***Review Article***

**Assessment of heavy metal pollution in Taihu Lake: a review**

**Abstract**

Heavy metal contamination and its associated risks in aquatic environments is a worldwide issue. This paper examined the available literature concerning the levels and trends of heavy metals in the water, sediment, and biota of Taihu Lake. It also assessed the extent of pollution and the potential human and ecological risks associated with the frequently detected heavy metals in the sediment and fish. Nineteen trace metals (Al, As, Cd, Ce, Co, Cr, Cu, Fe, Hg, La, Mn, Ni, Pb, Sb, Se, Sn, Sr, V and Zn) have been detected within Taihu Lake's water, sediment, and biota. The main source of these metals is from the anthropogenic activities occurring in the area surrounding the lake. When compared to other areas of the lake, the northern portion is extremely polluted due to the massive anthropogenic activities in the developed cities nearby. The sediment of Taihu Lake is classified as toxic according to the mean PEC quotients of As, Pb, Cr, Zn, Cu, Hg and Ni. The sediment in Taihu Lake is classified as heavily polluted according to the results from the modified degree of contamination and the Nemerow pollution index. Additionally, the potential ecological risk index indicates that organisms in Taihu Lake are at high risk. More studies are required to compare and also corroborate whether the recent decrease in the absolute values of some of the heavy metals is due to the good management practices adopted lately.

**Keywords**: Heavy metals; Human and Ecological Risk Assessment; Review; Taihu Lake.

1. **INTRODUCTION**

The phrase "heavy metals" has been used extensively in scientific literature during the past few decades to refer to an assemblage of metals and semimetals (metalloids) (Duffus, 2009). Generally, trace elements can be classified into two categories: non-essential elements, such as mercury (Hg), arsenic (As), cadmium (Cd), and lead (Pb), and essential elements, including zinc (Zn), iron (Fe), manganese (Mn), and chromium (Cr) (Fraga, 2005). Prolonged exposure to non-essential trace elements, even at low concentrations, is detrimental to organisms (Zheng *et al.*, 2011).

In recent years, the primary drivers of global change have transitioned from natural to human factors, with the latter significantly impacting the environment (Lewis and Maslin, 2015). The sources of heavy metals in aquatic environments can be categorized into natural sources, such as rock weathering, runoff, and riverbank erosion, and anthropogenic sources, including industrial and wastewater discharges, agricultural activities, liquid waste disposal, mining, damming, and transportation (Mucha, Vasconcelos and Bordalo, 2003; Pekey *et al.*, 2004; Zhu *et al.*, 2011). Anthropogenic heavy metals differ from the lithogenic types, they are extremely mobile and more bioavailable, hence more probable to adversely affect organisms in the aquatic environment (Tessier and Campbell, 1987). Due to the rapid population growth coupled with intensive domestic activities as well as a rise in industrialisation and agricultural production, heavy metals are continuously released into the aquatic environment where they persist, bioaccumulate and can be incorporated into the food chain (Tessier and Campbell, 1987; Bodin *et al.*, 2013; Bastami *et al.*, 2014). Heavy metals that are discharged from human activities into the aquatic environment are first absorbed by the suspended sediment before they are precipitated to form part of the surface sediment. The part that is absorbed by the sediment can be re-suspended and consequently released into the overlying water depending on the physical, chemical and biological factors that are involved in their desorption from the sediment (Hill, Simpson and Johnston, 2013; Fang *et al.*, 2016). Therefore, the sediment is mostly considered as an eventual receptor of pollutants as well as a potential secondary contamination source in the overlying water (Bermejo, Beltrán and Ariza, 2003). Consequently, sediment is largely viewed as the ultimate receiver of pollutants and a potential secondary source of contamination for the overlying water (Bermejo, Beltrán and Ariza, 2003). Evaluating the presence and distribution of heavy metals in water, sediment, and biota is crucial for examining the human impact on the aquatic environment and the risks associated with human activities (Bermejo, Beltrán and Ariza, 2003). To manage heavy metals in the aquatic environment, it is crucial to understand their sources, distribution, and potential ecological risks. The chemical speciation of heavy metals can be ascertained via sequential extraction procedures, which can provide important details on the elements' mobility, bioavailability, and toxicity (Tessier and Campbell, 1987; Simpson and Spadaro, 2016). However, complexities that are encountered during their performance in the laboratory entrammel their general application. As a result, total metal concentration is commonly utilized in evaluating the status of heavy metal pollution, as well as the potential ecological and human health risks (Duodu, Goonetilleke and Ayoko, 2016; Lin *et al.*, 2016; Villanueva and Ibarra, 2016).

