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Ecological risk assessment of heavy metals in the Sidi Boughaba Lake, Morocco

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Abstract: The goal of the research was to evaluate the heavy metal detection and potential ecological risks in lake's water. Geological formations consisting essentially of sandstone and quaternary marine or dune sands characterize the study area. With a climate of the Mediterranean type winters are mild and humid, whereas summers hot and dry. At the analysis center of the Faculty of Sciences, the monitoring of ETMs is carried out by ICP-MS, the processing of data and the validation of the analysis method have been drafted according to the NF T 90-120 standard applicable to the analysis in a laboratory. The analysis covers concentrations of heavy metals, which include Cu, Zn, Mn, Fe, Pb and As, in the water. Pollution load index (*PLI*) values were above one (>1) which indicates progressive deterioration of the water quality. However, contamination factor (*CF*) values of Pb and Cu, ranging from 8.31 to 15.68 and from 5.5 to 28.05 respectively, show that the studied water remains under a strong impact by Pb and Cu. Considering the severity of the ecological risk (*Er*) for a single metal, the descending order of contaminants is Cu > Pb > Mn > Fe > Zn. In relation to the total ecological risk index (*RI*), water from the lake shows low to considerable ecological risk.

Keywords: contamination factor, ecological risk assessment, heavy metal, lake, Morocco, Sidi Boughaba

INTRODUCTION

Lakes are important environments for their ecological and aesthetic value [Cardoso *et al.* 2009]. The aim is to preserve fresh water, supply and replenish groundwater [Uhlmann *et al.* 2011]. In recent years, metal contamination in the aquatic environment has attracted global attention, owing to the toxicity, persistence, and high bio-accumulative potential.

Heavy metals are natural components in rocks and mineral deposits, and their alteration and erosion naturally feeds surface waters with these metals at low levels. In addition, due to extensive evaporation and marine intrusion, the salinization of these water bodies contributes in a remarkable way to the qualitative and quantitative deterioration of the waters [Najy *et al.* 2021a] However, the increase in salinity favours the mobility of metals in the waters [Du Laing *et al.* 2008].

The existence of these metallic elements can be of natural or anthropogenic origin with high concentration levels compared to the geochemical background. They can form compounds with potential impacts on the environment [Rajbanshi 2009]. Some of these metals are needed as trace nutrients for life processes in plants and micro-organisms, but become toxic at higher concentrations. Others, such as Pb, Cr and Cd, have no known biological function, but they pose a real problem to aquatic life when their concentration exceeds the tolerated norm [Ghannam *et al.* 2015; Sa'idi 2010; Wuana, Okieimen 2011]. The dealing with these metals is not easy in nature and they accumulate in animals as well as in humans and with their high toxicity cause adverse effects.

In this study, Lake Sidi Boughaba is characterised by high levels of trace metal elements studied, greatly exceeding tolerated standards [Najy *et al.* 2021b]. Moreover, the degree of pollution and the risk for the lake were evaluated by certain risk indices, such as metal pollution index (*MPI*), contamination factor (*CF*) and pollution load index (*PLI*). *PLI* values were above one (>1) which indicates progressive deterioration of water quality.

MATERIALS AND METHODS

STUDY AREA

Lake Sidi Boughaba is located on the Atlantic coast of northwestern Morocco, oriented NNE–SSW (Fig. 1) [Najy *et al.* 2018] and is located in an interdunal depression. It stretches for 5.5 km in length, and a variable width from 100 to 350 m, and its depth varies between 0.5 and 2.50 m maximum.

The maximum water level occurs at the end of winter (March) and minimal just before the return of rain (September). Due to the large variation in the level (nearly 1 m), only a portion of this lake, which is sufficiently deep, remains filled with water throughout the year (well less than half of the surface) [Jacqumein 1987].

FIELD SAMPLING AND LABORATORY PROCEDURES

Surface water samples were collected monthly for two successive years (2016–2017). After sampling, samples were stored in polyethylene bottles pre-rinsed with acid and then with distilled water in the laboratory. The samples were transported to the laboratory, filtered and acidified with nitric acid to keep the samples' pH < 2 for trace metal analysis. The atomic absorption spectrometry (AAS) was used for the analysis of the metals concerned.

ECOLOGICAL RISK ASSESSMENT FOR HEAVY METALS IN WATER

The metal pollution index (*MPI*) is an evaluation technique that provides the composite influence and toxicity of each metal on the overall quality of water. The *MPI* represents the ratio of the measured concentration to a reference threshold value. The drinking water standards of the World Health Organization [WHO 2011] are used as maximum allowable concentrations (*MAC*) for the metals.

$$MPI = \sum_{i=1}^{n} \frac{C_i}{MAC_i} \tag{1}$$

where: n = number of heavy metals measured, C_i = concentration of i^{th} metal ($\text{mg}\cdot\text{dm}^{-3}$).

