Investigation in heavy metal contents of drinking water and fish from Darbandikhan and Dokan Lakes in Sulaimaniyah Province - Iraqi Kurdistan Region

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Abstract. Dokan and Darbandikhan lakes are the two major lakes in Iraqi Kurdistan feeding the population of Sulaimani province. To evaluate the suitability of water for aquatic life and drinking purposes, the heavy metal contents of drinking water and fishes from the lakes was investigated. The samples were collected from the reservoir (raw water), water after treatment (tank water) and water from residential areas (tap water) on monthly basis over a year. The results of copper, lead, cadmium and zinc analysis showed 6.2 – 56.9, 91.6 – 413.4, 4.0 – 35.6, 42.6 – 388.8 µg/L at Darbandikhan lake and 14.7 – 79.3, 83.5 – 265.9, 15.9 – 43.9, 1.8 – 112.9 µg/L at Dokan lake, respectively. Lead and Cadmium contents were exceeded the maximum permitted levels by WHO in all the water samples. Fish samples of ages 1-3 years from both lakes were also examined for copper, lead and cadmium. All the samples were analyzed using Inductively Coupled Plasma. These findings suggest the drinking water is contaminated with heavy metals, and the fishes were also found with far higher lead and cadmium content than are permitted. The results obtained are alarming and need urgent action to mitigate environmental pollution.

Keywords: Darbandikhan Lake; Dokan Lake; drinking water; heavy metals; water pollution

1. Introduction

Aquatic environment has been severely polluted through disposal of various chemical pollutants including heavy metals from hospitals and manufacturing plants. Trace level of these contaminates are considered a threat to the environment and can be harmful for human health and aquatic life, resulting in a serious environmental problem [1, 2]. Heavy metals are carcinogenic, mutagenic and reproductive toxicants, and thus pose a potential risk to public health. Therefore, the presence of heavy metals in aquatic environment as well as their accumulation in aquatic animal has potential adverse effects to human health [3, 4]. Water and marine environments polluted by heavy metals are considered a major environmental threat [5]. Water, whether it is surface (rivers, lakes, and ponds), ground or sea water may be polluted by natural or human activities and consequently causing harm to human and animal health. The polluted water may have undesirable color, odor, taste, turbidity, organic matter contents, harmful chemical contents, toxic and heavy metals, oily matters, radioactivity, high Total Dissolved
Solids (TDS), acids, alkalis etc. Pollution of the drinking water and that of food chain is by far the most worry-some aspect as elements or constituents of polluted water can act as toxins and can create severe health hazard to organisms, consequently the irrigation of such water introduces metals in the plant products and also contaminates the soil [6]. The aquatic environment with its water quality is considered the main factor controlling the state of health and disease in both cultured and wild fishes. Pollution of the aquatic environment by inorganic and organic chemicals is a major factor posing serious threat to the survival of aquatic organisms including fish [7]. The levels of metals in upper members of the food web like fish can reach values many times higher than those found in aquatic environment or in sediments [8].

Water pollution in Kurdistan region-Iraq has become one the major threats that affect the public health. The city of Sulaimaniyah is located on an elevation of 880 m in the region of Kurdistan in north-eastern Iraq and has a population of approximately more than 1.5 million inhabitants [9]. Dokan and Darbandikhan lakes are the two main water source that supply water to almost the entire Sulaimani province. Following several TV report alerts on the contamination of drinking water of Darbandikhan and Dokan lakes, this investigation was conducted to assess the safety of drinking water and fishes from both lakes for heavy metals. The investigation encompassed sample analysis from both lakes including reservoir water, tank water and tap water on monthly basis for one year to monitor the heavy metal (Lead, Cadmium, Zinc and Copper) contents. Also, to assess the safety of fishes (1-3 years age) in these lakes in terms of heavy metals and correlate the cumulative effects of the contaminated aquatic environment on the fishes.

Estimation and quantification of heavy metals in aquatic environments and their accumulations in fish and in other organisms such as plants and marine mammals have been studied in many reports [5, 10-14]. To the extent of our knowledge, there is no relevant research article covering these two important lakes in the north of Iraq for investigation in heavy metal contents in the present.

