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Spatial Assessment of Heavy Metals and Thermal Pollution in the Tigris River near Salah Al-Din Thermal Power Plant using Heavy Metal Pollution Index and Metal Index

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Abstract

The Tigris River is considered a major source of water in Iraq and crucial for various activities such as agriculture, anthropogenic and industry. Samarra city, which is located in Salah Al-Din province, is therefore considered one of its major river banks. The study examines the quality of Tigris River near Salah Al-Din thermal power plant, focusing on its heavy metal content using the heavy metal pollution index (HPI) and the metal index (MI). Samples were collected from two sites (1) before and (2) after the power plant in December 2023. Chromium (Cr), boron (B), arsenic (As), copper (Cu), silver (Ag), manganese (Mn) and nickel (Ni) were studied. The Cr, As, Ag and Ni levels were exceeding WHO limits at site 1, whereas Ag and Ni exceeded accepted levels at site 2. The levels of Cr, Ag and Ni for irrigation uses were unsuitable at site 1, while at site 2, only Ag and Ni were unfit for crop irrigation. Thermal pollution was also present in the selected area, exceeding WHO guideline at 35 ºC. The HPI and MI indices reveal high heavy metal pollution levels in Tigris water, making it unsafe for drinking and unsuitable for crop irrigation, as confirmed by the studied. The data show that Salah Al-Din thermal power plant significantly reduced heavy metal levels by almost half compared to site 1 data, primarily due to its high temperature and evaporation methods.

Keywords: Tigris; Heavy metal Pollution Index; Metal Index; Irrigation; Drinking water

1. Introduction

The growing global population has increased demand for electricity, which can be generated through thermal power plants. These plants use evaporation energy to generate steam, which powers turbines to generate electricity. The heat used to boil water can come from burning fuel, direct sunlight, or geothermal heat (Pan *et al.,* 2018).

Mesopotamia has been struggling with electricity shortages for years. Thermal power plants, half of which require water to evaporate, have been constructed near rivers like the Tigris and Euphrates, which are vital sources of drinking water and surface water for domestic and economic activities in Iraq. The Tigris River is considered a vital source of surface water for domestic use and economic activities in Iraq. The assessment of water quality in the Tigris has become an important issue in the coming years, especially due to the concern that fresh surface water will be scarce in the few years and that it is always susceptible to chemical and physical pollution (Chabuk *et al.,* 2020). The Tigris water is facing contamination due to toxic pollutants from industrial factories and thermal electrical plants, which discharge wastewater and warmer water into the river without proper treatment, posing a threat to the ecosystem for living organisms (Al-Ansari *et al.,* 2019). Excess consumption of essential trace elements in drinking water may lead to adverse health effects (Staniek and Wójciak, 2018). In particular, elements such as cadmium, copper, zinc, and lead have significant biological toxicity and are harmful to human health. If their concentration exceeds the necessary limit, they are harmful to organs such as the liver, kidney, digestive system, blood, nervous system, and brain (SCSEDRI, 2000).

The world's riverine ecosystems are under pressures due to human needs such as energy and electricity. Physical and chemical stressors have a huge impact on riverine ecosystems. Once the main physical stressor on river structures is thermal pollution, the major freshwater source which causes thermal pollution is thermoelectric power plants (Raptis *et al.,* 2016). The study focused on once-through cooling systems in river power plants, which absorb heat from steam and discharge warmer water to local sources through pipes from nearby water sources.

Thermal pollution, caused by warmer water from thermoelectric power plants, can cause a significant increase in water temperature in rivers or lakes, affecting the level of dissolved oxygen in the aquatic environment. This can harm all aquatic life, particularly in areas with high thermal emissions sources, particularly in the Middle East, according to Cook *et al.* (2015).

Freshwater quality river degradation, particularly about harmful chemical stressors such as heavy metals, is becoming more significant and necessitates expensive treatment. As discussed by Jazza *et al.* (2022), heavy metal pollution in drinking surface water is the main research area for researchers on water quality and can cause adverse impacts to human health, especially when their levels exceed the allowable limit in drinking water. The widely spread pollutants in water are heavy metals, therefore drinking water polluted with heavy metals becomes toxic and deleterious to humans and irrigation uses. The essential sources of heavy metals in riverine ecosystems are either natural or human activities (Bhardwaj *et al.,* 2017).

