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# Using Heavy Metals Pollution Indices for Assessment of Tigris River Water within Al-Tarmiya City, Northern Baghdad, Iraq

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## ABSTRACT

The objectives of the study were to (1) identify and measure the concentration of five toxic elements in the Tigris water, (2) determine the threat of these metals in water by various pollution indices such as pollution index (PI) as single index, metal index (MI) as integrated index, and potential ecological risk index (PERI) to assess the ecological risk. The results of this study showed that PI values for most elements were at nonaffected levels, except for Pb and Al metals, which were within slight and moderate levels, respectively. Whereas MI values indicate that all sites fall within a threshold of warning level. For the contamination factor, the values mostly lie in the low contamination level, except Al lies within the moderate range, which led to an increase in the contamination degree. For risk assessment, the values of ecological risk factors for all metals at all sites were within a low-risk level, less than 40. Also, the values of the ecological risk index in all sites were at a low-risk level, recorded at 17.70, 22.92, 22.62, and 21.79 in sites 1, 2, 3, and 4, respectively. We can conclude that the decrease in the levels of Er led to a decrease in the levels of PERI and vice versa.

**Keywords:** contamination factor, ecological risk factor, metal index, pollution index, potential, ecological risk index.

## INTRODUCTION

In the environment, heavy metals are usually present in extremely small amounts, but because of anthropogenic activities, their concentrations have grown. These elements are emitted into rivers by both natural and human activities (Sankhla et al., 2016; Zaynab et al., 2022; Jadaa and Mohammed, 2023). The natural processes that contribute to high concentration of heavy metals in river waters include weathering of rocks and soils, degradation of organisms, and air fallout, whereas the anthropogenic activities encompass mining (which can lead to acid mine drainage) and mineral processing, domestic, agricultural and industrial wastes, etc. (Sankhla et al., 2016; Zaynab et al., 2022; Jadaa and Mohammed, 2023). Furthermore, studies have shown that heavy metal pollution in different aquatic ecosystem related to many other anthropogenic factors, including large quantities of chemical fertilizers and pesticides, untreated industrial wastes, poor management of open dumpsites, etc. (Al Naggar et al., 2018; Al-Afify and Abdel-Satar, 2022). These pollutants persistence in aquatic systems for a long time even after removing the source without decomposition and cause damage to aquatic animals (Zaynab et al., 2022; Azar and Vajargah, 2023). Aquatic organisms absorb the pollutants directly from water and indirectly from food chains (Zaynab et al., 2022; Vajargah, 2021). Some of the toxic effects of heavy metals on fishes and aquatic invertebrates are; reduction of the developmental growth, increase of developmental anomalies, abnormal behaviors, physiological, histopathological changes, damage to biological molecules such as enzymes, proteins, lipids, nucleic acids, and DNA damage (Zaynab et al., 2022; Azar and Vajargah, 2023; Vajargah, 2021; Sattari et al., 2022; Al-Sarraj et al., 2022).

Pollution indices are many mathematical models that have been used to measure the pollution threat of heavy metals in aquatic environments. Huge quantities of data can be quickly calculated for the evaluation of possible risks due to metal exposure. Pollution index is an effective tool used in determining the quality of water based on its heavy-metal concentrations (Al-Afify and Abdel-Satar, 2022; Tanjung et al., 2019; Ahirvar et al., 2023) and provide an assessment with a single score on the parameters to interpret water quality (Liu et al., 2021; Dunca, 2018; Kumar et al., 2019). Contamination factor (Cf) is the ratio obtained by dividing the value of every element in the water by the stranded value of the same metal. In risk assessment, ecological risk index usually employed for freshwater resources and prevention of pollution. Different studies concerning the application of heavy metal pollution indices in Tigris River water within Baghdad City. Such as Al-Obaidy et al. (2016). Aljanabi et al. (2022); Al-Bahathy et al. (2023). But there is no study in this section of the river. Thus, this study was regarded as pioneering in this part of the river.

