Original Article

Assessment of Mercury Accumulation and Magnification in a Freshwater Food Chain: Sediment, Benthos and Benthivorous Fish

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ABSTRACT

Background: Present study was conducted to measure the level of total mercury (tHg) in sediments, benthos and benthivorous fish (i.e., common carp) for determining Biota (Benthos)-Sediment Accumulation Factor (BSAF), as well as Biomagnification Factor (BMF) of tHg between two trophic levels of benthos and benthivorous fish caught from Sanandaj Gheshlagh Reservoir (SGR) in the west of Iran.

Methods: Samples of sediments and benthos biomasses were collected from three sampling stations. Common carps were captured around the selected stations during July to December 2010.

Results: Means accumulated tHg (±SE) in sediments, benthos masses and muscle tissue of common carp were 117.66±9.72, 94.3±5.02 and 233.21±20.67 ng g^{-1} dry weight, respectively. Means accumulated tHg in benthos masses and muscle tissue of the common carp during the studying months showed no significant differences ($P>0.05$), while it was significantly differed in sediment samples ($P<0.05$). Results showed that there were statistically significant differences between accumulated tHg between sediment and benthos mass samples collected from the study sites ($P<0.05$).

Conclusion: During the study, all calculated BSAF measurements were less than one, indicating transmission of mercury from sediment to benthos was not considerable. However, mercury BMF_s was higher than one, denoting mercury biomagnification occurred from the benthos trophic level to the higher trophic level (i.e., common carp) in study site. Hence, the health considerations have to be taken in to the account for consumption of fishery products of SGR.

Keywords: Benthos, Bioaccumulation, Biomagnification, Common carp, Sediment.

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INTRODUCTION

Nowadays, accumulated heavy metal in marine sediments and the body of living organisms is an important concern worldwide [1]. Therefore, heavy metal contaminations studies in marine environments have attracted great attention worldwide, due to their toxicity, persistence and non-biodegradable features [2]. Heavy metals discharged into the marine environment could accumulate in sediments and will negatively affect other aquatic organisms and their health [3].

Mercury (Hg) in freshwater ecosystems is a remarkable issue for investigation in comparison to the other heavy metals due to its ability to be bioaccumulated in living organisms' tissues and seafood. Furthermore, this element is very toxic for the living organisms and their environments [4]. This heavy metal is harmful for the organs and tissues of animals and humans similarly [4].

Two main sources for mercury explosions have been recognized in the aquatic ecosystems. 1. Natural sources, indicating mercury concentration derived from parent rocks (erosion of the lithosphere) and 2. Anthropogenic sources such as; industrial processing, urban sewage and agricultural run-off [4]. It is known that mercury exists naturally in both organic and inorganic forms [5]. Inorganic mercury is converted to methylmercury by anaerobic microorganisms in the sediments of aquatic ecosystems. This component is the most dangerous compound derived from mercury [6]. Because of its high binding capacity with sulfhydryl proteins, this compound tends to be absorbed in the tissues of living organisms at significant amounts [4,7]. Mercury and its derivative compounds have no known biological activity; therefore, all mercury pollutants should be considered undesirable and potentially pernicious [6, 8].

Mercury could be accumulated and magnified throughout a natural food chain [4]. Mercury bioaccumulation refers to the accumulation of this element in tissues or organs of the living creatures. Biomagnification phenomena frequently occurs in the aquatic environments [4, 9], which is a condition where concentration of a polluting substance increases in living tissues during its transmission from one trophic level to

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the next trophic level [4]. Mercury biomagnification refers to increasing mercury concentration in every trophic level in comparison to the previous trophic level, while biomagnification factor (BMF) of mercury refers to the quantity of its transmission [4, 10]. However, in aquatic food chains, the highest concentrations of mercury accumulates occurred in top predatory fish such as; Sharks and Tuna [4].

Sediments at the bottom of an aquatic ecosystem are the main sink source of mercury [11]. The lifetime of mercury in the sediments is considerable and sediments plays an important role in mercury cycle in the natural ecosystems. Sediments could also act as one of the source of this pollutant for organisms [12]. Mercury can be released from the sediments to water column and exert its negative effects on water for human, fish, agriculture consumption and to the entire environment.

