PJN
ISSN 1680-5194

PAKISTAN JOURNAL OF NUTRITION

ANSInet
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan
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OPEN ACCESS Pakistan Journal of Nutrition

ISSN 1680-5194
DOI: 10.3923/pjn.2018.647.653

Research Article
Potential Health Impacts of Heavy Metal Concentrations in Fresh and Marine Water Fishes Consumed in Southeast, Nigeria

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Abstract

Background and Objective: Heavy metals refer to metallic chemical elements that have a relatively high density (4 g cm^{-3}) that is greater than that of water. The presence or absence of some heavy metals is known to cause various diseases in humans. This study aimed to measure the concentrations of arsenic (As), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), lead (Pb), manganese (Mn), mercury (Hg), nickel (Ni) and zinc (Zn) in fish products consumed in Southeast Nigeria using an atomic absorption spectrophotometer (AAS). **Methodology:** The fish samples were purchased from local markets and included imported fish from marine water sources and fish from freshwater rivers and ponds. The samples were washed, de-scaled (where applicable) and oven-dried separately at 105°C for 10 h. A portion (2.0 g) of each of the dried homogenised samples was digested in a digestion flask with 20 mL of a mixture containing 650 mL of concentrated HNO_3, 80 mL of perchloric acid ($HClO_4$) and 20 mL of concentrated H_2SO_4. The heavy metal analysis was conducted using a Varian AA240 atomic absorption spectrophotometer. **Results:** The concentrations of the heavy metals between the freshwater and marine fish samples did not follow a regular pattern. All the fish products had mean heavy metal concentrations below the permissible limits. The highest concentrations of chromium and mercury were 114.377 and 3.718 mg kg^{-1}, respectively. Mercury had a target hazard quotient>1.0. **Conclusion:** Consuming the sampled fish products has the potential to cause adverse health impacts if not controlled.

Key words: Heavy metals, fish, fresh and marine water, health risk, Nigeria

Received: June 24, 2017 Accepted: August 27, 2018 Published: November 15, 2018

Citation: K.K. Agwu, C.M.I. Okoye, M.C. Okeji and E.O. Clifford, 2018. Potential Health Impacts of Heavy Metal Concentrations in Fresh and Marine Water Fishes Consumed in Southeast, Nigeria. Pak. J. Nutr., 17: 647-653.

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Fish are widely acceptable in global menus due to their palatability, low cholesterol levels, tender flesh and ability to provide both a high source of animal protein and essential nutrients to the human diet[1,2]. Marine water contains many salts and covers about three-fourths of the Earth's surface, while fresh water contains almost no salt and comprises only one-fourth of all the water on earth. The occurrence of heavy metals in the environment may be caused by natural processes or by contamination resulting from human activities[3]. Heavy metals refer to metallic chemical elements that have relatively high density (4 g cm^{-3}) that is greater than water[4]. Some heavy metals are toxic to humans, including arsenic, lead, aluminium, mercury and cadmium, while others (trace elements) are part of enzymes, hormones and cells in the body, e.g., iron, iodine, copper, zinc, chromium, selenium, fluorine and manganese[5-7].

Fish have been reported as excellent indicators for heavy metal contamination in aquatic and marine environments because they occupy different levels of the food chain[8]. Consequently, fish constitute a major source of the transfer of heavy metals to man through the food chain[9,10]. In the human body, heavy metals such as lead have been reported to cause learning disabilities and impaired protein and haemoglobin synthesis, whereas cadmium has been reported as a cause of renal failure and calcium loss is responsible for malfunctioning in the peripheral and central nervous systems[11,12].

Nigeria imports marine water fish as frozen fish, while freshwater fish are harvested from rivers, streams and fish ponds. There is presently an increase in the production and consumption of fish products in Nigeria due to the awareness of the potential health benefits. Therefore, this study sought to evaluate the heavy metal concentrations of these fishes to compare the levels within and between them in order to ascertain the potential health impacts caused by their consumption.