The study objectives were: (1) measurement of the concentration of five impotent heavy metals (Ni, Zn, Pb, Cd, and Al) in the Tigris water, (2) to obtain a general ecological perspective on the water quality of this sector of river water by using different ecological indices depending on the concentration of heavy metals, such as the pollution index, metal index, contamination factor, degree of contamination, ecological risk factors, and potential ecological risk index. Furthermore, this study considered the first of its kind in this section of the river since the war 2003. As well, there is no study evaluated the ecological and toxicity potential of heavy metals. For this the data obtained from this research can be used as reference in the next studies.

## MATERIALS AND METHODS

### Description the river

The Tigris River is one of the longest transboundary rivers in west Asia; it is also considered one of the two most important sources of freshwater in Iraq, and its flow rate is controlled by a series of dams constructed upstream the river (Majeed et al., 2022a; Haghighi et al., 2023). The Tigris River reaches Baghdad Province about 5 kilometers north of Al-Tajy City (Ali et al., 2012; Majeed et al., 2021; Majeed et al., 2022b). The river running within Baghdad City about 49 km until it leaves the administrative borders of Baghdad Province. The river in northern Baghdad city runs within an agricultural area. Riverbanks vegetation includes groves of orange and other citrus trees. This section of the river is affected by agricultural activities especially fertilizers and pesticides, which consequently runoff directly into the river (Majeed et al., 2021; Nama, 2015; Majeed et al., 2023).

### Sampling sites

Samples were taken from subsurface river water from January to December 2022, in an agricultural area. A GPS was used to determine the geographical position of the sample sites. The first site lies within latitudes 33°37’07”N and longitudes 44°22’36”E in Al-Tarmiyah near Al-Falahat Village. Surrounded by farmlands. Here chemical fertilizers and pesticides are generally used in farming activities. Thus, this part of the river must be investigated because it is widely used for irrigating agricultural land. The second site is located on 33°33’35”N and 44°19’34”E near the Sheikh Hamed Mosque, upstream the meeting of two different water sources (Tharthar and Tigris water). The third site is located beside Al-Taji wool factory downstream the confluence of two different water (33°29’20”N and 44°18’18”E). The fourth and final site placed about three hundred meters away from Al-Muthana Bridge area, about 6 km below the confluence of two different water (Figure 1 and Table 1).

### Sampling and sample preparation for determination of metal ions

Water samples were collected from all the respective sampling sites of Tigris River. The samples were collected into prewashed 1 L polythene bottles with screw caps, and brought back to the laboratory with keeping them in refrigerate at 4°C. Digestion of water samples were carried out by high-purity concentrated nitric acid, then examine them as soon as possible (Marcovecchio et al., 2013; Baird et al., 2017).

### Analytical procedures for the detection of metals ions

The concentrations of lead, zinc, cadmium, nickel and aluminum in water samples were

**Table 1.** GPS data for each sampling site

| Site No. | Latitude | Longitude | Description |
|---|---|---|---|
| S 1 | 33°37'07"N | 44°22'36"E | Al-Falahat Village, Tarmiyah |
| S 2 | 33°33'35"N | 44°19'34"E | Sheikh Hamed Mosque |
| S 3 | 33°29'20"N | 44°18'18"E | Al-Taji wool factory |
| S 4 | 33°25'58"N | 44°20'38"E | Before Al-Muthana Bridge |

