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DETERMINATION OF HEAVY METALS CONCENTRATION IN FISH SPECIES FROM DADIN KOWA DAM CONSUMED IN SOME PARTS OF GOMBE STATE, NORTHEASTERN NIGERIA AND ITS HEALTH EFFECTS

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ABSTRACT

Despite increasing in industrial and agricultural activities near Dadin Kowa Dam, limited data exist on heavy metal contamination in its aquatic ecosystem. This study investigates metal concentration in commonly consumed fish species in northern parts of Nigeria and many parts of Africa to assess potential health risks. Heavy metals in fish originate from industrial discharge, agricultural runoff, and natural geological processes, necessitating continuous monitoring. Chronic exposure to Pb, Cd, As, Fe, Cu, and Ni is linked to neurological damage, renal failure, and carcinogenic effects, making their presence in food sources a serious concern. AAS analysis was performed using certified reference materials, and calibration was validated with standard solutions to ensure accuracy. The planet catfish was found to have high levels of lead (0.0237 mg/100g), while Cadmium contents in Red-tailed Synodontis were alarming (0.0560 mg/100g), beyond safety limits and potentially harmful to health. The greatest arsenic level was found in African Cat Fish (0.0655 mg/100g), which suggests that long-term exposure should be avoided. ANOVA results ($p < 0.05$) indicate significant variation in heavy metal accumulation between species, identifying Planet Catfish and Red-tailed Synodontis as the most contaminated. To minimize exposure risks, regular monitoring programs, public health advisories, and dietary guidelines on fish consumption should be implemented. Findings are compared against WHO/FAO (2021) guidelines for permissible heavy metal concentrations in fish.

Keywords: Heavy Metals, Fish Species, Dadin Kowa Dam, Consumed, Health Effects

INTRODUCTION

Heavy metals are defined as metals with a density greater than 5 mg/cm3 that have a detrimental effect on human life and are harmful when they exceed entrance limits (Agbugui et al., 2019, WHO 2011). Heavy metals are obtained through anthropogenic activities in the following areas: industry, mining, metal smelting, oil refining, agriculture, fertilization, and drainage (Agbugui et al 2013). When mining wastes are released into the environment without being properly treated, the concentration of contaminants, including heavy metals, increases and contaminates the water bodies nearby (Ahmad et al., 2014). However, in some land and water body areas with rapid industrial development, environmental degradation is becoming more and more serious. These pollutants can build up in the muscle tissues of marine species, potentially posing a health concern. It is believed that heavy metals pose a major hazard to the environment worldwide (Jiang et al., 2018). Toxic metals can be absorbed by marine fish through their diet as well as from the nearby water and sediment. For instance, (Leite et al. 2022) found that canned sardines from Brazil had a mean Pb level of 2.15 mg/kg. (Ogundiran et al., 2021) discovered that European pilchard from southwest Nigeria had a mean Cd level of 0.19 mg/kg. The Italian spiny dog fish was shown to have an average high amount of mercury (6.53 mg/kg) by (Spognardi et al., 2021) Pb levels (8.62 mg/kg) in tilapia from China's Pearl River Delta were noted by Leung et al. Each of these investigations suggested that heavy metals may have contaminated marine fish. High levels of exposure to metalloid elements and heavy metals have a deleterious effect on human health. Commonly seen as inorganic compounds in the oxidation state, cadmium can pass a variety of biological membranes and cause skeletal abnormalities, neurological illnesses, and frailty. Prolonged exposure to mercury damages the gland and the liver and weakens the immune system. Pb has been shown to be connected to neurological issues, cancer, hypertension, hematological consequences, and renal failure. Thus, it makes sense to speculate that eating fish tainted with heavy metals may be harmful to one's health. The lengthy biological half-life of heavy metals in living things is a significant issue. Since fish is known to be a high-protein food source worldwide, the accumulation of heavy metals in their bodies can have toxic effects on human health. Specifically, the concentration of heavy metals in their gills, liver, and kidneys is higher than in their muscles (Milenković et al 2016).