MATERIALS AND METHODS

Study design and location: A cross-sectional survey and experimental design were adopted in this study. The study area included the five states of Abia, Anambra, Ebonyi, Enugu and Imo in south-eastern Nigeria, as shown in Fig. 1. Locally consumed freshwater fish were randomly purchased from fish farmers in two major towns randomly selected in each of the five states. Marine-imported fish were also purchased at the local market in two major towns that were randomly selected in the study area.

Sampling and sample collection: A total of 26 samples that consisted of eight fish species consumed in the five states of Southeast Nigeria were collected and labelled FWFa, FWFb, FWFc, FWFd, FWFe, MWFa, MWFb, MWFc, MWFd, MWFe, MWFf, MWFg and MWFh. Two samples that represented the local breed from each of the five states and 2 samples that represented the eight imported marine species consumed in the study area were collected and are shown in Table 1.

Sample preparation: The fish samples were each washed, de-scaled (where applicable) and oven-dried at 105°C for 10 h. A portion (2.0 g) of each of the dried homogenised

Fig. 1: Map of the study area (insert, an enlargement).
Source: Administrative map of Nigeria

Table 1: Type and source location of sampled fishes

Sample No. of common scientific sample location	Label	Samples name	Sources	State/country
FWFa	2	Cat fish	*Clarias gariepinus* River	Niger Anambra
FWFb	2	Cat fish	*Clarias gariepinus* Afikpo	River Ebonyi
FWFc	2	Cat fish	*Clarias gariepinus* Ugwuaji	River Enugu
FWFd	2	Cat fish	*Clarias gariepinus* Imo River	Imo
FWFe	2	Cat fish	*Clarias gariepinus* Imo	Imo
MWFa	2	Cat fish	*Clarias gariepinus* marine water	Vietnam
MWFb	2	Yellow croaker	*Pseudotolithus* sp. marine water	Uruguay
MWFc	2	White croaker	*Pseudotolithus* sp. marine water	Uruguay
MWFd	2	Cod fish	*Gardus morhua* marine water	Norway
MWFe	2	Scumbria	*Euthynnus alletteratus* marine water	Holland
MWFf	2	Stavida	*Sardinella aurita* marine water	Canada
MWFg	2	Tilapia	*Tilapia zilli* marine water	Colombia
MWFh	2	Cod fish	*Gadus macrocephalus* marine water	Holland

samples was digested in a digestion flask with 20 mL of a mixture of 650 mL of concentrated HNO_3, 80 mL of perchloric acid ($HClO_4$) and 20 mL of concentrated H_2SO_4 as described in the literature[13]. The digestion flask and the mixture were heated until a clear digest was obtained. The digest was then allowed to cool and was increased to 100 mL by adding distilled water. Aliquots of the diluted solutions were analysed for heavy metals using an Atomic Absorption Spectrophotometer (AAS).

Preparation of reference solution: A series of standard metal solutions in the optimum concentration ranges were prepared. The reference solutions were prepared daily by diluting the single stock elemental solution with water that contained 1.5 mL of concentrated nitric acid/litre. A calibration blank was prepared using the entire reagent but excluding the metal stock solutions.

Sample analysis: The heavy metal analysis was conducted at Springboard Laboratory Awka, Anambra State. The heavy metal analysis was conducted using a Varian AA240 atomic absorption spectrophotometer according to the method described by the APHA[14]. Each sample was aspirated into the flame chamber where it was vaporised. The vaporised sample became atomised after the absorption of the AAS's light beam. The light beam was directed through the flame into the monochromator and onto the detector. Thus, the amount of light absorbed by the atomised element in the flame was measured. Since each metal has a distinct characteristic absorption wavelength, a source lamp composed of that element was used; thus, this approach ensured the method was relatively free from spectral or radiation interference. The amount of energy of the characteristic wavelength absorbed in the flame was proportional to the concentration of the element in the sample.

