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Metallic Micropollutants in the Harvest of *Oreochromis niloticus* (Linnaeus, 1757) from Polluted Waters: Wildlife and Human Concerns

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Abstract: Nile tilapia *(Oreochromis niloticus)* were sampled at four locations along Lake Maryût for eleven metal residues. Data were compared to certified levels for possible metal contamination. Generally, cadmium, lead, mercury, manganese and copper were above standard levels for unpolluted waters. The kidneys in *O. niloticus* were the principal store organs for most of the metals tested. In an outstanding result, the muscular edible tissue in *O. niloticus* was the principal destination for mercury. The majority of metals investigated as cadmium, copper, lead, mercury, zinc, chromium, cobalt, manganese and nickel exceeded most known accepted levels in fish tissue. Water lead seemed to correlate better with lead in composites of whole fish than in solitary organs. Mercury in water and fish tissue (particularly, the edible portion) exceeded all credited levels for human consumption and the protection of fish and predator, thus posing an inevitable hazard to the whole ecosystem of the lake, probably for 100 years to come.

Key words: Lake Maryût, pollution, tilapia, accumulation, metal residue, water, fish, standards, ecosystem, human consumer

Introduction

Available information suggests that the concentrations of toxic metals in many ecosystems are reaching unprecedented levels. Because of the steady load of contaminated dust in the air of the overcrowded cities, the ambient concentrations of toxic metals are now among the highest being ever reported. Because metals are elements that generally do not break down further into less harmful chemicals, they can accumulate where they are released (Kennicutt *et al*., 1992). Fish kill or injury due to metal contamination is considered the primary cause of reduced fish populations (Chapman, 1993). Behavioral avoidance of contaminants may be an additional cause of reduced fish populations (McNicol and Scherer, 1991).

Lake Maryût lines, the city of Alexandria (5 million inhabitants), Egypt, at its southern side. It is the smallest and most polluted among four shallow, brackish-water lakes (Maryût, Edku, Burullus & Manzalla) that fringe the Nile Delta. Lake Maryût used to be one of the most productive nationwide; but because of pollution problems, fish production now became far below the assimilative capacity of the lake. Since the early sixties, the lake has become a sink for industrial wastes and domestic wastewater; thus turning eutrophic. According to Thomas *et al*. (1994), this is particularly true for the main basin (6000 acres). However, other basins of the lake still receive abundant discharge.

Tolerance, action, and guidance levels are established for some of the most toxic and persistent contaminants found in fish. US States often use the Federal levels for deciding whether to issue consumption advisories or to close waters for commercial harvesting of all or certain species of fish (FDA, 1998). In many other parts of the world compliance levels or criteria similar to those mentioned above are not strictly enforced.

The freshwater tilapia, *Oreochromis niloticus* provides the main fishery of Lake Maryût. Due to pollution, fish catch of this species at Forn El-Gerayah along the main basin represents only 18.75% of what used to be in the past (Thomas *et al*., 1994). *O. niloticus* has special significance to the native consumer and satisfies selection criteria of a bioassay model. Concentrations of 11 trace elements (Cd, Cr, Co, Cu, Fe, Pb, Mg, Mn, Hg, Ni & Zn) were surveyed in both fish tissue (liver, kidney, gill and muscle) and water. Other aspects of water quality [pH, turbidity; dissolved oxygen, Do; chemical oxygen demand, COD; biochemical oxygen demand, BOD; hardness; alkalinity; chlorides and nutrient salts (orthophosphate-phosphorus, PO_4-P; ammonia-nitrogen, NH_4-N; nitrate-nitrogen, NO_3-N; nitrite-nitrogen, NO_2-N)] were also examined. Given that the environmental health criteria for toxic metals in developing communities may not provide adequate protection, more regional research for recommending appropriate criteria is an urgent need. This is an initial attempt towards a national advisory for regional coastal waters.

Materials and Methods

Sampling locations: Due to several urbanization and construction schemes, Lake Maryût (with an average depth of 120 cm) had been split apart into five principal basins; the main basin (MB; sampling location I) and four smaller basins (East, E; Northwest, NW; Southeast, SE; Southwest, SW) (Fig. 1). E and SE basins stand for sampling locations 2 and 3, respectively. It is noteworthy that the reference site (4) is a fish hatchery (FH) that operates under the auspices of the "General Authority of Fish Development".

Sampling of fish: A total approximate number of 160 individuals of *O. niloticus* were caught at random from the selected locations (Fig. 1). Equal numbers of both sexes were sampled for each assay. Fish and water were collected at three randomly repeated intervals between mid September and mid November 2000. In average, 12 fish were analyzed per sampling group. All samples were healthy, mature and of uniform size (15.00 $\pm$ 1.8cm) and weight (150 $\pm$ 10.0 g). Fish were caught in close meshed nets and transferred into large vessels filled with aerated water. In the lab, fish were placed in two-thirds filled 73.5 cm^3 aquaria and allocated into groups (12 individuals / aquarium/ location). Prior to sampling, fish were kept in closed freshwater systems equipped with physical & biological filters and aeration was monitored continuously. In such conditions, fish recovered quickly after capture. Immediately upon recovery, fish were sacrificed by a blow on the head. Livers, gill arches, kidneys and muscular tissue were, at once, dissected from the carcasses. Tissue samples were stored in a deep-freezer shortly after dissection until analyzed within 48 hours.

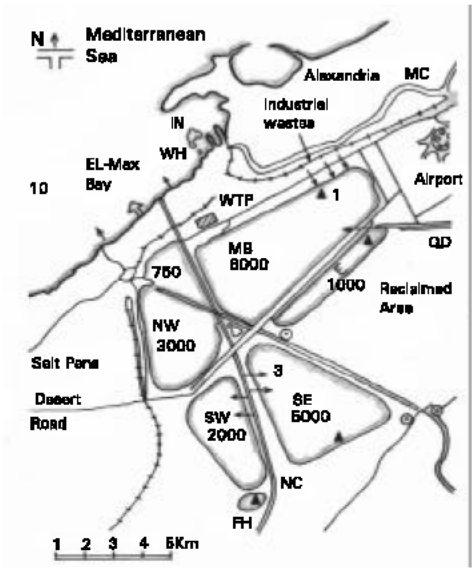

Fig. 1: Map of Lake Maryût area showing the geographic locations of sampling sites (1,2,3 and 4).

Sampling of lake water: Concurrently with fish harvesting, 2-3 liters of water were collected from each sampling station. One surface and one bottom water samples were mixed each time to form one composite sample ready for analysis. Surface water samples were collected about 20 cm below the water surface to avoid floating matter. Stoppered, acid-washed, polyethylene bottles were used as sampling devices. Water samples were filtered in the field using a polypropylene syringe fitted with a 0.45 μm millipore cellulose acetate filter and acidified for preservation.

