TRACE ELEMENTS IN WATER, FISH AND SEDIMENT FROM TUSKEGEE LAKE, SOUTHEASTERN USA

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Abstract. The concentrations of trace elements in water, sediment and fish samples from Tuskegee Lake located in Southeastern United States were investigated in this study. The Lake is utilized both as a source for municipal drinking water, and for recreational fishing. The water quality characteristics over two sampling periods, the speciation of metals in the Lake sediments, the risk to water column contamination and levels of heavy metals in largemouth bass (*Micropterus salmoides*) samples from the Lake were evaluated. The Lake water quality characteristics were mostly below the recommended drinking water standards by the United States Environmental Protection Agency (US EPA) and the European Union (EU) except for aluminum, iron, manganese and thallium. In addition, the average values of Cr, As, Mn, Zn and Cl^- in the water samples analyzed were higher than the respective reference values for fresh water. To study the speciation of metals in the Lake sediments, ten elements (Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, V, and Zn) in four grain sizes (< 710 μm – 250 μm, < 250 μm – 75 μm, < 75 μm – 53μm, and < 53 μm) were subjected to sequential extractions. Irrespective of grain size, the elements analyzed were distributed in both the non-residual and residual phases except Ni that was found only in the residual fraction. The potential risk to Lake water contamination was highest downstream (Sites 1 and 2) based on the calculated global contamination factors. From the calculated individual contamination factors, Mn and Pb followed by Zn, Cu, Cr, Co and V posed the highest risk to water contamination. Based on this study, the human health risks for heavy metals in fish caught from Tuskegee Lake are low for now, and irrespective of the source of fish, concentrations of metals in muscle tissues were all below the recommended Food and Agriculture Organization (FAO) maximum limits for Pb (0.5 mg Kg^{-1}), Cd (0.5 mg Kg^{-1}), Cu (30 mg Kg^{-1}), and Zn (30 mg Kg^{-1}) in fish.

Keywords: contamination factors, fish, heavy metals, ICP-OES, sediment, speciation, trace metals, water

1. Introduction

Fresh water Lakes support many life forms, provide recreation and game fishing to the communities, and it is also a good source of water for drinking water production by municipal water works. The contamination of soils, sediments, water resources, and biota by heavy metals is of major concern especially in many industrialized countries because of their toxicity, persistence and bioaccumulative nature. Recreational fishing is widespread in United States (Schleusner and Maughan, 1999) and the United States Environmental Protection Agency (US EPA) have provided fish and wildlife consumption advisories for Lakes, rivers and coastal waters. The EPA

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report shows a 7% increase in the number of advisories between 1999 and 2000 due to an increase in the number of assessments of chemical contaminants in fish and wildlife (US EPA, 2001). In the EPA report, 23% of the total Lake acreage and 9.3% of the total river miles in United States are under consumption advisories. In Alabama for example, mercury advisory is provided for its coastal waters.

Eating of fish is known to provide nutritional benefits to humans. Apart from being a good source of protein, fish is known to contain omega 3-fatty acids that help reduce the risk of certain types of cancer (Paul *et al.*, 2002; Terry *et al.*, 2001) and cardiovascular disease (La Vecchia *et al.*, 2001). Fish consumption is a major route of chemical exposure for humans (Dougherty, 2000) and most importantly, children are more at risk because of their greater intestinal absorptions (Chance and Harmsen, 1998). Elevated body burden levels of contaminants, developmental deficits and neurologic problems in children of some fish-consuming parents, nervous system dysfunction in adults, and disturbances in reproductive parameters have also been published (Johnson *et al.*, 1999).

Studies on heavy metals in rivers, Lakes, fish and sediments (Kļaviņš *et al.*, 2000; Grosheva *et al.*, 2000; Bortoli *et al.*, 1998; Elbaz-Poulichet *et al.*, 1996; Mannio *et al.*, 1995; Storelli and Marcotrigiano, 2001; Rashed, 2001; Gray *et al.*, 2000; Al- Yousuf *et al.*, 2000; Aucoin *et al.*, 1999; Zhou *et al.*, 1998; Allen-Gil and Martynov, 1995; Johansson *et al.*, 1995) have been a major environmental focus especially in the last decade. Sediments are important sinks for various pollutants like pesticides and heavy metals and also play a significant role in the remobilization of contaminants in aquatic systems under favorable conditions and in interactions between water and sediment. The direct transfer of chemicals from sediments to organisms is now considered to be a major route of exposure for many species (Zoumis *et al.*, 2001). The release of trace metals from sediments into the water body and consequently to fish will depend on the speciation (i.e. metals may be precipitated, complexed, adsorbed, or solubilized) of metals and other factors such as sediment pH and the physical and chemical characteristics of the aquatic system (Morgan and Stumm, 1991). Metals may distribute in sediments as exchangeable, carbonate bound, iron-manganese oxide bound, organic matter bound and residual bound species. The speciation of metals can be evaluated by carefully choosing the extracting solutions and digestion conditions.

Tuskegee Lake was constructed to help alleviate the water problems of the city and many inhabitants of the area also carry out recreational fishing on the Lake. Data on Tuskegee Lake water quality and the health status of the Lake are scarce but Khan *et al.* (1995) reported levels of heavy metal concentrations in sediments and two populations of crayfish collected from the Lake. It became necessary to carry out a detailed water quality assessment of Lake Tuskegee and to also investigate the potential risk to water column contamination from Lake sediments. For the municipal water works that relies on good quality source water, it makes good public health sense, good economic and environmental sense to prevent drinking water contamination at the source (US EPA, 2002). The major objectives of this research are: (1) to determine the water quality characteristics of Tuskegee Lake water samples and to assess the risk of Tuskegee Lake water contamination by Lake sediments; (2) to determine the levels of total extractable heavy metals (Co, Cr, Cd, Cu, Fe, Mn, Ni, Pb, V and Zn) and study the fractionation of these metals in the Lake sediments because of their environmental implications; (3) to determine the levels of Co, Cr, Cd, Cu, Fe, Mn, Ni, Pb, V and Zn in some fish samples because of the health implications to human populations consuming fishes from Tuskegee Lake.