Health risk assessment: In this study, the health risk estimates of the ingestion of metals from fish consumption were based on the data from heavy metal analysis and other data based on the EPA[15] guidelines. The following assumptions were made:

- The hypothetical body weight for adult humans was 70 kg.
- The bioavailability factor was 100% and the maximum absorption rate was 100%.

Estimated daily dose (EDD): The exposure dose caused by the ingestion of fish was calculated using the method proposed by the Agency for Toxic Substances and Diseases Registry (ATSDR)[16]

$$EDD = \frac{C \times IR \times AF \times EF}{BW}$$

where, EDD is the exposure dose (mg kg^{-1} day^{-1}), C is the contaminant concentration (mg kg^{-1}), IR is the fish intake rate for Nigeria, i.e., 36600 mg kg^{-1} = 36.6E-3 kg day^{-1} = 36.6 g day^{-1} =13.359 kg y^{-1}, AF is the bioavailability factor (in percentage) and represents the total amount of an ingested, inhaled, or contacted substance that actually enters the bloodstream and may possibly cause harm to a person. Typically, the bioavailability factor is assumed to be 1 (100%) for screening purposes (i.e., all of a substance to which a person is exposed is assumed to be absorbed) and EF is The exposure factor and is equal to 1. The EF is calculated by multiplying the exposure frequency by the Exposure Duration (ED) and dividing this value by the time period during which the dose is to be averaged, as shown below:

$$EF = \frac{F \times ED}{AT}$$

Where
F = Frequency of exposure (days/year)
ED = Exposure duration (years) and
AT = Average time (ED×65 days/year)

Target Hazard Quotient (THQ): The target hazard quotient (THQ) is used to quantify the amount of metal taken in through ingestion. The target hazard quotient was calculated based on the formula by Wang *et al*[17]. If the THQ or the total hazard index (THI) is below 1, no health risk is likely to occur as a result of the ingestion of fish. However, as the value of the THQ or THI increases, the level of risk associated with the ingestion of the fish also increases.

$$THQ = \frac{ED}{R_{ld}}$$

$$THI = \Sigma THQ$$

RESULTS

The analysis of the concentration of metals in the fresh and marine water fish samples consumed in Southeast Nigeria showed that chromium and mercury had the highest mean concentrations, with values of 114.337 and 3.718 mg kg^{-1}, respectively (Table 2). The Estimated Daily Intake (EDI) for adults was computed and is presented in Table 3. Table 4 presents the target hazard quotient of fish samples consumed in Southeast Nigeria and mercury was noted to have a THQ>1.0.

Table 2: Elemental concentrations in fresh and marine water fish samples

	Mean elemental concentration (mg kg^{-1})									
Sample	As	Cd	Cr	Co	Cu	Pb	Mn	Hg	Ni	Zn
FWFa	0.000	0.069	39.635	0.100	0.188	0.221	0.323	0.977	0.000	8.208
FWFb	0.000	0.058	54.176	0.050	0.094	0.328	0.551	3.718	0.000	8.193
FWFc	0.000	0.072	0.000	0.080	0.059	0.282	0.595	1.325	0.000	11.274
FWFd	0.000	0.081	0.000	0.113	0.046	0.783	0.435	1.018	0.000	9.061
FWFe	0.000	0.085	0.000	0.084	0.059	0.306	0.464	1.014	0.000	9.300
MWFa	6.710	0.087	0.000	0.090	0.065	0.530	0.208	0.951	0.000	11.272
MWFb	2.578	0.108	0.000	0.076	0.069	0.330	0.549	0.963	0.000	9.588
MWFc	2.016	0.070	114.377	0.000	0.027	0.270	0.195	0.930	0.000	12.794
MWFd	0.000	0.068	0.000	0.079	0.032	0.335	0.105	0.790	0.000	11.337
MWFe	0.000	0.151	36.050	0.064	0.062	0.333	0.152	0.960	0.000	12.347
MWFf	8.869	0.172	53.666	0.006	0.103	0.135	0.118	0.802	0.000	7.963
MWFg	9.983	0.158	45.672	0.064	0.066	0.349	0.332	0.833	0.000	21.213
MWFh	9.831	0.087	101.02	0.067	0.036	0.391	0.112	0.842	0.000	9.377

