DOI: 10.24996/ijs.2022.63.9.10

ISSN: 0067-2904

Assessment of Heavy Metals Concentration in Water and Fish of Dalmaj Marsh, Iraq

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Received: 12/9/2021 Accepted: 5/12/2021 Published: 30/9/2022

Abstract

Most marshes in Iraq face several challenges as aquatic environments, including pollution by various chemical agents and heavy metals. The current study deal with an analysis of the water quality of Dalmaj marsh as one of the closed aquatic environments in the middle parts of Iraq located between latitudes 32° 05′ to 32° 23′N and longitudes 45° 10′ to 45° 38′ E. The marsh is suffering from a shortage in water supply, especially during the summer. It will lead to a concentration of heavy metals that are washed and transported to the marsh from the surrounding watersheds through surface runoff. This work aims to analyze water and fish samples to assess heavy metals and their accumulated risk in fish tissues based on many indices. The 16 samples of water and nine samples of fish are collected and analyzed for concentration of heavy metals, i.e., Lead (Pb), Chromium (Cr), Nickel (Ni), Cadmium (Cd), Copper (Cu), Zinc (Zn). The water analysis results indicate that Chromium (Cr) only comes below the permissible limit in water. At the same time, the composite heavy metals pollution index (HPI) identified that the water samples are varied from light pollution to malignant pollution**.** Regarding fish samples, three indices, i.e., BAF, EDI, and HI, are used to test the accumulated concentration of heavy metals in fish tissues and to point out their risk to consumers. The results indicate that Pb and Ni are the more hazardous metals accumulated in many fish samples with increasing fish weight, while hazard index (HI) is an additive index of all tested heavy metals, indicating concern risk from most fish samples. The study recommends testing the marsh water pollution periodically.

Keywords: Heavy metals, Pollution, Fish, Marshes, Hazard index

تقييم تركيز المعادن الثقيلة في مياه واسماك هور الدلمج، العراق

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الخلاصة

تواجه معظم الاهوار في العراق العديد من التحديات، بما في ذلك التلوث بالعوامل الكيميائية والمعادن الثقيلة. تناولت الدراسة الحالية تحليل نوعية المياه في هور الدلمج كواحدة من البيئات المائية المغلقة في الأجزاء الوسطى من العراق الواقعة بين دائرتي عرض 32° 05′ إلى 32° 23′ شمالا وخطي طول 45° 10′ الى 45° 38′ شرقاً. الاهوار تعاني من نقص في إمدادات المياه خاصة خلال فصل الصيف مما سيؤدي إلى تركيز المعادن الثقيلة التي يتم غسلها ونقلها إلى الاهوار من مستجمعات المياه المحيطة عبر الجريان السطحي. يهدف البحث إلى تحليل عينات من المياه والأسماك لتقييم المعادن الثقيلة ومخاطرها المتراكمة في أنسجة الأسماك بناءً على العديد من المؤشرات. تم جمع 16 عينة من الماء و9 عينات من الأسماك وتحليلها لمعرفة تركيز المعادن الثقيلة، مثل الرصاص (Pb) والكروم (Cr) والنيكل (Ni) والكادميوم (Cd) والنحاس (Cu) والزنك (Zn). اشارت نتائج تحليل المياه إلى أن الكروم (Cr) فقط كان تركيزه دون الحد المسموح به بالمقارنة مع بقية المعادن الثقيلة. في الوقت نفسه، حدد مؤشر تلوث المعادن الثقيلة المركب (HPI) عينات المياه متنوعة من التلوث الضئيل إلى التلوث الحاد. فيما يتعلق بعينات الأسماك، تم استخدام ثلاثة مؤشرات، وهي BAF وEDI وHI لاختبار التركيز المتراكم للمعادن الثقيلة في أنسجة الأسماك ولإظهار مخاطرها على المستهلكين. تشير النتائج إلى أن الرصاص والنيكل هما أكثر المعادن خطورة المتراكمة في العديد من عينات الأسماك متناسب طرديا مع حجم الأسماك، في حين أن مؤشر الخطر (HI) كمؤشر مضاف لجميع المعادن الثقيلة المختبرة، يشير إلى وجود مخاطر في معظم عينات الأسماك. وتوصي الدراسة الى ضرورة اجراء اختبار تلوث مياه الأهوار بشكل دوري.

1. Introduction

The marshes environment in Iraq faces many challenges, including the shortage of water supply, an increase of pollutants, and a lack of attention to the ecosystem; all those factors lead to increasing the concentration of different chemical elements, including heavy metals in marshes. The risk of heavy metals is considered when accessing the human body through the food chain by eating livestock, poultry, and fish in an environment exposed to heavy metal pollution. Several studies have analyzed the heavy metals accumulation in fish tissues, representing a major human diet [1]. The concentration of heavy metals in aquatic environments is recently considered a problem because they are non-decomposable, and most have potential toxic risks to the organisms [2]. The harmful of heavy metals affect the vital cellular components and interfere with structural proteins, nucleic acids, and enzymes [3]. Metabolic activity in living organisms requires some heavy metals such as Zn, Cu, Mn, and Fe. Although toxic, they are necessary at a specific level, while Cd, Hg, Cr, and Pb are toxic elements even at low levels [4]. Heavy metals cannot be biologically or chemically decomposed but may accumulate heavily in fish tissues in polluted water and reach the human diet through the food chain [5].

