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Water Quality Assessment for the Southern Al-Hawizeh Marsh Using Diatom Indicators

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ABSTRACT

The current study was conducted to assess water quality in the southern Al-Hawizeh Marsh using epiphytic diatoms. Two types of plants were used, Phragmites australis and Tamarix aucheriana. Four study sites were selected at the southern Al-Hawizeh Marsh, plant samples were collected quarterly, double months for each season, starting from October 2020 to July 2021. Two of diatom indicators were applied, Trophic Diatom Index (TDI) and Specific Pollution Sensitivity Index (SPI). The results of TDI showed that the waters of the Southern Al-Hawizeh Marsh were generally at a mesotrophic level; the temporal results recorded the lowest values during the winter season at the oligotrophic level and the highest values of the index were recorded in the summer with a rich nutritional level (eutrophic). As for the results of the spatial index of TDI, the lowest values of the index were recorded in Well 11 as oligo-mesotrophic, while the highest rate was recorded at the Al-Keser site at the level of eutrophic. However, the SPI analysis results showed that the marsh's waters, in general, have moderate organic pollution or significant eutrophication. Autumn season has the highest index rates ranging from moderate to light pollution, while the spatial SPI index in the sites showed that the lowest rates of index were recorded by the Al-Sabelah site, and the highest rates of index were recorded by the site Well 11, both of them with a moderate to eutrophic of pollution.

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INTRODUCTION

The Mesopotamian marshes in southern Iraq are the largest complex of wetlands in Iraq and one of the most important water systems in the Middle East (Fawzi et al., 2016). The marshes play an important role in preserving biodiversity in the region due to their large area and the abundance of aquatic plants, as well as their separation from other systems (DouAbul et al., 2013). The marshes in the southern part of Iraq are among the most prominent areas that developed within the alluvial plain, creating a natural balance between the Tigris and Euphrates rivers and the Shatt Al-Arab leading to the Arabian Gulf. They represent an integrated ecosystem dating back more than 5,000 years and occupied a large area of southern Iraq (Al-Naqeeb et al., 2020). The United Nations Environment Program (UNEP, 2006) classified it as one of the most important centers of biodiversity in the world for these reasons.

The marshes are located in three provinces in southern Iraq: Basrah, Maysan and Dhi-Qar. The area of the marshes before drying is 20,000 km^2 and is usually divided into three main areas: the Hammar marsh at south of the Euphrates, the central marshes located between the Tigris and Euphrates rivers, and Al-Hawizeh marshes at east of the Tigris River (Al-Handal & Al-Shaheen, 2019). The Iraqi marshes extend on flat, low-lying land that qualifies them to

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contain and store surface water, which is characterized by its dry desert climate as a result of low water levels during the summer due to the lack of rain and low river water imports, which increase relatively in the winter when rain and water imports are available (Al-Sudani, 2017).

Al-Hawizeh Marsh represents the largest of the southern marshes, with an area of about 3000 km^2 and a depth of about 6 m. It is located near the city of Al-Amarah (Al-Shamary, 2016). The Al-Hawizeh Marsh is a shared water body between Iraq and Iran in terms of location and the sources of water incoming to it. (Al-Abbawy et al., 2021) The governorates of Basrah and Maysan, respectively, hold 67% and 33% of the area of the Iraqi part which stretches from Al-Musharrah sub-district in the Maysan governorate in the north to Al-Qurna city in the Basrah governorate in the south (Al-Asadi & Maatouq, 2013). Al-Hawizeh receives water from the eastern streams of the Tigris River, represented by Al-Mashreh and Al-Kahla, as well as from Iran via the Al-Tayyib and Karkheh rivers (Nashoor & Vartan, 2012).

Water quality is related to the purpose of different water uses such as drinking, recreation, fishing, agriculture and industry, and each of these uses has different chemical, physical and biological criteria necessary to support this use (Roy, 2019). Researchers have worked diligently to assess water quality, and the assessment can be divided into two types, the first type is based on instant measurements of physical and chemical factors related to water properties. The second type is based on the use of biological methods and is called biological indicators, as organisms are used to monitor water quality, through which long-term effects can be known (Panich-pal et al., 2009).

