

Seasonal variation in heavy metal content of tongue sole, *Cynoglossus brownii* and croaker, *Pseudotolithus typus* from Lagos and Delta states, Nigeria

Francisca George^{1*}, Ogamune, Raymond², Odulate, Dominic¹ and Arowolo, Toyin³

¹Department of Aquaculture and Fisheries Management, Federal University of Agriculture, P. M. B. 2240, Abeokuta, Ogun State, Nigeria

²Edo State Agricultural Development Programme, Benin City, Edo State, Nigeria

³Department of Environmental Resources Management, Federal University of Agriculture, P. M. B. 2240, Abeokuta, Ogun State, Nigeria

ABSTRACT

Aims: The aims of this study were to determine the levels of lead (Pb), Cadmium (Cd), Copper (Cu), Chromium (Cr) and Zinc (Zn) in two economically important Nigerian fish species, tongue sole, *Cynoglossus brownii* and Croaker, *Pseudotolithus typus* from Makoko and Koko in Lagos and Delta states respectively; compare the levels of these metals with recommended international tolerable levels thereby creating awareness on potential health risks of human consumption of these fish species.

Study design: The study locations were purposively selected, being coastal locations where major industries and crude oil exploration facilities are located; and with a high probability of discharging effluents with high levels of heavy metals. Twelve samples each of both fish species were purchased from landing sites in Makoko (Lagos State) and Koko (Delta State) respectively and transported in ice boxes to the laboratories for subsequent analyses

Place and Duration of Study: Department of Environmental Management and Toxicology, Federal University of Agriculture, Abeokuta (FUNAAB) between May, 2010 and April, 2011.

Methodology: Twelve samples each of tongue sole and croaker were collected bi-monthly from each sampling location in May, July and September, 2010 (Wet season) and November (2010) and January and March, 2011 (Dry season). Six samples each were analyzed for heavy metal contents using Atomic Absorption Spectrophotometry (AAS) after wet digestion of dried, milled samples of the fish muscles with 1:1 HNO₃: H₂O₂.

Results: Metal contents (µg/g, dry weight) for tongue sole in Lagos and Delta states during the wet season (April – October) were: Pb (0.330 and 0.149), Cd (0.097 and 0.063), Cu (0.869 and 0.434), Cr (1.184 and 0.826), Zn (7.612 and 7.890); for croaker: Pb (0.163 and 0.045), Cd (0.115 and 0.029), Cu (0.990 and 0.694), Cr (1.008 and 1.038) and Zn (6.756 and 6.168). For the dry season (November – March) metal contents obtained were: Pb (0.534 and 0.527), Cd (0.373 and 0.410), Cu (0.437 and 0.556), Cr (0.834 and 0.983), Zn (6.764 and 9.343) for sole; and Pb (0.210 and 0.213), Cd (0.264 and 0.307), Cu (0.442 and 0.483), Cr (0.577 and 0.597) and Zn (4.783 and 5.924) for croaker. Significant ($P = 0.05$) variations were observed in metal content between sole and croaker and also between dry and wet seasons notably for Cd, Cr and Cu. Generally, metal concentrations were higher in

sole than croaker; and Cadmium content was significantly ($P = 0.05$) higher in fish samples during wet season, while Chromium and Copper were significantly ($P = 0.05$) higher during the dry season. Cd and Cr levels in the test species were found to exceed recommended international tolerable levels.

Conclusion: Heavy metal contents varied among the fish species evaluated and also between seasons. During the dry season, chromium and copper contents of fish were significantly higher, while Cadmium content of fish was significantly higher during the wet season. Cadmium and Chromium contents exceeded international tolerable limits, thus continued consumption of these fish species could expose consumers to serious health risks arising from metal toxicity. A programme of continuous monitoring and control of the physical and chemical characteristics of the components and food products of Nigeria's coastal zone is recommended as a management tool for this important ecological zone.