Several scientists have studied the effect of heavy metals on marine species as well as human (Agbugui and Abe, 2013; Mensor and Said, 2018; Agbugui et al., 2019). Numerous international regulatory organizations, including the Food and Agriculture Organization (FAO), the European Union (EU), and the World Health Organization (WHO), have determined maximum allowable concentrations of heavy metals in food items (Atta et al., 2023). For instance, the European Food Safety Authority (EFSA, 2021) reported that the maximum tolerated limit (MTL) for lead in fish flesh is 0.3 mg/kg, while the mercury and cadmium levels were found to vary depending on the species of fish, ranging from 0.5 to 1.0 mg/kg wet weight and 0.05 to 0.3 mg/kg, respectively.

Alewu and Nosiri (2011) reported that heavy metals are either expelled, stored, or bioaccumulated within fish. Depending on a number of variables, different fish absorb heavy metals in different ways and at varying rates. It could be biological (species, size, gender, sexual maturity, and food supply) or environmental (water chemistry, temperature, and contamination levels). Humans are exposed to heavy metals due to their bodies' greater capacity to absorb these elements (Baharoma and Ishak 2015; Naeem et al., 2021).

Although several studies have investigated heavy metal contamination in aquatic ecosystems, limited research has been conducted on bioaccumulation patterns in fish species from Dadin Kowa Dam. This study aims to address this gap by evaluating heavy metal concentrations in commonly consumed fish and assessing potential health risks to local populations. Dadin Kowa Dam is located near agricultural and industrial zones, where potential sources of heavy metal contamination include fertilizer runoff, pesticide use, and industrial effluents. Understanding these contamination pathways is essential for assessing the risk of heavy metal bioaccumulation in aquatic species.

Given the potential health risks associated with heavy metal consumption, this study aims to: (i) quantify the concentrations of As, Ni, Pb, Fe, Cu, and Cd in fish from Dadin Kowa Dam, (ii) compare findings to international safety limits, and (iii) evaluate potential health risks associated with long-term consumption.

MATERIALS AND METHODS

The Study Area

As its clearly indicated in figure 1, Dadin Kowa dam is situated in Yamaltu Deba local government area of Gombe State, which occupies part of the central position of the North-Eastern part of Nigeria located at latitude 9º 48'00"N and longitude 11º 16' 00"E. The location is located 37 kilometers east of Gombe at latitude 11°28'54"N and longitude 10°19'19"N, with the Gongola river serving as the primary drainage system. The dam, which is a component of the River Gongola, has a surface area of 300 square kilometers and a water capacity of 800 million cubic meters. It is located in the drainage basin of Northeastern Nigeria. There is an Ashaka cement factory nearby, a village primarily made up of farmlands, and agricultural activity is carried out along the riverbed.