A large number of single- as well as multi-element methods, have been developed to assess heavy metal contamination and risk in the aquatic environment. Notably among them are the mean PEC quotients$ (QmPEC$ ), contamination factor $\left(C\_{f}^{i}\right),$ geo accumulation index$ (I\_{geo}$), modified degree of contamination ($mCd$), Nemerow pollution index ($nPi$), ecological risk factor ($E\_{r}^{i}$), Potential ecological risk index ($ R\_{i}$), target hazard quotient ($THQ$) among others.

Taihu Lake, the largest shallow freshwater lake, is located in the Changjiang Yangtze River Delta in eastern China. It spans a surface area of 2,250 square kilometers and has a volume of 4.4 billion cubic meters, borders Shanghai city, Jiangsu, Zhejiang, and Anhui provinces (Pu and Yan, 1998; Qin *et al.*, 2007; Zhao *et al.*, 2009). The lake's mean depth is 1.94 meters.. The region of Taihu Lake is among the most economically developed regions in China. The region has the highest population density, more than 1000 persons per kilometre square and an area of 36900 km2. The region is mostly covered with rivers with a total length of 1.2×105 km. These rivers play very essential roles in the region’s economic and also social development (Jiao *et al.*, 2010). In addition to providing drinking water for roughly 10 million indigenous people, it is used for recreation, transportation, fishing, flood control, biodiversity preservation, industry water supply, agricultural irrigation, and aquaculture. For instance, Taihu lake provides the indigenes with about 3×106 cubic metre of drinking water every year and water to irrigate about 73000 hectares of land, with about 25×108 cubic metre of water every year (Rajeshkumar *et al.*, 2018). The fastest and highest urbanization rate in the Taihu basin has led to a series of negative changes to the river systems such as flood disasters, water degradation as well as other ecological and environmental issues (Deng *et al.*, 2015). In May 2007, a significant instance of these adverse effects was observed when cyanobacterial blooms deprived nearly 4 million residents of Wuxi, an industrial city in the Taihu basin (Fig. 1), of drinking water for almost seven days (Guo, 2007; Yang *et al.*, 2008).

This paper's objectives were to: (1) review what is currently known about Taihu Lake's heavy metal concentrations and trends; (2) assess the extent of pollution as well as the potential ecological and human health risk related to the heavy metals.



**Figure 1** Taihu Lake catchment map

**2.0 RISK ASSESSMENT METHODS**

**2.1 Mean probable effect concentration quotient**

The toxicity of the sediments in Taihu Lake was predicted using the mean PEC quotient$ (QmPEC$ ), which was created by Macdonald, (2000) in the consensus-based Sediment Quality Guidelines (SQGs) technique. It was calculated as given below

$QmPEC=\sum\_{}^{}\frac{C\_{o}^{i} }{PEC\_{n}}$ $ $ (1)

where $C\_{o}^{i}$ represents the mean concentration of heavy metals in the sediment of Taihu Lake, as derived in literature (Table 2), and $PEC\_{n}$ corresponds to the respective PEC values. As, Cd, Pb, Cr, Ni, Cu, and Hg present in the sediment had benchmark PEC values of 33, 4.98, 128, 111, 459, 48.6, 149, and 1.06 mg/kg, respectively. Sediment $QmPEC$ < 0.5 is classified as non-toxic while $QmPEC$ > 0.5 is classified as toxic.

**2.2 Contamination factor**

The contamination factor $(C\_{f}^{i})$ was calculated using the equation developed by Hakanson (1980).

$C\_{f}^{i}=\frac{C\_{o}^{i}}{C\_{n}^{i}}$ (2)

where $C\_{f}^{i}$ represents the contamination factor, $C\_{o}^{i} $ indicates the mean concentration of each heavy metal, and $ C\_{n}^{i}$ signifies their background concentrations (with values of As 15, Cd 0.5, Pb 25, Cr 60, Zn 80, Cu 30, and Hg 0.25 mg/kg) (Hilton, Davison and Ochsenbein, 1985). $C\_{f}^{i}$ <1 means low contamination; 1 ≤ $C\_{f}^{i}$<3 means moderate contamination; 3 ≤ $C\_{f}^{i}$< 6 means considerable contamination and 6 ≤ $C\_{f}^{i}$ means very high contamination.