Six classes of water quality were used to evaluate the degree of anthropogenic metal input during different sampling periods as very pure <0.3, pure [0.3; 1.0), slightly affected [1.0; 2.0), moderately affected [2.0; 4.0), strongly affected [4.0; 6.0), and an *IPM* > 6.0 as severely affected.

Considering that, several researchers have established the ecological risk of sediments linked to metallic trace elements, but it has not been done for water, and this depends on the values of pH of the studied medium. In fact, high pH values facilitate precipitation in the sediments [Simpson, Spadaro 2016]. The most common method used is target hazard quotient and target cancer risk [El Nemr *et al.* 2016]. However, the potential ecological risk and the water contamination factor were calculated by Sharifi *et al.* [2016]. In this study, C^i_{ref} is the water quality index, defined

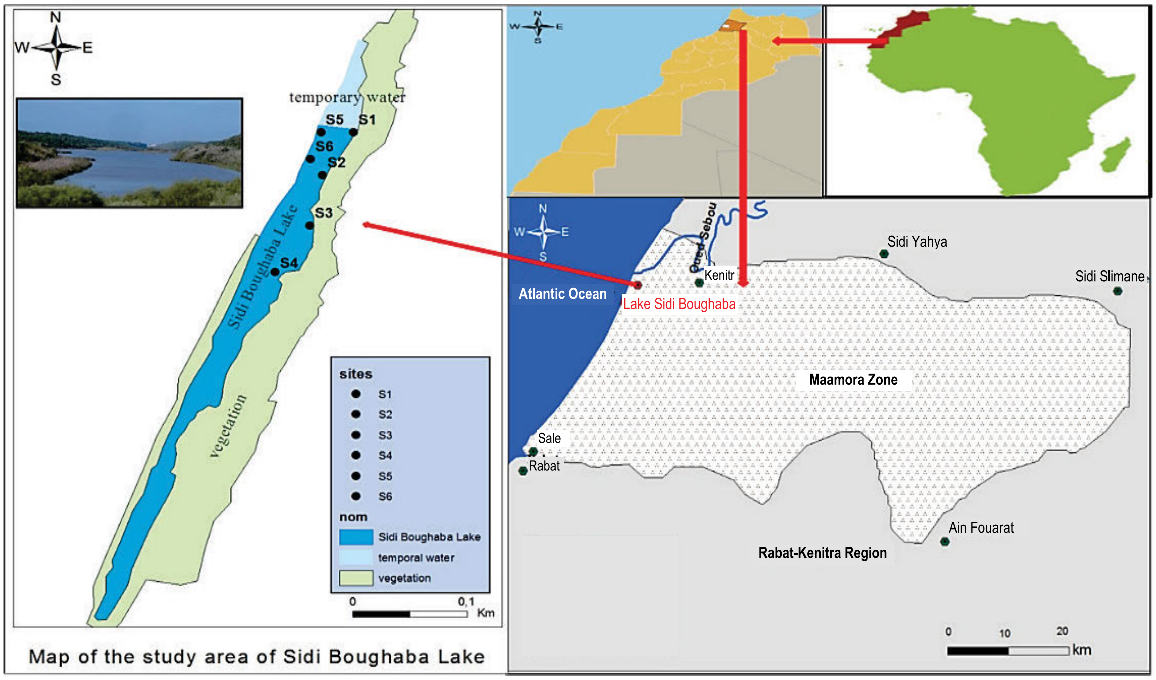

Fig. 1. Location of the study area; source: Najy *et al.* [2018].

by various guidelines, including the World Health Organization. The threshold values have been determined, for which levels of contamination and toxicity are available.

The contamination factor (*CF*) is calculated from Equation (2) and classified in Table 1 according to HAKANSON [1980].

$$CF = \frac{C_{\text{metal}}}{C_{\text{ref}}} \tag{2}$$

where: C_{metal} = concentration of a sample metal studied, C_{ref} = standard values of the same metal set by WHO.

Table 1. Index classification of water quality

Class	Quality class	*CF* value
1	low	*CF* < 1
2	moderate	1 ≤ *CF* <3
3	considerable	3 ≤ *CF* < 6
4	very high	*CF* ≥ 6

Source: HAKANSON [1980], modified.

For the evaluation of the pollution load index (*PLI*), we used the calculation of the index developed by TOMLINSON *et al.* [1980] according to Equation (3).

$$PLI = (CF_1 \cdot CF_2 \cdot CF_3 \cdot \ldots \cdot CF_n)^{\frac{1}{n}} \tag{3}$$

where: *CF* = n^{th} metal contamination factor, *n* = number of metals measured.

