Effects of Zinc, Lead and Copper Concentration levels on the Distribution of Macro-Invertebrates: A Case Study of River Sosiani, Eldoret Town, Kenya

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Abstract

The relationship between zinc and copper concentration levels and the distribution of benthic macro-invertebrates in river Sosiani, Eldoret has been investigated. Atomic Absorption Spectrophotometry (AAS) and the Dip-net method have established the concentration of zinc and copper and the number of macro-invertebrates, respectively. The study showed that the concentration of both copper and zinc were higher than the threshold levels and that the macro invertebrate species were fewer in the more polluted regions of the river. Thus, zinc and copper concentration levels play a role in the distribution of macro-invertebrate.

Introduction

Effects of and inorganic pollutants on the distribution and abundance of macro-invertebrate communities have been widely studied in temperate and polar environments [1-3]. However, limited studies have been carried out in the tropical zone due to logistical problems and inaccessibility of most tropical riverine habitats[5, 6]. As a result, the rate at which macro-invertebrates are continually destabilized and eliminated is not clearly understood, yet the council on environmental quality has identified macro invertebrates as the most reliable indicators of riverine environmental changes[4, 8]. In Australia macro - invertebrates are used to assess the levels of heavy metals from industrial and municipal wastes in general and specific river pollution[9].

Studies on this have reported significant negative effects of these pollutants on macro-invertebrates communities[2]. Simulated laboratory experiments with these pollutants have reported similar massive die offs of macro-invertebrates. This indicates that inorganic materials (heavy metals such zinc, copper and lead) in fresh water systems contribute significantly to the loss of macro-invertebrates. Mason[6] reported that members of the same genus differ variably in the susceptibility to pollutants, some are tolerant while others gets eliminated in the presence of a particular type of pollutant. Hence the macro-invertebrate species was used as units of analysis in this study. In this study the concentration levels of copper, lead and zinc has been determined and this concentration correlated with the macro-invertebrate species in river Sosiani. This study provides valuable baseline information for assessing the impacts of copper and zinc pollutants on the macro-invertebrates of river Sosiani.

Materials and Methods

Sample Collection and Analysis

Field sampling was carried out in two phases. Phase one was done in April-1997 (end of dry season), while phase two was done in February-1998 (end of wet season). The river was divided into two zones: upper zone (region before the river enters Eldoret town) and the middle zone (region within Eldoret town). For each zone at least ten random stations were selected 1km apart and from each, three samples were collected in triangular pattern[14]. From each station, macro invertebrates were sampled by scooping at least six times at different points using D-Shaped dip-net and then identified using the standard keys[9]. Filtration was done immediately the samples were brought to the laboratory and then preserved by addition of 0.2 ml concentrated hydrochloric acid by 50 ml of water.

The acidification prevents lose of trace elements by adsorption into the walls of polyethylene container. The samples were analyzed using Computer interfaced CTA2000 Atomic absorption spectrophotometer (AAS). Data obtained were analyzed using SPSS and Excel spreadsheet data packages.

Results

Heavy Metals in Water

Levels of Pb, Cu, and Zn in water varied from one station to another and among seasons (Tab.1). Ambient metal concentration showed only moderate variation among stations in the wet season but were greatly elevated at stations downstream from site A in the dry season. Zinc was the dominant metal measured at each station on both sampling occasions. Considerable seasonal variation in metal concentrations was observed at stations downstream from site A. Levels of Pb, Cu, and Zn were ten times higher at site B in the dry season than in the wet season and remained elevated at site B in the dry season.

Table 1. Concentrations µg/l of metals (soluble) in water at three sites on the Sosiani River, in the wet (February 1998) and dry (April 1997) season

Station	DRY Lead	Copper	Zinc	WET Lead	Copper	Zinc
SITE A	0.0	8.0	63.0	0.0	2.0	29.0
SITE B	25	20.0	4480.0	36.0	12.0	416.0
SITE C	15	12.0	3750.0	34	6.0	275.0

Zinc

Site A was located before the river passed through Eldoret town (from CPC industry up-stream). This was the Control Site). Site B was within town whereas Site C was located downstream after the town (from Huruma down-stream). If effluent from town contributed to changes in the water chemistry, one would expect an increase in all levels of elements in site B compared to either site A or B.