Table 3: Exposure dose caused by the daily ingestion of fresh and marine water fish samples

	Mean elemental concentration (mg kg^{-1})									
Sample	As$\times 10^{-3}$	Cd$\times 10^{-5}$	Cr$\times 10^{-2}$	Co$\times 10^{-5}$	Cu$\times 10^{-5}$	Pb$\times 10^{-4}$	Mn$\times 10^{-4}$	Hg$\times 10^{-4}$	Ni$\times 10^{-3}$	Zn$\times 10^{-3}$
FWFa	0.00	3.61	2.07	5.23	9.81	1.16	1.69	5.11	0.00	4.29
FWFb	0.00	3.03	2.83	2.61	4.91	1.71	2.88	19.40	0.00	4.28
FWFc	0.00	3.76	0.00	4.18	3.08	1.47	3.11	6.93	0.00	5.89
FWFd	0.00	4.24	0.00	5.91	2.41	4.09	2.27	5.32	0.00	4.74
FWFe	0.00	4.44	0.00	4.39	3.08	1.60	2.43	5.30	0.00	4.86
MWFa	3.51	4.55	0.00	4.71	3.40	2.77	1.09	4.97	0.00	5.89
MWFb	1.35	5.65	0.00	3.97	3.61	1.73	2.87	5.04	0.00	5.01
MWFc	1.05	3.66	5.98	0.00	1.41	1.41	1.02	4.72	0.00	6.69
MWFd	0.00	3.56	0.00	4.13	1.67	1.75	0.55	4.13	0.00	5.39
MWFe	0.00	7.90	1.89	3.35	3.24	1.74	0.80	5.02	0.00	4.46
MWFf	4.64	8.99	2.81	31.37	5.39	1.65	0.62	4.19	0.00	4.16
MWFg	5.22	8.26	2.39	3.35	3.45	1.82	1.74	4.36	0.00	11.10
MWFh	5.14	4.55	5.28	3.50	1.88	2.04	0.59	4.40	0.00	4.90
R_fD	3E-4	1E-3	1.5	3E2	4E-2	4E-3	1.4E-1	5E-4	2E-2	3E-1

Table 4: Target hazard quotient and total hazard index of fish samples

Sample	Mean elemental concentration (mg kg^{-1}) As × 10^{-3}	Cd × 10^{-2}	Cr × 10^{-2}	Co × 10^{-3}	Cu × 10^{-4}	Pb × 10^{-2}	Mn × 10^{-3}	Hg × 10^{-0}	Ni × 10^{-3}	Zn × 10^{-2}	THI
FWFa	0.00	3.61	1.38	1.74	24.60	2.89	1.21	1.02	0.00	1.34	1.12
FWFb	0.00	3.03	1.89	0.87	12.30	4.29	2.06	3.89	0.00	1.43	4.00
FWFc	0.00	3.76	0.00	1.39	7.71	3.69	2.22	1.39	0.00	1.96	1.49
FWFd	0.00	4.24	0.00	1.97	6.01	10.20	1.62	1.06	0.00	1.58	1.22
FWFe	0.00	4.44	0.00	1.46	7.71	4.00	1.73	1.06	0.00	1.62	1.16
MWFa	1.17	4.55	0.00	1.57	8.49	6.93	0.78	0.99	0.00	1.96	1.13
MWFb	0.45	5.65	0.00	1.32	9.01	4.31	2.05	1.01	0.00	1.67	1.13
MWFc	0.35	3.66	3.99	0.00	3.52	3.53	0.73	0.94	0.00	2.23	1.08
MWFd	0.00	3.56	0.00	1.38	4.18	4.38	0.39	0.83	0.00	1.98	0.93
MWFe	0.00	7.90	1.26	1.12	8.10	4.35	0.57	1.00	0.00	2.15	1.16
MWFf	1.55	8.99	1.87	0.10	13.50	4.12	0.44	0.84	0.00	1.39	1.01
MWFg	1.74	8.26	1.59	1.12	8.62	4.56	1.24	0.87	0.00	3.70	1.06
MWFh	1.71	4.55	3.52	1.17	4.70	5.11	0.42	0.88	0.00	1.63	1.03