Analysis of fish tissue and lake water: Prior to chemical analysis, fish tissue was digested in a mixture of nitric and perchloric acids according to the method described by APHA (1992). Concentrations of heavy metals were detected in filtered lake's water and digested fish tissue according to Riley and Taylor (1968). Except Hg, metals were measured by graphite furnace atomic absorption spectroscopy (Perkin-Elmer model 2380) under the recommended conditions and the detection limits (DL) in the manual for each metal. Hg was measured by cold vapor atomic absorption spectroscopy (Perkin-Elmer model 3100) at DL = 0.03. Physicochemical characteristics of water (pH, turbidity, DO, COD, BOD, hardness, alkalinity, chlorides, and nutrient salts (PO_4-P, NH_3-N, NO_3-N, NO_2-N) were measured by standard methods for the analysis of natural and treated wastewater as described by APHA (1992).

Data analysis: Statistical analysis was carried out using the statistical package for the Social Sciences (SPSS) software. Trace metal concentrations in water were measured in parts per million (ppm, mg L^{-1}) except for Hg that was measured in parts per billion (ppb, μg L^{-1}). All trace elements in fish organs were presented in ppm wet weight (ww) or the equivalent (μg g^{-1}). Hg was measured in fish tissue in ppb (μg kg^{-1}), but sometimes converted and tabulated as ppm for comparison. Since no apparent difference was reported between data of fish of different sex and because the sampling period was rather narrow, the attributes of sex and sampling intervals

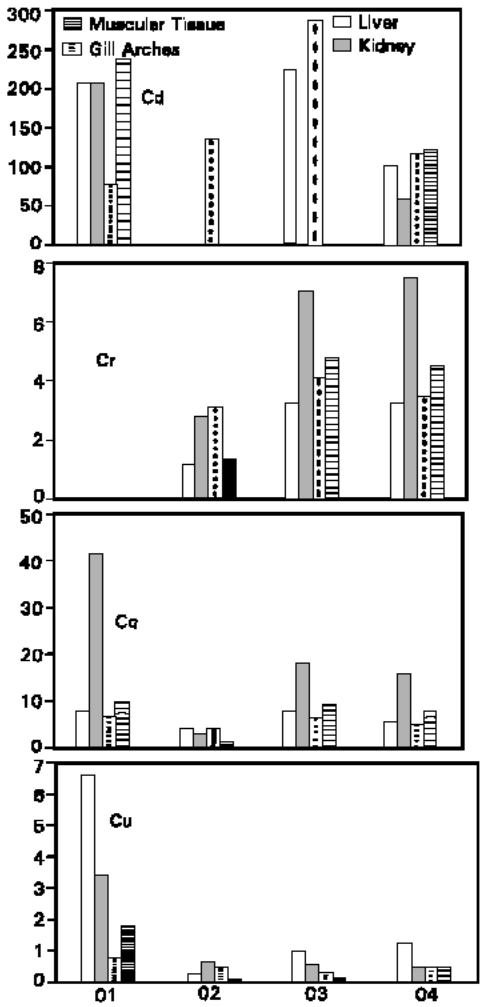

Fig. 2: BCF of Cd, Cr, Co and Cu in selected organs of *O. niloticus*, 1,2,3, and 4 stand for corresponding sampling locations.

were omitted. The normal probability, frequency distribution, arithmetic mean, standard deviation, standard error and % coefficient of variation (% CV) were determined according to Turner (1970). Analysis of variance (One-Way ANOVA) was calculated according to Snedecor and Cochran (1969). Duncan's multiple- range test was used to determine the specific differences between groups. Correlation coefficient (r) and regression coefficient (b) were also used. In all cases, $p < 0.05$ was the accepted significance level.

Bioconcentration factors (BCF) were used as the measure of the metal availability in the lake's water to fish (Wiener and Giesy, 1979). BCF between water and a certain organ is calculated according to the formula: $BCF = C_{org} / C_{water}$, where C_{org} is the metal concentration in the organism (dry weight) and C_{water} is the metal concentration in water. Wet weight (ww) is converted into dry weight (dw) according to the formula: ww concentration = dw concentration x [1 - (% moisture/100)] (Allen, 1991). To perform the conversion, moisture values for selected tissues were calculated (Table 2).

Precision and accuracy of the laboratory analyses were confirmed with procedural blanks, comparison to concentrations found in other studies and duplicate and reference material analyses.

Results and Discussion

Although international quality criteria adopted here for water and biologic subjects do not necessarily apply for the present data, yet they are taken here as guidance documents due to the lack of national or regional advisories.

Cadmium (Cd): Cd is a nonessential trace element that is potentially toxic to most fish and wildlife, particularly freshwater organisms (Robertson *et al.*, 1991). Water Cd, at all investigated sites, exceeded the MCL of 0.005 ppm (USEPA, 1987). Water Cd concentration range as low as 0.0008- 0.0099 ppm was found to be lethal to aquatic insects, crustaceans, and teleosts (Eisler, 1985a). Moore and Ramamoorthy (1984a) reported that the normal levels of Cd in freshwater is from 0.00001 to 0.0005 ppm. At water hardness of Lake Maryût (above 200 ppm), Cd criteria (USEPA, 1995) (Table 1) for the protection of aquatic life and human consumption (2.0 & 10.0 ppb, respectively) profoundly exceeded the current levels.

Compared with other settings, the current data show endangered ecosystem in Lake Maryût. All biota sampled from Aransas Dredge Spoil Islands (ADSI), Texas, had detectable levels of Cd, ranging from 0.1 ppm dw in sheepshead minnows to 1.5 ppm in fiddler crabs (Robertson *et al.*, 1991). In *O. niloticus*, Cd (1.0- 3.76 ppm dw, converted from ww) (Tables 2 & 5) dramatically exceeded the above range as well as the geometric mean (0.03 ppm ww) determined for the National Contaminant Biomonitoring Program (NCBP) (Schmitt and Brumbaugh, 1990). Similarly, Cd concentrations in fish collected from Mingo National Wildlife Refuge (MNWR) were approximately the same as the NCBP geometric mean (Charbonneau and Nash, 1993). On the contrary, some earlier reports recommended broader ranges and more elevated tissue Cd than what is accepted today. Eisler (1971) determined in a laboratory study with the mummichog (*Fundulus heteroclitus*) that whole body fresh weight concentrations exceeding 5.0 ppm dw were potentially lethal. Eisler (1985a) emphasized that concentrations exceeding 2.0 ppm whole body ww for vertebrate animals were considered an evidence of probable Cd contamination.