The common carp (*Cyprinus carpio*), known as a bottom fish in lentic waters, eats benthos and detritus, as its staple diet [13-14]. In addition, it has been shown that invertebrates living in deep sediments are frequently contaminated with pollutants accumulated in benthos, which in turn contaminates a natural food chain [4].

Szefer et al. [15] suggested an equation (Eq. 1) for calculating Biota-Sediment Accumulation Factor (BSAF) to explain the transmission of mercury from sediments of an aquatic ecosystems to the benthic invertebrates that are living in this environment.

BSAF = Hg in organisms inhabiting in sediments / Hg in associated sediments (1)

Also, BMF is obtained from the amount of accumulated mercury in one trophic level (as predator) divided by the amount of accumulated mercury in the previous trophic level (as prey) [16, 17], According to Eq. 2:

BMF = Concentration of Hg in n+1 trophic level / concentration of Hg in n trophic level (2)

Sediments and benthos are counted as suitable indicators for the presence of mercury in the aquatic ecosystems [18]. The amounts of Hg in benthos biomasses might be determined by measuring the amounts of Hg concentration in the sediments where these organisms live [19].

Based on biomagnification process, it can be expected that the concentration of total mercury (tHg) in the muscle tissue of common carp (as predator) be higher in compare with benthos biomasses (as prey) [4]. This could be a hidden danger for the local residences since they routinely consume this fish as an inexpensive and abundant source of protein in their daily food basket.

We selected Sanandaj Gheshlagh Reservoir (SGR), (Fig. 1), because this reservoir is the main local fishery resource of fishery products in the region and has been proven that this fresh water ecosystem is polluted by mercury [20].

Considering the above mentioned facts, this research project was designed to measure the concentrations of tHg in the sediments, benthos biomass and muscle tissue of common carp, and to calculate the BSAF and BMF levels of mercury during July and December 2010 in SGR. Our results demonstrate the extent of mercury bioaccumulation and biomagnification in this freshwater food chain, i.e., the sediment, benthos and benthivorous fish. In addition, our findings help the managers and policy-makers to make logical and informed decisions towards solving the issues related to the mercury pollution in this valuable ecosystem.

MATERIALS AND METHODS

Study Area, Sample Collection and Mercury Determination

The SGR (35° 25' – 35° 30' N and 46° 57' – 47° 03' E) is located in the northeast of Sanandaj city, Kurdistan province in the west of Iran. It covers nearly an area of 8.5 km^2, with the capacity of 224 million m^3 water (Fig. 1). The SGR is the main source to supply drinkable water and fishery products in the region. In addition, the local residents use SGR for land irrigation.

In present study, sediments and benthos samples were collected monthly (July to December 2010) from three different sampling stations (18 samples from each station) by stainless steel Ekman grab sampler (20×20 cm). Stations 1 and 3, had a depth lower than 17 meters, were located at the beginning of the two main branches entering the lake (rivers of Gheshlagh and Chehel Gazzi) and station 2 with variable depths of 17–30 meters was located at the center of the lake (Fig. 1). Different depths were chosen due varying water temperature, light penetration and dissolved oxygen concentration [5, 21], physio-chemical characteristics of water and the methylation process [22].

The common carp samples were captured, using a gill net with 5×5 cm mesh size, around the three stations from July to December 2010, each month 4 samples (total number = 24 samples). All collected samples were taken to the environmental sciences department laboratory of Kurdistan University in zipped plastic bags, in an icebox holding at 4 ºC. The sediment samples were sieved, with a mesh size of 250 microns. Then, benthic organisms were separated from sediments, using a stereomicroscope at X20 magnification, and were transferred to mercury-free screw cap bottles. Subsequently, they were fixed in buffered formalin 10% and stored in a refrigerator at 4 ºC [23]. The sediment samples were simultaneously kept in a refrigerator at –20 ºC until analysis [7]. Fish samples transported alive to the biology laboratory for biometry studies such as total length, total weight and age. After biometry procedure, a 10 gr muscle tissue was removed from edible parts of each fish and samples were frozen at -20 °C in small plastic bags until measurement [24].

