

**Original Article****Mercury Biomagnification between Two Trophic Levels of a Grazing Food Chain (Plankton and Planktivorous Fish) in a Fresh Water Ecosystem***Mehdi Khoshnamvand<sup>1</sup>, Kamran Almasieh<sup>2</sup>, Shahram Kaboodvandpour<sup>\*2</sup>*

Received: 30.06.2016

Accepted: 14.08.2016

**ABSTRACT**

**Background:** The Present study was carried out to track and calculate Biomagnification Factor (BMF) of total mercury (T-Hg) between two different trophic levels (i.e., plankton and a planktivorous fish) in a fresh water grazing food chain.

**Methods:** Experimental organisms were planktonic biomass and silver carp (*Hypophthalmichthys molitrix*) as a planktivorous fish. Silver carp samples were obtained from randomly selected points from different sampling stations. The concentrations of T-Hg in collected samples were determined by Advanced Mercury Analyzer.

**Results:** Means of T-Hg in planktonic biomass and muscle tissue of silver carp were  $78.21 \pm 3.13$  and  $367.12 \pm 26.43$  ng g<sup>-1</sup> dry weights, respectively. Mean T-Hg in plankton, sampled fish during the study months and amongst the sampling stations did not show significant differences. The BMF<sub>Hg(plankton-fish)</sub> was differ among months; moreover, calculated BMF was greater than 1 during study months, which means biomagnification was occurring in SGR. The concentration of T-Hg in the muscle tissue of all fish samples that weighed more than 850 gr was higher than the acceptable limits based on EPA (300 ng g<sup>-1</sup>) and WHO (500 ng g<sup>-1</sup>) standards. The highest BMF<sub>Hg</sub> was observed in August

**Conclusion:** It seems that mercury pollution of SGR has a natural source. The calculated BMF<sub>s</sub> were greater than 1 and the concentrations of T-Hg in muscle tissues of those samples weighing more than 850 gr were higher than FAO and WHO standards. Therefore, consumption of the SGR's silver carp must be accompanied by serious health considerations.

**Keywords:** Biomagnification, Grazing Food Chain, Mercury, Plankton, Silver Carp.

IJT 2017 (2): 21-28

**INTRODUCTION**

Mercury (Hg) in freshwater ecosystems is more common pollutant in comparison with other heavy metals due to its higher toxicity, bioaccumulation susceptibility in living organism's tissues and biomagnification throughout the natural food chains [1, 2]. Mercury naturally exists in both organic and inorganic forms [3-6]. Inorganic Hg could convert to methylmercury, a highly toxic compound, by anaerobic microorganisms in the sediments of aquatic ecosystems and planktons [7, 8].

Due to the high binding capability of methylmercury with sulfhydryl proteins, it could be accumulated in living organism's tissues at large amounts [2, 9]. Methylmercury is extremely poisonous, non-biodegradable, accumulates in living organism's tissues, biomagnifies in food

chains with long biological half-life and is able to be transmitted over natural food webs [1, 9, 10].

Planktons [8, 11], aquatic plants, fish tissues and organisms in higher trophic levels of a natural food chain [10, 12] can absorb methylmercury at the higher levels easily. Hence, the highest concentrations of methylmercury would be accumulated in the upper predatory fishes such as sharks and tuna [2]. There are no significant known biological rules for Hg and its compounds. However, all forms of Hg contaminations should be considered as undesirable and potentially harmful [6, 7, 13-15].

Mercury bioaccumulation in aquatic food chains often starts from planktonic trophic level [16, 17]. Mercury accumulates in phytoplankton tissues in both organic and inorganic forms, while zooplanktons only absorb the organic compounds

1. PhD Student Environmental Sciences, Research Center of Eco-Environmental Sciences, University of Chinese Academy of Sciences, Beijing, China.

2. Department of Environmental Sciences, University of Kurdistan, Sanandaj, Iran.

\*Corresponding Author: s.kaboodvandpour@uok.ac.ir

of Hg [16]. The sum of organic and inorganic Hg components called total Hg (T-Hg). Mercury speciation studies reported that 80 to 90 percent of T-Hg is methylmercury [2]. Assessing and determining Hg contamination in basic trophic levels could provide a comprehensive description of pollution at higher trophic levels (especially in the food chains that involves humans) [17].

Mercury biomagnification is a prevalent phenomenon in aquatic environments particularly in fresh water ecosystems [2, 17, 18]. Biomagnification refers to a condition that concentration of a pollutant in living organism's tissues increases from one trophic level to the next one [2]. Biomagnification factor (BMF) conveys the quantity of this transmission [2, 19].