Gills and liver of *O. niloticus* were the main targets of Cd (Fig. 2). As a matter of fact, fish flesh in the harvest of locations 2 and 3 was Cd-free, but was in locations 1 and 4, concentrations (0.65 and 0.39 ppm ww, respectively) were above the levels approved for fish fillet from clean waters. According to Life Systems Inc. (1989b), fish flesh samples collected from relatively unpolluted areas contained concentrations from 0.001 to 0.100 ppm Cd ww.

Chromium (Cr): The current Cr levels of in Lake Maryût (up to 0.015 ppm) (Table 3) are fairly below the MCL of 0.1 ppm (USEPA, 1987) and the numeric criterion (Table 1) for the protection of human consumer (USEPA, 1995). Cr is an essential trace element in human and some lab animals (Lee and Schultz, 1994), but in excess, it could have lethal and sublethal effects on fish and wildlife (Robertson *et al.*, 1991). In *O. niloticus*, Cr displayed the most uniform data with the highest tendency to accumulate in the kidney tissue (Fig. 2). No guidance documents are available for Cr in the edible part of fish; neither was it assessed by NCBP. In view of other sanctions, the present Cr concentrations (2.59- 12.75 ppm

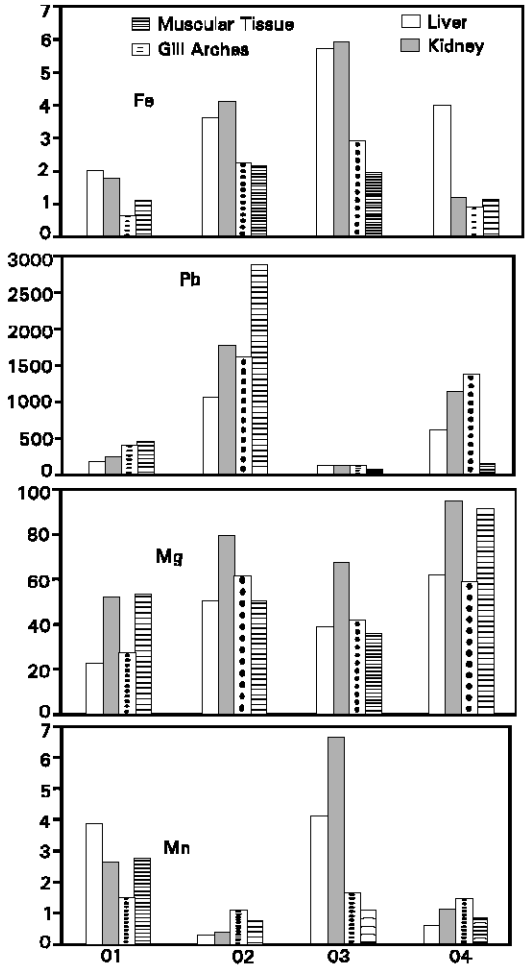

Fig. 3: BCF of Fe, Pb, Mg and Mn in selected organs of *O. niloticus*, 1,2,3 and 4 stand for corresponding sampling locations.

ww) are well below the levels validated by USEPA (53.8 ppm ww) for fish tissue (Pastorok, 1987). However, surveys of contaminants in edible shellfish conducted by FDA and the National Marine Fisheries Service reporting Cr levels from 0.1 up to 0.9 ppm ww (Adams *et al.*, 1993) disputed the above threshold and alerted to Cr condition of fish on the Lake Maryût. The present tissue Cr (14.39 to 47.2 ppm dw; converted from ww) (Tables 2 & 6) is also far above 4.0 ppm dw level suggested by Eisler (1986) as indicative of Cr contamination and the levels of 0.8 ppm ww suggested by Irwin (1988) to be definitely elevated.

Small mouth buffalo and longnose gar caught from different parts in the Guadalupe and San Antonio Rivers had Cr concentrations ranging from 4.1 to 8.7 ppm dw (Lee and Schultz, 1994). Although these levels are above the 4.0 ppm dw accepted by Eisler (1986), yet they are still far less than the current levels in *O. niloticus*. In Gulf Killifish (*Fundulus grandis*), sailfin molly (*Poecilia latipinna*) and amazon molly (*Poecilia formosa*) collected from the Salt Drain area, Robertson *et al.* (1992) detected Cr levels as low as 2.16- 2.61 ppm dw. In sheepshead minnows collected from South

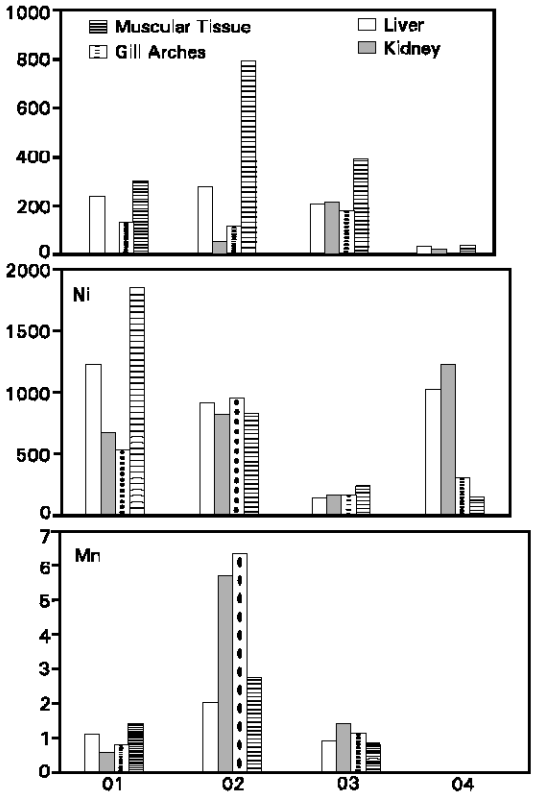

Fig. 4: BCF of Hg, Ni and Zn in selected organs of *O. niloticus*, 1,2,3 and 4 stand for corresponding sampling locations

Bludworth, Cr content was 1.7 ppm dw (Robertson *et al.*, 1991). Even in marine invertebrates, NOAA Mussel Watch Project Progress report (NOAA, 1989) indicated that none of the mussels and oysters in 169 sites examined in 1988 did exhibit an average Cr concentration in excess of 0.25 ppm ww. In view of the above reports, there could be a problem related to Cr-contamination in *O. niloticus* on Lake Maryût.

