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Spatio-Temporal Analysis of Heavy Metals Concentration in The Soil for A Selected Sites in Mosul City

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ABSTRACT

This study aims to assess the concentrations of heavy metals in the soil of Mosul City and analyzed their spatial distribution. A total of 48 soil samples were collected from different sites in the city during the autumn 2022 and spring 2023 from a depth of 0-15 cm. The concentrations of heavy metals, including cadmium (Cd), zinc (Zn), arsenic (As), and nickel (Ni), using an (XRF) device. are measured and their characteristics are analyzed chemically and physically. Then comparing the results with the standards set by the (WHO) The results indicated that the soil texture ranged from loam to sandy clay loam, while pH values vary between 7.09 and 7.88. Electrical conductivity ranged from 0.75-4.04 µS/cm, and organic matter content ranged from 1.53%-2.43%.

Cadmium levels ranged from 0.08-0.17 ppm and not exceeding the permissible limits. However, nickel concentrations range from 116.92-188.79 ppm, exceeding the permissible limits in all study areas. A decrease in nickel concentrations during spring is observed due to rainfall. Zinc concentrations ranged from 102.64-1187 ppm, exceeding the permissible limits in industrial areas. Arsenic levels ranged from 1.12-55.10 ppm, with higher concentrations in spring due to rainfall, reaching its highest concentration in the Kokjli area. Spatial distribution maps indicated that the impact of heavy metal concentrations in the Karameh industrial area had a greater effect on adjacent areas compared to the impact of the Wadi Akab industrial area, which is considered more polluted. These maps also revealed the influence of the eastern part of the city with elevated nickel concentrations during spring.

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التقييم والتوزيع المكاني للمعادن الثقيلة في ترب مناطق مختارة في مدينة الموصل

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الملخص

هدفت هذه الدراسة إلى تقييم تراكيز المعادن الثقيلة في تربة مدينة الموصل وتحليل توزيعها المكاني. تم جمع مجموعة من 48 عينة تربة من مواقع مختلفة في المدينة خلال فصلي الخريف 2022 والربيع 2023 من عمق 0-15 سم. تم قياس تراكيز العناصر الثقيلة، بما في ذلك الكادميوم (Cd) , الزنك(Zn) , الزرنيخ (As) والنيكل (Ni) باستخدام جهاز(XRF) وتحليل خصائصها كيميائيًا وفيزيائيًا. ومقارنة النتائج مع محددات منظمة الصحة العالمية, أظهرت النتائج أن نسيج التربة يتراوح بين التربة الطينية والتربة الطينية الرملية، في حين تراوحت قيم درجة الحموضة (pH) بين 7.09 و 7.88. وتراوحت التوصيلية الكهربائية من 0.75 إلى 4.04 ميكروسيمنز لكل سم، وتراوحت محتوى المادة العضوية من 1.53% إلى 2.43%.

أما للعناصر الثقيلة، فقد تراوحت تراكيز الكادميوم من 0.08 إلى 0.17 جزء في المليون، وتراوحت تراكيز الرصاص من 3.13 إلى 24.57 جزء في المليون، ولم يتجاوز كلاهما الحدود المسموح بها. ومع ذلك، فقد بلغت تراكيز النيكل من 116.92 إلى 188.79 جزء في المليون، متجاوزة الحدود المسموح بها في جميع مناطق الدراسة. ولوحظ انخفاض تراكيز النيكل خلال فصل الربيع بسبب الأمطار. وتراوحت تراكيز الزنك من 102.64 إلى 1187 جزء في المليون، وتجاوزت الحدود المسموح بها في المناطق الصناعية. وتراوحت تراكيز الزرنيخ من 1.12 إلى 55.10 جزء في المليون، مع تراكيز أعلى في فصل الربيع بسبب الأمطار، ووصل أعلى تركيز في منطقة كوكجلي. أظهرت خرائط التوزيع المكاني أن تراكيز المعادن الثقيلة في صناعة الكرامة كان لها تأثير أكبر على المناطق المجاورة مقارنة بتأثير صناعة وادي عقاب، التي اعتبرت أكثر تلوثًا. كما كشفت هذه الخرائط عن تأثير الجزء الشرقي من المدينة بتراكيز نيكل مرتفعة خلال فصل الربيع.

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Introduction

All countries, including our region, face significant environmental challenges, with one of the most prominent problems, the pollution. Humans are primarily responsible for environmental pollution as a result of a lack of environmental awareness, improper environmental handling, insufficient environmental planning, and the spread of industrial zones in residential areas (Al-Qaisi et al., 2014). These factors contribute to increasing environmental problems and reduce the environment's capacity to cope with pollution and restore its natural resources.

The accumulation of heavy metals in the soil can have adverse effects on the environment and human health. The inability to degrade them and their accumulation in human tissues negatively impact health, leading to metabolic disorders, blood-related diseases, and brain damage (Al-Hayani, 2018). The expansion of urban areas on the expense of agricultural lands and improper land use necessitates the use of modern techniques to detect soil pollution (Sonayei et al., 2009).

Geographical Information System (GIS) and remote sensing help in determinating and assessing soil quality, identifying pollution sources, and providing accurate data. They aid land cover studies, offering valuable insights for decision-makers to address pollution issues and improve the environment (Al-Mutawwa'ri., 2020).

Evaluating the concentrations of heavy metals in soil is crucial for understanding pollution levels and soil degradation (Kazem, 2017). Numerous studies have been conducted globally and in Iraq, as well as in other Arab and international countries, to assess environmental pollution and analyze heavy metal concentrations in soil (Al-Tamimi et al.,2022).

The current study aims to assess and identify soil pollutants resulting from human activities in specific areas of the central district of Mosul. It also aims to estimate the concentrations of heavy metals in the soil and to create an informational database, along with environmental mapping, to illustrate the distribution of contaminated heavy elements in the soil. Many researchers have focused on local assessing of heavy metals in Iraq, such as Al-Tamimi et al., (2022) in Basra Governorate. They measured concentrations of lead, copper, cadmium, and chromium, with concentration rates being (0.135, 0.842, 0.045, 1.162) respectively. AL-Heety et al., (2021), in Ramadi City measured concentrations of heavy metal elements including chromium, nickel, zinc, lead, and cadmium, with concentrations of (360.9, 286.6, 190.96, 130.75, 2.55) respectively. Al-Azzawi, (2020) in Mosul City, soil pollution with heavy metal elements in industrial areas was investigated, including copper, cobalt, cadmium, zinc, and nickel. The study revealed that all soil samples were contaminated and exceeded permissible limits.

Materials and Methods

This study is conducted in the city of Mosul, situated in the northwestern part of Iraq, and bounded by longitudes (43º 4' 0" - 43º 16' 0") East and latitudes (36º 10' 0" - 36º 30' 0") North. The city is divided by the Tigris River, separating it into two sides: the right bank and the left bank. Three sites were selected from each side, and their coordinates are determined using a GPS. as shown in figure (1).