Heavy metals are released into the environment through the geological areas of rivers, especially during rainfall activities such as soil leaching and erosion (Abdullah, 2013). Mining waste and untreated disposal such as heavy metals from diverse industries such as pharmaceutical production and industrial regions near the river, are major causes of heavy metal pollution caused by anthropogenic sources. Heavy metals are harmful to living organisms, particularly plants and animals (Gautam *et al.,* 2014). Metals like Cu are essential for life processes in plants and animals, while Pb and Cd have no known physiological functions. They are significant water pollutants due to their toxicity, persistence, and accumulation in aquatic species, and can cause harmful effects on human body systems even at low concentrations (Angon *et al.,* 2024).

Assessment of drinking water using indices is a very beneficial tool to solve water quality related problems (Naqeeb and Jazza, 2020). Moreover, assessment of first-rate irrigation water is critical for sustainable irrigation and minimizing potential effects on crops. This study aims to assess the drinking water quality and irrigation status with heavy metal levels and thermal pollution in Samara district at a new thermoelectricity power plant near Tigris River in Salah Al-Din province by using seven heavy metals chosen for HPI and MI indices estimation.

2. Methodology

2.1 Study locations, sampling and analysis

The Tigris river is considered one of the main rivers in Mesopotamia, and it originates from Turkey and flows into the Iraqi north. The Tigris is of primary importance in Iraq. In the study area the river passed through an agricultural area and near a new thermoelectricity power plant that used a lot of water for once-through systems. The area of study is also near the city of Samarra, which is located north of the capital city; Baghdad, at approximately 125 km (Figure.1).

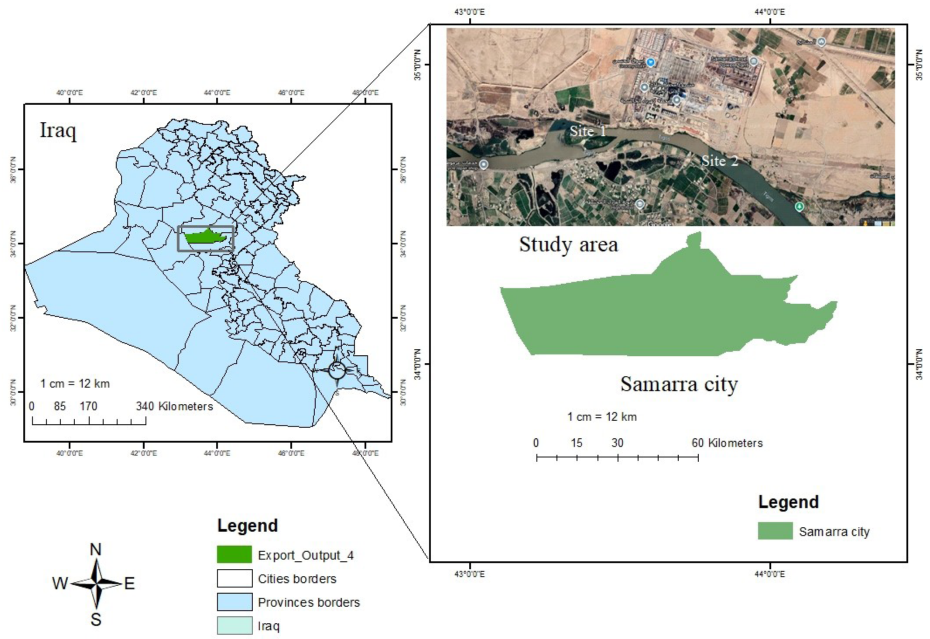

Figure 1. Sampling locations in Samarra city at the Salah Al-Din thermal power plant

The two sites were chosen during the wet season in December 2023 with coordinates 34.088318 and 43.972092. The sites were selected because of their strategic location near Samara City, particularly at a recently established thermoelectricity power plant. In terms of area, it is considered important due to the number of different farms for citrus, palm trees, crops, and grapes. Fourteen samples were collected from center of the river with sterilized polyethylene bottles (500 ml capacity). Except for the samples for temperature, all samples were stored at 4 ºC in laboratory iceboxes and analyzed within two weeks. The Ultrapure H_2SO_4 was used to acidify the samples, to maintain their pH levels below 2. This was done to avoid the adsorption and precipitation of heavy metals on the sample bottle wall (Rice *et al.,* 2012). The metals were calculated using an atomic absorption spectrometer model SHIMADZU AA-6200, whereas boron was calculated by UV-Vis spectrophotometer model V-530 JASCO. The results were obtained by professional technical employees at the Central Laboratory and Chemical Department in Engineering College of Tikrit University.