Cobalt (Co): Co has not yet been considered in compliance policies or MCL and NCBP guidelines. In *O. niloticus*, kidneys were the target organs of Co (Fig. 2). This conclusion received

Table 1: EPA numeric criteria of selected trace metals

Metal	Limit ($\mu g\ L^{-1}$)	
	Designated Use	
	Freshwater aquatic life	Human consumption
Cd	2.00 *	10.0 *
Cr		0.05 (mg L^{-1})
Cu	21.00 *	1.0 ++
Pb	7.70 *	50.0 * (adults)
Hg	0.012 *	144.0 ng L^{-1} *
Ni	160.00 +	632.0 *
Zn	570.00 ++	5.0 *1

One hour average concentration; * 4-day average concentration; + 24 hour average concentration; ++ Level not to be exceeded at any time; Unless otherwise stated, all concentrations are expressed as $\mu g\ L^{-1}$ (ppb); 1 mg/L (ppm) = 1,000 μg/L (ppb) = 1,000,000 ng/L (ppt, part per trillion).

Table 2: % Moisture of the different organs of *O. niloticus*

	Liver	Kidney	Gills	Muscles
% moisture	75.0	79.6	73.5	82.9
C.F	0.25	0.21	0.27	0.18

CF, conversion factors for each organ from wet weight to dry weight concentrations and vice versa

immense support from an earlier report in which Reed (1971) proved that the blood and blood-rich organs, particularly the kidney, were the principal sites of cobalt concentration. If any Co contamination is to be suggested (Table 3), this would be through emissions from native industries similar to grinding hard metal blades and also to emissions from the nearby hard metal industry (Iron & Steel Works). According to Linnainmaa *et al.* (1996), industries as wet-tip processes release high levels of airborne Co even when airborne total dust concentrations are low. Water bodies near such works can get polluted with the metal since most of the airborne cobalt is water-soluble (ionized). In *O. niloticus*, concentrations of Co in the liver (0.2 - 0.96 ppm dw) and in muscular tissue (0.06 - 1.1 ppm dw) (Tables 2 & 7) are considerably higher than the legal limits of NRC (1999-2000) for Co in dogfish muscle (0.182 ppm dw) (DORM-2) and liver (0.24 ppm dw) (DOLT-2), but fit with those of fish tissue from Flint River Basin (0.9 to 5.7 ppm) (USGS, 1997). It is however unclear whether or not the present Co magnitude in the lake is likely to present any hazard to fish and human.

Copper (Cu): In excess, copper could be toxic to a variety of fish and wildlife (USEPA, 1980, 1985). In surface waters, Cu was recommended not to exceed 1.0 ppm (USEPA, 1986) for the protection of human health. This limit takes into account ingestion of Cu through water and contaminated aquatic organisms (SRC, 1990). Water-Cu concentrations covered in

Table 3: Metal concentrations (Means ± SE) in mg L^{-1} (ppm) of lake water; 1, 2, 3 & 4 refer to corresponding sampling locations; MB, main basin; E, east basin; SE, southeast basin; FH, fish hatchery

	1 (MB)	2 (E)	3 (SE)	4 (FH)
Cd	0.015 ± 0.003^{a}	0.008 ± 0.02^{b}	0.009 ± 0.005^{b}	0.017 ± 0.003^{a}
Cr	BDL	0.015 ± 0.003^{a}	0.005 ± 0.0009^{b}	0.005 ± 0.0001^{b}
Co	0.09 ± 0.007^{a}	0.05 ± 0.003^{b}	0.12 ± 0.001^{c}	0.14 ± 0.001^{c}
Cu	0.049 ± 0.005^{a}	0.025 ± 0.001^{b}	0.012 ± 0.004^{c}	0.006 ± 0.002^{d}
Fe	0.080 ± 0.009^{a}	0.061 ± 0.007^{a}	0.048 ± 0.006^{b}	0.032 ± 0.005^{b}
Pb	0.20 ± 0.029^{a}	0.028 ± 0.004^{b}	0.26 ± 0.021^{a}	0.02 ± 0.003^{b}
Mg	150.0 ± 24.32^{a}	207.3 ± 29.90^{b}	179.1 ± 24.80^{a}	130.3 ± 16.20^{a}
Mn	0.169 ± 0.028^{a}	0.026 ± 0.006^{b}	0.09 ± 0.009^{c}	0.011 ± 0.002^{c}
Hg (ppb)	0.012 ± 0.001^{a}	0.005 ± 0.0005^{b}	0.019 ± 0.002^{a}	0.006 ± 0.0007^{b}
Ni	0.07 ± 0.020^{a}	0.091 ± 0.01^{a}	0.13 ± 0.006^{b}	0.06 ± 0.005^{a}
Zn	0.09 ± 0.010^{a}	0.03 ± 0.004^{b}	0.04 ± 0.009^{b}	BDL

BDL, below detection levels; different superscripts (a, b, etc.) differ significantly ($\alpha = 0.05$).

Table 4: Average values of some Physical and chemical qualities of lake water at locations 1, 2, 3 & 4

	MB (1)	E (2)	SE (3)	FH (4)
pH	7.0	8.0	8.3	8.2
Turbidity (NTU)	45.4	27.0	21.0	18.0
DO	7.5	7.8	8.1	7.5
BOD	59	55.0	70.0	39.0
COD	141.6	110	109.0	83.0
Hardness (total)	850	810	815.0	780.0
Ca Hardness	390	340	375.0	330.0
Mg Hardness	460	470	440.0	450.0
Alkalinity	500	330	370.0	360.0
Cl^-	2313	2520	1920.0	1980.0
PO_4^{-3}-P	0.26	2.9	0.58	0.38
NH_3-N	0.2	0.15	0.2	0.1
NO_3^{-2}-N 0.9	0.35	0.2	0.2	
NO_2^--N	0.008	0.015	0.1	0.08

DO, dissolved oxygen; BOD, biochemical oxygen demand; COD, Chemical oxygen demand; Cl^-, chlorides; PO_4^{-3}-P , phosphate-phosphorus; NH_3-N, ammonia - nitrogen; NO_3^{-2} - N, nitrate- nitrogen; NO_2^-- N, nitrite- nitrogen; Unless otherwise stated, all measurements are expressed as mg L^{-1} (ppm). no unit is defined for pH measurements; NTUs, nephelometric turbidity units

this study were below this level. However, Cu content as low as 0.005 ppm may suppress gill adenosine triphosphate (Novotny, 1995). According to Cu criteria for protecting aquatic life and human consumer (21.00 and 1.0 ppb, respectively) (USEPA, 1995), the current Cu might not pose a serious threat to aquatic life in the lake except at location 1 (49.0 ppb) (Table 3), but it renders water unsatisfactory for direct human use at other sites (6.0- 25.0 ppb).