DISCUSSION

The heavy metal concentrations for all fish samples did not show a consistent pattern.

Arsenic (As): Arsenic is found as a trace element in fish and other seafood products[2]. Some environmental protection agencies have reported that an intake of 1.0 mg day^{-1} of inorganic arsenic is sufficient to induce skin lesions after a few years[18]. The highest mean concentration of As in the fish samples was 9.983 mg kg^{-1} (dry weight) and was found in MWFg imported from Colombia. Arsenic was not detected in the freshwater fish samples. This value is higher than the 2 mg kg^{-1} (dry weight) limit recommended by the European Commission as the maximum permissible limit for marinefish[19]. This value is also higher than the value of 4.4 mg kg^{-1} which was reported in fish from the Black Sea in Turkey[20]. However, the finding of the present study does not translate into potential health risks since the target hazard quotient is less than 1.

Cadmium (Cd): The highest concentration of Cd in marine water fish was seen in the sample MWFf (0.172 mg kg^{-1}) which was imported from Canada. For the freshwater fish, the highest concentration was observed in the sample FWFe (0.085 mg kg^{-1}) from the Imo River in, Nigeria. The concentrations of Cd in all the fish samples, however, were below the NCBP concentration of 2.1 μg g^{-1} (dry weight) which is the threshold considered to be harmful to fish and predators[21,22]. Akan *et al*.[23] reported Cd concentrations of 0.11-1.03 μg g^{-1} in the flesh of *Clarias anguillaris* and *Synodontis budgetti* from the River Benue in Nigeria. Severe toxic symptoms can result from the ingestion of Cd and symptoms have been reported for Cd values ranging from 10-326 mg g^{-1} [9]. Fatal ingestions of Cd result in shock and acute renal failure and can occur from ingestion levels exceeding 350 mg g^{-1} [24].

Chromium (Cr): Chromium is an essential trace element but has been reported as a known carcinogen if ingested at a daily dose greater than 0.5 mg kg^{-1} of body weight[25]. Chromium was observed in varying concentrations in some fish samples but not in FWFc, FWFd, FWFe, MWFa or MWFb (where Cr was below the detectable limit). The highest concentration was observed in MWFc (114.337 mg kg^{-1}) which was imported from Uruguay. This value was more than the values reported in earlier studies[20] which ranged from <0.1-0.73 mg kg^{-1} dry weight. An intake of 0.03 mg kg^{-1} body weight has been suggested for adults who are 70 years old or older[26]. The results of the present study indicate a potential health hazard since the target hazard quotient was greater than 1.

Cobalt (Co): Cobalt is an essential trace element but the excessive intake of Co has been noted to lead to health complications[27]. The highest concentration from our study was in FWFd (0.113 mg kg^{-1}). This concentration is similar to the values reported by Gorur *et al*.[20] and Hamidalddin and AlZahrani[2], with range of <0.05-0.30 mg kg^{-1}. The result of the current study showed that the level of cobalt in fish did not pose any health risks.