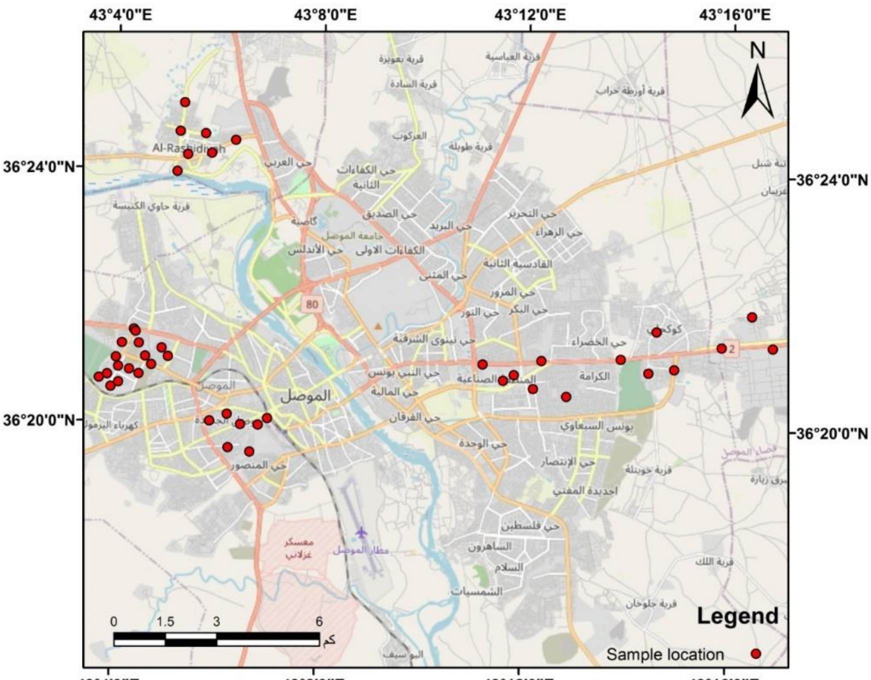

Fig.1. Map of the city of Mosul.

Soil samples are collected from the study sites at a depth of (0-15) cm during two specified periods, October 2022 and April 2023. Twenty-two samples are collected from each side of the city, eight samples from the industrial areas, and seven samples from residential and commercial areas, so, the total is 44 samples. Each sample is collected twice for further analysis.

The study sites on the right bank (the western part of Mosul) include the following areas: Mosul Jadida, Al-Islah Al-Zira'i, and Wadi Akab Industry. On the left bank, (the eastern part of Mosul), the study sites are Al-Rashidiya, Kokjali, and Karameh Industry. Notably, Wadi Akab Industry and Karameh Industry served as the primary industrial centers in the city and were located within their administrative boundaries. These areas featured workshops for car maintenance and repair, as well as various factories and plants, making them essential economic hubs in the city. The remaining sites are characterized by their mixed residential and commercial nature.

Description of the Study Area's Climate

Due to its elevation of two hundred and twenty meters above sea level, the climate of Mosul City is influenced by a semi-arid character. The summer months are marked by noticeable dryness and a significant rise in temperatures. On contrast, the winter months experience rainy precipitation, with temperatures dropping sometimes below freezing point. Both temperature and humidity levels are essential variables for estimating and comprehending environmental interactions. High and low temperatures have a direct impact on chemical and physical reactions, thereby affecting various environmental factors. These effects are also associated with heavy metals. Hence, when considering the impact of heavy metals on the environment, temperature and humidity must be taken into account as fundamental variables. For the autumn season of 2022 in Mosul, the respective rates of rainfall, humidity, and temperatures were (0.253, 29.583, 25.056) respectively. For the spring season of 2023, they were (0.355, 44.875, 18.21) respectively (IMOAS).

Methodology

Laboratory tests are conducted on the collected soil samples. The acidity level (pH) was determined using the Eutech pH 700 device, and the electrical conductivity was measured with the BC3020 electrical conductivity meter. Organic matter content was assessed using the Walkley-Black method, involving wet oxidation with dichromate. Additionally, the particle size distribution of the soil was analyzed. Furthermore, concentrations of selected heavy metal elements, including cadmium, lead, zinc, nickel, and arsenic, were measured in the soil samples using the X-Ray Fluorescence (XRF) device. The data included concentrations of heavy metal elements and coordinates for each soil sample. Furthermore, distribution maps of the heavy metal elements in the soil were created using the software ArcGIS 10.6.1, utilizing the database (element concentrations and sample coordinates).

To ensure accurate mapping, satellite imagery from the world view 2019 is employed as a georeferenced base map. This allows for overlaying the data on the imagery and obtaining spatial information. The interpolation method, specifically the Inverse Distance Weighting (IDW), is used to interpolate data points across the study area. Using (IDW) method in interpolation technology makes it easier for us to create maps for the chemical properties studied in this research. This is because it has provided reliable results, especially when the number of samples is more than 15 and the measurement methods are related to chemical properties. to obtain a continuous surface representation of heavy metal element concentrations in the soil, helping to identify areas of higher and lower pollution levels across the study area.

Results and Discussion

The chemical properties of the soil in the study area:

1- Soil Acidity (pH):

Soil pH is one of the key factors in determining soil pollution, as it plays a crucial role in the availability and mobility of elements within the soil (Al-Shurafi et al.,2023). The study reveals that the pH values are relatively similar for all the study sites. The highest pH value (7.88) is observed in the Karameh Industry area during the fall season. This can be attributed to the industrial nature of the area, as it lacks agricultural soil, making it inclined towards alkalinity (Salim and Alwaleed, 2019) as illustrated in Figure (2). On the other hand, the lowest pH value (7.09) is recorded in Mosul Jadida during the fall season.

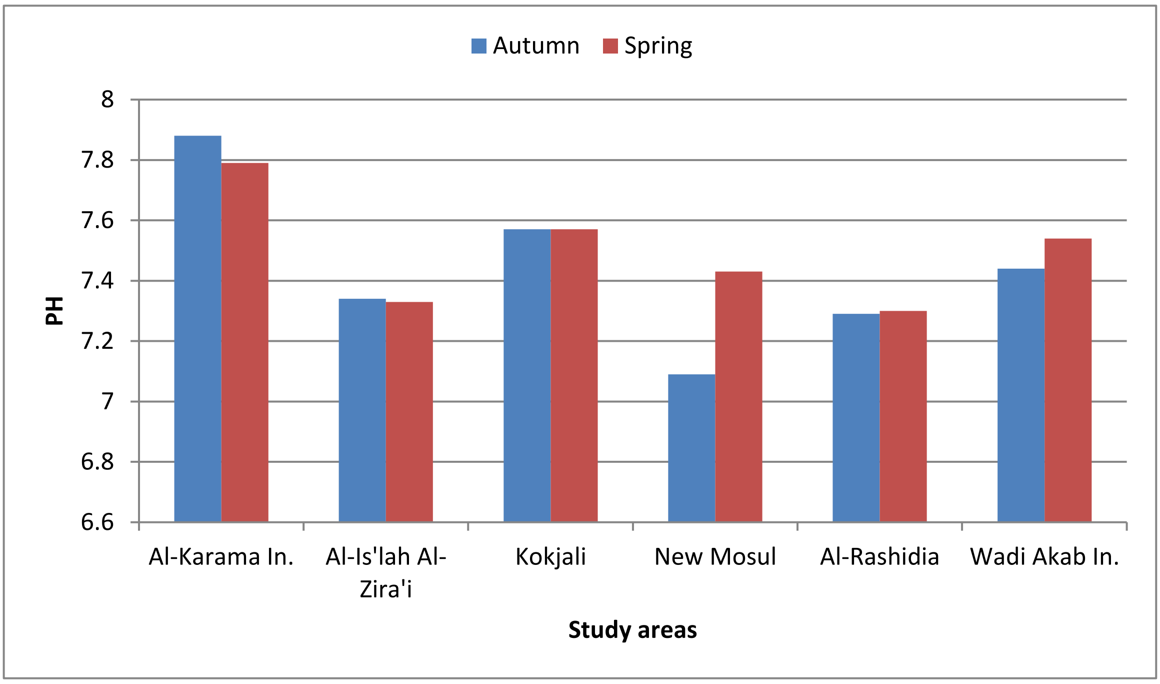

Fig.2. represents the values of soil acidity in the study area.

2-Electrical Conductivity (E.C.) of the Soil:

The results show variations in the electrical conductivity (E.C.) measurements of the soil samples during the study periods. The highest E.C. value (4.04 µs/cm) is recorded in Wadi Akab Industry area during the autumn season, The increase in electrical conductivity values is attributed to the elevated moisture levels during this season.

while the lowest value (0.75 µs/cm) is found in Al-Islah Al-Zira'i area during the spring season, as illustrated in Figure (3). These results are consistent with the findings of Shannon et al. (2020).

