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Assessment of the Risks of Heavy Metal Contamination in Irrigation Water, Soils and Crops in Agricultural Fields Near Some Oil Fields

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ABSTRACT

Background: The primary objective of the current study is to evaluate the environmental risks and heavy metal contamination in irrigation water, soil and crops cultivated in agricultural fields near certain oil fields.

Methods: Atomic absorption spectrometry was used to test and analyze water, soil and plant samples for Cadmium (Cd), Chromium (Cr), Lead (Pb), Copper (Cu), Iron (Fe), Manganese (Mn), Nickel (Ni) and Zinc (Zn).

Result: The samples extremely low concentrations of Cd, Cr and Pb were found in the laboratory, indicating that the local environment is free of these heavy metal contaminants. Fe was the dominant pollutant, exhibiting severely high concentrations, soil at the Amara site (BS) contained Fe at 85,369.62 mg/kg, far exceeding the WHO safety limit. Mn also showed significant contamination, with crop levels reaching 821.97 mg/kg, well above recommended guidelines. In contrast, concentrations of Cu (13.21-83.15 mg/kg), Ni (3.44-86.26 mg/kg) and Zn (52.88-174.40 mg/kg) in water, soil and crop samples were found to be within the permissible limits according to international standards. This stark divergence confirms that the multi-element contamination, as identified by the composite index, is primarily driven by Fe and Mn. The significant bioaccumulation of these metals in crops Fe at 645-673 mg/kg versus a 50-300 mg/kg standard, highlights a critical pathway from soil to the food chain. These findings unequivocally point to anthropogenic activities from the oil fields as the source of pollution, posing a direct threat to agricultural safety and potential human health risks.

Key words: Agricultural pollution, Heavy metal, Oil waste, Risk assessment.

INTRODUCTION

Heavy metals accumulate in soils, especially metals that are not biodegradable or thermally degradable, which affects the quality of cultivated agricultural soils and pollution levels reach the food chain, This accumulation comes from natural sources or various human activities such as poor drainage of sewage or the presence of oil fields within cities and incorrect methods of waste disposal and excessive use of chemical pesticides to combat pests (Kumar *et al.,* 2019). Many studies have indicated that heavy metals in crops such as Wheat, Rice and vegetables in addition to animals, can spread and accumulate and thus reach the population, causing health problems for humans (Mishra *et al.,* 2018; Ali *et al.,* 2020; Vyas and Shukla, 2020; Zakaria *et al.,* 2021). It has been found that continuous exposure to cadmium (Cd) causes serious problems such as lung cancer, kidney damage and blood pressure disorders (Sawut *et al.,* 2018). There are serious worries that heavy metals could enter the food chain from oil fields due to their close proximity to agricultural fields in some places. The source mostly determines the behavior and distribution of toxic metals, which include lead, chromium and cadmium. These metals can cause developmental abnormalities, organ damage and cancer (Bhardwaj, *et al.,* 2022), High concentrations of Nickel (Ni) in water and soil lead to its reaching the human body through absorption by plants and may lead to health risks such as allergies, lung damage and cancer (El-Naggar *et al.,* 2021). In addition to being a carcinogenic metal, Lead (Pb) is regarded as a hazardous metal that spreads, builds up and poses health hazards like diabetes, heart problems and stunted growth (Gundacker *et al.,* 2021). (Tumolo *et al.,* 2020) also stated that all living organisms are affected by Chromium (Cr), which poses a risk to human health due to its effects on DNA damage and the development of cancer. Depending on exposure levels, it can cause skin irritation. It is found in

