalues:	*8.424*	*2.194*	*1.667*	*1.137*
	Variance%:	*46.802*	*12.191*	*9.261*	*6.317*
	Cumulative %:	*46.802*	*58.993*	*68.255*	*74.571*

Contamination Factor

The level of sediment contamination by a metal is often expressed in terms of a contamination factor calculated as contamination factor (CF) equals to metal content in the sediment/ background value of metal (Wang et al., 2018). In this study, two background samples are analyzed and adopted as a reference value. According to Hakanson classification, CF < 1 refers to low contamination, 1 ≤CF ≤3 means moderate contamination, 3 ≤ CF ≤ 6 indicates considerable contamination, and CF > 6 indicates very high contamination (Forghani et al., 2023; Jin et al., 2022). As per elements Ag, As, B, Ba, Be, Cr, Ti, V, and Zn given in (Table 5), CF values are above the threshold for very high contamination. This suggests that these elements are present in the soil at concentrations significantly higher than the background values, posing a considerable risk to the environment and potentially to human health. The presence of these heavy metals in the soil could be attributed to various sources including industrial activities and anthropogenic pollution (Panghal et al., 2021). Additionally, elements like Cd, Co, Mo, Ni, Pb, Se, Th, and U exhibit CF values within the range of considerable contamination. While not as severe as very high contamination, these levels still indicate a notable presence of these elements in the soil, which may have adverse effects on the ecosystem and potentially pose risks to human health.

Bhuyan et al. (2019) identified several heavy metals including Mn, Ni, Cr, Cd with considerable to very high concentrations. These metals can pose potential environmental risks due to their elevated levels. Additionally, Cu, Pb, Zn, Co and V are found at moderate levels. However, As, Ba, Sr and Zr are present at relatively low concentrations

Table 5: Contamination Factor and Geo-accumulation index of soil samples in Erbil

Sample No.	Ag	As	B	Ba	Be	Cd	Co	Cr	Mo
1	6.40	27.63	103.70	1336.40	1070.80	5.05	53.00	345.98	24.84
2	6.99	26.27	94.97	1349.00	1025.07	4.94	51.45	346.46	23.55
3	6.22	26.53	79.60	1383.00	871.33	3.02	41.48	241.19	19.63
4	7.30	32.43	81.80	1233.00	691.96	4.70	40.64	244.56	22.27
5	5.22	25.03	62.17	515.00	474.23	3.40	30.69	174.08	17.15
6	5.20	24.77	60.03	516.90	370.77	4.61	34.37	174.26	17.42
7	8.61	38.17	86.17	965.86	676.80	9.83	68.24	264.59	24.12
8	7.52	35.70	74.97	341.35	491.30	3.52	46.66	250.41	20.80
9	8.63	36.33	66.87	387.77	609.62	9.93	78.72	295.85	20.80
10	8.50	37.40	64.47	272.40	313.87	3.13	89.68	256.15	19.38
11	7.50	36.53	60.53	451.67	233.39	5.09	51.83	197.73	18.90
12	8.51	33.13	55.03	268.60	344.05	4.14	80.10	260.00	15.96
13	7.84	38.50	65.60	327.13	258.54	3.17	62.54	203.56	19.68
14	8.22	37.80	58.63	236.26	262.70	3.17	69.46	234.43	19.35
15	9.38	41.67	56.67	271.60	205.33	5.14	50.60	233.99	21.54
16	9.71	40.47	59.73	185.78	303.96	8.96	88.88	276.17	44.93
17	6.88	29.00	39.23	637.69	51.76	4.16	30.15	184.53	14.10
18	6.34	29.27	38.77	453.21	20.77	2.80	43.65	257.45	13.66
19	6.90	28.67	40.43	629.67	25.57	2.50	67.71	317.82	12.74
