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Assessment of Heavy Metal Contamination in Soils Adjacent to Fossil Fuel Power Plants in Iraq: A Mini-Review

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ABSTRACT: Soil heavy metal pollution is a global environmental issue that has gained significant public attention due to concerns about human health and agricultural safety, making it a critical area of research both nationally and internationally. Heavy metals, including cadmium, mercury, arsenic, lead, and chromium, are toxic to biological systems. These HMs enter the soil agro-ecosystem through natural processes from parent materials and anthropogenic activities, particularly from fossil fuel power plants (FFPP). Although HMs are naturally occurring components in the Earth crust, most environmental pollution and exposure are accumulated in soils which reflects the present and deserves continued attention. The review study examined the distribution and accumulation of HMs in Iraqi soil, the results of previous studies over long periods showed that the soil of Iraq was not contaminated with HMs in the last century, the level of HMs in the soil increased with the progress of time in various cities of Iraq accordingly of the increase in power demand and industrial actions dependent on burning fuel, result in soil pollution in adjacent areas of FFPP project. Pervious study results specify that the average value of chromium (361 µg/g), nickel (284 µg/g), cobalt (16.62 µg/g) for Al-Ramadi PP, and cadmium (12.27 µg/g) for Al Nasiriyah area. Furthermore zinc (191 µg/g), lead (131 µg/g), Copper (37 µg/g), for Al Haidariy FFPP. Likewise, research conducted on fly ash release from FFPP in central and southern Iraq indicated high levels of cadmium, zinc, iron, magnesium and copper that exceed international limits due to fuel combustion. These studies confirm the extent of HMs pollution in Iraq and impact on environmental quality and human health. Effective management of HMs pollution from fossil fuel power plants necessitates systematic identification of pollution hotspots and assessment of control measures.

Keywords: Heavy metals, soil pollution, fossil fuel, toxic elements, environmental indicators

1. INTRODUCTION

Urban soil is a critical component of urban ecosystems, significantly impacting quality of life and health [1]. Heavy metals are known as metals and metalloids having high atomic weight and a specific gravity over 5, including Lead (Pb), Mercury (Hg), Copper (Cu), Arsenic (As), Chromium (Cr), Cadmium (Cd), Zinc (Zn) and Nickel (Ni). However from a biological standpoint, "heavy" refers to certain metals and, in some instances, metalloids that can be toxic to humans, animals and plants even at low concentrations [2]. HM contamination significantly threatens the environment and food security, driven by the rapid expansion of agriculture and industry, besides the disruption of natural ecosystems due to global population growth. Although HMs are naturally-occurring elements in the Earth crust, most environmental pollution and exposure are caused by human activities [3,4].

Soils are crucial in understanding pollution; the unsustainable use of soil resources has led to imbalances and disturbances, resulting in significant variations in their physical-chemical properties [5] and resistance to biodegradation or thermal degradation [6], leading to irreversible degradation and serious environmental consequences.

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In recent years, with the acceleration of urbanization and rapid social and economic development, there has been increasing public health interest related to environmental pollution. Human exposure to these metals is much higher as a result of the significant increase in their use in many industrial, agricultural, domestic, and technological applications.

The increasing population in Iraq has driven up electricity demand, making power plants significant sources of air pollution. These plants are often old, inefficient, and lack advanced technology to enhance efficiency and control emissions of pollutants, including ash and HMs like lead, zinc, and chrome. Iraq's power plants release significant pollutants into the air and water due to untreated or partially treated waste. Additionally, human activities related to these plants involve the use of harmful petrochemical materials, leading to air, water, and soil pollution from the combustion of low-quality fuels like heavy oil fuel (HOF).

The present review studies the distribution and accumulation of heavy metals in soils surrounding areas of fuel combustion industries especially FFPP and the negative impact on human health risk and the environmental condition, as one of the most important research areas at the national and international levels.

2. Fossil fuel power plant

Through the rapid development taking place today, electrical energy has become an integral part of the world's needs because it can be easily converted into other forms of energy, such as light, kinetic, or thermal energy through electrical devices [6]. The increasing need for electrical energy has led to diversification in its production sources according to the countries' capabilities to generate electrical energy from the sources available in this country, most countries in the Arab world depend on gas and oil power plants, especially the countries of the Arabian Gulf.

The idea of generating electricity is often to convert mechanical (rotational) energy into power Electricity is generated by magnetic induction and the device responsible for this conversion is the electricity generator vertigo. But the source of rotation is what differentiates between the types of generating stations, the most common power plants in the world are thermal power plants, hydroelectric power plants, internal combustion power plants (diesel-gas), nuclear power plants, wind power plants, and recent solar power plants [7].