Silver carp (*Hypophthalmichthys molitrix*) is a fish that feeds mainly in surface as well as median layer of water on phytoplanktons [20]. Due to the biomagnification process, it is expected that the concentration of T-Hg in the muscle tissue of this fish be higher than the concentration of T-Hg in plankton's biomasses [2].

The Sanandaj Gheslugh Reservoir (SGR) is the most important water source to supply drinkable water and fishery products in the region (Fig. 1). According to the field observations in the SGR watershed district, industrial activity was not developed in the region at all and the conventional agronomic practice was rain depending type, mostly without using chemical fertilizer and herbicides. Moreover, there are considerable amounts of mineral Hg components in the soil texture and bedrocks of the study site [21]. As a result, we assumed that the SGR is a typical freshwater ecosystem, naturally polluted by Hg [22].

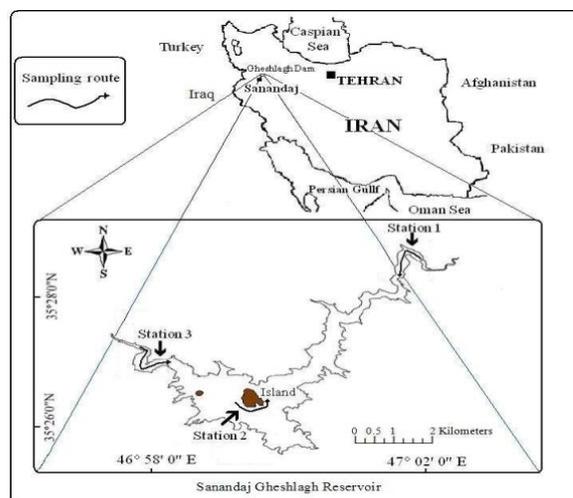
The objective of this study was to determine the concentrations of T-Hg in plankton's biomasses and muscle tissue of silver carp fish (as a plankton consumer) in SGR, to calculate biomagnification factor of Hg ( $BMF_{Hg}$ ) between two trophic levels of plankton and silver carp (related to a grazing food chain in a freshwater ecosystem). In addition, this is important to know whether in a naturally polluted water reservoir the concentration of Hg in its organisms (i.e. plankton and fish) changes or not? Since Hg pollution in this reservoir has negative effects on water quality for human consumption, fisheries, agriculture and so on, this information could help the managers and decision-makers to make an informed

decision towards solving the problems that are related to pollution.

## MATERIALS AND METHODS

### Study Area

Sanandaj Gheslugh Reservoir (SGR) ( $35^{\circ} 25' - 35^{\circ} 30' N$  &  $46^{\circ} 57' - 47^{\circ} 30' E$ ) is located in the Northeast of Sanandaj City, western Iran. The SGR covers an area of approximately  $8.5 \text{ km}^2$  with a capacity of 224 million  $\text{m}^3$  water (Fig. 1).



**Figure 1.** Sanandaj Gheslugh Reservoir (SGR) map and plankton sampling stations.

### Samples Collection

Plankton biomasses were collected monthly, from three different stations, during July to December 2010 (18 samples in total) using a motorboat and plankton net, with 25 cm and mesh size  $20 \mu$  (we used plankton net with  $20 \mu$  mesh size to catch all existing planktonic creatures in the SGR). Stations 1 and 3 were located at the end of the two main river branches entering the SGR (Gheslugh and Chehel Gazzi rivers) and station 2 was located at the center of the SGR (Fig. 1). The suitable sampling depths were determined using Secchi disk index, (a standard tool used to measure water clarity), so the sampling depth would not be more than the depth of light penetration [23]. The plankton samples were collected by pulling plankton net through water in each station over a distance of 1.5 – 3 km using a motorboat with 25 horsepower (model; YAMAHA).

Twenty-four silver carp fish were caught in the same period (4 samples per month). Sampling was done randomly from different parts of the

SGR using a 50 × 6 m gill net (with 5×5 cm mesh size), because silver carp is a mobile animal and we assumed that total Hg distribution in SGR is not even. The caught fish samples were taken alive to the fish biology laboratory in University of Kurdistan for biometric study, including total length, total weight, determination of sex through observation of sexual gonads and tissue sampling.

### Preparation of Samples

The plankton samples were transferred to mercury-free screw cap bottles, all used bottles had been immersed in cleaning liquid (sodium hypochlorite) for 24 h and then washed by 10% nitric acid (Merck Company) and deionized water. Except for planktons, all suspended particulates were separated under stereomicroscope and fixed with 4% grade A buffered formalin to prevent samples degradation prior to measurement of T-Hg concentration. Then fixed plankton samples were centrifuged (Model; Centurion, 2000 series) at 3200 rpm, for 20 min [23]. When fish biometric procedure was done, 10 gr of muscle tissue was separated from each fish and samples were frozen at -20 °C in small plastic bags until measurement of T-Hg [24]. Methylmercury is a volatile component, therefore, to prevent methylmercury evaporation, all samples were dried out using a freeze-dryer (OPERON, Model; FDCF – 12012) in -52 °C. Freeze-drying was preformed until constant weight obtained [18].

