



Total mercury and methylmercury concentrations in native and invasive fish species in Shadegan International Wetland, Iran, and health risk assessment

Zahedeh Rahmanikhah¹ · Abbas Esmaili-sari¹ · Nader Bahramifar¹

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Abstract

Human exposure to mercury (Hg) mainly occurs through consumption of aquatics, especially fish. In aquatic systems, the bioaccumulation of Hg across trophic levels could be altered by invasive species through changing community composition. The present study is aimed at measuring total mercury (T-Hg) and methylmercury (MeHg) concentrations in non-native (redbelly tilapia (*Tilapia zillii*)) and native (Benni (*Mesopotamichthys sharpeyi*) and common carp (*Cyprinus carpio*)) fish species throughout Shadegan International Wetland and comparing health risk of their mercury contents to the local population. The concentrations were measured using a direct mercury analyzer (DMA 80). The average values of T-Hg and MeHg for native fishes were 19.8 and 10.49 µg/kg. These concentrations for the invasive fish were 28 and 14.62 µg/kg respectively. Despite having less length and weight than the native fish species, tilapia showed significantly higher T-Hg content, yet the lowest concentration of MeHg was observed in common carp with larger body length and weight. Concerning mercury health risk to consumers, tilapia demonstrated the highest estimated weekly intake (EWI) and percentages of tolerable weekly intake (%TWI) for both T-Hg and MeHg, while the highest hazard quotient (HQ) values were obtained for tilapia and Benni. Taken together, the mercury concentrations in the two native and non-native fishes were acceptable according to the international safety guidelines although the local people shall be warned for consumption of tilapia. Furthermore, the low calculated value of tissue residue criterion (TRC) for the wetland fishes sounds a warning.

Keywords Methylmercury · Invasive species · Tilapia · Shadegan Wetland · Risk assessment · TRC

Introduction

Mercury (Hg) is a toxic element globally distributed and found in high concentrations in the aquatic environments. Human exposure to Hg mainly occurs through consumption of aquatics, especially fish which, if contaminated and be consumed long term and frequent, put people at high risk of being poisoned

(Sunderland 2006; Bonsignore et al. 2013; Di Lena et al. 2017; Jinadasa and Fowler 2019). In aquatic ecosystems, inorganic form of Hg (Hg²⁺) is converted to methylmercury (MeHg) by sulfate- and iron-reducing bacteria. MeHg has attracted special attention among alkyl mercury species (Me₂Hg, Et₂Hg, MeHgCl, and EtHgCl) because it binds with protein sulfhydryl group in the tissues of organisms and is highly bioaccumulable and biomagnificable throughout the aquatic trophic levels (i.e., food chain), consequently posing the highest risk of toxicity in humans. Organisms occupying higher trophic levels tend to accumulate larger loads of MeHg, thereby bringing adverse effects to human beings (Carrasco et al. 2011; La Colla et al. 2019). For this reason, many national agencies such as the European Commission (EC), the US Environmental Protection Agency (USEPA), and the World Health Organization (WHO) have issued guidelines to safeguard human health against consumption of fish taken from Hg-contaminated water bodies (European Commission 2004; USEPA 2000, 2001b; WHO 2008).

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- ✉ Zahedeh Rahmanikhah
z.rahmanikhah@modares.ac.ir; rahmanikhah4@gmail.com
- ✉ Abbas Esmaili-sari
Esmaili@modares.ac.ir

¹ Department of Environment, Faculty of Natural Resources and Marine Science, Tarbiat Modares University, P.O. Box 46414-356, Noor, Mazandaran, Iran

Wetlands are of high important ecological systems where approximately 40% of world's species live and breed providing a source of livelihood for more than a billion people (Gardner et al. 2015). Regionally, continental distribution of wetland areas is as order of Asia (31.8%), North America (27.1%), Latin America, and the Caribbean (15.8%), Europe (12.5%), Africa (9.9%), and Oceania (2.9%) (Davidson et al. 2018). However, these systems are under serious threat of loss and degradation from human impacts, and this occurrence consequently reduces wetland services to dependent people (Davidson 2018). Due to special biogeochemical conditions in wetlands, chemical contaminants have reduced the quality of wetland habitats and endangered their biota (Eagles-Smith and Ackerman 2014). Freshwater wetlands are faced with two major challenges, contaminants and invasive species which endanger the ecosystem services, especially food and water security (Eagles-Smith et al. 2008).