The FFPPs as thermal and gas electric power plants are the major contributors to air and soil pollution with HMs, this is caused by their use of fossil fuels in large quantities to generate the necessary heat for thermal power plants. Thermal power plants are considered the most widespread, despite all their disadvantages, as they cause pollution, the heavy fuel used and the incomplete and poor combustion method generate the largest possible amount of heavy metals and other pollutants.

In Iraq, power generation stations use three fuel types: natural gas, light fuel, and heavy fuel. Natural gas is the most cost-effective, efficient, and environmentally friendly option. Light fuel is costly due to its reliance on gasoil and imports from neighboring countries. Heavy oil fuel presents two types; crude oil is extracted directly from crude oil wells and heavy fuel, a by-product of refining raw fuel, is cheaper but of lower quality. These stations are distributed across all governorates and enhance the overall efficiency and productivity of power generation in Iraq. Representative Figure 1 shows a thermal power plant from the first combustion of fuel until the production of electrical energy.

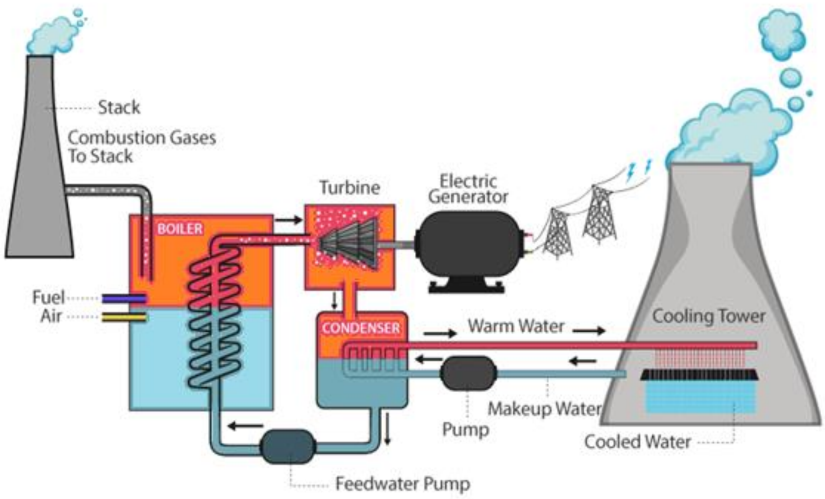

FIGURE 1. - Thermal power plant [6]

2.1 Environmental Impact of Fossil Fuel Thermal Power Plants

Fossil fuels as the primary energy source in most countries have led to many problems and negative impacts on the environment, such as global warming, air pollution, and its effect on the population's quality of lifecycle [7].

The rapid rise in energy consumption is due to population growth and urbanization. On the other hand, global energy consumption is expected to grow by 53% in 2030 [8].

Primary energy sources currently consist of 33% oil, 30% coal, and 24% natural gas. Together, these elements account for 87% of fossil fuel share in the global primary consumption [9]

The combustion of fossil fuels releases pollutants and greenhouse gases into the environment and destroys the ecosystem. In addition, the depletion of non-renewable resources that may be scarce or non-existent in the coming decades threatens energy security for future generations. Approximately 35 heavy metals are found in crude oil, 20 in gasoline and around 30 in fuel oil, in addition, fly ash is airborne particulate matter (PM) produced by heavy oil burning in the FFPP [10].

Fossil fuel combustion can release metals into the air as part of inorganic and organic materials, depending on the fuel type and combustion method. Some heavy metals can also catalyze the atmospheric conversion of main air pollutants into secondary products. Primary pollutants can undergo chemical reactions and transform into secondary contaminants, including ozone, acids, aerosols, peroxysil nitrate, and others [11].

The sulfur and nitrogen oxides react with clouds and raindrops forming acids, resulting in acid rain. This changes the soil's acidity and deposits some plankton and pollutants present in the air on the surface of the soil or water, leading to its pollution. These pollutants then enter the food basket, and their long-term accumulation affects the Earth's biosphere and human and animal health.

Human exposure to metal elements occurs through inhalation and ingestion of inhaled particles or entry of this mineral into the food basket in contaminated quantities of human food.

Researchers have increased interest in studying human exposure to these metals, especially in emissions sites, because they depend largely on proximity to emission sources and other local conditions.

2.2 Direct Exposure to HM

Health risks from power plant emissions depend significantly on the fuel composition, as the byproducts of combustion pose serious concerns for human health. Toxic elements such as chromium, copper, arsenic, mercury, cadmium, nickel, manganese, lead, and zinc have a tendency to accumulate in soil and water, indirectly entering the food chain of humans and livestock [12].

Extended exposure to these elements can result in health issues, including neurological, kidney, and endocrine disorders, as well as cardiovascular problems, hypertension, and cancer [13].