### Determination of Total Mercury

After samples freeze drying, homogenized solid tissue, with a weight of 50-100 ± 0.01 mg, was separated into the pre-cleaned combustion boats from the original dried tissue samples and T-Hg concentrations were determined by Advanced Mercury Analyzer (Model; LECO AMA 254, USA), [18] in the environmental laboratory of Tarbiat Modares University, with ASTM D-6722 standard on the basis of ng g<sup>-1</sup> dry weight (dry wt).

### Statistical Analysis

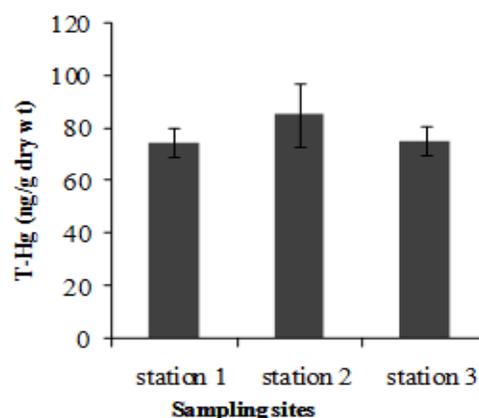
SPSS software, ver. 16 (Chicago, IL, USA) was used for statistical analyses. Data were tested for goodness of fit to a normal distribution using Kolmogorov-Smirnov's test and homogeneity of variances, using Bartlett's procedure. Mean T-Hg in the muscle tissue of silver carps and plankton masses during the studying months were compared using one-way analysis of variance

(ANOVA). ANOVA test was also used to compare T-Hg in plankton masses among three different sampling stations. Pearson's correlation test was used to determine the correlation between T-Hg in muscle tissue of silver carp and its total length and weight. Finally, for comparing T-Hg concentrations between male and female silver carps, Student's *t*-test was employed.

## RESULTS

The total weight and total length of silver carps varied between 300 to 1020 gr (average (± Standard Error) 665.77 ± 36.94 gr) and 32 to 49 cm (average (± Standard Error) 40.64 ± 0.82 cm), respectively (Table 1). The mean (± S. E.) of T-Hg concentration in total mass of planktons and muscle tissue of silver carps was 78.21 ± 3.13, and 367.12 ± 26.43 ng g<sup>-1</sup> dry weight, respectively (Table 1). During the summer months (except for September), the concentration of T-Hg in plankton biomass were higher than the autumn samples (Table 1).

The highest mean (± S.E.) of T-Hg in plankton biomass was observed in station 2 (85.02 ± 11.83 ng g<sup>-1</sup> dry wt). Means T-Hg (± S.E.) in plankton biomass at stations 1 and 3 were 74.51 ± 5.67 and 75.11 ± 5.60, respectively (Fig. 2). Averages T-Hg in plankton biomasses during the study months (*P* = 0.49) and among the sampling stations (*P* = 0.34) showed no significant differences.

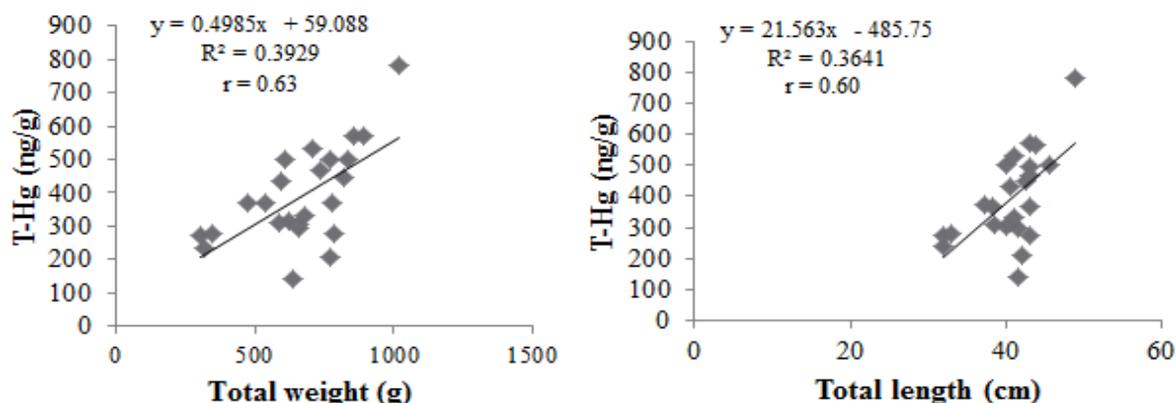


**Figure 2.** Means (± S.E.) T-Hg (ng g<sup>-1</sup> dry wt) in plankton's biomasses from sampling sites of Sanandaj Gheslgh Reservoir.