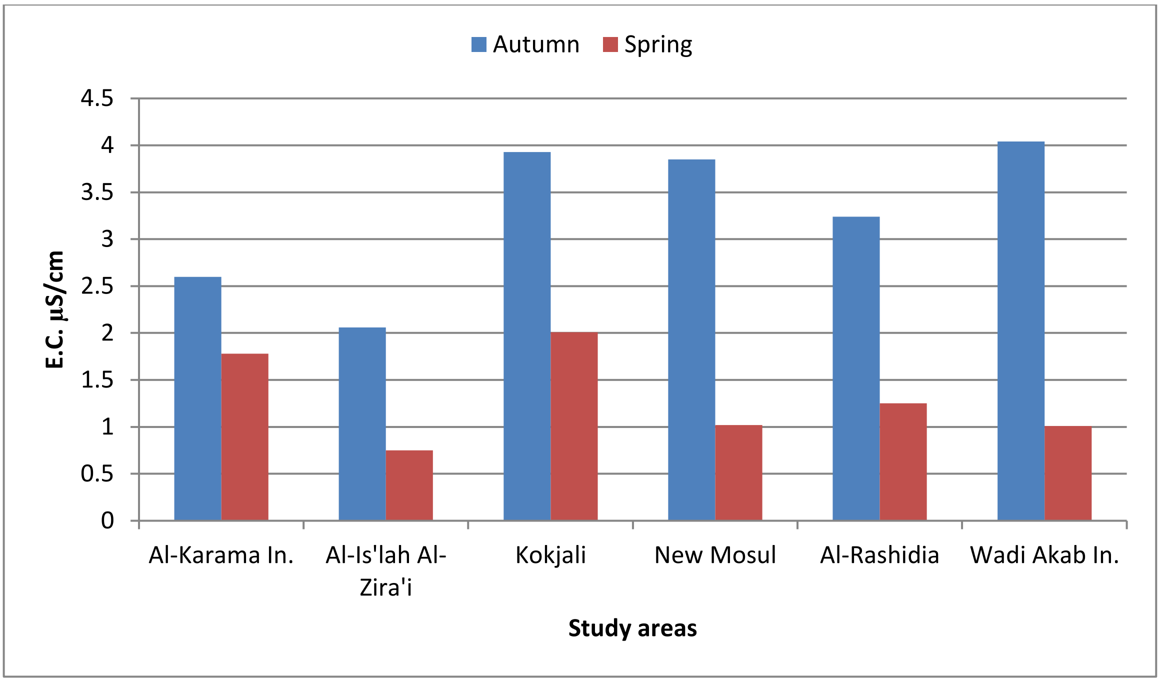

Fig. 3. represents the values of electrical conductivity in the study area.

3- Organic Matter Content:

The solid phase of the soil comprises both the organic and mineral components, with organic matter playing a significant role in influencing the physical and chemical properties of the soil (Saloum**.,**2020). The study's results reveal that the organic matter content varies between (1.53 - 2.43). The highest value is observed in the Rashidia area during the fall season, which can be attributed to its agricultural nature, as organic matter accumulates on the soil surface due to the decomposition of plant and animal materials (Salim and Alwaleed., 2019). as illustrated in Figure (4).

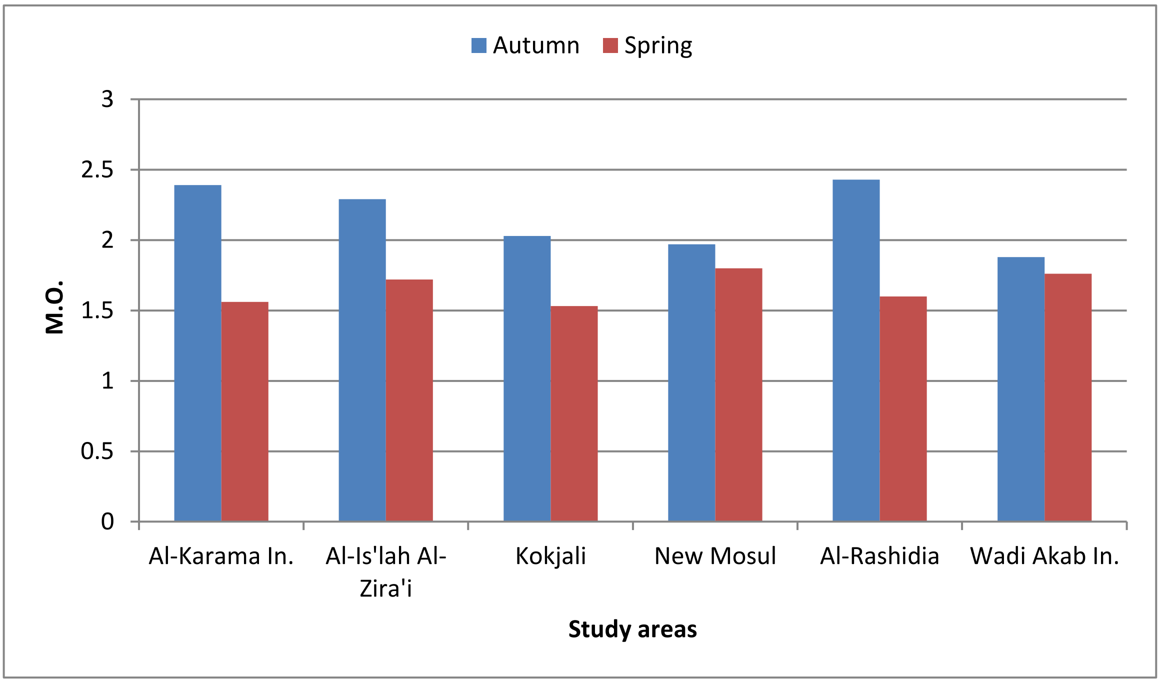

Fig.4. Organic matter values in the study area

Heavy Metals in Soil:

Cadmium (Cd):

The study reveales variations in the concentrations of cadmium in the soils of the study areas. The highest concentration is recorded as 0.17 (ppm) in the Rashidia area during the spring season, while the lowest concentration is 0.08 ppm in Wadi Akab Industrial area during the fall season. These concentrations are within the permissible limits set by the World Health Organization (WHO, 2006) for all the study areas, as shown in the figure (5). indicating that the soil in these regions is not contaminated with cadmium. These findings are consistent with a previous study of Al-Saadi et al. (2016). The increase in cadmium concentration rates across all regions during the spring season is attributed to the continuous exposure of surface soils to pollutants resulting from vehicular emissions and waste incineration processes. These activities contribute to the augmentation of cadmium concentration in the atmosphere, which subsequently settles in the soil through the action of rainfall. Cadmium predominantly remains within the uppermost 15 centimeters of the soil profile and tends to be retained there. This phenomenon is corroborated by the findings of Al-Hashimi and Al-Shammari (2020).

