Effects of Inorganic Pollutants on the Distribution and Abundance of Macro-Invertebrate Communities in River Sosiani

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The relationship between the concentrations of lead, zinc and copper on the distribution of benthic macro-invertebrates in River Sosian 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 concentrations of the pollutants were higher than the threshold levels and that the macro invertebrate species were fewer in the more polluted regions of the river. Thus, lead, zinc and copper concentration levels play a role in the distribution of macro-invertebrates.

Key words: benthic, macro-invertebrates, Dip-net, inorganic pollutants, habitat, organism.

INTRODUCTION

Effects of inorganic pollutants on the distribution and abundance of macro-invertebrate communities have been widely studied in temperate and polar environments (Owen, 1976; Ewer and Hall, 1978; Anderson, 1983; Barton, 1989). However, limited studies have been carried out in the tropical zone due to logistical problems and inaccessibility of most tropical riverine habitats (Hayward, 1992; Mason, 1994). 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 (FAO, 1994; Gower and Darlington, 1990). In Australia macro - invertebrates are used to assess the levels of heavy metals from industrial and municipal wastes in general and specific river pollution (Welch, 1992).

Studies on this have reported significant negative effects of these pollutants on macro-invertebrate communities (Parker and Hamr, 2001; Mackay et al., 2002; Barton, 1989). Simulated laboratory experiments with these pollutants have reported similar massive die offs of macro-invertebrates. This indicates that inorganic materials (heavy metals such as zinc, copper and lead) in fresh water systems contribute significantly to the loss of macro-invertebrates. Mason (1994) reported that members of the same genus differ variably in the susceptibility to pollutants; some are tolerant while others get eliminated in the presence of a particular type of pollutant. Hence, macro-invertebrate species can be used as units of analysis. In this study concentration levels of copper, lead and zinc have been determined and these levels are correlated with the macro-invertebrate species in River Sosiani. Thus, valuable baseline information for assessing the impacts of the heavy metal pollutants on the macro-invertebrates of the river is presented.

Materials and Methods

Sample Collection and analysis

Field sampling was carried out in two phases. Phase one was done in April-2003 (end of dry season), while phase two was done in February-2004 (end of wet season). The river was divided into two zones: upper zone (region before the river enters Eldoret town), that is the Kaptagat area up to just before KCC and the middle zone (region within Eldoret town), which is from KCC to lower Huruma. For each zone at least ten random stations were selected 1 km apart and from each, three samples were collected in triangular pattern as described by Poulton et al. (1995). Thus, sampling points were spread over a distance of 20 km. 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 (Welch, 1992). Filtration was done to separate water samples from macro-invertebrates. The water samples were immediately taken to the laboratory and preserved by addition of 0.2 ml concentrated hydrochloric acid and diluted by adding 50 ml of water.

The acidification prevents lose of trace elements by adsorption into the walls of polyethylene container. Micro-invertebrates were crushed, air dried and sieved through a 0.2 mm sieve as described by Okalebo et al. (1998). Accurately weighed 0.3 g of the ground samples were transferred to a digestion tube. About 4.4 ml digestion mixture, which had been prepared by taking 0.42 g selenium powder and 14 g of lithium sulphate that previously had been added to 350 ml 30% of conc. sulphuric acid was added slowly with care while cooling in an ice bath was added. Digestion was done at 360 ^{0}C for two hours in a block digester. The solution was allowed to cool and 50 ml of distilled de-ionized water added and the mixture well mixed to dissolve samples completely. The solution was made up to 100 ml with thorough mixing and allowed to settle for analysis using computer interfaced CTA2000 atomic absorption spectrophotometer (AAS) (WHO, 2006; Csuros, 2006). Data obtained were analyzed using SPSS and Excel spreadsheet data packages.

Results and Discussion

Heavy Metals in Water

Levels of Pb, Cu, and Zn in water varied from one station to another and change in season as can be shown in Table1.

Table 1. Concentration (μg/l) of metals (soluble) in water at three different sites along the Sosiani River during both the wet (February 2003) and dry (April 2004) seasons.

	DRY			WET		
Station	Lead	Copper	Zinc	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

Ambient metal concentration showed only moderate variation among stations in the wet season but was 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 the heavy metals were higher at site B and particularly zinc, which was ten times higher in the dry season than in the wet season and remained elevated at site B in the dry season.