Kidneys were the target organs for Cu in *O. niloticus* (Fig. 2). Cu in fish muscles was shown to be low, although high concentrations were found in livers (Moore and Ramamoorthy, 1984a; SRC, 1990). Compared to Cu residues in fish muscles collected from metal-contaminated lakes in Ontario (0.5- 1.4 ppm ww) (Bradley and Morris, 1986) and to Cu content in killifish (*Fundulus* sp.) from areas of high and low contamination (19.2 and 9.1 ppm dw, respectively) (Custer *et al.*, 1986) at Narragansett Bay, Rhode Island, the current Cu content in fillets of *O. niloticus*, particularly in fish group 1 (16.03 ppm ww) (Table 8) is considered highly hazardous to consumers. The current Cu levels are also above NCBP mean (0.82, 0.65 & 0.65) and 85th percentile 1.1, 0.9, and 1.0 ppm ww (Schmitt and Brumbaugh, 1990) for the years 1978-1979, 1980-1981 and 1984, respectively. So according to international measures, the catch of *O. niloticus* in all investigated sites is Cu-polluted regardless the fact that water Cu was below its MCL (1.0 ppm) (USEPA, 1987). Also, limits of Cu in fish and fishery products are 10- 100 ppm ww (Pastorok, 1987). Accordingly, the present Cu concentrations for *O. niloticus* might not much warrant concern.

Iron (Fe): In contrast to earlier reports showing Fe to be normally highest in the gills (Phillips and Russo, 1978) or in the liver (Charbonneau and Nash, 1993), the present data showed kidneys as the highest Fe stores (Fig. 3). In *O. niloticus*, Fe content (18.27-115.2 ppm ww) (Table 9) corresponds to the high residue concentrations of Fe (34- 107 ppm ww) in whole fish samples on MNW Refuge (Charbonneau and Nash, 1993). However, Fe contamination cannot be judged since Fe was neither analyzed in fish collected for the NCBP, nor was it considered in USEPA MCL or other plans.

Lead (Pb): Water Pb concentrations in all sampling sites were well above MCL (0.015 ppm) of USEPA (1987). In 1995, USEPA has promulgated the numeric criterion of water Pb for the protection of aquatic life as 7.70 ppb and human consumer as 50.0 ppb (for adults) (Table 1). Both criteria were based on 4-days average concentration at the present water hardness (above 200 ppm) in Lake Maryût. According to the above standards, Pb amplitude (Table 3) in all locations tested is hazardous.

Sources of Pb to the lake could be via the polluted municipal discharge from Umoum Drain (Fig. 1) with abundant agronomic wastes or the highly polluted surplus water from the lake proper (location 1) that is allowed to flow into the lower reach of Umoum Drain before pumping the mixed waters to the Mediterranean Sea. The less Pb-polluted reference site (4) receives customarily some flux from Nubarriya canal, which is relatively unpolluted. Although the water of location 1 contains pretty elevated amounts of Pb, yet the muscular tissue in its catch is Pb-free. It seems that Pb has a minor tendency to accumulate in fish fillet. In *O. niloticus*, Pb was always greater than all published NCBP geometric means (0.29, 0.19 & 0.17 ppm ww for the years 1977, 1979 & 1981, respectively) (Kurey, 1991) and 85th percentiles (0.22 & 0.11 ppm ww for 1984 and more recent years, respectively) (Schmitt and Brumbaugh, 1990).

According to Kurey (1991), Pb in both aquatic and terrestrial vertebrates localizes in hard tissue such as bone and teeth. These types of tissue were not targeted for the present assays. It appears however that Pb in *O. niloticus* possessed a major affinity to reside in the kidney and gills rather than in the liver and muscular tissue (Fig. 3). Moore and Ramamoorthy (1984a) reported that Pb residues in muscle tissue were only slightly lower than in specific organs. The sum of means of Pb concentrations (ΣPb) in the four selected types of tissue from location 2 (ΣPb2) (54.79 ppm ww) was significantly higher than ΣPb3 (27.05 ppm ww). Both were significantly higher than either ΣPb4 or ΣPb1 (16.09 and 12.14 ppm ww, respectively). For a given location, the sum ΣPb related more comprehensively to parallel water Pb than to its content in an individual organ (Table 10). The mechanism by which Pb accumulates in fish tissue seems rather controversial and needs further endeavour.

The present Pb data (0.47- 17.41 ppm ww) (Table 10) in *O. niloticus* is considered rather unsafe compared to Pb average concentration in fish from New Madrid area (0.21 ppm ww) (Kurey, 1991), to that in catostomids on the Big River in southeastern Missouri (0.1 - 0.8 ppm ww) (Schmitt *et al.*, 1984) and to that in common carp (3 ppm ww) and bluegill (0.4 ppm ww) from the upper Mississippi River (Wiener *et al.*, 1984). Other reports with comparable Pb levels include Longear sunfish (*L. megalotis*) and black redhorse (*Moxostoma duquesnei*). In brief, the present Pb levels in water (1.3- 13 times higher than USEPA MCL) and fish (4.2- 158.2 folds higher than the NCBP geometric mean) are considered hazardous to fish and predator despite the suggestion of Kurey (1991) that adult birds and juvenile precocial birds are relatively resistant to the toxic effects of dietary Pb.

Magnesium (Mg): Mg occurs naturally in sediment; it is one of the most common ions in freshwater and a major contributor to water hardness (USEPA, 1987). In *O. niloticus*, it seems that Mg tends to reside in the kidney (Fig. 3). In a survey along the Cache River National Wildlife Refuge, Mg content in composite samples of predator fish as spotted gar and white crappie was 1455- 10819 ppm dw, while in benthic feeding fish, it was 1304 - 9804 ppm dw in Small mouth

Table 5: Concentrations (ppm) of Cd (Means ± SE) in different tissue types of *O. niloticus* assayed on wet weight basis

Locations	Liver	Kidney	Gills	Muscular Tissue
1	0.77± 0.08 ^{a}	0.79± 0.09 ^{a}	0.35± 0.05 ^{b}	0.65 ± 0.08 ^{a}
2	BDL	BDL	0.30± 0.04	BDL ±
3	0.50±0.06 ^{a}	BDL	0.70±0.09 ^{b}	BDL ±
4	0.43±0.06 ^{a}	0.21±0.027 ^{b}	0.55±0.068 ^{a}	0.39±0.048^{a}

Similar superscripts (a, b, etc.) differ insignificantly; different superscripts differ significantly (α = 0.05).