Arsenic in the human body can damage peripheral nerves, particularly sensory fibres, resulting in significant olfactory disorders, including loss of smell and taste [14].

Cadmium can cause bone, kidney, and itai-itai disease, in addition to lung and prostate cancer, furthermore Problems include headaches, coughing, hypertension, lymphocytosis, emphysema, and testicular atrophy [15].

Copper can lead to abdominal pain, anaemia, diarrhoea, headache, liver, and kidney damage, in addition to metabolic disorders like vomiting and nausea [16,17].

Lead exposure can result in anorexia, chronic nephropathy, hypertension, insomnia, hyperactivity, learning difficulties, lower fertility, and Alzheimer's disease, in addition to neuron and renal damage [18-20].

Nickel can cause headaches, kidney, and cardiovascular diseases, in addition to dizziness, dermatitis, chest pain, difficulty breathing, lung, and nasal cancer. In addition to prostate cancer, zinc also causes ataxia, depression, gastrointestinal irritation, vomiting, haematuria, icterus, impotence, damage to the liver and kidneys, and lethargy [15] [21]. The toxic HM related to the FFPP and human health risks is shown in Figure 2.

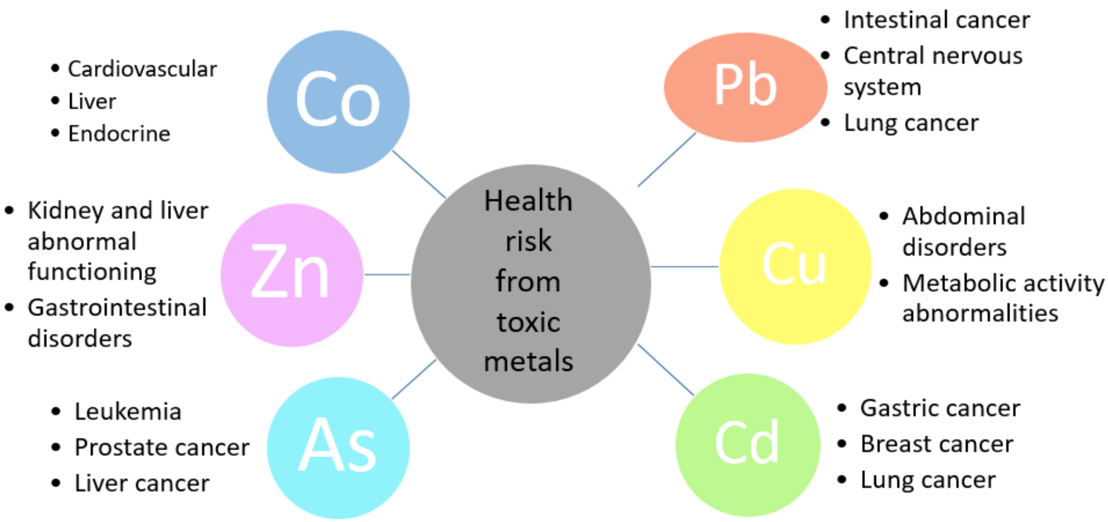

FIGURE 2. - **The main toxic HM related to the FFPP and human health risks**

3. Release mechanism of heavy metals in FFPP

Ash is generated from burning heavy oil fuel in power plants and primarily consists of carbon along with some metallic elements. Numerous researchers have investigated the applications of fly-ash, a byproduct material with diverse uses. Chemical analysis shows that it comprises high concentrations of V and Ni, along with hazardous elements including As, Cd, Co, Cr, Pb, Se, and trace amounts of Zn, Cu, Fe, and Mn. Combustion of heavy fuel concentrates most trace elements in ash to about 10 times their levels in the original fuel. The bottom ash from oily fuel combustion in FFPP contains a carbonaceous matrix along with elements such as V, Ni, Fe, Cr, Cu, Pb, Zn, Cd, and uranium.

Finally, the release of HM essentials in the production progression of FFPP contains fuel release when storage, handling, and transporting in addition to an oil spill at the plant were released to soil in addition to surface and groundwater [12] [22]. On the other hand, the key component of fly ash is airborne particulate matter (PM), which has varying chemical characteristics depending on the location [12,13]. PM constituents include HM like lead, zinc, selenium, arsenic, copper, cadmium, nickel, and vanadium, in conjunction with polycyclic aromatic hydrocarbons emitted during the combustion process in FFPP generation (Figure 3).