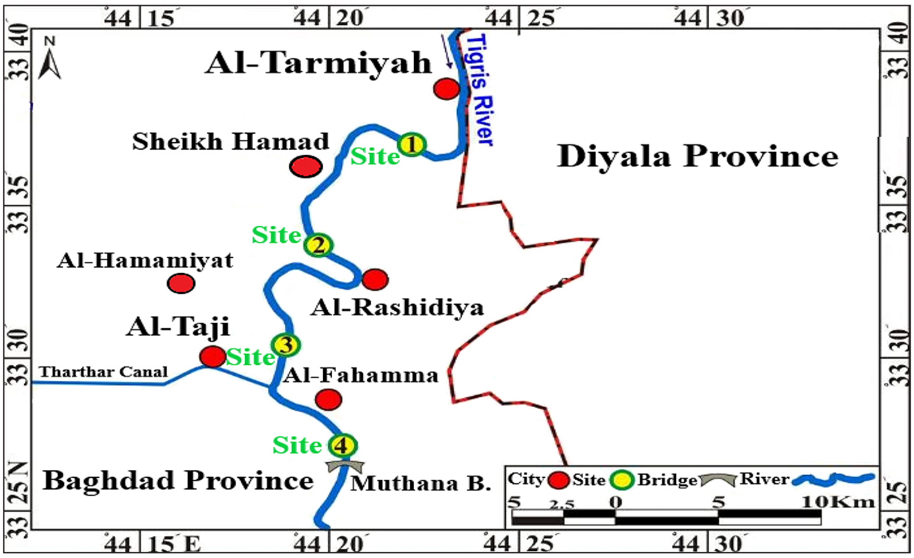


**Figure 1.** Map of study area during 2022

determined with an atomic absorption spectrophotometric (AAS) method listed in standard methods (Baird et al., 2017; Chen and Teo, 2001). This method is suitable for the determination of low concentrations. Ammonium molybdate method used to determine total silica ($SiO_2$) (Baird et al., 2017). The Eriochrome cyanine R colorimetric method used for detectable minimum concentrations of aluminium at 535 nm (Baird et al., 2017).

## Heavy metals concentrations

The descriptive statics including minimum, maximum values, mean and standard error are given in Table 2. standard value according to Iraqi river's-maintained standards (Law 25.1967).

## Pollution indices for assessing metal pollution in water

It is worth noting why we applied different indices. The answer to this question is that each index is specialized for specific purpose with a special formula.

Pollution index (PI) we used this index as a single index, to assess the impact of each element separately. Metal index (MI) we applied this index as an integrated index to examine the cumulative effect of each heavy metal. Useful for evaluating the quality of drinking water. Potential ecological risk index (PERI) is a useful index to evaluate the toxicity and biomagnifications potential of heavy metal in an aquatic system, provides us real-risk information. Depending on the following four premises; contamination factor ($C_f$), contamination degree ($C_d$), toxic response factor ($T_i$), and ecological risk factor ($E_r$) (Tanjung et al., 2019; Aljanabi et al., 2022; Caeiro et al., 2005). In other word; we can't calculate potential ecological risk index if we don't calculate contamination factor, contamination degree, and ecological risk factor.

## Pollution index

Which measures the individual effects of heavy metals on water quality. It was determined based on the method of Tanjung et al. (2019);

**Table 2.** Present the descriptive statics for metals in Tigris water within Al-Tarmiya area

| Sites metals | First site | Second site | Third site | Fourth site | Standard value mg/L |
|---|---|---|---|---|---|
| Lead mg/L | 0.0058-0.1416 0.0391±0.0102 | 0.018-0.075 0.0455±0.0058 | 0.0141-0.11 0.04±0.0076 | 0.014-0.12 0.0415±0.0085 | 0.0500 |
| Zinc mg/L | 0.008-0.096 0.033±0.007 | 0.015-0.075 0.032±0.005 | 0.11-0.089 0.039±0.009 | 0.014- 0.1442 0.042±0.01 | 0.5000 |
| Cadmium mg/L | 0.001-0.0041 0.0018±0.0003 | 0.0013-0.0046 0.0025±0.00032 | 0.001-0.004 0.0025±0.00032 | 0.00071-0.0042 0.00241±0.00032 | 0.00500 |
| Nickel mg/L | 0.0012-0.03 0.011±0.00275 | 0.0036-0.053 0.0162±0.0044 | 0.0036-0.0823 0.018±0.0068 | 0.0036-0.0411 0.0134±0.0036 | 0.1000 |
| Aluminm mg/L | 0.031- 0.44 0.222± 0.0449 | 0.0311-0.5 0.236 ±0.0436 | 0.025-0.54 0.244±0.0397 | 0.073-0.49 0.241±0.0464 | 0.1000 |