From Table 1, site A, which was the control, was located before the river passed through Eldoret town (from CPC industry up-stream). Site B was within town whereas site C was located downstream after town (from Huruma down-stream). If effluents 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 C.

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 sites A and either B or C.

Figures 1, 2 and 3 show the variation of heavy metals down stream at different stations. Zinc concentrations declined downstream from town after a distance of more than 1 km with changes in B and C. The same observation was noticed in both seasons. However, it was clear that more zinc deposits were found in river water during the dry season within or after town. A similar trend downstream was observed for copper as shown in Fig. 2.

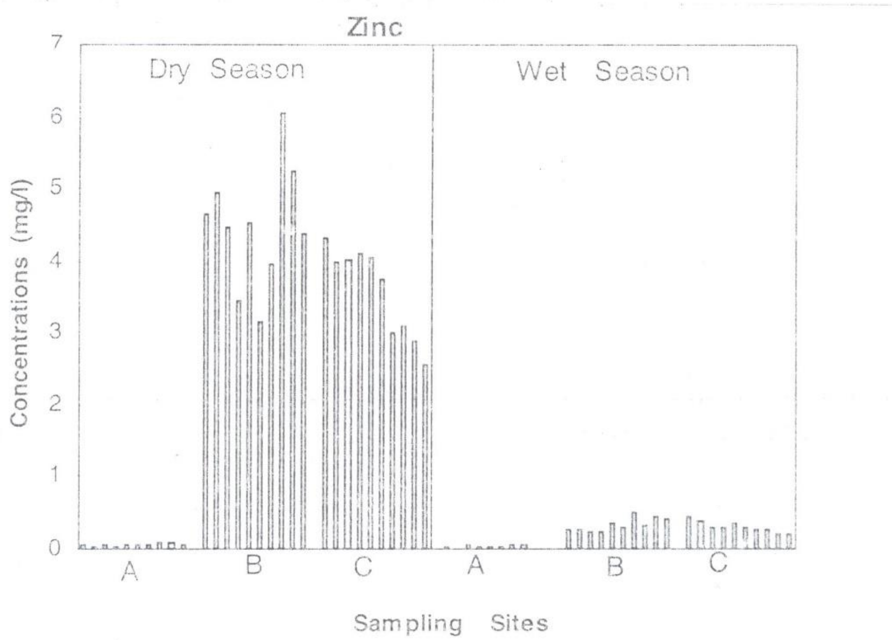

Fig. 1: Comparison of the levels of zinc (ppm) in 10 stations of experimental sites A and B during the wet and dry seasons in River Sosiani, (April, 2003 to Feb., 2004)

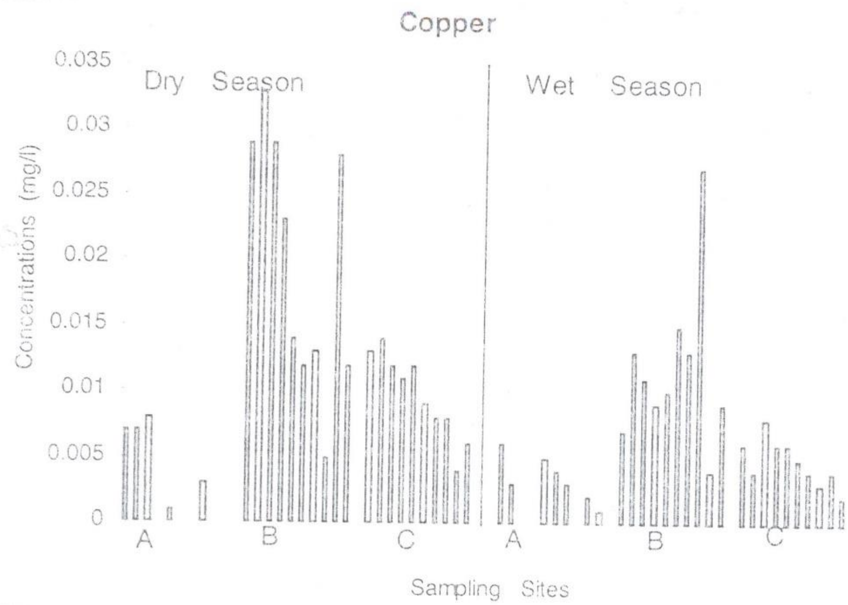

Fig. 2. Comparison of the levels of copper (ppm) in 10 stations of experimental Sites A and B during the dry and wet seasons in River Sosiani (April, 2003- February, 2004).

