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Variation in Sediment Heavy Metal Concentrations in West Point Lake Tributaries

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Abstract

Heavy metals are among the top three major contaminants within environmental pollution (Adki et al., 2014). In this study, sediment samples were collected from streams of varying surrounding land uses in LaGrange, Georgia. Sediment samples were tested for heavy metal concentrations and compared between forested and urban streams using a *t*-test to determine if there were significant differences in heavy metal concentrations between urban and forested streams. In this study, five heavy metals (calcium, chromium, magnesium, nickel, and zinc) were significantly higher in concentration in urban streams compared to the forested streams. However, based on previous literature, this does not appear abnormal for urban streams, as they are often more prone to runoff from highways and sidewalks. In addition to these five heavy metals, two replicates contained higher than average concentrations of cadmium. Cadmium is severely toxic to the body, and these high concentrations do appear alarming, although not all replicates from these sites had significantly high amounts of cadmium. Overall, urban streams appeared less healthy than the forested streams based on the significance of having higher concentrations of several heavy metals. Future studies should attempt to determine methods for reducing the concentrations of these metals in urban streams.

Introduction

Heavy metals are naturally occurring substances that are high in density and can be harmful to human health (Wei *et al.*, 1991). Heavy metals include mercury, cadmium, arsenic, chromium, lead, nickel, and zinc, to name a few. Some metals are of functional significance in the human body. For example, iron is an essential metal used in the hemoglobin of red blood cells to transport oxygen throughout the body (Gupta, 2014). Other metals, on the other hand, are classified as toxic and can lead to disease when present in higher concentrations. Cadmium, for example, can cause chronic obstructive pulmonary disease, emphysema, osteoporosis, hypertension, chronic damage to kidney tubules, and cancer to the lungs, kidneys, and pancreas (Vukićević, 2012). Lead is considered highly toxic, as it can affect children's brain development, and in high doses, lead can attack the nervous system and cause compulsions, seizures, and even death (Jiao *et al.*, 2016).

Heavy metals are nonbiodegradable, which means that they cannot be broken down in nature. Due to this, heavy metals will accumulate in the environment. Although they are naturally occurring elements, many compounds such as pesticides, solvents, and by-products from metal and chemical industries are also adding heavy metals into the environment (UNEP, 2007). Of all the diseases that face the world today, one quarter of those diseases are caused by environmental pollution (UNEP, 2007). Heavy metals are among the top three major contaminants to environmental pollution (Adki *et al.*, 2014).

Heavy metals found in the environment as a result of pollution make their way into the environment via several pathways, including surface runoff into streams and rivers and sediment transport (Heim and Schwarzbauer, 2013). Heavy metals may enter streams and rivers as a result of surrounding land use practices such as irrigation with contaminated water, industrial emission, and the use of fertilizers that contain metals. These heavy metals can lead to adverse effects in the organisms that live in the stream and then travel throughout the food chain.

Due to the strong link between streams and the surrounding landscape, streams are often classified by their surrounding land use. Typically, land use can be broken into distinctive categories such as urban, agricultural, and forested. Agricultural streams are streams that are at or near land used for agricultural use, such as those running alongside pastures or agricultural fields. These streams are at risk of contamination with heavy metals through activities related to agricultural use, including pesticides and fertilizer application. During precipitation periods, the contaminated soil within

Figure 1. Site photos of Long Cane Creek (a), West Point Lake tributary (b), Oseligee Creek (c), and Park Creek (d).

pastures and fields will run off into the nearby streams contaminating the streams with heavy metals from these agricultural practices. This results in heavy metal concentrations in agricultural streams often being significantly higher when compared to natural streams (Schulz 2001).

Urban streams are streams that run through cities and towns. Urban environments typically have much more impervious surface area relative to non-urban areass due to the paving of roadways and parking areas (Lepeška *et al.*, 2016). Increased impervious surface areas lead to an increase in the amount of runoff from these areas that often flows directly into surrounding streams. Urban streams frequently face contamination from oil leakage and wastewater from industrial buildings (Behbahaninia and Mirbagheri, 2008). Ewa Wojciechowska *et al.* (2019) found that when measuring heavy metal concentrations upstream and downstream from a surface runoff and stormwater retention tank, the downstream site was three times higher in certain heavy metals compared to the upstream site. Urban streams are often at a greater risk of exposure to some contaminants due to their proximity to industrial sites, whereas streams occurring in more rural or forested environments would not be exposed to these contaminants as readily.