In silver carp muscle tissue samples, the highest and lowest T-Hg (± S.E.), (ng g<sup>-1</sup> dry wt) were observed in August (501.75 ± 95) and November (297.50 ± 54), respectively (Table 1),

although a significant difference among monthly means of T-Hg in the muscle tissues of silver carps ( $P= 0.23$ ) was not seen. In addition, sex had no influence on T-Hg levels in the fish samples ( $P = 0.27$ ). In order to demonstrate the relationship

between T-Hg in the muscle tissue of silver carp and its morphometric variables (e.g., total weight and total length) we used Pearson's correlation test, and the result are shown in Figure 3.



**Figure 3.** The relationship of T-Hg ( $\text{ng g}^{-1}$  dry wt) in muscle tissue of silver carp from Sanandaj Gheslgh Reservoir with total weight and total length by Pearson's correlation test ( $P < 0.05$ ).

**Table 1.** Monthly means ( $\pm$  S.E.) of total Hg (T-Hg) concentrations ( $\text{ng g}^{-1}$  dry wt) in planktons and muscle tissue of silver carps (*Hypophthalmichthys molitrix*) collected from Sanandaj Gheslgh Reservoir, from July to December 2010 (and the means ( $\pm$  S.E.) of total weight and length of silver carps during the study period).

| Sampling months                        | T-Hg in plankton                   | T-Hg in silver carp                  | Total weight of silver carp         | Total length of silver carp        |
|--|------------------------------------|--------------------------------------|-------------------------------------|------------------------------------|
| July                                   | $86.60 \pm 7.32$                   | $370.25 \pm 64$                      | $620.8 \pm 113.77$                  | $39.02 \pm 2.42$                   |
| August                                 | $86.81 \pm 10.9$                   | $501.75 \pm 95$                      | $881.5 \pm 52.07$                   | $45.42 \pm 1.31$                   |
| September                              | $68.00 \pm 2.52$                   | $306.25 \pm 50.5$                    | $758.9 \pm 35.03$                   | $42.30 \pm 0.14$                   |
| October                                | $73.51 \pm 7.90$                   | $332.50 \pm 35$                      | $542.77 \pm 81.97$                  | $38.25 \pm 2.08$                   |
| November                               | $76.22 \pm 1.66$                   | $297.50 \pm 54$                      | $558.92 \pm 33.85$                  | $38.92 \pm 0.9$                    |
| December                               | $78.12 \pm 10.86$                  | $394.50 \pm 52.7$                    | $631.775 \pm 97.43$                 | $40.02 \pm 2.39$                   |
| <b>Total Mean <math>\pm</math> S.E</b> | <b><math>78.21 \pm 3.13</math></b> | <b><math>367.12 \pm 26.43</math></b> | <b><math>665.7 \pm 36.94</math></b> | <b><math>40.64 \pm 0.82</math></b> |

The mean ( $\pm$  S.E.) weight of plankton masses was ( $0.597 \pm 0.094 \times 10^{-3}$   $\text{gr m}^{-3}$  dry wt per cubic meter volume of water). The highest mean was seen in December ( $1.138 \pm 0.782 \times 10^{-3}$   $\text{gr m}^{-3}$  dry wt per cubic meter volume of water), while the lowest mean was recorded in September ( $0.268 \pm 0.052 \times 10^{-3}$   $\text{gr m}^{-3}$  dry wt per cubic meter volume of water), (Table 2).

The transmission amounts of T-Hg from plankton's masses to muscle tissue of silver carp during the months of July to December 2010 in the SGR were calculated [25] as shown in Table 2. According to the mentioned method:

Eqn. 1:

Amount of T-Hg transmission by plankton

to the next trophic level ( $\text{ng m}^{-3}$  dry wt per cubic meter volume of water) = plankton's T-Hg concentration ( $\text{ng g}^{-1}$  dry wt)  $\times$  plankton's masses amount ( $\text{gr m}^{-3}$  dry wt per cubic meter volume of water)

$\text{BMF}_{\text{Hg}}$  for different months are demonstrated in Table 3. It was calculated by dividing mean accumulated T-Hg concentration in the muscle tissues of silver carps as the consumer of planktons (predator) into mean accumulated T-Hg concentration in planktons as silver carp's staple food source (prey) [26]. During the studying months, all calculated  $\text{BMF}_{\text{Hg}}$  were higher than one (Table 3).