This work aimed at systematic investigation the risk and toxicity of heavy metals (copper, cadmium, lead and zinc) from Darbandikhan and Dukan lakes. The study demonstrates quantitative determination of these heavy metals in drinking water and fishes to ensure the suitability of drinking water and fishes from these two main lakes in Kurdistan region-Iraq for human consumption. This study provides a baseline for the assessment of heavy metal contamination, especially copper, lead, cadmium and zinc contamination, in the water and fishes in the two main lakes in Kurdistan region-Iraq.

2. Material and methods

2.1. Materials

The chemicals and solvents used for chemical analysis in this research were of high purity and were used as received. All solutions were prepared in deionized water.

2.1.1. Sampling and analysis. Water samples were collected from raw water, tank water and tap water at Darbandikhan and Dokan Lakes every month during June 2012 up to May 2013, except for August according to the method described in USGS, 2006. The samples were collected in a 1-liter polyethylene sampling and adjusted to pH of 2 using nitric acid. All the samples were refrigerated and transported to the laboratory as soon as possible, where they were stored at 4 °C before analysis. The selected heavy metals were determined following the standard method [15] using Inductively Coupled Plasma-Optical Emission Spectroscopy ICP-OES (model PerkinElmer, precisely Optima 2100/ USA). A total of eighteen fish specimens (1, 2 and 3 years) were collected from Darbandikhan and Dokan Lakes (Figure 1), followed by keeping them in a container of polystyrene icebox, then transferred to the Chemistry Laboratory freezer (-18 °C). From each fresh fish samples, portions from chest and tail muscles were cut and thoroughly homogenized, from which 50 gram was placed in drying oven at 70 °C for 72 h. The dried samples were then ashed in muffle furnace at 550 °C for72 h. From each ashed fish sample, 0.1 gram was added to concentrated acid, followed by boiling to ensure the samples were
completely dissolved. All the samples were measured at 220.3 nm, 228.8 nm and 327.4 nm for the analysis of Pb, Cd and Cu respectively, using ICP-OES. Standard solutions of heavy metal were prepared covering the concentration range of 10 mg/L to 50 mg/L.

Figure 1. A) Dukan lake, B) Darbandikhan lake.

2.1.2. Statistics: The results were statistically evaluated by analysis of variance. Factorial experiment with three replications was used for microbial, chemical and heavy metals in both Darbandikhan and Dokan Lakes applying XLSTAT program ver. 7.5.2. The experiment was setup in Complete Randomized Design (CRD) according to the linear model, Eq. (1):

\[ Y_{ijk} = \mu + \alpha_i + \beta_j + \alpha\beta_{ij} + \varepsilon_{ijk} \]  

(1)

where: \( i \) = source of water (Raw, Tank and Tap water). \( j \) = Months, \( k \) = replications. For heavy metal determination in the fish samples, the completely randomized design (CRD) was used to analysis the results using the same program mentioned above, the linear model below, Eq. (2):

\[ Y_{ij} = \mu + t_i + \varepsilon_{ij} \]  

(2)

where: \( \mu \) = Grand mean, \( t_i \) = The effect of fish ages (\( i = 1,2 \) and 3 ages). \( \varepsilon_{ij} \) = Randomized error.

All possible comparisons among the means were carried out by using Least Significant Difference (LSD) test at a significant level of (0.05 or 0.01) after showing their significance in general test.

3. Results and discussion
The problem with heavy metals is that they cannot be degraded or destroyed by cooking, they are particularly become dangerous when they present in food and drink which are readily consumed in raw state. Heavy metals to a small extend enter our bodies via food, drinking water and air. As trace elements, some heavy metals are essential to maintain the metabolism of the human body. However, at higher concentrations they can lead to poisoning [16].

3.1. Heavy metals in water
A. Copper (Cu) compounds are widely distributed in nature including surface water and some groundwater too [17]. Copper compounds are also used as agricultural pesticides and algae control, occurring in simple ionic form or in one of many complexes with groups, such as cyanides, chlorides and ammonia. Cu is considered both as an essential nutrient and drinking water contaminant [18].

