The Assessment Of Heavy Metal Pollution In Surficial Soils Of The Flint Creek And Flint River Watersheds: An Index Analysis Approach

Paul Okweye[1], Teferi Tsegaye[2], and Karnita Golson-Garner[2]

[1]Department of Chemistry and [2]Natural Resources and Environmental Sciences, Alabama A&M University, Normal, AL 35762

Introduction

Sedimentation due to erosion is a significant problem in Northern Alabama's rivers which leads to the contamination of the water and sediment with heavy metals and other pollutants. The overall surface water quality within the Flint Creek (FC) and Flint River (FR) watershed has been designated "fair" to "poor" (ADEM, 2002; Okweye, 2007). An Index Analysis approach such as Geo-accumulation Index (Igeo), Enrichment Factor (EF), Pollution Load Index (PLI) and Ecotoxicological Risk Assessment for sediment dwelling organisms using consensus-based sediment quality guidelines was used to assess the heavy metal pollution in surficial sediments of the Watersheds . No previous comprehensive study, to the author's knowledge, has outlined hazardous inputs of total recoverable elements from these polluted watersheds. The soil / sediment samples were analyzed using the EPA analytical method SW-6010B for total recoverable elements for environmental contaminants of concern (Al, Fe, Mn, As, and Pb). All metals analyzed for this study at both watersheds were statistically significant (at $P \leq 0.05$). The selected heavy metals were also studied to determine the presence of contaminants and extent of anthropogenic and lithogenic inputs from urban (FR) and rural (FC) activities.

*Corresponding Author:

E-Mail Address: paul.okweye@aamu.edu

Methods

MATERIALS AND METHODS

Sample Collection

Seventy-two soil/sediment samples were collected from six sites (upstream, midstream, and downstream from each watershed). Samples were transferred into EPA approved plastic bags and placed in a cooler at 4ºC and then transported to the Alabama A&M University Soil Physics Laboratory freezers for storage until processing and analysis. All soil/sediment samples for heavy metal analysis were sent to a United States Environmental Protection Agency (USEPA) approved laboratory - Environmental Testing and Consulting, Inc. in Memphis, Tennessee for analysis. The texture analysis was conducted at the University's soil physics laboratory. Overall, the mean percentage of the sand in sediments is 23.45%, silt 11.81%, and clay 64.74%.

DATA ANALYSIS

- Geoaccumulation Index, using Igeo = log2 (Cn/1.5Bn), (Fig. 4)
- Evaluation of the Enrichment Factors, using EFs = (Metal Concentration /Al in sediment) / (Metal Concentration /Al background average), (Fig. 5)
- Evaluation of the Pollution Load Index, PLI = n√(CF1 * CF2 * …* CF n), (Fig. 3)
- Ecological Risk Assessment (Fig. 1)

Results

Risk Effects of Sediment Metal Concentrations on Benthic Organisms of FC and FR watersheds

Risk Effects Conc	Sediment Metal Concentrations (mg kg^{-1})				
	Al	Fe	Mn	As	Pb
TEC[a]	NG	20,000	460	9.8	36
MEC[b]	NG	30,000	780	21.4	83
PEC[c]	NG	40,000	1,100	33	130
Ave. Conc	NG	20,450	1,531.67	10.48	35.67
Exceeded TEC (%)	NA	2.25	69.97	6.49	0
Exceeded MEC (%)	NA	0	49.08	0	0
Exceeded PEC (%)	NA	0	28.18	0	0

Figure 1. [a] Threshold Effect Concentration (TEC), [b] Mid-Point Effect Concentration (MEC), [c] Probable Effect Concentration (PEC), NG = No Guidelines, NA = Not Applicable, Red = Highly Significant Exceedances