In order to prevent the evaporation of methylmercury samples of sediments, benthos and fish were freeze dried at -52 °C for 24 hours (OPERON, FDCF-12012). Following this step, 50-100 ± 0.01 mg of homogenized solid sample was removed and grinded [18]. The tHg concentrations were measured in all samples, using an Advanced Mercury Analyzer (Model; Leco 254 AMA), on the basis of ng g^{-1} dry weight.

The research ethics for the experiments was approved according to national ethical guidelines for animal research in Iran.

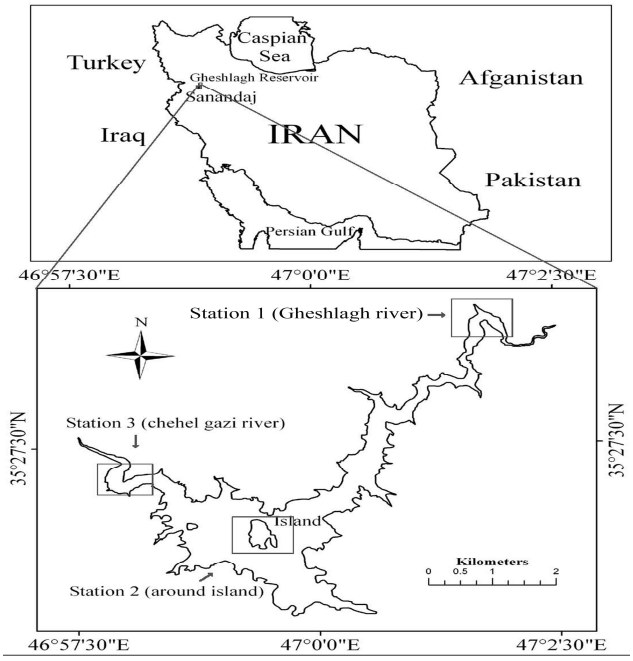

Figure 1. Location of study area and sampling stations (Sanandaj Gheshlagh Reservoir).

Statistical Analysis

Statistical analyses were performed using SPSS 16 software (*SPSS Inc., release 16*) and charts were drawn by Excel software (*MS Office 2013*). A *P*-value of less than 0.05 was considered as statistically significant differences. Kolmogorov-Smirnov and Bartlett tests were used to show whether the obtained data had normal distribution and homogeneity of variances, respectively. The mean tHg concentrations in sediments, benthos masses and muscle tissue of common carp were compared using One-way analysis of variance (ANOVA). Also, ANOVA test was used for the comparison of tHg concentrations in sediments and benthos masses for study stations. Finally, Duncan's test was applied to compare the means among the samples.

RESULTS

The results of measured tHg in sediments, benthos masses and common carp muscle tissue are shown in Table 1. In this study, benthos samples were mainly the members of Oligochaeta sub-class and Tubificidae family. In some samples, few numbers of Chironomidae families and Chironomus genus were identified (identification key: Thorp and Covich, 2009 [13]). Caught common carps were weighted between 330 to 753 gr (average 476 gr) and their total length were varied between 26.5 to 37 cm (average 30.64 cm).

The mean of accumulated tHg in the benthos masses and muscle tissue of common carp showed no significant differences ($F_{5, 10} = 2.16$, $P = 0.14$) and ($F_{5, 18} = 1.73$, $P = 0.2827$), respectively, though they were significantly differed from the accumulated tHg in sediment samples ($F_{5, 10} = 4.88$, $P = 0.02$).

Mean tHg in sediment samples in July was significantly higher ($P<0.05$), while the highest monthly mean of the accumulated tHg for the benthos masses muscle tissue of common carp were recorded in August (i.e., 115.89) and July (i.e., 321.5), respectively.

On the other hand, the lowest monthly mean accumulated tHg in sediment samples was observed in November and for both benthos and common carp's muscle tissue was in October (Table 1, Fig. 2). As previously mentioned, sediments and benthos samples were obtained from three different stations at different depths. Table 2 shows the means for accumulated tHg in sediments and benthos samples. The mean accumulated tHg in benthos samples ($F_{2, 10} = 5.37$, $P = 0.03$) and sediments ($F_{2, 10} = 7.88$, $P = 0.008$) among the various sampling stations demonstrated significant differences. Also, the highest accumulated tHg in benthos and sediment samples (Table 2) was observed at station 2 ($P<0.05$; deep zone).