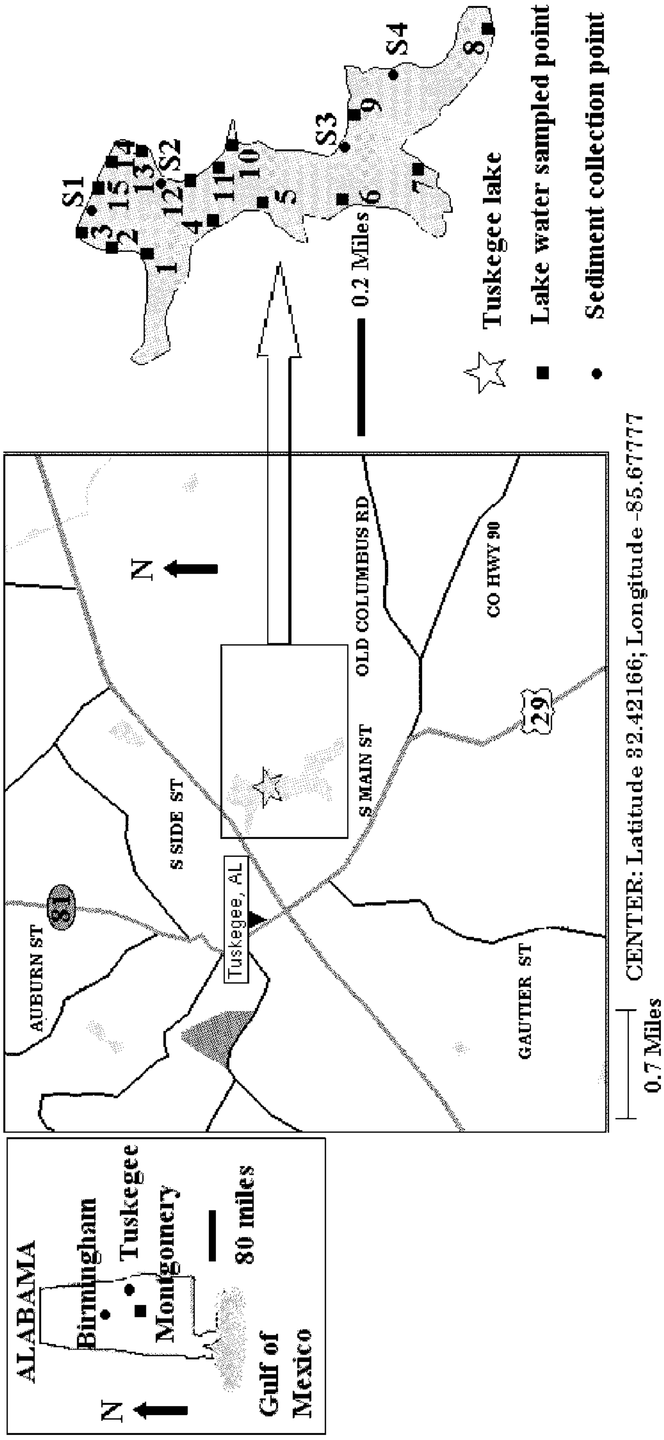
2. Materials and Methods

2.1. SITE DESCRIPTION

Lake Tuskegee is a freshwater man-made Lake owned by the city of Tuskegee and it is located within residential areas in Tuskegee, Alabama. Its latitude and longitude coordinates are 32.42166 and –85.67777 respectively. The proposal to excavate Lake Tuskegee was introduced in late 1947, shortly after a water shortage during the summer due to reduced flow from the cities main source, the Euphaubee Creek (Tuskegee News, 1947). The Lake, which was completed in March 1948, was anticipated to provide additional water needed to meet increased demand as well as to serve as a source of recreation. Apart from its recreational objectives, the Lake provides a source of additional fish protein to some inhabitants of the area. Lake Tuskegee is a 92-acre body of water that is fed by several large springs. It is separated into 2 smaller Lakes by a 1,000 ft long dam that has a maximum height of 23 ft. The Lake has a 17 ft deep key in the center to prevent seepage. In order to provide adequate strength for flood conditions, the base of the dam is 100 ft wide (Tuskegee News, 1948). A sewer line on concrete pillars over one neck of the Lake was extended into the stream below the dam and septic tanks on the surrounding hillsides were altered to prevent water contamination. After the development of the Lake, it was stocked with about 3,000 bream, bass and speckled catfish.

2.2. LAKE WATER COLLECTION AND ANALYSES

The location of Tuskegee Lake is given in Figure 1 along with the sampling points for water and sediment samples collected. Water samples were collected using open water grab sampler equipped with a simple pull-ring that allowed for sampling at various water depths (0–6 ft, > 6–12 ft and > 12–18 ft). Samples were collected between 5–10 m from the banks at a depth of 0–6 ft. Lake water samples were collected into acid washed polyethylene plastic containers with screw caps and amber glass bottles. Washing procedures for containers were as recommended in standard methods for waters and wastewaters (APHA, 1998). For general parameters determination, 1 L high density polyethylene (HDPE) bottles purchased from Fisher Scientific (New Jersey, USA) were thoroughly washed with metal free soap



CENTER: Latitude 32.42166; Longitude -85.67777

Figure 1. Location of Tuskegee and sampling points.

and rinsed many times with Milli-Q water (Barnstead). For metal determination, 1 L polyethylene bottles were washed with metal free soap, rinsed many times and finally soaked in 50% nitric acid for 24 hr before final rinse with Milli-Q water. Samples for total organic carbon (TOC) analysis were collected in 1 L amber glass bottles (Fisher Scientific New Jersey, U.S.A.) previously soaked in chromic acid to remove unwanted organics and finally rinsed many times with Milli-Q water. Water samples collected did not contain noticeable suspended materials hence samples were not filtered prior to analyses for water quality constituents.

For metal determination in Lake water samples, EPA method 3015 was used to digest samples using Ethos plus computerized microwave labstation (Milestone Inc., Monroe, CT 06468, U.S.A.) equipped with pressure and temperature controls. Concentrated nitric acid (5 ml) was added to 45 ml of water sample in a digestion vessel. Microwave digestion of blanks, standard reference material (SRM) 1640 and Lake water samples followed the two steps process below: Step 1: 160 °C for 10 min at 1050 W and finally, Step 2: 165 °C for 10 min at 1050 W. Element levels in the digests were determined with Perkin-Elmer DV 3300 inductively coupled plasma-optical emission spectrometer (ICP-OES). A 100 mg L^{-1} mixed standard (SPEX Certiprep, NJ, U.S.A.) containing 25 elements (Ag, Al, As, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, Pb, Sb, Se, Sn, Sr, Ti, Tl, V, Zn) and other 1000 mg L^{-1} single standards (Fisher Scientific, NJ, U.S.A.) of Hg, Th, and U were used to prepare calibration solutions. The validation of the procedure for metal determination was conducted by the analysis of SRM 1640: Trace elements in natural water. Samples were analyzed under the same experimental conditions used for procedural blanks and reference samples. All reference samples were purchased from National Institute of Standards and Technology (NIST), Gaithersburg, MD, U.S.A.

Other water quality parameters were also determined in the Lake water samples. pH and conductivity of samples were determined within few hours after sample collection using MultiLab P4 (Wissenschaftlich-Technische Werkstatten GmbH, Weilheim, Germany). Chloride and alkalinity were determined by argentometric and titrimetric procedures respectively (APHA, 1998). Ammonia and nitrate + nitrite were determined spectrophotometrically by the salicylate and cadmium reduction methods respectively (Hach, 1998). Total carbon (TC), inorganic carbon (IC) and total organic carbon (TOC) were measured with DC-180 Carbon Analyzer (Rosemount Analytical Inc., CA, U.S.A.) after appropriate calibrations.

2.3. SEDIMENT COLLECTION AND ANALYSES

Sediment samples were collected using a precleaned stainless steel Ekman dredge (6" × 6" × 6") made by Wildco Instruments (Sargein, MI, U.S.A.) and immediately placed in plastic bags. Samples were transported to the laboratory and air-dried in the laboratory at room temperature. Once air-dried, sediment samples were sieved into four major grain sizes (< 710 μm – 250 μm, < 250 μm – 75 μm,

< 75 μm – 53 μm, and < 53 μm). Sediment samples were stored in acid washed polyethylene bottles with plastic screw caps until time for extraction. The pH of the sediment was measured in water with a 1: 2.5 soil/solution ratio after equilibration for 30 min (McLean, 1982). The sediment fractions were subjected to a five-step sequential extraction technique (Tessier *et al*., 1979) but with modification at the final step. The final step in the sediment extraction was conducted by adopting the method of Gauthreaux *et al*., (1998). The extraction stages employed in this study are described as follows: *Extraction 1 – Exchangeable metals:* 16 ml of 1 M NaOAc at pH 8.2 (adjusted using NaOH) was added to the weighed sediment fraction in an Erlenmeyer flask, and the sample was shaken in an environmental chamber for 1 hr at a speed of 165 rpm under room temperature. *Extraction 2 – Metals bound to carbonates:* 16 ml of 1 M NaOAc, adjusted to pH 5.0 using HOAc, was added to the residue from Extraction 1, and the sample was placed back into the environmental shaker for 1 hr under the same settings described in Extraction 1.