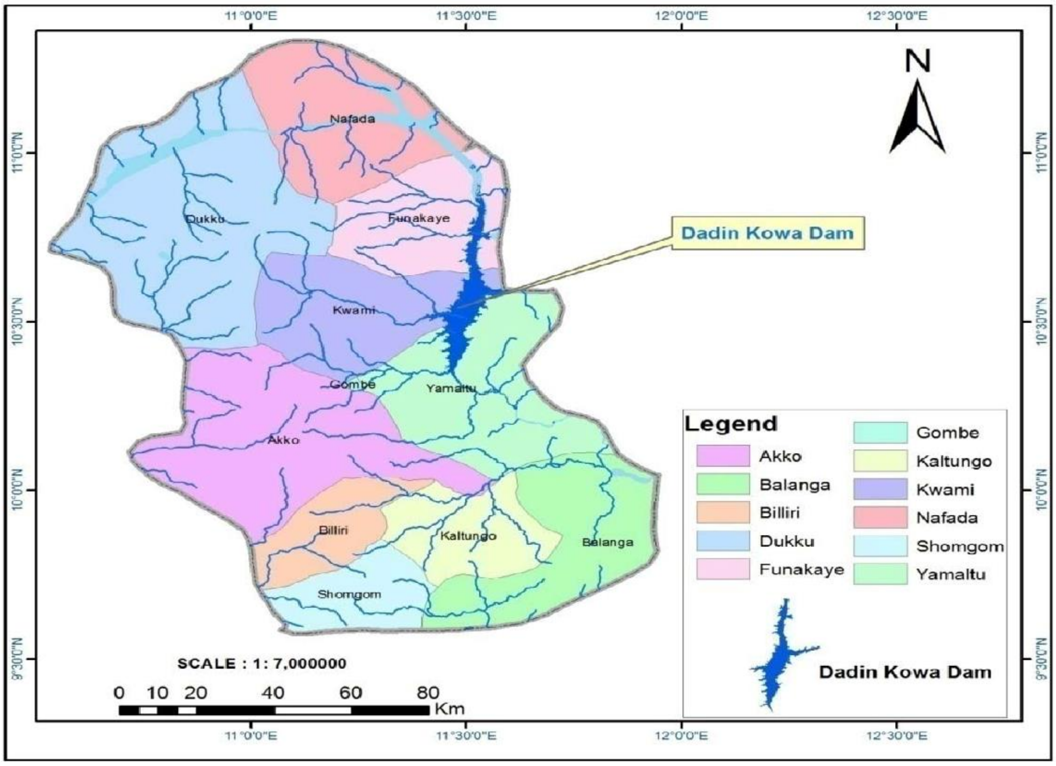

Figure 1: Location Map showing the study area at Dadin Kowa Dam (Google search/Wikipedia)

Sampling and Sample Preparation

Six (6) different kinds of fish were gathered from the Dadin Kowa Dam in northeastern Nigeria. To guarantee an accurate assessment of the heavy metals, representative, Fish were randomly collected from five different locations within Dadin Kowa Dam, considering variations in depth, proximity to pollution sources, and fishing activity. Immediately after collection, fish samples were stored in polyethylene containers, transported on ice at 4°C, and processed within 24 hours to prevent metal leaching. Gombe State University Biochemistry Laboratory received the samples, (figure 2 to 7) which included African catfish (Clarias grafinus), Red Tailed Synodontis or The Mandi (Synodontis Clarias), Blue catfish (Ictalurus furcatus), Planet Catfish (Loricariidae), Elephant Snout Fish (mormyrus kannume), and Gilded Catfish (Zungaro zungaro) respectively. To ensure accuracy, the AAS was calibrated using standard reference materials (SRM 1643f for trace metals in water). Spike recovery tests and triplicate analyses were conducted, achieving an average recovery of 95%

Figure 2: African Catfish (*Clarias grafinus*)

Figure 3: Red Tailed Synodontis (*Synodontis clarias*)

Figure 4: Blue catfish (*Ictalurus grafinus*)

Figure 5: Planet catfish (*Loricariidae*)

Figure 6: Elephant Snout Fish (*Mormyrus kannume*)

Figure 7: Gilded catfish (*Zungaro zungaro*)

Sample Preparation and Analyses of Heavy Metals Concentrations

Table1: The samples wet and dry weights for heavy metal measurements

Samples	Wet weight (g)	Dry weight (g)
Red tailed synodontis	41	16
Blue catfish	549	149
Elephant snout fish	341	72
Planet catfish	234	54
Gilded catfish	225	45
African catfish	1294	431

Table1 shows the weights of both wet and dry fish samples before the hevey metal analysis. The fish samples were prepared utilizing the AAS analytical technique with a wet digestion approach for the measurement of heavy metals (Pb, Fe, Cu, Ni, As, and Cd). Analytical method using a wet digestion procedure for AAS, to guarantee that the metals were distributed evenly throughout the sample, the samples were ground into a fine powder using a mortar and pestle and baked at 105°C in an oven. Samples were digested for 2 hours at 120°C until a clear solution was obtained. To minimize analyte loss, digestion was performed in a controlled temperature environment using a fume hood. The spectrometer was calibrated using standard solutions, the concentrations of Pb, Fe, Cu, and Cd in the fish samples was determined using AAS, while the equation developed by (USEPA, 2020), to estimate the hazard index (HI) in each of the fish sample.

$$HI = \sum HQ = HQ_{Fe} + HQ_{Mn} + HQ_{Cu} + HQ_{Pb} + HQ_{Co} + HQ_{Ni} + HQ_{Cd} + HQ_{Zn} \quad (1)$$

Where HI is hazard index and hazard HQ is quotients for all heavy metals. While the concentrations (C) of Pb, Fe, Cu, and Cd in the fish samples were determined using Equation (2).

$$C = \frac{A}{W_S} \times 100) \quad (2)$$

Where A is the AAS values and W_S is the weight of the dried sample.