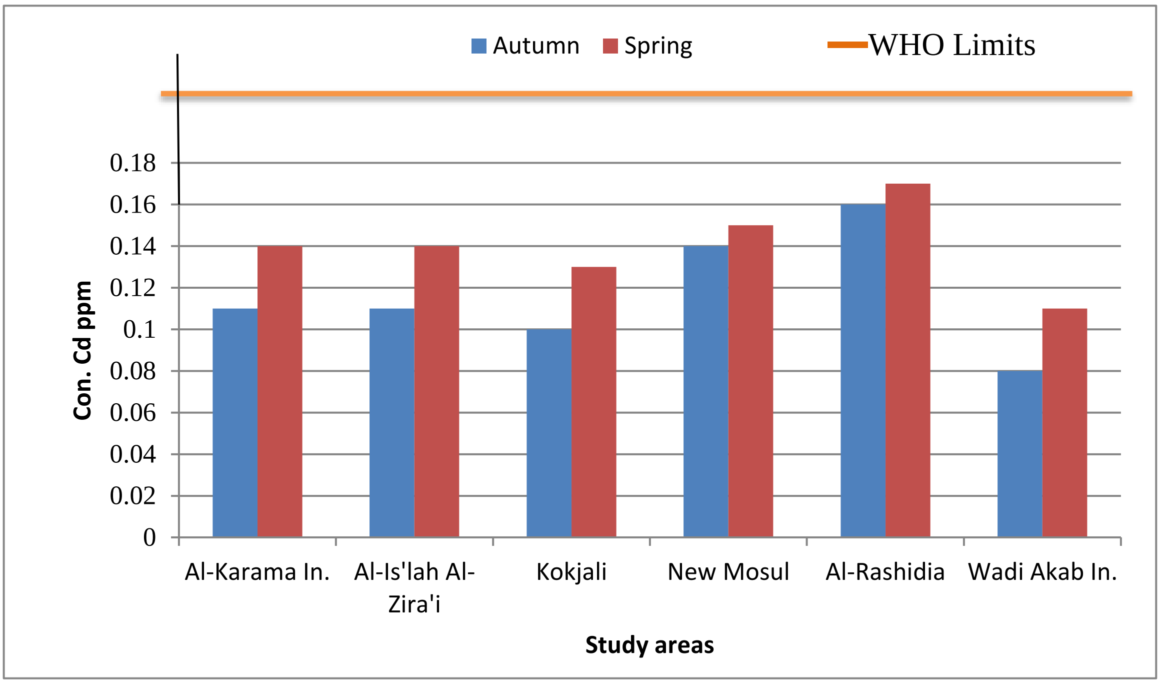

Fig.5. Values of cadmium element in the study area.

Spatial Distribution of Cadmium Concentration in Soil:

The spatial distribution map in Figure (6 a and b) , created using ArcMap and the interpolation method. It depicts the cadmium concentration levels in the soil of Mosul during the fall season. The map indicates the highest concentration in the northern region, particularly in the Rashidia area, with a high to moderate impact extending from the north to the south, including the old Mosul area and the Buseif region. Lower concentrations are found in the eastern and western parts of Mosul, reaching the lowest levels in the Kokjali and Wadi Akab areas. The cadmium concentration distribution remained consistent during the spring season.

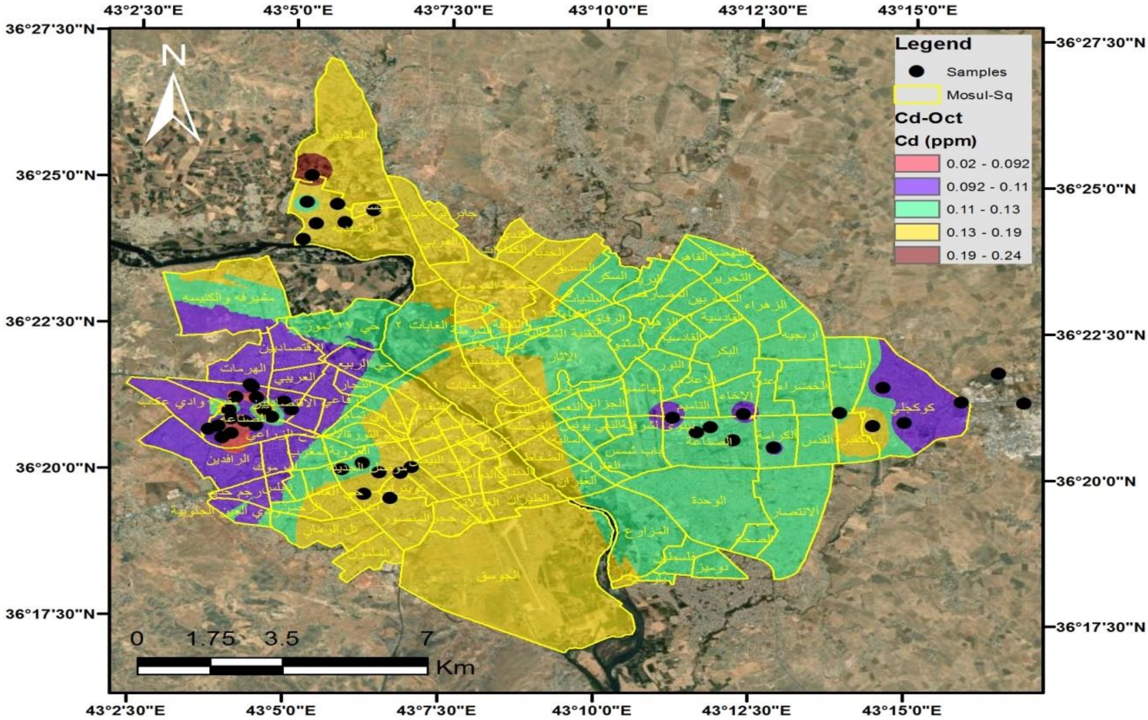

Fig.6-a. Spatial distribution of Cadmium in the autumn season

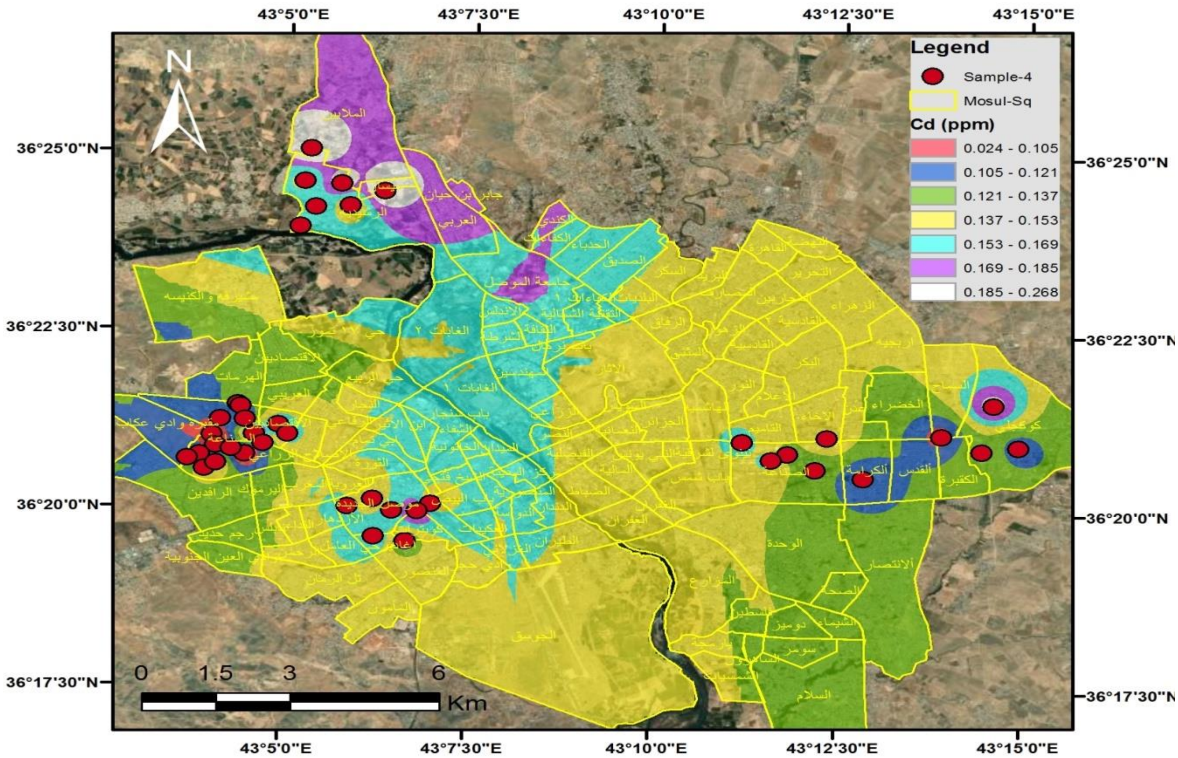

Fig.6-b. Spatial distribution of Cadmium in spring season

Zinc (Zn):

The analysis results as shown in Figure (7) indicate elevated concentrations of zinc in the study areas, surpassing permissible limits during the fall season in the Karameh Industrial, Al-Islaah Al-Zira'ei, and Wadi Akab Industrial areas with values of 780.79, 486.09, and

712.05 ppm respectively. However, during the spring season, the concentrations decrease in the mentioned areas. Nevertheless, the highest concentration of zinc is recorded in the Kokjali area during the spring season, exceeding the permissible limits at 1187.75 ppm, indicating soil contamination with this element. The cause of this contamination might be attributed to industrial activities and the presence of fuel combustion and municipal waste residues in those areas. Additionally, unauthorized oil filtering sites may contribute to the increased zinc content in the soil. Factors such as soil composition, aeration, organic matter, and pH value can affect zinc concentrations in the soil (Al-Hashimi and Al-Shammari., 2020).