Keywords: Heavy metal, *Cynoglossus brownii*, *Pseudotolithus typus*, Lagos, Delta, dry season, wet season, health risk

1. INTRODUCTION

Tongue sole, *Cynoglossus brownii* and croaker, *Pseudotolithus typus* are among the most commonly available and economically important fish species in Nigeria's maritime states. They contribute significantly to the animal protein intake of the urban population in these states. Compared to other coastal states, Lagos and Delta states are peculiar, with a blossoming shipping and freighting industry especially Lagos state, which doubles as Nigeria's industrial and commercial centre, having the highest number of industries and arguably the largest human population within a state in the country. As the commercial and industrial nerve centre of Nigeria, with an estimated population of over 9 million people [1][2], environmental concerns are normally focused on Lagos State. Over 60% of Nigeria's industries are cited in the state, each discharging its characteristic range of effluents, often containing heavy metals into the state's terrestrial and aquatic ecosystems. Water pollutants generally originate from definite or point; and dispersed (non point) sources. While point source pollutants are distinct and confined, including accidental spills from industrial sites that empty into streams or rivers, non-point sources, such as run-off, are diffuse and intermittent; and largely influenced by factors such as land use, climate, hydrology, topography, native vegetation and geology [3][4]. Common urban non point sources of pollution include urban run-off from streets or agricultural fields, characteristically containing a variety of pollutants like heavy metals, chemicals and sediments. Rural sources of non point pollutants are generally associated with agriculture, mining or forestry. Non point sources are difficult to monitor and control [5]. The hazard presented by a particular water pollutant depends on several factors including the concentration or toxicity of the pollutant in the environment, and the degree of exposure to people or other organisms [6]. It is estimated that over 80% of coastal pollution originates from land-based sources, including industrial, agricultural, oil and gas production and marine oil transportation activities [7]. Being a universal solvent, water would naturally dissolve toxic materials dumped into it, thereby putting living organisms in the water at risk. Recent works suggest that toxic materials threaten the ocean bottom as well as the entire marine ecosystem. The base of the marine food chain consists of planktonic life which occupies the upper 3mm of the ocean water. The young of most fin and shell fishes also reside in the upper few millimeters of the ocean; and tend to concentrate pollutants such as toxic chemicals and heavy metals. It is reported that concentrations of zinc, lead, and copper in the upper 3mm (or micro layer) is from 10 to 1000 times higher than in the deepest waters due to a process referred to as surface film enrichment [8]. Thus there is fear that disproportionate pollution of this micro layer will have serious effects on marine organisms [9][10][11], resulting in major impacts on

people and society as contaminated marine organisms transmit toxic elements or diseases to their consumers [9].

Heavy metal contamination of the aquatic environment has become a global challenge, mainly because heavy metals are not degradable; and most of them could have toxic effects not only on aquatic flora but also on consumers of aquatic food products [12]; they are therefore of particular concern in view of their persistence, potential toxic effects, indestructibility and ability to bio-accumulate in aquatic ecosystems [13][14]. Heavy metal concentrations in aquatic ecosystems are usually monitored by measuring their concentrations in water, sediments and biota [15][16]. Generally metal concentrations are low in water and attain considerably higher concentrations in sediments and biota [17]. Concerns over heavy metal pollution of the marine environment have been rising due to the human activities that contribute significantly to the release of these metals into the environment. It is reported [18] that heavy metals in the environment are brought about primarily by anthropogenic sources. Though heavy metals are a part of the natural environment and provide numerous benefits to society, those that get deposited in water bodies result from coal and oil combustion, internal combustion engines, local point sources, and direct deposition from air pollution, bedrock geology and soils [18].

The concern posed by heavy metals in the aquatic environment creates an immense threat to the existence of organisms thriving in the area and the ecological integrity of the habitat, particularly as heavy metals may enter the food chains, persist in the environment, bio-accumulate and bio-magnify, then increase exposure of consumers of aquatic products to serious health risks.

Croaker, *Pseudotolithus typus* and sole, *Cynoglossus brownii* are major components of fish landings from Nigerian coastal states, among which Lagos and Delta states are identified as being highly productive [19] [20] [21]. Apart from their relative abundance in the Nigerian artisanal fisheries, both sole and croaker are relished by consumers locally and internationally; and sole fillets feature prominently as export products to Europe. Generally, the two experimental fish species have high economic and nutritional significance in Nigeria.

