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Multiple approaches to assess human health risks from carcinogenic and non-carcinogenic metals via consumption of five fish species from a large reservoir in Turkey

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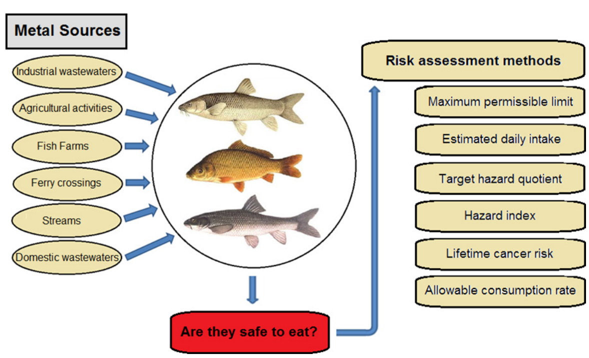
HIGHLIGHTS

- Metal concentrations in fish species were below the maximum permissible levels.
- EDI, THQ, TTHQ and CR were estimated for non-carcinogenic and carcinogenic risks.
- Fish consumption limits were determined to minimize risks to human health.

GRAPHICAL ABSTRACT



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ABSTRACT

Keban Dam Reservoir (KDR), located on the Euphrates River (Turkey), is an internationally important reservoir. In this study, levels of ten metals in 220 muscle samples of five fish species (mangar, common carp, Tigris scraper, Euphrates barbell and trout barb) taken from 11 sampling sites in the KDR were determined and compared with the results of previous studies carried out in other countries and Turkey. In addition, multiple approaches were used to assess human health risks from fish consumption. The significant spatial differences in concentrations of studied metals except As and Ni in Euphrates barbell were not found. However, concentrations of all metals except Cd showed significant seasonal differences. The concentrations of ten metals in fish species were lower than or comparable to those in fish species from other freshwater bodies. The metal concentrations in all fish species were found below the maximum permissible concentrations. No health risks of studied heavy metals on human were found by daily fish intake. The target hazard quotient (THQ) and total THQ values were below 1, which suggests there are no significant non-carcinogenic health risks for fish consumers. The cancer risk values calculated for inorganic arsenic in all fish species except Euphrates barbell did not exceed the 10^{-6} threshold. The allowable number of fish meals per month can be categorized as safe fish consumption. The results of this study revealed that the consumption of the examined fish species does not pose a significant risk to human health.

1. Introduction

Fish is an important part of a healthy human diet as it is an excellent source of high quality proteins, long chain omega-3 fatty acids, essential

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elements and liposoluble vitamins (Bosch et al., 2016; Rahman et al., 2012). It is recommended by the American Heart Association to eating fish at least twice a week, because two essential omega-3 fatty acids (DHA and EPA) found in fish may prevent blood clots, improve blood pressure, stabilize heart rhythms and reduce the risk of a heart attack (Neff et al., 2014; Fallah et al., 2011). Even though fish consumption provides numerous health benefits, fish can contain certain environmental contaminants, such as toxic metals, PCBs, pesticides, dioxins and PAHs, which may cause adverse effects on human health (Hellberg et al., 2012).

Due to their toxicological effects, non-biodegradable nature, bioaccumulation and biomagnification in the food chain and high persistence, heavy metal(loid)s are dangerous pollutants in the aquatic ecosystems (Noel et al., 2013; Djedjibegovic et al., 2012; Bosch et al., 2016; Karadede et al., 2004; Ferreira et al., 2008; Kelly et al., 2008; Shakoor et al., 2018; Waqas et al., 2017). Metals can be classified as essential, probably essential and non-essential. Cobalt, copper, zinc, iron and selenium are regarded as nutritionally essential elements because they play a significant role in human metabolism. Nickel, vanadium and boron are considered as probably essential elements which are not known to be essential to human health but may have some beneficial effects at low exposure levels. Arsenic, mercury, cadmium and lead are non-essential elements, with no known nutritional or beneficial effects and even with harmful effects at low concentrations. In addition, both essential and probably essential elements can also lead to toxic effects at high concentrations (Wei et al., 2014; Tuzen, 2009; Goyer et al., 2004; Makedonski et al., 2017; Raza et al., 2017; Shakoor et al., 2016).

Potential health risks of heavy metal(loid)s from fish consumption can be carcinogenic and non-carcinogenic (Yu et al., 2014; Copat et al., 2013). Therefore, the USEPA has developed various risk estimation approaches for both carcinogenic and non-carcinogenic metals. The target hazard quotient (THQ) and total THQ have been used to determine the health risks of non-carcinogenic metals (USEPA, 1989). Cancer slope factors (CSF) have been developed for estimating lifetime cancer risks (CR) associated with carcinogenic metals (USEPA, 1989; USEPA, 2016; Shakoor et al., 2015). Furthermore, the USEPA (2000) recommends that the maximum allowable fish consumption limits should be used to determine carcinogenic and non-carcinogenic risks. These human health risk estimation methods have been proved to their usefulness and validity and have been used by numerous investigators (Saha et al., 2016; Yi et al., 2017; Copat et al., 2013; Griboff et al., 2017). In our study, they were also applied to estimate the human health risks of heavy metal(loid)s associated with fish consumption.