The anthropogenic sources of heavy metals that are contaminated by the biotic environment are: metal smelting, refineries, plastics, and rubber plants, petrochemicals, incineration of waste containing plastic materials containing these metals, aquaculture, agriculture, printing, municipal waste, and electronic industry are the main sources of heavy metals that polluted the aquatic life environment [6, 7]. Natural and anthropogenic sources introduce heavy metals into aquatic environments [8]. Increasing human activities by changing the land use/land cover patterns within the watershed may degrade the quality of the water [9].

The source of heavy metals in the water is either natural, resulting from weathering and leaching of soil, or anthropogenic such as industrial and domestic waste, chemical fertilizers, and pesticides used in agriculture [10]. Heavy metals accumulate in surface waters through natural or anthropogenic sources or their presence in the atmosphere and agricultural activities where they move with surface runoff water to water bodies [11]. Heavy metals contamination of water, aquatic animals, and sediment has come from mining byproducts and untreated effluents disposal containing toxic metals [12].

The environmental and biological aspects of different fish species in terms of age, weight, swimming patterns, reproductive cycle, and feeding habits have a role in varying concentrations of heavy metals in their bodies [13]. The continuous exposure of the aquatic environment to heavy metal pollution increases toxicity and accumulation of heavy metals in the tissues of aquatic organisms such as fishes through feeding, digestion, skin, and gills, which leads to toxic effects that will threaten fish consumers [14]. Human health may be exposed to heavy metals risk through fish consumption, either carcinogenic or non-carcinogenic [15]. The ingestion of fish muscle with bioaccumulation of heavy metals significantly negatively affected human health [16].

The water of the marshes and swamps in Iraq are generally closed aquatic environments and are characterized by scarcity of water feeding, consequently leading to the rising of pollutants. The Dalmaj Marsh is one of the closed marshes in the middle of the alluvial plain of Iraq, and the marsh is fed through a channel [17]. Pollutants are transferred to the marsh from agricultural fields (fertilizers and pesticides) and sanitary landfill waste within the marsh basin [18].

The presence of agricultural activities includes fertilization, pesticides, and disposing and burning of the industrial and domestic wastes in the catchment of Dalmaj marsh producing different residues, which are leaching into the marsh water during crop fields irrigations rainfall-runoff processes, will aggravate the environmental challenges in the marsh. Fishing from the marshes of Iraq is one of the most important fish sources. Usually, fish is one of the most important diets consumed once or more per week by the Iraqi family and sometimes daily by the inhabitants who live in the marshes or nearby.

The current study aims to analyze marsh water and fish samples to achieve the following (a). To measure the heavy metals concentration in the marsh water, (b). Classified LULC within the marsh watershed based on Landsat 8 image using ENVI software and assessing their role in feeding pollutants into the marsh water (c). The standard indices were to estimate the accumulative concentration of heavy metals in the fish tissues collected from the marsh water.

2. Description of the study area

Dalmaj marsh is located within the Iraqi alluvial plain between Wasit and al_Qadisiya governorates and bounded by lat. 32° 05′to 32° 23′N and long. 45° 10′to 45° 38′E. The marsh is fed by water through an irrigation channel and surface runoff during rainy seasons from the surrounding valley basins in the northern and northwestern marsh. Soil barriers ban the southern and south-eastern parts of the marsh. Geologically, the basin is located on a stable shelf and covered by quaternary alluvium depression filling marsh sediments. In western parts, aeolian sands are dispersed, and the area's climate is semi-arid, with temperatures rising to 53℃ during the summer season [19].

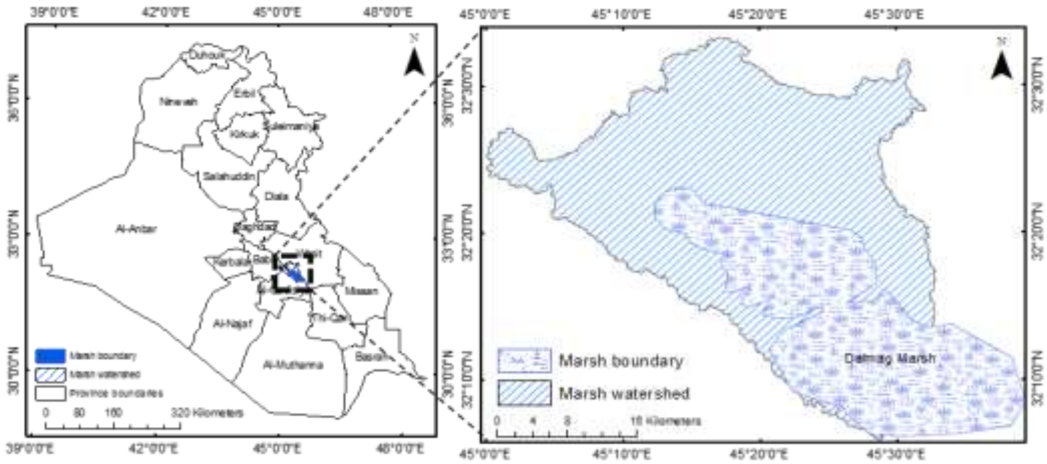

Figure 1-Location of the study area

3. Materials and Methodology

Water samples and different types and weights of fish are collected from Dalmaj marsh and prepared to analyze heavy metals.