Extraction 3 – Metals bound to iron and manganese oxides: 40 ml of 0.04 M $NH_2OH{\bullet}HCl$ in 25% ($^v/_v$) HOAc was added to the residue from Extraction 2 and the sample was placed in an Ethos Plus digestion microwave labstation. The extraction was carried out at 96 ± 3 °C for 1 hr. *Extraction 4 – Metals bound to organic matter:* Step 1: 6 ml of 0.02 M HNO_3 and 10 ml of 30% H_2O_2 (adjusted to pH 2.0 using HNO_3) were added to the residue from Extraction 3. The sample was then placed into the microwave and heated at 85 ± 2 °C for 2 hr. Step 2:6 ml of 30% H_2O_2 at pH 2.0 was added to the sample and again heated in the microwave 85 ± 2 °C for 3 hr. Step 3: 10 ml of 3.2 M NH_4OAc in 20% ($^v/_v$) HOAc was added to the sample and placed into the environmental shaker for 30 min with the same settings previously described in Extraction 1. *Extraction 5 – Residuals:* 20 ml of 70 % HNO_3 was added to the residue from Extraction 4, and was digested in the microwave at 140 °C for 1 min.

The Ethos Plus microwave labstation was used during the extractions because of its reliability to follow the temperature and pressure program during digestions. The Ethos Plus microwave labstation provided greater accuracy and higher extraction efficiency due to its ability to reduce sample losses during digestion. The extracts collected were analyzed using ICP-OES to determine the concentrations of the following elements: Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, V, and Zn. Also method blanks were analyzed for all metal determinations. Validation of instrument accuracy and precision was carried out through the analysis of SRM 1944 – Trace elements in New York/New Jersey sediment. SRM 1944 was subjected to concentrated nitric acid digestion only and finally analyzed for total extractable metals using the ICP-OES.

2.4. FISH COLLECTION AND ANALYSIS

Three samples of largemouth bass (*Micropterus salmoides*), the most common type of fish in Lake Tuskegee and widely consumed were caught with fishing rods using artificial bass bates. Also for comparison purposes, another three largemouth bass (*Micropterus salmoides*) and three striped bass (*Morone saxatilis*) samples were purchased from Farmers market located on Buford highway, Atlanta, GA, U.S.A. All fish samples obtained were kept on ice in the field and transported to the laboratory. In the laboratory, fish weight and length were taken and samples were frozen until ready for acid digestion. Prior to microwave digestion, fish samples were removed from the refrigerator and allowed to thaw. Known weights (wet weight) of fish muscle, vertebral column, gills, and liver samples were then digested in Ethos Plus microwave labstation as follows: Between 1–4 g of each fish sample was placed in digestion vessel each containing 15 ml of nitric acid and content was subjected to microwave program as follows: Step 1: 25–96 °C for 20 min at 1000 W; Step 2: hold at 96 °C for 30 min; Step 3: 180 °C for 10 min at 1000 W; hold at 180 °C for 10 min then cooled to room temperature. Step 4: 2 ml of 30% hydrogen peroxide was added to each digest in the vessel and the mixture was again subjected to Step 3 above. Digests were finally made up to 25 ml in acid washed standard flasks and then placed in acid washed 60 ml polyethylene bottles. The levels of Co, Cr, Cd, Cu, Fe, Pb, Mn, Ni, Zn and V in digests were then determined using ICP-OES. To check the accuracy of the methodology used for fish, bovine liver (SRM 1577b) from NIST were passed through the same analytical process used for the fish samples. Method blanks were also conducted for all metal determinations in fish.

3. Results and Discussion

3.1. STANDARD REFERENCE MATERIALS

Table I shows the results of the analysis of SRM 1640, SRM 1944 and SRM 1577b reference samples. The measured values of elements in each of the reference standards were comparable to the respective NIST certified reference values. The standard reference materials were used in the validation of the analytical technique for total metals determination only and no attempt was made to sequentially extract SRM 1944.

3.2. WATER QUALITY RESULT

Table II shows the water quality constituents of Tuskegee Lake water, reference freshwater values and other global published values on Lakes in different continents. The pH of Tuskegee Lake water samples during sampling 1 (pH range: 6.98–7.63) and sampling 2 (pH range: 7.06–7.68) were near neutral or slightly

TABLE I

Total metal determinations in NIST refrrence samples

Element	NIST certified values for SRM 1640 μg L^{-1}	Measured values in SRM 1640 μg L^{-1}	NIST certified values for SRM 19644 mg Kg^{-1}	Measured values in SRM 1944 mg Kg^{-1}	NIST certified values forSRM 1577b mg Kg^{-1}	Measured values in SRM 1577b mg Kg^{-1}
Aluminum	52 ± 1.5	50.5 ± 4.78			3^{b}	
Antimony	13.79 ± 0.42	11.1 ± 4.57				
Arsenic	26.67 ± 0.41	32.4 ± 5.11	18.9 ± 2.8	15.6 ± 1.37	0.05^{b}	nd
Barium	148.0 ± 2.2	166 ± 0.80				
Beryllium	34.94 ± 0.41	40.7 ± 1.06	1.6 ± 0.3	nd		
Boron	301 ± 6.1	na	301 ± 6.1	na		
Cadmium	22.79 ± 0.96	26.2 ± 0.15	8.8 ± 1.4	11.5 ± 0.6	0.50 ± 0.03	0.39 ± 0.03
Chromium	38.6 ± 1.6	38.4 ± 1.12	266 ± 24	242 ± 2.1		
Cobalt	20.28 ± 0.31	21.1 ± 0.01	14 ± 2	16.1 ± 0.02	0.25^{b}	0.16 ± 0.03
Copper	85.2 ± 1.2	94.5 ± 3.29	380 ± 40	352 ± 6.9	160 ± 8	166.25 ± 3.65
Lithium	50.7 ± 1.4	na				
Nickel	27.4 ± 0.8	26.0 ± 0.5	76.1 ± 5.6	71.3 ± 0.6		
Potassium	994 ± 27	1240 ± 158.7				
Rubidium	2.00 ± 0.02	na	2.00 ± 0.02	na	13.7 ± 1.1	
Zinc	53.2 ± 1.1	46.0 ± 4.5	656 ± 75	579 ± 5.5	127 ± 16	116.85 ± 1.49
Iron	34.3 ± 1.6	33.4 ± 0.43			184 ± 15	188.1 ± 2.48
Lead	27.89 ± 0.14	35.5 ± 1.68	330 ± 48	306 ± 0.1	0.129 ± 0.004	0.10 ± 0.03
Manganese	121.5 ± 1.1	130 ± 3.2	505 ± 25	476 ± 4.7	10.5 ± 1.7	9.50 ± 0.18
Molybdenum	46.75 ± 0.26	49.4 ± 1.34			3.5 ± 0.3	
Selenium	21.96 ± 0.51	15.9 ± 2.32			0.73 ± 0.06	
Silver	7.62 ± 0.25	9.16 ± 1.45			0.039 ± 0.007	
Strontium	124.2 ± 0.7	133 ± 0.7			0.136 ± 0.001	
Vanadium	12.99 ± 0.37	13.3 ± 0.01	100 ± 9	99.1 ± 1.16	0.123^{b}	0.12 ± 0.03
Calcium	7.045 ± 0.089^{a}	7.74 ± 0.01^{a}			116 ± 4	
Magnesium	5.819 ± 0.056^{a}	6.31 ± 0.18^{a}			601 ± 28	
Silicon	4.73 ± 0.12^{a}	5.04 ± 0.28^{a}				
Sodium	29.35 ± 0.31^{a}	34.7 ± 0.35^{a}				