Wetlands are vulnerable to invasive and opportunistic species (Zedler and Kercher 2004). That is, invaders can substantially alter characteristics of aquatic ecosystems such as community composition and ecosystem energetics. These changes could potentially disrupt many ecosystem phenomena, including the accumulation and magnification of bioaccumulative and biomagnifying contaminants such as Hg through trophic pathways of food webs (Johnson et al. 2014).

Shadegan International Wetland, with an area of 537,731 ha, is the largest wetland in Iran and the 34th of the 1201 registered Ramsar sites in the world (Kaffashi et al. 2012). It has been recorded in the UNESCO's Natural Heritage List and designated as a wildlife sanctuary in 1974 (Chaharlang et al. 2016). Although being well known as a unique natural ecosystem with great national and international significance, the wetland is suffering from many pollution sources, including agricultural runoff, urban and industrial wastewater, and solid wastes (Hosseini Alhashemi et al. 2011). In addition to pollutants, the redbelly tilapia (*Tilapia zillii*) as a non-native fish species has complicated and exacerbated the ecological status of the wetland. Tilapia is omnivorous, is tolerant of a wide range of environmental conditions, and has a rapid growth rate and high fecundity. This species has displaced resident taxa, degraded trophic cascades (community composition), and altered ecosystem energetics (Khaefi et al. 2014). Consequently, the considerable success of the invader fish has decreased the population of the native species and in turn made them a predominant food for local inhabitants. The increased consumption of this invasive fish (redbelly tilapia) necessitates the assessment of human health to pollutants. Owing to be a generalist in feeding habits, the redbelly tilapia has a potential for food chain lengthening and/or shortening through competition and predation and, in turn, could change health threat for consumers due to altering the pollutant accumulation pathways. In the present study, we measured total mercury (T-Hg) and methylmercury (MeHg)

in two native (Benni (*Mesopotamichthys sharpeyi*) and common carp (*Cyprinus carpio*)) and one non-native (redbelly tilapia (*Tilapia zillii*)) fish species from sites throughout Shadegan International Wetland. Subsequently, we compared and evaluated the following indices between the native and invasive fish species: ratios of Hg to MeHg, hazard quotient (HQ), and health risk of local inhabitants based on standards of WHO and USEPA. In addition, tissue residue criterion (TRC) for fish was also investigated in this wetland.

Material and methods

Study area

This study was conducted along Shadegan Wetland located in Khuzestan province at the head of the Persian Gulf (30° 00'–31° 00' N and 48° 20'–49° 20' E; Fig. 1). There are several town and villages surrounding the wetland on which the livelihood of about one hundred thousand of people depends. Fishing is their main occupation and fish is the staple food.

Questionnaire

In order to sample fishes for Hg measurements, first we had to identify the most popular fish species among the wetland residents. We asked the residents to fill in a questionnaire to identify the most popular fish and attain other necessary information to calculate the wetland TRC and health risk assessment of marginalized people as well.

The primary communities exposed to these contaminated fish were the adjacent villages where there is the most dependency on the wetland. Four villages close to the wetland fisheries were chosen. Firstly, in each village, a random set of households (proportional to the village population) were selected. The total number of households to be questioned was determined using the Fisher equation (1998). This equation calculates sample size from an unknown population. In this study, the percentage of the population consuming fish at least once a week was needed to be determined in the region, which according to the local Department of Health and Nutrition was 80%. The questionnaire was conducted in February and March 2017 over a total number of 246 households in all four villages. The questionnaire was designed to figure out the following information: (1) the most common fish species consumed from the wetland and the sea, (2) the number of meals containing fish per week, (3) the weekly incidences of tilapia consumption, (4) the amount of fish used per meal, and (5) body weight of the person who is questioned and 6-controlling questions (the accuracy of the answers was evaluated with questions about the type and amount of fish consumed in the last meal).