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groundwater and groundwater, as well as areas near chemical and tanning facilities. Oil extraction and processing are potential anthropogenic sources of a wide range of elements. These include essential elements such as Copper (Cu), Zinc (Zn), Iron (Fe) and Manganese (Mn), which can become hazardous contaminants at elevated concentrations, disrupting soil microbial ecosystems and posing non-carcinogenic health risks such as neurotoxicity and gastrointestinal diseases. The potential of Cu to oxidize and degrade numerous vital enzymes in soil microorganisms makes it dangerous and a high concentration of Cu in the soil can endanger the ecosystem and a variety of creatures that live there. In terms of the diversity and richness of microorganisms, its high concentrations in the soil may be hazardous to the environment and impact soil functioning (Fagnano *et al.,* 2020). For many livings things Fe is a necessary nutrient and a vital element. It is regarded as a secondary contaminant and as its concentration in soil and water rises, it may affect human health by affecting the liver, pancreas, blood cells, stomach issues and nausea. In addition, vegetables with high iron content are ugly and black (Akhtar *et al.,* 2022). In trace amounts Mn a naturally occurring oxidizing and reducing mineral, is a necessary nutrient, elevated concentrations of it in soil and water can enter the food chain and result in non-cancerous health issues like neurotoxicity symptoms in people (Erikson and Aschner, 2019). Zinc (Zn) also plays an important role in stimulating many growth and reproduction enzymes (Imsong *et al.,* 2023), as it is linked to DNA and cell division in moderate quantities, while increasing its concentration leads to poor appetite, diarrhea, vomiting, nausea and headaches and affects the human immune system. Therefore, its concentration should be limited in water and soil suitable for agriculture (Natasha *et al.,* 2022). Consequently, this study provides a comparative environmental risk assessment to determine the concentrations of eight heavy metals (Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn) in irrigation water, soil and crop samples taken from agricultural fields close to two separate oil fields (Ajil in central Iraq and Amara in the south) and evaluates the results according to international safety standards.

MATERIALS AND METHODS

Study site

The experiment was conducted in the year 2023-2024, all experimental tests were conducted at the Environmental Research Center, University of Technology, Iraq and two sites were selected to conduct the study. The first is the agricultural fields near the Ajil oil field (A), located in Salah al-Din Governorate in central Iraq, 180 km north of the capital, Baghdad (Latitude 34.50° N, Longitude 43.20° E). The second is the agricultural fields near the Amara oil field (B), located in Maysan Governorate in southern Iraq, 320 km southeast of the capital, Baghdad (Latitude 31.85° N, Longitude 47.15° E).

Sample collection

Samples were collected from agricultural fields and included: Irrigation water (W), soil (S) and different crops (C), with four replicates for each sample from both locations (A and B). The agricultural fields are approximately 5 km away from the oil fields, separated by an earthen barrier to prevent farmers from using the lands near the oil fields for agricultural purposes (Fig 1). Oil processing operations are accompanied by secondary gases that are burned and released into the atmosphere (Fig 2), causing air pollution in the surrounding areas and it is expected that the cultivated crops will be polluted by it during breathing processes (Ukaogo and Onwuka, 2020), The water used to get rid of the oil salinity in the fields is poured into the surrounding soil without treatment (Fig 3). This poses a long-term danger, as this water, with the heavy element particles it carries, may penetrate the groundwater and reach the soil of the agricultural fields nearby, causing pollution. Consequently, the pollution reaches the cultivated crops and from there to the human consumer (Rashid *et al.,* 2023). Water samples were taken from wells used for irrigation, soil was collected from a depth of 25 cm and crop samples were collected randomly without specifying the crop type, including the entire plant.

Examination methods

Standard testing methods were used to test the heavy metals of the samples. Water samples were filtered using

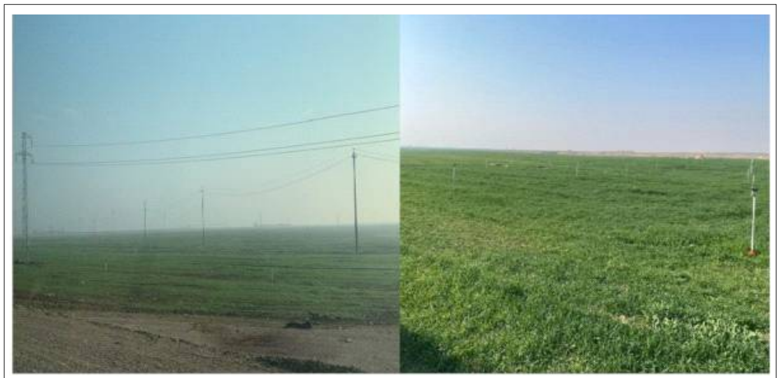

Fig 1: Agricultural fields from which samples were collected.

filter paper and preserved by adding (1 ml) of nitric acid to prepare them for testing, while soil and plant samples were digested by adding a mixture of nitric acid (10 ml) and hydrochloric acid (30 ml) to (0.5 g) of the sample after drying and grinding it, then it was heated at 60°C for two hours (Fig 4), filtered and the volume was completed to (100 ml) with deionized water (Bialkowski and Proskurnin, 2019), Heavy elements (Cd, Ni, Pb, Cr, Cu, Fe, Mn and Zn) were examined at the Environmental Research Center/University of Technology using an Atomic Absorption Spectroscopy AAS 6300 from Shimadzu, Japan, according to the approved standard method 3030 E.