1.2 Abbreviations and Acronyms

Water samples were collected from Dalmaj Marsh on 30 March 2017, including 16 samples from selected sites to cover the marsh water body (Figure 1) using one-liter bottles. The samples are tested for heavy metals, i.e., Lead (Pb), Chromium (Cr), Nickel (Ni), Cadmium (Cd), Copper (Cu), Zinc (Zn). Nine samples of fishes belonging to three species with different weights were collected, i.e., *Mesopotamichthys sharpeyi* (Günther, 1874), including samples no 1 and 4-8, *Leuciscus vorax* (syn. *Aspius vorax* Heckel, 1843) (Sample 9), and samples 2&3 of *Carassius sp.* (Figure 2). The eight heavy elements were analyzed for each sample, i.e., lead (Pb), chromium (Cr), nickel (Ni), cadmium (Cd), copper (Cu) and zinc (Zn).

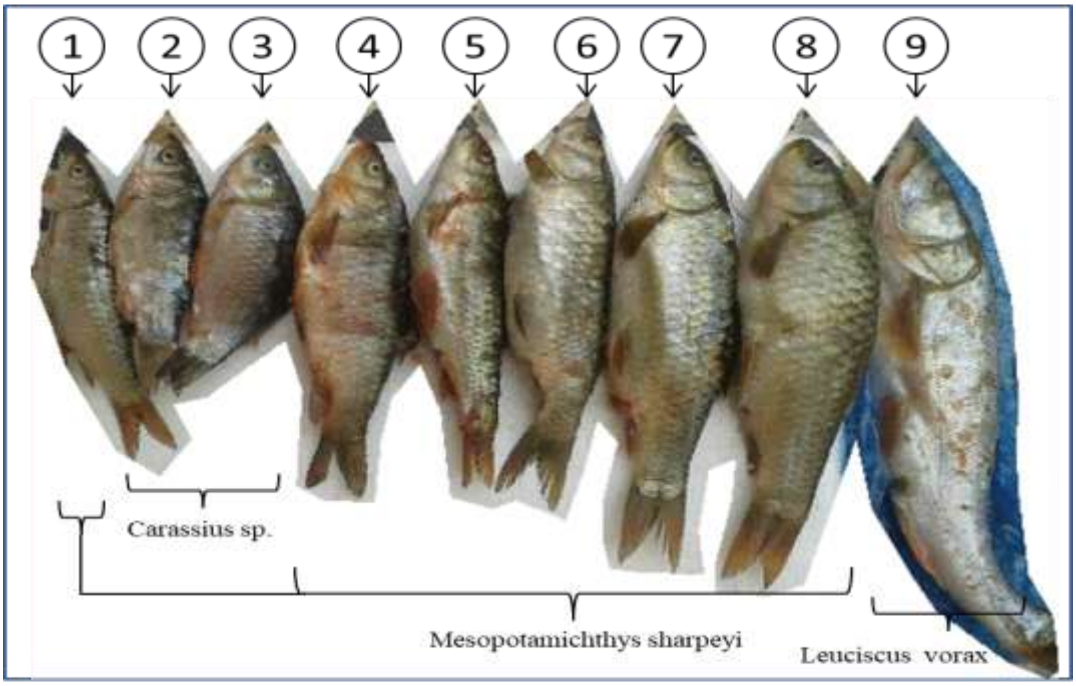

Figure 2-Fish species with different weights collected from Dalmaj Marsh.

3.2 Preparation of samples

The water samples are filtered with filter paper and diluted up to 50 ml with double distilled water. Analyze by atomic absorption spectrophotometer. The fish samples are prepared by oven drying at 105°c. Taking 0.2 g of the portion after achieving constant weight for the analysis and digested with mixture ratios of nitric acid (HNO_3), perchloric acid ($HClO_4$), sulfuric acid (H_2SO_4) until it become clear. Then they were filtered by No. 42 filter paper and diluted to 2 ml with double distilled water, then analyzing the samples using atomic absorption spectrophotometer.

3.3 Downloading of Landsat-8 data

To classify the land use/land cover in the watershed of Dalmaj marsh during the period of water samples analysis, Landsat-8 imagery (Eleven bands) acquired on April 7th 2017, are downloaded from the Earth explorer website (https://earthexplorer.usgs.gov, accessed date 09/04/2017). Indeed, the Land use/Land cover (LULC) plays an important factor in supplying the pollutant elements to the marsh water, including heavy metals.

3.4 Assessment of heavy metals risk

To assess the impact of heavy metals concentration in marsh water and fish tissues on human health; several indices, including composite heavy metal pollution index (HPI), Bioaccumulation factor (BAF), estimated daily intake (EDI), and hazard quotient (HI) are used as follows: -

3.4.1 Composite heavy metal pollution index (HPI):

The heavy metal pollution index (HPI) is a rating technique that provides the composite influence of individual heavy metals on the overall quality of water [20, 21]. The Heavy metal pollution index (HPI): HPI index was developed by assigning a relative weightage factor (*wi*) for each chosen parameter [10].

The composite heavy metal pollution index (HPI) of water sample contains a number of different parameters that will be calculated following Tiwari et al. [20], Chaturvedi, et al. [22]:

$$HPI = \sum_{i=1}^{n} HPI^{i} \; . \qquad ......(1)$$

Where HPI^i is the pollution index corresponding to the i^{th} heavy metal ion and may be calculated as:

$$HPI^{i} = \omega_i . Q_i \qquad ....(2)$$

ωi is the relative weightage factor defined as Wi

$$\omega_i = \frac{W_i}{\sum_{i=1}^{n} W_i} \qquad ....(3)$$

The proportionality constant is considered as 1 for all the parameters. A sub-index Qi for i^{th} parameter is calculated as,

$$Q_i = \frac{Mi - Ii}{Si - Ii} \times 100 \qquad ......(4)$$

Mi =Measured concentration of the i^{th} parameter, Ii =Highest desirable concentration of the i^{th} parameter, and Si =Maximum permissible concentration of the i^{th} parameter [22].