**Table 2.** Mean T-Hg transmissions and 95% confidence interval (in parenthesis) for planktons during July to December 2010 from Sanandaj Gheshlagh Reservoir.

| Months        | T-Hg in plankton mass<br>(Mean± S.E.), (ng g <sup>-1</sup> dry wt)<br>(A) | Plankton mass<br>(Mean ± S.E. × 10 <sup>-3</sup> )<br>(gr m <sup>-3</sup> dry wt)<br>(B) | T-Hg transmission × 10 <sup>-3</sup><br>m <sup>-3</sup> (ng dry wt)<br>(A × B) |
|---------------|---|--|--|
| July          | 86.60±7.32  | 0.585 ± 0.091  | 50.66 (27.8, 41.14)  |
| August        | 86.81 ±10.9   | 0.662 ± 0.158  | 57.46 (0, 96.14)   |
| September     | 68.00 ± 2.52  | 0.268 ± 0.052  | 18.22 (0, 78.95)   |
| October       | 73.51 ± 7.90  | 0.401± 0.057   | 29.47 (0, 107.88)  |
| November      | 76.22 ± 1.66  | 0.528 ±0.142   | 40.24 (10.7, 67.73)  |
| December      | 78.12 ± 10.86   | 1.138 ± 0.782  | 88.9 (0, 187.77)   |
| Mean of total | <b>78.21 ± 3.13</b>   | <b>0.597 ± 0.094</b>   | <b>46.69 (37.07, 57.73)</b>  |

**Table 3.** Biomagnification factor ( ±S.E.) of Hg<sub>(plankton-fish)</sub> for different months (July to December, 2010) in Sanandaj Gheshlagh Reservoir.

| July        | August      | September   | October     | November    | December    | Mean total  |
|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| 4.28 ± 0.59 | 5.78 ± 0.87 | 4.50 ± 0.79 | 4.52 ± 0.46 | 3.90 ± 0.61 | 5.05 ± 0.68 | 4.69 ± 0.35 |

## DISCUSSION

In aquatic ecosystems, planktons assumed as the primary trophic level in a grazing food chain. They have short bio-cycle in aquatic ecosystems and responds quickly to the environmental changes and pollutions. Consequently, these organisms are appropriate bio-indicators for measuring accumulation of heavy metals such as Hg in these ecosystems particularly in lotic water sources [8, 23]. In addition, silver carp is an economic species, cultivated more than any other species of fish in different parts of the world after grass carp. Therefore, propagation of this species has to be accompanied with a great care and high quality assurance. Accordingly, assessing the amount of any kind of contamination including the concentration of heavy metals in edible tissues of silver carp is vital in terms of human health and safety. SGR is a naturally mercury polluted aquatic ecosystem [21, 22, 27]. Nevertheless, the qualities of SGR fisheries products have to be assessed and monitored to ensure health considerations.

The comparison of T-Hg in muscle tissue of silver carp in the present study with other species of fish in other parts of the world showed that the level of T-Hg concentration in SGR's silver carp was high and this indicated that Hg bioaccumulation occurred in muscle tissue of our silver carp (Tables 1 and 4). Mean concentration

of T-Hg in plankton biomass was also remarkable (Table 5). This was expected as it was reported that the level of Hg in SGR water was higher than Iranian standard and WHO limits (1 µg l<sup>-1</sup>) [28].

The calculated BMF<sub>Hg</sub><sub>(plankton-fish)</sub> demonstrated that Hg biomagnification was occurred from planktonic food level to silver carp's level (Table 3). Although, the higher level of T-Hg could be due to the vary sources (i.e, direct absorption from Hg polluted water and or different food sources), it seems that SGR's plankton biomass is the main sources of accumulated T-Hg in the muscle tissue of silver carp as a planktivorous fish [20]. Furthermore, this means that consumption of the SGR's silver carp must be accompanied by serious health considerations because silver carp is the most commonly consumed fish in the region. The concentration of T-Hg in the muscle tissue of all samples weighted more than 850 gr was higher than the limits allowed by US Environmental Protection Agency (300 ng g<sup>-1</sup>) and WHO (500 ng g<sup>-1</sup>) [24, 29] during all study months during present research. The highest Provisional Tolerable Weekly Intake (PTWI) of Hg for every kg of human body is 5 ppb (5 ng g<sup>-1</sup> or 5 µg/kg), [27]. Hence, a person weighing 70 kg is allowed a safe intake of up to 350 ng g<sup>-1</sup> Hg per week. Accordingly, for the silver carp from SGR, the maximum permitted consumption would be 953 gr of fish per week, with this assumption that there is no other source of Hg in the diet. The highest

BMF<sub>Hg</sub> was observed in August and since weight and length are among the most influential factors for increasing Hg concentration in the muscle tissue of fishes [2, 15, 30, 31], it seems that the higher level of measured T-Hg in the muscle tissue of SGR's silver carp in this month was due to the increasing the length and weight of fish samples during this time (Table 1 and Figure 3). Similar results were reported in previous studies [30, 31]. Also, our results showed that sex has no significant influence on the Hg accumulation rate in silver carp from SGR and Hg content is only affected by silver carp's weight and size [29].