The present study was carried out to evaluate seasonal variability in level of some common heavy metal pollutants (cadmium, chromium, lead, copper and zinc) in the flesh of croaker and sole; compare the levels of these metals in the fish species with international tolerable levels and finally provide information on the quality of the fish species; and possible health challenges inherent in the consumption of fish with high levels of heavy metals.

2. MATERIAL AND METHODS

Two fish species, *Pseudotolithus typus* (croaker) and *Cynoglossus brownii* (sole) which are lentic and benthic fishes respectively were used for the study. Fish samples were procured from fishermen at landing sites at Makoko, located in the Lagos Mainland Local Government Area, LGA, Lagos State (6° 29' 44" N 3°23'39"E); and Koko (6° 0' 11.31" N 5° 28' 32.36" E)

in the Warri North LGA, Delta State, Nigeria as shown in Fig. 1.

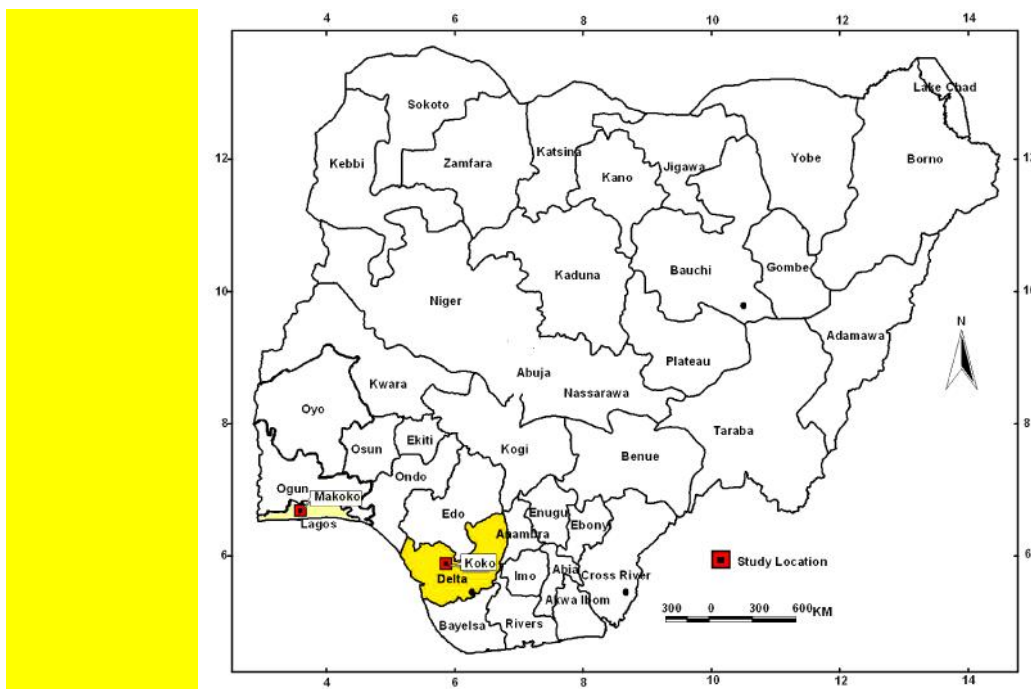


Figure 1: Map showing sampling locations, Makoko, Lagos and Koko, Delta states

Sampling was done six times in May, July, September (Wet season) and November, January, and March (Dry season) at Makoko, Lagos State and Koko, Delta State, Nigeria. Fish samples were procured fresh from fishermen at landing sites in the study locations; and preserved by cooling in ice buckets till they were transferred into deep freezers in the laboratory and kept frozen at -20°C until analysis.

Prior to analysis frozen fish samples were allowed to defrost at room temperatures for about two hours. The thawed fish samples were oven dried at 105°C for about 12h until a constant weight was obtained. Thereafter dried fish samples were homogenized using a ceramic mortar and pestle. Samples were prepared with utmost care to avoid contamination. Hand-gloves were worn throughout the analytical procedures, and precautions were taken to carry out all preparations under strict sanitary laboratory conditions. Where drying was not completed in one day, samples were kept in desiccators and oven-drying was continued the following day.

All glass wares used were washed and rinsed severally with distilled water; then washed in 10% HCl before use.