Table 1- US EPA Standards, weights and relative weights of heavy metals in water

Parameter	US EPA 2007 standards[1]	weight (wi)	relative wt. (*wi*)
Pb	0.21	5	0.192
Cr	1.1	4	0.154
Ni	0.074	4	0.154
Cd	0.04	5	0.192
Cu	0.0048	3	0.115
Zn	0.09	2	0.077

[1] US EPA, National Recommended Water Quality Criteria - Aquatic Life Criteria Table

Meanwhile, marsh water's composite heavy metal pollution index (HPI) will be classified according to classes mentioned by Zhaoyong et al. [23] and Zhao, et al. [24] and listed in Table 2.

Table 2- Heavy metal pollution index HPI

Classification	HPI
Clean	Less than 1
Light pollution	1.01-2.0
Pollution	2.01- 3.0
Heavy pollution	3.01 – 5.0
Malignant pollution	Greater than 5.0

3.4.2 Bioaccumulation factor (BAF)

Many environmental and physiological factors affect the bioaccumulation potential of heavy metals in fish, such as trophic levels, lipid content, fish age, and bioaccumulation capacity [25]. The bioaccumulation factor measures the accumulation of heavy metals in fish from the water and is calculated according to the following equation [16, 25, 26]:-

$$BAF = \frac{C_f}{C_w} \qquad \text{…………………(5)}$$

Where Cf is the pollutant concentration in fish (mg/kg) and Cw is the pollutant concentration in water (mg/ l).

3.4.3 Estimated daily intake (EDI)

The estimated daily intake (EDI) of heavy metals through ingestion of fish from swamps and marshes is calculated as follows [12, 26, 27]:

$$EDI = \frac{C \times W_F}{W_{AB}} \qquad \text{…………….(6)}$$

Where C is pollutant concentration in food (mg/kg), WF is the average daily consumption of fish in this area (65 g/ day/ person), and WAB is average body weight (70 kg for adults). The measurement unit of EDI is mg/kg bw/day.

3.4.4 Hazard Index (HI)

The calculation formula of THQ was mentioned by many authors [12, 14, 26, 28-33] as follows:-

$$THQ = \frac{E_F \times E_D \times F_{IR} \times C}{RfD \times W_{AB} \times T_A} \qquad \text{…….. (7)}$$

Where EF= exposure frequency (365 days/ year), ED=exposure duration (70 years), FIR= food ingestion rate (About 65 g/ person/ day), C= pollutant concentration in food (μg/g), RfD= oral reference dose (μg/ kg/ day/), WAB = body weight (about 70 kg) TA= average exposure time (365 days/ year× 70 years).

The hazard index (HI) is the combined effects of the individual metal and is calculated as the summation of the non-carcinogenic risks. The calculation formula of HI is given in equation 8 [15, 26, 34-36]:

$$HI = \sum_{i=1}^{m} THQ_i \qquad \text{………… (8)}$$

Where THQi is the target hazard quotients of i tested the heavy metal. If the HI < 1, the local consumer of fishes are denoted to be safe; if HI > 1, then the heavy metals concentration are denoted unsafe for consumption by peoples [33, 37, 38].

4. Results and discussion

To show the impact of human activities within the marsh watershed on the amount of heavy metal pollution of the water and fishes of the marsh; LULC classification and assessment of heavy metal concentrations are carried out as follows:

4.1 Classification of land use/land cover

According to Landsat-8 image processed with ENVI 5.3 software using supervised-spectral angle mapper (SAM) method; seven classes of LULC are identified (Figure 3). The main classes are bare lands which are seasonal cultivated fields covering 26.7% of the area, followed by water body of the marsh of 22.1% and agriculture fields of 15.8%, 12.9%

wetlands, 12.3% shallow water and aquatic vegetation, and salty soils covering 8% of the area. In contrast, the remaining area is covered by shallow water and unclassified classes. According to LULC classification results, about 42% of the marsh watershed was occupied by seasonal cultivated and agricultural fields, indicating that the source of heavy metals comes from agriculture fertilizers, pesticides, and randomly dumped waste via runoff during rainy seasons.

4.2 Heavy metals concentration in water

The heavy metals analysis in Dalmaj marsh water was conducted to assess the heavy metal contents in fishes living in the marsh. The results are listed in Table 3, and spatially distributions are shown in (Figure 4). The results indicate that the chromium (Cr) only comes below the permissible limit (1.1 mg/l) with a concentration of 0.08 to 0.87 mg/l. In contrast, lead (Pb) comes below permissible in samples located in shallow water near to marsh boundary, with a concentration range from 0.088 to 2.365 mg/l, whereas Nickel (Ni) was not detected in four samples i,e., 1,11,12 and 13 and other samples comes above the permissible limit with a range from 0.066 to 1.106 mg/l. The heavy metals of Cadmium (Cd), Copper (Cu), and Zinc (Zn) come above the permissible limits. The spatial distribution indicates that the maximum heavy metal concentrations are located in deeper water sites (Figure 4h).

To give a comprehensive idea of the concentration of heavy metals, a composite heavy metal pollution index (HPI) was calculated as shown in Table 3 and illustrated spatially on a map in Figure 4a-g. HPI values were classified according to the classes mentioned by Zhaoyong, et al. [23] and Zhao, et al. [24] (Table 2). According to the HPI values, marsh water was classified into four classes, ranging in pollution from light to malignant pollution, with maximum pollution in the deeper water (Figure 4h).