From Fig. 2, less copper concentration occurred in site A while 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 wastes. The concentration of copper ions was higher in wet season than in dry season for sites B and C, unlike in site A, indicating that copper in site A was representative of "normal" copper ions in the unpolluted Sosian River.

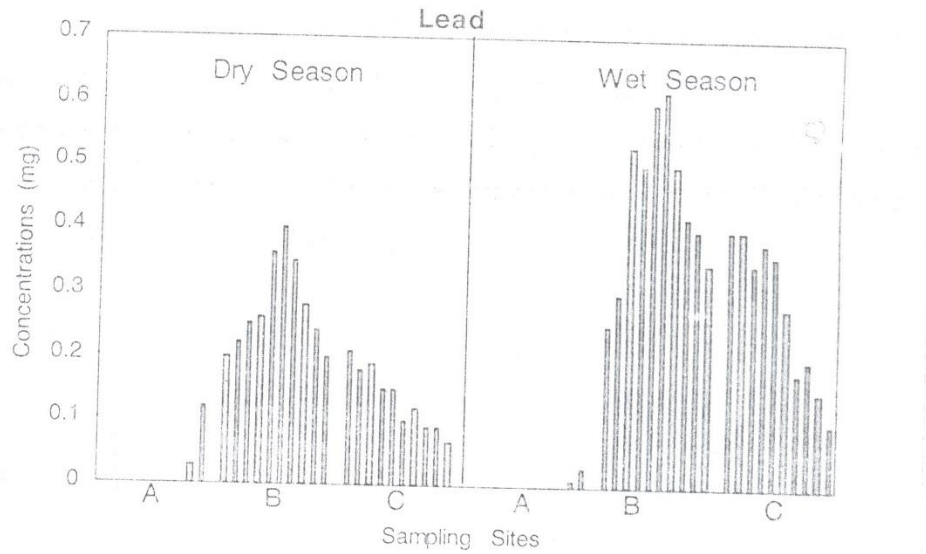

Fig.3: Comparison of the levels of lead (ppm) in 10 stations of experimental Sites A (control), B and C during the dry and wet seasons in River Sosiani (April 2003 to February 2004)

From Figure 3 it was observed that lead levels increased downstream, especially at site B ($F = 312$, $df = 9$, $p<0.05$), suggesting that pollution is associated with several activities that take place in town. Lead levels at points B and C were highly elevated in wet season due to runoff. High levels of lead were also reported in tissues.

Bioaccumulation of metals by benthic invertebrates

4 (a), (b), (c) show levels of the heavy metals in benthic invertebrates.

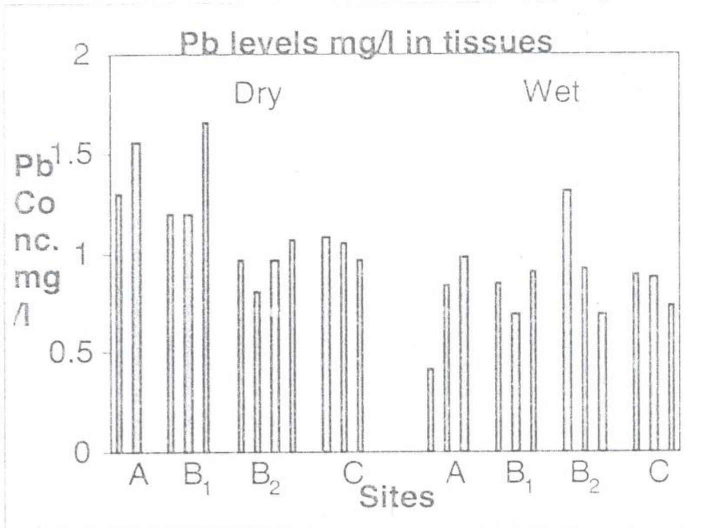

Fig.4 (a): Concentrations of Pb in *ishnura elegans* at three sites on the Sosian River in the dry (April 2003) and wet (February, 2004) seasons