Analysis of Zinc in water was in general agreement with this hypothesis (F=256.258, df = 9, $p<0.001$). There was a clear difference between site A and either B or C. The changes in B and C showed that Zinc concentration declined downstream from town after a distance of more than 1 km (Fig.1). This observation was similar in both seasons. However, it was clear that more Zinc deposits were found in water during the dry season within or after the river passed town.

Copper

The trend in copper was similar downstream. Less copper concentration occurred in site A. Site B had more concentration than site C

(F=296, df=9, $p<0.05$), strongly suggesting that the source of copper was from industrial effluents, sewage and other domestic waste (Fig. 2). The concentration of copper ions was higher in wet season compared with dry season for sites B and C. This was not the case with site A, indicating that the copper in site A was representative of "normal" copper ions in the unpolluted Sosian River.

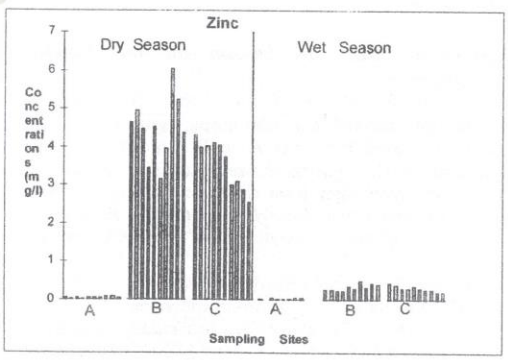


Fig. 1: Comparison of the levels of zinc (ppm) in 10 stations of experiments sites A and B during the wet and dry seasons in River Sosiani, (April, 1997 to Feb., 1998)

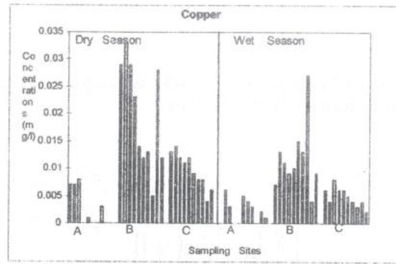


Fig. 2 Comparison of the levels of copper (ppm) in 10 stations of experimental Sites A and B during the dry and wet seasons in River Sosiani (April, 1997-February, 1998)

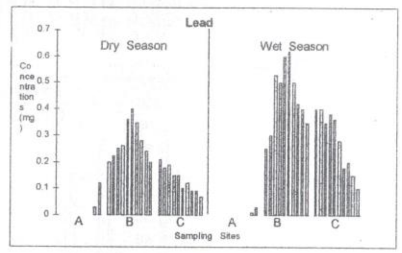


Fig. 3: Comparison of the levels of Lead (ppm) in 10 stations of experimental Sites A (control), B and C during the dry and wet seasons in River Sosiani (April 1997 to February, 1998).

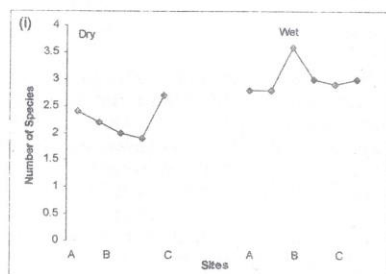


Fig. 4 Numbers of Species (i) and individuals (ii) at the three sites on the Sosian River in the dry (April 1997) and wet season (February 1998). Data are means ±1.0 SD seasons