The box plot in Figure 5a shows that 25 -75% of nickel and cadmium concentrations are varied in narrow ranges, and nickel shows the extreme concentration of 1.067 and 1.106 (mg/l) in samples 6 and 7, respectively. While, the heavy metals of Pb, Cr, Cu, and Zn are recognized with high concentrations but do not show outliers or extreme values.

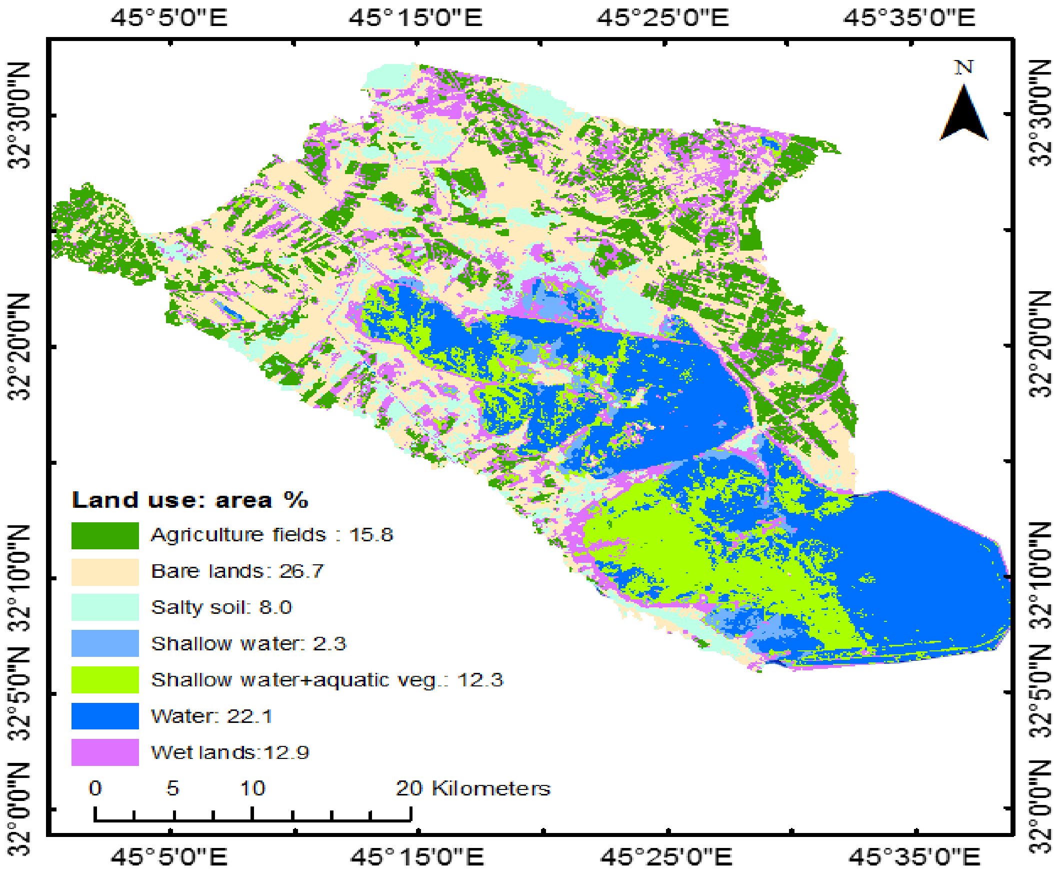

Figure 3-Land use/ land cover (LULC) classes in the study area.
Source: Land sat 8 collected on 7th April 2017 and classified by ENVI v 5.3 software.

Table 3- Concentration (mg/l) of heavy metals and heavy metal pollution index (HPI) in Dalmaj marsh.

Water samples no.	Pb	Cr	Ni	Cd	Cu	Zn	HPI
1	0.176	0.109	-	0.079	0.361	0.689	1.41
2	0.280	0.311	0.079	0.092	0.446	0.935	2.14
3	0.773	0.722	0.087	0.125	0.878	2.406	4.99
4	0.815	0.677	0.099	0.131	1.090	2.489	5.30
5	0.861	0.692	0.092	0.137	0.959	2.713	5.45
6	1.592	0.841	1.067	0.145	1.378	3.908	8.93
7	2.365	0.871	1.106	0.162	1.690	4.130	10.32
8	0.231	0.433	0.066	0.105	0.295	1.365	2.50
9	0.365	0.552	0.075	0.122	0.510	1.815	3.44
10	0.515	0.603	0.081	0.117	0.483	1.791	3.59
11	0.121	0.097	-	0.074	0.133	0.607	1.03
12	0.088	0.085	-	0.057	0.091	0.484	0.80
13	0.095	0.080	-	0.064	0.087	0.511	0.84
14	2.244	0.810	0.124	0.208	2.131	3.652	9.17
15	1.752	0.737	0.118	0.193	1.865	3.296	7.96
16	2.121	0.753	0.122	0.187	1.936	3.351	8.47
Min.	0.088	0.08	0.066	0.057	0.087	0.484	0.8
Max.	2.365	0.871	1.106	0.208	2.131	4.13	10.32
Mean	0.900	0.523	0.260	0.125	0.896	2.134	4.771
SD	0.832	0.294	0.387	0.046	0.707	1.287	3.305

4.3 Concentration of heavy metals in fish tissues.

The analysis of the accumulated concentration of heavy metals in fish tissues listed in Table 4 identifies two metals, i.e., Cr and Cd, showing relatively low concentration. In contrast, Pb, Ni, Cu, and Zn show high concentrations in fish tissues. The box plot diagram in Figure 5b shows that no outliers or extreme values was detected in all the heavy metals concentrations. Mainly, the concentrations of all measured heavy metals are increased with increased fish weights (Figure 5d).