[a] Unit = mg L^{-1}; na: not analyzed; nd: not detected

[b] non certified value.

alkaline. Also for both periods, the Lake water was dilute with conductivities ranging between 81.2–87 μS cm^{-1}. The variations in the average pH and conductivity values between the two sampling periods were less than 0.2 pH units and 2.75 μS cm^{-1} respectively (Table II). The mean conductivity values obtained for Tuskegee Lake water samples were higher than the mean conductivity values reported for two acidic Lakes (Blue Mountain Lake and Lake Success) in the northeastern United States (Sprenger *et al.*, 1987) but over 15 times lower than the reported mean conductivity value for 36 Lakes in Lapland (Finland) and 81 Lakes in Southern and Central Finland (Mannio *et al.*, 1995).

TABLE II

Mean (± SD) or ranges of water quality constituents of Tuskegee Lake and other global published freshwater values

Parameter	pH	Phenolphthalein alkalinity	Total alkalinity (mg CaCO3 L^{-1})	Conductivity (μS cm^{-1})	Phosphate (mg L^{-1})	Sulfate (mg L^{-1})	Chloride (mg L^{-1})	Nitrate + Nitrite (mg L^{-1}	Ammonium (mg L^{-1})
Tuskegee Lake (Sampling 1)	7.24 ± 0.25	Zero	17.64 ± 2.22	85.2 ± 134	0.42 ± 0.83	7.04 ± 1.08	16.56 ± 2.17	0.9 ± 0.28	0.03 ± 0.01
Tuskegee Lake (Sampling 2)	7.44 ± 0.14	Zero	29.67 ± 1.29	82.48 ± 0.71	0.07 ± 0.04	8.76 ± 2.04	9.31 ± 0.64	0.53 ± 0.65	0.13 ± 0.04
Reference values for freshwater (Markert, 1994)							8.0		
Blue mountain Lake, NE, U.S.A.[c] (Sprenger *et al.*, 1987)	5.3–6.2			23.5–30		8.8–22.6			
Lake Success, NE, U.S.A.[c] (Sprenger *et al.*, 1987)	4.0–5.0			22.7–30.0		7.9–16			
Siberian Pond[e] (Gladyshev *et al.*, 2001)	7.7–9.5								
16 Latvian Lakes[c] (Kļaviņš *et al.*, 1998)	6.5–8.10					7.9–62.6			
210 Lakes in Norway (Rognerud and Fjeld, 2001)	6.26 ± 0.63								
36 Lakes in Lapland, Finland[b] (Mannio *et al.*, 1995)	5.7			1300		26 μeq L^{-1}	14 μeq L^{-1}	< 0.05 μeq NO_3^- L^{-1}	

TABLE II

continued

Parameter	Ag (μg L^{-1})	Al (μg L^{-1})	As (μg L^{-1})	Ba (μg L^{-1})	Be (μg L^{-1})	Ca (mg L^{-1})	Cd (μg L^{-1})	Co (μg L^{-1})	Cr (μg L^{-1})	Cu (μg L^{-1})
Tuskegee Lake (Sampling 1)	0.19 ± 0.35	173.2 ± 52.6	0.06 ± 0.23	47.49 ± 9.5	nd	4.88 ± 1.26	nd	0.3 ± 0.5	2.05 ± 1.37	1.21 ± 1.76
Tuskegee Lake (Sampling 2)	0.53 ± 0.52	155.1 ± 153.3	0.6 ± 2.2	22.0 ± 7.7	0.1 ± 0.2	6.82 ± 1.89	0.001 ± 0.005	0.03 ± 0.09	0.03 ± 0.10	0.5 ± 0.9
Reference values for freshwater (Markert, 1994)			0.5			2	0.2	0.5	1	3
Blue mountain Lake, NE, U.S.A.[c] (Sprenger *et al.*, 1987)		13–71		0.05–0.16						
Lake Success, NE, U.S.A.[c] (Sprenger *et al.*, 1987)		50–128					0.05–0.40			
Nacharam Lake, India[d] (Govil *et al.*, 1999)			9.5 ± 1.5	106.7 ± 13.7			8.9 ± 3.5			
Siberian Pond[e] (Gladyshev *et al.*, 2001)		0.3 ± 0.04[a]				38.6 ± 2.35	< 1		2.03 ± 0.2	2.29 ± 0.43
16 Latvian Lakes[c] (Kļaviņš *et al.*, 1998)						1.5–74.1	0.01–0.08	0.03–0.09		0.32–0.96
Scottish mountain Lake, Scotland (Yang *et al.*, 2002)							0.09–0.23			0.18–2.02
36 Lakes in Lapland, Finland[b] (Mannio *et al.*, 1995)		63	0.17				0.02		0.24	0.28

TABLE II
continued

Parameter	Fe (mg L^{-1})	K (mg L^{-1})	Mg (mg L^{-1})	Mn (μg L^{-1})	Mo (μg L^{-1})	Ni (μg L^{-1})	Pb (μg L^{-1})	Sb (μg L^{-1})	Se (μg L^{-1})	Sn (μg L^{-1})	Sr (μg L^{-1})
Tuskegee Lake (Sampling 1)	0.34 ± 0.14	2.29 ± 0.11	1.99 ± 0.05	58.4 ± 25.7	0.01 ± 0.02	nd	0.7 ± 2.7	nd	1.1 ± 1.9	0.3 ± 1.1	24.9 ± 1.6
Tuskegee Lake (Sampling 2)	0.28 ± 0.15	2.58 ± 0.72	2.35 ± 0.90	107.7 ± 52.8	0.5 ± 0.6	6.6 ± 2.4	0.1 ± 0.3	nd	nd	nd	30.6 ± 8.5
Reference values for freshwater (Markert, 1994)	0.5	2	4	5		0.3	3			50	
Blue mountain Lake, NE, U.S.A.[c] (Sprenger *et al.*, 1987)				36–219			0.1–0.8				
Lake Success, NE, U.S.A.[c] (Sprenger *et al.*, 1987)				103–144			0.9–5.0				
Nacharam Lake, India[d] (Govil *et al.*, 1999)	0.070 ± 0.009			23.0 ± 35.9	5.8 ± 1.6		8.8 ± 3.6		7.2 ± 0.8		1069.4 ± 94.2
Siberian Pond[e] (Gladyshev *et al.*, 2001)	0.29 ± 0.06		15.54 ± 0.39	0.06 ± 0.01[a]		1.86 ± 0.2	2.26 ± 0.15				
16 Latvian Lakes[c] (Kļaviņš *et al.*, 1998)				1.50–7.90		0.15–0.85	0.03–0.18				
Scottish mountain Lake, Scotland (Yang *et al.*, 2002)						0.14–0.30	0.51–1.19				
36 Lakes in Lapland, Finland[b] (Mannio *et al.*, 1995)	0.087			15		0.25	0.25				