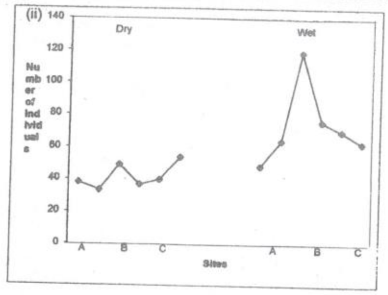
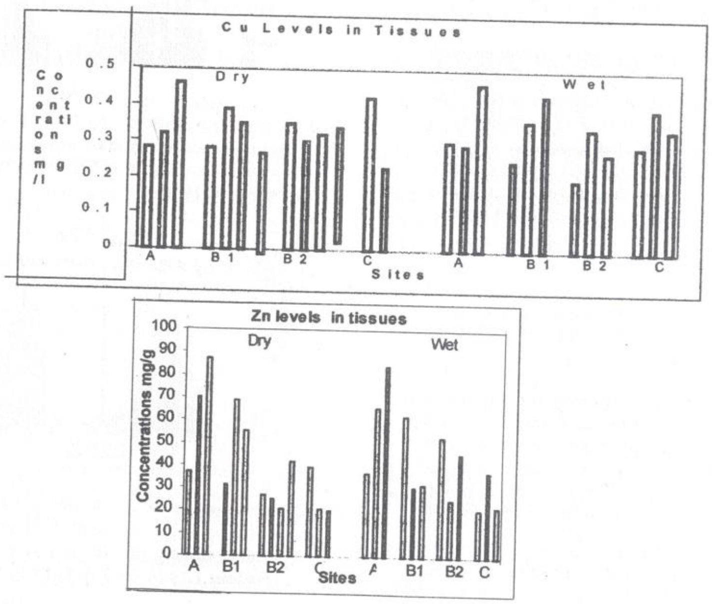


Fig. 5 Concentrations of Pb, Zn, and Cu in *ishnura elegans* at three sites on the Sosian River in the dry (April 1997) and wet (February, 1998) seasons



Bioaccumulation of Metals by Benthic Invertebrates

Levels of Pb, Cu, and Zn in benthic invertebrates were significantly elevated at stations downstream from site A during both seasons (Fig.5). Although metal concentrations decreased at site C, concentrations remained elevated above site A values at this downstream station on several occasions. Considerable variation in metal concentrations among individual organism was observed. During seasons, Pb, Cu, and Zn levels were generally much higher in site B than in the two sites A and C. Seasonal variation in benthic invertebrates was observed, but this variation was not necessarily related to ambient concentrations.

Effects of Site and Season on the Macro-Invertebrates

Analysis of the effects of site (Table 2) on macro-invertebrates showed that, the mean number for most species increased from site A to B (highest) and then decreased to C. *Baetis rhodan* and *Ishmular elegans* showed the most significant difference among the three sites. At the same time, *Isoperlagramatica* and *Ecdyonurus venusus* showed the least mean number of species in site B.

From Table: 3, one could clearly note an overall increase in the mean number of most macro-invertebrates from the dry to the wet season. Particularly *Baetis rhodan, Dineutus sp* and *Hydropsyche instabilis* ($F=6.558$, $F=18.40$ and $F=18.405$, $df=1$ and $p<0.05$) being the most significantly different. Exceptions are *Isoperlagramatica* and *Ecdyonurus venusus* ($F=0.671$ and $F=2.475$ at $df=1$ and

$p<0.05$) that showed a decreased mean number of species from the dry wet season.

Table 2: Mean number of selected macro-invertebrate species at the three sites on the Sosiani River in the dry (April 1997-June 1997) and wet (December, 1997- February 1998) periods

SPECIES	SITES			F	df
	Site A	Site B	Site C		
Ishnura elegans	2.700	6.250	3.600	4.153 *	2
Hydropsycheinstabilis	3.350	4.400	3.350	0.342	2
Baetis rhodan	0.600	1.700	1.900	3.766 *	2
Isoperlagrammatica	3.650	0.000	0.900	2.127	2
Ecdyonurus venusus	0.550	0.150	0.800	2.217	2
Chironomus thummi	0.000	5.00E-02	0.100	1.024	2
Corixa dorsalis	5.0E-02	0.000	0.200	1.247	2
Dineutus sp	0.150	0.650	0.350	2.643	2
Caenis maesta	0.000	0.000	0.200	3.027 *	2

* -Indicates significance of $p<0.05$.