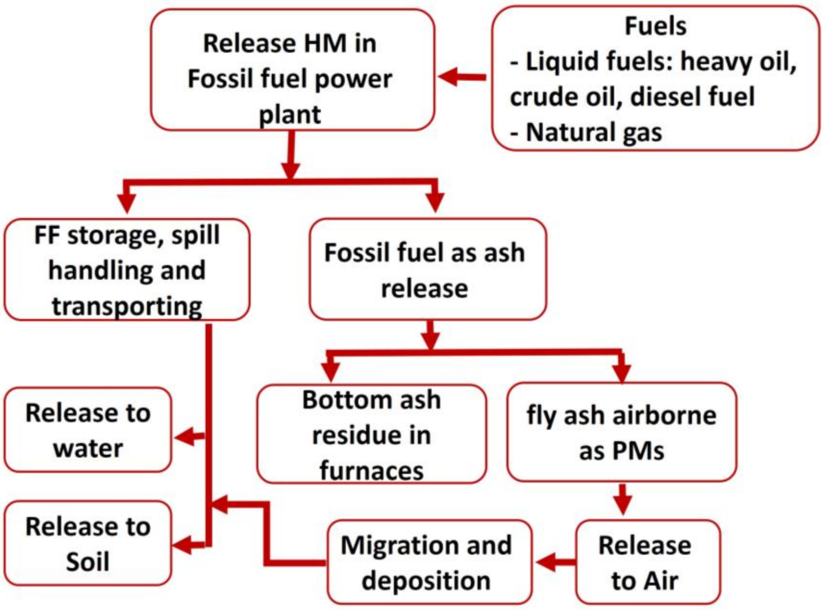

FIGURE 3. - **The mechanism of HM release in FFPP**

4. Environmental indicators to measure soil pollution

Basic soil pollution indicators such as chemical composition, biological activity, and physical properties provide valuable information. However, for more precise analysis, advanced indicators such as the Geological accumulation index Igeo, Contamination factor CF, Ecological risk index RI, and Pollution load index PLI, are used to measure the impact of Heavy Metal soil pollution from fossil fuel power plants. These delve into assessing the level of contaminants and their potential impact.

4.1 Contamination factor CF

The contamination factor CF associates the concentration of a particular HM in a soil sample to its natural level concentration level (background) proposed by Hakanson, 1980 [22, 23]. CF is calculated as the following equation:

$$CF = \frac{Cm}{Bm} \qquad (1)$$

Where: Cm is the average value of HM, and Bm is the baseline (background) concentration of HM. CF is classified into four-classes as follows: CF < 1 (Low soil contamination), 1< CF < 3 (Moderate soil contamination), 3 < CF < 6 (Major soil contamination), CF > 6 (Extreme soil contamination) [24,25].

4.2 Index of geo accumulation (Igeo)

Muller (1969) proposed a method to assess sediment pollution levels, which researchers have widely used to evaluate heavy metal contamination across various fields [26]

The index of geo accumulation environment takes into account background concentration but also considers a normalization factor based on the geochemical composition of the soil. This aims to account for natural variations in element levels depending on the geology of the region [25, 26], Igeo is calculated as the equation (2):

$$Igeo = \log_2\left(\frac{Ci}{N.Bi}\right) \qquad (2)$$

Where:

N = normalization factor compensating for lithogenic effects on background content, typically valued at 1.5, Ci = level of i-HM in the soil, Bi = the baseline (background) concentration of i-HM, and Igeo is classified into five classes as follows.

Igeo < 0 (Uncontaminated soil), 0 < Igeo < 1 (Slightly soil contamination), 1 < Igeo < 3 (Moderately soil contamination), 3 < Igeo < 5 (Heavy soil contamination), 5 < Igeo (Extreme soil contamination) [26,27].

4.3 Pollution load index PLI

Pollution load index evaluates the overall limits of soil pollution by combining individual CF values for multiple HM contaminants of concern, PLI is applicable to enhance the quality of soil through monitoring programs [25,26] [27]. PLI is calculated as the equation (3):

$$PLI = (CF_1 \times CF_2 \ldots\ldots\ldots\ldots CF_n)^{\frac{1}{n}} \qquad (3)$$

Where:

CFi = contamination factor for the ith heavy metal in the soil, n= the number of HM. PLI categorization as classified into five classes as the following:

PLI < 1 (Not polluted soil), 1 < PLI < 2 (Low levels of soil pollution), 2 < PLI < 3 (Moderate soil polluted), 3 < PLI < 4 (High soil polluted), 4 < PLI < 5 (Very high polluted), 5 < PLI (Extreme level of pollution with HM) [25] [27].