Diatoms, a well-known group of algae which serve as a guide for assessing water quality (bioindicators) (Noga et al., 2014; Stevenson, 2014). These organisms constitute one of the main dominant groups of plant-attached algae (epiphytic) in still water systems as well as effective indicators of environmental changes, because they respond sensitively and quickly to physical and chemical changes affecting water quality (Winter & Duthie, 2000; Lobo et al., 2002; Al-Shaheen & Al-Handal, 2017; Al-Ahmady et al., 2019).

Diatoms are among the most effective algal groups as bioindicators due to their global distribution, short life cycle, high diversity, and rapid response to even very small variations in the physical and chemical properties of their aquatic environment (Vassal et al., 2021). Pollution affects diatoms in various ways, such as by depriving them of sunlight, making them toxic, or altering their physical and chemical properties to hinder growth and reproduction (Lobo et al., 2016). There are many features that distinguish diatoms from others that make them preferred for water quality assessment (Khudher & Al-Jasimee, 2019).

Diatoms are among the most dominant types of algae in most aquatic ecosystems, where they are sensitive to low concentrations of pollutants compared to other algal groups (Hassan & Shaawiat, 2015). These species differ in the function they perform and the habitat in which they settle; they may be planktonic, benthic, or periphyton. Numerous international studies have published various diatom indicators, typically categorized into two types: pollution indicators and nutritional indicators.

As a result of the impact of the southern part of Al-Hawizeh Marsh in Basrah Governorate for two long periods from the first drying during the nineties of the last century until its flooding in 2003 to return to drought in 2009 due to lack of water revenues and then flooding again in 2018, it was necessary to study the environment of this marsh to identify the impact of the two drought periods on the water quality of this area, so the current study aimed to assess the water quality of the Southern Al-Hawizeh Marsh based on the application of two types of diatom indicators, the trophic diatom index (TDI) and Specific Pollution Sensitivity Index (SPI) to identify the nutritional status and organic pollution in the study area based on diatoms as one of the basic components of life in the waters of the Iraqi marshes.