2.2 Heavy metal pollution indices

Seven metals were chosen as mentioned in Table 1 during December 2023. As well, two heavy metal indices have been used to assess the quality of the Tigris river at selected sites. The data obtained were compared with WHO (2022) guidelines for suitability of Tigris water to drinking uses and FAO guidelines to assess the studied sample water for irrigation purposes.

2.2.1 Heavy metal pollution index (HPI)

In order to assess the water quality of the Tigris River that contained heavy metals in the study area, several heavy metal pollution indices were proposed (Karaouzas *et al.,* 2021). The HPI index was used to measure the impact of each heavy metal on the overall water quality and assess its acceptability for human consumption. The HPI also represents the total quality of water with respect to heavy metals. To calculate HPI, the following equations (Eq) were used according to Mohan *et al.,* (1996):

Eq1: $$\mathrm{Wi} = \frac{K}{\mathrm{Si}}$$

Wi: is the unit of weightage, K: is the constant of proportionality (K = 1), and Si: is the recommended standard for i^{th} parameter.

Eq2: $$\mathrm{Qi} = \frac{([\mathrm{Mi}-\mathrm{Ii}])}{(\mathrm{Si}-\mathrm{Ii})}$$

Qi: is sub index of the ith parameter, Mi: is the monitored value of heavy metals of ith parameter in µg/L, Ii: is the ideal value, Si: refer to the standard value of the i^{th} metals.

Eq3: $$\mathrm{HPI} = \frac{\sum_{i=1}^{n} Wi\,Qi}{\sum_{i=1}^{n} Wi}$$

n: is the total number of parameters in the test.

HPI gives a simple picture of pollution by summing all values by one value; a higher HPI value (> 100) is considered contaminated, whereas a lower HPI value (< 100) means not contaminated by heavy metals (Appiah-Opong *et al.,* 2021).

2.2.2 Metal index (MI)

The metal index (MI) was preliminarily described by Tamasi and Cini (2004). The MI is an index that illustrates the composite effects of each metal on the overall water quality. Equation 4 provides the MI index. where MI is the metal index, Ci is the concentration of each heavy metal in the solution, MAC is the maximum allowed concentration of each metal, and the subscript i indicating the ith sample.

Eq4: $$\mathrm{MI} = \sum_{i=1}^{n} \frac{Ci}{(MAC)i}$$

MI value > 1 is a threshold of warning (Rezaei *et al.,* 2019) as shown in table 2.

3. Results and Discussion

3.1 Surface water quality of drinking water

The study analyzed Tigris river samples for heavy metals, finding most metals present, with Cu and Mn metals having zero values in the water samples. The other metals were found with variation values, all of which values were compared with WHO (2022) (Table 3), to assess the quality of surface water at sites 1 and 2. The Cu level at site 1 was 0.37021 mg/L, whereas that at site 2 was 0.0237 mg/L, which is at the acceptable limit level of the WHO at site 2. While concentrations of B at the two sites appeared acceptable. Whereas As showed an unacceptable level at site 1, whilst at site 2 it appeared acceptable level of As. Heavy metals such as Ag and Ni increased above

Table 1. WHO and FAO guidelines for selected heavy metals (WHO, 2022; FAO, 1999)

Heavy metal	Symbol	units	WHO	FAO
Chromium	Cr	mg/L	0.05	0.1
Boron	B	mg/L	2.4	0.75
Arsenic	As	mg/L	0.01	0.1
Copper	Cu	mg/L	2	0.2
Silver	Ag	mg/L	0.1	0.1
Manganese	Mn	mg/L	0.08	0.2
Nickel	Ni	mg/L	0.07	0.2

Table 2. Classification of MI index (Rezaei *et al.,* 2019)