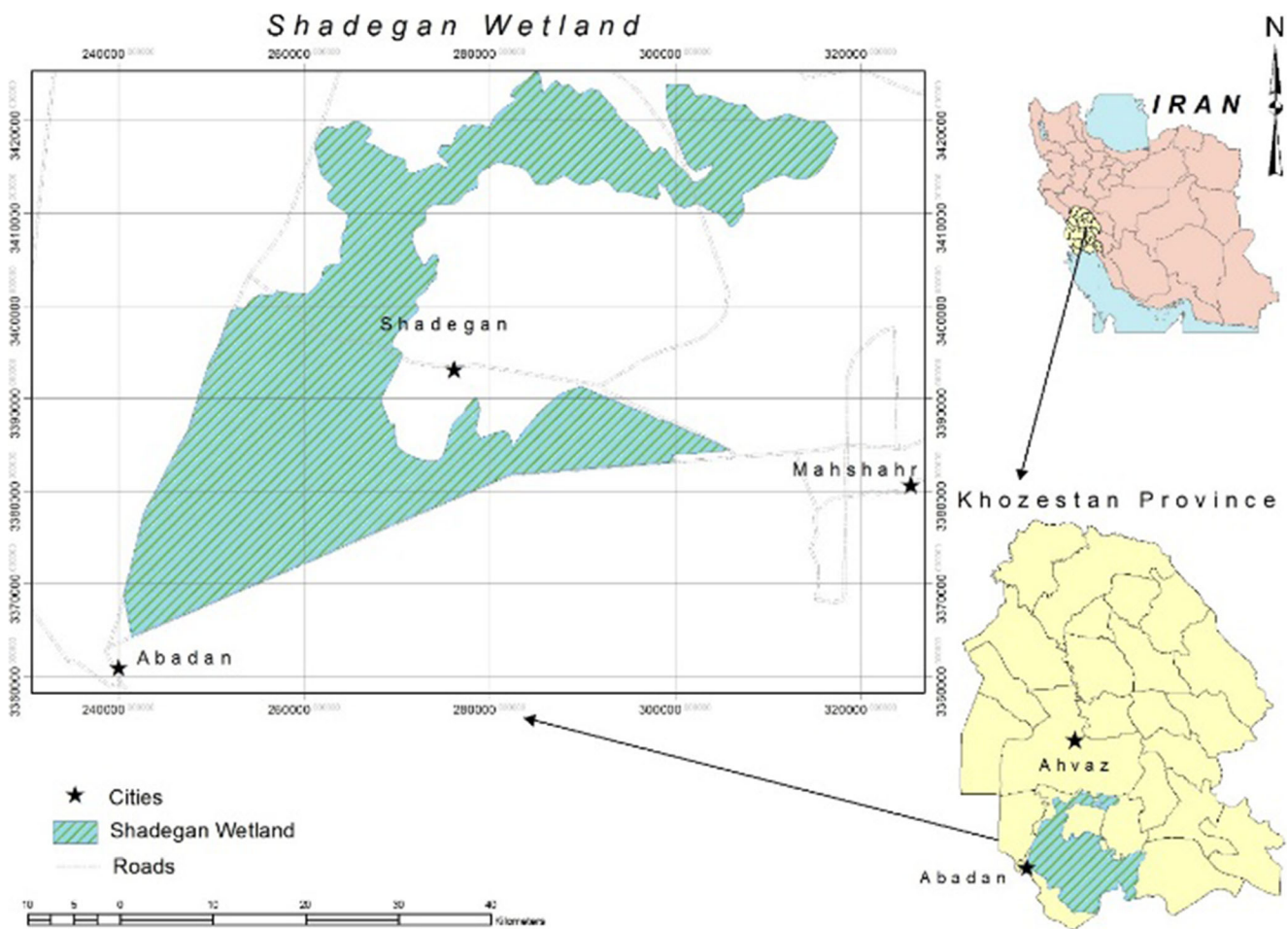


Fig. 1 Map of the Shadegan Wetland

The analysis of the questionnaires indicates that the local inhabitants mostly ate Benni and common carp (i.e., the highest consumption), and tilapia at least once a week.

Fish sample collection

After analyzing the questionnaire results, the most commonly used fishes, including *T. zillii* (tilapia), *C. carpio* (carp), and *M. sharpeyi* (Benni), were sampled. All of the species were forage or omnivore, and the samples were tried to be at the typical size often caught by the local inhabitants which is around 1 kg.

To assess the T-Hg and MeHg concentrations in the muscle tissue of the three above-mentioned fish species, a total of 53 fishes were sampled. The sampling process was conducted in April 2017, and all of the sampling locations were close to the main fisheries. The samples were caught during the night with a bottom gillnet. Each sample was carried while wearing gloves (vinyl gloves free from powder), individually wrapped in aluminum foil, packed in two plastic bags, and then labeled and stored on ice (USEPA 2000). After transporting them to the laboratory, the fishes were rinsed and their length and

weight were measured. Then, the samples were filleted and a portion of the dorsal muscle tissue was bagged and frozen until mercury measurement.