Three important indices, including bioaccumulation factor (BAF), estimated daily intake (EDI), and hazard index (HI), are calculated as given in Tables 5, 6, and 7, respectively. The estimated propensity of metal accumulation in many types of fishes based on average values of bioaccumulation factor shows the Ni (63.27) > Zn (10.53) > Cu (7.64) > Pb (7.45) > Cd (2.52) > Cr (0.44) Table 5, and their values mainly are increased with an increase of fish weight. Despite high trophic levels of heavy metals in marsh water, factors like age, weight, and low lipid content of fishes affect the bioaccumulation factor, adding to that the impact of spatial variation of heavy metal concentrations in marsh water. The zinc (Zn) shows low BAF compared to its concentration in marsh water due to the consuming parts of zinc by fish body requirements. The boxplot of BAF values shows no outliers or extreme values for all tested heavy metals in fish tissues (Figure 5c).

The results of EDI values identified the concentration of Pb and Ni in fish samples 5, 6, 7, 8, and 9 are overcome the acceptable daily intake values (0.00357), (0.012), and RfD values (0.0035), 0.02, respectively, that mean the consumption of the fishes is unsafe and lead to risk need to be a concern. In contrast, other EDI values of heavy metals come below the ADI and RfD concentrations.

Target hazard quotient (THQ) is one of the important indices in evaluating the risk of any heavy metal concentrations in fish tissues, while hazard index (HI) represents exposure to more than one heavy metal in additive effect [39]. Fishes are the main meal in the areas surrounding the marshes of Iraq. Accordingly, the THQ and Hazard index (HI) values are calculated as presented in Table 7. The analysis of the results identified the heavy metals of lead (Pb) and nickel (Ni) show an increase in the value of THQ > 1, indicating a potential risk for adults needs to be a concern. In terms of individual metals; lead (Pb) is the element that induced a high risk for marsh fish consumers with THQ values from 1.961 – 3.802 in five fish samples (5-9), followed by Nickel (Ni) with of 1.087 and 0,959 in fish samples 8 and 9 respectively. In comparison, the concentrations of Chromium (Cr), Cadmium (Cd), Copper (Cu), and Zinc (Zn) come with THQ < 1, consequently, the ingestion of fishes are a bit risky. However, the additive impact of all measured metals illustrated by the hazards index (HI) shows eight fish samples out of ten come with HI > 1, indicating unsafe consumption of fishes from Dalmaj Marsh.