RESULTS AND DISCUSSION

Test results

Tables 1, 2 and 3 show the results of heavy metal tests for the samples used in the study as follows:

Water samples

The results of the Table 1 indicate that the Ajil site (AW) recorded the highest concentrations, as Fe reached 2526.48 µg/L, followed by Mn: 503.13 µg/L, then Zn: 65.03 µg/L, Ni: 40.48 µg/L and Cu: 17.53 µg/L, while the concentrations of Cd, Cr and Pb were below the detectable limits (0.00 µg/L). The Amara site (BW) recorded the following concentrations: Fe: 15662.80 µg/L, Mn: 471.35 µg/L, Zn: 75.30 µg/L, Ni: 53.70 µg/L, Cu: 17.08 µg/L. Meanwhile, the concentrations of Cd, Cr and Pb were below the detectable limits (0.00 µg/L).

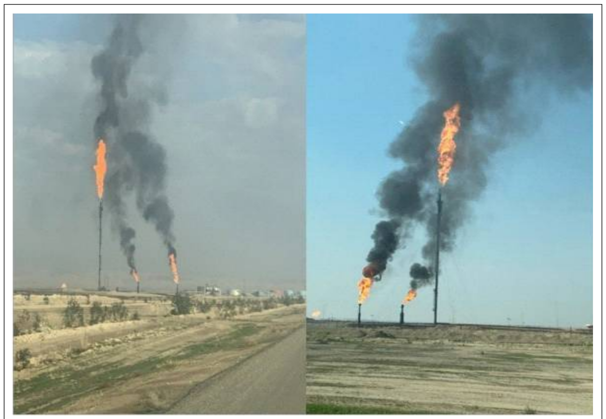

Fig 2: Gases associated with oil processing operations.

Fig 3: The soils adjacent to the oil fields.

Soil and crop samples

The results of Table 2 showed that the soil samples (AS) at the Ajil site (A) had the highest concentration of Fe: 71859.23 mg/kg, followed by Mn: 942.85 mg/kg, Zn: 72.88 mg/kg, Ni: 17.08 mg/kg and Cu: 10.62 mg/kg. While the concentrations of Cd, Cr and Pb were undetectable (0.00 mg/kg). As for crop samples from the same site, Fe recorded the highest concentration of 673.40 mg/kg, followed by Mn: 759.79 mg/kg, Cu: 16.17 mg/kg, Zn: 56.67 mg/kg and Ni: 3.71 mg/kg. Concen-trations of Cd, Cr and Pb were undetectable (0.00 mg/kg).

The results of Table 3 showed that the soil samples (BS) at Amarah site (B) recorded the highest concentration of Fe: 85369.62 mg/kg, followed by Zn: 174.40 mg/kg, Ni: 86.26 mg/kg, Cu: 83.15 mg/kg and Mn: 338.56 mg/kg. The concentrations of Cd, Cr and Pb were undetectable (0.00 mg/kg). As for crop samples (BC) from the same site, Mn recorded the highest concentration of 821.97 mg/kg, followed by Fe: 645.41 mg/kg, Zn: 52.88 mg/kg, Cu: 13.21 mg/kg and Ni: 3.44 mg/kg. Concentrations of Cd, Cr and Pb were undetectable (0.00 mg/kg).