**2.3 Modified degree of contamination**

Modified degree of contamination ($mCd$) is a more expedient method for evaluating the asperity of contamination at a site. Unlike other single factor element indices, $mCd$ provides an advantage by considering the cumulative effects of multiple contaminants in the area (Brady *et al.*, 2015). The $mCd$ was calculated as:

$mCd=\frac{1}{n}\sum\_{i=1}^{n}C\_{f}^{i}$ (3)

where $mCd$ is the modified degree of contamination,$ C\_{f}^{i}$ is the contamination factor. The classification for the modified degree of contamination is as follows: < 1.5 means unpolluted; 1.5 ≤$ mCd $<2 means slightly polluted; 2 ≤$ mCd $< 4 means moderately polluted; 4 ≤$ mCd $< 8 means moderately to heavily polluted; 8 ≤$ mCd $< 16 means heavily polluted; 16 ≤$ mCd $< 32 means severely polluted and ≥ 32 means extremely polluted.

**2.4 Nemerow pollution index**

The Nemerow pollution index ($nPi$) serves as a tool to assess heavy metal pollution at a specific location (Duodu, Goonetilleke and Ayoko, 2016) and reveals the overall impact of heavy metals (Yan *et al.*, 2016). The calculation of the Nemerow pollution index ($nPi$) was done as follows:

$nPi=\sqrt{\frac{(C\_{fm}^{i})^{2}+ (C\_{fmax}^{i})^{2}}{2}}$ (4)

where $nPi$ stands for the Nemerow pollution index, $C\_{fm}^{i}$represents the arithmetic mean of the contamination factor for all heavy metals, and$C\_{fmax}^{i}$ signifies the highest contamination factor among the heavy metalsThe classification for the Nemerow pollution index is as follows: < 1 is unpolluted; 1 ≤ $nPi$ < 2.5 is slightly polluted; 2.5 ≤ $nPi$ < 7 is moderately polluted and ≥ 7 is heavily polluted.

**2.5 Geo accumulation index**

The geo-accumulation index was calculated using the equation developed by Muller (1969).

$I\_{geo}=log\_{2}\left(\frac{C\_{0}^{i}}{K×C\_{0}^{i}}\right) $ (5)

where, $I\_{geo}$ is the geo accumulation index, $K$ is the background matrix correction factor ($K$ = 1.5),$ log\_{2}$ is the logarithm to the base of 2 and the rest mean the same as in Eq. 2. The background values of Chinese continental crust (As 1.9, Cd 0.055, Pb 15, Cr 55, Zn 86, Cu 38 and Hg 0.08 mg/kg) (Tong, 1995) were used. $I\_{geo}$< 0, means unpolluted; 0-1, means unpolluted to moderately polluted; 1-2, means moderately polluted; 2-3, means moderately to strongly polluted; 3-4, means strongly polluted; 4-5, means strongly to very strongly polluted; > 5, means very strongly polluted.

**2.6 Ecological risk factor and potential ecological risk index**

The ecological risk factor for the individual metals as well as the potential ecological risk index for all the metals under consideration were calculated according to Eq. 6 and 7 (Hakanson, 1980).

$E\_{r}^{i}=T\_{r}^{i}C\_{f}^{i}$ (6)

 $R\_{i}=\sum\_{}^{}E\_{r}^{i}$ (7)

where, $E\_{r}^{i}$ is the ecological risk factor for each heavy metal, $T\_{r}^{i} $denonotes the toxic response factor of each metal [As 10, Cd 30, Pb 5, Cr 2, Zn 1, Cu 5 and Hg 40 (Fu *et al.*, 2013) ] and$ R\_{i}$ is the Potential ecological risk index for all the heavy metals. $E\_{r}^{i}$< 40, represent low risk; 40-80, represent moderate risk; 80-160, represent considerable risk; 160-320, represent high risk and > 320, represents very high risk. Also, $ R\_{i}$< 110, 110 ≤ $R\_{i} $< 200, 200 ≤ $R\_{i} $< 400 and ≥ 400 represents low, moderate, considerable, severe ecological risk respectively.

**2.7 Target hazard quotients**

The danger of heavy metals on human health linked with eating fish from Taihu Lake was evaluated using the target hazard quotient ($THQ$) approach. The following equations were used in the calculations:

$EDI=\frac{C\_{o}^{i}×DC}{1000×BW}$ (8)

$THQ=\frac{EDI}{RfD}$ (9)

where $C\_{o}^{i}$ denotes the mean heavy metal concentration in fish, $DC$ signifies the daily fish consumption (0.071 kg/day/person) (Food and Agricultural Organization (FAO), 2008), $BW$ is the average adult body weight in China (58.1 kg) (Gu *et al.*, 2006) and $RfD$ is the oral reference dose, table 3 (USEPA, 2013).