4.4 Ecological risk index RI

Degree of potential risk index of HM soil contamination is based on contamination factor (CF) values, HM toxicity and ecological response of each metal, the risk index is suggested by Hakanson, 1980 [25]. On the other hand, RI indicates the potential ecological risk index of all HM for the region by summing individual potential factors. This allows for a more comprehensive valuation of the potential health and environmental hazards posed through the overall contamination [25][28]. RI is calculated as the following equation:

$$RI = \sum_{n} CF_i \times Tr_i \quad (4)$$

Where: CFi= contamination factor for i-HM.

n =number of analyzed HM pollutants, Tr_i = response toxic factor of i-HM indicating the risk posed by the HMs and the environment's vulnerability to its pollution computed as (Cadmium is 30, Arsenic is 10, Lead, Copper and Nickel are 5, Chrome is 2, Zinc and Manganese are 1) [28]. The revised RI categorization is classification into four classes as follows:

RI< 150 (Low risk of contamination), 150 < RI < 300 (Moderate risk of contamination), 300 < RI < 600 (High risk of contamination), RI > 600 (Extreme level of risk contamination) [25] [28].

5. Locally Pervious Study on FFPP

The issue of soil pollution with HMs is one of the significant issues because of the damage it causes to the environment and public health. The concentrations of HM in Iraq were studied in the last century adopted by [29], where 720 soil samples were analyzed to determine the contents of elements (chromium, nickel, zinc, lead, and copper). In the soil of the Mesopotamian Plain, Iraq. The researchers concluded that the sediments of the Mesopotamian Plain were relatively free of pollution at that time.

According to data from the Iraq CSO Department of Statistics [30] indicates that 70 power generation stations are operating across Iraq. Of these, 91.5% rely on fossil fuels, distributed among four regions: 16 stations in the central region, 8 in the northern region, 14 in the Middle Euphrates area, and 18 in the southern region. Study adopted by [31] to evaluate the influence of FFPP of AL Dora on soil pollution parameters. Twenty-four soil samples were collected from the area south of Baghdad around the power plant project, to analyze the concentration of Cr, Zn, Pb, and Ni. The study showed an irregular rise in metal concentration near the plant, with average levels sequence order of Zn > Pb > Cr > Ni. Contamination factor ranked as Pb > Zn > Ni > Cr. Furthermore, 56.25% of samples exhibited a moderate concentration factor and 41.66% displayed a moderate pollution load factor. The average Index Geo-accumulation (Igeo) shows a sequence of Pb > Zn > Ni > Cr, indicating anthropogenic influence on soil pollution, which is further affected by plant pollutants, all RI levels had low ecological risk potential.

Another study was carried out to study HM contamination in the areas inside and around the activities of the Daura refinery. In the experimental work, HM including Zn, Ni, Pb, and Cd were measured in 17 sites around the Doura refinery. Results specify that the average value of nickel and zinc is 100 mg/kg and 62 mg/kg, respectively [32]. With some exceptions, the majority of zinc, nickel, and lead concentrations accumulate in an upper layer and decrease with depth, except for cadmium. [32].

Another study was conducted for thermal power plants in central-southern Iraq to study the effect of the station on emissions polluted by heavy metals. 18 fly ash samples were collected from the stations, and the concentration of HM including Fe, Zn, Cu, Mn, Cd, and Cd) was analyzed. Some metal concentrations were higher than the international limitation. Generally, the increase in HM concentrations in fly ash samples is due to fuel combustion processes that lead to the release of metallic material, which depends on the geology of the study area and the geochemical properties of the fuel in addition to the type of fuel available in each unit of the FFPP [33].

The concentrations of HM and their environmental risks were evaluated in the soil neighboring electrical power generators in the city of Ramadi, Iraq. The finding obtained presented average concentrations of HM are arranged in the ranked order: chromium (360.90 µg/g), nickel (283.65 µg/g), zinc (190.96 µg/g), lead (130.75 µg/g), copper (36.54 µg/g), Co (16.62 µg/g), and Cadmium (2.55 µg/g) were HM concentration exceed the limitations of USEPA of hazardous waste combustion facilities [34]. The substantial correlations among the HM concentrations. Furthermore, the finding of the assessment of the potential environmental risk factor displayed that downward order. Very severe for Ni, Cd, and Co, heavy for Zn, and light for Cr and Pb. Finally, the potential environmental risk index RI is categorized as severe environmental risks for all HM measurements [35].

The study reported in [36] assessed soil contamination from emissions of the FFPP in Al Khairat, an irrigation area in Karbala city. The investigation of plant leaves samples were taken from 100 to 400 meters away from the power plant, downwind. The results revealed a significant increase in heavy metal concentration, with Hg>Pb>Cd. Additionally, the area near the power station was negatively impacted by gas emissions, rendering the soils unsuitable for irrigation.

The study by [37] measured the concentration of HM in the soil of Shattrah, Al-Nasiriyah governorate by using an atomic absorption spectrophotometer method in seven different locations in the city. The results indicate that there was the order of Pb, Zn, Ni, Cu, and Cd with average values arranged (172, 66, 21.5, 21, and 12.27) ppm respectively.