Table 6: Concentrations (ppm) of Cr (Means ± SE) in different tissue types of *O. niloticus* assayed on wet weight basis

Locations	Liver	Kidney	Gills	Muscular Tissue
1	4.02±0.5 ^{a}	3.65±0.5 ^{a}	5.54±0.6 ^{a}	2.59±0.3 ^{b}
2	4.42±0.6 ^{a}	8.93±0.9 ^{b}	12.75±1.4 ^{c}	3.63±0.4 ^{a}
3	3.96±0.5 ^{a}	7.34±0.9 ^{b}	5.4±0.7 ^{a}	4.28±0.6 ^{a}
4	4.04±0.5 ^{a}	7.88±0.1 ^{b}	4.6± 0.6 ^{a}	4.09±0.6^{a}

Similar superscripts (a, b, etc.) differ insignificantly; different superscripts differ significantly (α = 0.05).

Table 7: Concentrations (ppm) of Co (Means ± SE) in different tissue types of *O. niloticus* assayed on wet weight basis

Locations	Liver	Kidney	Gills	Muscular Tissue
1	0.15±0.019 ^{a}	0.79±0.1 ^{b}	0.16±0.02 ^{a}	0.16±0.02 ^{a}
2	0.05±0.006 ^{a}	0.03±0.004 ^{b}	0.06±0.007 ^{a}	0.01±0.001 ^{b}
3	0.24±0.03 ^{a}	0.2±0.03 ^{a}	0.20±0.03 ^{a}	0.12±0.01 ^{b}
4	0.19±0.03 ^{a}	0.46±0.06 ^{b}	0.19±0.02 ^{a}	0.20±0.03^{a}

Similar superscripts (a, b, etc.) differ insignificantly; different superscripts differ significantly (α = 0.05).

Table 8: Concentrations (ppm) of Cu (Means ± SE) in different tissue types of *O. niloticus* assayed on wet weight basis

Locations	Liver	Kidney	Gills	Muscular Tissue
1	89.8 ±12.1 ^{a}	35.47±4.3 ^{b}	10.05±1.06 ^{c}	16.03±1.7 ^{c}
2	5.80±0.7 ^{a}	15.17±1.7 ^{b}	12.65±1.51 ^{b}	3.14±0.4 ^{a}
3	12.18 ±15.0 ^{a}	6.80 ±0.8 ^{b}	2.47±0.3 ^{c}	2.24±0.4 ^{c}
4	7.76±1.04 ^{a}	3.06±0.4 ^{b}	3.08±0.37 ^{b}	3.06±0.4^{b}

Similar superscripts (a, b, etc.) differ insignificantly; different superscripts differ significantly (α = 0.05).

Table 9: Concentrations (ppm) of Fe (Means ± SE) in different tissue types of *O. niloticus* assayed on wet weight basis

Locations	Liver	Kidney	Gills	Muscular Tissue
1	90.05±11.1 ^{a}	29.85± 4.3 ^{b}	19.5±2.3 ^{b}	23.52±2.5 ^{b}
2	80.67±10.9 ^{a}	76.6±8.7 ^{a}	55.24±6.5 ^{b}	34.64±4.0 ^{c}
3	115.2 ±14.3 ^{a}	100.3±12.8 ^{a}	62.06±8.8 ^{b}	28.1±3.2 ^{c}
4	91.86 ±12.04 ^{a}	23.24± 2.9 ^{b}	22.93±3.37 ^{b}	18.27±2.1 ^{b}

Similar superscripts (a, b, etc.) differ insignificantly; different superscripts differ significantly (α = 0.05).

Table 10: Concentrations (ppm) of Pb (Means ± SE) in different tissue types of *O. niloticus* assayed on wet weight basis

Locations	Liver	Kidney	Gills	Muscular Tissue
1	0.47±0.05 ^{a}	1.72± 0.2 ^{b}	9.95±1.3 ^{c}	BDL
2	17.41±2.1 ^{a}	10.49±1.2 ^{b}	12.23±1.6 ^{b}	14.66±1.5 ^{a}
3	7.7 ±1.0 ^{a}	7.0±0.8 ^{a}	9.18±1.2 ^{a}	3.17±0.4 ^{b}
4	3.18 ±0.4 ^{a}	4.83± 0.5 ^{a}	7.5±0.9 ^{b}	0.58±0.07

Similar superscripts (a, b, etc.) differ insignificantly; different superscripts differ significantly (α = 0.05).

Table 11: Concentrations (ppm) of Mg (Means ± SE) in different tissue types of *O. niloticus* assayed on wet weight basis

Locations	Liver	Kidney	Gills	Muscular Tissue
1	836.4± 107.4 ^{a}	1612.8 ±213.5 ^{b}	1078.8±109.2 ^{c}	1447.4±180.5 ^{b}
2	2627.5±337.3 ^{a}	3478.4±470.1 ^{b}	3444.1±490.4 ^{b}	1917.6±223.6 ^{c}
3	1728.8 ±246.5 ^{a}	2563.9±321.1 ^{b}	2010.6±259.6 ^{c}	1175.8±152.8 ^{d}
4	2013.4±249.8 ^{a}	2638.1±329.2 ^{b}	2117.3±280.7 ^{a}	2168.3±274.9 ^{a}

Similar superscripts (a, b, etc.) differ insignificantly; different superscripts differ significantly (α = 0.05). Data are expressed as means±SE

Table 12: Concentrations (ppm) of Mn (Means ± SE) in different tissue types of *O. niloticus* assayed on wet weight basis

Locations	Liver	Kidney	Gills	Muscular Tissue
1	161.6± 19.3 ^{a}	91.62± 11.7 ^{b}	69.1±8.6 ^{b}	83.96±10.1 ^{b}
2	1.55±0.19 ^{a}	1.71±0.2 ^{a}	7.46±0.9 ^{b}	3.24±0.4 ^{c}
3	94.8 ±12.4 ^{a}	127.3±14.2 ^{b}	42.32±5.3 ^{c}	18.67±2.1 ^{d}
4	1.62±0.2 ^{a}	2.63±0.3 ^{a}	4.42±0.5 ^{b}	1.69±0.2 ^{a}

Similar superscripts (a, b, etc.) differ insignificantly; different superscripts differ significantly (α = 0.05).

Table 13: Concentrations (ppb) of Hg (Means ± SE) in different tissue types of *O. niloticus* assayed on wet weight basis

Hg	Liver	Kidney	Gills	Muscular Tissue
1	0.71± 0.09 ^{a}	BDL	0.45±0.06 ^{c}	0.67±0.08 ^{a}
2	0.36± 0.05 ^{a}	0.05±0.006 ^{b}	0.17±0.02 ^{c}	0.72±0.09 ^{d}
3	1.02±0.13 ^{a}	0.9±0.11 ^{a}	0.99±0.12 ^{a}	1.4±0.18 ^{b}
4	0.05±0.006 ^{a}	0.02±0.003 ^{a}	BDL	0.04±0.004^{a}

Similar superscripts (a, b, etc.) differ insignificantly; different superscripts differ significantly (α = 0.05).