20	8.76	34.63	49.43	387.03	43.38	3.30	68.00	211.96	16.01
21	9.16	41.30	50.20	278.74	29.69	4.00	51.93	231.71	14.98
22	8.47	36.77	40.17	424.13	34.12	3.25	63.57	194.30	12.94
23	8.22	32.43	44.23	339.92	37.24	2.85	52.27	210.32	13.63
24	7.81	32.07	40.50	561.83	14.59	3.22	53.62	198.78	12.34
25	7.52	32.47	101.77	188.62	1001.00	3.62	58.43	277.72	31.01
26	8.53	31.30	116.13	388.34	1136.82	11.15	76.15	299.46	33.72
27	8.89	37.43	102.53	824.08	974.85	3.58	54.50	321.95	28.90
28	8.43	34.93	94.47	411.54	887.32	4.51	58.52	356.77	28.51
29	7.63	37.43	94.80	328.82	575.55	3.55	63.59	567.11	30.10
30	9.80	50.80	115.87	324.79	1213.27	12.62	75.21	1323.92	31.49
31	10.15	51.90	121.03	159.42	1323.56	15.86	132.28	575.22	32.58
32	11.21	58.67	140.37	277.93	1193.21	4.88	76.90	750.05	37.55
33	11.14	55.03	125.13	778.95	867.34	9.43	66.34	466.62	34.15
34	6.94	58.63	122.93	840.74	1012.73	38.47	82.94	758.62	30.70
35	10.12	58.77	122.87	235.87	740.00	12.10	58.06	586.40	34.36
36	9.95	51.57	127.23	2307.83	911.24	21.78	78.01	860.92	32.68
37	6.88	36.40	88.83	1372.50	446.61	9.83	108.48	1315.24	24.90
38	8.75	46.47	101.43	170.90	807.10	8.92	76.50	1177.95	29.17
39	10.10	54.90	110.37	342.82	660.99	4.18	56.02	348.79	31.59
40	9.91	55.63	105.07	643.68	577.87	5.00	34.90	298.99	31.29
41	9.68	53.17	91.13	249.69	480.72	3.41	54.11	312.92	26.63
42	8.13	43.63	74.67	336.68	441.66	3.52	44.62	269.82	21.18
43	10.74	56.43	92.47	191.36	439.70	4.22	56.12	330.81	25.26
44	9.16	46.07	87.03	497.34	290.46	3.16	44.05	259.50	24.43
45	8.81	48.80	87.23	560.79	248.40	4.70	40.83	231.67	24.85
46	10.24	54.80	88.30	110.82	531.20	12.18	65.62	320.78	26.30
47	9.47	48.67	73.80	452.64	190.43	3.19	53.87	252.34	21.11
48	10.06	52.90	80.53	424.03	334.76	3.56	54.46	252.39	23.30
49	9.34	46.73	147.13	227.28	1112.52	3.64	112.37	273.25	38.34
50	9.22	45.60	137.80	902.08	1222.77	9.24	99.81	331.87	37.45
51	10.63	45.07	133.27	253.43	1202.72	11.00	118.95	597.54	35.98
52	9.36	46.70	140.30	892.03	1012.29	9.36	85.40	362.00	36.32
53	11.57	51.60	143.90	277.77	1232.79	13.22	102.90	434.03	38.83
54	11.03	53.53	148.43	823.59	1032.33	10.22	86.42	459.80	38.74
55	9.04	43.93	98.30	226.86	482.13	9.17	79.88	300.14	28.88
56	10.17	47.90	97.37	227.84	541.14	9.79	104.53	337.70	30.82
57	8.76	41.63	86.63	301.82	318.08	3.76	62.59	299.09	27.84
58	10.33	50.03	94.13	458.65	489.41	10.72	81.31	334.89	29.72
59	9.14	43.40	90.83	263.03	424.35	9.15	64.29	341.10	28.67
60	8.57	39.50	77.97	145.46	413.34	10.99	62.23	337.67	26.38
61	9.68	45.87	114.90	701.12	698.58	3.86	98.12	307.85	34.44
62	5.80	28.47	83.03	190.23	308.26	19.22	82.67	930.34	22.47
63	8.31	38.50	79.70	366.54	548.37	19.29	82.13	929.70	29.34
64	9.05	44.13	92.20	277.27	610.52	19.08	191.54	898.59	24.84
65	7.92	39.17	111.77	392.69	453.13	18.67	189.40	964.04	30.90
Background concentration	8.48	41.65	102	335	532	18.88	190.47	931	27.87
Sd	1.46	9.45	30	394	371	6.24	30.58	277	7.68
Min	5.20	24.77	39	111	15	2.50	30.15	174	12.34
Max	11.57	58.77	148	2308	1324	38.46	191.54	1324	44.90
Mean	8.68	41.71	89.50	509	58	7.78	71.45	412	26.09
I Geo	-0.14	-0.09	-0.04	2.20	0.73	0.44	-0.58	-0.08	0.10
CF	1.02	1.00	0.88	1.52	0.11	0.41	0.38	0.44	0.94