**3.0 OCCURRENCE AND VARIATION OF HEAVY METALS IN WATER, SEDIMENT AND BIOTA OF TAIHU LAKE**

 Nineteen heavy metals have been detected at least once in the water, sediment as well as biota of Taihu Lake. They include Al, As, Cd, Ce, Co, Cr, Cu, Fe, Hg, La, Mn, Ni, Pb, Sb, Se, Sn, Sr, V and Zn. The sources of these metals are mainly anthropogenically emanating from the discharge of untreated industrial as well as domestic solid and wastewater due to rapid urbanization and industrialization currently and in the past.

**Table 1**. Heavy metals in water (µg/l), sediment (mg/kg dry weight) and biota (mg/kg dry weight) of Taihu Lake.

|  |  |  |  |
| --- | --- | --- | --- |
| Metal  | Range in water | Range in sediment  | Range in Biota  |
| Hg | - | 0.01-1.22 | 0.037-0.32 |
| As | 1.16-12.03 | 6-64 | 0.04-3.99 |
| Cd | 0.031-2.97 | 0.027-3.61 | 0.003-1.76 |
| Pb | 0.95-55.4 | 5.508-320 | 0.035-27.18 |
| Cr | 0.27-97.71 | 9.35-464.9 | 0.285-3.94 |
| Zn | 2.49-367.1 | 24-7390 | 10.1-907 |
| Mn | 0.01-7.53 | 232.7-1133.5 | 0.515-17.1 |
| Ni | 0.28-50.39 | 4.28-114.9 | 1.89-6.35 |
| Cu | 0.96-78.29 | 12.6-5470 | 1.06-83.88 |
| Fe | - | 176.96-84000 | 7.55-92.2 |
| Sb | 1.170-10.40 | 1.21-2.14 | - |

Specifically, Zn and Cd are believed to come from the use of additives by local factories that manufacture synthetic rubber and PVC materials in Changzhou and Zn is also related to electroplating processes. Cr was also specifically linked with the manufacture of leather by the locals whiles the concentration of Sn was attributed to a natural source (Mucha, Vasconcelos and Bordalo, 2003).

Furthermore, Taihu Lake's sediment was the only place where Ce, La, Co, V, and Se were detected Their concentration ranges in the sediment are 58.8-72.6 mg/kg, 34.8-39.5 mg/kg, 7.5-26.4 mg/kg, 66.7-139.2 mg/kg and 0.16-1.17 mg/kg dry weight respectively (Wang *et al.*, 2003; Yuan *et al.*, 2011; Liu *et al.*, 2012; Wei and Wen, 2012; Ohore *et al.*, 2019). The concentration of Co and Se were comparable to what was found in China by other researchers (Li *et al.*, 2008; Li and Zhang, 2010b, 2010a). The concentration of Co was comparable to what was detected at the global level (Szymanowska, Samecka-Cymerman and Kempers, 1999; Karadede and Ünlü, 2000; Klavinš *et al.*, 2000; Chandra Sekhar *et al.*, 2004; Pekey, Karakaş and Bakoglu, 2004; Nguyen *et al.*, 2005; Krishna, Satyanarayanan and Govil, 2009). Sn, Sr and Al were only detected once in Taihu Lake's sediment and water with concentration ranges of 0.030-1.230 µg/l and 53.7-141 mg/kg and 11.6-83.2 mg/g, respectively (Yuan *et al.*, 2011; Tao *et al.*, 2012).