Distribution of Total Heavy Metals in Surface Water and Soil/Sediment

		Heavy Metals in Surface Water (n = 96), mg/kg						Heavy Metals in Soil/Sediment (n = 72), mg/kg					
	Sites	Al	Fe	Mn	As	Pb	Sites	Al	Fe	Mn	As	Pb
Flint River	Upstream						Upstream					
	Ave	48.55	59.89	6.50	1.75	5.14	Ave	10,342.00	29,625.00	1,004.75	9.01	14.45
	Max	93.60	91.00	10.10	5.00	20.30	Max	14,300.00	33,800.00	1,140.00	13.20	17.50
	Min	8.00	20.00	4.00	ND	ND	Min	5840.00	14,000.00	908.00	5.41	10.50
	Midstream						Midstream					
	Ave	164.91	130.33	9.30	1.74	11.95	Ave	11,240.00	17,425.00	735.25	8.27	27.93
	Max	409.00	276.80	15.00	5.00	32.60	Max	10,900.00	18,800.00	1,190.00	15.20	57.90
	Min	28.00	32.00	7.00	ND	ND	Min	9,320.00	16,000.00	420.00	5.73	11.80
	Downstream						Downstream					
	Ave	131.31	167.10	20.84	3.30	29.91	Ave	21,000.00	19,900.10	1463.75	6.67	20.75
	Max	200.70	330.50	29.00	8.00	123.00	Max	25,800.00	25,600.00	1,820.00	8.21	28.70
	Min	80.00	45.00	13.00	ND	ND	Min	13,600.00	12,000.00	962.00	3.89	15.40
Flint Creek	Upper Reach						Upper Reach					
	Ave	142.85	193.16	27.045	1.85	7.79	Ave	11452	12442.50	862.90	3.93	13.29
	Max	221.30	340.20	47.60	4.50	34.10	Max	16500	21400.00	2010.00	6.76	17.60
	Min	41.00	51.00	10.30	ND	ND	Min	6290	5720.00	127.00	2.75	8.85
	Middle Reach						Middle Reach					
	Ave	122.65	185.94	46.96	0.85	9.26	Ave	10148	10725.00	9055.00	3.96	21.78
	Max	171.80	230.90	84.60	2.40	37.90	Max	12000	12200.00	1400.00	4.38	49.40
	Min	63.00	169.01	13.60	ND	ND	Min	8920	10100.00	626.00	3.63	11.80
	Lower Reach						Lower Reach					
	Ave	150.81	155.09	45.83	0.80	4.08	Ave	6622	7745.00	504.08	5.55	17.07
	Max	329.80	310.10	90.00	2.20	17.30	Max	9990	10900.00	1630.00	15.10	42.90
	Min	86.00	9.00	19.60	ND	ND	Min	5310	3300.00	56.40	1.21	4.83

Figure 2. Distribution of Total Heavy Metals in Surface Water and Soil/Sediment.

Contamination Factor (CF) and Pollution Load Index (PLI) For Flint River and Flint Creek Watersheds

	Site Code	PLI	Contamination Factor (CF) Al	Fe	Mn	As	Pb
Flint River	Upstream	0.459	0.081	0.906	1.088	0.440	0.580
	Midstream	0.333	0.127	0.369	0.683	0.214	0.590
	Downstream	0.596	0.294	0.492	1.971	0.272	0.973
Flint Creek	Upstream	0.362	0.187	0.381	0.728	0.181	0.662
	Midstream	0.323	0.138	0.237	1.286	0.141	0.590
	Downstream	0.264	0.112	0.196	1.095	0.103	0.514

Figure 3. CFs and PLIs for Flint River and Flint Creek

Geo-accumulation Factor Soil/Sediment Samples

	Site ID Code	Al	$Igeo_{Al}$	Fe	$Igeo_{Fe}$	Mn	$Igeo_{Mn}$	As	$Igeo_{As}$	Pb	$Igeo_{Pb}$
Flint River	Upstream - D (cont)	6485	NR	42750	NR	924.5	NR	12.5	NR	11.6	NR
	Upstream- U (ref)	14200	0.000595	16500	0.000624	1085	0.007075	5.52	0.441546	17.3	0.136724
	T & W** (ref)	80000	0.000106	47200	0.000218	850	0.007755	NR	NR	20	0.118257
	NASC*** (ref)	89000	0.000095	40000	0.000257	465	0.031894	28.4	0.858216	NR	NR
	Midstream - D (cont)	10120	NR	17450	NR	579.5	NR	6.075	NR	11.8	NR
	Midstream - U (ref)	12360	0.000719	17400	0.001215	891	0.006868	10.47	0.165822	44.05	0.053409
	T & W** (ref)	80000	0.000111	47200	0.000199	850	0.007224	NR	NR	20	0.119001
	NASC*** (ref)	89000	0.000101	40000	0.000236	465	0.013204	28.4	0.061313	NR	NR
	Downstream - D (cont)	23550	NR	23200	NR	1675	NR	7.725	NR	19.45	NR
	Downstream - U (ref)	18450	0.000525	16600	0.000582	1251	0.005708	5.6	0.351171	22.05	0.129446
	T & W** (ref)	80000	0.000121	47200	0.000206	850	0.008429	NR	NR	20	0.143213
	NASC*** (ref)	89000	0.000109	40000	0.000243	465	0.015412	28.4	0.069476	NR	NR

