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Research Article

Seasonal Variation of Mercury (Hg) in Fish Species, Water and Sediment from the Meiliang Bay of Taihu Lake, China

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Abstract

Mercury concentrations were determined in water, sediment and fish from the Meiliang Bay of Taihu Lake, China, during June (summer) and December (winter) in 2016. The mercury concentrations were higher in the water sample in June, whereas in sediment they were lower in December season. Similarly, the trend of mercury concentration found in the fishes in the mean concentration were in decreasing order *Carassius carassius*, *Cyprinus carpio* and *Pelteobagrus fulvidraco*, respectively ($p<0.01$). The tissues captured during June accumulated a higher significant different amount of mercury compared to the December, which was attributed to a higher influx of agricultural waste, sewage and sludge by heavy rainfall and floods from the river mouth to the northwest of Meiliang Bay, which must entering from Zhihugang river therefore, it is in fact difficult to utilize information of sediment erosion. In addition, fish tissues of gills, liver, kidney and intestine showed greater accumulation then muscle. This investigation indicated that fish products from the Meiliang Bay of Taihu Lake were still safe for human consumption. The tissues accumulated non-essential metal mercury, which is also found June was high concentrations in both sediment and water, is primarily the results of anthropogenic activities.

Keywords: Mercury; Seasonal variation; Freshwater fishes; Water; Sediment; Taihu Lake

Introduction

Lake Taihu is the third largest freshwater lake in China. Located in the Changjiang (Yangtze) River delta in eastern China, Taihu (meaning "Great Lake" in Chines) is a large shallow (mean depth ~ 2 m) eutrophic lake, with an area of 2338 km^2 and a volume of 4.4 billion m^3 [1]. Approximately 40 million people live in cities and towns within the Taihu watershed. The climate in the Taihu Lake area is controlled by subtropical monsoons, and the water temperature ranges from 1.5-32.5 °C, averaging 17.6 °C between 1991 and 1999 and 18.2 °C during 2005 and 2006 [2]. The lake is a key drinking water source for the local human population (estimated to be ~10 million), with tourism, fisheries, and shipping being additionally important economic functions [3]. A large volume of waste water id discharged directly through the mouths of rivers entering Taihu Lake without treatment, which results in severe water pollution [4]. Meiliang Bay is one of the most eutrophied bays in the northern part of Taihu Lake [5], Dramatic increases in nutrient loading, resulting from urban and agricultural development in its watershed have fueled accelerated eutrophication [6], characterized by increasingly severe, toxin producing cyanobacterial blooms during summer months [7,8]. Such blooms can affect the drinking water supply [9]. This symptom of eutrophication represents one of the greatest threats to the quality, safety, ecological integrity and sustainability of our water resources worldwide [10-12]. Lakes may serve as the main sink of anthropogenic pollutants from terrestrial ecosystems. Mercury produced by human activities is indirectly or directly transported into lakes in particulars and/or dissolved states. Generally, particulate state is the mail form of the mercury in the freshwater bodies. Mercury can also be transported in the particulate form and settled in sediment. Moreover, the mercury contents in suspended solids (SS) are generally several times higher than those of bottom sediments, and are hundred times higher than those of dissolved state in the water body [13,14]. With climate change all over the world, many studies on the influence of rainfall and runoff on reservoirs and lakes have been reported [15]. Mercury has become of increasing concern because of its toxicity, non-biodegradable and persistent nature, and the bio-enrichment ability in food chain [16]. In our daily life, we are all exposed to some forms of mercury through the air we inhale, the water we drink and the food we eat [17]. The signal of mercury pollution has been found worldwide in various archives such as sediments, peat bogs and glacier ice. Among these archives, a great number of studies have indicated that mercury in sediments plays a critical role in the cycle of mercury in aquatic ecosystem [18]. Mercury discharged from anthropogenic sources may accumulate in bottom sediments as the suspended particles on which they are adsorbed settle out [19]. On the other hand, coagulation, flocculation and co-precipitation can also cause removal of mercury from the water column to sediment due to changes in pH of waters during estuarine mixing [20]. As estimated by [21], the total mercury concentrations in surface sediments fluctuate from 0.02 to 0.4 mg/kg in uncontaminated or less contaminated rivers, and can be as high as100 mg/kg in urban, industrial or mining areas. As the major sink for mercury in aquatic systems, sediments have been suggested as more significant tools for the better understanding of mercury pollution status than the analysis of the overlying water column as a

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result of discontinuity and fluctuation in water flows [22].