TABLE II

continued

Parameter	Ti (μg L^{-1})	Tl (μg L^{-1})	V (μg L^{-1})	Zn (μg L^{-1})	U (μg L^{-1})	Th (μg L^{-1})	Na (mg L^{-1})	TOC (mg L^{-1})
Tuskegee Lake (Sampling 1)	3.7 ± 1.2	5.1 ± 3.9	0.01 ± 0.03	5.7 ± 2.9	nd	26.6 ± 55.8	3.74 ± 0.21	4.46 ± 0.49
Tuskegee Lake (Sampling 2)	1.6 ± 1.8	11.3 ± 9.9	0.2 ± 0.3	5.5 ± 4.4	nd	20.5 ± 14.7	3.31 ± 0.24	1.34 ± 1.23
Reference values for freshwater (Markert, 1994)				5			5	
Blue mountain Lake, NE, U.S.A.[c] (Sprenger *et al*., 1987)				5–30				
Lake Success, NE, U.S.A.[c] (Sprenger *et al*., 1987)				21–142				
Nacharam Lake, India[d] (Govil *et al*., 1999)			19.5 ± 2.8					
Siberian Pond[e] (Gladyshev *et al*., 2001)				0.02 ± 0.02[a]			39.03 ± 2.15	
16 Latvian Lakes[c] (Kļaviņš *et al*., 1998)				2.87–6.80				
Scottish mountain Lake, Scotland (Yang *et al*., 2002)				1.9–3.55				
210 Lakes in Norway (Rognerud and Fjeld, 2001)								3.5 ± 2.8
36 Lakes in Lapland, Finland[b] (Mannio *et al*., 1995)				1.84				7.3

SD: standard deviation; nd: not detected; [a] values in mg L^{-1}; [b] median values reported; [c] water samples filtered with 0.45 μm membrane filter; [d] filtered immediately; [e] water samples filtered through plankton net (0.08 mesh size).

Irrespective of the sampling period, phenolphthalein alkalinity was zero and total alkalinity was only due to bicarbonate. The significance (mg L^{-1}) of the major cations and anions during the two sampling periods follows the order: $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$ and $HCO_3^{-} > Cl^{-} > SO_4^{2-} > NO_3^{-}$. The range of TOC (0.11–5.53 mg L^{-1}) for both periods did not suggest gross pollution of the Lake by organic contaminants. The mean TOC levels (sampling 1: 4.46 ± 0.49 mg L^{-1} and sampling 2: 1.34 ± 1.23 mg L^{-1}) in this study were comparable to the mean level (3.5 ± 2.8 mg L^{-1}) reported for 210 Lakes in Norway (Rognerud and Fjeld, 2001) but the minimum and maximum TOC values in this study were below the corresponding values obtained for Lapland and Southern and Central Finland (Mannio *et al.*, 1995). Organic carbon sources that may pollute the Lake arise from both the remains of both plants and animals (usually in form of tannin, lignin and humic substances) and from anthropogenic sources. The observed levels of ammonia were negligible (0.02–0.17 mg L^{-1}) for both sampling periods. Ammonia is very toxic to fish and its presence in high concentration in an aquatic body may indicate pollution due to industrial discharges, sewage intrusion and agricultural runoffs.

The average values of Cr, As, Mn, Zn and Cl^{-} in Tuskegee Lake water samples were higher than the respective reference values for fresh water (Markert, 1994). The result of this study (Table II) also suggests that except for iron and manganese, the arsenic, barium, cadmium, molybdenum, lead, selenium, strontium and vanadium in Tuskegee Lake water samples were consistently lower than the corresponding reported values for Nacharam Lake (Govil *et al.*, 1999) located in an industrial area in Hyderabad (Andhra, India). The average levels of magnesium, calcium, sodium, aluminum and lead reported for a Siberian pond (Gladyshev *et al.*, 2001) were higher than the reported mean values for Tuskegee Lake water samples but the mean values of iron, chromium and copper levels for both studies were comparable. However, the concentrations of aluminum, iron, manganese and thallium found in some of the Lake water exceeded their respective US EPA drinking water standards and European Union (EU) directives. Thus, Tuskegee Lake water will require chemical and biological treatment at the municipal water works in order to serve as good drinking water.

3.3. TUSKEGEE LAKE SEDIMENT

3.3.1. *Total Extractable Metals from the Sediment Grain Fractions*

Table III shows the total extractable metals from Tuskegee Lake sediments and other global published values for Lake sediments. Sediment sample obtained from Site 4 had the highest enrichment of cadmium, chromium, copper, iron, nickel and vanadium compared to Sites 1- 3. With the exception of zinc, the average values of cadmium, chromium, copper and lead in this study were higher than the corresponding values obtained for Lake Pontchartrain (Byrne and DeLeon, 1986) and St. Louis Bay sediments (Lytle and Lytle, 1980). However, the mean levels of cadmium and copper obtained in this study were comparable to previous reported

TABLE III

Mean of total extractable metals from Lake Tuskegee sediments and published mean sediment values in some countries (mg Kg^{-1} dry weight)

Element	LELs	Tuskegee Lake[a], AL, U.S.A.	Tuskegee Lake[†], AL, U.S.A.	Lake Pontchartrain[b] LA, U.S.A.	Calcasieu river/ Lake[c], LA, U.S.A.	St. Louis Bay[d] MS, USA MS, USA	Lake Zurich[e,f] Switzerland	Latvia Lakes[g], Latvia	Siberian Pond[h], Russia	Lake Macquarie[i], Australia
Cd	0.6	0.56 ± 0.72	0.94 ± 0.55	0.16	0.98	< 0.09	1.7	0.28–5.31	< 1.0	2.1 ± 0.2
Co		1.59 ± 1.17	< 3.0[‡]							
Cr	26	10.36 ± 6.49		6.33	19.1	7.98			61.13 ± 7.64	
Cu	16	6.84 ± 2.33	4.80 ± 1.33	5.33	6.91	6.38	37	1.33–16.34	20.5 ± 2.75	36 ± 3
Fe	2*	3011.2 ± 3165.5							21 ± 1.1**	
Mn	460	53.43 ± 38.16						14.28–81.17	671.5 ± 104.3	
Ni	16	8.94 ± 12.66	2.13 ± 0.56					2.04–13.27	30.1 ± 7.86	
Pb	31	14.84 ± 9.78	25.35 ± 5.21	7.83	9.90	12.24	97	6.64–83.21	16.67 ± 1.76	
V		9.14 ± 4.04								
Zn	120	8.72 ± 4.99	19.84 ± 3.6	24	35.6	47	232	15.32–78.43	115.8 ± 63.2	152 ± 32

* Unit: %; [a] This study, mean ± SD; [†] Khan *et al.*, 1995; [∫] wet weight basis, [‡] Unit = μg Kg^{-1}; [b]Byrne & DeLeon, 1986; [c]Berk *et al.*, 1990; [d]Lytle & Lytle, 1980; [e] Von Gunten *et al.*, 1997, [f] result for 1978 sediment core at a depth of 3.9 cm; ** unit in g Kg^{-1}; [g]Kļaviņš *et al.*, 1998 (range of means for 16 Lake sediments); [h] Gladyshev *et al.*, 2001; [i] Kirby *et al.*, 2001 (values reported for Wyee Bay); LELs: Lowest levels in Provincial. Sediment Quality Guidelines by the Ontario Ministry of Environment and Energy.