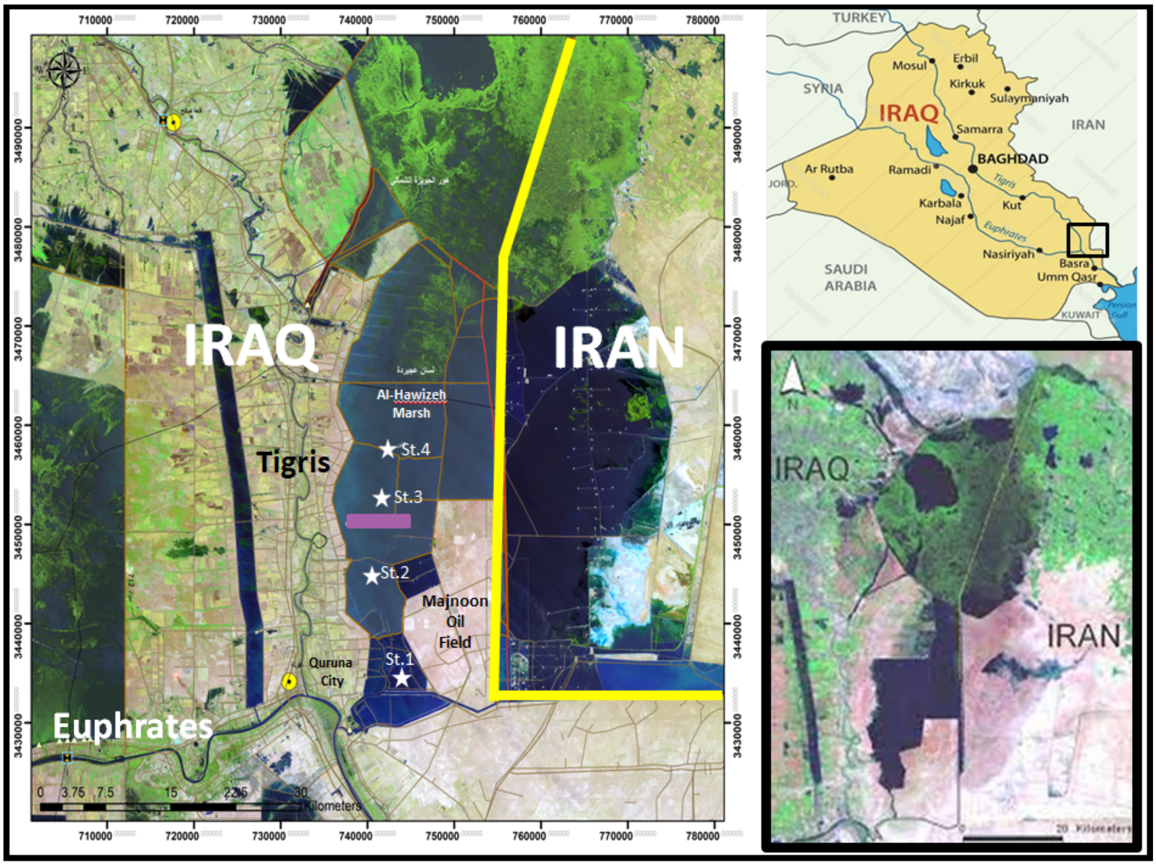

Fig. 1. Map of study sites in the southern Al-Hawizeh Marsh, Iraq.

MATERIALS AND METHODS

The southern Hawizeh Marsh is located in the north of Basrah Governorate, with a total area of about 322 km^2, and is bordered on the north by the Lisan Ajirdah dam, which is the border between the governorates of Basrah and Maysan, on the east by the Iranian border, and bordered on the west by Al-Qaim and Al-Qurna city, and from the south by the Al-Suwaib town. The agricultural lands are separated from the Hawizeh Marsh by a dam about 35 km long The southern outlet of Hawizeh marsh is the Al-Suwaib river, which connects with the Shatt Al-Arab river through the Al-Suwaib regulator. This marsh suffered from drought from the end of 2009 until October 17, 2018, and the barrier between the arrival of water to Basrah was the Lisan Ajiradah dam, which is located to reserve water in the northern part of the Hawizeh Marsh located in the Maysan Governorate, as well as its use for military convoys and border police (Water Resources Directorate/ Personal Communication).

Four sites were selected to collect samples for the current study, all of which are located in the southern Hawizeh Marsh in Basrah Governorate, on the western side of the Majnoon oil field (Fig. 1), the locations of these sites were determined by means of a Geographic Positioning System (GPS).

The study sites are characterized by the rapid flow of water, and the soil dams some of them submerged in water and others visible above the surface of the water are spread on the edges of which scattered assemblies of *Phragmites australis* (Cav) Trib Ex Steud, with very small numbers of *Typha domingensis* Pres., while there are many dense aggregations of *Tamarix aucheriana* (Decne. Ex Walp.) Baum in the water and on the edges of the earthen embankment, but the majority of these bushes are dead. The study area is active in the movement of boats

Table 1. Coordinates of the study sites.

Sites	GPS coordinate
Al-Zardan	N: 31° 00' 723" E: 47 ° 32' 263"
Al-Keser	N: 31° 04' 303" E: 47 ° 33' 065"
Al-Sabelah	N: 31° 06' 977" E: 47 ° 32' 392"
Well 11	N: 31° 08' 889" E: 47 ° 33' 278"

entering and leaving the marsh for the purpose of transportation and fishing for fish and birds.

Plant samples were collected from the four selected study sites in the southern Hawizeh Marsh during the period from October 2020 to July 2021. The differences were expressed quarterly. Samples of *P. australis* and *T. aucheriana* were randomly collected for each site twice during the same season. At least five pieces were taken from the submerged part of the plant from the stem and leaves with a length of 5-10 cm for each piece. Each plant sample was placed separately in a plastic bag, each containing a small amount of water from the environment, and then added 4% formalin to preserve it. Diatoms were isolated from the plant in vitro by taking 10 g of wet weight of the plant sample and placing it in a box containing 100-50 ml of distilled water, then shaken manually for about 5 minutes, then the algae suspension was taken and preserved with 4% formalin. Half the volume of the suspension was used for the taxonomical purpose, and the remaining half was for counting. Hot hydrogen peroxide (H_2O_2) technology was selected for the purpose of cleaning the skeletons of diatoms according to the method used by Taylor et al. (2007a) and Al-Handal & Wulff (2008).