Copper (Cu): Copper is an essential trace element. It facilitates iron uptake and serves as a constituent of respiratory enzyme complexes in the human body. The highest mean concentration was observed in FWFd (0.188 mg kg^{-1}) from the Imo River in Nigeria. The highest mean value in the present study was below the permissible limit set by the FAO/WHO (i.e., 3 mg kg^{-1} body weight)[20]. However, mean value observed in the present study was less than the value reported in the study by Usero *et al.*[28], with range of 0.4-1.5 mg kg^{-1}.

Lead (Pb): Lead is a potential carcinogen and can cause adverse health effects[29]. In the present study, Pb was detected in all the samples. The highest mean concentration was observed in FWFd (0.783 mg kg^{-1}). Current study showed lead values in all samples. These values were found to be below the permissible limit of 2.0 mg kg^{-1} in dry fish weight[30]. Turkmen and Ciminli[31] reported higher values of Pb in fish products from Turkey which ranged from 0.09-6.95 mg kg^{-1} but Gorur *et al.*[20] reported lower Pb values in fish products from the Black Sea in Turkey (range: <0.001-0.06 mg kg^{-1}).

Manganese (Mn): Manganese is an essential trace element but its excessive intake has a negative effect on fertility, the central nervous system and embryo and foetal development[32]. Manganese was detected in all samples at levels below the permissible limit of 2.5 mg kg^{-1}. The highest mean concentration was observed in FWFc (0.595 mg kg^{-1}) which was from the Ugwuaji River in Nigeria. This observed value was within the range (mg kg^{-1}, dry weight) reported in previous studies[20,33,34].

Mercury (Hg): Acute or chronic exposure to Hg can produce adverse health effects during human developmental stages. In the present study, the highest concentration of Hg was observed in FWFb (3.718 mg kg^{-1}) which came from the Afikpo River in Nigeria and the minimum value from all samples was 0.79 mg kg^{-1} (MWFd) which was imported from Norway. The Canadian Food Inspection Agency (CFIA) has set the Hg limit at 0.2 mg kg^{-1} (dry weight) of fish[26]. In the present study, all fish samples had mercury concentrations higher than the permissible limit of 0.2 mg kg^{-1} set by the CFIA and had THQ values> 1. The consumption of these fish products has potential health risks from the perspective of possible bioaccumulation. The mercury concentration in fish products was reported to range from 0.004-0.056 mg kg^{-1} dry weight in Port Klang[33].

Nickel (Ni): Nickel is an essential trace element in humans and is believed to contribute to physiological processes as a co-factor in the absorption of iron from the intestines. However, at higher levels in the human body, nickel can become toxic or act as a carcinogen[35]. In the present study, Ni was below the detectable level.

Zinc (Zn): Zinc is an essential trace element whose deficiency results in retarded growth, loss of taste, dermatitis, alopecia, hypogonadism and decreased fertility[9]. An excessive intake of Zn can cause acute poisoning. The highest mean concentration of Zn in our study was 21.213 mg kg^{-1} and was observed in MWFg which was imported from Colombia. The concentration of Zn across all samples was lower than the maximum permissible limit of 30 μg g^{-1} [36].

CONCLUSION

The present study identified the presence of a wide range of heavy metals in fish samples consumed in Southeast Nigeria. All fish products had heavy metal concentrations below the permissible limits, except for the heavy metals of chromium and mercury. However, only mercury had a target hazard quotient>1.0; therefore, the consumption of fish products has the potential to cause adverse health impacts in humans. Further studies are required to ascertain the source of mercury contamination in the freshwater fish samples. Different regulatory agencies are urged to conduct periodic heavy metal assessments to avert possible adverse public health hazards.