Unlike urban and agricultural streams, forested streams do not have a point source for contamination of heavy metals. These streams occur in areas that are densely populated by plant species that make up a dense riparian buffer. Often human activities do not significantly impact forested streams because the riparian vegetation filters out contaminants before they can enter the stream. Heavy metals found in forested streams are often a result of certain plant species dying in the stream and allowing the heavy metals to accumulate after the decomposition of the species, or of contaminants that make their way into a given stream as a result of upstream runoff within the surrounding watershed.

Given the intricate linkage between overall stream health and the surrounding landscape and the variability in potential sources of heavy metal contamination, it is important to assess the degree of heavy metal variation among streams in relation to surrounding land use. The overall objective of this study was to assess the variation in heavy metal concentrations found in four different freshwater streams with varying land use, including urban, agricultural, and forested. We hypothesized that if sediment cores were taken from agricultural, urban, and forested streams, then there would be a significant difference in the heavy metal concentrations among the streamss with some heavy metals being more often associated with streams surrounded by certain land use.

Materials and Methods

Study Area

Four freshwater streams located in Troup County, GA (West Central GA, USA) were used as study sites (Fig. 1). These streams are all tributaries to the Chattahoochee River

Table 1. Values represent mean +/- 1 standard error (SE) for each in-stream site measurement.

Site	Width (m)	Conductivity (µS)	pH	Temperature (°C)	Dissolved Oxygen[1] (mg/L)
Park Creek	2.86 ± 0.53	145.3 ± 43.9	7.5 ± 0.05	12.13 ± 0.32	3.69
Oseligee Creek	2.3 ± 0.21	242 ± 0.57	7.56 ± 0.08	14.83 ± 0.33	9.09
West Point Lake Tributary	1.16 ± 0.34	42.46 ± 14.37	6.45 ± 0.19	14.2 ± 0.47	6.27
Long Cane Creek[2]	8.5	80.6	6.75	14.9	8.69

[1] Only one measurement was taken for dissolved oxygen at each site.
[2] Only one measurement was taken for all measures for this site.

and vary in their surrounding land use but are of similar size and order, with most being first-order streams. Long Cane Creek runs through farmland used for agriculture. The West Point Lake tributary is a forested creek located within Long Cane Park, a state park managed by the U.S. Army Corps of Engineers, and it is not in frequent contact with humans or urban runoff. Oseligee Creek and Park Creek are urban creeks that run through the city of LaGrange, GA.

Sample Collection and Processing

In the fall of 2019, three replicate sediment core samples were collected at each site using a multi-stage sediment sludge sampler (AMS, Inc., USA). Replicate cores were taken from the middle, left, and right of the stream channel along a 100-m reach at each site. Sediment samples were placed into labeled, sterile Whirl-pak bags, placed in a cooler, and returned to the lab, where they were then frozen at -20°C until processing. Stream water conductivity, pH, temperature, and dissolved oxygen measurements were taken at each site using Extech ExStik meters (Extech Instruments, USA), and the channel width at each sediment collection site was also measured.

Upon processing, samples were thawed, placed into a crucible, and placed into a drying oven and baked for 48 hours at 20°C to remove all moisture. Samples were then placed into sediment collection bags and submitted for total elemental analysis of priority pollutants via acid digestion through the Agricultural and Environmental Services Laboratory at the University of Georgia, College of Agricultural and Environmental Sciences (Athens, GA).

Data Analysis

All statistical analyses were performed using Jamovi (2019), and p-values less than 0.05 were considered significant. A principle component analysis was conducted to see how the samples were grouped based on their heavy metal profiles. A scree plot was created to discern how many principle components were required to explain the variation among the samples based on their heavy metal profiles.

Following this, and based on site surrounding land uses, study sites were grouped together as either urban or forested to allow for *t*-tests to compare heavy metal concentrations between the sites. Oseligee Creek and Park Creek were grouped together as urban sites, and Long Cane Creek and the West Point Lake tributary were grouped together as forested, since Long Cane Creek had a dense riparian buffer. *T*-tests were then performed comparing the heavy metal concentrations between urban and forested sites.