Finally, the study conducted by [38] aimed to assess the impact of the FFPP on soil HM content, with sampling stations selected at Abu Gharq, Al-Diwaniyah, Al Khairat and Al-Haidariya Power Plants, located at distances of 20, to 200 meters from the power plant. The finding indicated that the soil's heavy metal content was higher near the stations and decreased with distance from them.

The average value of the HM sequence ranked Pb, Zn, Ni, Cu, and Cd for Al-Khaairat FFPP. Furthermore Zn, Pb, Ni, Cu, and Cd for Abu Garaq, Al-Diwaniay and Al-Haidariy FFPP. HM increases were due to proximity to pollution sources, which release fuel combustion products and fly ash with high levels of HM, as well as the composition of the underlying rocks that influence the soil's heavy element content.

Table 1. - Mean heavy metal concentrations (mg/Kg) in soil samples from the previous study in Iraq

Study area	*Zn*	*Pb*	*Ni*	*Cu*	*Cr*	*Co*	*Cd*	Ref.
Mesopotamia Plain	54	9	23	26	4.9	21	-	[29]
Al Nasiriyah	66	172	21.5	21	-	-	12.27	[37]
Dora Refinery	62	13	100	-	-	-	0.21	[32]
Dora PP	66	87	32	-	45	-	-	[31]
Ramadi PP	191	131	284	37	361	16.62	2.55	[34]
Al Khairat PP	96	106	59	25			3	[38]
Abu Garaq PP	186	159	102	36	-	-	7	[38]
Al Diwaniay PP	220	182	99	38	-	-	9	[38]
Al Haidariy PP	302	203	122	41	-	-	9.5	[38]

6. Conclusion

Managing the environmental risks of fuel and energy complex facilities has become a current priority for the global community to control and comprehensively reduce environmental pollution. It should also be the case in Iraq. Today, the phenomenon of Iraqi environmental pollution has become one of the major problems facing the health of society, whether through pollution of its weather, water, or soil. The increase in heavy metal concentrations in Iraqi soil over time is a result of the increase in human actions that work through burning fuel, especially the FFPP project which indicates the existence of a major environmental problem unless work is done to monitor it and strict international regulations are followed to maintain a sustainable environment. The previous study found that the maximum values of heavy metals (in mg/kg units) were 361 for Cr, 284 for Ni, and 16.62 for Co in the Al-Ramadi PP area. The value for Cd was 12.27 in the Al Nasiriyah area. Additionally, the values for Zn, Pb, and Cu were 191, 132, and 37 in the Al Haidariy FFPP area. On the other hand, HM content in the soil around the FFPP project was highest near the stations and decreased with distance, suggesting that fuel burning furthermore fuel storage, handling, transportation, and spills contributed to this contamination.

It is appropriate to evaluate environmental risks based on geographical monitoring and environmental indicators to know and determine the sources of pollution and how pollutants spread, to build engineering and economic plans to reduce polluting emissions and treat the resulting pollution, if possible, to reduce the occurrence of negative consequences on the environment and the biosphere. Fly ash, a key component, contains airborne particulate matter including HM from combustion. Addressing key challenges can reduce the environmental impact of thermal power generation, supporting global sustainable development and conservation efforts. In the short term, transitioning to natural gas units and eventually adopting renewable energy is essential to decrease fossil fuel emissions and chemical pollution. Future research should focus on advanced pollution control technologies to lessen the environmental and health effects of trace metal emissions from heavy fuel oil combustion.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

REFERENCES

[1] R. Gautam, E. Priyadarshini, A.K. Patel, and T. Arora, "Assessing the impact and mechanisms of environmental pollutants (heavy metals and pesticides) on the male reproductive system: a comprehensive review," *J. Environ. Sci. Health, Part C*, vol. xx, no. xx, pp. 1-28, 2024.

[2] B. Li, J. Song, M. Guan, Z. Chen, B. Tang, Y. Long, R. Mao, J. Zhao, W. Xu, and Y. Zhang, "With spatial distribution, risk evaluation of heavy metals and microplastics to emphasize the composite mechanism in hyporheic sediments of Beiluo River," *J. Hazard. Mater.*, vol. 462, p. 132784, 2024.

[3] H.S. Budi, M.J. Catalan Opulencia, A. Afra, W.K. Abdelbasset, D. Abdullaev, A. Majdi, M. Taherian, H.A. Ekrami, and M.J. Mohammadi, "Source, toxicity and carcinogenic health risk assessment of heavy metals," *Rev. Environ. Health*, vol. 39, no. 1, pp. 77-90, 2024.