Aljanabi et al. (2022) and Caeiro et al. (2005) by using the Equation 1.

$$PI = \frac{\sqrt{(Ci/Si)^2_{max} + (Ci/Si)^2_{min}}}{2} \quad (1)$$

where: *Ci* – the metal concentration, *Si* – the metal value as determined by water quality limits.

Pollution index divided into 5 categories as descriptive below in Table 3 (Tanjung et al., 2019; Aljanabi et al., 2022; Goher et al., 2014).

**Table 3.** Explain categorization values of the pollution index

| Classes | Description |
|---|---|
| PI <1 | No effect |
| 1 < PI < 2 | Slightly affected |
| 2 < PI < 3 | Moderately affected |
| 3 < PI < 5 | Significant impact |
| PI > 5 | Severely harmed |

## Metal index

The index applied to determine the total water quickly for each site, calculated via the Equation 2 (Aljanabi et al., 2022; Caeiro et al. (2005); Anitha et al., 2021; Astuti et al., 2021; Kasa and Reddythota, 2023).

$$Metal\ index = \sum_{i=1}^{n} \frac{Ci}{MAC} \quad (2)$$

where: *Ci* – represents the mean concentration of each element, *MAC* – denotes the maximum allowable concentration as proposed by Ministry of Health, Iraq (Law 25.1967), MI value >1 is a threshold of warning (Aljanabi et al., 2022; Astuti et al., 2021).

## Potential ecological risk index

The calculation of PERI involves the following steps as proposed by Ahirvar et al. (2023); Håkanson (1980).

- first, the calculation of contamination factor and the degree of contamination;
- second, the calculation of the ecological risk factor;
- third, the calculation of the potential ecological risk index.

Contamination factor – is the first step towards the risk assessment. It was used to determine the contamination of single elements (Kasa and Reddythota, 2023; Hakanson, 1980; Ojekunle et al., 2016). $C_f$ was calculated according to the Equation 3:

$$C_f = C_m / C_b \quad (3)$$

where: $C_f$ – refers to the contamination factor, $C_m$ – represent the average level of elements in water, $C_b$ – represent the standard value for the same elements (the reference value).

The standard value was obtained from Iraqi river's-maintained standards (Law 25.1967). According to Hakanson (1980); Agwu et al. (2023) the contamination factor is grouped into four categories as explained in Table 4.

## The degree of contamination

Contamination index was used to measure the quality of water (Kumar et al., 2019; Backman et al., 1998) calculated by the Equation 4 proposed by Edet and Offiong (2002); Kumar et al. (2019); Pobi et al. (2019); Sahoo and Sahu (2022).

$$C_d \sum C_f \quad (4)$$

The calculation of the contamination degree made alone for every place of sampling as a result of the summation of contamination factors (Kumar et al., 2019; Pobi et al., 2019; Sahoo and Sahu, 2022). Based on Backman et al. (1998) and Agwu et al. (2023) the $C_d$ values is categorized into three classes (Table 4).

### Ecological risk factor or risk factor

Ecological risk factor is quantitatively calculated to express the potential ecological risk with Equitation 5 suggested by Liu et al. (2021); Håkanson (1980); Egbueri (2020) and Proshad et al. (2021). Each metal contamination factor was multiplied by its toxic response factor to calculate the risk posed each heavy metal to the aquatic ecosystem.

$$Er = C_f \times T_i \quad (5)$$

where: $C_f$ – the contamination factor, $T_i$ – the toxic response factor.