Average Daily Dose and Health Risk Index:

The health risk index (HRI) is the ratio of the average daily dose (AD) in mg/kg of the body weight per day of heavy metals to an oral reference dosage (RfDo) in mg/kg/day. The RfD (Equation 2) refers to the maximum daily consumption of certain heavy metals that do not have any adverse consequences on human health, and the values for Cu, Zn, Cd, and Pb are 0.04, 0.3, 0.001, and 0.004 mg/kg/day, respectively (USEPA 2020).

$$D = \frac{Cm}{W} \times D \quad (3)$$

The average daily dose (AD) was calculated using Equation (3), where Cm is the geometric mean concentration of the heavy metals in the samples, W is the average adult weight of 70 kg, and D is the average daily intake of heavy metals from the samples in mg/day, all these were estimated from the acceptable daily intake per 70 kg weighted adult (FAO/WHO, 2011).

The Health Risk Index (HRI) was used to assessed the health risks associated with ingestion of the heavy metals into human body by using Equation (4)

$$HRI = \frac{AD}{RfDO} \quad (4)$$

If HRI>1, potential human health risk is high and the samples are not safe for consumption. This happens when AD>RfDo for a particular heavy metal.

RESULTS AND DISCUSSION

Results

The outcome shows the amounts of lead (Pb), arsenic (As), cadmium (Cd), iron (Fe), copper (Cu), nickel (Ni), and other heavy metals in six different fish species: blue catfish, African catfish, planet catfish, red-tailed synodontis, blue catfish, and gilded catfish.

Table 2 shows concentration of heavy metals is measured in milligrams per hundred grams, and the mean and standard error of the mean values are displayed for each species of fish. Only African catfish, planet catfish, and red-tailed synodontis exhibited measurable activity concentrations of Pb Lead in fish species in Dadin Kowa Dam, with planet catfish exhibiting the highest concentration (0.0237 mg/100g). Pb contents in golden catfish, elephant snout fish, and blue catfish are below the detection limit (BDL).

Table 2: Concentrations of heavy metals (Pb, As, Cd, Fe, Cu, and Ni) given mg/100g for fish species

Samples	Concentrations mg/100g					
	Pb	As	Cd	Fe	Cu	Ni
Blue catfish	B.D.L	0.0428	0.0057	0.3894	0.0426	0.0751
	0.0000	0.0421	0.0056	0.3885	0.0423	0.0759
	0.0000	0.0426	0.0053	0.3897	0.0421	0.0753
Mean	0.0000	0.0425	0.0055	0.3892	0.0423	0.0754
SEM	0.0000	0.0006	0.0005	0.0003	0.0001	0.0004
Elephant snout fish	B.D.L	0.0112	B.D.L	0.1762	0.0265	0.0183
	0.0000	0.0115	0.0000	0.1743	0.0269	0.0185
	0.0000	0.0113	0.0000	0.1759	0.0263	0.0187
Mean	0.0000	0.0072	0.0000	0.1755	0.0266	0.0183
SEM	0.0000	0.0001	0.0000	0.0053	0.0003	0.0002
African catfish	0.0042	0.0654	0.0324	0.1105	0.0852	0.1354
	0.0046	0.0653	0.0321	0.1187	0.0856	0.1349
	0.0048	0.0659	0.0328	0.1162	0.0854	0.1336
Mean	0.0045	0.0655	0.0324	0.1151	0.0854	0.1342
SEM	0.0002	0.0024	0.0013	0.0024	0.0012	0.0015
Planet catfish	0.0239	0.0145	0.0085	0.5641	0.3157	0.2346
	0.0235	0.0143	0.0082	0.5653	0.3142	0.2321
	0.0237	0.0148	0.0086	0.5615	0.3138	0.2327
Mean	0.0237	0.0145	0.0084	0.5636	0.3146	0.2331
SEM	0.0012	0.0005	0.0003	0.0081	0.0072	0.0054
Red tailed synodontis	0.0062	0.0289	0.0571	0.1723	0.1232	0.1625
	0.0068	0.0282	0.0534	0.1715	0.1226	0.1637
	0.0064	0.0285	0.0575	0.1731	0.1254	0.1628
Mean	0.0065	0.0285	0.0560	0.1723	0.1237	0.1629
SEM	0.0001	0.0003	0.0021	0.0015	0.0047	0.0032