**Figure 2** Concentration of Heavy metals in some fish species in Taihu Lake

The heavy metal concentrations varied in the water, sediment as well as biota of Taihu Lake. The sequence of the frequently detected heavy metals in the water, sediment and biota are Zn > Cu >Ni> As >Cr > Pb > Cd, Zn > Cu > Cr > Pb > Ni >As > Cd > Hg and Zn > Cu > Pb > As > Cr > Cd > Hg respectively. Evidently, Zn and Cu are the most abundant heavy metals in Taihu Lake. This trend has not changed as a recent study carried out in Gonghu bay of Taihu Lake obtained a similar trend of heavy metal concentration Zn > Cu > Pb > As > Mn in the water (Ding *et al.*, 2020). Nevertheless, the absolute values of some heavy metals in the lake have decreased. For instance, the mean concentration of Cr, Cu and Pb in the sediment have decreased from 462, 68.9 and 75.3 in the year 2000 (Wang *et al.*, 2003) to 27.72, 41.5 and 41.17 in 2010 (Tao *et al.*, 2012), and further to 7.19, 13.99 and 8.53 in 2016 (Rajeshkumar *et al.*, 2018), respectively. Again, the mean concentration of Cu, Cr, Cd and Pb [10.07, 6.18, 0.93 and 11.62 µg/L, sampled in 2010 (Jiang *et al.*, 2012)] in the water have decreased to [1.6, 2.84, 0.74 and 6 µg/L, sampled in 2016 (Rajeshkumar *et al.*, 2018)]. Also, in the same study, the mean concentration of the heavy metals in the sediment (Cu, Cr, Cd and Pb) have decreased from (27.72, 41.5, 0.82 and 41.17 mg/kg) to (7.19, 13.99, 0.50 and 8.53 mg/kg), respectively. These decreases in the heavy metal concentrations may be ascribed to the stringent and good environmental management practices that have been adopted recently such as the closure of heavily polluting industries around the Lake and regular dredging. The decrease in some heavy metal concentrations obtained herein is consistent with what previous researchers obtained in the sediments of Lakes from 1970 to 2018 across the globe (Niu *et al.*, 2021).

However, this trend was not clear in the other heavy metals and fish because different heavy metals, as well as fish species, were detected at different sampling times. Seasonal variation of the heavy metals in Taihu Lake has not been dealt with much, only a recent study tried to address it. In that study, the concentration of the detected heavy metals (Cu, Cr, Cd and Pb) in both the water and sediment were generally higher in winter than the other seasons (spring, summer and autumn). This can be attributed to the high anthropogenic activities in winter than the other seasons. The comparisons of the frequently detected heavy metals in the sediment of Taihu Lake with other lakes in China as well as the world are given in table 2.

 The heavy metals were spatially distributed in the Lake. In most cases, the concentrations of the heavy metals were higher in the northern part especially Zhushan bay and lower at the southern and eastern parts. Also, the general concentration trend of the metals in the sediment was high at the north, northwest and western parts of the lake especially Zhushan bay and lower at the southern part. The high concentration of the metals both in the water and sediment at the northern part especially Zhushan bay can be imputed to the inputs from rivers. The levels of the heavy metals in the sediment were higher than in the water. Since the lake is shallow, wind wave action coupled with other factors may induce the metals to re-suspend and this could serve as a source of internal pollution in the Lake.