The toxic response factors used in this study were cadmium, zinc, lead, nickel and aluminum have hazardous reaction factors of 30, 1, 5, 5 and 1, respectively (Kasa and Reddythota, 2023; Proshad et al. 2021; Ukah et al., 2019).

### Potential ecological risk index or risk index

The Equitation 6 of the potential ecological risk index is as follows (Egbueri, 2020; El Morabet et al., 2022; Tamanna et al. 2023).

$$RI = \sum E_r \quad (6)$$

where: $E_r$ – ecological risk factor; $RI$ – Potential ecological risk index, $\sum RI$ – summation of risk index.

The following categories were used to describe the ecological risk factor and ecological risk index (Table 5).

## RESULTS AND DISCUSSION

### Pollution index

The results of PI according to Tanjung et al. (2019) and Goher et al. (2014) ranged from "No effect" to "Moderately affected" for over-all metals. Lead ions ranged between 0.77 in site 2 and 1.42 in site 1, while zinc ions were in the range of 0.077-0.145 in sites 2 and 4, respectively. For cadmium ions ranged from 0.41 in site 3 to 0.48 in site 2, whereas for nickel ions the value fluctuated between 0.14 in site 1 and 0.26 in site 2, as well, Al ranged from 2.50 in site 2 to 2.92 in site 4 (Table 6). Also, PI values for most elements were less than 1, except Pb and Al exceeded the low permissible limits slightlyin all sites (Table 3). This may be related to discharge of various anthropogenic activities. Our results compatible with Aljanabi et al. (2022) showed that PI values of Zn were less than 1 while Pb and Ni ions exceeded 1 in Tigris River water, related that to the anthropogenic activities. As well Goher et al. (2014) obtained the same results in Ismailia Canal water, showed that

**Table 4.** Explain the levels of contamination for $C_f$ and $C_d$

| Contamination factor | Contamination degree | Level of effect |
|---|---|---|
| The value less than 1 | The values less than 1 | Low effect |
| The values between 1 and 3 | The values between 1 and 3 | Moderately |
| The values between 3 and 6 | The value more than 3 | High effect |
| The value more than 6 | | Severely effect |

**Table 5.** Categories of ecological risk factor and ecological risk index based on Proshad et al. (2021); Marara and Palamuleni (2019) and Tamanna et al. (2023)

| E*r* | RI | Level of ecological risk |
|---|---|---|
| The value less than 40 | The value less than 150 | low |
| The values between 40 and 80 | The values between 150 and 300 | moderate |
| The values between 80 and 160 | The values between 300 and 600 | considerable |
| The values between 160 and 320 | The value more than 600 | highly |
| The value more than 320 | | severely |

PI values for aquatic life criteria of Zn and Ni ions were less than 1 "No effect level". For Pb and Cd ions the PI exceeded 1. While for Al ions the index exhibits serious effect, the value reached 321.31.

## Metal index

Metal index is another index can be applied to evaluate if river water in each site is acceptable for aquatic life by computing all measured metals (Table 6). The values of MI were 3.5, 4.0, 4.0 and 3.9 in sites 1, 2, 3 and 4, respectively as we shown in Figure 2 and Table 6. According to metal index output (Table 3), all selected sites fell into the "threshold of warning" category (MI> 1). Similarly, Aljanabi et al. (2022) showed that MI values were above the threshold of warning in Tigris River attributed that to the industrial and human activities. Globally, Goher et al. (2014) showed that MI values reached 165 for aquatic life criteria in Ismailia Canal water, related that to the presence of different pollutants in the canal. Shankar (2019) showed that groundwaters of Peenya industrial area in India very poor water quality the value reach 150.5. The mean MI concentration was found to be 10.36 for Twenty-three samples, due to influence of urban, industrial, and agricultural activities.