Table 5: continued.

Sample No.	Ni	Pb	Sb	Se	Th	Ti	U	V	Zn
1	131.52	10.99	1.64	4.95	16.21	412.73	2.58	834.02	798
2	139.20	11.68	1.86	4.75	19.83	424.81	2.62	1187.07	413
3	149.33	12.07	2.91	5.15	19.83	476.15	2.68	1174.20	604
4	156.00	11.91	1.98	4.50	15.15	395.27	2.14	1000.40	566
5	119.93	9.31	1.48	2.91	10.06	260.77	1.73	826.55	499
6	126.00	10.54	1.67	4.36	13.52	395.27	2.16	966.85	402
7	182.90	18.62	2.35	1.81	20.94	6682.37	3.83	1148.83	471
8	154.48	14.63	1.98	6.04	18.33	560.32	3.06	888.99	568
9	190.77	19.14	2.48	9.71	27.45	4130.30	4.28	1075.47	467
10	170.73	15.18	2.13	6.60	22.47	618.00	3.30	862.87	523
11	146.67	13.16	1.83	4.06	14.78	378.58	2.46	834.77	430
12	158.77	16.11	2.11	1.75	25.28	5684.80	3.59	1033.43	412
13	150.67	13.77	1.91	5.51	16.28	484.37	3.34	681.43	512
14	162.20	15.49	2.00	6.59	19.28	614.08	3.34	880.72	349
15	164.76	14.83	2.03	5.07	18.98	494.51	3.13	1050.40	437
16	176.32	17.57	2.43	2.54	26.76	6660.60	3.77	1474.60	511
17	113.83	12.67	1.49	3.90	16.66	416.16	2.08	649.74	717
18	135.17	12.97	1.86	5.16	21.20	488.62	2.48	1525.10	323
19	125.00	12.33	1.63	5.15	16.19	473.27	2.38	757.68	732
20	162.75	14.80	2.17	6.58	18.67	609.66	3.16	745.36	371
21	168.72	16.90	2.24	6.36	19.83	629.30	3.33	834.68	352
22	152.66	16.13	2.02	5.93	18.94	571.43	2.93	750.49	404
23	155.39	15.00	2.10	5.94	18.00	549.53	3.11	849.05	378
24	135.17	15.33	1.87	6.34	17.90	576.18	2.97	696.08	426
25	152.33	14.80	2.08	6.22	18.60	561.33	3.73	1246.30	341
26	188.67	19.40	2.55	10.13	23.38	6246.90	4.03	1390.50	576
27	179.54	16.51	2.45	7.52	26.09	684.09	3.87	1380.20	668
28	181.19	17.47	2.43	2.14	26.39	6068.70	3.51	1392.83	670
29	194.15	16.58	2.31	7.64	22.78	662.18	3.02	1555.50	645
30	332.56	21.00	2.98	12.94	26.99	4302.13	2.99	1647.00	770
31	355.67	23.16	3.33	15.09	26.79	4623.33	4.38	1796.00	804
32	293.00	18.13	3.06	7.87	25.94	587.89	3.80	2032.80	815
33	246.10	18.78	2.97	3.21	28.68	655.05	4.16	1732.80	844
34	284.27	41.40	3.92	38.15	28.47	5061.33	4.87	1601.07	788
35	258.56	21.49	3.09	11.83	26.14	4644.47	4.00	1629.60	789
36	255.25	26.66	3.26	21.32	52.69	4694.30	4.02	1910.90	792
37	233.15	16.20	2.39	3.64	24.16	675.55	2.38	2181.60	810
38	237.01	17.47	2.71	3.84	27.88	686.84	3.10	1444.30	769
39	6942.14	16.61	2.67	7.18	16.91	523.60	3.61	1191.80	736
40	194.42	13.35	2.42	4.02	12.28	312.11	2.59	1040.30	832
41	206.66	15.03	2.56	7.15	16.91	494.85	4.01	909.71	787
42	167.33	14.10	2.20	6.28	16.11	450.38	3.26	887.01	763
43	202.33	15.39	2.61	5.40	20.84	404.63	3.97	979.76	822
44	172.00	13.44	2.30	5.42	18.69	399.55	3.11	1016.27	827
45	184.40	12.46	2.25	4.07	15.81	301.67	2.42	881.05	837
46	224.42	20.30	2.86	11.42	19.61	4395.47	4.53	999.62	819
47	181.72	13.97	2.30	6.52	20.23	468.57	3.20	762.05	818
48	190.35	15.27	2.51	7.49	18.69	554.62	3.40	978.48	728
49	196.23	16.20	2.68	7.30	23.50	568.97	3.40	1303.40	776
50	206.57	17.40	2.82	3.15	30.16	656.98	3.43	1832.60	827
51	230.46	19.70	3.08	10.58	34.74	4380.60	4.28	1989.70	834
52	209.89	17.33	2.83	2.74	27.25	629.16	4.14	1626.10	787
53	254.33	21.73	3.43	12.72	35.92	4821.60	6.12	2051.40	812
54	247.55	18.70	3.24	3.42	32.85	690.90	4.65	1999.13	782
55	196.88	17.30	2.57	2.35	26.30	626.22	3.87	1371.70	828
56	214.83	18.63	2.86	9.53	29.06	4211.73	3.95	1808.33	832
57	189.31	14.40	2.42	7.22	23.28	506.42	3.20	1188.33	811
58	213.21	18.63	2.77	9.86	29.11	4218.50	4.34	1405.33	854
59	198.19	16.17	2.49	2.58	25.55	644.48	3.74	1469.33	824
60	188.54	18.00	2.45	10.01	24.37	3891.20	4.28	1176.00	855
61	193.84	16.40	2.60	7.98	20.42	581.95	4.67	978.04	770
62	335.67	20.83	2.41	18.56	33.32	3522.60	2.85	1538.60	788
63	207.66	15.55	2.66	8.13	27.48	2249.52	3.90	1120.07	784
64	195.17	17.53	2.52	8.95	24.16	1878.40	4.22	1279.98	781
65	249.25	19.53	2.46	13.47	26.78	1742.76	3.25	1243.35	797
Background concentration	222.21	18.53	2.49	11.21	25.47	1810.60	3.74	1261.67	789
Sd	838.46	4.44	0.49	5.45	6.73	2019.39	0.79	399.72	175
Min	113.83	9.31	1.48	1.75	10.06	260.77	1.73	649.74	323
Max	6942.14	41.40	3.92	38.15	52.69	6682.37	6.12	2181.60	855
Mean	298.67	16.68	2.44	7.33	22.89	1804.13	3.46	1241.51	669
I Geo	4.38	0.574	0.071	1.181	0.463	1.3	0.127	0.205	-0.47
CF	1.344	0.9	0.982	0.654	0.899	0.996	0.925	0.984	0.847

About table (5) above, the index of geo-accumulation (I_{geo}) is computed using the equation:

$$I_{geo} = log_2 Cn/1.5\ Bn$$

Where *Cn* is the measured concentration of the element in the sediment fraction; and *Bn* is the geochemical background value in the earth's crust where average shale value taken from Erbil City. The constant *1.5* is used to compensate for possible variations with respect to background due to lithogenic variations. Six classes of geo-accumulation indices are distinguished (Table 6).

Table 6: Classes of geo-accumulation indices.