Results

Table 1 contains a summary of the site measurements for each stream. Both streams classified as urban showed conductivity and pH measures that were slightly higher than those of the streams classified as forested.

The results of the heavy metals analysis for each site are presented in Table 2. All heavy metal concentrations from all replicates, except two, were within normal range. However, one replicate from Park Creek and one from the West Point Lake tributary had higher than normal (>2.4 ppm) measures for cadmium.

Table 2. Mean ± 1SE concentration in parts per million (ppm) of each heavy metal measured in the sediment samples for each study site. Values listed as "NaN" or without SE represent an n<2 due to heavy metal concentrations below the detection threshold.

Site	Al	As	B	Ca	Cd	Cr	Cu	Fe
Park Creek	6398 ± 2037	NaN	39.8 ± 13	738 ± 127	1.67 ± 0.51	59.6 ± 19.9	9.33 ± 2.47	16612 ± 4901
Oseligee Creek	7205 ± 570	NaN	33.2 ± 4.96	797 ± 200	1.5 ± 0.18	35.3 ± 16.5	7.46 ± 2.88	15359 ± 2012
West Point Lake Tributary	8031 ± 2046	NaN	37.8 ± 7.91	217 ± 26.4	1.68 ± 0.36	19.3 ± 1.97	10.1 ± 0.72	17599 ± 3230
Long Cane Creek	3514 ± 1809	2.4	10.2 ± 0.19	211 ± 55	0.55	15.8 ± 5.6	4.88	4802 ± 58.9

Site	K	Mg	Mn	Mo	Na	Ni	P	Pb
Park Creek	146 ± 17	370 ± 27	324 ± 154	0.85	NaN	5.32 ± 1.54	222 ± 55.7	6.48 ± 2.29
Oseligee Creek	568 ± 209	1071 ± 76.2	254 ± 95.8	0.54 ± 0.02	69.1 ± 43.4	4.07 ± 1.3	83.5 ± 40.9	10.4 ± 1.34
West Point Lake Tributary	129 ± 44.7	211 ± 61.8	268 ± 52.7	0.787 ± 0.077	NaN	2.57 ± 0.36	191 ± 50.8	8.09 ± 2.11
Long Cane Creek	187 ± 45.5	287 ± 138	585 ± 268	0.52	NaN	2.15 ± 0.96	90.7 ± 30.3	4.01 ± 2.54

Site	S	Zn
Park Creek	60.1 ± 19.4	19.5 ± 2.44
Oseligee Creek	68.8 ± 31.7	26.5 ±3.36
West Point Lake Tributary	88.7 ± 1.73	18.2 ±1.37
Long Cane Creek	50.9 ± 10.6	8.37 ±1.87

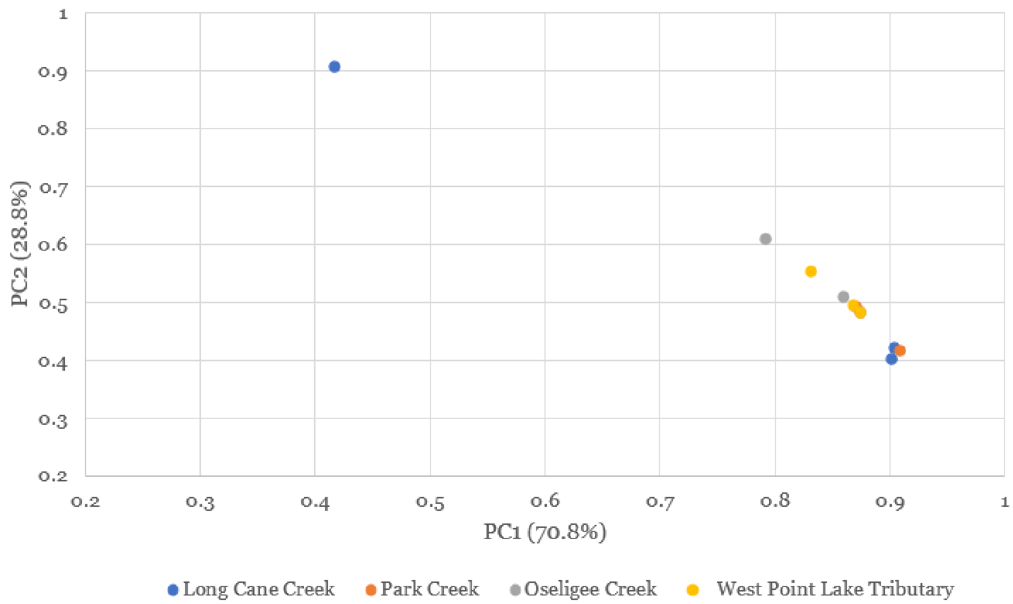

Figure 2. PCA plot of PC1 and PC2 created from heavy metal concentrations measured in stream sediment at each site.