Contrary to expectations, the results indicated that contamination with hazardous elements Cadmium, Chromium and Lead is not present, whether in irrigation water or in soils and cultivated crops. The reason for this is the possible absence of rocks bearing these elements in the studied areas or their absence in the water accompanying production. It may also be due to the distance between agricultural fields and oil fields and the pollutants that accompany them, which was confirmed by Onakpa *et al.* (2018) and Awad *et al.* (2022) were mentioned that keeping agricultural areas away from oil sources could avoid contamination with dangerous metals that could be transferred to food. Several studies have reported that cadmium accumulation in soil and plants typically results from the use of agricultural technology and industrial activities, as well as from sewage sludge, it is also present in soils with low pH (Aslam, *et al.,* 2023). Its direct effect is to inhibit microbial activity and the metabolism of beneficial microorganisms by affecting their respiration, in addition to altering the soil physicochemical properties. It also affects plant physiology by competing with cadmium for the uptake of beneficial plant nutrients (Alengebawy *et al.,* 2021), It also affects plant physiology by competing with cadmium for the uptake of beneficial plant nutrients and The phenotypic effects of cadmium on plants include decreased the size and weight of roots and shoots; cytotoxicity, which results in decreased chlorophyll content and reduced photosynthetic efficiency; and metabolic processes, which include cell damage and chlorosis Hayat *et al.,* (2019).

Particles of chromium are present in the environment and are released by liquid waste from mining, tanneries, construction, painting, photographing, printing and medical industries, Because it pollutes the environment, it is seen as a serious health risk (GracePavithra *et al.,* 2019), Additional environmental sources of chromium include, liquid fuel-powered power plants, waste from industries and rocks that have been worn by air and water (Shahid *et al.,* 2017), Toxic chromium seeps into water bodies and then onto adjacent fields when industrial waste is released into the soil (Coetzee, *et al.,* 2020), Although chromium contamination isn't an international problem, local biogeochemical cycles may be affected by high levels of this contaminant due to metal penetration into the soil, water, or atmosphere (Yang *et al.,* 2022), Chromium benefits plants at low concentrations, but at high concentrations, it inhibits growth by affecting seed germination and photosynthesis efficiency. It can also damage root cells, leading to plant death and reduced productivity (Ao *et al.,* 2022).

Lead is a toxic heavy metal and a major pollutant that poses health risks when present in water, soil and plants, even at low concentrations (Blanco *et al.,* 2021), This element can be found naturally in a variety of forms, such as lead sulfide or complex ores. Acid rain, car emissions, the burning of petroleum and natural gas and wastewater from homes and businesses are some of the industrial processes that discharge its byproducts into the biosphere (Chowdhury *et al.,* 2022; Kumar *et al.,* 2020). Because lead has detrimental and toxic effects on soil biodiversity and microbiota, it is a problem when it accumulates in water and then soil. In cultivated plants, this results in stress through cell dysfunction, which can lead to weak roots, decreased chlorophyll synthesis, slowed seed germination and overall plant weakening. Additionally, it can build up in specific plant sections and make its way into the food chain, impacting public health and human systems and eventually leading to chronic diseases (Kushwaha *et al.,* 2018).

The positive results in the absence of these elements in the studied areas do not represent concerns from an environmental or health perspective, despite the many studies mentioned above that showed the risk of increased concentrations of the three elements under study, Cadmium, Chromium and Lead. Ongoing research and testing of these components must be done, nevertheless, in the same locations but with different samples and conditions.

The results of the copper element showed that the proportions were within the limit permitted by the World

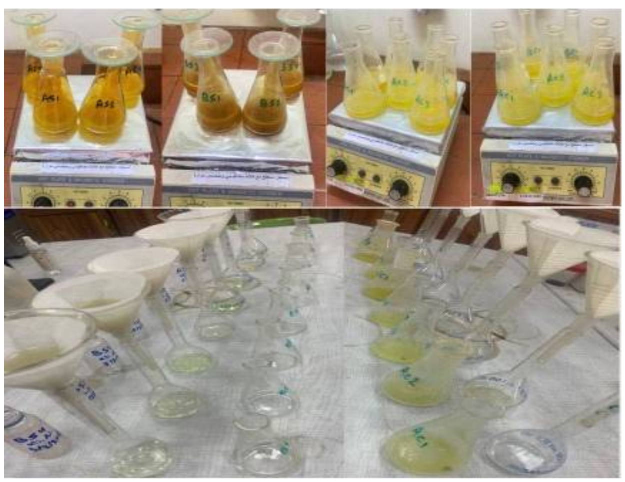

Fig 4: Digestion of soil and plant samples.

Table 1: Heavy metal test results for water samples*.