Samples	**Concentrations mg/100g**					
	Pb	**As**	**Cd**	**Fe**	**Cu**	**Ni**
Gilded catfish	B.D.L	0.0034	B.D.L	0.2624	0.0583	0.0862
	0.0000	0.0037	0.0000	0.2632	0.0587	0.0864
	0.0000	0.0031	0.0000	0.2675	0.0581	0.0867
Mean	0.0000	0.0034	0.0000	0.2644	0.0584	0.0863
SEM	0.0000	0.0002	0.0000	0.0029	0.0015	0.0012

Table 3: Mean concentration and range of heavy metals (mg kg^{-1}), in fish species

Species	**Pb (mg/100g)**	**As (mg/100g)**	**Cd (mg/100g)**	**Fe (mg/100g)**	**Cu (mg/100g)**	**Ni (mg/100g)**
Blue catfish	B.D.L (0.0000)	0.0425 ± 0.0006	0.0055 ± 0.0005	0.3892 ± 0.0003	0.0423 ± 0.0001	0.0754 ± 0.0004
Elephant snout fish	B.D.L (0.0000)	0.0113 ± 0.0001	B.D.L (0.0000)	0.1755 ± 0.0053	0.0266 ± 0.0003	0.0183 ± 0.0002
African catfish	0.0045 ± 0.0002	0.0655 ± 0.0024	0.0324 ± 0.0013	0.1151 ± 0.0024	0.0854 ± 0.0012	0.1342 ± 0.0015
Planet catfish	0.0237 ± 0.0012	0.0145 ± 0.0005	0.0084 ± 0.0003	0.5636 ± 0.0081	0.3146 ± 0.0072	0.2331 ± 0.0054
Red tailed synodontis	0.0065 ± 0.0001	0.0285 ± 0.0003	0.0560 ± 0.0021	0.1723 ± 0.0015	0.1237 ± 0.0047	0.1629 ± 0.0032
Gilded catfish	B.D.L (0.0000)	0.0034 ± 0.0002	B.D.L (0.0000)	0.2644 ± 0.0029	0.0584 ± 0.0015	0.0863 ± 0.0012

Notes:
B.D.L: Below Detection Limit. For calculations, B.D.L is considered as 0.0000 mg/100g.
SEM: Standard Error of Mean indicates the precision of the sample mean.

Discussions

Lead (Pb)

Only African catfish, planet catfish, and red-tailed synodontis were found to contain lead, with planet catfish having the highest concentration (0.0237 mg/100g). Pb contents in golden catfish, elephant snout fish, and blue catfish are below the detection limit (B.D.L.).

Arsenic (As)

African catfish has the highest concentration of arsenic (0.0655 mg/100g). The concentrations of other species, such as red-tailed synodontis and blue catfish, are particularly noteworthy; golden catfish has the lowest quantity (0.0034 mg/100g).

Cadmium (Cd)

Blue catfish, African catfish, world catfish, and red-tailed synodontis are fish that contain cadmium; the greatest concentration is found in red-tailed synodontis (0.0560 mg/100g). The concentrations of gilded and elephant catfish are below detection limits.

The maximum amount of Cd allowed in fish by the European Union is 0.05 mg/kg (0.005 mg/100g). These thresholds are exceeded by red-tailed synodontis, suggesting a possible health concern if routinely consumed.

Iron (Fe)

African catfish has the lowest iron concentration (0.1151 mg/100g), while planet catfish has the greatest value (0.5636 mg/100g). The synthesis of hemoglobin requires iron. Although helpful in moderation, overindulgence can have negative health effects. The level is within safe bounds, and if the high Fe content of Planet catfish meets nutritional requirements, it may be advantageous.

Copper (Cu)

Elephant catfish has the lowest concentration of copper (0.0266 mg/100g) and planet caatfish has the greatest concentration (0.3146 mg/100g).

Although too much copper can harm the liver and induce gastrointestinal irritation, it is essential for several bodily processes.

Nickel (Ni)

Elephant catfish has the lowest concentration of nickel (0.0183 mg/100g) while planet catfish has the highest content (0.2331 mg/100g).