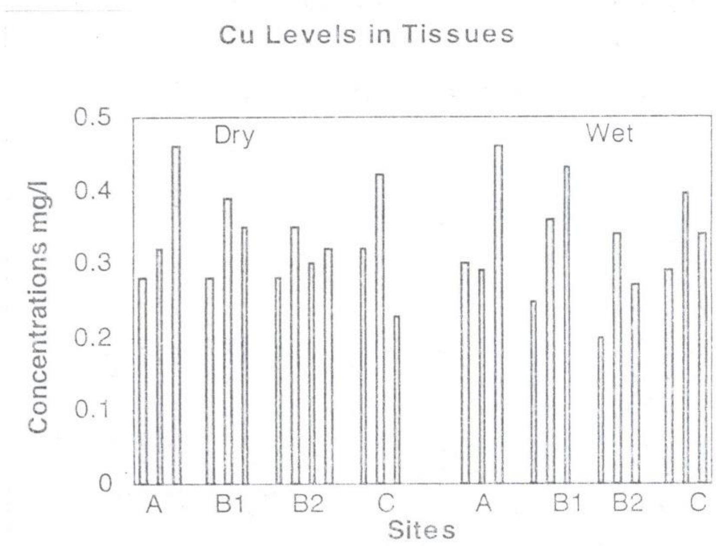

Fig.4 (b): Concentrations of Cu in *ishnura elegans* at three sites on the Sosian River in the dry (April 2003) and wet (February, 2004) seasons

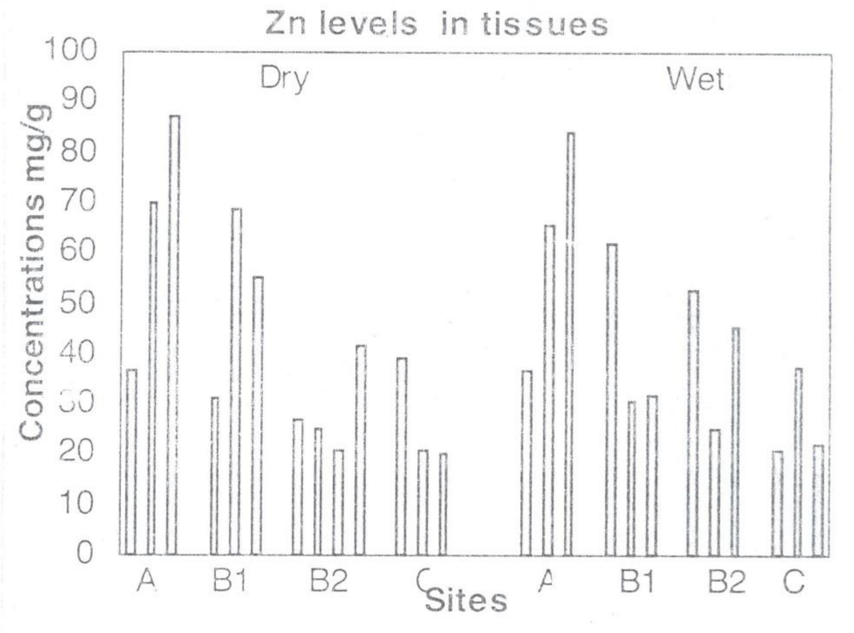

Fig.4(c): Concentrations of Zn in *ishnura elegans* at three sites on the Sosian River in the dry (April 2003) and wet (February, 2004) seasons.

It is clear from Fig.4 that levels of Pb, Cu, and Zn in benthic invertebrates were significantly elevated at stations downstream from site A during both seasons. Although metal concentrations decreased at site C, the levels remained elevated above site A downstream on several occasions. There was considerable variation in metal concentrations among individual organisms studied. During both 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 on macro-invertebrates as reported in Table 2 shows that the mean number for most species increased from site A to B (highest) and then decreased to C.

Table 2: Mean number of selected macro-invertebrate species at the three sites on the Sosiani River in the dry (April 2003-June 2003) and wet (December, 2003- February 2004) 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 $p<0.05$.

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.