In Tables 4 and 5, we compared T-Hg in the muscle tissue of silver carp and plankton's biomass from SGR with similar studies in other aquatic ecosystems in different parts of the world. These comparisons showed that the level of T-Hg in fish muscle depends on species type, season (time), level and sources of pollution [2]. We suggest a lab experiment to evaluate the effect of species type and different exposure time as well as different type of Hg speciation on the rate of Hg absorption in edible tissues of fish and upper trophic level members (e.g., Human) for future studies.

**Table 4.** Comparison of mean T-Hg in muscle tissue of different fish species from different regions in the world.

| Species                                   | T- Hg ( $\mu\text{g g}^{-1}$ dry wt)<br>Muscle        | Site  | References        |
|---|---|---|-------------------|
| <i>Chondrostoma toxostoma</i>             | 3.25  | Cecina River, Italy                             | [32]              |
| <i>Tilapia mossambica</i>                 | 0.14  | Mexicali valley, Mexico                         | [33]              |
| <i>Myleus rubripinnis</i>                 | 0.013   | Maroni River (French Guiana)                    | [34]              |
| <i>Epinephelus coides</i>                 | 3.923   |   |                   |
| <i>Tinca tinca</i>                        | 0.32  | Aquatic Zahlinice Ecosystem<br>(Czech Republic) | [18]              |
| <i>Ctenopharyngodon idella</i>            | 0.05  |   |                   |
| <b><i>Hypophthalmichthys molitrix</i></b> | <b>0.367</b>  | <b>SGR, Iran</b>                                | <b>This study</b> |
|   | <b>T- Hg (<math>\mu\text{g g}^{-1}</math> wet wt)</b> |   |                   |
| <i>Ciclha monoculus</i>                   | 0.35  | Amazonian region, Brazil                        | [35]              |
| <i>Hoplias malabaricus</i>                | 0.41  |   |                   |
| <i>Colossoma macropomum</i>               | 0.04  |   |                   |
| <i>Piaractus mesopotamicus</i>            | 0.09  |   |                   |
| <i>Cyprinus carpio</i>                    | 0.79  | Ya-Er Lake, China                               | [36]              |
| <i>Hypophthalmichthys molitrix</i>        | 0.429   |   |                   |
| <i>Carassius carassius</i>                | 0.423   |   |                   |
| <i>Ophiocephalus argus cantor</i>         | 0.827   |   |                   |
| <i>Ctenochromis horei</i>                 | 0.15  | Lake Tanganyika, Tanzania                       | [37]              |
| <i>Neolamprologus boulengeri</i>          | 0.2   |   |                   |
| <i>Mastacembelus cunningtoni</i>          | 0.22  |   |                   |
| <i>Clarias theodora</i>                   | 0.22  |   |                   |

**Table 5.** Comparison of mean T-Hg ( $\text{ng g}^{-1}$  dry wt) of planktons in different regions of the world and the result of this study.

| Plankton        | Location                        | Mean T-Hg ( $\text{ng g}^{-1}$ dry wt) | References        |
|-----------------|---------------------------------|--|-------------------|
| Phytoplankton   | Terra Nova bay, south pole      | 39                                     | [17]              |
| Zooplankton     |                                 | 65                                     |                   |
| Plankton        | Natural lakes of Quebec, Canada | 85 – 432                               | [38]              |
|                 | Littoral zones of reservoirs    | 360 – 671                              |                   |
|                 | Pelagic zones of reservoirs     | 70 – 538                               |                   |
| Zooplankton     | 15 study lakes, Wisconsin, USA  | 33 – 206                               | [39]              |
| Zooplankton     | Superior lake, Canada           | 44.5-101                               | [40]              |
| Plankton        | Talawaan watershed, Indonesia   | 400 – 118000                           | [8]               |
| Phytoplankton   | Grande marsh, Colombia          | 520                                    | [11]              |
| Zooplankton     |                                 | 940                                    |                   |
| <b>Plankton</b> | <b>SGR</b>                      | <b>78.21</b>                           | <b>This study</b> |

## CONCLUSION

The planktons and silver carps from the SGR are contaminated by mercury. Furthermore, during the studying period, all calculated  $BMF_{Hg}$  (plankton-fish) were higher than one, which indicated the transmission of Hg from plankton to silver carp was significant. Due to the toxic effects of Hg on human health, it is necessary to implement sever health consideration in related to consumption of silver carp from SGR. Since this reservoir is the most important fishery and drinking water source in the region, further surveys are necessary to verify the results of this study and assess the negative health effects of Hg pollution on local population as well as tracking total Hg in other living parts of SGR ecosystem.