Figure 2A demonstrates the highest Cu concentration of the raw water, tank water and tap water were (56.4, 56.9, 56.9) µg/L respectively during May 2013, whereas the lowest values were (7.2, 6.2 and 8.2) µg/L respectively during June and July 2012. Likewise, at Dokan lake the highest Cu concentration of the same water sources were (56.9, 56.9 and 56.9) µg/L in May 2013 and the lowest values were (7.2, 6.2 and 8.2) µg/L during July 2012 (Figure 2B).
It has been concluded that concentration of copper in drinking water can vary widely, depending on variations in pH, hardness, and copper availability in the distribution system [19]. This might explain the present results too. On the other hand, the maximum acceptable concentration of copper in drinking water according to [20-23] were (2 mg/L) (≤1.0 mg/L) (1.3 mg/L) (1 mg/L) and (2 mg/L) respectively. Accordingly, copper content in all the studied water samples during this investigation were within the safe margin for drinking purposes.

Figure 2. The mean values of Cu concentrations (µg/L) of (raw, tank and tap water), during the monitoring period June 2012 - May 2013. A) Darbandikhan lake B) Dokan lake.

B. Cadmium (Cd) as it is shown in (Figure 3A) the highest cadmium concentration values in Darbandikhan lake raw water, tank water and tap water were (34.3, 35.6 and 35.3) µg/L respectively during April 2013 and the lowest values were (4.8, 4.3, and 4.0) µg/L respectively during June 2012; While, at Dokan Lake the maximum values of the water sources were (42.5, 41.9 and 43.9) µg/L respectively during May 2013 and the minimum values were (19.8, 15.9 and 18.5) µg/L respectively during June 2012 (Fig. 3B). These results in almost all the samples of both lakes were exceeded the level (3 µg/L) recommended by [24] and the recommended level (5 µg/L) by [22].

The increase in cadmium level indicates the pollution of water by industrial activities [25] due to excessive uses of steel plating and nickel cadmium batteries. Exposure to cadmium causes kidney
damage [26]. Similar conclusions were made by [27] when they recorded the concentration of 16.0 – 29.2 µg/L.

**Figure 3.** The mean values of Cd concentrations (µg/L) of (raw, tank and tap water), during the monitoring period June 2012 - May 2013. A) Darbandikhan lake B) Dokan lake.

C. Lead (Pb) figure 4A shows that the highest value of lead concentration at the Darbandikhan lake of the raw water, tank water and tap water were (387.4, 413.4 and 921) µg/L respectively during November 2012 and the lowest values were (104.4, 91.6 and 395.9) µg/L respectively during February 2012; Whereas in Dokan Lake the highest Pb values of the water sources were (265.9, 253.1 and 226.7) µg/L respectively during May 2013 and the lowest values were (83.5, 125.1 and 119) µg/L respectively during April 2013 (Figure 4B).

The lead concentrations in all investigated water samples during the studied period exceeded the level of 10 µg/L recommended by [28]. The high concentration of this heavy metal may be due to the discharge of industrial effluents and municipal wastes, geological formation, weathering and erosion of soil during rainy seasons [29]. The lead concentration in drinking water, may be due to the of old
water piping system used to water suction as well as to water distribution. Additionally, one source of high lead concentration may originate from fuels and oils which used for water pumping process or the formula and the type of soil [30].

![Figure 4](image)

**Figure 4.** The mean values of Pb concentrations (µg/L) of (raw, tank and tap water), during the monitoring period June 2012 - May 2013. A) Darbandikhan lake B) Dokan lake.

D. Zinc (Zn) The highest zinc concentration of Darbandikhan lake were from raw water, tank water and tap water were (350.1, 350.3 and 388.3) µg/L respectively during January 2012 and the lowest values were (42.6, 70.6 and 67.0) µg/L respectively during June 2012 (Figure 5A); While at Dokan lake the highest zinc concentration of the same water sources were (39.0, 55.0 and 112.9) µg/L respectively during May 2013 and the lowest value were (2.1, 2.4 and 1.8) µg/L during January 2012, respectively (Figure 5B). The high concentration of Zn may be due to discharge from small industries, sewages, various domestic and household sources [28], or it might be due to the release of metals to environment by both natural and anthropogenic sources especially mining and oil industrial activities [31]. Similar conclusions were made by another researcher [32, 33].

Unlike other heavy metals (Cu, Pb and Cd) reported in this study, the concentration of Zn in all the investigated water samples during the studied period were lower than the levels (3 mg/L) recommended by [34]; while levels lower than 5 mg/L recommended by [35]. Therefore, all the studied water samples were considered within the permitted Zn content.