Because of mercury has been listed as one of the priority pollutants by many international agencies [23], such as United Nations Environment Programme, World Health Organization and Food and Agriculture Organization of the United Nations. Many previous studies have shown the contributions of mining and smelting activities to the concentration of mercury in ecosystems [24,25]. Chinese researchers have also conducted several investigations on mercury enrichment characteristics in fluvial, lacustrine and estuarine sediments [26,27] investigated the surface sediment in the north part of the Taihu Lake and reported that the mercury concentration was between 0.034 and 0.046 mg/kg. Whereas, and [28,29] studied surface sediment from more than 20 sites in the Taihu Lake and indicated that the concentration of mercury varied between 0.063 and 0.33 mg/kg with a mean value of 0.097 mg/kg, far above the mean earth crust concentration (0.04 mg/kg).

Fishes is an important part of the human diet because of its high nutritional quality [30]. However, non-essential trace elements in the edible tissues of fish have been detected due to the bioaccumulation in organisms and the highly persistent and non-biodegradable properties of these elements [31]. In a freshwater system, fish is usually among the topper consumers. Some of these elements (such as Hg) have been reported to be biomagnified via food chains both in marine and freshwater systems [32]. If the trace element levels are elevated enough, they can pose potential health risks to humans via fish consumption [33]. Many factors, such as environment conditions, contaminant levels, the length of food chains, and the physiochemical properties of contaminants, can influence the trophic transfer behavior of mercury in aquatic biota is complex and needs more field research.

Hg in sediments has correspondingly received more and more worldwide attention. A search on Web of Science using “mercury; sediment” as search phrases will give almost 6000 records in return since 1900. Researchers have studied Hg enrichment in part of rivers, lakes, estuaries and reservoirs throughout China [18,34]. The Taihu Lake is a significant drinking water resource and a typical shallow hyper-eutrophic lake in China. A lot of researches have been carried on the pollution of Taihu lake and its catchment but most of them considers the issue of sediments pollution. Through the research conducted investigation had shown mercury pollution in Taihu Lake was mainly come from the northern part of Meiliang Bay [35]. However, as a large and shallow lake, mercury pollution did not affect the lake uniformly; the seasonal distribution and pollution levels of mercury in Taihu Lake need to be systematically evaluated. Concentrations of total mercury in the range of 0.063-0.99 mg/kg with an average of 0.091 ± 0.19 (n=290) mg/kg were reported in surface sediments from Lake Taihu; the highest concentration was approximately one order of magnitude greater than that in the background lakes [32], Similarly literaturereported that the mercury showed obvious biomagnifications along the food web in the lake, although the bioaccumulation factor of mercury was relatively low compared to that of other aquatic ecosystems [36,37] observed that some heavy metal concentrations a total of 198 samples of 24 fish species from Taihu Lake. The presence of mercury element is evident in Lake Taihu. At present, regulation of pisciculture, dredging, waste disposal and the water diversion project from Changjiang River to Lake Taihu have been used to ease pollution pressure and to meet the water demands of the lower areas of Lake Taihu since 2007[38]. Recently studies have been reported focusing on the seasonal pollution levels of heavy metals contamination in water, sediment, fish and oyster from Meiliang Bay, Taihu Lake 2019. Only a few studies have been conducted to investigate the distribution and diversity of mercury element in the different azimuths of water, sediment and different fish species around the lake. Therefore, in the present study, the main objectives were accumulation and two seasonal pollution of mercury in water, sediment, fish species from in the Meiliang Bay, Taihu Lake.

Materials and Methods

Study area and sampling

We selected seven sampling sites based on pollution sources from different land used types in the Meiliang Bay, Taihu Lake as follows: S1 is located in the north outer bay were believed to be affected by intense levels of anthropogenic activity; S2 were located in the central area of the lake and the reservoirs; S3 drinking water resource area free of nearby factories and other pollution sources; S4-S5 are located in the north of bay former drinking water resource (now area stop); S6 is located in the north of bay usually suffer heavy blooms in summer; and S7 is located near the north of bay where there is less anthropogenic pollution coming from the surrounding land. In recent years, physicochemical problems and heavy metal pollution have increased dramatically due to release of pollutants from sediment and storm runoff, leading to serious water quality problems in Xi’an City, and suffered serious heavy metals contamination due to nonpoint and point source pollution. Two sampling campaigns were conducted from during June when the biomass began to increase, and from during December, 2016.