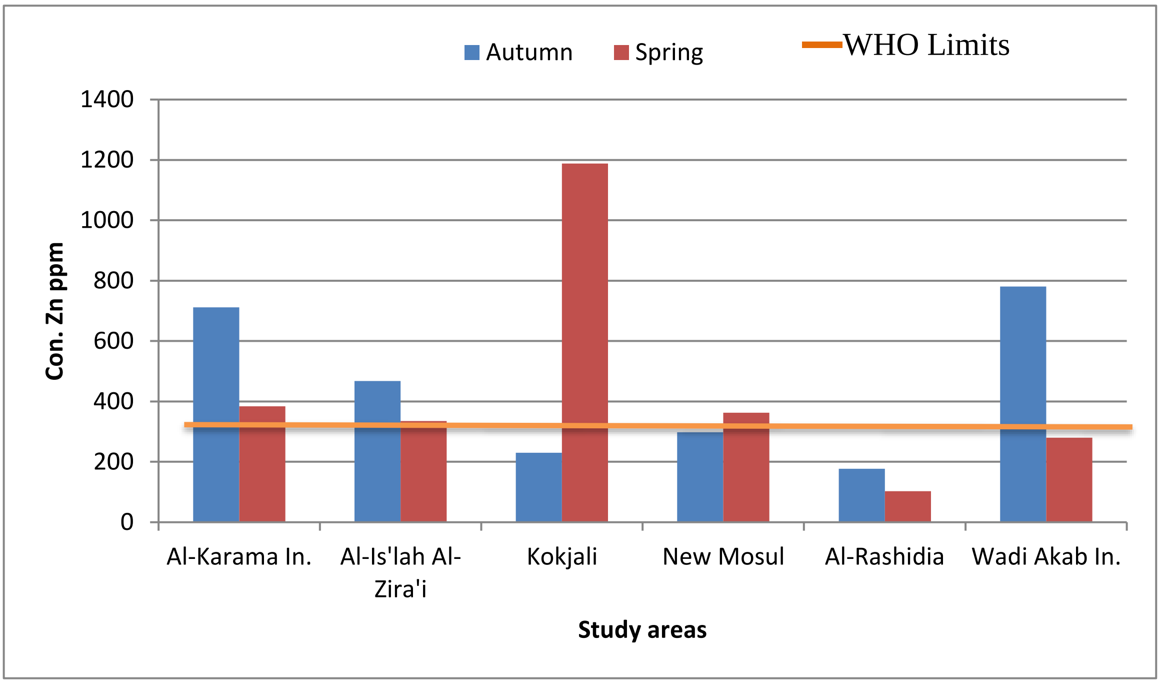

Fig.7. Values of Zinc element in the study area.

Spatial Distribution of Zinc Concentration in Soil:

The spatial distribution map in Figure. (8 a and b), created using ArcMap and the interpolation method. It displays the zinc concentration levels in the soil of Mosul during the fall season. The map indicates the highest zinc concentration in the eastern part of the city, specifically in the Karameh Industrial and the western part, particularly in Wadi Akab Industrial. The concentration decreases towards the eastern part of the city, reaching its lowest level in the northern part, particularly in the Rashidia area, and in the extreme eastern part, specifically in the Kokjali area. During the spring season, there is an increase in the area of zinc concentration, along with a decrease in zinc concentration levels in the city as shown in Figure (8).