Samples \ Elements	Cd (µg/L)	Cr (µg/L)	Pb (µg/L)	Cu (µg/L)	Fe (µg/L)	Mn (µg/L)	Ni (µg/L)	Zn (µg/L)
AW	0.00	0.00	0.00	17.525	12526.48	503.125	40.475	65.025
BW	0.00	0.00	0.00	17.075	15662.8	471.35	53.7	75.3
Standard specifications in water (µg/L) (WHO)	3	50	10	2000	300	100	70	3000

AW: Water samples of Ajil oil site, BW: Water samples of Amarah oil site.

* Each number represents the average of four replicates.

Health Organization and this is a good indicator from an environmental perspective, as the presence of copper within specific concentrations is required due to its importance for plant and human health. It is a double-edged sword, as an increase in its concentrations may lead to harm to the plant or humans (Zhen *et al.,* 2022; Numaan *et al.,* 2024). Copper sources vary depending on the environment. It increases in areas with industrial activity or near oil fields, as the results of these fields release varying levels of various elements, including copper, into groundwater or soil. These elements are then cumulatively transferred to plants and from there to human consumers (Masindi and Muedi, 2018). Sources of copper in the agricultural sector can be due to fertilizers and pesticides used, or from animal waste, which leads to its accumulation in the soil and subsequent uptake by plants (Zhang *et al.,* 2019), Copper toxicity disrupts the ecosystem when present at higher than normal levels. Its presence in soil is affected by several factors, including pH, as it increases in acidic soils and poses a threat to the effectiveness of soil microorganisms (Namee *et al.,* 2023), which play a positive role in decomposing soil organic matter. Its effect occurs through the destruction of cell membranes and consequently, the breakdown of microbial proteins (Wang *et al.,* 2019). Copper can react with other elements, such as zinc, leading to reduced absorption of these elements compared to their free state. High levels of copper can also produce free hydroxyl radicals, which increase levels of reactive oxygen (ROS) species and thus damage plant cells, potentially leading to plant death and reduced yields (Wu *et al.,* 2016), Considering the positive concentrations of copper shown in the current study, we can say that the studied areas are environmentally safe from this element, but continuous monitoring is necessary to avoid the possibility of its increase in different conditions.

While iron showed a significant increase in all samples used in the study, with concentrations exceeding the permissible limit, the cause may be oil pollutants, water associated with production and refining process emissions that settle in soil and waterway (Weldeslassie *et al.,* 2018), or it may be due to natural corrosion of fuel pipes and tanks made of iron (Chukhin and Andrianov, 2022; Mahdi *et al.,* 2023), Many studies indicate that the soil near oil fields is rich in iron due to the dissolution of its compounds in groundwater or the effect of the accompanying organic

Table 2: Results of heavy metal tests for samples from the Ajil oil field site (A)*.

Samples \ Elements	Cd (mg/kg)	Cr (mg/kg)	Pb (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Ni (mg/kg)	Zn (mg/kg)
AS	0.00	0.00	0.00	10.62	71859.23	942.845	17.0775	72.875
Standard specifications in soil (mg/kg) (WHO)	0.8-1.0	50-100	50-100	50-100	20,000-50,000	200-800	30-50	150-300
AC	0.00	0.00	0.00	16.165	673.395	759.79	3.705	56.67
Standard specifications in plant (mg/kg) (WHO)	0.01-0.5	0.1-1.0	0.1-5.0	5-20	50-300	20-500	0.5-5.0	15-150

AS: Soil samples, AC: Crop samples.

*Each number represents the average of four replicates.

Table 3: Results of heavy metal tests for samples from the Amarah oil field site (B)*.

Samples \ Elements	Cd (mg/kg)	Cr (mg/kg)	Pb (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Ni (mg/kg)	Zn (mg/kg)
BS	0.00	0.00	0.00	83.15	85369.62	338.555	86.26	174.395
Standard specifications in soil (mg/kg) (WHO)	0.8-1.0	50-100	50-100	50-100	20,000-50,000	200-800	30-50	150-300
BC	0.00	0.00	0.00	13.205	645.41	821.965	3.435	52.875
Standard specifications in plant (mg/kg) (WHO)	0.01-0.5	0.1-1.0	0.1-5.0	5-20	50-300	20-500	0.5-5.0	15-150

BS: Soil samples, BC: Crop samples.