The scree plot produced during the PCA suggested two components that explained approximately 99% of the variation, and the resulting PCA plot was created using PC1 (70.8%) and PC2 (28.8%) (Fig. 2). No clear pattern was discerned from the distribution of points based on PC1 and PC2.

The results of independent *t*-tests comparing sediment heavy metal concentrations in urban versus forested streams showed significantly different heavy metal concentrations for five of the heavy metals quantified. Calcium concentrations were significantly different between the two groups ($p<0.001$), with urban creeks having a higher concentration. Similarly, chromium ($p=0.045$), magnesium ($p=0.023$), nickel ($p=0.051$), and zinc ($p=0.018$) all showed significantly higher concentrations in urban streams as opposed to the more forested streams.

Discussion

Overall, all heavy metal concentrations were observed to be within the acceptable range except for the two sites in which one replicate at each had higher cadmium levels. Urban sites did show significantly higher measures for 5 additional metals when compared to forested sites. Wojciechowska *et al.* (2019) suggest that urban streams will naturally experience higher levels of heavy metal concentration, specifically in nickel, zinc, and chromium, which our results also indicated. This suggests that even though there was a significant difference between urban and forested streams, there likely would not be significance between different urbans streams regarding heavy metals. The increase of heavy metals in urban streams is likely due to the runoff from highways and sidewalks (Wojciechowska *et al*. 2019). Further research should be undergone to support these claims.

The PCA plot does not show separation of urban and forested streams based on their heavy metal profiles. This is likely because Long Cane Creek does suffer from contamination through upstream pollution and is near land used for agriculture. West Point Lake tributary has also had a known history of its water levels rising and lowering. This constant change could also lead to contamination in the stream at the site where we sampled. Pobi *et al.* (2019) discovered through their research that there were higher levels of heavy metals in streams right after the monsoon season compared to the dry season. They suggest that runoff from around the stream will cause contamination. This supports the claim of contamination of channel sediment via rising and lowering water levels in the West Point Lake tributary.

One replicate from Park Creek and one from the West Point Lake tributary had higher than normal (>2.4 ppm) measures for cadmium. Cadmium is highly toxic (Vukićević, 2012). According to the Water Quality Association (WQA), cadmium may contaminate streams through corrosion of galvanized pipes, erosion of natural deposits, discharge from metal refineries, and from waste batteries and paints (WQA, 2020). Park Creek is an urban stream, so it is more likely to suffer from the wastewater runoff, whereas the West Point Lake tributary may suffer from natural erosion, since this stream is forested. In addition, the West Point Lake tributary may receive inputs and deposits of heavy metals from West Point Lake during times of high-water levels, given that West Point Lake is a potential sink for surrounding runoff.

Overall, levels of heavy metals in streams should not stay elevated. If they do, then the aquatic community could suffer through heavy metal poisoning. The U.S. Environmental Protection Agency (EPA) has found several ways to reduce heavy metal concentrations in aquatic communities. One of these ways is through the usage of plants. Plants can be used to reduce wind and water erosion that spread materials containing heavy metals. Some plant species can absorb heavy metals and concentrate them in their tissues. Another way to decrease heavy metal concentrations in the stream is by adding chemicals to the soil that would create minerals with the heavy metals that would not be easily absorbed by plants, animals, or people (EPA, 2000). The heavy metal will stay in the environment, but it will be an adjuvant of a lesser harmful compound.

Additional studies to identify potential sources of the heavy metals found elevated in these specific sites would be beneficial and could be used to develop remediation methods to reduce the amounts of heavy metals entering streams. The data produced by this study also helps identify a potential subset of metals to target when doing heavy metal analysis so that researchers do not necessarily have to test for the full spectrum of heavy metals when examining the urbanization level of streams.

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