Perennial diatoms slides were made by placing about 1 ml of a cleaned diatoms suspension on the cover slide and letting it dry at room temperature, away from dust. Next, we flip the dry cover slide onto a microscope slide that contains 0.5 ml of Naphrax, a high refractive index compound. Then the slide was placed on a hot plate at about 100°C for a few seconds to eliminate all air bubbles. Finally, the slide was marked to be ready for examination by a compound light microscope. The permanent diatom slides were examined using a compound optical microscope.

Relative abundance of all diatom species encountered in all samples was estimated by counting 400 valves in each permanent slide. Counting was made in transapical lines across the cover slip until 400 counts was reached (Al-Shaheen, 2016) . RA was estimated according to the formula:

RA = (n/N) x 100

Where:

n: number of valves of each species counted

N: total number of valves of all species (400).

The following sources were used to diagnose diatoms: Witkowski et al. (2000), Novelo et al. (2007), Taylor et al. (2007b), Al-Kandari et al. (2009), Cantonati et al. (2017).

1. Trophic Diatom Index (TDI)

This index was calculated mathematically according to the equation explained by Kelly et al. (2001) and as follows:

$$\textbf{TDI} = \left[\left(\frac{\sum aj\, sj\, vj}{\sum aj\, vj}\right) . 25\right]\text{-}25$$

Where:

aj = abundance or proportion of a particular species.

sj = sensitivity of the particular species to a nutrient, ranging from 1- 5.
vj = value of the index of the particular species (1-3).
The sensitivity values and the index value for each species were extracted according to the special tables shown in Kelly et al. (2001).

2. Specific Pollution Sensitivity Index (SPI)

This index was calculated mathematically based on the equation shown by Zelinka and Marvan (1961) as follows:

$$\mathbf{SPI} = \frac{\sum aj\ sj\ vj}{\sum aj\ vj}$$

Where:
aj = relative abundance of the given species in the sample.
sj = the sensitivity of the particular species of pollutant ranges from 1- 5.
vj = value of the index of the given species 1-3.
The sensitivity and index values for each species were extracted according to the special tables described in Cemagref (1982).

RESULTS AND DISCUSSION

The current study recorded 29 species of diatoms belonging to 15 genera; some them were have the sensitivity and index values which the study focused on to calculate the values of the two in both indices TDI and SPI (Table 2).

The results of the TDI analysis of epiphytic diatoms on *P. australis* and *T. aucheriana* showed that the waters of the study area in the southern Hawizeh Marsh were generally of a mesotrophic level, with the overall average of the guide reaching 56.13. According to the Temporal (seasonal) guide results, all stations recorded the lowest index values during the winter season, with Al-Kasr station recording the lowest at 26.46, indicating a poor nutritional level (oligotrophic). On the other hand, Al-Sabelah station recorded the highest index values, reaching 61.37 in the summer, indicating a rich nutritional level (eutrophic) (Table 3).

With regard to the spatial results of TDI, the lowest values were recorded in the site Well 11 (49.27) with a nutritional level of little or weak to medium (Oligo-mesotrophic), while the highest value of the index was recorded by the Al-Kasr site, where the index value reached 61.16 with an nutritional level High or rich (Eutrophic).

The application results of TDI for the current study ranged from the oligo to the eutrophic level, but most of the index values are the mesotrophic level. Diatom species such as *S. meneghinianus* and *E. gibba* appear in waters with low discharge and high electrical conductivity (Blinn and Herbst, 2003). According to Van Dam et al. (1994) The species *E. gibba* diagnosed in our current study is tolerant of very low concentrations of nitrogen, while the species *C. euglypta*, *G. acuminatum*, *N. rostellata*, *N. clausii*, *N. sigma*, *S. neoastraea* and *T. fasciculata* are tolerant of high nitrogen concentrations, on the other hand, most species of diatoms recorded in the study area prefer to live in nutrient-rich (Eutrophic) environments. Cantonati et al. (2017) that the diatom *G. acuminatum* grows at a high trophic level, but is sensitive to above-average organic pollution with their classes alpha and beta, while the species *N. clausii* has been recorded in rivers polluted with industrial waste, therefore it is tolerant to medium-alpha pollution. *M. smithii* was also found to live in nutrient-rich waters.