## Assessing contamination factors and contamination degree

The contamination factor index utilized to determine the degree of enrichment for every metal over a certain period of time. Table 7 and Figure 3 show the contamination factor values for all the metals in each site along 2022 and can be organized as follows: Zn ranged from 0.064 to 0.083, for Ni ranged from 0.110 to 0.180, for Cd ranged from 0.365 to 0.508, for Pb ranged from 0.782 to 0.909 and for Al ranged between 2.228 and 2.442. Also, can be seen that the $C_f$ values mostly lies in the low contamination level except Al lies within moderate range. Based on the average $C_f$ values, there are the following sequence: Al > Pb > Cd > Ni > Zn (Table 7). Agwu et al. (2023) indicating very high levels of $C_f$ reached 6 in Ebonyi River, Nigeria, demonstrated the dangers associated with anthropogenic and agricultural activities around the bank of the river. As well, Pobi et al. (2019) recorded very high values of contamination factor in stream water within Durgapur manufacturing region, India, related that to the discharge of waste water and industrial effluents direct into the stream. As well, the values of degree of contamination for heavy metals indicated that all sites at


**Figure 2.** Metal index for Tigris water within 2022

**Table 6.** Pollution index and metal index of metals for river water samples

| PI | | | | | | |
|---|---|---|---|---|---|---|
| Sites | Pb | Zn | Cd | Ni | Al | MI |
| 1 | 1.42 | 0.096 | 0.42 | 0.14 | 2.65 | 3.550 |
| 2 | 0.77 | 0.077 | 0.48 | 0.26 | 2.50 | 4.0033 |
| 3 | 1.10 | 0.11 | 0.41 | 0.41 | 2.70 | 4.0025 |
| 4 | 1.20 | 0.145 | 0.42 | 0.20 | 2.92 | 3.943 |

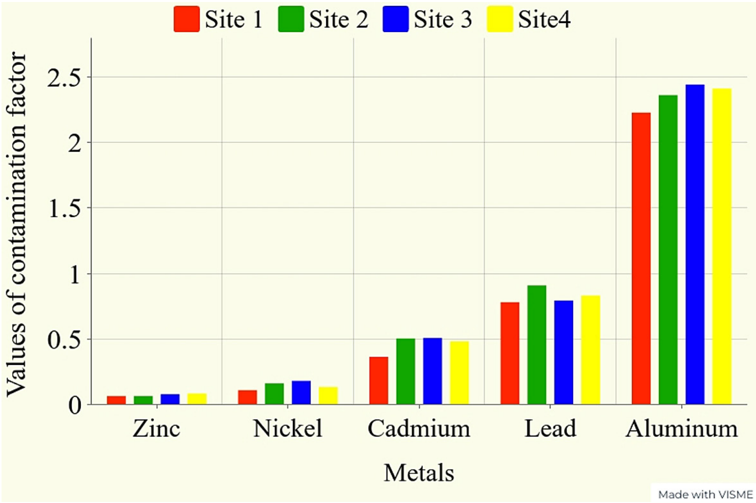


**Figure 3.** The contamination factor of metals in Tigris water

**Table 7.** Calculations of both contamination factors and degrees of contamination

| | $C_f$ | | | | | | |
|---|---|---|---|---|---|---|---|
| Sites | Zn | Ni | Cd | Pb | Al | $C_d$ | Contam. level |
| 1 | 0.065 | 0.110 | 0.365 | 0.782 | 2.228 | 3.55 | high level |
| 2 | 0.064 | 0.162 | 0.504 | 0.909 | 2.362 | 4.00 | high level |
| 3 | 0.079 | 0.180 | 0.508 | 0.793 | 2.442 | 4.00 | high level |
| 4 | 0.083 | 0.134 | 0.508 | 0.831 | 2.412 | 3.96 | high level |
| Average | 0.072 | 0.146 | 0.465 | 0.828 | 2.361 | | |
| Level | low | low | low | low | medium | | |
| $\sum C_d$ = 15.52 | | | | | | | |