3.2. Heavy metals in fish

A. Copper the analytical results of copper content in fishes from Darbandikhan Lake showed 6.40, 4.96 and 3.61 µg/g in three, two and one year old fishes respectively. Whereas copper content in fishes
from Dokan Lake was found to be 7.12, 6.80 and 6.86 µg/g for the fish ages respectively (Table 1). It can be noted that copper deposition in fish muscles are almost age dependent, however the copper concentration in the fish samples was less than the food and agriculture organization FAO-permitted level of 30µg/g [36].

![Figure 5.](image)

**Figure 5.** The mean values of Zn concentrations (µg/L) of (raw, tank and tap water), during the monitoring period June 2012 - May 2013. A) Darbandikhan lake B) Dokan lake.

B. Cadmium content in fish from Darbandikhan Lake showed 32.55, 26.39 and 18.38 µg/g for the fishes of 3-1 year, respectively. Again, the results are shown age dependent, however, Cd content in fishes from Dokan Lake showed slightly higher levels 35.26, 34.75 and 34.02µg/g for the same age groups, respectively (Table 1).

Correlating the Cd content in the water lake with these finding in the fish muscles, explains the effect of the polluted environment on the fishes. Dietary preferences and food quality have also been considered as factors to explain age-related increases in Cd concentration, since these variables can affect metal bioaccumulation in wild fish [37]. The Cadmium concentration in the fish samples was far above the maximum permitted level of (0.05 µg/g) by food and agriculture organization and the world health organization [38].

C. Lead the test results of lead content in fishes from Darbandikhan Lake showed 26.21, 14.04 and 10.72 µg/g for three, two and one year old fishes, respectively, while in fishes from Dokan Lake were 33.08, 30.84 and 28.56 µg/g for the same age group respectively (Table 1). The lead level in the fish
samples was far above the maximum permitted level of (1.5µg/g) by food and agriculture organization and the world health organization [38].

Table 1. Heavy metals content in fishes (1-3 years) from Dokan and Darbandikhan lakes.

| Heavy Metals | Darbandikhan | Dokan |
|--------------|--------------|-------|
|              | Fish Age (Year) |     |
|              | 1 Year | 2 Year | 3 Year | LSD | 1 Year | 2 Year | 3 Year | LSD |
| Cu           | 3.61  | 4.96  | 6.40  | LSD (0.01) | 6.86 | 6.80 | 7.12 | LSD (0.01) |
| Cd           | 18.38 | 26.39 | 32.55 | LSD (0.01) | 34.02 | 34.75 | 35.26 | LSD(0.05) |
| Pb           | 10.72 | 14.04 | 26.21 | LSD (0.01) | 28.56 | 30.84 | 33.08 | LSD (0.01) |

These results could partially come from the absence of strict legal obligation of dumping materials into the rivers and lakes by the public, further, the absence of regulations for good sanitation in terms of sewage and drains management along the path of the lakes. The conclusive results are obvious of having high content of heavy metals in raw water and subsequently in the fishes living in such polluted environment. These results have to be taken into consideration by the authorities particularly if long-term consumption is taken into account. In authors view there are several factors contribute in heavy metal contamination in potable water of Darbandikhan and Dokan:

i. The absence of an environmental protection system to protect rivers and the lakes becoming a scrap yard by public. Various junk objects were identified during this study, including tiers, shoes, cans, clothing, car parts and many metallic items.

ii. The absence of physical barriers along the river/lake paths to prevent the contamination results from the runoff water in raining season.

iii. The quality of materials used for water storage tank, piping and distribution of potable water must be at the standards recommended by ISO regulations for drinking water.

iv. The water tanks must thoroughly be protected from sources of contamination; especially the metallic lids and the ladders used into the tank. Indeed, the current system is unsafe and could well pause a source of contamination.

v. The water tanks are made of concrete, which is subject to erosion by time and consequently its cleaning would be so difficult that contaminants may harbor in the eroded pockets.

4. Conclusions

In summary, the results of this study to monitor some water safety parameters of Darbandikhan and Dokan lakes during June 2012 – May 2013, the following conclusions are made: most of the investigated samples of raw, tank and tap water from both Darbandikhan and Dokan lakes revealed high heavy metal content of Cd and Pb, exceeding the standards recommended by WHO and FAO organizations. The heavy metal content of Cd and Pb in fishes of all ages from both lakes was higher than the maximum permitted levels recommended by WHO organization. This is an alarming for research scholars and governmental decision makers to assess current water pollution situation and monitor systematically to mitigate this pollution.