Table 3: Mean number (± 1 SE) of selected macro-invertebrate species at the two seasons in the Sosiani River in the dry (April 1997-June 1997) and Wet (December, 1997- February 1998) periods

SPECIES	SEASON		F	df
	Dry	Wet		
Ishnura elegans	3.633	4.733	1.106	1
Hydropsyche instabilis	1.133	6.267	18.405 *	1
Baetis rhodan	0.867	1.933	6.558 *	1
Isoperlagrammatica	2.133	0.900	0.671	1
Ecdyonurus venusus	0.700	0.300	2.475	1
Chironomus thummi	6.67E-02	3.33E-02	0.341	1
Corixa dorsalis	0.000	0.166	2.397	1
Dineutus sp	0.000	0.767	18.400 *	1
Caenis maesta	0.000	0.133	3.027	1

* -Indicates significance of **$p<0.05$.**

Table 4: The table shows the Pearson correlation (r-values at, $p<0.05$) between the Concentration levels of the pollutants and the total number of Macro-invertebrates at various sites and seasons

	Pollutant	Site	Season	r values	r values
Heavy Metals	Zinc	A	Wet	0.053	0.053
			Dry	-0.003	-0.003
		B	Wet	-0.34	-0.34
			Dry	-0.71*	-0.71*
	Copper	A	Wet	0.057	0.057
			Dry	0.024	0.024
		B	Wet	-0.391	-0.391
			Dry	-0.057	-0.057

* -Shows significance level of $p<0.05$

Discussion

Pollutant concentration levels

Analysis of ambient pollution levels, bioaccumulation and benthic community structure suggested that pollutants at site B impacted the Sosian River. At site B, the mean concentrations were higher during the dry season than during the wet season (Table 1). The slightly low mean concentration of zinc during wet season in the two sites could be attributed to the dilution effect of the large volume of rainwater[5]. The concentrations of zinc in site B were much higher than the threshold levels for the benthic community, less than 100 ug/l[4]. This could be attributed to the disposing of untreated industrial and municipal effluents into the River.

The mean concentrations of copper during both dry and wet seasons did not significantly differ within site A, (Fig.2). Though they slightly differed between sites A and B (Fig. 2), whereby in site B copper concentrations were also above the threshold levels (greater than > 10 ug/l) as in zinc. Comparing the two seasons the Lead concentrations appeared to be more elevated during the rain season (Fig.3). These could be attributed to the wash-off from the mechanic garages, 'Jua' Kali sheds and some from the industries.

Bioaccumulation of Metals by Benthic Invertebrates

Benthic communities at stations downstream within B and C were highly contaminated by heavy metals. These results support findings of other researchers and demonstrate that levels of metals in benthic invertebrates are good indicators of potential impacts[8]. In a more comprehensive survey of metal contamination in benthic communities at Sosian River, we found that metal levels in benthic invertebrates were poorly correlated with ambient levels[10], suggesting that water was not the primary route exposure to these organisms[11]. Alternatively, the ability of some benthic invertebrates to regulate essential metals[12], particularly at higher concentrations, may explain this poor relationship.

Benthic Community Structure

Assessment of the effects of metals on benthic structure was dependent on which community level measure was employed. Several researchers have reported that reduced species richness and abundance are indicative of heavy metal impact in lotic ecosystem[12]. These measures were especially useful at the Sosian river in both the wet and the dry seasons, as the number of species was not similar at sites A, B and C as the number of individuals significantly increased downstream to B then reduced slightly at C. The sensitivity of species richness and abundance to pollutant impact during the dry season was as a result of high pollutant concentration levels. This led to the replacement of sensitive organisms (e.g. *hydropsyche instabilis*) by tolerant organisms (e.g. *Ishnura elegans*).

The high number of individuals during the wet season also could be attributed to the low concentrations of the pollutants due to dilution[13]. For example whereas the numbers of species *hydropsyche instabilis* was significantly greater during the wet season than the dry downstream (6.26 ± 0.846 vs 1.133 ± 0.062, $p<0.03$), the number of species of *Ishnura elegans* was not significantly different in the two (4.733 ± 0.739 vs 3.633 ± 0.739). These result demonstrated that measures of total richness and abundance were sensitive to pollution by heavy metals and did reveal important changes in community structure.