Samples were digested according to the wet digestion procedure [22], by digesting 10.00 g of dried sample in 60 ml of freshly prepared 1:1 $\text{HNO}_3/\text{H}_2\text{O}_2$ solution at 160°C on a hot plate for about one hour until the volume of contents was reduced to about 5 ml. Contents were then filtered and the filtrate transferred to a standard flask and made up to 25 ml with distilled de-ionized water. This was stored in plastic bottles and the concentrations of Pb, Cr, Cu, Cd and Zn were evaluated using air-acetylene flame AAS (AAnalyst 200, Perkin Elmer).

Data obtained were subjected to one-way Analysis of Variance (ANOVA) [23]; and significantly different means were separated using the methods of Duncan. The values obtained were presented as Least Significance Differences (LSD) of means at $P = 0.05$.

3. RESULTS AND DISCUSSION

Levels of Pb, Cd, Cu, Cr and Zn observed in the Sole and Croaker during the dry season (November – March) at both study locations compared with international tolerable values are presented in Table 1; while those for the wet season (April – October) are presented in Table 2.

Table 1: Heavy metal content of fish samples during the dry season (November–March)

Metal content (µg/g) of fish samples*					
Metals	LS	LC	DS	DC	International standards
Pb	0.330±0.31	0.163±0.05	0.149±0.13	0.045±0.05	0.200 [24]
Cd	0.097±0.03	0.115±0.09	0.063±0.05	0.029±0.03	0.050 [24]
Cu	0.869±0.48	0.990±0.57	0.434±0.22	0.694±0.29	3.280 [25]
Cr	1.184±0.60	1.008±0.15	0.826±0.18	1.038±0.12	0.730 [25]
Zn	7.612±0.83	6.756±0.83	7.890±0.80	6.168±0.34	30.000 [24]

*LS (Lagos sole), LC (Lagos Croaker), DS (Delta sole), DC (Delta croaker)

Table 2: Heavy metal content of fish samples during the wet season (April – October)

Metal content (µg/g) of fish samples*					
Metals	LS	LC	DS	DC	International standards
Pb	0.534±0.62	0.210±0.14	0.527±0.61	0.213±0.27	0.200 [24]
Cd	0.373±0.14	0.264±0.15	0.416±0.24	0.307±0.18	0.050 [24]
Cu	0.437±0.14	0.442±0.23	0.556±0.15	0.483±0.18	3.280 [25]
Cr	0.834±0.32	0.517±0.37	0.983±0.36	0.597±0.44	0.730 [25]
Zn	6.764±1.56ab	4.783±1.87b	9.343±2.82a	5.724±2.08ab	30.000 [24]

*LS (Lagos sole), LC (Lagos Croaker), DS (Delta sole), DC (Delta croaker). Rows with different superscripts are significantly ($P < 0.05$) different.

Pb ranged from 0.045 (DC) to 0.330 µg/g (LS) during the dry season; with the level in LS being higher than tolerable International standard (0.200 µg/g) during the season. Cd levels were higher in all experimental samples except DC during the dry season; and ranged from 0.029 (DC) to 0.115 µg/g (LC). Cu ranged from 0.434 (DS) to 0.990 µg/g (LC) but was lower in all experimental samples than the International tolerable value of 3.280 µg/g [25]. Cr levels were higher in all experimental fish samples during the dry season than the

International tolerable value of 0.730 µg/g [25], ranging from 0.826 µg/g in DS to 1.184 in LS. Zn level ranged from 6.168 µg/g in DC to 7.612 µg/g in LS; but were below the International tolerable value of 30.000 [24].

Heavy metal content of experimental fish species was not significantly different between species or location during the dry season. As shown on table 2, levels of Pb (0.210 – 0.534 µg/g in LC and LS respectively) and Cd (0.264 – 0.416 µg/g in LC and DS respectively) were higher in experimental fish during wet season than tolerable levels of 0.200 (Pb) and 0.050 (Cd) according to [24]. Also, levels of Pb and Cd in sole during the dry season were similar in both study locations; but higher than tolerable values, while Cr levels were higher in Delta than Lagos state. Levels of Cu and Zn in sole were higher in Delta during the dry season, but lower than tolerable values. Similar trends as reported above were observed for all trace metals in croaker during the dry season. With the exception of Cu and Zn, trace metal content of sole was higher in Lagos than Delta state; with Pb and Cr levels being higher than reported tolerable levels during the wet season. Zn and Cu levels of Croaker were higher in Lagos than Delta state, but lower than tolerable values during the wet season.