At high concentrations, nickel is regarded as a carcinogen and can trigger allergic reactions. The daily tolerated dose (TDI) is approximately 0.2 mg/kg of body weight. Because of the bioaccumulation issues, continuous monitoring is required; however, the levels here are quite low, suggesting minimal risk.

Table 4: Statistical significant differences in heavy metal concentrations between the fish species and metals

Species	Blue catfish	Elephant snout fish	African catfish	Planet catfish	Red tailed synodontis	Gilded catfish
Pb	0.0000	0.0000	0.0045	0.0237	0.0065	0.0000
As	0.0425	0.0113	0.0655	0.0145	0.0285	0.0034
Cd	0.0055	0.0000	0.0324	0.0084	0.0560	0.0000
Fe	0.3892	0.1755	0.1151	0.5636	0.1723	0.2644
Cu	0.0423	0.0266	0.0854	0.3146	0.1237	0.0584
Ni	0.0754	0.0183	0.1342	0.2331	0.1629	0.0863

```
df =pd .Data Frame(data)
# performing ANOVA for each metal
anova_results = {} for metal in df.Columns[1:]:
f_val, p_val = f_oneway(df[metal], df[metal], df[metal], df[metal], df[metal], df[metal])
Anova_Results[metal] = {'F-value': f_val, 'p-value': p_val}
```

Statistical analysis

The relationship between the dependent variable (Ksat) and the associated parameters (predictors) was evaluated using the multiple Regression Analysis. The significance of the observed correlation coefficient results was analyzed using the factor analysis and Pearson's correlation method to explain relationship between sample parameters and/or variables. Principal Component Analysis (PCA) is one of the multivariate statistical techniques based on data reduction of an original data set while retaining the inherent interdependencies present in the original data set (Satyanarayanan et al., 2016). CA was performed with the aid of Ward's linkage method and squared Euclidean distance as a measure of similarity between samples and/or parameters (Zhang et al., 2014)

CONCLUSION

The estimated daily intake (EDI) of heavy metals in these fish species was compared with WHO tolerable daily intake levels. The calculated hazard index (HI) for cadmium in Red-tailed Synodontis exceeds 1.0, indicating potential health risks with long-term consumption. The elevated levels of cadmium and lead in Planet Catfish and Red-tailed Synodontis suggest possible contamination from upstream agricultural activities and industrial effluents. Future studies should assess sediment and water quality to pinpoint contamination sources. These findings align with similar studies on Nigerian water bodies, where cadmium and lead contamination in fish have been linked to industrial pollution and improper waste disposal as reported. Given the bioaccumulative nature of heavy metals, prolonged exposure through fish consumption may lead to chronic health effects such as neurotoxicity and kidney damage. Public awareness on recommended fish intake levels is crucial. To mitigate contamination risks, we recommend implementing a quarterly monitoring program for fish and water quality, enforcing stricter waste disposal regulations, and conducting community outreach programs on safe fish consumption practices. Based on the findings and related scholarly insights, it is recommended that there should be; Continuous Environmental Surveillance, i.e. there is need to **i**mplement regular monitoring of heavy metal levels in Dadin Kowa Dam to ensure public health safety and environmental protection. This includes periodic sampling and analysis to track changes over time; among others.

REFERENCES

Ahmad, A. Sarah, Assessment of Abandoned Mine Impacts on Concentrations and Distribution of Heavy Metals in Surface Sediments of Catchments Around Sungai Lembing Abandoned Tin Mine, Iranica Journal of Energy & Environment 5, (4): (2014).

Agbugui M. O., Abhulimen E. F., Inobeme, A. and Olori, E. (2019). Biodiversity of Fish Fauna in River Niger at Agenebode, Edo State, Nigeria. Egyptian Journal of Aquatic Biology and Fisheries. 23(4): 159-166. www.ejabf.journals.ekb.eg (Scopus)

Agbugui, M.O and Deekae, S.N. (2013). Assessment of the physico-chemical parameters and quality of water of the New Calabar-Bonny River, Port-Harcourt, Nigeria. Cancer Biology 4 (1):1-9. www.cncerbio.net.1

Alewu, B, and Nosiri, C. (2011). Pesticides and human health. In: Stoytcheva M, editor. Pesticides in the Modern World – Effects of Pesticides Exposure. InTech (2011). p. 231–50. Available from: http://www.intechopen.com/books/pesticides-in-the-modern-world-effects-ofpesticides-exposure/pesticide-and-human-healt