Class	Characteristics	MI value
1	Very pure	< 0.3
2	pure	0.3 - 1
3	Slightly affected	1 - 2
4	Moderately affected	2 - 4
5	Strongly affected	4 - 6
6	Seriously affected	> 6

the allowed limits in WHO at both sites. The increased heavy metal levels of Ag and Ni above the standard levels may result in the following: Ag occurs naturally in the form of sulfides, oxides, and certain salts, which are highly insoluble and immobile. Ag ions are generally present in the oxidation state, with the ionic compounds silver nitrate and Ag chloride being the most important forms of Ag in drinking water. Ag can also appear as nanoparticles in aquatic bodies as a result of wastewater or industrial discharge (Banu *et al.,* 2021). Ni metals are mostly employed in the manufacturing of stainless steel and Ni alloys. Additionally, Ni is commonly used in household products such as batteries and car bearings. Thus, there is plenty of increased input of Ni from urban areas (Barałkiewicz and Siepak, 1999). However, in areas with high pollution, where groundwater naturally mobilizes Ni, or where Ni leaches from Ni or chromium-plated taps, stainless steel devices, or materials in contact with water, the contribution of Ni from water may be substantial. The principal source of Ni in drinking water is leaching from metals that come into contact with the drinking water. As known, heavy metals, according to the WHO (2022), have limits for permissible use, above these concentrations, they are considered toxic to all living organisms.

3.2 Surface water quality for irrigation

The area surveyed with the Tigris river is primarily an agricultural area with numerous plant farms, making it crucial to evaluate the quality of irrigation water. The Cr level before the thermoelectric plant (Site 1) was unacceptable according to FAO (1999) (Table 4), while the second site appeared acceptable at 0.0237 mg/L. The concentrations of B, As, Cu and Mn were in a suitable range for the irrigation, by the way, the other metals (Ag and Ni) recorded higher concentrations than those that depended on the FAO (1999) guidelines. Ag is considered vital and toxic for many biological systems, and its content in environmental samples is increasing with the increasing use of its compounds as well as silver-containing products in industry and medicine (Yang and Rose, 2005). The primary source of Ni in drinking water is leaching from metals that are in contact with drinking water. For example pipes and Ni may also be present in some groundwater as a consequence of dissolution from Ni or other bearing rocks. Ni is also released into the environment via various anthropogenic activities, like smelting, metal mining, vehicle emissions, fossil fuel burning, household waste disposal, municipal and industrial wastes disposal, application of fertilizer and organic manures application (Terry and Banuelos, 2000). In the FAO guidelines, the limit uses concentrations of metals that are slightly higher than the WHO guidelines for the quality of drinking water due to FAO guidelines dealing with plants.

3.3 Thermal pollution

Since the mid twentieth century, anthropogenic surplus heat discharged as cooling water from power plants has been identified as a type of pollution in aquatic

Table 3. Heavy metal levels in Tigris water samples according to the WHO 2022 (All data shown in mean ± SD at mg/L)

HMs	Cr	B	As	Cu	Ag	Mn	Ni
WHO 2022	0.05	2.4	0.01	2	0.1	0.08	0.07
Site 1	0.37021 ± 0.155	0.033115 ± 0.031	0.01137 ± 0.015	0 ± 0	0.519 ± 0.132	0 ± 0	0.684 ± 0.193
Site 2	0.0237 ± 0.015	0.010192 ± 0.014	< 0.01 ± 0	0 ± 0	0.499 ± 0.191	0 ± 0	0.428 ± 0.203

Table 4. Heavy metal levels in Tigris water samples according to the guidelines of FAO 1999 (All data shown in mean ± SD at mg/L)

HMs	Cr	B	As	Cu	Ag	Mn	Ni
FAO 1999	0.1	0.75	0.1	0.2	0.1	0.2	0.2
Site 1	0.37021 ± 0.155	0.033115 ± 0.031	0.01137 ± 0.015	0 ± 0	0.519 ± 0.132	0 ± 0	0.684 ± 0.193
Site 2	0.0237 ± 0.015	0.010192 ± 0.014	< 0.01 ± 0	0 ± 0	0.499 ± 0.191	0 ± 0	0.428 ± 0.203