high level, Cd more than 3 (Table 7 and Figure 4). The values were 3.55, 4.00, 4.00, 3.96 for sites 1, 2, 3, 4, respectively. The results degree with Agwu et al. (2023) in the Ebonyi River recorded high levels of $C_d$ index as result of increasing of $C_f$ due to increasing in heavy metals concentrations. Also, Pobi et al. (2019) indicates that very high values of contamination index in stream water within Durgapur manufacturing region, because of excessive discharge of toxic waste and wastewater into the stream water. Conversely, Tamanna et al. (2023) showed that the values of $C_d$ Upper Banar River fell into the low level of pollution ($C_d < 1$). We can conclude that the increasing in the levels of contamination factor index led to increasing in the level contamination degree index.

## Ecological risk assessment

The ecological risk indices for single and all metals, determined as ecological risk factor and ecological risk index, respectively.

## Ecological risk factor

$E_r$ as the individual ecological risk index, for all metals were categorized as low risk, $E_r$ less than 40 (Table 5) (Proshad et al., 2021; Marara and Palamuleni 2019; Tamanna et al. 2023). Additionally, the average $E_r$ values for zinc, nickel, cadmium, lead and aluminium for all sites were 0.0729, 0.734, 13.950, 4.145, 2.361, respectively as well, follow the sequence, Cd > Pb > Al > Ni > Zn as shown in Table 8 and Figure 5. According to the findings, cadmium is the most serious ecological risk in the Tigris water. ranged from 10.95 to 15.235 and zinc having the lowest ecological risk, ranged between 0.064 and 0.08.

A similar result obtained by Marara and Palamuleni (2019) showed that cadmium the most significant ecological risk. Despite the concentrations ranging from 0 to 0.110 mg/l in the Klip River, South Africa attributed that to its toxic effects even at low levels (Nordberg et al., 2015).

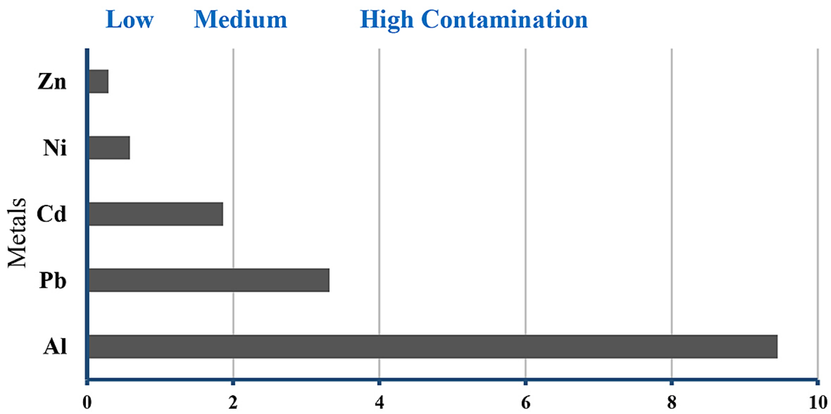


**Figure 4.** The degree of contamination of metals in Tigris water

In another study, Pobi et al. (2019) also recorded high ecological risk values of cadmium in natural stream water of Durgapur industrial zone, India. Agwu et al. (2023) indicated that high level of cadmium more than 360 in Ebonyi River, indicate a significant risk to the aquatic life, while the other metals like Pb, Zn, Ni lies in low to moderate ecological threat.

## Potential ecological risk index

The values of ecological risk index were 17.70, 22.92, 22.62 and 21.79 in sites 1, 2, 3 and 4, respectively. Based on the classification proposed by Proshad et al. (2021); Tamanna et al. (2023); Marara and Palamuleni (2019) all sites were at low risk level (ERI < 150) as we shown in