Table 3 describes variation in metal contents between wet and dry seasons. Generally, significant ($P = 0.5$) variation was observed between these seasons in Cd, Cu and Cr levels, with Cu and Cr being higher during the dry than wet season; and Cd being higher during the wet than the dry season.

Table 3: Seasonal variation in metal content of Sole and Croaker

Season	*Metal contents (µg/g)				
	Pb	Cd	Cu	Cr	Zn
Wet	0.34 ±0.11	0.34 ±0.04 a	0.48±0.04 b	0.73±0.10 b	6.70±0.64
Dry	0.17 ±0.05	0.08 ±0.02 b	0.75±0.12 a	1.01±0.09 a	7.11±0.30

*Columns with different superscripts are significantly ($P < 0.05$) different

Variability of metal content of fish with season was established in the present study in line with previous studies [26][27][28]. While Cadmium content was higher during the wet season, copper and chromium levels were higher during the dry season; and zinc and lead contents were similar at both seasons.

Table 4 describes variation in metal content between experimental fish species. Pb and Zn were significantly ($P = 0.5$) higher in Sole than in Croaker.

Table 4: Variation in metal content between fish species

Fish Species	*Metal contents (µg/g)				
	Pb	Cd	Cu	Cr	Zn
Sole	0.41 ±0.12 a	0.26 ±0.06	0.56 ±0.08	0.95 ±0.10	7.92 ±0.51 a
Croaker	0.13 ±0.04 b	0.19 ±0.04	0.62 ±0.10	0.76 ±0.10	5.83 ±0.44 b

*Columns with different superscripts are significantly ($P < 0.05$) different

204

205 As shown below (Table 5), observed differences in metal content of Sole and Croaker
206 between Lagos and Delta states were not statistically significant.

207 **Table 5: Variation in metal content of Sole and Croaker between Lagos and Delta**
208 **states**

209 **Location**

210 **(States)**

Metal contents (µg/g)

	Pb	Cd	Cu	Cr	Zn
Delta	0.28±0.10	0.23±0.04	0.65±0.11	0.86±0.11	6.38±0.46
Lagos	0.27±0.11	0.23±0.06	0.54±0.05	0.85±0.09	7.37±0.61

214

215 Metal (Pb, Cd, Cu, Cr and Zn) concentrations in the two fish species and sampling locations
216 were compared with international standards. As expected, the metals were more
217 concentrated in sole, a benthic fish than croaker, a pelagic fish; except for Cu where the
218 concentrations in croaker were higher than in sole; and Cd where concentrations found in
219 Croaker from Lagos State (LC) was higher than those found in Sole. The higher
220 concentrations of heavy metals in sole, a benthic fish confirmed reports that metals
221 concentrate more in the sediments and benthic region of aquatic environments [17][29]
222 rather than the water column. Species variation in metal accumulation had also been widely
223 reported [30][31][32], thus the observed affinity for croaker to accumulate Cu and Cd in
224 higher quantities than sole.

225 In general, lead values obtained in this study were similar to those reported in previous
226 studies on freshwater fish species in Nigeria [33], lower than those reported for fresh and
227 processed *Tilapia* and *Chrysichthys* species in Ghana [34]; and higher than levels in various
228 freshwater fish species in the Philippines [31]. Lead levels in both experimental fish and
229 study locations exceeded international tolerable levels during the wet season, but only in
230 Lagos sole in the dry season, possibly due to increased influx of metal pollutants from run-off
231 into the aquatic environment during the wet season. Lead is known to exert its most
232 significant effects on the nervous system, the hematopoietic system and the kidney. It has
233 effects on the nervous system including motor disturbances.

234 The concentration of Cadmium in all the experimental fish were higher than the international
235 tolerable level of 0.05µg/g [24], except in Delta croaker during the dry season with a
236 concentration of 0.029µg/g. Cadmium concentrations in this study were higher than those
237 earlier reported [28][29] and exceeded the international tolerable limit as noted in the
238 Philippine study [30]. Adverse effects of cadmium exposure may include chronic renal
239 failure, kidney stones, liver damage, lung cancer, osteomalacia, increased possibility of
240 hypertension, prostate cancer, and proteinuria. Chronic cadmium exposure has been
241 reported to cause mild anemia, skeletal lesions, Itai-itai disease, anosmia, and yellowing of
242 teeth [30].