*Each number represents the average of four replicates.

acids that seep into the soil (Castro *et al.,* 2022). Some plants have a high capacity to absorb heavy elements, which explains why iron is high in plants due to its presence in abundant quantities in water and soil (Al-aamel and Al-maliky, 2023). High iron levels in water cause a change in color and taste, contribute to the formation of sediments, or may interact with some compounds, resulting in toxic substances. High iron levels in soil reduce its fertility due to its effect on the pH level and reduce the absorption of other nutrients (Dietrich and Burlingame, 2020; Dvorak and Schuerman, 2021), as for its high levels in plants, it may cause yellowing of leaves, inhibit growth and accumulate in plant tissues, thus reaching the food chain (Santos *et al.,* 2019).

The results also indicated that the manganese concentration exceeded the permissible limits of international standards. The reason may be the leakage of drilling fluids rich in this element, or associated water, or emissions into the water and subsequently into the soil and then the plants (Sobri *et al.,* 2024), or it may be due to the dissolution of minerals, a decrease in the acidity of the soil, or the use of fertilizers and pesticides containing this element (Dey *et al.,* 2023), This increase leads to the deposition of manganese oxides and has negative effects on beneficial microorganisms, causing an imbalance in the nutritional balance and affecting the low production of cultivated crops (Khoshru *et al.,* 2023), Despite its importance in plant life processes, manganese is required in small quantities. Depending on the availability of manganese, plants must either utilize it efficiently under restricted conditions or detoxify this excess mineral, based on the physicochemical characteristics of the soil, particularly in acidic soils and the redox processes that result in elevated levels of this element, manganese can have a harmful effect on plants when it is present in high concentrations and proportions Rengel, (2015), as for its danger to human health, high concentrations of it lead to problems in the nervous, digestive and reproductive systems (Yin *et al.,* 2021).

These high levels, which could be dangerous if they accumulate over the long term, require a comprehensive analysis of the studied areas to determine the main causes that lead to the rise of this element in these areas and to take some ongoing measures and treatments to reduce the existing pollution.

As for the results of the nickel and zinc elements, they showed that indicated levels lower than the internationally permitted limits, which may be due to the scarcity of natural resources in rock formations, low rates of chemical weathering and their lack of use in large quantities in drilling and production operations (Mudd and Jowitt, 2022; Aljanabi *et al.,* 2022), This indicates the absence of toxicity from these elements and the safety of the water in the studied areas. These positive results reduce the severity of iron and manganese pollution and emphasize the importance of a comprehensive assessment of heavy elements in areas close to oil fields.

CONCLUSION

This study evaluated the potential environmental risks resulting from heavy metal contamination of irrigation water, soil and crops grown in agricultural areas adjacent to the Ajil and Amara oil fields in Iraq. The results of the experiment revealed that there was contamination resulting from increased Iron and Manganese levels in all types of samples studied, with concentrations exceeding the permissible limit set by the WHO. This contamination is likely the result of industrial activities resulting from oil operations, leakage of production fluids, or perhaps the corrosion of pipelines or leakage of untreated water used in oil fields. In contrast, the results indicated the absence of contamination with highly toxic elements such as Cadmium, Chromium and Lead, as concentrations below the permissible limits were recorded in all samples studied. This may be attributed to the scarcity of sources from local industries such as tanning and chemical industries, in addition to the efficiency of the barrier separating the oil fields from agricultural areas. Concentrations of Copper, Nickel and Zinc also gave readings within the environmentally safe limits in all samples. The combined contamination of Iron and Manganese demonstrates a direct pathway for these contaminants to enter the food chain, potentially posing health risks to crop consumers, including gastrointestinal diseases and neurotoxicity, particularly when exposed to these elements over extended periods.

Recommendation

Immediately address iron and manganese contamination using soil improvement and bioremediation techniques, monitor and track trends in water, soil and crop contamination in these areas, take strict measures to enforce regulations for the safe disposal of petroleum product and emissions, conduct further studies on the sources of emissions from oil fields and conduct studies of other elements in different agricultural areas to ensure human safety and health.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the study's design, data collection, analysis, decision to publish or manuscript preparation.

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