habitats (Rivers) (Scherer, 1975). These heat emissions, referred to as thermal pollution, affect water temperature, which in turn impacts water quality and biota. Excess heat in rivers can be traced for long distances downstream from the source (Prats *et al.,* 2012). Thermal pollution in lakes and rivers affects the entire aquatic food web from benthic organisms (Vandysh, 2009). Aquatic ecosystems are often used as sinks for thermal pollution from anthropogenic activities. Therefore, studying the effect of heat on the Tigris River near Salah Al-Din thermal power plant in Samarra is important. The mean temperature at site 1 before the plant had a natural temperature of 11 ºC (Table 5). Whereas at site 2, after the plant appeared to be increasing in temperature at 35 ºC, according to the guidelines of FAO (1999), obtained data on temperature is considered at the maximum allowed limit accepted for irrigation. This finding is similar to Al-Aboodi's (2018) results, who mentioned an increase in water temperature in the wet season of about 45% at the outlet of the power plant compared with other sites. As is well known, once-through systems withdraw water from a source as cooling fluid and then return it to surface water. Once-through systems do not normally consume water within a power plant but indirectly consume water in downstream rivers or any source of water through increased evaporation resulting from reservoirs and increased water temperature (Gude, 2015). Cool water is generally palatable than warm water (WHO, 2022). Natural microorganisms, especially bacteria that live in water, prefer warm water to growth (30 ºC) (Felip *et al.,* 1996). This results in changes in odor, color, taste, and corrosion (WHO, 2022). In addition, most bacterial pathogens potentially transmitted by water infect the gastrointestinal tract and are excreted in the feces of infected humans and animals (Cabral, 2010). Increased water temperature helps bacterial pathogens duplicate their numbers. In conclusion, warm water enhances the degradation of rivers water quality.

Many global papers have discussed the impact of thermal pollution from thermoelectricity plants on river (Murrant *et al.,* 2017).

3.4 Heavy metal Indices

3.4.1 Heavy metal pollution index (HPI)

The HPI index is a crucial tool for assessing heavy metals, representing all values in a single value. It was determined using seven heavy metal means during the wet season. Table 6 details the calculation and comparison of HPI index values with WHO (2022) critical values. For drinking purposes of Tigris surface water near the chosen thermoelectricity power plant, the HPI value at site 1 appeared at 286.9, the results fall within the category of high heavy metal pollution according to (Appiah-Opong *et al.,* 2021). This could be due to the presence of high Cr, Ag and Ni concentrations in the surface water of the Tigris River. The high concentration of the mentioned metals, particularly Cr and Ni, could be attributed to the impact of the Baiji city landfill site (Hammash and Abed, 2022). Also, the study approved that the landfill site is causing pollution of the surface water of the Tigris with heavy metals, which is located north of Samarra city, about 103.6 km. As well, discharge of different types of sewage from Samarra city and medical landfill from Samarra Drugs Industries (SDI) directed to Tigris river without treatment may have a powerful effect on the quality of water and increased the level of different heavy metals (Ibrahim *et al.,* 2018).

Table 5. Temperature calculation and comparison with FAO and WHO Guidelines

Sites and Guidelines	Temperature mean
Site 1	11
Site 2	35
FAO, 1999	35
WHO, 2022	Cool water

In table 7 revealed the results of HPI in site 2 with values at 156.2. The value also falls into the high pollution category, but the vigorous thing in results that decreased the values of HPI to almost the half value compared with the HPI value in site 1. The only explanation for these results could be the process like filtration performed by the thermoelectric power plants. As is known, thermoelectric power plants draw large quantities of water for cooling purposes and condense steam from the turbine exhaust and then return this water to the waterway after increasing its temperature (Scanlon *et al.,* 2013).

Briefly, Salah Al-Din thermal power plant intakes the cooling water from the Tigris river and then enters it into condenser units. After that, the water is send to the boiler units. Natural fossil oil is used to boil Tigris water in a boiler, creating steam that drives turbines that produce electricity. After that, the low steam returns to the condenser, then warm water returns to the river. Therefore, two factors may help to decrease the HPI value at site 2, namely, the higher temperature in the boiler and the evaporation from the condenser to the atmosphere (Lee *et al.,* 2018), as shown in Figure 2.

For the suitability of the water of the Tigris River for irrigation near the studied power plant, the HPI index using the FAO guidelines (1999) was assessed (Table 8, 9). The results conducted in the mentioned tables give the HPI value in front of the power plant at 231.3. The results for location beyond the power plant show the HPI value at 137.9. Hence, the values of the two sites exceeded the standard set by the FAO for using water for irrigation, the surface water also fell into the pollution category for irrigation. Most lands surrounding power plant are considered agricultural lands uses. The area is famous for Citrus and Palm trees, which are known

Table 6. HPI index value at site 1 for drinking use (units of heavy metals shown in μg/L)