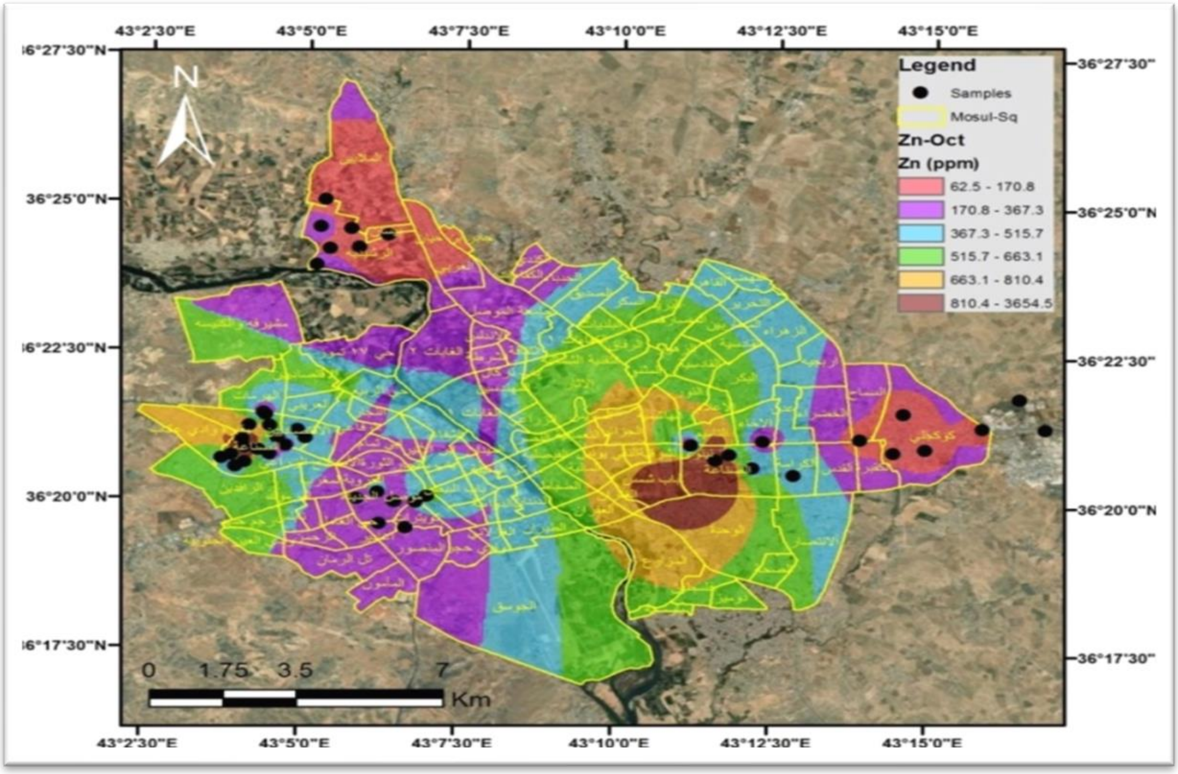

Fig.8-a. Spatial distribution of zinc in the autumn season

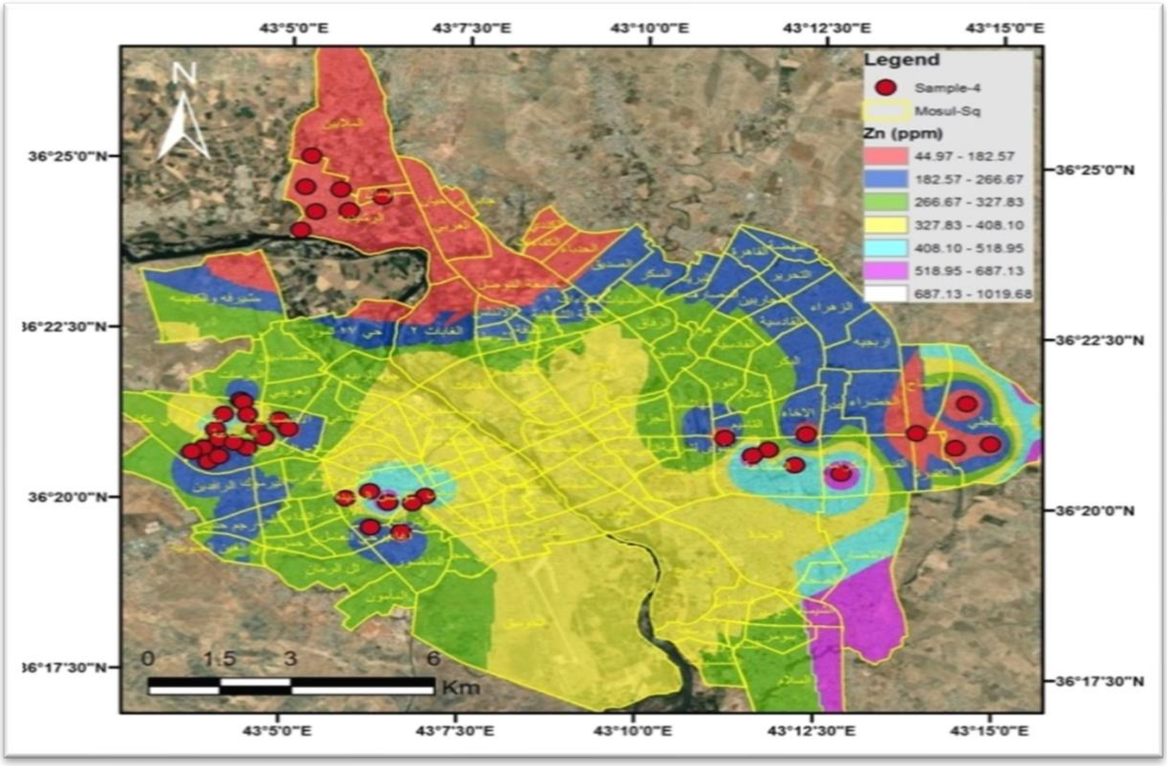

Fig.8-b. Spatial distribution of zinc in the spring season

Nickel (Ni):

Figure (9) displays the results of nickel concentration levels in the study areas, indicating that all regions have exceeded the permissible limits set by the World Health Organization (WHO, 2006). Consequently, the soil in all areas is considered polluted with nickel. The highest concentration is recorded in Wadi Akab Industrial area (183.97 ppm) during the fall season, while the lowest concentration is found in Al-Islaah Al-Zira'ei area (116.92 ppm) during the spring season. The elevated nickel concentrations can be attributed to the presence of industrial waste, auto repair shops, and dyeing activities, along with heavy traffic from various transportation means. This finding is consistent with previous research conducted by Muslim (2019). Figure (9) also illustrates that nickel concentrations decrease in all areas during the spring season due to leaching in the soil over the study period.

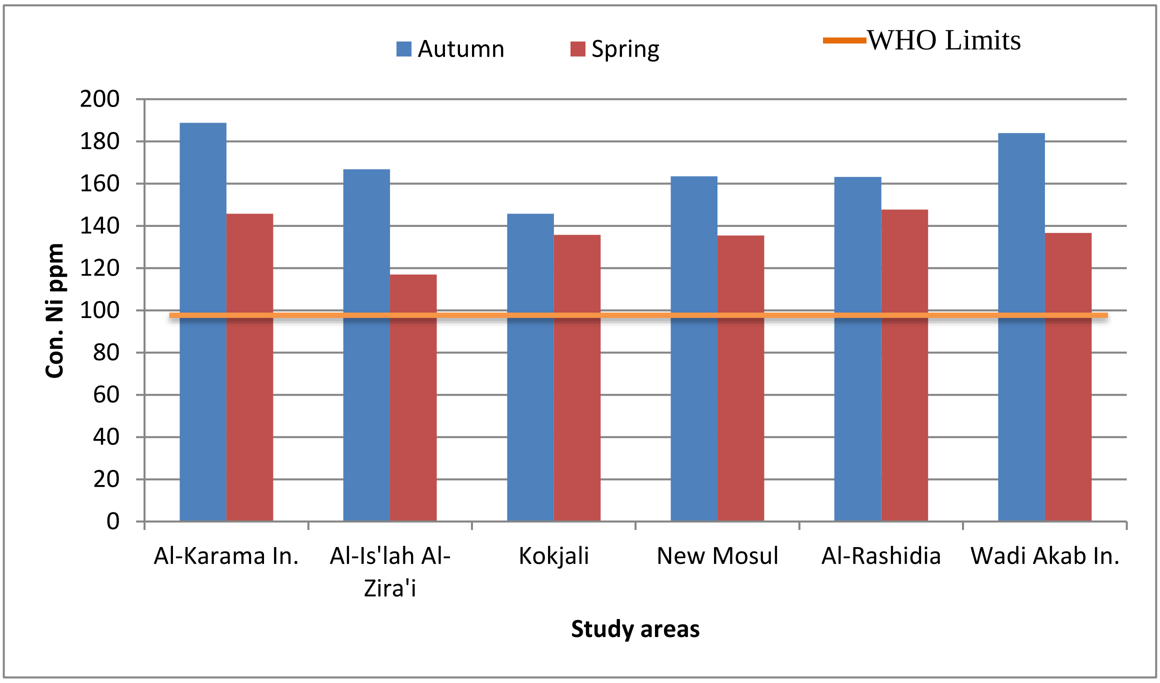

Fig. 9. Values of Nickel element in the study area.

Spatial Distribution of Nickel Concentration in Soil:

The spatial distribution map in Figure (10 a and b) is created using ArcMap and the interpolation method. It shows the nickel concentration levels in Mosul's soil during the fall season. The map indicates the highest nickel concentration in the eastern part of the city then its north to south, as well as in the far west. The nickel concentration decreases from the city center towards its north and south. The lowest impact of nickel is observed in the far eastern part of the city, specifically in Kokjali area. During the spring season, a relative decrease in nickel concentration is observed in most areas of the city compared to the fall season, as shown in Figure (10).