Class	Value	Sediment Quality
0	I_{geo} 0	Practically uncontaminated
1	I_{geo} 0-1	Uncontaminated to moderately contaminated
2	I_{geo} 1-2	Moderately contaminated
3	I_{geo} 2-3	Moderately to heavily contaminated
4	I_{geo} 3-4	Heavily contaminated
5	I_{geo} 4-5	Heavily to extremely contaminated
6	I_{geo} 5-6	Extremely contaminated

The geo-accumulation index provides an indication of the contamination level of each element compared to the background value. The index values allow for the classification of the contamination level into six categories. A negative I_{geo} value indicates low contamination, values between 0 and 1 indicate moderate contamination, values between 1 and 2 indicate moderately contaminated, values between 2 and 3 indicate heavily contaminated, values between 3 and 4 indicate very heavily contaminated, and values greater than 4 indicate extremely contaminated.

Greater I_{geo} values are indicative of much greater levels of contamination in metals, such as nickel (Ni), lead (Pb), titanium (Ti), and selenium (Se), as compared to their natural background levels. For example, Ni and Ti exhibit severely contaminated and moderately contaminated statuses, respectively, indicating that environmental quantities of these elements have been extensively impacted by human activity.

Analyzing table (5), it can be observed that the I_{geo} values vary for each element. Comparing our results with Al-Rubaiee and Al-Owaidi (2022) and Al-Dulaimi and Al-Mallah (2024), it is found that the geo-accumulation index values for Cr exhibit a range of 0.12 to 0.59, with a mean value of 0.28. This indicates a moderate degree of contamination suggesting that the industrial activities in the studied area may have contributed to the accumulation of chromium in the soil. Similarly, for Mn, the geo-accumulation index values range from 0.90 to 1.51, with a mean of 1.17 indicating a moderate to high degree of contamination. The higher geo-accumulation index values for Mn may be attributed to industrial emissions or other anthropogenic activities in the area.

The variations in geo-accumulation index values for Cr, Mn, Ni, Cu, and Zn suggest different degrees of contamination potentially influenced by local industrial activities, geological characteristics, and specific anthropogenic inputs. Further analysis including comprehensive site-specific investigations and consideration of additional factors is necessary to fully understand the implications of heavy metal contamination and to inform appropriate mitigation measures for environmental protection and human health preservation (Al-Sheraefy et al., 2023).

Comparing the findings of this study with Khudhur et al. (2018), which was conducted on soils in the vicinity of Erbil Steel Factory (ESC), it is evident that there are variations in the geo-accumulation index values for the same elements in both studies. For example, the geo-accumulation index values for Cr in this research range from 6.59 to 9.71 indicating a high degree of contamination, while Khudhur et al. (2018) found different results (the geo-accumulation index values for Cr range from -2.19 to -1.47) which suggests a moderate to high degree of contamination. These differences in values may be attributed to variations in the industrial processes, local soil characteristics, and the proximity to pollution sources in the respective study areas. Furthermore, it is evident that there are differences in the geo-accumulation index values for the elements Cr, Ni and Zn between the two studies.

To compare our results with another study by Amjadian et al. (2016) and Al-Sheraefy et al. (2023) conducted in Erbil metropolis, we can see more or less the same trend for the same heavy metals studied by both parties. The only exception is that the anthropogenic intensity in this study is higher, while the trend looks more or less the same.

A recent study conducted by Khudhur et al. (2021) in Erbil's north industrial area showed that the majority of the studied elements were uncontaminated to moderately contaminated beside cadmium, which was strongly associated with this study too. Lead, however, was not matching with our study due to the newly implemented environmental standards and procedures in the area which led to the decrease in the anthropogenic input of the heavy metals in the area.

There are variations between the geo-accumulation index reported by Salah et al. (2013) and that of this study presented. Salah et al. (2013) stated that Cu, Zn, Ni, Pb, Mn, Co, Cr, and Cd are generally uncontaminated urban soils with negative I_{geo} values for most metals, except for Cd, which showed slight contamination. In contrast, this study finds a broader range of elements including Ag, As, B, Ba, Be, Cd, Co, Cr, Mo, Ni, Pb, Sb, Se, Th, Ti, U, V, and Zn.

As to compare the current results with that conducted by Al-Dulaimi and Al-Mallah (2024) on Erbil's Eucalyptus tree leaves, it is clear that the geo-accumulation index results of Ni and Pb are consistent, while others are ranking differently.

Conclusion

18 heavy and toxic metals in 65 soil samples collected from different land uses in the city of Erbil are analyzed by ICP-MS and used for a variety of analytical methods including correlation coefficient, R-mode factor analysis, geo-accumulation index, and contamination factor. The results show that heavy metals including Ag, As, B, and Be show inconsistent distribution across the studied areas pointing to the uneven distribution of their primary causes: industrial production and untreated sewage sludge. Heavy metals are found to be significantly associated with the identified components using the R-mode factor analysis, which explained a range of percentages of the overall variation.

Ni, Ba, and as show contamination enrichment when studied with contamination factor analysis, which is consistent with other parameters use. Geo-accumulation index reveals the increased amount of Ti, Si, Ba, and Ni. Combining the study of R-mode and I_{geo}, we can extract three factors of this enrichment. The extreme industrial activities and anthropogenic input can be the factor number one. Lithological factor is the second, and the final factor is the winter season of the sampling

From the results of this research, it is concluded that heavy and toxic metals in soil are significantly influenced by anthropogenic input including traffic and industrial activities. Different land uses also affected the studied elements such as the increased concentration of Pb, Cd and Zn in industrial areas and roadsides. While Arsenic is higher in agricultural lands.