Water quality parameters

Physico-chemical parameters like temperature, pH and dissolved oxygen (DO) of the lake water were measured. Water samples were collected on spot using water sampler for the detection of physicochemical parameters. Temperature and pH were determined using a microprocessor pH meter (Model No. HI 98139, HANNA Instruments Ltd, Germany). Other parameters like dissolved oxygen (mg/L), Suspended soil (mg/L), Total nitrogen (mg/L), Total phosphate (mg/L), were analyzed on using kits (HANNA Test kits, Hanna Instruments Ltd., Germany).

Heavy metal analysis

Water: Prior to collecting the water samples, borosilicate bottles (125-mL) were cleaned with an alkali detergent, soaked overnight in dilute HNO_3, and heated in a muffle furnace at 450 ºC for at least 4 h; this pretreatment process removed any organic matter and trace mercury that was adsorbed on the vessels. In this, 100 mL of unfiltered water sample were gathered at seven sampling sites at two different seasons from within Meiliang Bay, Taihu Lake. An aliquot of water was filtered through a single use 0.45-lm Polyvinylidene Fluoride (PVDF) membrane (Millipore) with a single-use syringe. After rinsing the borosilicate bottles 3 times with the samples based on the liquid-liquid extraction methods as described by [39]. The mercury concentrations were measured using hydride generation-atomic fluorescence spectrometry HS-55/1 analytic Jena AG, 07745

Jena, Germany.

Sediment: Each sediment sample was placed in a 50-mL centrifuge tube, which was cleaned by acid washing, rinsed with double-deionized water to remove any organic matter, and Hg adsorbed on the vessel. All sample tubes were sealed with Parafilm to avoid cross contamination, transported in an ice-cooled container to the laboratory within 24 hr of collection, and stored in the refrigerator (4°C) until analysis. Lake sediment samples were subjected to acid digestion following (Liang et al. 2004) [40]: 0.1 g of dry weight (dw) sample (accurate to 0.0001 g) was placed inside a 25 mL glass tube covered with a glass ball; 5 mL double-deionized water and 5 mL fresh aquaregia ($HCl+HNO_3$, V/V, 3:1) were added; digested at 95°C in water bath for 5 min. Subsequently, 1 mL Br Cl solution (1.08 g of reagent grade KBr and 1.52 g reagent grade $KBrO_3$ dissolved in 100 mL of low-Hg HCl, accurate to 0.0001 g) was added to oxidation at 95°C in a water bath for 30 min, then the sample was diluted to 25 mL with double-deionized water, and reacted overnight for complete digestion after cooling. Following oxidation, 0.2 mL $NH_2OH{\cdot}HCl$ solution (25 g of reagent grade $NH_2OH{\cdot}HCl$ was dissolved in 100 mL double-deionized water, accurate to 0.0001 g). The final mercury concentration was measured using hydride generation- atomic fluorescence spectrometry HS-55/1 analytic Jena AG, 07745 Jena, Germany.

Fish tissues: *C. carassius, C. carpio and P. fulvidraco* have high market value and are the main fish products in Taihu Lake. Fish samples were bought immediately after they were caught by local fishers. The size of fish we selected was 17-21 cm for all species. Frozen fish samples were thawed at room temperature and dissected using stainless steel scalpels. 0.5 g of accurately weighed epaxial muscle on the dorsal surface of the fish, the entire liver, kidney and intestine and two gill racers from each sample were dissected for analysis. Dissected samples were transferred to Teflon beaker were performed in an acid digestion to prepare the sample for heavy metal analysis (Kenstar closed vessel microwave were digested with 5 mL of nitric acid (65%) and after complete digestion the samples were cooled at room temperature and diluted with Milli-Q water to 25 mL. All the digested samples were analyzed three times for mercury using hydride generation- atomic absorption spectrometry HS-55/1 analytic Jena AG, 07745 Jena and the instrument was calibrated with standard solutions prepared from commercially available chemicals Merck, Germany [41]. The accuracy of the mercury measurements for each analytical batch was determined using three certified reference materials: TORT-2 (Lobster hepatopancreas, National Research Council of Canada); NIST 1566b (Oyster tissue, National Institute of Standards and Technology, USA); NIST 2977 (Mussel tissue, National Institute of Standards and Technology, USA); and IAEA 433 (Marine sediment, International Atomic Energy Agency, Austria). The recoveries of the standard reference materials for Hg ranged from 96% to 104%, respectively.