**Table 2.** Comparison of heavy metal concentration in the sediment (mg/kg) of Taihu Lake with other Lakes

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Lake location | As | Cd | Pb | Cr | Zn | Cu | Hg | Ni | References |
| ***Taihu Lake*** | ***21.9*** | ***1.33*** | ***63.9*** | ***147.5*** | ***679*** | ***462*** | ***0.17*** | ***48.7*** | ***This study***  |
| Lake Caizi | 40.98 | 0.53 | 33.13 | 92.68 | 105.47 | 22.86 | 0.05 | - | (Jiang *et al.*, 2018) |
| Chagan Lake | 6.6 | 0.084 | 20.4 | 38 | 40 | 14.5 | 0.018 | 16.8 | (Cheng *et al.*, 2015) |
| Chaohu Lake | 3.6 | 0.109 | 20.9 | 54 | 53 | 17.8 | 0.035 | 20.8 | (Cheng *et al.*, 2015) |
| Dalonghu Lake | 5.4 | 0.085 | 19.1 | 23 | 26 | 9.7 | 0.014 | 10.4 | (Cheng *et al.*, 2015) |
| Dongting Lake | 14.4 | 0.501 | 39 | 102 | 127 | 53.9 | 0.092 | 48.2 | (Cheng *et al.*, 2015) |
| Fuxian Lake | 9.2 | 0.49 | 34.8 | 109 | 99 | 59.6 | 0.054 | 39.8 | (Cheng *et al.*, 2015) |
| Gaoyou Lake | 14.6 | 0.17 | 31.6 | 94 | 97 | 35.9 | 0.04 | 51.5 | (Cheng *et al.*, 2015) |
| Honghu Lake | 11.4 | 0.301 | 33.1 | 104 | 110 | 44.4 | 0.071 | 49.6 | (Cheng *et al.*, 2015) |
| Hongze Lake | 15.2 | 0.16 | 28.9 | 90 | 86 | 34 | 0.033 | 48.2 | (Cheng *et al.*, 2015) |
| Liangzi Lake | 16.4 | 0.3 | 35.6 | 91 | 92 | 37.5 | 0.084 | 34.2 | (Cheng *et al.*, 2015) |
| Lianhuan Lake | 4.6 | 0.053 | 19 | 18 | 22 | 5.9 | 0.01 | 6.8 | (Cheng *et al.*, 2015) |
| Nansi Lake | 17.6 | 0.233 | 29.3 | 88 | 91 | 37.8 | 0.046 | 39.7 | (Cheng *et al.*, 2015) |
| Poyang Lake | 12.1 | 0.238 | 42.3 | 63 | 100 | 27.7 | 0.076 | 26.1 | (Cheng *et al.*, 2015) |
| Qilu Lake | 12.1 | 0.851 | 42.9 | 164 | 153 | 64.9 | 0.142 | 65.4 | (Cheng *et al.*, 2015) |
| Ulansuhai Lake | 8.7 | 0.141 | 21 | 65 | 71 | 24.2 | 0.028 | 28.9 | (Cheng *et al.*, 2015) |
| Wanghua Lake | 9.8 | 0.102 | 17.9 | 50 | 51 | 19 | 0.014 | 23.6 | (Cheng *et al.*, 2015) |
| Xingyun Lake | 11.5 | 0.6 | 78.2 | 86 | 121 | 68.4 | 0.111 | 41.6 | (Cheng *et al.*, 2015) |
| Yangzonghai Lake | 11.4 | 0.683 | 32 | 115 | 113 | 96.7 | 0.065 | 50.6 | (Cheng *et al.*, 2015) |
| Dianchi lake | - | - | 65.76 | 115.18 | 154 | 90.05 | 0.25 | 45.97 | (Wei and Wen, 2012) |
| Songhua Lake | - | - | - | 42.3 | 87.7 | 16.7 | - | 17.6 | (Hao *et al.*, 2013) |
| Baiyangdian Lake | - | - | - | 64.0 | 62.5 | 25.5 | - | 29.2 | (Gao *et al.*, 2015) |
| Erhai lake | 26.9 | 1.1 | 47.4 | 103.8 | 109 | 63.1 | - | 52.2 | (Lin *et al.*, 2016) |
| Longjiang lake | 11.33 | 0.35 | 22.09 | 46.87 | 72.06 | 21.47 | - | 27.44 | (Liu *et al.*, 2018) |
| Hulun lake | - | 0.09 | 20.87 | 31.37 | 48.43 | 16.17 | - | 15.61 | (Guo *et al.*, 2015) |
| Huoshaohei lake | 5.09 | 0.23 | 18.99 | 25.86 | 47.51 | 9.30 | - | 12.98 | (Liu *et al.*, 2018) |
| Xingkai lake | - | 0.14 | 21.63 | 75.95 | 60.35 | 19.65 | - | 25.35 | (Guo *et al.*, 2015) |
| Jingbo lake | - | 0.26 | 28.98 | 90.78 | 126.25 | 32.45 | - | 47.40 | (Guo *et al.*, 2015) |