The study, using a categorization system developed by Hakanson, has determined how contaminated sediments were with a variety of metals. Previous studies suggested the area was relatively free of harmful metal contamination, but there have been reports where metal levels are abnormally high. Because baseline concentrations and the impact of human activities vary, the study has stressed the need to consider context when assessing contamination levels. In addition, heavy metal contamination in the region needs to be monitored and managed on a continual basis because of the emission of heavy metal-containing effluent from the chlor-alkali business.

Erbil metropolis as one of the most important cities in Iraq due of its location has a heavy load of traffic including various types of heavy and light vehicles and machineries including petroleum product transportation leads to the need of extensive air and soil quality monitoring program and implementing more restrictions to this extensive anthropogenic input.

Acknowledgements

Our deepest thanks go to our family for their constant support and encouragement during the field work. Furthermore, we would like to express our heartfelt gratitude to my committed colleagues in the department for their essential ideas and teamwork, which substantially improved the study process. Lastly, we sincerely appreciate the corrections and notes from the reviewers and editors to improve the manuscript.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

References

Mohammed, F.A., Smail, S.Q., and Kettanah, Y.A., 2013. Environmental Significance of Major and Trace Elements in the Soils of Selected Areas in Erbil City, Kurdistan Region, Northern Iraq. Iraqi National Journal of Earth Science (INJES), 13, pp. 15-32. https://doi.org/10.33899/earth.2013.79658

Al Obaidy, A.H.M. and Al Mashhadi, A.A., 2013. Heavy Metal Contaminations in Urban Soil Within Baghdad City, Iraq. https://doi.org/10.4236/jep.2013.41008

Al-Bassam, Kh.S. and Hak, J., 2006. Metallic and Industrial Rocks and Minerals. In: Geology of Iraq. Edited by S. Z. Jassim, and J. C. Goff, Published by Dolin, Prague and Moravian Museum, Brno, Chapter 20, pp. 288-302.

Al-Dulaimi, T. and Al-Mallah, A., 2024. Comprehensive Evaluation of some Heavy Metals in Dust Deposited on Eucalyptus Tree Leaves and their Health Effects in Erbil City, Northern Iraq. Iraqi Geological Journal, 57, pp. 267-287. https://doi.org/10.46717/igj.57.1a.19ms-2024-1-30

Al-Sheraefy, R., Al-Mallah, A. and Hussien, A., 2023. Spatial Distribution of Heavy Metals in the Soil of Different Area at Right Bank in Mosul City, Northern Iraq, Part 1. Iraqi Geological Journal, 56, pp. 40-61. https://doi.org/10.46717/igj.56.1c.4ms-2023-3-15

Al-Hamzawi, A.A. and Al-Gharabi, M.G., 2019. Heavy Metals Concentrations in Selected Soil Samples of Al-Diwaniyah Governorate, Southern Iraq. SN Applied Sciences, 1(8), 854. https://doi.org/10.1007/s42452-019-0892-7

Ali, H., Khan, E. and Ilahi, I., 2019. Environmental Chemistry and Ecotoxicology of Hazardous Heavy Metals: Environmental Persistence, Toxicity, and Bioaccumulation. Journal of Chemistry, 2019. https://doi.org/10.1155/2019/6730305

Alkan, U., Çalışkan, S., Birden, B. and Cindoruk, S., 2000. Effluent Discharges and Size of Fecal Pollution Along Mudanya Coasts, Symposium Book of Marmara Sea 2000, 11–12 Nov. 2000. In B. Öztürk, M. Kadıoğlu, and Öztürk, H. (Eds.), Türk Deniz Araştırmaları Vakfı, Publ. No: 5, pp. 536-542. (in Turkish)

Al-Khafaji, S. and Jaafar, S., 2023. Heavy Metals Pollution Assessment in Soil of Al-Zubair area, Southern Iraq. Iraqi National Journal of Earth Science (INJES), 23, pp. 91-104. https://doi.org/10.33899/earth.2023.139641.1072

Al-Khafaji, S. and Jalal, K., 2021. Spatial Characteristics and Heavy Metals Pollution in Urban Soils of Basrah, Iraq. Indian Journal of Ecology. 21, pp. 969-978.

Al-Rubaiee, A.K.H. and Al-Owaidi, M.R., 2022. Assessment of Heavy Metal Contamination in Urban Soils of Selected Areas in Hilla City, Babylon, Iraq, Iraqi Journal of Science, pp. 1627-1641. https://doi.org/10.24996/ijs.2022.63.4.21

Amjadian, K., Sacchi, E. and Rastegari Mehr, M., 2016. Heavy Metals (HMs) and Polycyclic Aromatic Hydrocarbons (PAHs) in Soils of Different Land Uses in Erbil Metropolis, Kurdistan Region, Iraq. Environ Monit Assess, 188, 605.https://doi.org/10.1007/s10661-016-5623-6

Balkıs, N. and Çağatay, M.N., 2001. Factors Controlling Metal Distributions in the Surface Sediments of the Erdek Bay, Sea of Marmara, Turkey. Environment International, 27, pp. 1-13. https://doi.org/10.1016/s0160-4120(01)00044-7