REFERENCES

1. Rashed, M.N., 2001. Egypt monitoring of environmental heavy metals in fish from Nasser Lake. Environ. Int., 27: 27-33.
2. Hamidalddin, S.H.Q. and J.H. AlZahrani, 2016. An assessment of some toxic, essential elements and natural radioactivity, in most common fish consumed in Jeddah-Saudi Arabia. Food Nutr. Sci., 7: 301-311.
3. Franca, S., C. Vinagre, I. Cacador and H.N. Cabral, 2005. Heavy metal concentrations in sediment, benthic invertebrates and fish in three salt marsh areas subjected to different pollution loads in the Tagus Estuary (Portugal). Mar. Pollut. Bull., 50: 998-1003.
4. Grant, R., 1987. Grant and Hackh's Chemical Dictionary. McGraw-Hill, New York.
5. Iwegbue, C.M.A., S.O. Nwozo, E.K. Ossai and G.E. Nwajei, 2008. Heavy metal composition of some imported canned fruit drinks in Nigeria. Am. J. Food Technol., 3: 220-223.
6. Abduljaleel, S.A. and M. Shuhaimi-Othman, 2011. Metals concentrations in eggs of domestic avian and estimation of health risk from eggs consumption. J. Biol. Sci., 11: 448-453.
7. Abduljaleel, S.A., M. Shuhaimi-Othman and A. Babji, 2011. Variation in trace elements levels among chicken, quail, guinea fowl and pigeon eggshell and egg content. Res. J. Environ. Toxicol., 5: 301-308.