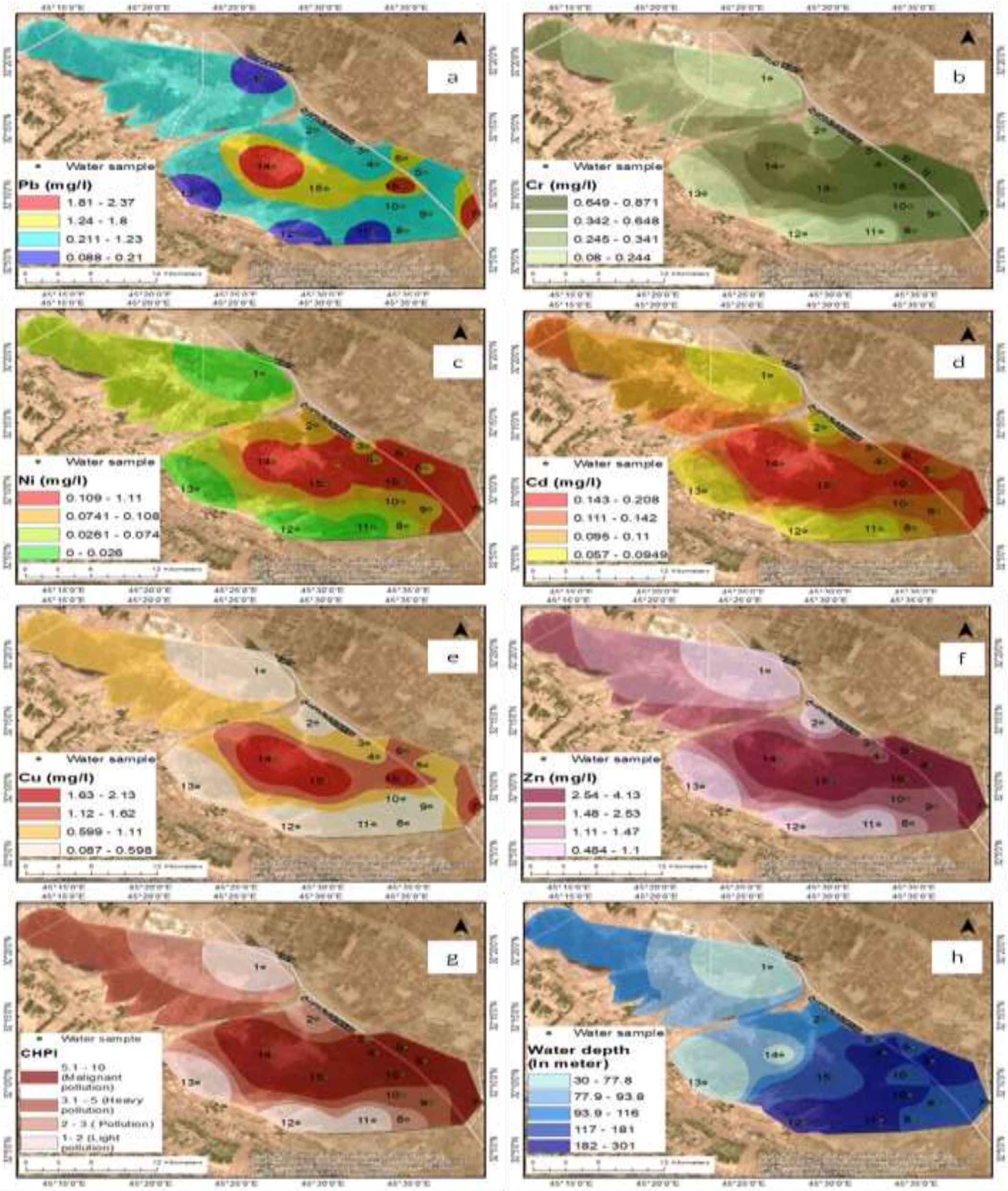

Figure 4-Spatial distribution of heavy metals concentration (mg/l) in the water of Dalmaj marsh, a). Lead (Pb), b). Chromium (Cr), c). Nickel (Ni), d). Cadmium (Cd), e). Copper (Cu), f). Zinc (Zn), g). Composite heavy metal pollution index (HPI) and h). Water depth in meters.

Table 4- Heavy metals concentrations (mg/kg) in fish tissues

Fish sample no.	Fish Wt.(kg)	Pb	Cr	Ni	Cd	Cu	Zn
1	0.22	1.3215	0.116	3.52	-	2.65	14.18
2	0.32	0.9021	0.0988	1.931	-	4.211	10.53
3	0.41	3.567	0.1509	8.063	0.0815	3.842	19.06
4	0.52	2.624	0.2135	6.81	0.112	6.106	17.71
5	0.63	7.392	0.1853	17.306	0.0933	5.755	24.25
6	0.78	10.524	0.329	12.215	0.2718	7.913	30.1
7	0.95	6.821	0.385	16.913	0.516	11.56	26.82
8	1.15	14.33	0.2655	23.422	0.4092	8.723	32.0
9	1.45	12.811	0.3192	20.651	0.715	10.816	27.49
Min.		0.9021	0.0988	1.931	0.0815	2.65	10.53
Max.		14.33	0.385	23.422	0.715	11.56	32
mean		6.699	0.229	12.315	0.314	6.842	22.46
SD		4.996	0.101	7.685	0.244	3.122	7.432

Table 5- Bioaccumulation factor (BAF) of heavy metal concentrations in fish tissues.

Heavy metals	**BAF in fish samples**									**Average**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Pb	1.47	1	3.97	2.92	8.22	11.7	7.58	15.93	14.24	7.45
Cr	0.22	0.19	0.29	0.41	0.35	0.63	0.74	0.51	0.61	0.44
Ni	18.09	9.92	41.43	34.99	88.92	62.76	86.9	120.34	106.11	63.27
Cd	-	-	0.65	0.9	0.75	2.18	4.13	3.28	5.72	2.52
Cu	2.96	4.7	4.29	6.82	6.42	8.83	12.9	9.74	12.07	7.64
Zn	6.65	4.93	8.93	8.3	11.36	14.11	12.57	15	12.88	10.53

Table 6- Estimated daily intake (EDI) compared to Acceptable daily intake (ADI) of each heavy metal in fish tissues

Heavy metals	**EDI of Fish sample**									**ADI [a, b] (mg/kg bw/day)**	**RfD (mg/kg/day)**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**		
Pb	0.0012	0.0008	0.0031	0.0023	**0.0064**	**0.0091**	**0.0059**	**0.0124**	**0.0111**	0.00357	0.0035
Cr	0.0001	0.0001	0.0001	0.0002	0.0002	0.0003	0.0003	0.0002	0.0003	0.00217	0.003
Ni	0.0031	0.002	0.0070	0.006	**0.0150**	**0.012**	**0.015**	**0.0203**	**0.02**	0.012	0.02
Cd	-	-	0.0001	0.0001	0.0001	0.0002	0.0005	0.0004	0.0006	0.001	0.001
Cu	0.0023	0.0037	0.0033	0.0053	0.0050	0.0069	0.0100	0.0076	0.0094	0.5	0.037
Zn	0.0123	0.0091	0.0165	0.0154	0.0210	0.0261	0.0232	0.03	0.0238	0.133	0.3

a Onsanit, et al. [40], b Hosseini, et al. [41]

Table 7- Target hazard quotient THQ of heavy metals for each fish sample and hazard index (HI)

Parameter	**THQ of fish sample**								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Pb	0.239	0.239	0.946	0.696	**1.961**	**2.792**	**1.810**	**3.802**	**3.399**
Cr	0.036	0.031	0.047	0.066	0.057	0.102	0.119	0.082	0.099
Ni	0.163	0.090	0.374	0.316	0.803	0.567	0.785	**1.087**	**0.959**
Cd	-	-	0.076	0.104	0.087	0.252	0.479	0.380	0.664
Cu	0.067	0.106	0.096	0.153	0.144	0.199	0.290	0.219	0.271
Zn	0.044	0.033	0.059	0.055	0.075	0.093	0.083	0.099	0.085
HI	0.549	0.498	**1.599**	**1.390**	**3.128**	**4.005**	**3.566**	**5.669**	**5.477**