According to our findings in the investigation of water and fish safety of Darbandikhan and Dokan site we recommend:

- Based on the current results, it is recommended to carry out further studies and researches in order to ensure the suitability of drinking water and fishes for human consumption.
- The official bodies concerned with water safety must be informed on these results.
- Comprehensive sampling regime of tap waters from both Darbandikhan and Dokan lakes for chemical, heavy metal and microbial analysis.
• In addition to the current parameters used, the samples must be analyzed for other hazards parameters that were not conducted in this investigation, such as, Arsenic and Mercury…. etc. on a systematic basis.
• Blood testing of the population that uses water of Darbandikhan and Dokan for heavy metals to be considered.
• Same investigations can be conducted on the bottled drinking water whether locally produced or imported.

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References
[1] Aziz K H H 2019 Application of different advanced oxidation processes for the removal of chloroaacetic acids using a planar falling film reactor Chemosphere 228 377-83
[2] Fu J, Hu X, Tao X, Yu H, Zhang X 2013 Risk and toxicity assessments of heavy metals in sediments and fishes from the Yangtze River and Taihu Lake, China Chemosphere 93 1887-95
[3] Aziz K H H, Omer K M, Hamarawf R F 2019 Lowering the detection limit towards nanomolar mercury ion detection via surface modification of N-doped carbon quantum dots New J. Chem. 43 8677-83
[4] Aziz K H H, Miessner H, Mueller S, Mahyar A, Kalass D, Moeller D, Khorsid I, Rashid, M A M 2018 Comparative study on 2, 4-dichlorophenoxyacetic acid and 2, 4-dichlorophenol removal from aqueous solutions via ozonation, photocatalysis and non-thermal plasma using a planar falling film reactor J. Hazardous Mater. 343 107-15
[5] Dural M, Göksu M Z L and Özak A A 2007 Investigation of heavy metal levels in economically important fish species captured from the Tuzla lagoon Food Chem. 102 415-21
[6] Nriagu J, Udofia E, Ekong I and Ebuk G 2016 Health Risks Associated with Oil Pollution in the Niger Delta, Nigeria Int. J. Environ. Res. Public Health 13 346
[7] Saeed S M and Shaker I M 2008 Assessment of heavy metals pollution in water and sediments and their effect on Oreochromis niloticus in the northern delta lakes, Egypt in: 8th Int. Symposium on Tilapia in Aquaculture, Central Laboratory for Aquaculture Research, Agricultural Research Center (Limnology dept.) p 475-490
[8] Stancheva M, Makedonski L and Petrova E 2013 Determination of heavy metals (Pb, Cd, As and Hg) in black sea grey mullet (Mugil cephalus) Bulgarian J. Agri. Sci. 19 30-4
[9] Ahmed T M, Ahmed B, Aziz B K, Bergvall C and Westerholm R 2015 Native and oxygenated polycyclic aromatic hydrocarbons in ambient air particulate matter from the city of Sulaimaniyah in Iraq Atmospheric Environ. 116 44-50
[10] Kabir M I, Lee H and Kim G 2010 Zink of surface sediment in rural river basin as a potential priority to diffuse pollutants Desalination Water Treat. 19 113-8
[11] Sures B, Taraschewski H and Rokicki J 1997 Lead and cadmium content of two cestodes, Monobothrium wageneri and Bothriocephalus scorpii, and their fish hosts Parasitol. Res. 83 618-23
[12] Fernandes C, Fontainhas-Fernandes A, Cabral D and Salgado M A 2008 Heavy metals in water, sediment and tissues of Liza saliens from Esmoriz–Paramos lagoon, Portugal Environ. Monitoring Assess. 136 267-75
[13] Wang Y, Chen P, Cui R, Si W, Zhang Y and Ji W 2010 Heavy metal concentrations in water, sediment, and tissues of two fish species (Triplophysa pappenheimi, Gobio hwanghensis) from the Lanzhou section of the Yellow River, China Environ. Monitoring Assess. 165 97-102
[14] Mendil D and UluözlüÖ D 2007 Determination of trace metal levels in sediment and five fish species from lakes in Tokat, Turkey Food Chem. 101 739-45
[15] Association A P H, Association A W W, Federation W P C and Federation W E 1915 Standard methods for the examination of water and wastewater (USA: American Public Health Association)