Chemicals, reagents, and instruments

HgCl₂ (99.5%, Merck, Sigma) standard solution was prepared by dissolving the appropriate amount of salt in nitric acid 65% and deionized water. Methylmercury (II) chloride (95%, ALFA Aesar) standard solution was prepared by dissolving salt in methanol and deionized water.

The solvents were methanol (99%) and toluene (99%), and the acids were hydrochloric acid (37%) and nitric acid (65%) (all Merck). The reagents were sodium bromide (99%, Merck), L-cysteine hydrochloride monohydrate (98.5%, Merck), sodium acetate (99%, LOBA Chemie), and sodium sulfate anhydrous (99%, Merck). L-Cysteine solution (1% v/w) was prepared daily by dissolving 1 g L-cysteine chlorohydrate, 12.5 g anhydrous sodium sulfate, and 0.775 g sodium acetate in deionized water to 100 ml.

The samples and chemicals were weighed using an analytical balance (KERN ALJ-A/AM). The shaking system was an

orbital shaker (FSA model: OS20LD). A centrifuge (Centurion Scientific EB Series) was used to separate phases during the extraction process. Total mercury and methylmercury concentrations were measured using a dual-cell direct mercury analyzer (DMA 80; Milestones SrL, Italy). It was calibrated between the range of 5 µg/kg and 2 mg/kg Hg, and the absorbance was measured at 253.7 nm as a function of mercury concentration.

Mercury measurement

No pretreatment was done to measure the T-Hg concentration. The samples were taken out of the freezer 1 h before the analysis to reach to room temperature (Ipolyi et al. 2004). The muscles were homogenized, and about 0.02 g wet tissue was weighed into a nickel combustion vessel and introduced in the DMA 80, a thermal decomposition, amalgamation/atomic absorption spectrophotometry (TDA/AAS) technique according to the 7473 method of USEPA (USEPA 2007).

To extract methylmercury, a modified method was used; about 2 g of the wet homogenized tissue was weighted into a 20-ml glass tube. 0.5 g NaBr and 10 ml HCl were added, and the suspension was shaken for 5 min using a mechanical shaker. Then, 8 ml toluene was added and vigorously shaken for 20 min again. The final suspension was centrifuged at 3000 rpm for 20 min, and the above organic phase containing methylmercury was taken with a pasture glass pipette and spilled into another glass tube containing 6 ml of L-cysteine solution 1% (v/w). To ensure the complete extraction of MeHg, 7 ml toluene was added to a tube containing HCl, mixed and centrifuged, and then upper phase was collected and added to previous value of toluene.

The back extraction of methylmercury from organic to aqueous phase was performed; the tube containing about 15 ml toluene and 6 ml L-cysteine aqueous solution was shaken vigorously for 20 min and centrifuged for 20 min at 3000 rpm. The lower aqueous phase (3–4 ml; L-cysteine solution containing methylmercury) was taken and placed into a smaller glass vial and stored in the fridge until the analysis. This extract is stable up to a week in glass vials in the refrigerator (Calderón et al. 2013; Maggi et al. 2009; Aazami et al. 2011). Finally, 100 µl of the extract was introduced into the DMA auto sampler to detect MeHg concentration.

Quality control

To prevent error in Hg and MeHg measurements in low amounts, the laboratory dishes particularly the glasswares were washed with diluted nitric acid and ultrapure water and then dried (Fernández-Martínez and Rucandio 2013). The limits of detection (LOD) and quantification (LOQ) were determined based on 3 and 10 times the standard deviation of 10 blanks divided by the slope of the calibration curve. LOD

was 1.05 µg kg⁻¹ and LOQ was 3.5 µg kg⁻¹. The accuracy of the chemical analysis of total mercury and methylmercury was checked using samples spiked with standard solutions of mercury and methylmercury, respectively. Recovery varied between 88 and 107% for total mercury and ranged from 85 to 108% for methylmercury. The used standard reference material (SRM) for accuracy of the method was NRC TORT-2 (Institute for National Measurement Standards, Canada) for T-Hg and MeHg. The percent recoveries were between 90 and 101% for T-Hg and between 88 and 97% for MeHg. In order to check reproducibility of the method, some of the measurements of the different samples and extracts were replicated (3 replications for the same one) and the relative standard deviation (RSD) was obtained lower than 2.6%. Moreover, a blank reagent sample was extracted and analyzed for MeHg content along with the other samples by performing all of the extraction process without including the fish sample to ensure that no mercury contamination exist in the reagent materials.