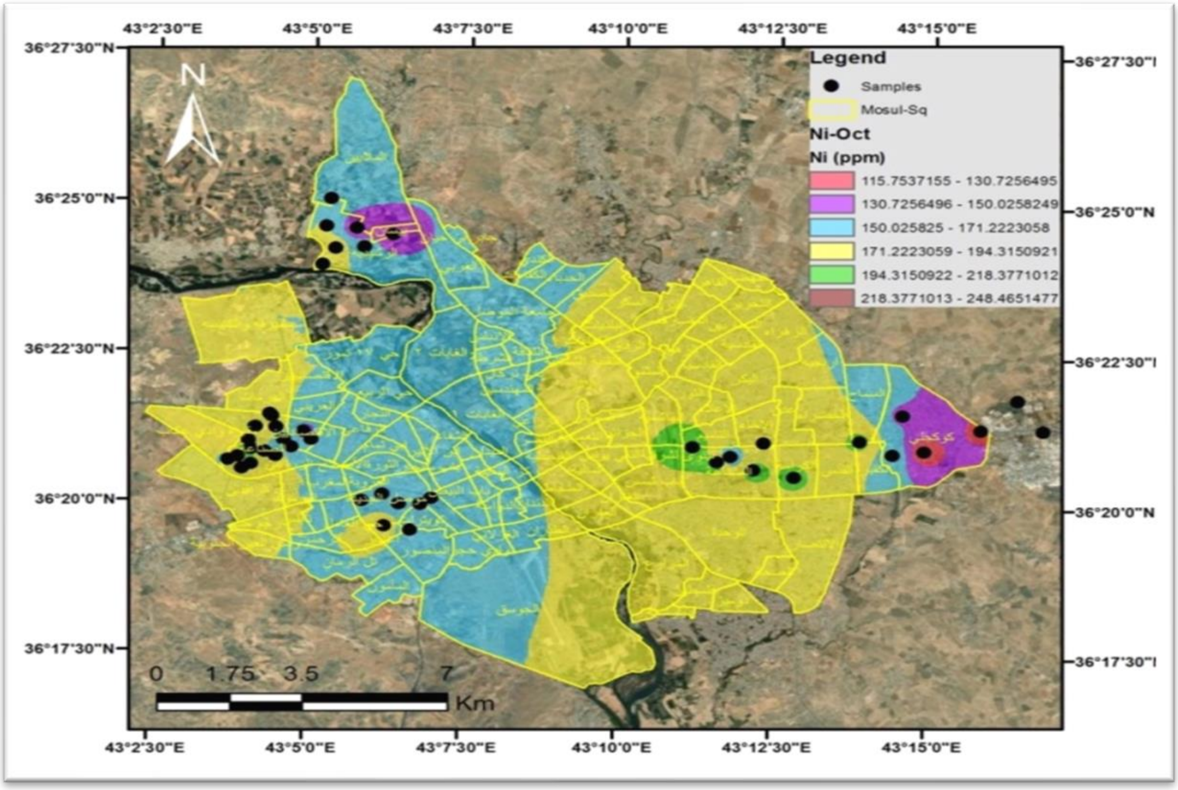

Fig.10-a. Spatial distribution of nickel in the autumn and spring season

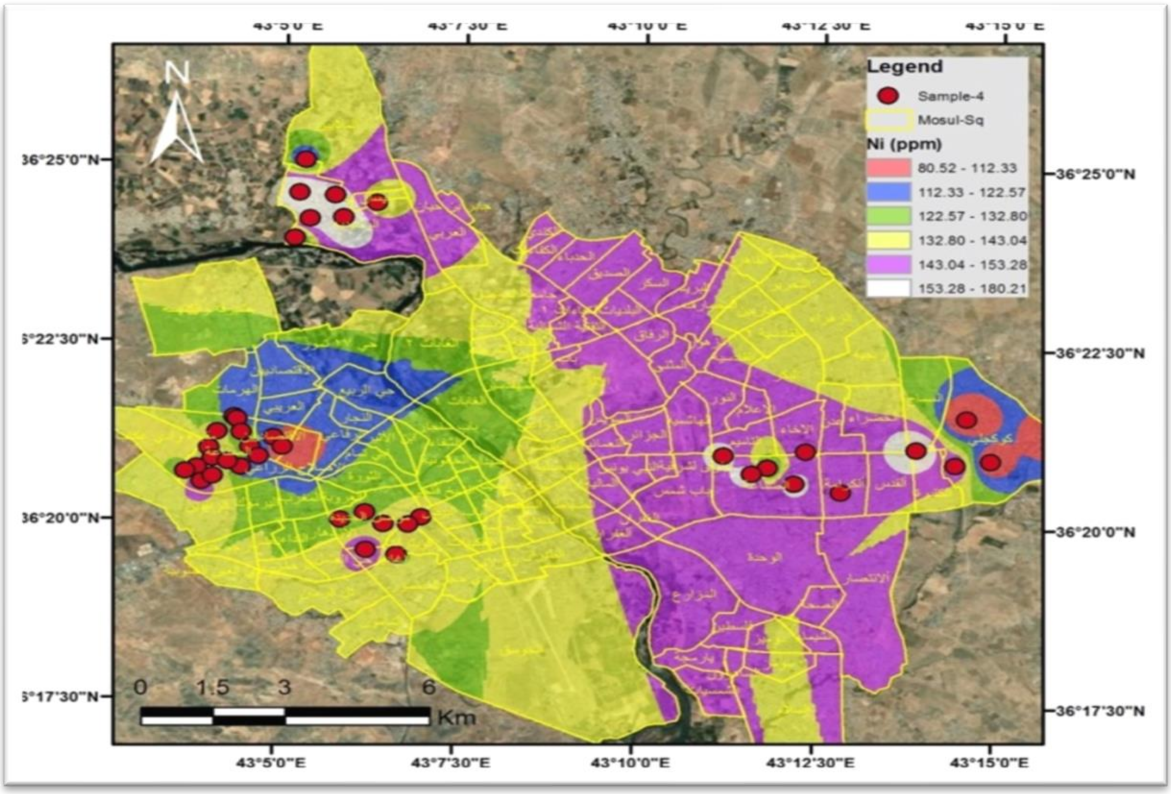

Fig.10-b. Spatial distribution of nickel in the autumn and spring season

Arsenic (As):

The analysis results show a decrease in arsenic concentrations during the fall season in all study areas. However, during the spring season, arsenic levels increase in all study areas and exceed the permissible limits set by the World Health Organization (WHO, 2006). The highest concentration of arsenic is recorded in Kokjali area (55.10 ppm) during the spring season, as shown in Figure **(**11) The reason for the increased arsenic levels is attributed to the global process of soil adsorption, which prevents leaching of the element through the soil during the rainy season and forms complexes that retain the element (Gunadasa et al., 2023).

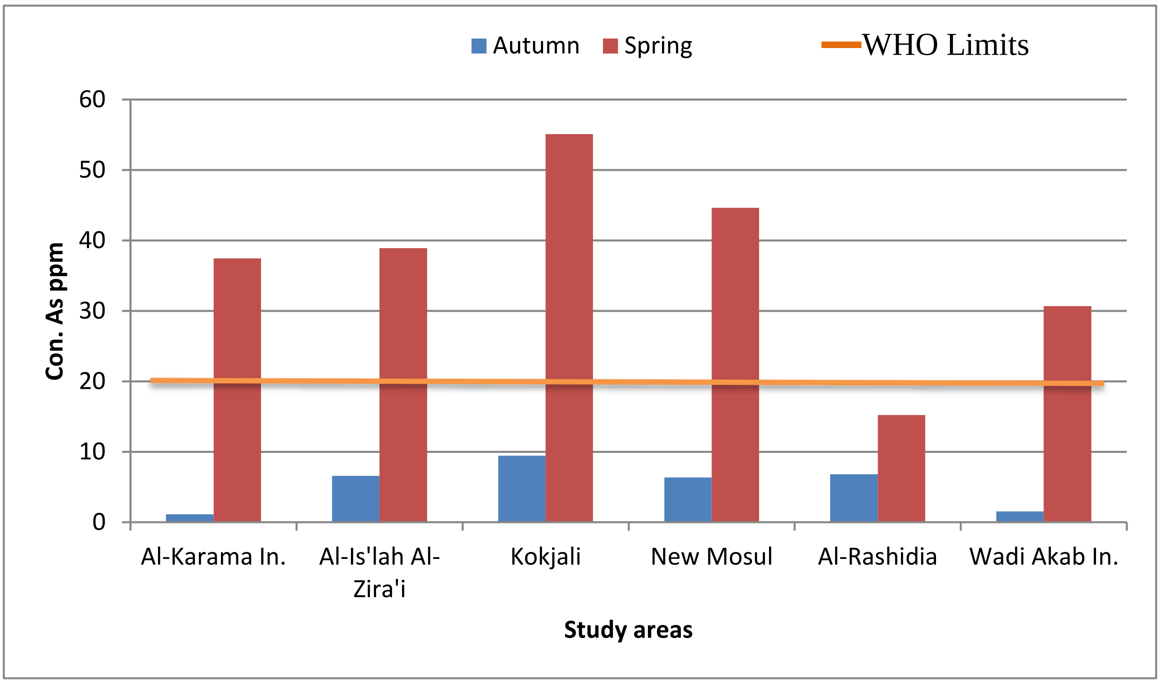

Fig. 11. Values of Arsenic element in the study area.