## ACKNOWLEDGMENTS

This work was supported by Department of Environmental Sciences, University of Kurdistan. The authors would like to thank the Department of Environmental Sciences (Tarbiat Modares University). We would also like to show our gratitude to editors and anonymous reviewers of this journal for their comments on the earlier version of the manuscript. The authors also declare that there is no conflict of interests in this study.

## REFERENCES

- Eagles-Smith CA, Ackerman JT. Mercury bioaccumulation in estuarine wetland fishes: Evaluating habitats and risk to coastal wildlife. *Environ Pollut* 2014;193:147-55.
- Eisler R. Mercury hazards to living organisms: CRC Press; 2006.
- Wang X, Qu R, Wei Z, Yang X, Wang Z. Effect of water quality on mercury toxicity to *Photobacterium phosphoreum*: Model development and its application in natural waters. *Ecotoxicol Environ Saf* 2014;104:231-8.
- Zalups RK. Molecular interactions with mercury in the kidney. *Pharmacol Rev* 2000;52(1):113-44.
- Storelli M, Giacomini-Stuffler R, Marcotrigiano G. Total and methylmercury residues in cartilaginous fish from Mediterranean Sea. *Mar Pollut Bull* 2002;44(12):1354-8.
- Verta M, Salo S, Korhonen M, Porvari P, Paloheimo A, Munthe J. Climate induced thermocline change has an effect on the methyl mercury cycle in small boreal lakes. *Sci Total Environ* 2010;408(17):3639-47.
- Jagtap R, Maher W. Measurement of mercury species in sediments and soils by HPLC-ICPMS. *Microchemical J* 2015;121:65-98.
- Rumengan IF, Rumampuk D, Limbong D, Arai T, Miyazaki N. Total mercury contents in plankton collected from Talawaan Watershed, north Sulawesi, Indonesia. *Otsuchi Mar Sci* 2003;28:80-3.
- Beldowski J, Miotk M, Beldowska M, Pempkowiak J. Total, methyl and organic mercury in sediments of the Southern Baltic Sea. *Mar Pollut Bull* 2014;87(1):388-95.
- Nguetseng R, Fliedner A, Knopf B, Lebreton B, Quack M, Rüdell H. Retrospective monitoring of mercury in fish from selected European freshwater and estuary sites. *Chemosphere* 2015;134:427-34.
- Marrugo-Negrete J, Benitez LN, Olivero-Verbel J. Distribution of mercury in several environmental compartments in an aquatic ecosystem impacted by gold mining in northern Colombia. *Arch Environ Contam Toxicol* 2008;55(2):305-16.
- Sedláčková L, Kružiková K, Svobodová Z. Mercury speciation in fish muscles from major Czech rivers and assessment of health risks. *Food Chem* 2014;150:360-5.
- Mailman M, Stepnik L, Cicek N, Bodaly RD. Strategies to lower methyl mercury concentrations in hydroelectric reservoirs and lakes: A review. *Sci Total Environ* 2006;368(1):224-35.
- Gao Y, Shi Z, Long Z, Wu P, Zheng C, Hou X. Determination and speciation of mercury in environmental and biological samples by analytical atomic spectrometry. *Microchem J* 2012;103:1-14.
- Canli M, Atli G. The relationships between heavy metal (Cd, Cr, Cu, Fe, Pb, Zn) levels and the size of six Mediterranean fish species. *Environ Pollut* 2003;121(1):129-36.
- Mason R, Reinfelder J, Morel F. Bioaccumulation of mercury and methylmercury. *Mercury as a Global Pollutant*: Springer; 1995. p. 915-21.
- Bargagli R, Monaci F, Sanchez-Hernandez J, Catani D. Biomagnification of mercury in an Antarctic marine coastal food web. *Mar Ecol Prog Ser* 1998;169:65-76.
- Houserova P, Kubán V, Kráčmar S, Sitko J. Total mercury and mercury species in birds and fish in an aquatic ecosystem in the Czech Republic. *Environ pollut* 2007;145(1):185-94.
- Gobas FA, McCorquodale JR, Haffner G. Intestinal absorption and biomagnification of organochlorines. *Environ Toxicol Chem* 1993;12(3):567-76.
- Spataru P, Gophen M. Feeding behaviour of silver carp *Hypophthalmichthys molitrix* Val. and its impact on the food web in Lake Kinneret, Israel. *Hydrobiologia* 1985;120(1):53-61.