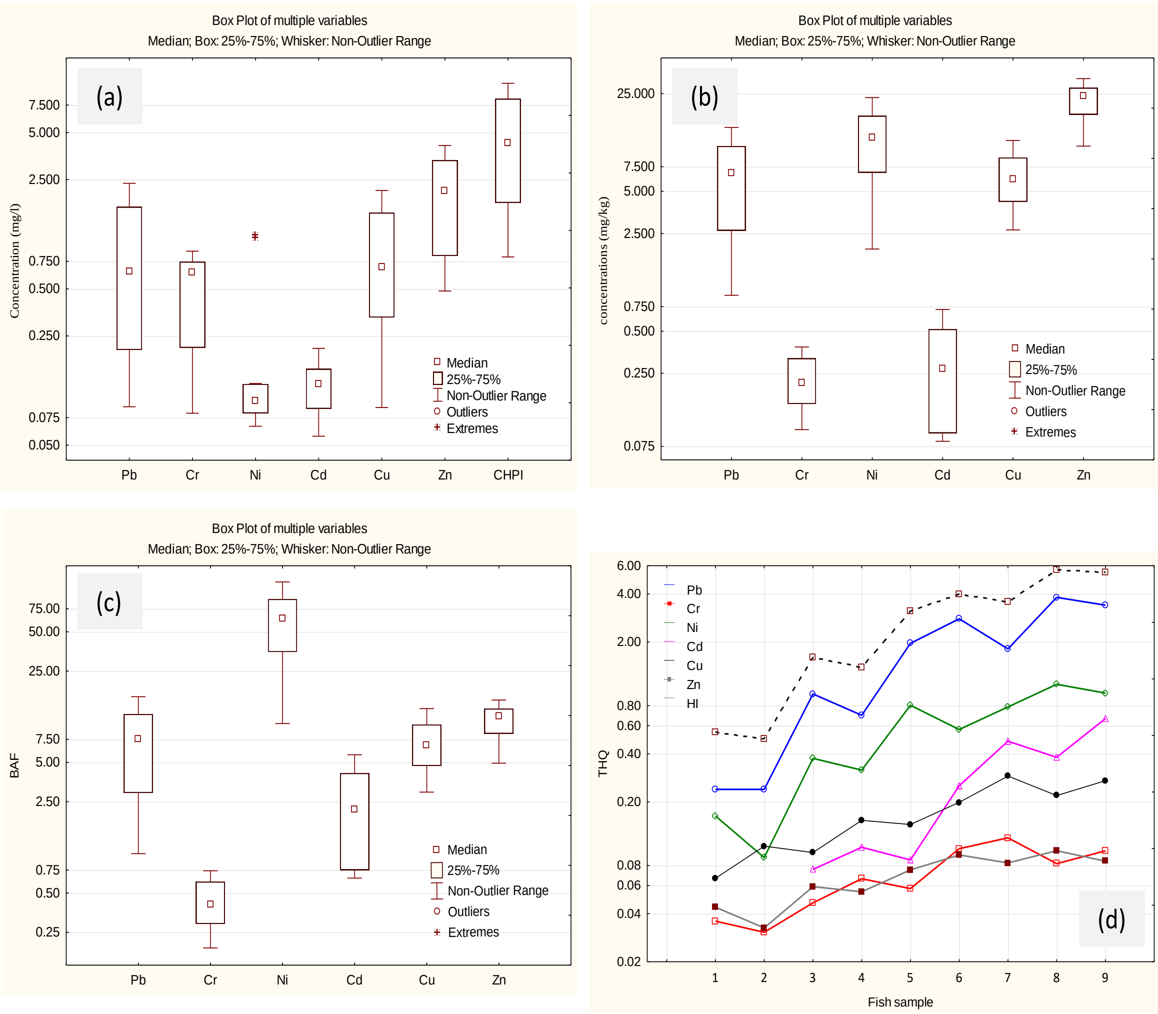

Figure 5-Box plot and line diagrams of heavy metal concentration risks in Dalmaj marsh water and fish tissues, a). The concentration of heavy metals and pollution index (HPI), b). heavy metals concentration in fish tissues, c). Values of bioaccumulation factor (BAF) and d). Target Hazard Quotient (THQ) of heavy metals and hazard index (HI).

5. Conclusions and recommendations

The obtained results revealed that the concentration of heavy metals in Dalmaj marsh water is above the permissible limits except for Chromium (Cr). The spatial distribution of heavy metals identifies the maximum concentration of all heavy metals in the deep water sites. According to the heavy metal pollution index, HPI; all the sites in marsh water are polluted to various degrees, consequently impacting the aquatic lives in the marsh. The fertilizers and pesticides used in the agriculture field and damped domestic and industrial wastes in the catchment of the marsh are the main factors of water pollution with heavy metals. However, the accumulated heavy metals in the fish tissues, as proved by analysis according to bioaccumulation factor (BAF), estimated daily intake (EDI), and hazard index (HI), refers to significant hazards of consumption fishes as the main diet by the residents of nearby the marsh and even the peoples get the marsh fishes from the markets. The current study recommends periodic monitoring of the concentration of heavy metals and other chemical elements in the marshes, water, and all aquatic lives and awareness of the residents about the risk of fish as the main meals.

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