Spatial Distribution of Arsenic Concentration in Soil:

The spatial distribution map in Figure (12 a and b) is created using ArcMap and the interpolation method is shows the arsenic concentration levels in Mosul's soil during the fall season. The highest concentration is distributed in the northeastern part of Mosul, particularly in the Rashidiyah and Kokjali areas, and decreases as we move towards the city center. The least impact of arsenic concentration is observed in some areas of the eastern part of Mosul, specifically in Nabi Yunus and Bab Shams areas, as well as parts of the western part of the city, particularly in Wadi Akab Industrial area. During the spring season, the highest concentration of arsenic is observed in the southwestern part of the city, particularly in Al-Mawsil Al-Jadidah area, and gradually decreases as we move towards the north and east of the city, reaching the lowest concentration in the Rashidiyah and Kokjali areas, as shown in Figure (12).

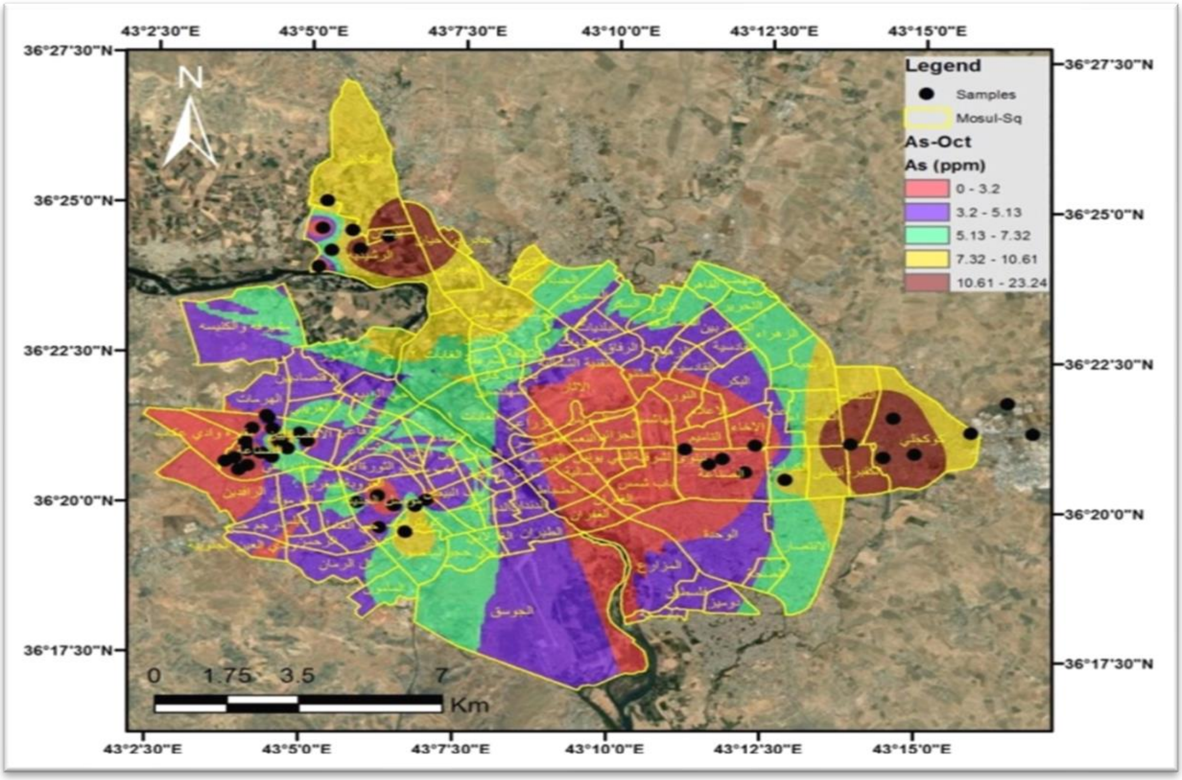

Fig.12-a. Spatial distribution of arsenic in the autumn season

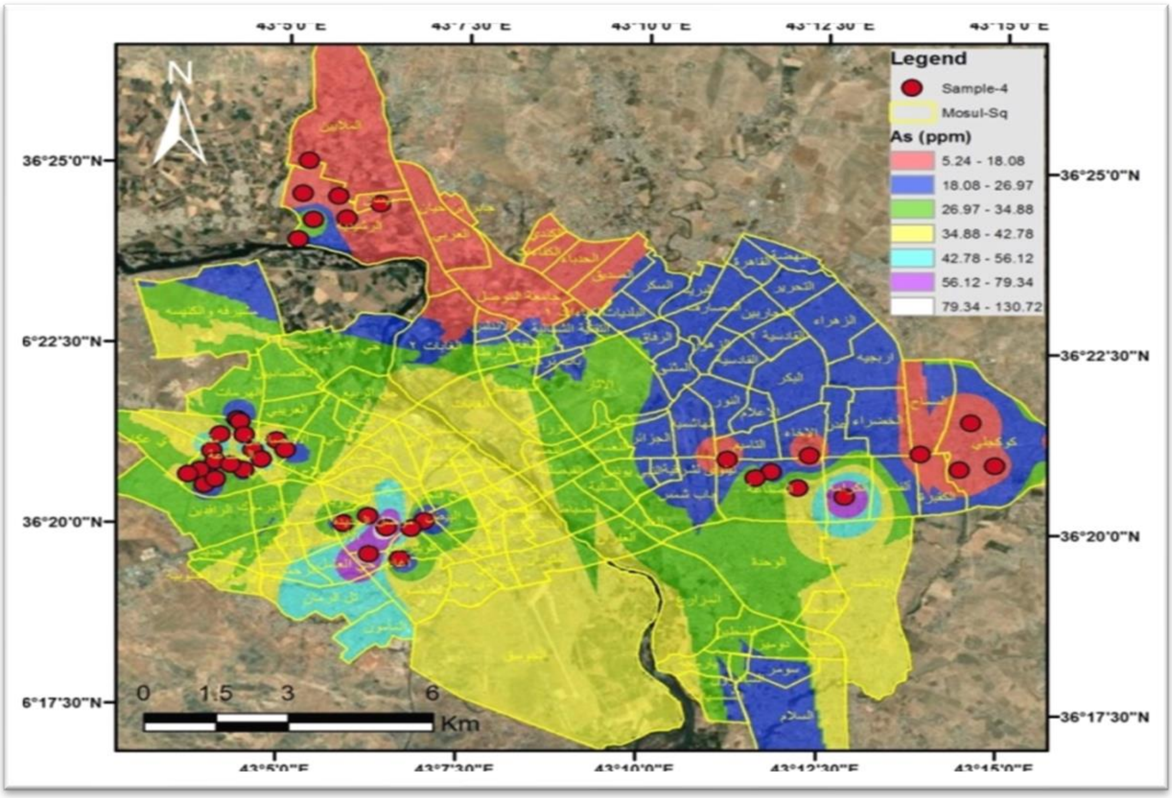

Fig.12-b. Spatial distribution of arsenic in the spring season

Conclusion

1- The study has shown that soil in all regions is contaminated with the element nickel during both autumn and spring seasons. Additionally, industrial areas have been found to be contaminated with the element zinc, exceeding the permissible limits set by the World Health Organization (WHO) for both seasons.

2- The study has indicated that concentrations of cadmium and arsenic have increased during the spring season and decreased prior to the rainy season at the beginning of autumn. This can be attributed to the accumulation of cadmium in the soil and the formation of complexes with arsenic.

3- It has been observed that soil in industrial areas experiences higher levels of heavy metal pollution compared to soil in residential areas.

4- Spatial distribution maps illustrate the spread of heavy metal concentrations in different areas of the city, indicating specific geographic patterns. Pollution hotspots with high accumulations of heavy metals have been identified.

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