Values of *PLI* are categorised in a qualitative way from which sampling sites are assessed. *PLI* > 1 indicate high pollution, *PLI* = 1 the pollution level is very low, and *PLI* < 1 no pollution generated by the metals studied.

The ecological risk index (*ER*) was also calculated by HAKANSON [1980] to highlight the qualitative state of the sampled sites and helped to predict to what extent the sites were exposed to metallic deterioration.

$$ER = T_i \tag{4}$$

where: *ER* = ecological risk, *CF* = metal defilement factor of every substantial metal assessed in correlation with the quality rule standard given by MACDONALD *et al.* [2000], and T_i = potential natural hazard coefficient of a specific overwhelming metal as per HAKANSON [1980], which are 5 for Cu, Ni and Pb, 2 for Cr and 1 for Mn and Zn [ISLAM *et al.* 2015].

The potential ecological risk caused by all the metals was ascertained by the total ecological risk index (*RI*), as indicated by Eq. (5).

$$RI = \sum_{n=1}^{n} ER_n \tag{5}$$

where: ER_n = potential ecological risk factor for the n^{th} heavy metal, *n* = total number of measured heavy metal concentrations.

Values of *ER* are divided into five categories, while *RI* values into four [HAKANSON 1980] (Tab. 2), and higher *ER* and *RI* values indicate a higher risk to ecosystems.

Table 2. Hakanson classification ecological risk (*ER*) and potential ecological risk index (*RI*)

ER class	*ER* range	Grad of ecological risk	*RI* range	Grad of ecological risk
0	<40	low risk	<110	low risk
1	40 ≤ *ER* < 80	moderate risk	110 ≤ *RI* < 200	moderate risk
2	80 ≤ *ER* < 160	considerable risk	200 ≤ *RI* < 400	considerable risk
3	160 ≤ *ER* < 320	high risk	≥ 400	very high risk
4	≥320	very high risk		

Source: HAKANSON [1980], modified.

The tools or index mentioned above will allow us to determine whether metallic contamination linked to water can negatively affect aquatic organisms.

RESULTS AND DISCUSSION

WATER QUALITY INDEX

Metal pollution index (*MPI*) mean values for different time period have been pooled from the dissolved trace metals to understand the spatial variations of metal pollution (Fig. 2). The waters of the lake are characterised by class VI (*MPI* > 6) with minimum and maximum values respectively of the order of 27.69 and 51.45 were registered at site 2 and site 5. Values of the *MPI* indicated that the water quality was seriously affected.

As shown in Figure 2, pollution load index (*PLI*) values in the lake water ranged between 3.07 and 6.68 (average 5.25). All *PLI* values exceeded 1 in water samples, as previously described. Most of the lake's water comprises coastal waters, runoff and

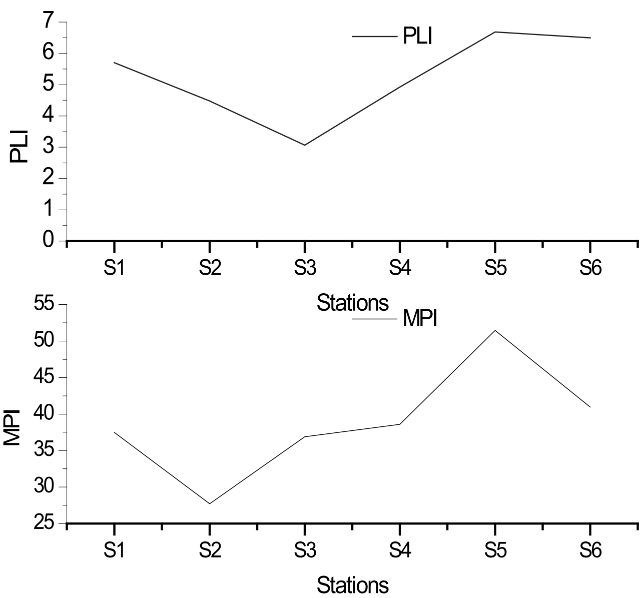

Fig. 2. Heavy metal contamination in lake water at investigated stations: pollution load index (*PLI*), metal pollution index (*MPI*); source: own study

storm water. Thus, there are no discharges directly passing through this body of water, which suggests that the main sources of these metals can be attributed to natural processes.

Contamination factor (*CF*) values along the lake ranged from 5.5 to 28.05 for Cu, 0.79 to 2.13 for Zn, 8.31 to 15.68 for Pb, 1.96 to 3.69 for Fe and 4.74 to 11.25 for Mn and, respectively. Based on the average *CF* value for the five heavy metals analysed, the sequence was Cu > Pb > Mn > Fe > Zn (Fig. 3). To be more precise, *CF* < 3 for Zn at five sampling stations suggests their moderate enrichment and contamination, and considerable contamination with *CF* from 3 to 6 for Fe and Mn. Other studied elements, namely Cu and Pb, showed very high contamination with *CF* > 6. Additionally, with a mean value of 11.79, the *CF* for Cu varied greatly across the study area, and it was the largest among all the studied elements.