Keban Dam Reservoir (KDR), located on the Euphrates River (Turkey), is used as a source of hydroelectric power, for fishing, aquaculture production and recreation. However, it receives both domestic and industrial wastewaters. Agricultural practices are also one of important sources of contamination due to the use of chemical fertilizers and pesticides in the basin. Although there are several studies on heavy metal concentrations in fish living in the KDR (Ural and Danabas, 2015; Danabas and Ural, 2012), these studies were restricted to only a few fish species living in the reservoir and to specific areas of the reservoir. Therefore, in this study, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn concentrations were investigated in the muscle tissues of five fish species (mangar, Tigris scraper, Euphrates barbell, common carp and trout barb) collected from 11 sampling sites in the KDR.

The main goals of the present study were to perform risk assessment for carcinogenic and non-carcinogenic metals associated with consumption of fish species living in the Keban Dam Reservoir, to compare the levels of metals with published data from previous studies carried out in other countries and Turkey, and to investigate seasonal and spatial variations of heavy metal(loid)s in fish species.

2. Materials and methods

2.1. Study area

Located between latitudes 35°20′ and 38°37′ N, and longitudes 38°15′ and 39°52′ E, the Keban Dam Reservoir (KDR), with a volume of 30.6 km^3 and a surface area of 675 km^2, is the second largest reservoir in Turkey. The KDR was built for hydroelectric power generation and it was the first and most upstream of several large-scale dams to be built on the Euphrates River (Varol and Sünbül, 2017).

2.2. Sample collection and preparation

In our study, 11 sampling sites (S1–S11) on the Keban Dam Reservoir were selected (Fig. 1). The brief description of sites selected for this study is given in Table 1. Five fish species belonging to the Cyprinidae family were considered in the present study: mangar (*Luciobarbus esocinus*), Tigris scraper (*Capoeta umbla*), common carp (*Cyprinus carpio*), Euphrates barbell (*Luciobarbus mystaceus*) and trout barb (*Capoeta trutta*). These fish species highly consumed by the local population were collected seasonally in November 2014 (autumn), February 2015 (winter), May 2015 (spring) and August 2015 (summer). They were caught using gill nets at sampling sites. In this study, 2–3 fish of similar size from the same species were collected from each site at each sampling time. Fish that were large enough to be consumed by people were preferred. In addition, water samples from each site per season were taken. All fish and water samples were immediately transported to the laboratory on ice boxes after collection. Body weights and total lengths of collected fish species were measured (Table S1). In this study, the age and sex differences were not considered. Fish were dissected and muscle tissues were obtained. For muscle tissue of each target species per site per season, a composite sample (consisting of 2–3 individuals) was prepared and homogenized, and 50 g test portions were stored at −20 °C until analysis of metals. Water samples were filtered, acidified and stored at 4 °C until analysis.

2.3. Metal analysis and quality control

In the present study, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn concentrations were determined in water samples ($n = 44$) and muscle tissues of fish ($n = 220$). For this, 1.0 g of previously homoginesed fish muscle sample was placed in teflon vessels and digested with 8 mL HNO_3 (65%) and 2 mL H_2O_2 (30%) using a four-step digestion program in a microwave digestion system (Table S2). At the end of digestion process, the digested sample solutions were cooled to room temperature and diluted to 50 mL with deionized water. The concentrations of As, Cd and Pb in the extracts were determined using graphite furnace atomic absorption spectrophotometry (GFAAS; Thermo Scientific iCE 3000, USA), while the concentrations of other metals were determined using flame atomic absorption spectrophotometry. The concentrations of ten metals in water samples were measured by GFAAS. Triplicate analyses were performed and the results were expressed as mean values.

Method accuracy was confimed by analyzing a certified reference material (CRM) for heavy metal(loid)s in lobster hepatopancreas (TORT-3, National Research Council of Canada). CRM was analyzed with every 11 samples digested. The recoveries of studied metals were between 94.4 and 105.7% (Table S3).

2.4. Health risk assessment of metals

In this study, multiple approaches were used to assess the human health risks from fish consumption: (1) comparions of metal concentrations in fish muscles with the maximum permissible concentrations (MPCs) for fish set by international standards; (2) comparison of estimated daily intake (EDI) values of metals with the respective tolerable daily intake (TDI) values (Yi et al., 2017); (3) estimation of target hazard