| Wudalianchi lake | - | 0.16 | 24.70 | 92.07 | 82.73 | 32.28 | - | 38.35 | (Guo *et al.*, 2015) |
| Keqin lake | 6.51 | 0.19 | 17.85 | 24.48 | 39.76 | 10.36 | - | 13.98 | (Liu *et al.*, 2018) |
| Hongyan lak | 8.36 | 0.20 | 20.83 | 41.47 | 65.05 | 17.73 | - | 22.37 | (Liu *et al.*, 2018) |
| Qijiapao lake | 6.24 | 0.21 | 18.21 | 33.35 | 52.67 | 12.50 | - | 16.79 | (Liu *et al.*, 2018) |
| Xiaolonghupao lake | 8.01 | 0.28 | 21.50 | 45.11 | 79.69 | 19.36 | - | 24.43 | (Liu *et al.*, 2018) |
| Dalonghupao lake | 7.98 | 0.23 | 22.35 | 39.27 | 69.47 | 15.14 | - | 20.82 | (Liu *et al.*, 2018) |
| Nanshan lake | 5.74 | 0.27 | 20.43 | 31.65 | 56.30 | 12.70 | - | 14.60 | (Liu *et al.*, 2018) |
| Xihulu lake | 7.09 | 0.33 | 24.22 | 43.80 | 75.47 | 16.76 | - | 22.83 | (Liu *et al.*, 2018) |
| Talahong lake | 6.23 | 0.24 | 20.13 | 33.85 | 54.31 | 13.87 | - | 16.46 | (Liu *et al.*, 2018) |
| Amuta lake | 5.10 | 0.27 | 20.12 | 26.65 | 50.63 | 9.72 | - | 13.95 | (Liu *et al.*, 2018) |
|  |  |  |  |  |  |  |  |  |  |
| Hope Lake, USA | - | 0.52 | 21.6 | 48.4 | 129 | 22.5 | - | 39.55 | (López, Gierlowski-Kordesch and Hollenkamp, 2010) |
| Vembanad Lake, India | - | 1.9 | 35.3 | 110.7 | 208.8 | 31.50 |  | 48.2 | (Selvam *et al.*, 2012) |
| Kalimanci Lake, Macedonia | - | 56.58 | 6059 | - | 8420 | 415.1 | - | 45 | (Vrhovnik *et al.*, 2013) |
| Maharlu Lake, Iran | - | 4.7 | 135.4 | 127.2 | 52.1 | 61.3 | - | 135.2 | (Forghani, Moore and Qishlaqi, 2012) |
| Bafa Lake in Germany | - | - | 20 | 90 | 95 | 45 | 0.4 | 68 | (Yilgor, Kucuksezgin and Ozel, 2012) |
| Kapulukaya Dam Lake, Turkey | - | 0.98 | 19.51 | 32.7 | 43.65 | 17.5 | - | 81.28 | (Kankılıç, Tüzün and Kadıoğlu, 2013) |
| Lake Koronia, Greece | - | - | - | 394.36 | 86 | 17 | - | - | (Fytianos and Lourantou, 2004) |
| Nasser Lake, Egypt | - | - | - | 79 | 143 | 109 | - | 122 | (Rashed, 2001) |
| Lake Victoria, Tanzania | - | 2.5 | 37.7 | 11 | 36.4 | 21.6 | 0.1 | - | (Kishe and Machiwa, 2003) |
| Lake Balaton, Hungary | - | 0.43 | 43 | 20 | 73 | 17 | - | 33 | (Nguyen *et al.*, 2005) |
| Selected Lakes, Poland | - | 3.3 | 64 | 165 | 131 | 18.6 | - | 6.5 | (Samecka-Cymerman and Kempers, 2001) |
| Rawal lake, Pakistan | - | 0.42 | 0.69 | 1.69 | 58.57 | 0.17 | - | 28.42 | (Zahra *et al.*, 2014) |
| Lake Kariba, Zambia | - | 0.08 | 14 | 64 | 49 | 30 | - | 53 | (Nakayama *et al.*, 2010) |
| Lake Baringo, Kenya | - | 0.76 | 20.62 | 2.17 | 193.6 | 18.45 | - | 39.72 | (Ochieng, Lalah and Wandiga, 2007) |
| Lake Chini, Malaysia | - | 2.22 | 30.64 | - | 96.85 | 8.84 | - | - | (Ahmad and Shuhaimi-Othman, 2010) |
| Norwegian Lakes, Norway |  | 0.86 | 99.4 | 26.5 | 131 | 40.4 | 0.26 | 18 | (Rognerud and Fjeld, 2001) |
| Lake Macquarie, Australia | - | 2.1 | - | - | 152 | 36 | - | - | (Ikem, Egiebor and Nyavor, 2003) |
| Lake Texoma, USA | 11 | 2 | 10 | 30 | 89 | 38 | - | 17 | (An and Kampbell, 2003) |