Table 3: Mean number (± 1 SE) of selected macro-invertebrate species at the two seasons in the Sosiani River in the dry (April 2003-June 2003) and Wet (December, 2003- February 2004) periods.

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

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

From Table: 3, it can be noted clearly that there was an overall increase in the mean number of most macro-invertebrates from the dry to the wet season. *Baetis rhodan*, *Dineutus sp* and *Hydropsyche instabilis* (F = 6.558, F = 18.40 and F = 18.405, df = 1 and $p<0.05$) showed a greater difference. However, *Isoperlagramatica* and *Ecdyonurus venusus* (F = 0.671 and F = 2.475 at df = 1 and $p<0.05$) were exceptions that showed a decreased mean number of species from the dry to wet season.

Pollutant concentration levels

From Table 1 analysis of ambient pollution levels, bioaccumulation and benthic community structure suggest 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. The slightly low mean concentration of zinc during wet season in the two sites could be attributed to the dilution factor of large volume of rainwater (Hayward, 1992). The concentrations of zinc in site B were much higher than the threshold levels for the benthic community, less than 100ug/l (FAO, 1994). This could be attributed to the disposing of untreated industrial and municipal effluents into the River.

Fig.2 shows that the mean concentration levels of copper during both dry and wet seasons did not differ significantly within site A, while the levels differed slightly between sites A and B. Site B reported higher copper levels that were above the threshold levels (greater than > 10 ug/l), the same as for zinc. Comparison of the two seasons as evidenced from Fig.3 shows that lead concentrations appeared to be more elevated during the rainy season. This could be attributed to the wash-off from the mechanic garages or 'Jua Kali' sheds and industries.

Bioaccumulation of metals by benthic invertebrates

Benthic communities at stations downstream within sites B and C were highly contaminated with heavy metals. These results support findings of other researchers and demonstrate that levels of metals in benthic invertebrates are good indicators of potential impacts (Gower and Darlington, 1990). In a more comprehensive survey of metal contamination in benthic communities at Sosian River, it was found that metal levels in benthic invertebrates were poorly correlated with ambient levels (Kiffney and Clements, 1996), suggesting that water was not the primary route exposure to these organisms (Hare et al, 1990). Alternatively, the ability of some benthic invertebrates to regulate essential metals (Prat and Bowers, 1992), particularly at higher concentrations, may explain this poor relationship.

Benthic Community structure

Assessment of the effects of metals on benthic structure was dependent on the type of community level measure that was employed. Several researchers have reported that reduced species richness and abundance are indicative of heavy metal impact in lotic ecosystem (Prat and Bowers, 1992). 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. Figures 5 (i) and (ii) show that the number of individuals significantly increased downstream from site A to B then reduced slightly at C. These figures show the number of species at different sites during the two seasons.

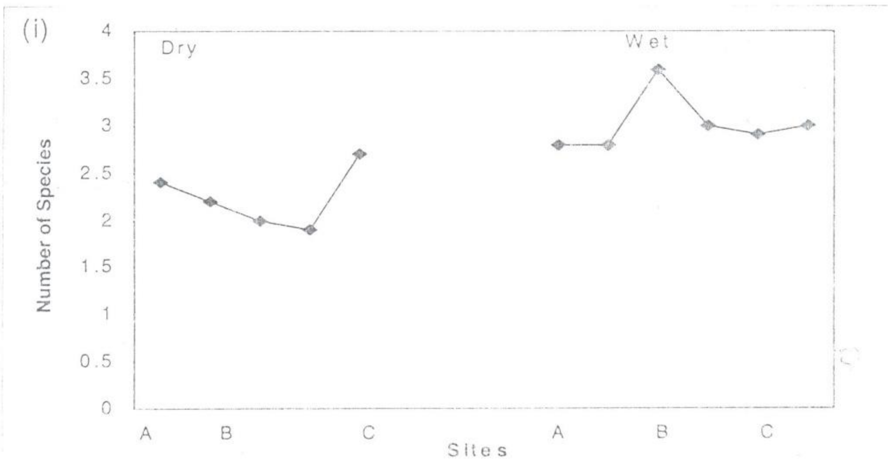

Fig. 5 (i). Numbers of species at the three sites along the Sosian River in the dry season (April 2003) and wet season (February 2004). Data are means ±1.0 SD seasons