Based on equations 1 and 2, as presented previously, the Benthos-Sediment Accumulation Factor as well as Biomagnification Factor of mercury between trophic levels of benthos and common carp for different months are presented in Table 3.

During the study, all calculated BSAF values were less than one, indicating that the transmission of mercury from sediments to benthos was not considerable. However, mercury BMF throughout the study period was greater than one, suggesting that mercury biomagnification from trophic level of benthos to trophic level of common carp was significant (Table 3).

Table 4 shows a comparison between $BSAF_{Hg}$ of the SGR with other studies in the different parts of the world. Also, table 5 compares level of accumulated tHg in the SGR common carp muscle tissue with similar studies.

Table 1. Mean tHg (ng g^{-1} dry wt) in sediments, benthos masses and common carp's muscle tissue from SGR (July to December 2010).

Sampling months	Sediments	Benthos	Muscle tissue of common carp
July	171.69	93.95	321.5
August	130.77	115.89	239.5
September	119.24	97.46	183.5
October	93.66	79.1	169.5
November	91.93	81.58	213.5
December	98.67	97.84	271.75
Mean (± S.E.)	117.66 ± 9.72	94.3 ± 5.02	233.21 ± 20.67

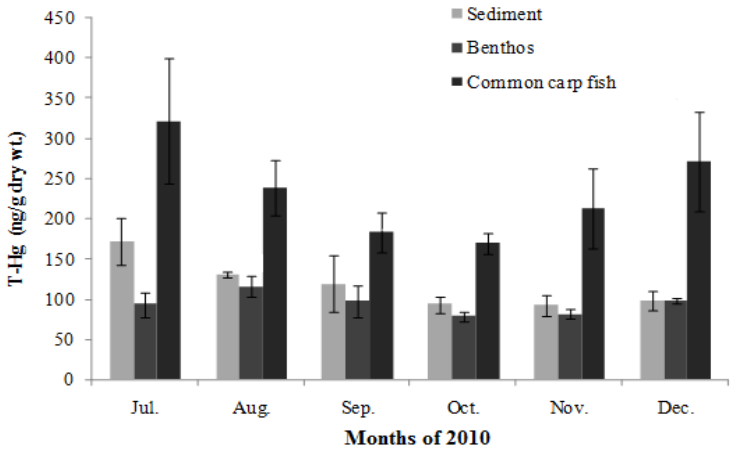

Figure 2. Mean (± S.E.) accumulated tHg (ng g^{-1} dry wt) in SGR's sediments, benthos masses and common carp (July to December 2010).

Table 2. Mean ± S.E. accumulated tHg (ng g^{-1} dry wt) in sediments and benthos masses from various sampling stations of SGR.

Samplingstations	Sediments, Mean ± S.E	Benthos, Mean ± S.E
Station 1	12.05 ± 105.61	5.68± 81.91
Station 2	19.86± 147.04	11.83 ± 110.69
Station 3	12.63 ± 92.49	5.6 ± 90.3

Table 3. The calculated Biota (Benthos)-Sediment Accumulation Factor (BSAF) and Biomagnification Factor (BMF) of mercury in different months of 2010 from the SGR.

BSAF or BMF	July	August	September	October	November	December	Mean
BSAF	0.55	0.89	0.82	0.84	0.89	0.99	0.8
$BMF_{(Fish\text{-}Benthos)}$	3.42	2.07	1.88	2.14	2.62	2.78	2.47

Table 4. A comparison between means tHg (ng g^{-1} dry wt) in sediments, benthos masses and Biota-Sediment Accumulation Factor (BSAF) at different sites of the world with the results of this study.

Study area	Mean tHg in sediments (ng g^{-1} dry wt)	Mean tHg in benthos (ng g^{-1} dry wt)	BSAF	References
Ranger lake, Canada	137.01	163.7	1<	[23]
Scheldt estuary, Belgium	462.82	97.78	1>	[25]
Guaymas bay, Mexico	1000	230	1>	[26]
Ganga river, India	67	118	1<	[18]
SGR	**117.66**	**94.3**	**1>**	**This Study, 2010**

Table 5. A comparison between mean accumulated tHg in the muscle tissue of the common carp from SGR (µg g^{-1} dry wt) and means accumulated tHg in the muscle tissue of other fish species in different parts of the world.