Health risk assessment

Risk assessment method evaluates or estimates the risk of a pollutant for a given population (Okati and Esmaili-sari 2018). To assess the health risk of mercury for people living next to Shadegan Wetland, weekly intake of Hg was estimated using Eq. 1 (USEPA 2001b):

$$EWI = C_m \times IR / BW \quad (1)$$

where EWI is the estimated weekly intakes (µg/kg), C_m is the mercury concentration in the fish muscle (µg/g), IR is the intake rate of fish consumed per week (g), and BW is the human body weight (kg). The exact amount of fish consumption and the average body weight were determined using the results of the questionnaires. The average value of IR and BW for the people in the vicinity of the wetland was 2310 g/week and 76.5 kg respectively.

The potential environmental risk assessment was calculated by the following equation (USEPA 2001b):

$$HQ = EDI / RfD \quad (2)$$

where HQ is the hazard quotient, EDI is the estimated daily intake (µg Hg/kg bw day), and RfD is the reference dose. EDI is resulted from EWI divided by 7, and RfD is the USEPA reference dose based on noncancer effects for human health (0.1 µg Hg/kg bw day) or acceptable daily intake determined by WHO (0.23 µg Hg/kg bw day).

Tissue residue criterion

Tissue residue criterion is the amount of the contaminant concentration in fish tissue that is allowed based on the

total fish consumption-weighted rate of the target population (USEPA 2001a).

According to the EPA recommendation, developing a TRC and subsequently water quality criterion for methylmercury using local data (e.g., the fish consumption rate) rather than the default values is ideal (USEPA 2010). The methylmercury fish tissue residue criterion for freshwater and estuarine fish is calculated as:

$$TRC = [BW \times (RfD - RSC)] / FI \tag{3}$$

where TRC is the tissue residue criterion in fish (mg methylmercury/kg fish), RfD is the reference dose of 0.0001 mg methylmercury/kg body weight-day, RSC is the relative source contribution (mg methylmercury/kg body weight-day) (RSC will be subtracted from RfD amount if marine fish is consumed), BW is the human body weight (kg), and FI is the fish intake (kg/day).

According to the questionnaire results in this study, target population did not consume any marine fish and so RSC was considered zero amount.

This could be a criterion for monitoring the wetland to provide the inhabitants health.

Statistical analysis

Data analysis was performed using SPSS software (version 13.0). All results are presented as the mean ± standard deviation (SD). The Kolmogorov–Smirnov test was applied to assess the normality and homogeneity of the T-Hg and MeHg data. Significant differences were determined using one-way ANOVA, followed by the Tukey test to compare the means of T-Hg and MeHg concentrations as well as the length and weight among the fish species. The differences were considered statistically significant when $p < 0.05$. The relationship between the T-Hg and MeHg concentrations and the length of each species were evaluated by Pearson’s correlation analysis. One sample t test was performed to compare methylmercury concentrations with the calculated TRC for the wetland.

Results and discussion

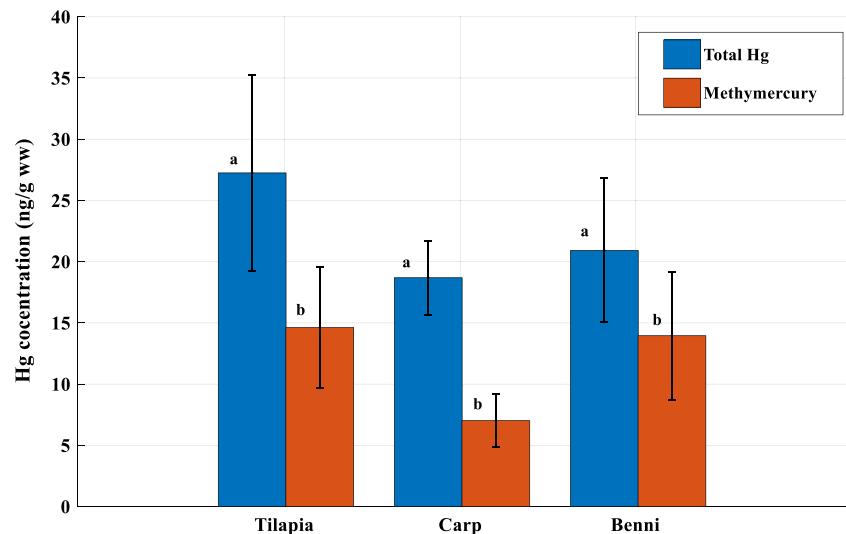
The amounts of the two measured forms of mercury in the three fish species are presented in Table 1. T-Hg and MeHg were in the range of 14 to 43 $\mu\text{g kg}^{-1}$ ww and 4 to 28 $\mu\text{g kg}^{-1}$ ww, respectively. The highest level of T-Hg (43 $\mu\text{g/kg}$ ww) was detected in tilapia with a length of 19.1 cm and a weight of 137 g. The average values of T-Hg and MeHg for native fishes were 19.8 and 10.49 $\mu\text{g/kg}$. These concentrations for the invasive fish were 28 and 14.62 $\mu\text{g/kg}$ respectively. In general, tilapia exhibited significantly higher concentration of T-Hg when compared with the two native fish species ($p < 0.05$) (Fig. 2). As Fig. 2 shows, common carp had significantly lower concentration of methylmercury in comparison with tilapia and Benni while there was no significant difference between methylmercury contents of tilapia and Benni. In 2010, a study was conducted on *M. sharpeyi* and reported levels of T-Hg (0.042 mg/kg dry weight) which was similar to the observed data in the present study (Taravati et al. 2012). Another research measured the two forms of mercury in common carp in the Ya-Er Lake of China exhibited fairly similar contents of T-Hg and MeHg (78.88, 39.29 $\mu\text{g/kg}$ ww, respectively) as well as the ratio of MeHg to T-Hg (44%) (Jin et al. 2006). In addition, according to the established guidelines, all of the detected levels of methylmercury in the native and non-native fish species were lower than the maximum level (0.5 mg/kg ww) reported by WHO and FAO (FAO/WHO 2011).