values by Khan *et al.*, (1995) for Tuskegee Lake sediments, but the values of lead and zinc reported by Khan *et al.* (1995) were twice the corresponding values obtained in this study (Table III). The average levels of cadmium, chromium, copper, and zinc in Calcacieu river/Lake sediments (Berk *et al.*, 1990) were also higher than the corresponding values obtained for these metals in this study. In another report, the mean copper (10.9 ± 1.2 mg Kg^{-1}), lead (21.1 ± 9.5 mg Kg^{-1}) and zinc (64.7 ± 21.4 mg Kg^{-1}), except chromium in the upper 2.54 cm of sediments taken from Lake Boeuf sediments Southern Louisiana (Aucoin *et al.*, 1999) were consistently higher than the corresponding mean values obtained for these elements in this study (Table III). Comparisons with Zurich sediments (Von Gunten *et al.*, 1997) also revealed that zinc, lead and copper values in Lake Zurich sediments were higher than the corresponding values for Lake Tuskegee sediments. Also report on the average values of cadmium, chromium, copper, manganese, nickel, lead and zinc in Siberian pond (Gladyshev *et al.*, 2001) were higher than the mean values obtained in this study. Similarly, the average values reported for Lake Marquarie sediments (Kirby *et al.*, 2001) with respect to cadmium, copper and zinc for all seven sampled locations were higher than the corresponding values in this study. The reported average values of cadmium, copper, manganese, nickel, lead and zinc in some Latvian Lakes (Kļaviņš *et al.*, 1998) were also higher than the average values obtained for these elements in Tuskegee sediments. Out of the sixteen Lakes studied by Kļaviņš *et al.* (1998), the percentages of Lakes that had mean sediment values higher than Tuskegee Lake mean sediments values were as follows: Pb (69%), Zn (100%), Cd (44%), Cu (50%), Ni (25%) and Mn (38%). Irrespective of depth of sampling, the levels of cadmium, cobalt, chromium, iron, manganese, lead, vanadium and zinc in Lake Baikal sediments (Grosheva *et al.*, 2000) were consistently higher than the corresponding values reported for these elements in this study. The high results posted for Lake Baikal was due to the history of industrial discharges into Lake Baikal in Russia. Finally, the sediment results in this study for cadmium, chromium, copper, iron, lead, manganese, nickel and zinc were lower than the Ontario (Canada) Ministry of Environment and Energy Provincial Sediment Quality Guidelines (PSQG) Lowest Effect Levels (LELs) for the above metals (Table III). The LELs indicates levels of sediment contamination by various elements that can be tolerated by the majority of benthic organisms (Ontario Ministry of Environment, 1993). We suggest that the relatively lower values obtained for Tuskegee Lake sediments relative to most Lake sediments already discussed may be due to the lesser impact of anthropogenic sources of pollution in the Tuskegee area.

3.3.2. *Effect of Grain Size on Metal Distribution*

The amount of total extractable metals increased generally with deceasing grain size (Table IV). Literature suggests that metals generally have relative potential for sorption onto clay minerals, hydrous oxides, and organic matter surfaces, all of which tend to be found in the smaller grain sizes (Salomons, 1980; Sager, 1992; Schoer, 1985).

3.3.3. *Chemical Fractionation of Metals in Sediments and its Environmental Implications*

Irrespective of sampling point and grain size fraction, the distribution of metals in the Tuskegee sediment samples generally followed the order below for the various metals studied.

Fe: residual > Fe/Mn oxides > organically bound > carbonate bound > exchangeable; Mn: exchangeable > carbonate bound > Fe/Mn oxides; V: Fe/Mn oxides > organically bound > residual; Cr: organically bound > residual > Fe/Mn oxides > exchangeable > carbonate bound; Cu: organically bound > Fe/Mn oxides > residual > carbonate bound > exchangeable; Zn: organically bound $\approx$ Fe/Mn oxides $\approx$ carbonate bound phases; Pb: carbonate > Fe/Mn oxides > organically bound; Ni: residual phase; Cd: carbonate $\approx$ Fe/Mn oxides $\approx$ organically bound $\approx$ residual phase; Co: exchangeable $\approx$ carbonate $\approx$ Fe/Mn oxides $\approx$ organically bound $\approx$ residual phase.

The study of the distribution of metals in the Lake sediments showed that the iron in Lake Tuskegee sediments existed largely in the sedimentary matrix (residual phase) and in the iron and manganese oxides phases (reducible species). The residual phase represents metals largely embedded in the crystal lattice of the sediment fraction and should not be available for remobilization except under very harsh conditions. Fe/Mn oxides exist as nodules, concretions, cement between particles, or as a coating on particles and are excellent trace element scavengers (Jenne, 1968).

TABLE IV

Grain Sizes versus Heavy metal concentrations in sediment fractions (mg Kg^{-1} dry weight)

	Site 1				Site 2			
Grain size[a]	< 710–250	< 250–75	< 75–53	< 53	< 710–250	< 250–75	< 75–53	< 53
Cd	0.1	0.2	0.6	0.6	0.0	0.1	0.0	0.3
Co	0.5	0.8	1.9	4.4	0.2	0.4	0.3	1.2
Cr	3.7	5.7	12.8	14.7	2.1	5.1	5.3	15.4
Cu	1.4	3.0	12.8	22.8	0.8	2.6	3.6	21.3
Fe	724.0	1576.7	3707.6	3807.4	221.7	631.1	547.8	1844.9
Mn	28.7	68.3	124.0	165.2	6.8	24.6	20.6	83.3
Ni	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pb	4.5	15.6	43.0	59.5	1.8	9.6	8.0	47.3
V	2.7	6.4	16.3	18.7	1.3	4.4	3.9	16.4
Zn	2.9	6.7	23.5	34.7	1.0	2.9	5.2	22.1

	Site 3				Site 4			
Grain size[a]	< 710–250	< 250–75	< 75–53	< 53	< 710–250	< 250–75	< 75–53	< 53
Cd	0.0	0.1	0.3	0.2	1.0	1.3	2.1	2.1
Co	0.7	1.3	8.3	3.7	0.5	0.6	1.2	1.2
Cr	2.9	4.7	9.2	9.5	11.9	16.1	25.4	26.7
Cu	1.1	1.7	5.6	5.6	3.2	4.5	11.8	16.7
Fe	561.9	1033.1	2097.6	1802.7	5414.0	6996.3	9091.0	9207.6
Mn	4.6	5.5	16.3	18.2	39.4	57.9	92.3	106.7
Ni	0.0	0.0	12.7	6.9	0.0	3.0	51.0	56.8
Pb	2.6	6.3	17.1	19.6	1.7	3.4	6.6	7.6
V	2.3	4.8	10.9	11.9	7.3	10.2	20.5	21.7
Zn	2.5	3.1	5.5	4.6	2.8	3.9	10.2	15.5

[a] Grain size in micron meter (μm).

Manganese and cobalt were largely associated with the exchangeable, carbonate and Fe/Mn oxides species in the sediment. Exchangeable species usually relates to the adsorbed metals on the sediment surface. Manganese and cobalt in exchangeable forms can be easily remobilized into the Lake water and the release of lead, cadmium, zinc, copper and iron into the water column may be reduced due to coprecipitation into carbonates. The carbonate fraction is influenced by pH and the observed pH of the sediments at Sites 1–4 ranged from 5.86–5.13, with Site 4 being the most acidic. Lead and cadmium distributed more as carbonates, Fe/Mn oxides and as oxidizable species (organic matter forms). Acidic pH condition is known to influence the sorption of lead by organic matter fraction in sediments (Baruah *et al.*, 1996). Copper, chromium and zinc existed mostly as oxidizable species and also as iron and manganese oxides forms (reducible forms). Under oxidizing conditions, metals present in both natural organic matter (due to complexation and peptization) and living organisms (as a result of bioaccumulation of metals) may be remobilized into the aquatic environment. Copper and chromium removal required strong acid condition hence their poor association with the carbonate and exchangeable phases. Nickel associated largely in the sedimentary matrix and may be less available for remobilization into the water column except under harsh conditions. Site 4 that is highly clayey in texture had higher enrichment of extractable cadmium, chromium, copper, iron, nickel, and vanadium.