Local studies on evaluating the water quality of the marshes using diatom index are very few if not rare, as there are only two published studies on the marshes. Our current study aligns with the findings of Abu-Hadal and Al-Hassany's (2020) study on the Abu Zark Marsh. This

Table 2. The diatoms species encountered in the current study sites in the southern Al-Hawizeh Marsh with the sensitivity and index values of diatoms species according to Cemagref (1982) and Kelly et al. (2001).

Diatom Species	The sensitivity and index values			
	TDI		SPI	
	s	v	s	v
Campylodiscus bicostatus W.Smith ex Roper 1854				
Campylodiscus clypeus (Ehrenberg) Ehrenberg ex Kützing 1844				
Cocconeis euglypta Ehrenberg 1854	2	2	3	1
Diplonies sp.	1	1	1	1
Epithemia gibba (Ehrenberg) Kützing 1844	1	1	5	3
Epithemia operculata (C.Agardh) Ruck & Nakov 2016	1	1		
Gyrosigma acuminatum (Kützing) Rabenhorst 1853	5	2	4	3
Gyrosigma eximium (Thwaites) Boyer 1927	5	2		
Mastogloia smithii Thwaites ex W.Smith 1856				
Mastogloia albertii Pavlov, Jovanovska, Wetzel, Ector & Levkov 2016				
Navicula digitoradiata (W.Gregory) Ralfs 1861	4	1	2	3
Navicula rostellata Kützing 1844			3	3
Nitzschia clausii Hantzsch 1860			2	3
Nitzschia elegantula Grunow 1881	4	1		
Nitzschia obtusa W.Smith 1853	4	2		
Nitzschia sigma (Kützing) W.Smith 1853			2	3
Plagiotropis lepidoptera (W.Gregory) Kuntze 1898				
Pleurosigma elongatum W.Smith 1852				
Sellaphora sp.1	5	1		
Sieminovis sp.1	5	1		
Stephanocyclus meneghinianus (Kützing) Kulikovskiy, Genkal & Kociolek 2022			2	1
Stephanodiscus neoastraea Håkansson & Hickel 1986				
Surirella striatula Turpin 1828	3	1		
Tabularia fasciculata (C.Agardh) D.M.Williams & Round 1986				
Tabularia tabulata (C.Agardh) Snoeijs 1992	5	2	2	3
Tryblionella apiculata W.Gregory 1857			2	3
Tryblionella coarctata (Grunow) D.G.Mann 1990				
Tryblionella granulata (Grunow) D.G.Mann 1990	4	1		
Tryblionella scalaris (Ehrenberg) Siver & P.B.Hamilton 2005			3	1

study found that the majority of TDI values dropped in the stations during the fall and winter seasons, indicating a generally poor nutritional level, with the exception of the second and third stations, which recorded a rich and medium nutritional level in winter, respectively. Overall, the nutritional condition of the marshes ranged from poor to medium.

In the study of Al-Naqeeb (2021) that was conducted in the Hawizeh marsh located in Maysan Governorate, specifically in the Umm Al-Naaj marsh, the results of the TDI index within the average nutritional level for all sites except for the fifth site in summer, which recorded a weak to moderate level, and the sixth site during the spring season, which recorded a rich nutritional level.

Changes in physical and chemical environmental factors reflect in the diatoms' numbers, species, living conditions, and growth. Therefore, scientists started using diatoms as biological

Table 3. Values of the Trophic Diatom Index (TDI) and its taxonomic categories for study sites in the southern Hawizeh Marsh during the period from October 2020-July 2021.

2021 Summer 57.66	2021 Spring 49.36	2021 Winter 43.33	2020 Autumn 47.55	Sites TDI
51.05 Mesotrophic	46.86 Oligo-mesotrophic	37. 56 Oligo-mesotrophic	52.81 Mesotrophic	Al-Zerdan 56.95 Mesotrophic
48.05 Oligo-mesotrophic	50.52 Mesotrophic	26.46 Oligotrophic	45.66 Oligo-mesotrophic	Al-Keser 61.16 eutrophic
61.37 eutrophic	48.87 Oligo-mesotrophic	40.59 Oligo-mesotrophic	49.48 Oligo-mesotrophic	Al-Sabelah 53.45 Mesotrophic
53.07 Mesotrophic	53.14 Mesotrophic	29.69 Oligotrophic	35.82 Oligo-mesotrophic	Well 11 49.27 Oligo-mesotrophic
Mesotrophic				General average 56.13

Table 4. The values of the Specific Pollution Sensitivity Index (SPI) and its taxonomic categories for the study sites in the southern Hawizeh Marsh during the period from October 2020 to July 2021.