Total mercury accumulation in fish is associated with fish species as well as environmental and ecological parameters, such as nutritional habits, status of the species in food web position, and habitat pollution (Polak-Juszczak 2017). Fish position in food chain is very effective in mercury bioaccumulation. All three fishes are omnivore with different food preferences, and there is a slight difference in their trophic levels. The food of Benni often contains plants. Common carp feeds on benthic organisms, plant material, and organic sewage (Coad 2019). Tilapia can replace its food sources and consumes macrophytes, detritus, phytoplankton, and insects. It browses on live benthic and midwater invertebrates but does not disturb the bottom as aggressively as common carp;

Table 1 The concentrations of T-Hg ($\mu\text{g/kg}$ ww) and MeHg ($\mu\text{g/kg}$ ww) in muscle tissue of two native and one non-native fish species and the ratio of MeHg to T-Hg (mean ± SD, and range)

| Species | Fish type | n | Weight (g) | Length (cm) | T-Hg (ng/g ww) | MeHg (ng/g ww) | %MeHg in Hg |
|--|-----------|----|-----------------|--------------|----------------|----------------|---------------|
| Benni (<i>Mesopotamichthys sharpeyi</i>) | Native | 15 | 353.67 ± 120.57 | 30.46 ± 3.62 | 20.92 ± 5.88 | 13.95 ± 5.23 | 66.06 ± 12.41 |
| | | | 190.00–517.00 | 24.30–35.00 | 15.31–36.88 | 8.42–27.95 | 46.89–84.41 |
| Common carp (<i>Cyprinus carpio</i>) | Native | 18 | 532.00 ± 392.75 | 31.10 ± 5.62 | 18.69 ± 3.02 | 7.02 ± 2.16 | 37.30 ± 8.45 |
| | | | 204.00–1637.00 | 25.00–46.40 | 13.97–24.05 | 4.23–12.41 | 28.26–59.01 |
| Tilapia (<i>Tilapia zillii</i>) | Invasive | 20 | 124.71 ± 33.28 | 18.52 ± 1.39 | 28.00 ± 8.54 | 14.62 ± 4.91 | 53.28 ± 3.66 |
| | | | 89.00–219.00 | 16.70–22.00 | 13.97–43.00 | 7.43–24.59 | 46.31–60.10 |

Fig. 2 Comparison of total and methylmercury concentrations in two native (Benni and common carp) and one non-native (tilapia) fish species. The letters a and b indicate the existence of significant difference (statistical comparisons were done for T-Hg and MeHg separately)



juvenile tilapia also consumes larval fish, and adults frequently feed on macrophytes (Dadebo et al. 2014; Tilapia Farming website 2012). It is unclear which food sources of fish in the wetland are more contaminant with mercury. This is remarkable that rapidly growing fish (e.g., tilapia) accumulate Hg faster than slow growing ones (Dutton 1997).