Table V shows the individual (C_f^i) and global ($C_f = \sum C_f^i$) contamination factors for ten elements in the Tuskegee Lake sediments analyzed. The individual contamination factors (ICF) for the various sampling sites were calculated from the result of the fractionation study by dividing the sum of the first four extractions (i.e. the exchangeable, carbonate bound, Fe/Mn oxide forms and the oxidizable forms) by the residual fraction for each site. The global contamination factor (GCF) for each site was calculated by summing the ICF for all the ten elements obtained for a site. The ICF reflects the risk of contamination of a water body by a pollutant. The number of toxic elements determined in a sediment sample and their respective calculated ICF influences the GCF. The applicability of many toxic elements in calculating GCF is significant because it reflects the overall potential risks posed by the toxic elements to the lake environment and to biota. The higher the levels of the mobilizable fractions (i.e. exchangeable species, carbonate bound metals, Fe/Mn oxides species and organic matter bound metals) in the sediments, the higher the potential risk to Lake water contamination by Lake sediment. The remobilization of metals from Lake sediment into the water column will be influenced by factors such as pH, chemical forms of the trace elements, and the physico-chemical characteristics of the water column.

Sites 1 and 2 generally had higher individual and global contamination factors when compared to Sites 3 and 4. The high trend for Sites 1 and 2 may be attributed to the increased movement of contaminants downstream or towards the drainage point. A drainage point a few meters from site 1 helps to prevent local flooding of the Lake. Nickel, iron and cadmium posed the lowest risks to Lake water contamination. Lead and manganese posed the highest risks to water contamination followed by zinc, copper, chromium, cobalt and vanadium.

3.4. TRACE ELEMENTS IN TUSKEGEE FISH SAMPLES

Table VI shows the mean values of ten heavy metals (mg Kg^{-1} wet weight) in pooled liver, muscle, gills and backbone of bass samples collected from Tuskegee Lake and the open market in Atlanta, Georgia. Generally, the levels of heavy metals in the gills, liver and backbone irrespective of source of sample were higher than the result obtained for muscle, which is the most consumed part of fish. The higher level of trace elements such as lead and chromium in liver relative to other tissue parts may be attributed to the high affinity or strong coordination of metallothionein

TABLE V

Individual (C^i_f) and global (C_f) contamination factors of ten elements in Tuskegee Lake sediments

Site	Individual contamination factors (C^i_f)										Global contamination factor, $C_f = \sum C^i_f$
	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn	
Site 1	1.5 ± 1.0	5.0 ± 4.2	2.2 ± 0.4	4.2 ± 2.3	0.8 ± 0.2	29.6 ± 7.2	–	22.6 ± 8.2	2.7 ± 0.7	5.4 ± 3.1	73.9 ± 10.2
Site 2	1.1 ± 1.1	6.2 ± 4.4	6.3 ± 3.6	14.0 ± 10.4	0.9 ± 0.1	31.5 ± 8.7	–	37.1 ± 28.3	5.1 ± 1.2	6.4 ± 4.2	108.7 ± 13.0
Site 3	0.2 ± 0.2	7.1 ± 3.1	3.1 ± 1.4	2.8 ± 1.7	0.4 ± 0.2	2.5 ± 1.0	–	8.3 ± 1.4	3.4 ± 1.1	1.1 ± 0.5	28.9 ± 2.9
Site 4	0.2 ± 0.1	1.8 ± 0.4	0.7 ± 0.1	2.6 ± 1.4	0.3 ± 0.1	6.8 ± 2.5	–	1.8 ± 0.7	1.3 ± 0.1	1.87 ± 1.5	17.4 ± 2.0

TABLE VI

Mean (± SD) of heavy metals (mg Kg^{-1} wet weight) in Open market and Tuskegee Lake fish samples

Sample Collection	Tissue Type	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Largemouth bass: Open market (n = 3)	Liver	0.37 ± 0.08	0.04 ± 0.01	0.01 ± 0.01	20.49 ± 11.23	24.95 ± 6.65	0.66 ± 0.17	0.19 ± 0.33	0.11 ± 0.08	0.02 ± 0.02	56.69 ± 2.40
Mean age (yrs): 2.7 ± 0.6	Muscle	0.02 ± 0.03	0.01 ± 0.01	0.00 ± 0.01	0.14 ± 0.15	2.02 ± 0.35	0.12 ± 0.02	0.00 ± 0.00	0.04 ± 0.05	0.03 ± 0.02	3.45 ± 0.42
Mean weight (g): 540.7 ± 154.6	Gill	0.03 ± 0.04	0.01 ± 0.01	0.07 ± 0.07	0.65 ± 0.48	34.08 ± 4.65	2.78 ± 0.38	0.32 ± 0.33	0.04 ± 0.07	0.04 ± 0.04	22.35 ± 2.35
Mean Length (cm): 9.8 ± 0.8	Backbone	0.02 ± 0.03	0.00 ± 0.00	0.03 ± 0.03	0.43 ± 0.11	4.59 ± 0.45	3.71 ± 0.47	0.17 ± 0.26	0.03 ± 0.04	0.03 ± 0.02	22.29 ± 1.69
Striped bass: Open market (n = 3)	Liver	0.13 ± 0.01	0.02 ± 0.01	0.00 ± 0.00	42.36 ± 3.44	41.98 ± 14.20	0.34 ± 0.03	0.24 ± 0.20	0.27 ± 0.02	0.04 ± 0.00	36.84 ± 4.06
Mean age (yrs): 2 ± 0	Muscle	0.04 ± 0.02	0.00 ± 0.00	0.00 ± 0.00	0.51 ± 0.40	3.31 ± 1.99	0.14 ± 0.02	0.27 ± 0.06	0.12 ± 0.05	0.00 ± 0.00	3.76 ± 0.35
Mean weight (g): 630.6 ± 12.4	Gill	0.07 ± 0.02	0.02 ± 0.03	0.01 ± 0.02	0.64 ± 0.41	33.71 ± 0.60	1.25 ± 0.26	2.89 ± 1.77	0.21 ± 0.02	0.04 ± 0.00	15.11 ± 2.54
Mean Length (cm): 10.3 ± 0.3	Backbone	0.02 ± 0.02	0.00 ± 0.00	0.00 ± 0.00	0.35 ± 0.09	4.90 ± 1.47	2.02 ± 0.30	3.29 ± 5.04	0.14 ± 0.06	0.09 ± 0.03	16.46 ± 1.67
Largemouth bass: Tuskegee Lake (n = 3)	Liver	0.23 ± 0.08	0.15 ± 0.06	0.32 ± 0.16	2.18 ± 0.41	244.57 ± 95.61	1.69 ± 0.71	0.11 ± 0.20	0.02 ± 0.04	0.00 ± 0.00	21.90 ± 3.63
Mean age (yrs): 2.7 ± 1.2	Muscle	0.01 ± 0.01	0.01 ± 0.00	0.01 ± 0.02	0.32 ± 0.13	3.58 ± 0.54	0.19 ± 0.02	0.00 ± 0.00	0.02 ± 0.03	0.00 ± 0.01	6.01 ± 1.47
Mean weight (g): 613.4 ± 620.7	Gill	0.03 ± 0.02	0.00 ± 0.01	0.06 ± 0.08	0.22 ± 0.19	20.28 ± 22.39	2.58 ± 2.27	0.00 ± 0.00	0.06 ± 0.09	0.03 ± 0.05	13.94 ± 12.52
Mean Length (cm): 10.2 ± 2.9	Backbone	0.00 ± 0.00	0.00 ± 0.00	0.02 ± 0.03	0.17 ± 0.07	11.60 ± 9.05	5.05 ± 1.01	0.00 ± 0.00	0.04 ± 0.03	0.03 ± 0.01	20.27 ± 4.58
Health Criteria (mg Kg^{-1})				8	120				4		480
CCFAC ML (mg Kg^{-1})		0.5							0.2		
ULCs (mg Kg^{-1} wet weight)					10				1		40
FAO (mg Kg^{-1})		0.5			30				0.5		30