[4] W. Jadaa and H. Mohammed, "Heavy metals–definition, natural and anthropogenic sources of releasing into ecosystems, toxicity, and removal methods–an overview study," *J. Ecol. Eng.*, vol. 24, no. 6, 2023.

[5] M. Gavrilescu, "Water, soil, and plants interactions in a threatened environment," *Water*, vol. 13, no. 19, p. 2746, 2021.

[6] "Fossil Fuel - Thermal Power Plant And Effects Of Fossil Fuel," Byjus.com, 2011. https://byjus.com/physics/fossil-fuel/

[7] I. Manisalidis, E. Stavropoulou, A. Stavropoulos, and E. Bezirtzoglou, "Environmental and health impacts of air pollution: a review," *Front. Public Health*, vol. 8, p. 505570, 2020.

[8] Q. Hassan, M. Al-Hitmi, V.S. Tabar, A.Z. Sameen, H.M. Salman, and M. Jaszczur, "Middle East energy consumption and potential renewable sources: An overview," *Clean. Eng. Technol.*, vol. 12, p. 100599, 2023.

[9] F. Musharavati, K. Sajid, I. Anwer, A.S. Nizami, M.H. Javed, A. Ahmad, and M. Naqvi, "Advancing Biodiesel Production System from Mixed Vegetable Oil Waste: A Life Cycle Assessment of Environmental and Economic Outcomes," *Sustainability*, vol. 15, no. 24, p. 16550, 2023.

[10] V.B. Vouk and W.T. Piver, "Metallic elements in fossil fuel combustion products: amounts and form of emissions and evaluation of carcinogenicity and mutagenicity," *Environ. Health Perspect.*, vol. 47, pp. 201-225, 1983.

[11] Gautam, R., Priyadarshini, E., Patel, A.K. and Arora, T. "Assessing the impact and mechanisms of environmental pollutants (heavy metals and pesticides) on the male reproductive system: a comprehensive review." *Journal of Environmental Science and Health, Part C*, pp.1-28, 2024

[12] A. R. Gupta, S. Bandyopadhyay, F. Sultana, and D. Swarup, "Heavy metal poisoning and its impact on livestock health and production system," *Indian J. Anim. Health*, vol. 60, no. 2, 2021.

[13] F. O. Ohiagu, P. C. Chikezie, C. C. Ahaneku, and C. M. Chikezie, "Human exposure to heavy metals: toxicity mechanisms and health implications," *Mater. Sci. Eng.*, vol. 6, no. 2, pp. 78-87, 2022.

[14] M. Thakur, M. Rachamalla, S. Niyogi, A. K. Datusalia, and S. J. S. Flora, "Molecular mechanism of arsenic-induced neurotoxicity including neuronal dysfunctions," *Int. J. Mol. Sci.*, vol. 22, no. 18, p. 10077, 2021.

[15] N. Zuhra et al., "Human Health Effects of Chronic Cadmium Exposure," in *Cadmium Toxicity Mitigation*, Springer Nature Switzerland, pp. 65-102. 2024.

[16] L.M. Haase, T. Birk, A.M. Bachand, and K.A. Mundt, "A health surveillance study of workers employed at a copper smelter—effects of long-term exposure to copper on lung function using spirometric data," *Journal of Occupational and Environmental Medicine*, vol. 63, no. 8, pp. e480-e489, 2021.

[17] M.A. Karimova, "Effect of Iron and Copper Element on Physiological Processes in the Body," *Research and Education*, vol. 3, no. 1, pp. 187-191, 2024.

[18] S. Gunturu and T. S. Dharmarajan, "Copper and zinc," in *Geriatric Gastroenterology*, pp. 1-17, 2020. [Online]. Available: https://doi.org/10.1007/978-3-319-90761-1_25-1.

[19] A.M. Cybulska et al., "Are cadmium and lead levels linked to the development of anxiety and depression?-A systematic review of observational studies," *Ecotoxicology and Environmental Safety*, vol. 216, p. 112211, 2021.

[20] B. Du et al., "Environmental and human health risks from cadmium exposure near an active lead-zinc mine and a copper smelter, China," *Science of The Total Environment*, vol. 720, p. 137585, 2020.

[21] W. Ahmad, R.D. Alharthy, M. Zubair, M. Ahmed, A. Hameed, and S. Rafique, "Toxic and heavy metals contamination assessment in soil and water to evaluate human health risk," *Scientific Reports*, vol. 11, no. 1, p. 17006, 2021

[22] S. Padma, S. Ghosh, B. Srinivas, K.C. Ghanta, and S. Dutta, "Bioremediation of Heavy Metals—Its Pros and Cons," in *Heavy Metal Remediation: Sustainable Nexus Approach*, Cham: Springer Nature Switzerland, pp. 213-235. 2024

[23] R.N. Khalef, A.I. Hassan, and H.M. Saleh, "Heavy metal's environmental impact," in *Environmental impact and remediation of heavy metals*, IntechOpen, 2022.