HMs	Si	Mi	Wi	Mi-Ii	Si-Ii	Qi*100	Wi Qi	Σ Wi	HPI
Cr	50	370.	0.02	370.	50	740.4	14.808	0.15770238	93.89839
B	2400	33.1	0.000416	33.1	240	1.37916666	0.000574653	0.15770238	0.003644
As	10	11.3	0.1	11.3	10	113	11.3	0.15770238	71.65396
Cu	2000	0	0.0005	0	200	0	0	0.15770238	0
Ag	100	519	0.01	519	100	519	5.19	0.15770238	32.91009
Mn	80	0	0.0125	0	80	0	0	0.15770238	0
Ni	70	684	0.01428571	684	70	977.142857	13.95918367	0.15770238	88.516
		ΣMi	0.15770238			ΣWi Qi	45.25775833		
						HPI	**286.9**		

Si: Standard permissible limit; Mi: Monitor value; Wi: Unit weight value; Ii: The ideal value; HMs: Heavy Metals.

Table 7. HPI index value at site 2 for drinking use (units of heavy metal shown in μg/L)

HMs	Si	Mi	Wi	Mi-Ii	Si-Ii	Qi*100	Wi Qi	Σ Wi	HPI
Cr	50	23	0.02	23	50	46	0.92	0.15770238	5.833774
B	2400	10	0.000416	10	2400	0.41666666	0.000173611	0.15770238	0.001101
As	10	10	0.1	10	10	100	10	0.15770238	63.41058
Cu	2000	0	0.0005	0	2000	0	0	0.15770238	0
Ag	100	499	0.01	499	100	499	4.99	0.15770238	31.64188
Mn	80	0	0.0125	0	80	0	0	0.15770238	0
Ni	70	428	0.0142857	428	70	611.428571	8.734693878	0.15770238	55.3872
		ΣMi	0.157702			ΣWi Qi	24.64486749		
						HPI	**156.2**		

Si: Standard permissible limit; Mi: Monitor value; Wi: Unit weight value; Ii: The ideal value; HMs: Heavy Metals.

for their ability to tolerate high levels of heavy metals (Ahmad *et al.,* 2012), and other agricultural lands for crop. In comparison between values 1 and 2 for HPI, which gives confirmation of what was revealed in the second paragraph, the values also decreased to almost half the value in site 2 compared with the value of site 1.

3.4.2 Metal pollution index (MI)

The purpose is to use a metal index to determine Tigris water near power plant suitability for drinking and irrigation uses and to confirm the results of the HPI index. The MI results ranged from 23.5 at site 1 to 12.5 at site 2 (Table 10). Both MI values exceeded the limit values that determine the purity of surfaces water for drinking use, which classify as seriously affected (Rezaei *et al.,* 2019). Therefore, it is necessary to use water from treatment stations for drinking. In the discussion paper of Ibrahim *et al.* (2018), the Tigris River in Samarra was polluted by heavy metals. As documented in Ahmed and Al-Shandah (2024), the paper also showed that Tigris water at Qayyarah city, which is located in Nineveh province, north Salah Al-Din province, within the coordinates 35°47'06.79" N, 43°17'22.82" E was also unsuitable for

Figure 2. Represent all gas exhaust from Salah Al-Din thermal power plant. A-Smoking emissions from power plant produced from burning fossil fuel used to boil water in boilers. B-Evaporation produced from condensers into the atmosphere.

Table 8. HPI index value at site 1 for Irrigation use (units of heavy metals shown in µg/L)

HMs	Si	Mi	Wi	Mi-Ii	Si-Ii	Qi*100	Wi Qi	Σ Wi	HPI
Cr	100	370.2	0.01	370.2	100	370.2	3.702	0.15770238	23.4746
B	750	33.1	0.001333 333	33.1	750	4.413333333	0.005884444	0.15770238	0.037314
As	100	11.3	0.01	11.3	100	11.3	0.113	0.15770238	0.71654
Cu	200	0	0.005	0	200	0	0	0.15770238	0
Ag	100	519	0.01	519	100	519	5.19	0.15770238	32.91009
Mn	200	0	0.005	0	200	0	0	0.15770238	0
Ni	200	684	0.005	684	200	342	1.71	0.15770238	10.84321
		ΣMi	0.046333 333			ΣWi Qi	10.72088444		
						HPI	**231.3**		

Si: Standard permissible limit; Mi: Monitor value; Wi: Unit weight value; Ii: The ideal value; HMs: Heavy Metals.

drinking purposes due to pollution by heavy metals from sewage discharge. As in the HPI results, the data confirm the role of the power plant in decreasing the values of the MI almost to half, which works as filtration. Moreover, in the explanation in the HPI index section regarding the filtration of power plant to heavy metal, another reason may be that the facility was opened in 2022, therefore still as a new facility to pollute the Tigris water.