BaptistaNeto, J.A., Smith, B.J. and Mcallister, J.J., 1999. Heavy Metal Concentrations in Surface Sediments in Anearshore Environment, Jurujuba Sound, SE Brazil. Environmental Pollution, 108, pp. 1-9. https://doi.org/10.1016/s0269-7491(99)00233-x

Bhuyan, M.S., Bakar, M.A., Rashed-Un-Nabi, M., Senapathi, V., Chung, S.Y. and Islam, M.S., 2019. Monitoring and Assessment of Heavy Metal Contamination in Surface Water and Sediment of the Old Brahmaputra River, Bangladesh. Applied Water Science, 9(5), pp. 1-13. https://doi.org/10.1007/s13201-019-1004-y

Bodur, M.N. and Ergin, M., 1994. Geochemical Characteristics of the Recent Sediments from the Sea of Marmara. Chemical Geology, 115, pp. 73-101. https://doi.org/10.1016/0009-2541(94)90146-5

Casado-Martinez, Buceta, J.L., Belzunce, M.J. and Del Vals, T.A., 2006. Using Sediment Quality Guidelines for Dredged Material Management in Commercial Ports from Spain. Environment International, 32, pp. 388–396. https://doi.org/10.1016/j.envint.2005.09.003

CCREM (Canadian Council of Resource and Environment Ministers)., 1987. Canadian Water Quality Guidelines. Prepared by the Task Force on Water Quality Guidelines. https://doi.org/10.1080/02508068708686599

D.I.E., 2003. Statistical Report of Turkey, Publication of Turkish State Institute of Statistics. (in Turkish)

EPA, 1991. GEO-EAS (Geostatistical Environment Assess- Ment Software) Version 1.2.1 User's Guide, Environmen- tal Monitoring Systems Laboratory, US Environmental Protection Agency (EPA). EPA/600/8-91/008, Las Vegas, USA.

Ergin, M. and Bodur, M.N., 1999. Silt/Clay Fractionation in Surficial Marmara Sediments: Implication for Water Movement and Sediment Transport Paths in a Semi-Enclosed and Two-Layered Flow System (Northeastern Mediterranean Sea). Geo-River Letters, 18, pp. 225–233. https://doi.org/10.1007/s003670050072

Ergin, M., Saydam, C., Baştürk, Ö., Erdem, E. and Yörük, R., 1991. Heavy Metals Concentrations in Surface Sediments from Two Coastal Inlets (Golden Horn Estuary and Izmit Bay) of the northeastern Sea of Marmara. Chemical Geology, 91, pp. 269–285. https://doi.org/10.1016/0009-2541(91)90004-b

Fabris, G.J., Monahan, C.A. and Batley, G.E., 1999. Heavy Metals in Waters and Sediments of Port Phillip Bay, Australia. River and Freshwater Research, 50, 503–533. FAO 1989. Food Safety Regulations Applied to Fish by Major Importing Countries. Fisheries Circular No. 825, FAO, Rome. https://doi.org/10.1071/mf98032

Fletcher, P. and Sposito, G., 1989. The Chemical Modelling of Clay/Electrolyte Interactions for Montmorillonite. Clay Minerals, 24, pp. 375-391. https://doi.org/10.1180/claymin.1989.024.2.14

Forghani, G., Ehenzi, Z., Jafari, H., Moore, F. and Kazemi, G.A., 2023. Human Health Risk Assessment of Potentially Toxic Elements in the Soil and Groundwater Resources in Arid Areas: A Case Study of the Mojen Plain, Northeast Iran. Arabian Journal of Geosciences, 16(1), 35. https://doi.org/10.1007/s12517-022-11012-6

Förstner, U. and Salamons, W., 1980. Trace Metal Analysis on Polluted Sediments, Part:1: Assessment of Sources and Intensities. Environmental Technology Letters, 1, pp. 494-505. https://doi.org/10.1080/09593338009384006

Gonçalves, E.P.R. and Boaventura, R., 1991. Sediments as Indicators of the River Ave Contamination by Heavy Metals. Raposa, Integrated Approaches to Water Pollution Problems, pp. 209-218, London: Elsevier. https://doi.org/10.1201/9781482286694-32

Gonçalves, E.P.R., Soares, H.M.V.M., Boaventura, R.A.R., Machado, A.A.S.C. and Silva, J.C.G.E., 1994. Seasonal Variations of Heavy Metals in Sediments and Aquatic Mosses from the Cavado River Basin (Portugal). Science of the Total Environment, 114, pp. 7-24. https://doi.org/10.1016/0048-9697(94)90322-0

González-Macías, C., Schifter, I., Lluch-Cota, D.B., Méndez-Rodríguez, L. and Hernández-Vázquez, S., 2006. Distribution, Enrichment and Accumulation of Heavy Metals in Coastal Sediments of Salina Cruz Bay, Mexico. Environmental Monitoring and Assessment, 118(1), pp. 211–230. https://doi.org/10.1007/s10661-006-1492-8

Groot, A.J., Zschuppe, K.H. and Salomons, W., 1982. Standardization of Methods of Analysis for Heavy Metals in Sediments. Hydrobiologia, 92, pp. 689-695. https://doi.org/10.1007/978-94-009-8009-9_68

Güven, K.C., Saygı, N. and Öztürk, B., 1993. Survey of Metal Contents of Bosphorus Algae, Zostera Marina and Sediments. Botanica Marina, 36, pp. 175-178. https://doi.org/10.1515/botm.1993.36.3.175