Statistical analysis

The data were statistically analyzed by the statistical package has done using SPSS software (version 20). The means and standard deviations of the water quality and mercury concentrations in water, sediment and fish tissues calculations were performed by Microsoft Excel 2010.

Results and Discussion

Physicochemical parameters

The physicochemical parameters of the water column such as temperature, pH, DO, SS, TN, and TP significant different season are presented in ($p<0.05$) respectively. The physicochemical are very important because they have a significant effect on the water. Furthermore, anthropogenic activities results in significantly decrease of surface water quality of aquatic systems in watersheds. Among the external factors temperature and pH is one of the most important factors which influence the aquatic ecology [42]. Significant difference in the water quality was observed the surface water at each sampling site from in the Meiliang Bay, Taihu Lake. Seasonally, the average water temperature was 25.4 ± 2.64 ºC and 10.7 ± 0.38 ºC in June and December, respectively. The fluctuations in water temperature were relatively small during each sampling period; however, there was a significant difference in temperature between two seasons. The mean value of water temperature was found within the permissible limits set by [43]. The sites in aquaculture (Agricultural area), livestock farming (Live stock form), and urban residential areas (urban residential area) showed lower water transparency than those in agricultural (Agricultural area) and rural residential areas (rural area). The highest water transparency was recorded in the sites located in drinking water protection area (drinking water production area). The lake water showed neutral to alkaline conditions; the pH in June was in the range of 8.94 ± 0.4 which is distinctly lower than the range of 7.41 ± 0.33 measured in December season. Dissolved oxygen refers to the oxygen gas that is dissolved in the water and made available to aquatic life. The solubility of oxygen increases with decrease the temperature [44]. As was expected the highest value of DO was recorded during December season might be due to temperature in this season was low [45]. This suggests that the discharge of industry and domestic wastewater induced serious organic pollution in these rivers, since the decrease of DO was mainly caused by the decomposition of organic compounds [46]. Moreover, extremely low DO content usually indicates the degradation of an aquatic system. The DO mean concentrations significant different were showed fluctuations between seasons, with the lowest value (11.1 ± 1.03 mg L) in June, and in December it was the highest value (11.97 ± 0.58 mg L), respectively. The lowest value of DO was observed during June that could be due to the less or no rainfall and increase in temperature that lead to decrease in dissolved oxygen results due to the rate of oxygen consumption from aquatic organisms and high rate of decomposition of organic matter. This can be ascribed to the discharge of industrial and domestic sewage, which put large amounts of alkaline ions into the river system, since conductivity depends mostly on ion concentration in surface water [47]. In addition suspended soil, total nitrogen and total phosphate showed wide fluctuation, the mean concentration ranged following order 107.5 ± 8.61, 1.92 ± 0.45 and 0.06 ± 0.01 during June and 17.7 ± 8.61, 1.55 ± 1.10 and 0.03 ± 0.00 during December season respectively. The concentrations of SS, TN and TP were higher in June than December season due to the lower water flow during June which could assistance to accumulate the nutrients in water Taihu Lake. Similarly, the SS, TN and TP average concentrations significant different were fluctuations between two seasons, with the lowest value (47.26 ± 8.61; 1.55 ± 1.10 and 0.03 ± 0.00 mg/g) in December, and in June it was the highest value (101.57 ± 17.7; 1.92 ± 0.45 and

0.06 ± 0.01 mg/g), respectively.Result of SS, TN and TP investigation failed to reflect the current water pollution in the Meiliang Bay, Taihu Lake, whereas SS, TN and TP were a better indicator of today's water pollution than the sediments. This suggests that measures of nutrient abatement from domestic wastewater are strongly needed to recover the water quality of this river considering that it receives large amounts of wastewater from households every year [48]. Although a series of countermeasure to the eutrophication of Lake Taihu has been implemented, the impact of these countermeasures needed to be evaluated. From the SS, TN and TP investigation, it can be concluded that mercury pollution has not been effectively controlled and Zhihugang River still acted as the main contributor of mercury in the Meiliang Bay which was the main reason for the hypertrophic state of the northern part of Taihu Lake [14]. This suggests that it is urgent to control point pollutions in the Meiliang Bay, Taihu watershed.

