***Review Article***

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

**Abstract**

Heavy metal contamination in aquatic environments is a worldwide issue. Numerous methods have been devised to evaluate the risks associated with exposure to these metals. 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. However, there is no health risk for humans who consume fish from the lake. 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; Taihu Lake; Human and Ecological Risk Assessment; Review.

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 et al. 2003; Pekey et al. 2004a; 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 et al. 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 et al. 2003). Consequently, sediment is largely viewed as the ultimate receiver of pollutants and a potential secondary source of contamination for the overlying water (Bermejo et al. 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 et al. 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 et al. 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 et al. 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 et al. 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 et al. 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 2010a, b). The concentration of Co was comparable to what was detected at the global level (Szymanowska et al. 1999; Karadede and Ünlü 2000; Klavinš et al. 2000; Chandra Sekhar et al. 2004; Pekey et al. 2004b; Nguyen et al. 2005; Krishna et al. 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. 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 et al. 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 et al. 2012) |
| Bafa Lake in Germany | - | - | 20 | 90 | 95 | 45 | 0.4 | 68 | (Yilgor et al. 2012) |
| Kapulukaya Dam Lake, Turkey | - | 0.98 | 19.51 | 32.7 | 43.65 | 17.5 | - | 81.28 | (Kankılıç et al. 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 et al. 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 et al. 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 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. However, there is no health risk for humans who consume fish from Taihu Lake. 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.

**Conflict of interests**

The author declares no conflicts of interest

**COMPETING INTERESTS DISCLAIMER**:

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

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