Species	tHg	Study area	References
Oreochromis aureus	0.04	Lake Mead, USA	[27]
Anguilla Anguilla	4.1	Cecina river, Italy	[28]
Huso huso	1.4	Caspian Sea	[29]
Acipenser persicus	0.33		
Acipenser stellatus	0.67		
Acipenser stellatus	0.06		
Myleus rubripinnis	0.13	Maroni River (French Guiana)	[30]
Semaprochilodus vari	0.396		
Doras micropoeus	0.1252		
Pseudancistrus barbatu	0.104		
Tinca tinca	0.32	Aquatic Zahlinice Ecosystem (Czech Republic)	[9]
Ctenopharyngodon idella	0.05		
Cyprinus carpio	**0.233**	**SGR**	**This Study, 2010**

DISCUSSION

Our field observations in the catchment basins leading to the SGR suggest that there was no major industrial activity in the region, and the majority of agriculture was based on dry farming that used no pesticides. In addition, according to the evidence for the presence of high levels of mercury in the compound of maternal stones of catchment basins that lead into SGR, it seems that mercury pollution in this reservoir has a natural source [20].

The results of present study showed that there was a statistically significant differences in contents of tHg among sediment samples ($P<0.05$). Therefore, the amounts of accumulated tHg during the summer months were higher than those in autumn (Table 1, Fig. 2). This could be affected by the reduction of dissolved oxygen in water body during the summer, due to the increasing water temperature compared to autumn. These conditions could accelerate the methylation process and the amount of bioavailable mercury in the sediments, which is in a dynamic equilibrium with the pore water mercury [31].

The highest concentration of tHg in common carp muscle tissue observed in July (Table 1, Fig. 2). As described in materials and methods section, all common carp captured randomly and samples caught in July had the highest weight and age. Bioaccumulation, long biological half-life and persistence of mercury in fish body are the main reasons for the increasing amounts of mercury with higher weight and age [4, 32]. In consistent with our findings other studies have reported similar results [32, 33]. The lower accumulated tHg was observed in October due to the reduction in the above mentioned parameters [8].

The mean tHg in benthos samples and sediments between sampling stations demonstrated significant differences (Table 2). The highest amount of accumulated tHg in sediment and benthos samples was measured in the deeper zones ($P<0.05$), (station 2). As the water depth increases in an aquatic ecosystem, we expect not only a decline for sun light penetration, but also a rise in anaerobic condition due to dissolved oxygen reduction which provides suitable environment for sulfate bacteria [21]. These bacteria are able to ease methylation process and release organic mercury compounds at higher levels (e.g., methylmercury). Consequently, the amount of accumulated tHg often is high in sediments and benthos biomasses. Similar results have been reported by other researchers [23,25], although ecological needs, behavior, species, habitat, age and body size of organisms are known as the influential factors on the rate of heavy metals accumulation in the tissues of aquatic organisms [8,34].

All calculated BSAF values reported here were lower than one (with mean 0.88), (Table 3), demonstrating transmission of mercury from sediments to benthos of SGR was not remarkable. Perhaps this is due to the composition and texture of sediments in SGR reservoir. Changing physical and chemical properties of sediments could reduce the bioavailability of mercury for benthic invertebrates [35]. Oppositely, SGR common carp showed that its muscle had a considerable ability to accumulate mercury. So that all BMF values were more than one (mean 2.47; Table 3). Consequently, our findings provided evidence that there was a remarkable transmission of tHg from benthos to common carp tissues.

As mentioned earlier, common carp feeds on benthos biomasses [14]. Hence, the health considerations have to be taken in to the account for consumption of fishery products of SGR. As it is the only natural fishery resource in the region and common carp is the most consumed fish in study area due to its low price.

CONCLUSION

This study provided evidence that the sediments, benthos biomasses and common carp muscle tissue from the SGR reservoir were contaminated with mercury. Although all values of BSAF as documented by this study were lower than one, the mercury BMF values during this study were higher than one, demonstrating mercury biomagnification from benthos to fish and their environment. Because the SGR is the most important fishery source in Sanandaj region, consuming fish from this aquatic ecosystem should be based on completely hygiene considerations.

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