Table 14: Concentrations (ppm) of Ni (Means ± SE) in different tissue types of *O. niloticus* assayed on wet weight basis

Ni	Liver	Kidney	Gills	Muscular Tissue
1	22.0± 2.8 [a]	10.1±1.1 [b]	10.2±1.3 [b]	23.6±2.8 [a]
2	21.2± 2.9 [a]	16.2±1.9 [b]	24.1±2.6 [a]	13.9±1.7 [b]
3	4.44±0.5 [a]	4.4±0.51 [a]	5.7±0.7 [a]	5.60±0.7 [a]
4	15.6±0.2 [a]	15.8±1.7 [a]	5.01±0.7 [b]	13.5±1.5 [a]

Similar superscripts (a, b, etc.) differ insignificantly; different superscripts differ significantly (α = 0.05).

Table 15: Concentrations (ppm) of Zn (Means ± SE) in different tissue types of *O. niloticus* assayed on wet weight basis

Zn	Liver	Kidney	Gills	Muscular Tissue
1	25.3± 2.7 [a]	11.4±1.5 [b]	19.5±2.2 [c]	23.5±2.8 [a]
2	15.8±1.9 [a]	37.1±4.2 [b]	52.5±6.6 [c]	15.1±1.8 [a]
3	9.25±1.1 [a]	12.0±1.7 [a]	12.3±1.7 [a]	5.96±0.7 [b]
4	16.7±1.9 [a]	23.2±2.8 [b]	22.9±2.8 [c]	18.3±2.1 [a]

Similar superscripts (a, b, etc.) differ insignificantly; different superscripts differ significantly (α = 0.05).

buffalo and carp (Smith and Inmon, 1991). Current Mg levels in *O. niloticus* (with a minimum average of 3346 ppm dw) (Tables 2 & 11) match the levels in benthic feeders and are at least twice as high as that level (785- 1420 ppm dw) reported for a bunch of fish species including common carp, river carpsucker, gizzard shad, white bass, wiper and walleye in the Kirwin National Wildlife Refuge (KNWR) (Allen, 1991). Although Mg was not detected in dogfish muscle and liver, the present levels are substantially exceeding the certified reference levels of non-defatted- (LUTS-1) (89.5 ppm dw) and partially-defatted (TORT-2) (601 ppm dw) lobster hepatopancreas (NRC, 1999- 2000). Taking into account that Mg is not potentially harmful to fish and wildlife (Swann, 2000) and that little is known concerning whether or not elevated levels of Mg in fish tissue are harmful to the organism itself and to human and other wildlife species which consume the organism (Irwin 1991), the present Mg levels might not be the major concern

Manganese (Mn): Mn was above its EPA MCL (0.05 ppm) (USEPA, 1987) only in the water of location 1 (0.17 ppm) (Table 3). Most tissue Mn in *O. niloticus* was accumulated in kidneys (BCF, 6733) followed by the liver (BCF, 4211) (Fig. 3). Mn was not assessed by the NCBP. However, a range of 4.08 to 28.0 ppm dw in a variety of fish in KNWR, were within the ranges found in many western US drain water (Allen and Wilson 1991). This range is still far less than the current data (Tables 2 & 12), which show that Mn in *O. niloticus* had a wide-range concentration (6.2- 606.0 ppm dw) and pretty high BCF values and do not seem to correspond to the above concept. Current Mn data in liver and muscular tissue is extremely higher in groups 1 and 3 (up to 127 folds) than dogfish data (3.66 in muscle and 6.88 ppm dw in liver) (NRC, 1999- 2000). Mn in lobster hepatopancreas (13.6 ± 1.2 ppm dw) (TORT-2) and in non defatted lobster hepatopancreas (8.02 ± 0.86 ppm, dw) (LUTS-1) (NRC, 1999- 2000) is only 1.2- 2% of the present liver data in fish groups 1 and 3. Therefore, Mn contamination in fish from locations 1 and 3 is possible. However, nothing so far is approved as legal Mn limits in the edible portions or even composites of whole fish.

Mercury (Hg): Murray (1978) reported that water containing less than 0.2 ppb Hg is unlikely to have a deleterious effect on fish. Atchison *et al.* (1987) gave the lowest observed effect concentration (LOEC) for Hg in water on fish as 0.3 ppb (inorganic Hg) for flathead minnow and 0.9 ppb (methyl Hg) for brook char. The present data in *O. niloticus* (0.005- 0.019 ppb) (Table 13) fall within the above-mentioned limits. However, these thresholds are pretty high and might not bestow substantial protection for human and wildlife. In a stricter and more protective criterion, Hg concentrations in lakes were set at 0.00001- 0.00005 ppm (Eisler, 1987). Hg also was recently limited to 0.012 μg L^{-1} and 144.0 ng L^{-1} for the protection of aquatic life and human consumer, respectively (USEPA, 1995). Although current Hg levels might not cause potential threat to aquatic life (criterion: 0.012 ppb), they seriously exceeded the MCL (criterion: 2 x 10^{-5} ppb) (USEPA, 1987) and Eisler's criterion (5 x 10^{-8} ppb) and are definitely hazardous to human consumption (criterion: 144.0 ng L^{-1}) (Table 1).

The main sources of Hg into the lake's environment are through constant emissions from industrial discharge as "El-Nasr Chemicals". Given that Hg is highly volatile (Moore and Ramamoorthy, 1984a), the role of sewage treatment and anthropogenic activities (Eisler, 1987) in polluting the lake's environment with Hg cannot be ignored. Sewage treatment discharges mainly come up via East- and West Treatment Plants (Fig. 1). Anthropogenic sources are reported to contribute more Hg into the environment than do natural sources (Eisler, 1987). The adverse impact of Hg in lakes and rivers is not restricted to aquatic biota, but extends to other categories of wildlife and human, because Hg is one of the few metals that bioconcentrate in organisms and biomagnify through the food chain (Smith and Inmon, 1991). Eisler (1987) emphasized that Hg-predator protection levels for birds, which consume fish, and other organisms should not exceed 0.1 ppm. Unfortunately, the current muscular tissue range exceeded this limit by up to 14 x 10^3 folds.