[24] M. Arab, N. Bidin, K. Chaudhary, and R. Hosseinian, "Characterization of pollution indices in soil surrounding a power plant by laser induced breakdown spectroscopy," *Anal. Lett.*, vol. 48, no. 2, pp. 360-370, 2015. [Online]. Available: http://dx.doi.org/10.1080/00032719.2014.942911.

[25] B. P. Ahirvar, P. Das, V. Srivastava, and M. Kumar, "Perspectives of heavy metal pollution indices for soil, sediment, and water pollution evaluation: An insight," *Total Environ. Res. Themes*, vol. 6, p. 100039, 2023. [Online]. Available: https://doi.org/10.1016/j.totert.2023.100039.

[26] Y. Xian, M. Wang, and W. Chen, "Quantitative assessment on soil enzyme activities of heavy metal contaminated soils with various soil properties," *Chemosphere*, vol. 139, pp. 604–608, 2015. [Online]. Available: https://doi.org/10.1016/j.chemosphere.2014.12.060.

[27] Y. Xu, B. Seshadri, B. Sarkar, H. Wang, C. Rumpel, D. Sparks, M. Farrell, T. Hall, X. Yang, and N. Bolan, "Biochar modulates heavy metal toxicity and improves microbial carbon use efficiency in soil," *Sci. Total Environ.*, vol. 621, pp. 148–159, 2018. [Online]. Available: https://doi.org/10.1016/j.scitotenv.2017.11.214.

[28] Y. Zhang, D. Wu, C. Wang, X. Fu, and G. Wu, "Impact of coal power generation on the characteristics and risk of heavy metal pollution in nearby soil," *Ecosyst. Health Sustain.*, vol. 6, no. 1, p. 1787092, 2020. [Online]. Available: https://doi.org/10.1080/20964129.2020.1787092.

[29] "Environmental statistics for Iraq (Electric energy indicators)," *Central Organization for Statistics and Information Technology (COSIT)*, https://www.cosit.gov.iq/ar/, Nov. 2023.

[30] A. A. Hanna and M. A. Al-Hillali, "Measurement and standardization of some pollutant elements in the Mesopotamian plain sediments, Iraq," *GEOSURV*, Int. Rep. no. 1525, 1986.

[31] J. A. A. Abbas, "Spatial distribution of some heavy metals pollution parameters for soils surrounding Al-Dora Power Plant, South Baghdad, Iraq," *Plant Arch.*, vol. 20, no. 2, pp. 6639-6654, 2020. [Online]. Available: https://plantarchives.org/20-2/6639-6654%20(6996).pdf.

[32] R.H. AL-Anbari, M.M. AL-Kaissi, and M.A. Al-Ameri, "Distribution of some heavy metals pollution caused by AL-Daura Refinery in the surrounding region," *Eng. and Tech. Journal*, vol. 31, p. 20, 2013.

[33] I. Kamil Ahmed, "Concentrations of some heavy elements in fly ash samples from thermal electric power stations in the middle and south of Iraq," *Journal of Physics: Conference Series*, vol. 1032, no. 1, p. 012044, May 2018.

[34] US Environmental Protection Agency (USEPA). "Screening level ecological risk assessment protocol for hazardous waste combustion facilities." (1998).

[35] L.F. AL-Heety, O.M. Hasan, and E.A.M.S. Al-Heety, "Heavy metal pollution and ecological risk assessment in soils adjacent to electrical generators in Ramadi City, Iraq," *Iraqi Journal of Science*, pp. 1077-1087, 2021.

[36] F. K. Fuliful and G. J. Habi, "Heavy metals emitted from power plant in Al-Khairat city effect on the surrounding soil," in *AIP Conf. Proc.*, vol. 2290, no. 1, 2020. [Online]. Available: https://doi.org/10.1063/5.0028087.

[37] M. A. Hasan, "Evaluation of the concentration of some heavy elements of selected soils from Shatrah City," *Indian J. Public Health Res. Dev.*, vol. 10, no. 7, 2019. [Online]. Available: http://dx.doi.org/10.5958/0976-5506.2019.01634.6.

[38] J. Hamza and Luma, "A study of the effect of electric power plants on the soil content of some heavy elements (Ni, Pb, Cu, Cd, Zn, Mn, Fe)," *IOP Conf. Ser.: Earth Environ. Sci.*, vol. 1262, no. 8, p. 082017, Dec. 2023. [Online]. Available: https://doi.org/10.1088/1755-1315/1262/8/082017.