	Site ID Code	Al	$Igeo_{Al}$	Fe	$Igeo_{Fe}$	Mn	$Igeo_{Mn}$	As	$Igeo_{As}$	Pb	$Igeo_{Pb}$
Flint Creek	Upstream - D (cont)	14950	NR	18000	NR	618.5	NR	5.14	NR	13.23	NR
	Upstream- U (ref)	7955	0.001162	6885	0.001369	1106	0.005591	2.72	0.579604	13.35	0.186047
	T & W** (ref)	80000	0.000116	47200	0.000201	850	0.007298	NR	NR	20	0.124599
	NASC*** (ref)	89000	0.000104	40000	0.000236	465	0.013333	28.4	0.055631	NR	NR
	Midstream - D (cont)	11050	NR	11200	NR	1093	NR	4.005	NR	11.8	NR
	Midstream - U (ref)	9245	0.000969	10250	0.000875	718.5	0.009366	3.915	0.340909	31.75	0.074765
	T & W** (ref)	80000	0.000112	47200	0.000191	850	0.007944	NR	NR	20	0.119098
	NASC*** (ref)	89000	0.000101	40000	0.000225	465	0.014521	28.4	0.047152	NR	NR
	Downstream - D (cont)	8940	NR	9235	NR	930.5	NR	2.935	NR	10.28	NR
	Downstream - U (ref)	4305	0.002032	6255	0.001404	77.65	0.084677	8.155	0.126997	23.87	0.093819
	T & W** (ref)	80000	0.000109	47200	0.000187	850	0.007765	NR	NR	20	0.112444
	NASC*** (ref)	89000	0.000099	40000	0.000221	465	0.014194	28.4	0.036589	NR	NR

Figure 4.

Enrichment Factor Results Applied to Metal Normalized by Al for Flint Creek and Flint River Watersheds.

	Site ID Code	Al	Fe	Mn	As	Pb
Flint River	Upstream	5.78 Sig.E	2.48 Mod.E	0.00078 Dep.E	2.35 Mod.E	0.81 Dep.E
	Midstream	6.67 Sig.E	2.36 Mod.E	0.00095 Dep.E	1.24 Dep.E	0.32 Dep.E
	Downstream	4.45 Mod.E	0.405 Dep.E	0.00068 Dep.E	2.32 Mod.E	0.63 Dep.E
Flint Creek	Upstream	10.32 Sig.E	5.95 Sig.E	0.00077 Dep.E	4.78 Mod.E	1.05 Dep.E
	Midstream	8.85 Sig.E	4.02 Mod.E	0.00118 Dep.E	3.32 Mod.E	0.44 Dep.E
	Downstream	1.91 Dep. E	0.66 Dep.E	0.0109 Dep.E	1.59 Dep.E	0.58 Dep.E

Sig. E Significantly Enriched (EF = 5-10)
Mod. E Moderately Enriched (EF = 3-5)
Dep. E Depletion to Minimal Enrichment (EF < 3)

Figure 5. Enrichment Factor Results for Flint Creek and Flint River Watersheds

Results and Discussion

- All the heavy metals of concern were detected in all sediment samples for this study.
- Metals in bed sediments (depositional) was, in general, higher than in reference (upland) sediments.
- All the metals analyzed showed significant variation in average concentration (Fig. 2)
- Geo-accumulation Index classification, indicate that the two watershed areas are "moderately" polluted in Mn, As, and Pb, and "unpolluted to moderately" polluted in Al and Fe. The upstream (FR) would be ranked as "moderately to strongly" polluted in As, and, "moderately polluted" in Pb and Mn (Fig. 4).
- There was higher heavy metal contamination factor (CF), and pollution load index (PLI) for FR (Fig. 3), Results indicate that a human induced factor was responsible for about 90%, while about 10% was naturally induced (Fig. 3).

The results of the ecological risk assessment for the watersheds revealed that :

- Over 46% of the samples exceeded the TEC for all heavy metals
- Up to 90% of samples exceeded the PEC for Mn,
- while the Fe content exceeded the PEC in 12.5% of samples (Fig. 1).

Conclusions

- Flint Creek (FC) sediments have higher levels of environmental contaminants than Flint River (FR) sediments.
- Calculations for a multi-tiered assessment approach for the study and estimated degree of contamination was very high, indicating "serious" anthropogenic pollution.
- The increased anthropogenic influence, 90% in the Flint Creek and Flint River, has probably resulted in a reduction in benthic biodiversity, where pollutant-tolerant species may probably be found to take over the vacated niche.
- Long-term bioaccumulation of these contaminants can result in impacts, it should be cause for concern, and further study focusing on the impact assessment of heavy metals in the Flint Creek, and Flint River watersheds is needed.

Reference(s)

Okweye, et. al., 2007. Distribution of heavy metals in surface water of Wheeler Lake Basin. Journal of Envi. Monitoring and Restoration, vol. 33, pp. 91-100.

Acknowledgments

This study was supported by grants obtained from USDA Evans Allen and USDA-CSREES Southern Region Water Quality Project. The authors wish to thank Dr. Malinda W. Gilmore and Linda Skeete McClellan for their technical support.