The three fish species exhibited different means of length and weight: tilapia, 18.46 cm and 123.5 g; common carp, 31.1 cm and 532 g; and Benni, 30.46 cm and 353.67 g (Table 1). Despite having less length and weight than the native fish species, tilapia showed significantly higher T-Hg content ($p < 0.05$). However, the lowest concentration of MeHg was observed in common carp with larger body length and weight which could be attributed to somatic growth dilution as a mechanism for reducing bioaccumulation (Pickhardt et al. 2005). The correlation of T-Hg and MeHg concentrations with fish length displayed different species-related values (Table 2). As to T-Hg, the highest ($r = 0.759$) and lowest ($r = 0.077$) correlation was observed for tilapia and Benni, respectively. For MeHg, the order of common carp > tilapia > Benni was observed.

The highest amounts (about 80 to 100%) of bioaccumulated MeHg in a food web could be detected in fish species occupying the third and fourth levels of a food chain and are older than 3 years. These aquatics have enough lifespan to accumulate mercury (USEPA 2009). To evaluate this item, we used the

study that Fatemi et al. did in 2009. They examined the relationship between age, weight, and length of common carp in Iran. Comparing the length and weight of carp fish in this study with their results showed that the majority of our fish samples were at the age of 2 to 3 years. There were only two cases of 5 years and one 6 years old among the samples. In the present study, higher concentration of methylmercury was observed for common carp with 5 and 6 years (but not 80 to 100%).

The ratio of MeHg to T-Hg concentration (express as a percentage) was 34% (in 25–34 cm) and 54% (in 38–46 cm) for common carp, and it was 53% (in 24–27 cm) and 75% (in 31–35 cm) for Benni. There were not such variations for tilapia because it is a fish with a small size. This percent value was 53% for tilapia samples.

Health risk assessment

In the present study, we used EWI, %TWI, and HQs to assess mercury health risk associated with fish consumption (see Table 3). Tilapia demonstrated the highest EWI and percentage of TWI for both T-Hg and MeHg, and the Benni samples were at the next lower level. %TWI of T-Hg and MeHg in the native fish species ranged between 10.5–27.75 and 7.93–52.84, respectively. For the non-native fish, this value varied from 10.57 to 32.46 and 13.96 to 46.42. Analysis of the questionnaire illustrated that fish consumption by native people is

Table 2 Statistical analysis results of correlations between T-Hg and MeHg concentrations with fish length of each fish species. p value > 0.05 shows no correlation and < 0.01 shows correlation at 99%

| Species | Fish type | n | R (T-Hg) | p value | R (MeHg) | p value |
|--|-----------|-----|------------|-----------|------------|-----------|
| Benni (<i>Mesopotamichthys sharpeyi</i>) | Native | 15 | 0.08 | > 0.05 | 0.48 | > 0.05 |
| Common carp (<i>Cyprinus carpio</i>) | Native | 18 | 0.31 | > 0.05 | 0.88 | < 0.01 |
| Tilapia (<i>Tilapia zillii</i>) | Invasive | 20 | 0.76 | < 0.01 | 0.81 | < 0.01 |

Table 3 Estimated weekly intake (EWI) and share percent of EWI in TWI (%TWI) based on the standards of FAO/WHO (4 µg/kg bw for Hg and 1.6 µg/kg bw for MeHg (JECFA 2007, 2011)), estimated daily intake

(EDI) of MeHg and hazard quotient (HQ) based on RfD of USEPA (a) and acceptable daily intake determined by WHO (b). All parameters were calculated with average concentrations of T-Hg and MeHg

| Species | Fish type | EWI (total Hg) | %TWI (total Hg) | EWI (MeHg) | %TWI (MeHg) | EDI (MeHg) | HQ (a) | HQ (b) |
|--|-----------|----------------|-----------------|------------|-------------|------------|--------|--------|
| Benni (<i>Mesopotamichthys sharpeyi</i>) | Native | 0.63 | 15.75 | 0.42 | 26.25 | 0.06 | 0.60 | 0.26 |
| Common carp (<i>Cyprinus carpio</i>) | Native | 0.56 | 14.00 | 0.21 | 13.12 | 0.03 | 0.30 | 0.13 |
| Tilapia (<i>Tilapia zillii</i>) | Invasive | 0.84 | 21.00 | 0.44 | 27.5 | 0.06 | 0.60 | 0.26 |

three times per week and in their typical fish meals they use common carp, Benni, and tilapia. Considering the consumption of all three fishes, therefore, the EWI values for T-Hg and MeHg were 0.68 and 0.36, respectively, and the local people exposure to T-Hg and MeHg are about 17% and 22.5% of the safe amount established by WHO. The variation of EWI was more for MeHg than for T-Hg; the maximum percentage for MeHg was much higher than that for T-Hg suggesting the fact that the measurement of MeHg in fish is more reliable than T-Hg for health risk assessment.