Summer 3.33	Spring 3.39	Winter 3.35	Autumn 3.96	Sites SPI
3.79 moderate pollution	3.34 moderate pollution	3.91 moderate pollution	4.13 light pollution	Al-Zerdan 3.33
3.90 moderate pollution	3.41 moderate pollution	3.65 moderate pollution	4.26 light pollution	Al-Keser 3.38
3.35 moderate pollution	3.48 moderate pollution	2.68 heavy pollution	3.96 moderate pollution	Al-Sabelah 3.26
3.69 moderate pollution	3.97 moderate pollution	4.07 light pollution	4.69 better quality	Well 11 3.81
moderate pollution or significant eutrophication				General average 3.39

evidence to assess the aquatic environment and its quality (Armstrong & Brasier, 2005). Szabó et al. (2005) indicated that diatoms sensitive to pollution will suffer from a decrease in their species with an increase in pollution in their environment, while the species and numbers of diatoms tolerant or resistant to pollution increase and become dominant.

The Specific Pollution Sensitivity Index (SPI) is one of the most widely used guides on diatoms in European and non-European countries (Lavoie et al., 2009). Nunes et al. (2003) confirmed that the SPI serves as a benchmark and undergoes constant updates, encompassing a vast list of diatom species. On the other hands, the SPI is appropriate in lakes in Spain and Turkey (Blanco et al., 2004; Ács et al., 2005).

The results of the SPI showed that the water of the study area was in general moderate pollution or Significant eutrophication, with an overall index of 3.39 . The worst water quality recorded at Al-Sabelah in the category of heavy pollution during the winter season, while the well 11 site achieved the best water quality by registering the highest values of the in the autumn season (Table 4).

The results of applying the SPI index in the current study ranged from a good water quality level to a severe pollution level, but the majority of the index values are medium pollution and this matches the result of the TDI index.

Regarding the water quality of the current study area, the diatoms species *C. bicostatus*, *C. clypeus* and *C. euglypta*, *G. acuminatum*, *M. smithii*, *N. rostellata*, *E. gibba* and *S. neoastraea* indicated that the water quality is within the second category of medium- beta pollution (β-mesosaprobous), as well as, our study also recorded the presence of *N. clausii*, *N. sigma* and *T. fasciculata* that grow in medium-alpha polluted water (α- mesosaprobous) (Van Dam et al., 1994), the presence of diatom *C. meneghiniana* is evidence of medium to high pollution (α-meso- polysaprobous) (Van Dam et al., 1994; Soininen et al., 2004; Hosmani, 2013).

Although diatom *G. acuminatum* is found in high trophic level waters, it is sensitive to above-average organic pollution of alpha and beta quality, as well as for the species *N. clausii* that was recorded in rivers polluted with industrial waste, therefore it is tolerant to medium pollution - alpha, while diatom *N. sigma* is found in seacoasts and estuaries of high eutrophication, also the tolerance of organic pollutants up to the alpha-medium level has been recorded for *T. apiculata* (Cantonati et al., 2017). Sanal and Demir (2018) recommended the use of GDI and SPI to monitor the environmental condition in Turkey lake because these indicators also incorporate all diatom species within the samples.

CONCLUSION

The effectiveness of the Trophic Diatom Index (TDI) and Specific Pollution Sensitivity Index (SPI) in assessing nutritional status and organic pollution levels in the southern part of Al-Hawizeh Marsh in Basrah Governorate was confirmed in the current study. According to the TDI index, the waters of this marsh were generally at mesotrophic level, while the analysis results of SPI index showed that the waters have moderate to rich levels of organic pollution. The results of this study are important as it gave the environmental status of the marsh after two periods of drought, and gave an idea of the reasons that may lead to the failure to restore good levels of the marsh's environment and life. In general, this enables officials to take the results of this study into consideration for future procedures to assess the situation and develop plans for the best restoration of this important environment in southern Iraq.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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