**Table 8.** Depicts the ecological risk factor and potential ecological risk index

| | $E_r$ | | | | | | |
|---|---|---|---|---|---|---|---|
| Sites | Zn | Ni | Cd | Pb | Al | ERI | Pollution degree |
| 1 | 0.065 | 0.550 | 10.95 | 3.91 | 2.228 | 17.70 | Low risk |
| 2 | 0.064 | 0.812 | 15.1355 | 4.547 | 2.362 | 22.920 | Low risk |
| 3 | 0.078 | 0.902 | 15.235 | 3.966 | 2.442 | 22.62 | Low risk |
| 4 | 0.083 | 0.670 | 14.477 | 4.155 | 2.412 | 21.79 | Low risk |
| Mean | 0.0729 | 0.734 | 13.950 | 4.145 | 2.361 | | |
| $\sum RI$ =85.04 | | | | | | | |

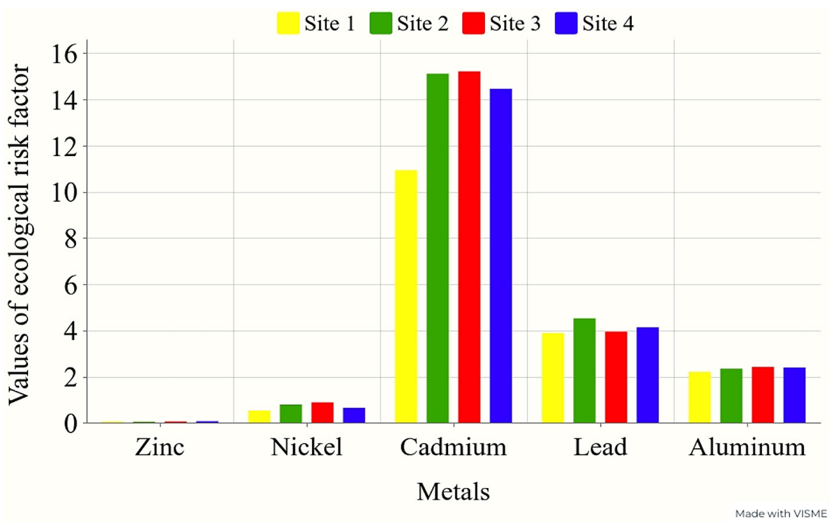


**Figure 5.** The ecological risk factor

Table 8. Similarly, Tamanna et al. (2023) showed that the ERI values for the Upper Banar River water lies within low ecological risk ranged between 7.24 and 12.16 attributed that to the sufficient water flow. Another study (Proshad et al., 2021) in Louhajang River, Bangladesh, the level of ecological risk index ranged between low and moderate risk. Affected by high concentrations of Ni, Cd, and Cr due to agricultural and aviation activities. Also, in natural stream of Durgapur industrial zone, India Pobi et al. (2019) showed that the values of PERI ranged between moderate and high level, related that to the industrial emissions into the water directly. In contrast, Agwu et al. (2023) indicates serious ecological risk in Ebonyi River, the value of potential ecological risk index exceeded the threshold threat above 1000 as result of high level of ecological risk index for As, Hg and Cd exceeded 320. We can conclude that the increasing in the levels of ecological risk factor led to increasing in the levels of potential ecological risk index.

## CONCLUSIONS

The application of single and integrated pollution indices in the present study indicates the pollution status of heavy metals in Tigris River water within Al-Tarmiya City. The results indicated that the values of single heavy metal pollution indices like pollution index and contamination factor were within the low contamination level for most elements except Al, which exceeded slightly. Whereas. The values of integrated indices as metal index and contamination degree were within high level, as a result of collective impact of metals. For risk assessment, the values of potential ecological risk index were within low risk level in all sites, related to low values of individual ecological risk index for all metals.

Additionally, we can conclude that single indices provide the contamination status of water for individual metals, whether it is low, moderate, or highly contaminated. As well, the result indicates that an increase in the levels of single indices led to an increase in the levels of integrated indices due to the cumulative impact of metals in water. Generally, the ecological perspective of Tigris river water within Al-Tarmiya area were within non effected and acceptable level due to sufficient water flow. The elevated levels of some metals can be attributed to various anthropogenic activities.


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