Hinkle, M., Briggs, P.H., Motooka, J.M. and Knight, R.J., 1995. Analytical Results for Soil Samples and Plots of Results of R-Mode Factor Analysis of Soil and Soil-Gas Data; Dixie Valley Known Geothermal Resource Area, Northern Dixie Valley, Nevada, No. 95-485, US Geological Survey. https://doi.org/10.3133/ofr95485

Jin, B., Wang, J., Lou, W., Wang, L., Xu, J., Pan, Y. and Liu, D., 2022. Pollution, Ecological Risk and Source Identification of Heavy Metals in Sediments from the Huafei River in the Eastern Suburbs of Kaifeng, China. International Journal of Environmental Research and Public Health, 19(18), 11259. https://doi.org/10.3390/ijerph191811259

John, P.M., Sanjeevan, V. and Gopinath, A., 2023. Distribution of Vanadium in the Surficial Sediments of Prydz Bay, Indian Sector of the Southern Ocean. Soil and Sediment Contamination: An International Journal, 32, pp. 363-375. https://doi.org/10.1080/15320383.2022.2090501

Khudhur, N.S., Khudhur, S.M. and Ahmad, I.N., 2018. 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, 9(1), 1-11.

Khudur, N., Yassin, S.Q., Hassan, A.S. and Omar, M.N., 2021. Applying Some Indices for Soil Pollution Assessment in Northern Industrial Area from Erbil Governorate. Al-Qadisiyah Journal of Pure Science, 26, pp. 45-58. https://doi.org/10.29350/qjps.2021.26.4.1385

Khudur, S. and Khudur, N., 2015. Soil Pollution Assessment from Industrial Area of Erbil City, Journal of Zankoy Sulaimani, 17, pp. 227-240. https://doi.org/10.17656/jzs.10440

Kilgour, B. W., 1991. Cadmium Uptake from Cadmium-Spiked Sediments by Four Freshwater Invertebrates. Bulletin Environmental Contamination and Toxicology, 47, pp. 70–75. https://doi.org/10.1007/bf01689455

Krauskopf, K.B., 1979. Introduction to Geochemistry. (p. 6172nd ed.). Tokyo: McGraw-Hill Kogakusha, Ltd.

Kumar, A., Bisht, B.S., Joshi, V.D. and Dhewa, T., 2011. Review on Bioremediation of Polluted Environment: A Management Tool. International Journal of Environmental Sciences, 1(6), pp. 1079–1093.

Kumar, R., Bhargava, K. and Choudhury, D., 2016. Estimation of Engineering Properties of Soils from Field SPT Using Random Number Generation. INAE Letters, 1, pp. 77-84. https://doi.org/10.1007/s41403-016-0012-6

Lee, B.S., Bullister, J.L., Murray, J.W. and Sonnerup, R.E., 2002. Anthropogenic Chlorofluorocarbons in the Black Sea and Sea of Marmara. Deep Sea Research I, 49, pp. 895-913. https://doi.org/10.1016/s0967-0637(02)00005-5

Lucas, M.F., Caldeira, M.F., Hall, A., Duarte, A.C. and Lima, C., 1986. Distribution of Mercury in Sediments and Fishes of the Kagoon of Averio, Portugal. Water Science and Technology, 16, pp. 247–252. https://doi.org/10.2166/wst.1986.0189

MacLeod, N., 2021. R-Mode Factor Analysis. In: Daya Sagar, B.S., Cheng, Q., McKinley, J., Agterberg, F. (eds) Encyclopedia of Mathematical Geosciences. Encyclopedia of Earth Sciences Series. Springer, Cham.

Merian, E. 1991. Metals and Their Compounds in the Environment. Occurrence Analysis and Biological Relevance ISBN 0-89573-562-8, VCH New York. https://doi.org/10.1002/9783527619634

Mohajane, C. and Manjoro, M., 2022. Sediment-Associated Heavy Metal Contamination and Potential Ecological Risk Along an Urban River in South Africa. Heliyon, 8(12). https://doi.org/10.1016/j.heliyon.2022.e12499

Molvaer, J., Knutzen, J., Magnusson, J., Rygg, B., Skei, J., and Sørensen, J. 1997. Classification of Environmental Quality in Fjords and Coastal Waters, Veiledning. SFT-veiledning nr. 97: 03. TA-1467/1997. 36 P. (In Norwegian).

Mora, S. and Sheikholeslami, M. R., 2002. Final Report: Interpretation of Caspian Sea Sediment Data. ASTP: Contaminant Screening Programme, 27 P. https://doi.org/10.2172/6949064

Muniz, P., Danular, E., Yannicelli, B., Alonso, J. G., Medina, G. and Bicego, C., 2004. Assessment of Contamination by Heavy Metals and Petroleum Hydrocarbons in Sediments of Montevideo Harbour (Uruguay). Environment International, 29, pp. 1019-1028, https://doi.org/10.1016/s0160-4120(03)00096-5

Qiu, Z.J., Fan, H.R., Goldfarb, R., Tomkins, A.G., Yang, K.F., LI, X.C., Xie, L.W. and Liu, X., 2021. Cobalt Concentration in a Sulfidic Sea and Mobilization During Orogenesis: Implications for Targeting Epigenetic Sediment-Hosted Cu-Co Deposits. Geochimica et Cosmochimica Acta, 305, pp. 1-18. https://doi.org/10.1016/j.gca.2021.05.001