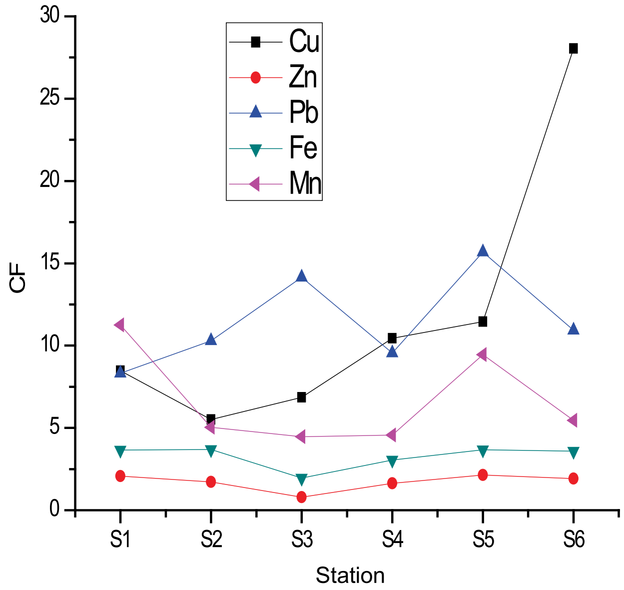

Fig. 3. Contamination factor (*CF*) of heavy metals in lake water in investigated stations; source: own study

HEAVY METAL RISK CHARACTERISATION IN LAKE SIDI BOUGHABA

The potential ecological hazard index was developed by Hakanson [1980], who coordinated the concentration of heavy metals with ecological impact, environmental impact, toxicology, and it was utilised to evaluate the substantial metal contamination and environmental danger. The ecological risk posed by heavy metals in the water of Lake Sidi Boughaba was calculated by applying Equation (4). Spatial distribution of potential ecological risk (Er^i) is shown in Figure 4. It was discovered that the single risk indices (Er^i) for substantial metals could be grouped in the order of Zn < Fe < Mn < Pb < Cu. The normal biological danger for Cu in the considered territory was 58.97; it showed that Cu represented a direct hazard to nearby environments.

In order to quantify the overall potential ecological risk of heavy metals in water, the values of *ER* and *RI* were shown in Figure 4. The values in six sampling sites ranged from 89.85 to 205.86, with an average of 128.09. The lower and the higher *RI* values were observed at site 2 and site 6, respectively. The high *RI* values recorded are reflected in the presence of high levels of the metallic trace elements studied. In 33.33% of the sampling sites, the five heavy metals posed moderate risk, 50% posed low risk, and 16.66% considerable risk.

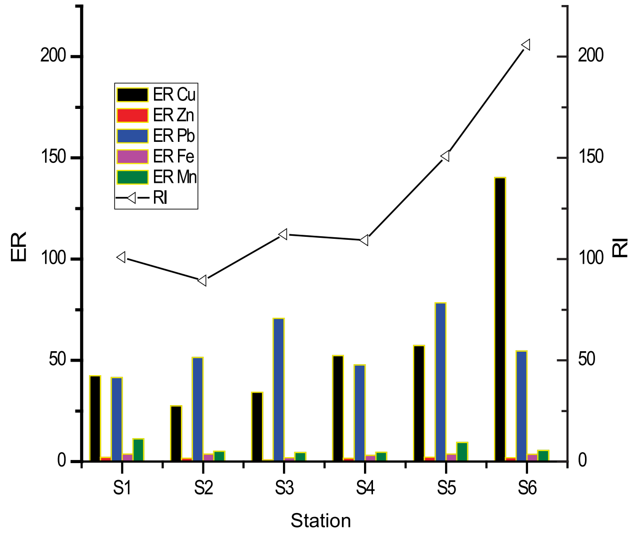

Fig. 4. The distribution of potential ecological risk (*ER*) and total ecological risk (*RI*) in water at investigated stations; source: own study

CONCLUSIONS

The results of the study show that the levels of metallic trace elements in the waters of Lake Sidi Boughaba present a high risk for aquatic life. Based on various recommendations for water quality, it is revealed that almost all of the elements studied exceed standard values, which signify moderate to frequent threats.

The study of contamination and ecological risk expressed by the contamination factor (*CF*), metal pollution index (*MPI*), pollution load index (*PLI*) and total ecological risk index (*RI*) revealed a remarkable effect, an abnormal contamination and a serious ecological risk. However, lead and copper are the most polluting elements at the lake level with a very high potential ecological risk.

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