Metal concentration

Water: The results of mercury increased were significant different average mean concentrations in selected seven sampling sites from in the Meiliang Bay, Taihu Lake shown in ($p<0.05$). In general the concentration pattern of the mercury in water sample indicted an average expressed in Hg µg/L of 0.034 for Tuo shan, 0.068 for Meiliang Hu, 0.058 for Sha zhu nan. 0.053 for Xiao wan li, 0.041 for Mashan shui chang, for 0.052 Long tou zhu and 0.035 for Wu tang men during June season respectively. During in December season of the mercury mean concentration in water sample indicted an average expressed in Hg µg/L of 0.054 for Tuo shan, 0.075 for Meiliang Hu, 0.068 for Sha zhu nan. 0.057 for Xiao wan li, 0.059 for Mashan shui chang, for 0.062 Long tou zhu and 0.035 for Wu tang men respectively. Based on the average of mercury in sampling sites the following decreasing sequential order is observed S1 > S3 > S6 > S5 > S4 > S2 > S7 respectively Higher values of mercury observed in the discharging from Zhihugang River mouth/channels closed to the Meiliang Bay [49]. The average concentration of mercury in water 0.048 and 0.058 µg/L was observed significant different during June and December season respectively which was much lower than the WHO standard level for drinking water.

Interestingly, the lower value of mercury was observed 0.048 ± 0.005 µg/L during December which the lower concentration of heavy metals might be due to the dilution effect of water [32,50]. The metals in water were seasonally varied, where June season exhibited higher than 0.058 ± 0.003 µg/L during June might be attributed to the domestic sewage and effluents from the port area (Wang et al., 2012) [32]. In the study, the concentration of mercury in Taihu Lake was significantly lower than that found in a previous investigation conducted by [32], who reported that the mercury concentrations in the lake water varied from 140-760 ng/L. However, the present results show that the mercury concentration in water from Taihu Lake is much greater than in background lakes in the USA [51], Sweden [52] and even reservoirs in geologically mercury -enriched areas of China [53]. Eleven percent of the water samples exceeded the second class mercury standard of the Chinese environmental standards for surface water (0.001 mg/L) (GB 5749-2006). The data indicate that there was a significant difference in the mercury concentration between the two seasons. [32] a similar reported seasonal variation was observed for mercury reported that the concentration of mercury in water from Lake Taihu was higher in May than in September. These measurements were recorded on the same boat and during the same period as the samples for the present study. The low in dissolved oxygen concentration in June season indicated that the primary productivity was higher in this season. Therefore, the increasing mercury concentration in the lake water in June may lead to higher concentrations of mercury than December season.