243 Chromium concentrations in the present study were found to be lower than levels previously
244 reported [35], but higher than the IAEA standard of 0.730µg/g for chromium [25] and those

245 reported [28] for some Nigerian freshwater fish species including *Clarias gariepinus*, *C.*
246 *anguillaris* and *Oreochromis niloticus*. Reported health effects of chromium toxicity include
247 haemolysis, renal and liver failure, cancer and damage to circulatory and nervous tissues
248 [35][36].

249 Mean concentrations of zinc in this study were lower than the reported standard of 3.280ppm
250 [25]. Zinc deficiency has been associated with dermatitis, anorexia, growth retardation; poor
251 wound healing, hypogonadism with impaired reproductive capacity.

252 Also, the study showed more heavy metal pollution in fish samples from Lagos than those
253 from Koko, except for Zn, where the concentrations in Delta were more than those of Lagos
254 state. Zinc concentrations in experimental samples were much lower than the international
255 tolerable limits.

256

257 **Conclusion**

258 Trace metal contents of the two economically important fish species evaluated varied with
259 season and among species, with the benthic species studied (Sole) having significant higher
260 levels of Pb and Zn than the pelagic species, Croaker. Cu and Cr levels were significantly
261 higher during the dry season; and Cd level in fish species were significantly higher during the
262 wet season. Reported studies on variation in metal content of economically important
263 Nigerian fish species are generally lacking especially for marine species; thus it is important
264 that findings of this research be published to educate consumers on possible health hazards
265 associated with fish consumption.

266 **Acknowledgements**

267 Authors acknowledge with thanks the financial support of the Institute of Food Security,
268 Environmental Resources and Agricultural Research (IFSERAR) of the Federal University of
269 Agriculture, Abeokuta. This project was funded by the Research Grant
270 (UNAAB/IFSERAR/33/2009).

271 **Authors' Contribution**

272 This project was conceived by Author 1 (FG) who suggested the constitution of a research
273 team headed by Author 4 (TA) and comprising Authors 1 and 2 (DO) for evaluation of quality
274 and safety of seafood in Nigeria. Author 2 (RO) collected experimental samples and carried
275 out the laboratory analyses with the assistance of other authors. Statistical analyses were
276 carried out by FG, while the first manuscript was drafted by author 2 (RO). All authors
277 approved the contents of the final paper for publication in BJAST.

278 **References**

- 279 1. Lagos State Nigeria: Nigeria Information & Guide. Accessed 12 July 2013. Available:
280 http://www.nigeriagallery.com/Nigeria/States_Nigeria/Lagos_State.html
- 281 2. NPC. National Population Commission, <http://www.population.gov.ng/>. 2006.
- 282 3. Fernandez, LG., Olalla, HY. Toxicity and bioaccumulation of lead and cadmium in
283 marine protozoan communities. *Ecotoxicology and Environmental Safety*, 2000; 47, 266-
284 276.