A HQ value < 1.0 means that health risk is insignificant (Liu et al. 2009). Generally speaking, the low, moderate, and high health risk for mercury pertains to HQ of 0.1 to 1, 1.1 to 10, and HQ > 10, respectively (Rantetampang and Mallongi 2014). The highest HQ values were obtained for tilapia and Benni, yet the lowest for common carp. This result suggests that the mercury concentrations in the muscle tissue of these fish species would not present unacceptable risk to humans.

TRC

In this study, we also calculated the fish tissue residue criterion (TRC) based on fish consumption pattern of local inhabitants.

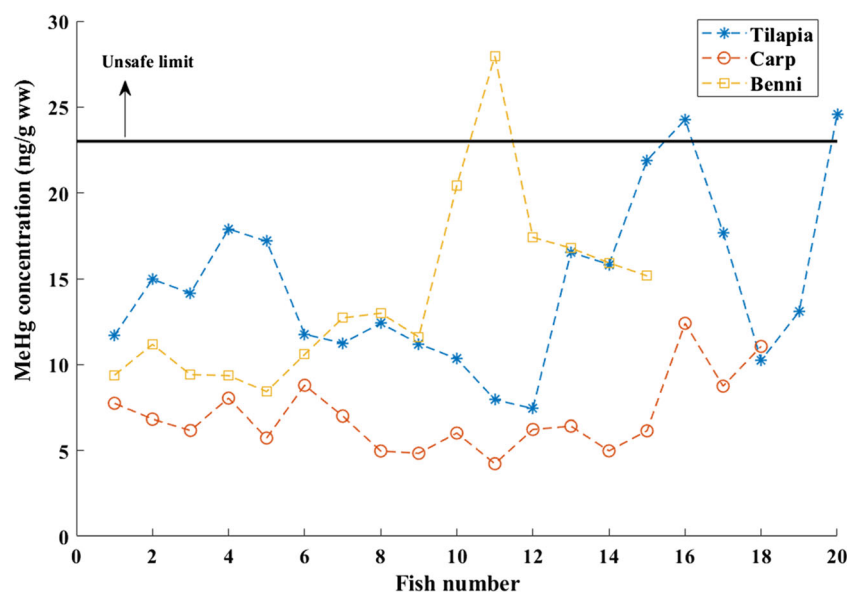
The TRC represents an allowable limit for fish mercury concentration in this study area.

From the EPA viewpoint, obtaining a fish tissue residue water quality criterion for methylmercury rather than a column-based water quality criterion is more appropriate since TRC represents spatial and temporal complexities happening in aquatic ecosystems. One other problem is that the TRC interferes with methylmercury bioaccumulation. Furthermore, measuring the concentration of methylmercury in fish tissue is easier than that in water and is less changeable over time.

The average value of the fish TRC was calculated 0.023 mg/kg using Eq. 3. It was a low value compared with EPA default value (0.3 mg methylmercury/kg fish). EPA calculates TRC based on default values for FI (17.5 g fish/day) and BW (70 kg) (USEPA 2010). As Fig. 3 depicts, the methylmercury concentrations in the wetland fish samples were significantly lower than the TRC value ($p < 0.01$). The high rate of fish consumption (FI) by local inhabitants has decreased the TRC, but the low mercury amount in the fishes has compensated it fairly.

Low amount of TRC sounds a warning for this wetland because local inhabitants are heavily dependent on its

Fig. 3 Comparison of MeHg concentrations of the fishes (ng/g) with the wetland calculated TRC (23 ng/g). The unsafe limit is shown with a horizontal line



resources and a slight increase in the amount of mercury concentration puts them at high levels of health risk.

Conclusion

This is the first study comparing mercury bioaccumulation in non-native fish with native fish species in Iran (Shadegan International Wetland), and the findings make several contributions to the current literature. From the human health risk point of view, the mercury concentrations in the two native and non-native fishes were acceptable according to international safety guidelines. Even if tilapia is completely replaced by the two other species, there will still be a low health risk for mercury poisoning. However, the generalizability of these results is subject to a certain limitation; the health risk assessment was not carried out for pregnant women and children who are always at higher risks.

The low concentration of mercury measured for tissue residue criterion necessitates a consistent monitoring of the mercury concentration in the wetland fish.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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