Sediment: Seasonal distribution of mercury concentrations in sediment sample increased were significant different are presented from in the Meiliang Bay, Taihu Lake in ($p<0.05$). The mean concentration of Hg were observed during June season in Tuo shan (0.60 µg/g), followed by Meiliang Hu (0.63 µg/g), Sha zhu nan (0.50 µg/g), Xiao wan li (0.61 µg/g), Mashan shui chang (0.57 µg/g), Long tou zhu (0.59 µg/g), and Wu tang men (0.58 µg/g). During in December season in Tuo shan (0.66 µg/g), followed by Meiliang Hu (0.68 µg/g), Sha zhu nan (0.60 µg/g), Xiao wan li (0.61 µg/g), Mashan shui chang (0.59 µg/g), Long tou zhu (0.64 µg/g), and Wu tang men (0.52 µg/g) respectively. Mercury concentrations in sediment were higher significant different in June than December season due to the lower water flow during June which could assistance to accumulate in sediment [32]. The average concentrations of mercury in sampling sites were in the decreasing significant different order of: S1 > S2 > S5 > S6> S4> S3> S7 during both season June and December treated wastes from petroleum, fertilizers and pesticides industries [32,37,54,55], indicates its higher input, which might be originated from the urban and industrial wastes [56]. Whereas [57] and [58] found that a reduction in pH from 7.0 to 5.0 had a substantial effect on mercury, resulting in moderate to large increases in the net mercury rate at both low and high concentrations of DO. In Taihu Lake, intensive algal blooms may consume a high amount of CO_2, creating a neutral-alkali water environment (8.94-9.31 in June and 7.41-8.31 in December), which higher pH may inhibit Hg methylation. In the June seasons, when the freshwater inflow in the Taihu Lake is largely anoxic, dissolved metal concentrations tend to be very low and the metal partitioning in those conditions favours absorption to suspended particles and the sediment [59-61]. Generally increased dissolved oxygen level lead to the oxidation of the bottom sediments, which when re suspended brings metal in to the water column causing secondary pollution. Higher values were observed for mercury during June season is observed. The higher values of mercury in the sediments (in the discharge point from channels) is primarily attributed to the external source mainly due to manufacturing, channel, rubber paint, tannery and metal based industries located (industrial complexes) in the region and in the northern side [7]. In addition, coagulation, precipitation process which often happens during the mixing of freshwater and saltwater in the estuarine regions, where it could be the lower pH and dissolved oxygen that occurs due to the low flow condition in the creek region [57]. Whereas [62,63] also found that the northern region exhibited the highest Hg pollution in surficial lake sediments, which congruent with The mercury content in central area was significantly lower than that in any other region of the lake, indicating that the effects of anthropogenic mercury deposition on central Taihu Lake have been reduced due to gradual pollutant deposition during water flow transportation. However, the seasonal trends in the more polluted during June being very similar to those in the during December season suggest that the seasonal changes in metal concentration observed in fish are probably due to changes in the water and sediment quality influencing levels of metal exposure.

Earlier reports suggest that metal accumulation can be increase in the presence of dissolved organic carbon [64].

Fish species: The seasonal accumulation of mercury in fish species is important both with respect to nature management and human consumption. The present study documents accumulation of mercury in fish species from in the Meiliang Bay, Taihu Lake. However, the concentrations may be raised in coastal ecosystems due to the release of industrial waste agricultural and mining activities [65]. The aquatic organisms exposed to mercury from the run-off water tend to accumulated it in their body but fishes are more commonly affected than other species [66]. In the present study, the level of the mercury seasonal accumulation in muscle, gills, liver, kidney and intestine of *C. carassius, C. carpio and P. fulvidraco* was determined during June and December seasons are summarized In spite of living in the same ecological conditions, the three different fish species demonstrated variations in accumulation of metal which might be attributed to their feeding habits, trophic levels and the contamination gradients of these sources. The patterns of accumulation for mercury in the fish tissues were decreased significant different in the order of liver > gills > kidney > intestine > muscle in *C. carassius*; liver > gills > kidney > intestine > muscle in *C. carpio* and liver > gills > kidney > intestine > muscle in *P. fulvidraco* June season respectively. In December season following order of liver > gills > kidney > intestine > muscle in *C. carassius*, liver > gills > kidney > intestine > muscle in *C. carpio* and liver > gills > kidney > intestine > muscle in *P. fulvidraco* shown in Fig 4 respectively. The hierarchy of mean concentration of mercury analyzed is June as follows: *C. carassius* (0.069 μg/g) > *C. carpio* (0.065 μg/g) > *P. fulvidraco* (0.068 μg/g) respectively. December as follows: *C. carassius* (0.163 μg/g) > *C. carpio* (0.134 μg/g) > *P. fulvidraco* (0.118 μg/g) respectively. The dissimilarities in the metal levels could be attributed to the habitat and feeding behavior of each individual species. Majority of the species thrive in shallow depths feeding on small algae, diatoms, detritus and organic matter. The species with the highest metal concentration, June then compare to December season. This seasonal variation has the highest possibility to intake contaminants from the land as well the untreated effluents from the industries. It was reported that *C. carassius, C. carpio and P. fulvidraco* are important freshwater fish which are resistant to highly polluted habitats and are used as bio-indicator species in understanding environmental pollution [67]. Whereas, [68] and [69] reported that O. niloticus and *C. carpio* contribute a lot in understanding toxic mechanism of cadmium exposure in aquatic organisms. The three economically important tropical fish *C. carassius, C. carpio and P. fulvidraco* are selected as study animals since they are known to have wide resistance to metal poisoning and are widely cultured in Taihu Lake region as a protein source. The purposes of this study were to determine mercury levels in these fish organs such as muscle, gills, liver, kidney and intestine and to compare accumulated levels in tissues of these three species under the same ambient conditions. Tissue accumulation and toxic effects of metals in fish largely depend upon the physical and chemical characteristics of water. It was shown that mercury toxicity is affected by water hardness, temperature, pH and dissolved oxygen [70]. Heavy metals accumulate mainly in metabolically active tissues such as muscle, gills, liver, kidney and intestine under the effect of low concentrations for prolonged periods [71]. The levels of mercury were found to be higher in liver followed by gills, intestine, and kidney and muscle tissues in *C. carassius, C. carpio and P. fulvidraco* [72].