Akan J.C, Salwa Mohmoud, Bashir Shetima Yikala and Victor Obioma Ogugbuaja (2012). Bioaccumulation of smeheavy metals in fish samples from river Benue in Vinikilang, Adamawa State, Nigeria. American Journalof Analytical Chemistry. DOI: https://doi.org/10.4236/ajac.2012.311097

Atta, M. I., Zehra, S. S., Dai, D. Q., Ali, H., Naveed, K., Ali, I., ... & Ali, I. (2023). Amassing of heavy metals in soils, vegetables and crop plants irrigated with wastewater: Health risk assessment of heavy metals in Dera Ghazi Khan, Punjab, Pakistan. *Frontiers in plant science*, *13*, 1080635.

Baharoma, Z.S. and Ishaka, M.Y (2015). Determination of heavy metal accumulation in fish species in Galas River, Kelantan and Beranang mining pool, Selangor. Procedia Environmental Sciences 30 320 – 325. doi: https://doi.org/10.1016/j.proenv.2015.10.057 .

European Food Safety Authority (EFSA), Carrasco Cabrera, L., & Medina Pastor, P. (2021). The 2019 European Union report on pesticide residues in food. *EFSA Journal*, *19*(4), e06491.

FAO/WHO (2011). Food and Agriculture Organization/World Health Organization. Joint Expert Committee on Food Additives. Summary and conclusions.

53rd Meeting, Rome. www.fao.org/fileadmin/templates/.../2002-09-10.

Jiang, Q., He, J., Ye, G. & Christakos, G. Heavy metal contamination assessment of surface sediments of the East Zhejiang coastal area during 2012–2015. Ecotoxicol. Environ. Saf. 163, 444–455 (2018).

Leite, L. C. S., de Lima, N. V., Melo, E. S. D. P., Cardozo, C. M. L., & do Nascimento, V. A. (2022). Exposure to toxic metals and health risk assessment through ingestion of canned sardines sold in Brazil. *International Journal of Environmental Research and Public Health*, *19*(13), 7678.

Mensoor M. and Said, A. (2018). Determination of Heavy Metals in Freshwater Fishes of the Tigris River in Baghdad. Fishes. 3, 23 6pp; https://doi.org/10.3390/fishes3020023.

Milenković N, Damjanović M, Ristić M: Study of Heavy Metal Pollution in Sediments from the Iron Gate (Danube River), Serbia and Montenegro. Polish J Environmen Stud 2016, 14: 781–787.

Naeem, S., Ashraf, M., Babar, M.E. (2021). The effects of some heavy metals on some fish species. Environ Sci Pollut Res 28, 25566–25578 (2021). https://doi.org/10.1007/s11356-021-12385-z

Ogundiran, A. A., Babarinde, N. A., Ofudje, E. A., & Ogundiran, O. O. (2021). Removal of Heavy Metals from Aqueous Solutions using Modified Irish Potato Leaf as Low Cost Biosorbent: Kinetic and Thermodynamic Studies. *J. Sci. Technol*, *22*, 257-271.

Spognardi, S., Bravo, I., Rea, R., Cappelli, L., & Papetti, P. (2021). A perspective on the potential health risks from PCBs and heavy metals contamination of M. merluccius from Mediterranean Sea. *International Journal of Food Safety, Nutrition and Public Health*, *6*(2), 85-103.

Satyanarayanan, M., Eswaramoorthi, S., Subramanian, S., Periakali, P., 2016. Factor analysis of rock, soil and water geochemical data from salem magnesite mines and surrounding area, Salem, Southern India. Appl. Water Sci. https://doi.org/10.1007/s13201-016-0411-6.

USEPA, (2020). DDT - A review of scientific and economic aspects of the decision to ban its use as a pesticide. Washington US EPA; 1975.

WHO (World Health Organization) (2011). Chromium, Nickel and Welding. International Agency for Research on Cancer. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, France

Zhang, X., Qian, H., Chen, J., Qiao, L., 2014. Assessment of Groundwater chemistry and status in a heavily used semi-arid region with multivariate statistical analysis. Water 6, 2212–2232. https://doi.org/10.3390/w6082212.