- 285 4. Linnik, PM., Zubenko, IB. Role of bottom sediments in the secondary pollution of
286 aquatic environments by heavy metal compounds. Lakes and Reservoir: Research and
287 Management, 2000; 5, 11-21.
- 288 5. Botkin, DB., Keller, EA. Environmental Science, second ed., John Wiley and sons,
289 New York, 1998.
- 290 6. Pye, VI., Patrick, R. Ground water contamination in the United States. Science,
291 1982; 22, 713-718.
- 292 7. Ducrotoy, JP., Elliot, M., De Jonge, V. The North Sea: An evaluation. Marine
293 Pollution Bulletin, 2000; 41, 5-23.
- 294 8. Millero, FJ. Chemical Oceanography, second ed.; CRC Press, Boca Raton, Florida,
295 1996.
- 296 9. Greig, RA., Wenzloff, DR., Adams, A., Nelson, B., Shelpuk, C. Trace metals in
297 organisms from ocean disposal sites of the Middle Easter United States. Archives of
298 Environmental Contamination and Toxicology, 1977; 6 (1), 395 – 409.
- 299 10. van Leussen, W. Aggregation of particles settling velocities of mud flocs. A review:
300 In Physical Processes in Estuaries. J. Dronkers and W. van Leussen (Eds.), 1988; Pp. 347-
301 403, Springer-Verlag, Berlin, Hiedelberg.
- 302 11. Albering, HJ., van Leusen, SM., Moonen, EJC., Hoogewerff, JA., Kleinjans, JCS.
303 Human health risk assessment: A case study involving heavy metal soil contamination after
304 the flooding of the river Meuse during the winter of 1993-1994. Environmental Health
305 Perspectives, 1999; 107(1), 37-43.
- 306 12. MacFarlane, GB., Burchett, MD. Cellular distribution of Cu, Pb, and Zn in the Grey
307 Mangrove, *Avicennia marina* (Forsk.). Vierh Aquatic Botanic, 2000; 68, 45–59.
- 308 13. Censi, P., Spoto, SE., Saiano, F., Sprovieri, M., Mazolla, S. Heavy metal in coastal
309 water system. A case study from the North Western Gulf of Thailand. Chemosphere, 2006;
310 64: 1167 – 1176.
- 311 14. Storelli, MM., Storelli, A., D'ddabbo, R., Marano, C., Bruno, R. and Marcotrigiano
312 GO. Trace elements in loggerhead turtles (*Caretta caretta*) from the eastern Mediterranean
313 Sea: Overview and evaluation. Environmental Pollution, 2005; 135, 163–170.
- 314 15. Camusso, M., Vigano, L., Baitstrini, R. Bioaccumulation of trace metals in rainbow
315 trout. Ecotoxicology and Environmental Safety, 1995; 31, 133–141.
- 316 16. Adegbola, R.A., Adewuyi, G.O., Adekanmbi, A.I. Analysis of fish samples as a
317 biomarker of levels of pollutants in Ona River, Ibadan, Oyo State, Nigeria. Journal of Applied
318 Chemistry, 2012; 2 (3), 32-37.
- 319 17. Namminga, HN., Wilhm, J. Effects of high discharge and oil refinery cleanup
320 operation on heavy metals in water and sediments in Skeleton Creek. Proceedings of the
321 Oklahoma Academy of Science, 1976; 56: 133–138.