8. Karadede-Akin, H. and E. Unlu, 2007. Heavy metal concentrations in water, sediment, fish and some benthic organisms from Tigris River, Turkey. Environ. Monit. Assess., 131: 323-337.
9. Sivaperumal, P., T.V. Sankar and P.G.V. Nair, 2007. Heavy metal concentrations in fish, shellfish and fish products from internal markets of India vis-a-vis international standards. Food Chem., 102: 612-620.
10. Kaplan, O., N.C. Yildirim, N. Yildirim and M. Cimen, 2011. Toxic elements in animal products and environmental health. Asian J. Anim. Vet. Adv., 6: 228-232.
11. Sultana, R. and D.P. Rao, 1998. Bioaccumulation patterns of zinc, copper, lead and cadmium in grey mullet, *Mugil cephalus* (L.), from harbour waters of Visakhapatnam, India. Bull. Environ. Contam. Toxicol., 60: 949-955.
12. Castro-Gonzaleza, M.I. and M. Mendez-Armenta, 2008. Heavy metals: Implications associated to fish consumption. Environ. Toxicol. Pharmacol., 26: 263-271.
13. Adrian, W.J., 1973. A comparison of a wet pressure digestion method with other commonly used wet and dry-ashing methods. Analyst, 98: 213-216.
14. APHA., 1995. Standard Methods for the Examination of Water and Wastewater. 20th Edn., APHA, Washington, DC., USA.
15. EPA., 2004. An examination of EPA risk assessment principles and practices. Environmental Protection Agency (EPA), Washington, DC. http://www.epa.gov/osa/pdfs/ratf-final.pdf.
16. ATSDR., 2005. Public health assessment guidance manual (Update). Department of Health and Human Service, Atlanta, Georgia. https://www.atsdr.cdc.gov/hac/phamanual/pdfs/phagm_final1-27-05.pdf.
17. Wang, X., T. Sato, B. Xing and S. Tao, 2005. Health risks of heavy metals to the general public in Tianjin, China via consumption of vegetables and fish. Sci. Total Environ., 350: 28-37.
18. Roychowdhury, T., H. Tokunaga and M. Ando, 2003. Survey of arsenic and other heavy metals in food composites and drinking water and estimation of dietary intake by the villagers from an arsenic-affected area of West Bengal, India. Sci. Total Environ., 308: 15-35.
19. European Commission, 2011. Commission regulation (EU) No 420/2011 of 29 April 2011 amending Regulation (EC) No 1881/2006 setting maximum levels for certain contaminants in foodstuffs. Official J. Eur. Union, L111: 3-6.
20. Gorur, F.K., R. Keser, N. Akcay and S. Dizman, 2012. Radioactivity and heavy metal concentrations of some commercial fish species consumed in the Black Sea Region of Turkey. Chemosphere, 87: 356-361.
21. Schmitt, C.J. and W.G. Brumbaugh, 1990. National contaminant biomonitoring program: Concentrations of arsenic, cadmium, copper, lead, mercury, selenium and zinc in U.S. freshwater fish, 1976-1984. Arch. Environ. Contam. Toxicol., 19: 731-747.
22. Robertson, S.M., L.R. Gamble and T.C. Maurer, 1989. Contaminant survey of la Sal Vieja, Willacy country, Texas. US Fish Wild Service, Study Identifier 89-2-100. https://ecos.fws.gov/ServCat/DownloadFile/21627?Reference=23108.
23. Akan, J.C., S. Mohmoud, B.S. Yikala and V.O. Ogugbuaja, 2012. Bioaccumulation of some heavy metals in fish samples from river Benue in Vinikilang, Adamawa State, Nigeria. Am. J. Anal. Chem., 3: 727-736.
24. NAA-NRC., 1974. Recommended Dietary Allowances. 8th Edn., National Academy Press, Washington, DC.
25. O'Brien, T.J., S. Ceryak and S.R. Patierno, 2003. Complexities of chromium carcinogenesis: Role of cellular response, repair and recovery mechanisms. Mutat. Res./Fundam. Mol. Mech. Mutagen., 533: 3-36.
26. Health-Canada, 2007. Human health risk assessment of mercury in fish and health benefits of fish consumption. Bureau of Chemical Safety, Food Directorate, Health Products and Food Branch.
27. De Boeck, M., M. Kirsch-Volders and D. Lison, 2003. Cobalt and antimony: Genotoxicity and carcinogenicity. Mutat. Res./Fund. Mol. Mech. Mutagen., 533: 135-152.
28. Usero, J., C. Izquierdo, J. Morillo and I. Gracia, 2003. Heavy metals in fish (*Solea vulgaris*, Anguilla anguilla and *Liza aurata*) from salt marshes on the Southern atlantic coast of Spain. Environ. Int., 29: 949-956.
29. Zhuang, P., M.B. McBride, H. Xia, N. Li and Z. Li, 2009. Health risk from heavy metals via consumption of food crops in the vicinity of dabaoshan mine, South China. Sci. Total Environ., 407: 1551-1561.
30. WHO., 1996. Guidance for Drinking Water Quality. 2nd Edn., World Health Organization, Geneva.
31. Turkmen, M. and C. Ciminli, 2007. Determination of metals in fish and mussel species by inductively coupled plasma-atomic emission spectrometry. Food Chem., 103: 670-675.
32. Gerber, G.B., A. Leonard and P. Hantson, 2002. Carcinogenicity, mutagenicity and teratogenicity of manganese compounds. Crit. Rev. Oncol. Hematol., 42: 25-34.
33. Khandaker, M.U., K. Asaduzzaman, S.M. Nawi, A.R. Usman and Y.M. Amin *et al*., 2015. Assessment of radiation and heavy metals risk due to the dietary intake of marine fishes (*Rastrelliger kanagurta*) from the straits of Malacca. PloS One, Vol. 10. 10.1371/journal.pone.0128790
34. Tuzen, M., 2009. Toxic and essential trace elemental contents in fish species from the Black Sea, Turkey. Food Chem. Toxicol., 47: 1785-1790.
35. Mendil, D., O.F. Unal, M. Tuzen and M. Soylak, 2010. Determination of trace metals in different fish species and sediments from the River Yeşilırmak in Tokat, Turkey. Food Chem. Toxicol., 48: 1383-1392.
36. FAO. and WHO., 1984. List of Maximum Level Recommended for Contaminants by the Joint FAO/WHO Codex Alimentarius Commission. 2nd Edn., Food and Agriculture Organization of the United Nations, Rome, pp: 1-8.