Health Criteria: US EPA, 1983; CCFAC ML (Codex committee on food additives and contaminants maximum levels; CCFAC, 2001); ULCs: Upper limits of concentrations by Russia (Federal Standards, 1989); FAO: FAO, 1983.

protein with these elements. In addition, the liver is the principal organ responsible for the detoxification, transformation, and storage of toxic materials and it is an active site of pathological effects induced by contaminants (Evans et al., 1993). The gills perform the function of respiration through oxygen uptake and exhalation of carbon dioxide and ammonia. The gills are directly in contact with water and pollutants that may also be present in water. Thus, the concentrations of metals in gills reflect the concentration of metals in the waters where the fish lives, whereas the concentrations in liver represent storage of metals (Roméo *et al.*, 1999). A variety of factors such as sex, age, season, spawning periods, choice of food by younger and older fish and variations in pollutants exposures across fish species may influence uptake, retention and bioaccumulation of contaminants in fish tissues.

The mean levels of chromium, copper, lead and zinc in gill, liver, muscle and backbone of fishes analyzed were below the health criteria established by the United States Environmental Protection Agency (US EPA) for human health risk for carcinogens (US EPA, 1983). The pooled mean copper levels in liver of striped (42.36 ± 3.44 mg Kg^{-1}) and largemouth (20.49 ± 11.23 mg Kg^{-1}) bass samples from the open market exceeded the 10 mg Cu Kg^{-1} upper limit concentrations (ULCs) by Russia (Federal Standards, 1989) and the European guideline (MAFF, 1995). Also the mean zinc levels in the liver of striped (36.84 ± 4.06 mg Kg^{-1}) and largemouth (56.69 ± 2.40 mg Kg^{-1}) bass samples from the open market also exceeded both the Food and Agriculture Organization (FAO) maximum limit of 30 mg Zn Kg^{-1} (FAO, 1983) and the European guideline of 50 mg Zn Kg^{-1} (MAFF, 1995). The pooled mean lead level in liver of striped bass samples was also higher than the Codex Committee on Food Additives and Contaminants (CCFAC) draft guideline of 0.2 mg Pb Kg^{-1} fish (CCFAC, 2001) and the pooled mean concentration of cadmium in liver of all bass samples irrespective of source were also higher than the CCFAC draft guideline of 0.05 mg Cd Kg^{-1} (CCFAC, 2001). According to the data obtained in this study and irrespective of source of fish, the mean lead levels in muscle of all species were below the maximum limits by the CCFAC (0.2 mg Kg^{-1}), FAO (0.5 mg Kg^{-1}), and MAFF (2 mg Kg^{-1}). Concentrations of metals in muscle tissues were also below the recommended maximum limits (Table VI) with respect to cadmium, copper, and zinc. Humans may face less risk from consumption of fish muscles but there may be concerns for individuals consuming fish livers.

The age of fish did not correlate significantly with cadmium ($r = 0.47$, $n = 9$, $P < 0.05$), chromium ($r = 0.52$, $n = 9$, $P < 0.05$), iron ($r = 0.46$, $n = 9$, $P < 0.05$) and nickel ($r = 0.41$, $n = 9$, $P < 0.05$) concentrations in liver. Also there was no significant correlation ($P < 0.05$) between lead concentrations in liver, muscle, gill and backbone with age. However, chromium correlated significantly with manganese ($r = 0.84$, $n = 9$, $P < 0.05$) and iron ($r = 0.83$, $n = 9$, $P < 0.05$) in liver. Manganese ($r = 0.81$, $n = 9$, $P < 0.05$) and iron ($r = 0.79$, $n = 9$, $P < 0.05$) both correlated significantly with zinc in the gills of fish. The levels of chromium ($r = 0.91$, $n = 9$, P

< 0.05) and vanadium ($r = 0.80$, $n = 9$, $P < 0.05$) in the gills correlated significantly with age of fish. There were also strong associations between cadmium and lead concentrations on one hand and between manganese and zinc in muscle of fish.

The result of the fish analysis was compared to other published values on largemouth bass. The mean levels of chromium (0.01 mg Kg^{-1}), copper (0.32 mg Kg^{-1}) and lead (0.02 mg Kg^{-1}) in this study were consistently lower than the corresponding values reported for chromium (1.99 mg Kg^{-1}), copper (1.18 mg Kg^{-1}) and lead (1.15 mg Kg^{-1}) in largemouth bass collected from Lake Boeuf in Southeastern Louisiana (Aucoin *et al.*, 1999). However, the mean zinc level (6.01 mg Kg^{-1}) obtained for Tuskegee Lake largemouth bass was higher than the reported mean value of zinc (4.62 mg Kg^{-1}) in Lake Boeuf bass samples. Zinc (3.38 mg Kg^{-1}), copper (0.10 mg Kg^{-1}), and manganese (0.04 mg Kg^{-1}) values reported by Lewis *et al.*, (2002) for largemouth bass in Blackwater river, considered a reference site and classified as an 'outstanding Florida water' (Northwest Florida Management District, 1992) were consistently lower than the corresponding values obtained in this study.

4. Conclusions

The health status of Tuskegee Lake with respect to water quality, risk to water column contamination by heavy metals in the Lake sediment and quality of fish caught from the Lake for human consumption were investigated in this study. The Lake water quality characteristics were mostly below the recommended drinking water standards by the United States Environmental Protection Agency (US EPA) and the European Union (EU) except for aluminum, iron, manganese and thallium. From the fractionation study, risk to water contamination was highest downstream (Sites 1 and 2) based on the calculated global contamination factors obtained for the Lake sediments. Based on the calculated individual contamination factors, manganese and lead followed by zinc, copper, chromium, cobalt and vanadium posed the highest risk to Lake water contamination. With respect to lead, chromium, copper and zinc, the human health risks for some carcinogens in largemouth bass from Tuskegee Lake are presently low. Also risks from consumption of fish muscles irrespective of source of fish are low since the levels of lead, cadmium, copper and zinc in fish muscles analyzed were all below their respective FAO permissible limits. However, humans consuming fish livers may face considerable risk from ingestion of toxic metals at unacceptable concentrations. The cost of treating source water obtained from Tuskegee Lake for municipal drinking water production will be less if contamination of the water column is minimal. Therefore, there is need to protect Tuskegee Lake from anthropogenic sources of pollution to reduce environmental risks and this study may provide valuable database for future research on Tuskegee Lake.

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