Romankevich, E.A., 1984. Geochemistry of Organic Matter in the Ocean. Berlin, Heidelberg, New York: Springer and Verlag. https://doi.org/10.1002/iroh.19860710423

Sahuquillo, A., Rigol, A. and Rauret, G., 2003. Overview of the Use of Leaching/Extraction Tests for Risk Assessment of Trace Metals in Contaminated Soils and Sediments. TrAC Trends in Analytical Chemistry, 22(3), pp. 152-159. https://doi.org/10.1016/s0165-9936(03)00303-0

Salah, E., Turki, A. and Noori, S., 2013. Heavy Metals Concentration in Urban Soils of Fallujah City, Iraq. Journal of Environment and Earth Science, 3(11), pp. 100-112. https://doi.org/10.4236/jep.2015.611112

Sarı, E. and Çağatay, M. N., 2001. Distributions of Heavy Metals in the Surface Sediments of the Gulf of Saros, NE Aegean Sea. Environment International, 26, pp. 169–173. https://doi.org/10.1016/s0160-4120(00)00097-0

Sastre, A.S.J., Vidal, M., and Rauret, G., 2002. Determination of Cd, Cu, Pb and Zn in Environmental Samples: Microwave-Assisted Total Digestion Versus Aqua Regia and Nitric Acid Extraction, Analytica Chimica Acta, Vol. 462, pp. 59-72. https://doi.org/10.1016/s0003-2670(02)00307-0

Sedgwick, P., 2012. Pearson's Correlation Coefficient. BMJ: British Medical Journal (Online), 345. https://doi.org/10.1136/bmj.e4483

Shiganova, T., Tarkan, A., Dede, A. and Cebeci, M., 1995. Distribution of the Ichthyo-Jellyplankton Mnemiopsis leidyi Agassiz, 1965 in the Marmara Sea. Turkish Journal of River Sciences, 1, pp. 3–12.

Soares, H.M.V.M., Boaventura, R.A.R., Machado, A.A.S.C. and Esteves da Silva, J.C.G., 1999. Sediments as Monitors of Heavy Metal Contamination in the Ave River Basin (Portugal): Multivariate Analysis of Data. Environmental Pollution, 105, pp. 311–323. https://doi.org/10.1016/s0269-7491(99)00048-2

Topçuoğlu, S., Kırbasoglu, Ç., and Gundor, N. 2002. Heavy Metals in Organisms and Sediments from Turkish Coast of the Black Sea, 1997–1998. Environment international, 27, pp. 521-526. https://doi.org/10.1016/s0160-4120(01)00099-x

Topçuoğlu, S., Kırbaşoğlu, Ç. and Yılmaz, Y.Z., 2004. Heavy Metal Levels in Biota and Sediments in the Northern Coast of the Marmara Sea. Environmental Monitoring and Assessment, 96, pp. 183–189. https://doi.org/10.1023/b:emas.0000031726.01364.47

Topçuoğlu, S., Kırbaşoğlu, Ç. and Güngör, N., 2001. Heavy Metals in Organisms and Sediments from Turkish Coast of the Black Sea. Environment International, 27, pp. 521–526. https://doi.org/10.1016/s0160-4120(01)00099-x

Ünlü, S. and Alpar, B., 2006. Sources and Geochemical Constraints of Hydrocarbons in Surface Sediments of Gemlik Bay (Marmara Sea, Turkey). Chemosphere, 64, pp. 764–777. https://doi.org/10.1016/j.chemosphere.2005.10.064

Ünlü, S., Alpar, B., Aydın, S., Akbulak, C., Balkıs, N., Barut, I., Meric, E., Aksu, A., and Kirbasoglu, C., 2006. Anthropo- Genic Pollution in Sediments from the Gulf of Gemlik (Marmara Sea, Turkey); Cause–Result Relationship. Fresenius Environmental Bulletin, 15(12a), pp. 1521–1560. https://doi.org/10.1016/j.chemosphere.2005.10.064

USEPA (United States Environmental Protection Agency), 1999. Update of Ambient Water Quality Criteria for Ammonia.

Uz, B., Esenli, F., Manav, H. and Aydos, Z., 1995. Authigeneous Mineral Composition of Pyroclastic Rocks Between Karamürsel and Yalova–NW Anatolia. Geosound, 27, pp. 135–147 (in Turkish).

Wang, W.H., Luo, X.G., Wang, Z., Zeng, Y., Wu, F.Q. and Li, Z.X., 2018. Heavy Metal and Metalloid Contamination Assessments of Soil Around an Abandoned Uranium Tailings Pond and the Contaminations' Spatial Distribution and Variability. International Journal of Environmental Research and Public Health, 15(11), 2401. https://doi.org/10.3390/ijerph15112401

Wuana, R.A. and Okieimen, F.E., 2011. Heavy Metals in Contaminated Soils: A Review of Sources, Chemistry, Risks and Best Available Strategies for Remediation. International Scholarly Research Notices, 2011. https://doi.org/10.5402/2011/402647

Yüksek, A., Okuş, E. and Yılmaz, N., 2004. The Effect of Dissolved Oxygen on the Distribution of Demersal Fish and Benthic Organisms in the Sea of Marmara (30–300 m). National Ecology and Environment Congress, pp. 219–228. Abant: Bolu. https://doi.org/10.1016/j.dsr.2023.104003