**ECOLOGICAL AND HUMAN HEALTH RISK ASSESSMENT OF HEAVY METALS**

The extent of pollution in addition to the ecological and human health risk circumstantial with As, Cd, Pb, Cr, Zn, Cu, Ni and Hg which were the frequently detected heavy metals in the sediment as well as fish of Taihu Lake was assessed in order to get a clear view of the extent of pollution, the ecological and human health risk by employing the following: mean PEC quotient $(QmPEC$), contamination factor $(C\_{f}^{i})$, modified degree of contamination ($mCd$), Nemerow pollution index ($nPi$), geo accumulation index ($I\_{geo}$), ecological risk index ($R\_{i}$) and target hazard quotients ($THQ$). The results of the mean PEC quotient $(QmPEC$) are displayed in Fig. 3, with the exception of Cd and Hg which had values below the red line (< 0.5), the rest of the heavy metals had values above the red line (< 0.5) which means they are toxic to sediment organisms. The heavy metals can be arranged according to the $QmPEC$ as Cu > Zn > Cr > Ni > As > Pb > Cd > Hg.

Results of the contamination factor for each of the heavy metals under consideration are shown in Fig. 3B. It ranged from 0.94 to 15.4 which can be interpreted as low and very high contamination respectively. Cu had the highest contamination factor followed by Zn. With the exception of Hg which was within low contamination, the rest were from moderate to very high contamination. The contamination factor obtained herein is higher than that obtain in the overlying water and sediments of Nkozoa Lake (Southern Cameroon) (Noa Tang *et al.*, 2021). The metals can be arranged in order of decreasing contamination factor as Cu > Zn > Cd > Pb > Cr >As > Hg.

**Figure 3** The mean PEC quotients (A) and contamination factor (B) of the heavy metals in Taihu Lake

The geo-accumulation index was also used to assess the degree of contamination by the heavy metals in the sediment of Taihu Lake and the results are shown in Fig. 4A. The pollution level is from unpolluted (Cr) to strongly polluted (Cd). The heavy metals considered can be arranged according to increasing order of geo-accumulation index as Cr < Hg < Pb < Zn < As < Cu < Cd.

The modified degree of contamination ($mCd$) was valued at 5, indicating moderate to heavy pollution, while the Nemerow pollution index ($nPi$) was valued at 7, indicating heavy pollution.

**Figure 4** The geo-accumulation index (A) and ecological risk factor (B) of the heavy metals in Taihu Lake

The ecological risk factors $(E\_{r}^{i})$ for the individual metals ranged from 5 (low risk) to 77 (moderate risk) Fig 4B. The metals can be arranged in order of increasing $ E\_{r}^{i}$ as Cr < Zn < Pb < As < Hg < Cu < Cd. The potential ecological risk index ($R\_{i}$) for the heavy metals in the sediment of Taihu Lake was 269 and it implies high ecological risk.

Fishes from Taihu Lake are important aquatic products for the indigenes of the Lake basin. The target hazard quotients ($THQ$) for the metals under consideration are shown in Table 3. The estimated maximum daily intake ($EDI$-max) for each of the heavy metals under consideration are less than the oral reference dose $(RfD)$.

**Table 3** Estimated ($THQ$) for the heavy metals from fish consumption in Taihu Lake

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Heavy metal | As | Cd | Pb | Cr | Zn | Cu | Hg |
| $RfD$ (mg/kg/day) | 0.0003 | 0.001 | 0.004 | 0.003 | 0.3 | 0.04 | 0.00016 |
| $EDI$ -mean (mg/kg/day) | 3.97E-06 | 1.41E-06 | 2.02E-05 | 3.16E-06 | 0.00177 | 3.99E-06 | 3.06E-07 |
| $EDI$ -max (mg/kg/day) | 4.62E-06 | 1.93E-06 | 2.92E-05 | 4.81E-06 | 0.00045 | 4.96E-06 | 3.91E-07 |
| $THQ$ -mean | 0.01325 | 0.00141 | 0.00505 | 0.00105 | 0.00059 | 9.99E-05 | 0.00191 |
| $THQ$ -max | 0.01535 | 0.00193 | 0.00729 | 0.00160 | 0.00149 | 0.00019 | 0.00244 |
| % average contribution to $THQ$  | 56.7100 | 6.02217 | 21.6305 | 4.50792 | 2.52958 | 0.42756 | 8.17215 |

Again, the maximum and mean target hazard quotients $(THQ$-max and $THQ$-mean) for the heavy metals are lower than 1.This implies that, people will not experience significant health risk when they consume fish from Taihu Lake.

**4. CONCLUSION**

This study reviewed the available data regarding the concentrations and patterns of heavy metals in Taihu Lake. The level of pollution and the possible harm to the environment and public health that the commonly found heavy metals could cause were also assessed. The majority of the lake's pollution comes from human activities. In comparison with the southern, eastern and the western parts, the northern part is heavily polluted due to the high rate of anthropogenic activities in highly developed cities like Wuxi, Changzhou and Yixing Suzhou. The sediment of Taihu Lake is classified as toxic based on the mean PEC quotients. Also, sediment-dwelling organisms, as well as other organisms in Taihu Lake, are at high risk according to the potential ecological risk index. The absolute values of some heavy metals have decreased recently due to the good environmental management practices that have been put in place. However, more current studies on the frequently detected heavy metals are required to affirm this fact.

**COMPETING INTERESTS DISCLAIMER**:

Author has declared that he has no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

**Disclaimer (Artificial intelligence)**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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