Mercury is a neurotoxin that causes behavioral deficits in vertebrates, decreases in survival and growth rates, causes learning disabilities, and metabolism. The world Health Organization has recommended that dietary mercury should not exceed 0.001 μg/g (wet weight basis). It is well known that mercury accumulated in substantially high levels can be very toxic for fish, especially for young and eggs which are very sensitive to the pollution. Target organs, such as liver, intestine, kidney and gills are metabolically active tissues and accumulate mercury of higher levels. Thus, it is not surprising that the liver, intestine of *C. carassius, C. carpio and P. fulvidraco* had the highest levels of metals except in the case of other tissues. Especially the mercury contents in the tissues of fish were lower than Chinese Food Health Criterion. Previous studies also indicated that different contents of mercury in different fish species might be a result of different ecological needs, metabolism and feeding patterns [73,74] pointed out that Cd, Cu and Zn contents in edible muscles of pelagic fish species were lower than for benthic fish species. However, this study showed that the Hg contents in muscles of *P. fulvidraco* (pelagic fishes) were almost 8 times of that in *C. carpio* and 2 times of that *C. auratus* (benthic fishes). The concentration of mercury between *P. fulvidraco* and *C. auratus* also exhibited significant difference season ($p<0.05$). It is well known that substantial accumulation of mercury can be toxic for fish species [32,37].

The concentrations of mercury were highest in the sediments, intermediate in fish and lowest in the water. Fish generally had higher levels of mercury compared with those in fish at the upper-middle and middle-lower layers. Mercury concentrations were ranked as follows: sediments>fish>water. Our results support the hypothesis that the sediment is the major sink for mercury pollution and plays an important role uptake by fish [75]. The mercury contained in the sediment are then absorbed and stored in the tissues [76]. As a consequence, controlling the sources of contamination of water and sediments in the aquatic system is the key method for protection of the fish resource. The results of our study clearly demonstrated in the Meiliang Bay mercury contamination, and the seasonal pollution in sediments was closely related to industrial production, anthropogenic activities, and input and output channels, especially in the northern lake region. Lake sediment is considered to be an important source of inorganic and organic Hg in the water column. Overall, a lot of studies have been published on the heavy metal pollution in the water and sediments throughout the Taihu Lake, although analyses of the heavy metal contents of its sediments have been extensively used for monitoring pollution. Accompanying the extensive industrial and agricultural activity surrounding the lake, millions of tons of partially and untreated domestic and industrial sewage are discharged into the northern region of the lake every year from the Wuxi, Changzhou, and Wujin region [77-80]. However, they found that, in comparison with the eastern and southern parts of the lake, pollution was generally higher in the western parts; in particular pollution in the northern parts of the lake was most serious [78]. The concentration gradient between the fish and the water above the sediment drives the diffusion of mercury [53]. In general, the diffusion fluxes of mercury were higher significant different in June than in December season at all sampling sites from in the Meiliang Bay, Taihu Lake. The net depositional flux of mercury observed in June could be due to an elevated mercury concentration in the interface water caused by disturbances of the sediment and anthropogenic input from a contaminated river. It is possible that the high mercury diffusion flux contributed to the higher concentration of mercury in the lake water in June, but a reasonable explanation for the higher mercury diffusion flux in June is still not forthcoming.