For irrigation purposes, the FAO guideline was used to determine the suitability of the Tigris water in site 2 to irrigation for agriculture. As in clear in table 11, Seven heavy metals were selected in this investigation for the MI index due to their great importance to Tigris surface water, especially for irrigation in some rural areas of Samarra city (Salah Al-Din thermoelectric power plant). The MI index value at site 1 was 12.4 which was unsuitability for irrigation purposes. Similarity at site 2 was 7.4, which was also unsuitability for irrigation used. These data confirm that Tigris water is polluted by heavy metals and unfit for crop irrigation. Abdulateef and Naser (2021) found that the Tigris water in the Baghdad capital south of the study area was unsuitability for crop agriculture due to high levels of polluted heavy metals. As with the results for the HPI index, the values for the MI index decrease to almost half at site 2. Using a large amount of water for evaporation (steam) and untraditional cooling technology in a new Salah Al-Din thermoelectric power plant helped decrease the level of heavy metals at the second studied site (Pan *et al.,* 2018).

Table 9. HPI index value at site 2 for Irrigation use (units of heavy metals shown in µg/L)

HMs	Si	Mi	Wi	Mi-Ii	Si-Ii	Qi*100	Wi Qi	Σ Wi	HPI
Cr	100	23	0.01	23	100	23	0.23	0.15770238	1.458443
B	750	10	0.001333333	10	750	1.333333333	0.001777778	0.15770238	0.011273
As	100	10	0.01	10	100	10	0.1	0.15770238	0.634106
Cu	200	0	0.005	0	200	0	0	0.15770238	0
Ag	100	499	0.01	499	100	499	4.99	0.15770238	31.64188
Mn	200	0	0.005	0	200	0	0	0.15770238	0
Ni	200	428	0.005	428	200	214	1.07	0.15770238	6.784932
		ΣMi	0.0463333			ΣWi Qi	6.391777778		
						HPI	**137.9**		

Si: Standard permissible limit; Mi: Monitor value; Wi: Unit weight value; Ii: The ideal value; HMs: Heavy Metals.

Table 10. MI index value at site 1, 2 for drinking use (units of heavy metals shown in µg/L)

HMs	Ci	MAC	Ci/ MAC	Symbol	Ci	MAC	Ci/MAC
Cr	370.2	50	7.404	Cr	23	50	0.46
B	33.1	2400	0.013791667	B	10	2400	0.004166667
As	11.3	10	1.13	As	10	10	1
Cu	0	2000	0	Cu	0	2000	0
Ag	519	100	5.19	Ag	499	100	4.99
Mn	0	80	0	Mn	0	80	0
Ni	684	70	9.771428571	Ni	428	70	6.114285714
		MI	23.50922024			MI	12.56845238

Ci: Mean concentration; MAC: Maximum Allowable Concentration; HMs: Heavy Metals

Table 11. MI index value at site 1, 2 for Irrigation use, units all data shown in µg/L

HMs	Ci	MAC	Ci/ MAC	Symbol	Ci	MAC	**Ci/MAC**
Cr	370.2	100	3.702	Cr	23	100	0.23
B	33.1	750	0.044133333	B	10	750	0.013333333
As	11.3	100	0.113	As	10	100	0.1
Cu	0	200	0	Cu	0	200	0
Ag	519	100	5.19	Ag	499	100	4.99
Mn	0	200	0	Mn	0	200	0
Ni	684	200	3.42	Ni	428	200	2.14
		MI	12.46913333			MI	7.473333333

Ci: Mean concentration; MAC: Maximum Allowable Concentration; HMs: Heavy Metals

4. Conclusion

The Tigris River near Salah Al-Din thermoelectric power plant is being monitored for heavy metal levels, which are crucial for assessing water suitability for drinking and irrigation. Results showed high levels of heavy metals at site 1 and medium levels at site 2. Drinking water quality at both sites is unsafe for human use without treatment. The Tigris water is also unsuitable for irrigation for long-term crops. The study reveals that the thermoelectric power plant's role in heavy metal contamination is unexpected, resulting in decreased levels at site 2. This may be due to evaporation and high temperatures used to generate electricity.

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