21. Akbarpour A, Nasri F, editors. Assessment of heavy metals pollution in Gheshlagh Dam watersheds, Sanandaj, Iran. Proceedings of the 22nd Symposium on Geo Science; 2004.
22. Sourì B, Watanabe M. Mercury concentration in some calcareous soils of western Iran with a focus on pedological evolution and weathering process. *Environ Earth Sci* 2013;70(3):1249-62.
23. Suthers IM, Rissik D. Plankton: A guide to their ecology and monitoring for water quality: CSIRO publishing; 2009.
24. Voegborlo R, Akagi H. Determination of mercury in fish by cold vapour atomic absorption spectrometry using an automatic mercury analyzer. *Food Chem* 2007;100(2):853-8.
25. Wong AH, McQueen DJ, Williams DD, Demers E. Transfer of mercury from benthic invertebrates to fishes in lakes with contrasting fish community structures. *Can J Fish Aquat Sci* 1997;54(6):1320-30.
26. Connell DW. Biomagnification by aquatic organisms-a proposal. *Chemosphere* 1989;19(10-11):1573-84.
27. Khoshnamvand M, Kaboodvandpour S, Ghiasi F. A comparative study of accumulated total mercury among white muscle, red muscle and liver tissues of common carp and silver carp from the Sanandaj Gheshlagh Reservoir in Iran. *Chemosphere* 2013;90(3):1236-41.
28. Amani K. Determination of pollutants concentration in Sanandaj Gheshlagh Reservoir water and its branches. Department of Environment Protection. Sanandaj, Iran; 2008.p.127-8.
29. Jewett SC, Zhang X, Naidu AS, Kelley JJ, Dasher D, Duffy LK. Comparison of mercury and methylmercury in northern pike and Arctic grayling from western Alaska rivers. *Chemosphere* 2003;50(3):383-92.
30. Romeo M, Siau Y, Sidoumou Zn, Gnassia-Barelli M. Heavy metal distribution in different fish species from the Mauritania coast. *Sci Total Environ* 1999;232(3):169-75.
31. Farkas A, Salánki J, Specziár A. Age-and size-specific patterns of heavy metals in the organs of freshwater fish *Abramis brama* L. populating a low-contaminated site. *Water Res* 2003;37(5):959-64.
32. Scerbo R, Ristori T, Stefanini B, De Ranieri S, Barghigiani C. Mercury assessment and evaluation of its impact on fish in the Cecina river basin (Tuscany, Italy). *Environ pollut* 2005;135(1):179-86.
33. Gutiérrez-Galindo EA, Muñoz GF, Flores AA. Mercury in freshwater fish and clams from the Cerro Prieto geothermal field of Baja California, Mexico. *Bull Environ Contam Toxicol* 1988;41(2):201-7.
34. Régine M-B, Gilles D, Yannick D, Alain B. Mercury distribution in fish organs and food regimes: Significant relationships from twelve species collected in French Guiana (Amazonian basin). *Sci Total Environ* 2006;368(1):262-70.
35. Farias RAd, Hacon S, Campos R, Argento R. Mercury contamination in farmed fish setup on former garimpo mining areas in the Northern Mato Grosso State, Amazonian region, Brazil. *Sci Total Environ* 2005;348(1):128-34.
36. Jin L, Liang L, Jiang G, Xu Y. Methylmercury, total mercury and total selenium in four common freshwater fish species from Ya-Er Lake, China. *Environ Geochem Health* 2006;28(5):401-7.
37. Campbell L, Verburg P, Dixon D, Hecky R. Mercury biomagnification in the food web of Lake Tanganyika (Tanzania, East Africa). *Sci Total Environ* 2008;402(2):184-91.
38. Tremblay A, Lucotte M, Schetagne R. Total mercury and methylmercury accumulation in zooplankton of hydroelectric reservoirs in northern Quebec (Canada). *Sci Total Environ* 1998;213(1):307-15.
39. Watras C, Back R, Halvorsen S, Hudson R, Morrison K, Wente S. Bioaccumulation of mercury in pelagic freshwater food webs. *Sci Total Environ* 1998;219(2):183-208.
40. Back RC, Gorski PR, Cleckner LB, Hurley JP. Mercury content and speciation in the plankton and benthos of Lake Superior. *Sci Total Environ* 2003;304(1):349-54.