Pearson's correlation (PC) matrix results for the physicochemical parameters and dissolved mercury concentration in water, sediment, three common freshwater fishes *C. carassius, C carpio and P. fulvidraco* (muscle, gills, liver, kidney, intestine) was calculated to see i ($p<0.05$, $p<0.01$). The correlations between mercury and the physicochemical parameters depended on the chemical properties and migration forms of the elements, and were also restrained by the variations of the parameters in situ [81]. In present study, the external inputs (terrestrial, anthropogenic, sedimentary) of mercury appeared to play a more important role than the hydrography and biogenic processes [82]. The mercury in water and sediments did not show any correlation showed significant positive correlation suggesting similar sources of input (human or natural) for mercury in the river water [83]. High correlations between specific heavy metals in water may reflect similar levels of contamination and/or release from the same sources of pollution, mutual dependence and identical behavior during their transport in the lake system [18,84]. The similarity in mercury associations in the gills indicates that it is the principal tissue for concentrating these metals and also due to its contact directly with the pollutants in the aquatic medium. The large surface area of the gills is also a possible reason for the accumulation of mercury [85]. The changes or possible variations in the association of metals also depend on the feeding habits and growth period of individual species. The positive relationship also indicates that the input of dissolved and bioavailable metals is more compared to the flow condition, which in turn accumulates (or) increases in the organisms and in sediments in time.

Comparison study

A comparative of the mercury concentration is presented for all the three components (water, sediment and fishes) from in the Meiliang Bay, Taihu Lake and with other water bodies studies shown in. There have been several studies on mercury concentrations in water, sediment and fishes conducted in the same lake. In the present study distribution of average concentration 0.05 and 0.02 Hg μg/L in surface water indicate are increased significant different June then December season and decreased of 25-50% for Hg than the stipulated Environmental Protection Agency (EPA) value. In sediment mercury concentration 0.58 and 0.01 μg/g increased significant different June then December season and increased with decreased a 25% of Hg than other water bodies Mercury do not degrade in water but are generally not found in high concentrations, primarily due to deposition in sediments enter the food chain via the feeding of benthic animals [86]. The above concentration pattern clearly demonstrates that apart from natural source, considerable amount is available as bioavailable form the external input (anthropogenic source) which will be automatically absorbed into the organisms present in the Meiliang Bay, Taihu Lake. As a mercury concentration of most of the sampling sites exceed some well documented standard values and agreement with some previous studies in Taihu Lake and other water bodies In addition, metal levels in fish flesh from developed industrial areas (such as in an Canada lake) and mining areas (such as in an Bosnia river and Vietnam Delta) were usually higher than the present study are a and other areas. For the non-essential trace elements, were comparable with the previous results in fish from the same lake [87,88], our data was comparable to the results in fish *C. carassius, C carpio and P. fulvidraco* (0.16, 0.13 and 0.12 μg/g during June and 0.06, 0.06 and 0.06 μg/g of *C. carassius, C carpio and P. fulvidraco* during December season) in fish collected from the same lake in 2016, except for the large largemouth bass, which had a mean concentration of 1.24 mg/g was reported by [32], and 0.04-0.28 mg/g in another study conducted by [53]. There are many studies monitoring the contamination levels of mercury in fish from other water bodies to explore the contamination status of mercury from in the Meiliang Bay, Taihu Lake, we listed some data published in recent years from other water bodies in USA, China, Canada, and Bosnia. Compared our data with the published results, the mercury concentrations in water, sediment and fishes from in the Meiliang Bay, Taihu Lake were similar to or lower than the values reported, demonstrating that the contamination levels from in the Meiliang Bay were low.

Conclusion

In conclusion, results of the present study indicate that mercury concentrations in water, sediment and three common freshwater fishes demonstrated great two seasonality due to accumulation of mercury types. Generally increase in significant different concentrations of the tested, metals were found in the June compared to with those during December season [32,49,53]. This investigation is aimed at revealing differences in the accumulation pattern of mercury in fish and inhabiting sediments that are characterized by varying metal bioavailability. The overall pollution load was remarkably higher in June than in December season. The data also reveals that in the Meiliang Bay, Taihu Lake is getting polluted and necessary preventive measures must be adopted to make the best possible use of available freshwater resources in the study area [89-130].

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