- 322 18. Skejelkvale, BL., Andersen, T., Fjeld, E., Mannio, J., Wilander, A., Johanson, K. et.
323 al. Heavy metal surveys in Nordic Lakes: Concentrations, geographic patterns and relation
324 to critical limits. *Ambio*, 2001; 30 (1): 2-10.
- 325 19. Ssentongo, GW.; Ukpe, ET. and Ajayi, TO. Food and Agriculture Organization of the
326 United Nations (FAO). Marine fishery resources of Nigeria: A review of exploited fish stocks.
327 Available online at: <http://www.fao.org/DOCREP/003/R9004E/R9004E00.HTM>, 1986.
- 328 20. Ogbonna, JC. Reducing the impact of tropical shrimp trawling fisheries on the living
329 marine resources through the adoption of environmentally friendly techniques and practices
330 in Nigeria. In: FAO. Tropical shrimp fisheries and their impact on living resources. Shrimp
331 fisheries in Asia: Bangladesh, Indonesia and the Philippines; in the Near East: Bahrain and
332 Iran; in Africa: Cameroon, Nigeria and the United Republic of Tanzania; in Latin America:
333 Colombia, Costa Rica, Cuba, Trinidad and Tobago and Venezuela, 2001; pp. 188 – 215.
334 FAO Fisheries Circular. No. 974. Rome. 378pp.
- 335 21. Food and Agriculture Organization of the United Nations, FAO. The FAO Fishery
336 and Aquaculture Country Profiles. Available at:
337 www.fao.org/fi/website/FISearch.do?dom=country, 2007.
- 338 22. Asegbeloyin, JN, Onyimonyi, AE., Ujam, OT., Ukwueze, NN., Ukoha, PO.
339 Assessment of toxic trace metals in Selected Fish Species and Parts of Domestic Animals.
340 *Pakistan Journal of Nutrition*, 2010; 9 (3), 213-215.
- 341 23. Steel, RG., Torie, JA. Principles and procedures of statistics. A biomedical
342 Approach, second ed. McGraw-Hill International, Auckland, 1981.
- 343 24. European Commission, EC, 2005. Commission Regulation (EC) No. 78/2005 of 19
344 January 2005 amending Regulation (EC) No 466/2001 as regards heavy metals, L 16/43–
345 45.
- 346 25. International Atomic Energy Agency, IAEA-407. Trace elements and methylmercury
347 in fish tissue, 2003; 4pp
- 348 26. Olojo, EAA., Olurin, KB., Oluberu, SA. Seasonal Variation in the Bioaccumulation of
349 Heavy Metals in the Tissues of *Oreochromis niloticus* and *Chrysichthys nigrodigitatus* in
350 Lagos Lagoon Southwest Nigeria. *Academic Journal of Plant Sciences*, 2012; 5 (1), 12-17.
- 351 27. Aktan, N., Tekin-Özan, S. Levels of some heavy metals in water and tissues of chub
352 mackerel (*Scomber japonicus*) compared with physico-chemical parameters, seasons and
353 size of the fish. *The Journal of Animal and Plant Sciences*, 2012; 22(3), 605-613.
- 354 28. Oyakhilome, GI., Aiyesanmi, AF., Adefemi, SO., Asaolu, SS. Heavy Metals
355 Concentration in Sediment and Fish Samples from Owena Multi-Purpose Dam, Ondo State,
356 Southern Nigeria. *British Journal of Applied Science and Technology*, 2013; 3(1), 65-76.
- 357 29. Ogoyi, DO., Mwita, CJ., Nguu, EK., Shiundu, PM. Determination of Heavy Metal
358 Content in Water, Sediment and Microalgae from Lake Victoria, East Africa. *The Open*
359 *Environmental Engineering Journal*, 2011; 4, 156-161.
- 360 30. Ashraf, MA., Maah, MJ., Yusoff, I. Bioaccumulation of Heavy Metals in Fish Species
361 Collected From Former Tin Mining Catchment. *International Journal of Environmental*
362 *Research*, 2012; 6(1), 209-218.

- 363 31. Akan, JC., Salwa, M., Yikala, BS., Chellube, ZM. Study on the Distribution of Heavy
364 Metals in Different Tissues of Fishes from River Benue in Vinikilang, Adamawa State,
365 Nigeria. British Journal of Applied Science & Technology, 2012; 2 (4), 311-333.
- 366 32. Solidum, JM., De Vera, MJD., Abdulla, ADC., Evangelista, JH., Nerosa, MV.
367 Quantitative Analysis of Lead, Cadmium and Chromium found in Selected Fish marketed in
368 Metro Manila, Philippines. International Journal of Environmental Science and Development,
369 2013; 4 (2), 207-212.
- 370 33. Eletta, OAA., Adekola, FA., Omotosho, JS. Determination of concentration of heavy
371 metals in two common fish species from Asa River, Ilorin, Nigeria. Toxicology and
372 Environmental Chemistry, 2003; 85 (1-3), 7-12.
- 373 34. Essuman, KM. Evaluation of heavy metal content in Fresh and processed fish from
374 Yeji. FAO, 2008. Accessed 12 July 2013. Available:
375 <ftp://ftp.fao.org/docrep/fao/008/y9155b/y9155b03.pdf>
- 376 35. Burger, J., Gochfeld, M. Heavy metals in commercial fish in New Jersey. Env. Res.
377 2005; 99: 403-412.
- 378 36. Wasser, WG., Feldman, NS. Chronic renal failure after ingestion of over-the-counter
379 chromium picolinate. Annals of Internal Medicine, 1997; 126: 410.
- 380 37. Jeejeebhoy, KN. The role of chromium in nutrition and therapeutics and as a
381 potential toxin. Nutrition Reviews, 1999; 57: 329-335. Adegbola, R.A., Adewuyi, G.O.,
382 Adekanmbi, A.I. Analysis of fish samples as a biomarker of levels of pollutants in Ona River,
383 Ibadan, Oyo State, Nigeria. Journal of Applied Chemistry, 2012; 2 (3), 32-37.