[16] Renge V, Khedkar S and Pande S V 2012 Removal of heavy metals from wastewater using low cost adsorbents: a review Sci. Revs. Chem. Commun. 2 580-4

[17] Muhammad S, Tahir Shah M and Khan S 2001 Health risk assessment of heavy metals and their source apportionment in drinking water of Kohistan region, northern Pakistan. Microchem. 98 334-43

[18] Edition F 2010 Guidelines for drinking-water quality WHO Chronicle 38 104-8

[19] Council N R 2000 Copper in Drinking Water (Washington DC: National Academy Press)

[20] Alobaidy A H M J, Abid H S and Maulood B K 2010 Application of water quality index for assessment of Dokan lake ecosystem, Kurdistan region, Iraq J. Water Resour. Prot. 2 792

[21] Lomborg B 2003 The skeptical environmentalist: measuring the real state of the world, (Cambridge: Cambridge University Press)

[22] Directive C 1998 On the quality of water intended for human consumption Official J. European Commun. 330 32-54

[23] Li Z and Jennings A 2017 Worldwide regulations of standard values of pesticides for human health risk control: A review Inter. J. Environ. Res. Public Health 14 826

[24] Mohod C V and Dhote J 2013 Review of heavy metals in drinking water and their effect on human health Inter. J. Innov. Res. Sci. Engin. Technol. 2 2992-6

[25] Li B, Wang Q, Huang B and Li S 2001 Evaluation of the Results from a Quasi-Tessier’s Sequential Extraction Procedure for Heavy Metal Speciation in Soils and Sediment by ICP-MS, The Japan Society for Analytical Chemistry 17 1561-1564

[26] Rajappa B, Manjappa S and Puttaiah E 2010 Monitoring of heavy metal concentration in groundwater of Hakimaka Taluk, India Contemp. Engin. Sci. 3 183-90

[27] Kafia M S, Slaiman G M and Nazanin M S 2009 Physical and chemical status of drinking water from water treatment plants on Greater Zab River J. Appl. Sci. Environ. Manag. 13 89-92

[28] Commission E E 1998 Council directive 98/83/EC on the quality of water intended for human consumption Off. J. Eur. Commun. L. 330 54

[29] Kaushik A, Kansal A, Kumari S and Kaushik C 2009 Heavy metal contamination of river Yamuna, Haryana, India: assessment by metal enrichment factor of the sediments J. Hazardous Mater. 164 265-70

[30] Bartram J, Cotruvo J, Exner M, Fricker C and Glasmacher A 2003 Heterotrophic plate counts and drinking-water safety (USA: IWA Publishing)

[31] Duruibe J O, Ogwuegbu M and Egwurugwu J 2007 Heavy metal pollution and human biotoxic effects Inter. J. Phys. Sci. 2 112-8

[32] Aziz R J, Al-Zubaidy F S, Al-Mathkhury H J, Musenga J 2014 Physico-chemical and biological variables of hospitals wastewater in Erbil City, Iraqi J. Sci. 55 84-92

[33] Sharma R, Agrawal M and Marshall F 2007 Heavy metal contamination of soil and vegetables in suburban areas of Varanasi, India Ecotoxicol. Environ. Saf. 66 258-66

[34] WHO 2004 Guidelines for drinking-water quality (Geneva: World Health Organization)

[35] Patrick R J 2011 Uneven access to safe drinking water for First Nations in Canada: Connecting health and place through source water protection Health Place 17 386-9

[36] Nauen C E 1983 Compilation of legal limits for hazardous substances in fish and fishery products FAO Fisheries Circular (FAO) 764 102

[37] Andres S, Ribeyre F, Tourencq J N and Boudou A 2000 Interspecific comparison of cadmium and zinc contamination in the organs of four fish species along a polycmetallic pollution gradient (Lot River, France) Sci. Total Environ. 248 11-25

[38] WHO 1976 List of maximum levels recommended for contaminants by the Joint FAO/WHO Codex Alimentarius Commission-Second series(Geneva: World Health Organization)