Hg accumulated in *O. niloticus* in a uniform pattern with the highest magnitude in the muscular tissue in general and in fish group 2 in particular (BCF, 802) (Fig. 4). Hg levels in *O. niloticus* exceeded the NCBP mean (0.10 ppm ww) and 85th percentile (0.17 ppm ww), the maximum NCBP level (0.37 ppm ww) for recent years and FDA action level (1.0 ppm ww). Current data were also far above levels reported for other ecosystems. On the Guadalupe and San Antonio Rivers, Hg levels in fish ranged from 0.04 to 0.42 ppm ww (Lee and Schultz, 1994). Fish from the Salt Drain area (Robertson *et al.*, 1992) and upper Mississippi River (Weiner *et al.*, 1984) had low levels of Hg (0.039- 0.242 and 0.158- 1.43 ppm dw, respectively). All biota sampled on Aransas Bay dredge spoils (0.04- 0.22 dw) were below the level (0.5 ppm ww; 2.5 ppm dw) accepted for typical clean tissue (Abernathy and Cumbie 1977). Kurey (1991) also reported that none of the mean concentrations of Hg in carp from New Madrid Refuge, Missouri, were above established guidelines or alert levels (Crisp, 1987). The present Hg data in fish liver (200- 4080 ppm dw) exceeded by several hundred folds Hg content in carp on the upper Mississippi River (0.092- 7.91 ppm dw) (Weiner *et al.*, 1984), in dogfish liver (1.99 ppm), in non-defatted lobster hepatopancreas (0.112 ppm) and in defatted

lobster hepatopancreas (0.27 ppm).
Fish fillet is the part of major human concern. Hg in fillets of *O. niloticus* (222.2- 7777.8 ppm dw) exceeded the FDA action level (1.0 ppm ww) for edible fish portion (40- 1400 folds) and the reference Hg content in dogfish muscle (4.64 ppm dw) (NRC, 1999-2000). The present data also exceeded the NCBP geometric means and 85th percentile by up to 14000 folds. The highest Hg value (0.71 ppm) reported in Asiatic clams from a contaminated source of Shenandoah River in Virginia (Ator *et al.*, 1998) was considered hazardous although it was below the FDA action level and far less than what is reported here. These data seriously alert to the Hg status in the lake's ecosystem.

Nickel (Ni): Some of the current Ni data in water (0.06-0.13 ppm) are within or slightly above the MCL (0.1 ppm) (USEPA, 1987) and the criteria set for the protection of aquatic life (160.00 μg L^{-1}) and human consumer (632.0 μg L^{-1}) of USEPA (1995). In *O. niloticus*, Ni is mainly accumulated by the liver and kidney (Fig. 4) confirming the findings of Moore and Ramamoorthy (1984a) that it tends to accumulate in tissues with high metabolic activity.
Ni was not measured for the NCBP; but based on some earlier reports, the present data (5.01- 24.11 ppm ww) imply fish contamination with Ni. The Panel on Nickel (1975) considered Ni levels below 0.75 ppm ww (about 3.75 ppm dw) normal for aquatic organisms. On KIRWIN National Wildlife Refuge, Ni was BDL in common carp, white bass and walleye, but measured 1.04-1.26 ppm ww in river carpsucker, gizzard shad and wiper (Allen, 1991). In fiddler crabs, sheepshead minnows and tadpoles from Bludworth, Ni ranged from 1.0 to 10 ppm dw (Robertson *et al.*, 1991). All sorts of tissue sampled for Ni in this study (5.01- 132.3 ppm ww) (Table 14) are far above the limits shown before. The present data match more data (9.5-13.8 ppm ww) of fish from lakes and rivers heavily contaminated with metals (Hutchinson *et al.*, 1976). However, Phillips and Russo (1978) denied some of the above aspects as they noted that Ni does not accumulate in aquatic organisms. Charbonneau and Nash (1993) also concluded the absence of Ni contamination on MNWR with a maximum Ni residue concentration of 23.8 ppm dw in fish sampled in Clarence Cannon NWR. Based on views of both parties, the harvest of *O. niloticus* from Lake Maryût is unlikely to present a serious Ni contamination problem.

Zinc (Zn): Water Zn was BDL at the reference site (4) and below the MCL (5.0 ppm) (USEPA, 1987) in all other sites (0.03- 0.09 ppm). Criteria for the protection of aquatic life and human consumer (0.57 & 0.005 ppm, respectively) (USEPA, 1995) indicate that Zn status in the lake's water is not likely to contaminate aquatic life but it won't be appropriate for human consumption (Table 15). Values of Zn ranging from 16.7 to 23.2 ppm ww in the catch of location 4 appears to be normal for wild types of *O. niloticus* given that Zn was BDL in the water of this location. The highest BCF of Zn was for gills (6483) and kidneys (5880) of catch group 2; muscular (2807) and liver (2100) tissue had remarkably less BCF levels (Fig. 4). The entire average values that exceeded the NCBP geometric mean (21.7 ppm ww) (Schmitt and Brumbaugh, 1990) were in the gills (52.1 ppm) and kidneys (37.05 ppm) of fish harvest 2. However, many other values in *O. niloticus* were below the maximum NCBP concentration (118.4 ppm ww) (Schmitt and Brumbaugh, 1990). Zn content in fillet of yellow perch (*Perca flavescans*), bluegill, and black crappie (*Pomoxis nigromaculatus*) from recreational and industrial-river zones was 100- 109 ppm dw (Moore and Ramamoorthy, 1984a). Muscle tissue from omnivorous and carnivorous fish from industrial and agricultural areas of the lower Great Lakes contained 16 to 88 and 3 to 9 ppm Zn ww, respectively (Brown and Chow, 1977). Concentrations of Zn in edible tissue from fish inhabiting streams contaminated by Pb mining ranged from 4.0 to 24.0 ppm ww (Schmitt and Finger, 1987). Zn concentrations in fillet of *O. niloticus* match the above values (5.96- 23.5 ppm ww; 33.11-130.55 ppm dw) (Tables 15 & 2), but the risk imposed on man and wildlife is questionable given that Zn is an essential trace element to life. In many countries, still there are no established limits for trace metals in fish/shellfish and fishery products. Local patterns of fish/shellfish consumption or trace metal contamination may differ from international averages. In order to decide local alert levels, it is suggested that the estimated safe and adequate dietary intake for metals (μg/person/day) be used to calculate Levels of Concern. Both maximum permitted amounts of chronic fish/shellfish consumption and maximum permitted levels of contamination of a given metal have to be given careful consideration. For a finer prescript, numerous studies with multiple sample analyses and multiform statistical approaches are required. Executive administration bodies similar to US "Clean Water Act" and "Fish Consumption Advisory" are also due to take part in the development of local ecosystems.

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