Changes in composition of dominant macro-invertebrate group also resulted from replacement of sensitive organisms by tolerant organisms downstream from site A to B. In general, abundance of *hydropsyche instabilis* did not increase significantly, with a concomitant significant increase in abundance of *Ishnura elegans*. Previous studies have reported that similar shifts in percentage composition of these groups are indicative of metal impact[13-18]. It can be concluded that the composition of benthic communities at Sosian River was an indicator of pollution impact than species richness or macro-invertebrate abundance[10].

Integrated Assessment of Pollution Effects

Relating the ambient pollutant concentration levels, tissue concentrations and benthic community structure, there was some good light on the degree of impact of metals from site A to site B and from dry to wet seasons. The correlation analysis values between the ambient levels and the number of benthic invertebrates were low, suggesting that there were other factors that influenced the distribution of macro-invertebrates families. Though, the results of this study indicated that pollution had a stronger effect on macro-invertebrate families relative to other forms of disturbance cited by Hayward[5]. He had observed that macro-invertebrates families were more stable during the dry season due to factors such as reduced stream dislodgment and sufficient food supply resulting from reduced flooding and shifting community structure.

Measurement of ambient metal and organic pollution concentrations revealed spatial patterns of metal distributions (e.g. upstream to downstream) and indicated a strong seasonal component to pollutant inputs. Elevated metal concentrations in benthic organisms and altered benthic community structure at site B clearly indicated that this site was impacted. Because of temporal variability in ambient concentrations, community structure and metal levels in benthic communities may be better indicators of impact than either ambient metal level. We suggest that a more frequent sampling program is necessary to characterize temporal variability in these systems. In contrast, to the ephemeral conditions in water, benthic communities integrate changes in exposure conditions over time and provide a continuous monitor of water quality[12].

Stream bio-monitoring of benthic invertebrate communities are frequently employed to assess impacts of contaminants over time. The major limitations of in-stream studies, particularly those involving comparisons of upstream and downstream stations include the difficulty locating reference sites, selecting appropriate end points (metrics)[8], and establishing a direct cause-and-effect relationship between contaminant levels and selected end points[11-13]. Furthermore, assessing contaminant impacts on lotic systems is complicated by seasonal variability. For example, many western streams undergo dramatic increase in discharge during the period of spring runoff, resulting in significant changes in water quality. Good agreement between predicted toxicity and observed ecological effects has been reported, particularly in situations where ambient toxicity is relatively high[10].

Conclusion and Recommendations

In the current study, measurement of metals in benthic invertebrates and assessment of benthic community structure provided additional evidence that downstream sites B and C were impacted. The levels of the heavy metals; Pb, Zn, and Cu levels were above threshold levels. The levels were extremely elevated during the dry season than during the wet season. From this study it could also be concluded that pollution levels in urban streams increased with increasing population. The source of pollutants Pb, and Zn, seemed to be from the town (municipal wash-off) and industrial effluents.

Variability in metal concentrations among species and absence of species from some sites may limit the use of bioaccumulation studies for monitoring metal impacts. The predator dragonfly *Ishnura elegans* was abundant at Sosian River. Because of its large size, metal levels in individual organisms could be measured.

This study indicates that pollutants affect the distributions and abundance of macro invertebrate fauna. Different species respond differently to different pollutants whose concentrations are similarly influenced by weather pattern's seasonality. In this study *Ishnura elegans* appead to be pollutant resistant as compared to *Hydropsyche instabilis* which was so vulnarable during the dry season in the highly impacted regions of the river. However, there is need for a long term study of a dominant species to ascertain conclusively the type of pollutant affecting it and the role of other forms of pollution on its diversity. We therefore recommend *Ishnura elegans* as an appropriate species for monitoring metal bio-availability and contamination at Sosian River. And also for this study to more conclusive at least three years should be set a side for it. Whereby, seasonal pollutant variations and the corresponding macro-invertebrate change downstream for at least three seasons.

Future studies should focus on the study of pollutant sediment levels and correlation with the invertebrates existing there. Also Studies of the speciation of the heavy metals in river Sosiani, the effects of pollutants (heavy metals) on the Amphibians of the Sosian River; and *Ishnura elegans or Hydropsyche instabilis* in relation to pollution could be carried out.

This information is crucial to management and quality control of Sosiani River, which is an important source of domestic water supply.

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