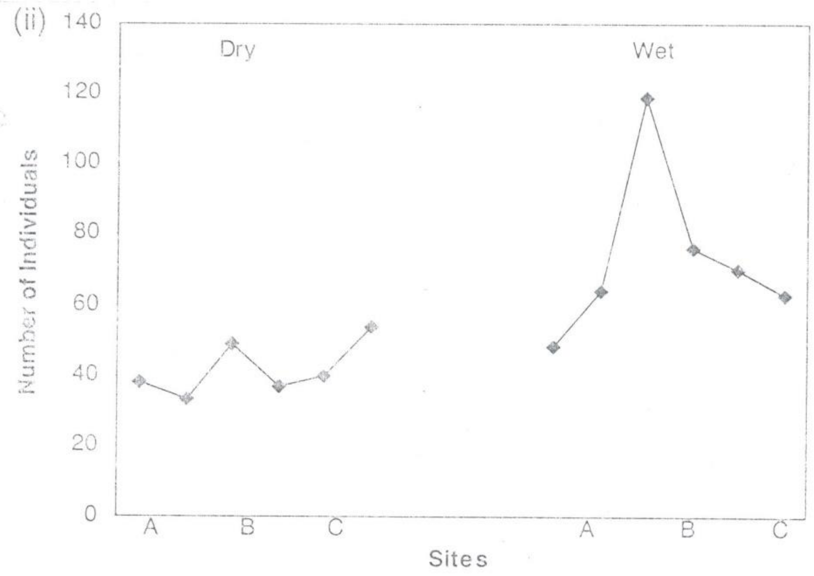

Fig.5 (ii). Individuals (ii) at the three sites on the Sosian River in the dry (April 2003) and wet season (February 2004). Data are means ±1.0 SD seasons

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 such as *hydropsyche instabilis*) by tolerant organisms like *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 (Burrows and Whitton, 1983). 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 seasons (4.733± 0.739 vs 3.633± 0.739). These results demonstrate 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 (Burrows and Whitton, 1983; Poulton et al, 1995; Clements and Kiffney, 1995; Hickey and Clements, 1998; Beltman et al, 1999). It can be concluded that the composition of benthic communities in Sosian River was an indicator of pollution impact than species richness or macro-invertebrate abundance (Kiffney and Clements, 1993).

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 sites A to B and from dry to wet seasons.

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
Zinc	A	Wet	0.053
		Dry	-0.003
	B	Wet	-0.34
		Dry	-0.71*
Copper	A	Wet	0.057
		Dry	0.024
	B	Wet	-0.391
		Dry	-0.057
Lead	A	Wet	0.068
		Dry	-0.005
	B	Wet	-0.47
		Dry	-0.82*

- -Shows significance level of $p<0.05$

The correlation analysis values between the ambient levels and the number of benthic invertebrates were low, as seen from table 4, suggesting that there were other factors that influenced the distribution of macro-invertebrates families. Though, the results of this study indicate that pollution had a stronger effect on macro-invertebrate families relative to other forms of disturbance cited by Hayward (Hayward, 1992). It had been 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.

Measurements of ambient metal and organic pollution concentrations revealed spatial patterns of metal distributions. A strong seasonal component to pollutant inputs was reported when moving along the river downstream. Elevated metal concentrations in benthic organisms and altered benthic community structure at site B clearly indicated that this site was impacted.

Due to temporal variability in ambient concentrations, community structure and metal levels in benthic communities may be better indicators of impact than either ambient metal level. 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 (Prat and Bowers, 1992).

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 of locating reference sites, selecting appropriate end points (metrics) (Gower and Darlington, 1990), and establishing a direct cause-and-effect relationship between contaminant levels and selected end points (Hare et al, 1990; Prat and Bowers, 1992; Burrows and Whitton, 1983). 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 (Kiffey and Clements, 1993).

Conclusions

Measurement of metallic levels in benthic invertebrates and assessment of benthic community structure in River Sosian provided additional evidence that downstream sites B and C were impacted. The levels of heavy metals; Pb, Zn, and Cu were above threshold levels. These levels were extremely elevated during the dry season than during the wet season. 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 in Sosian River.

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. The *Ishnura elegans* appeared to be pollutant resistant as compared to *Hydropsyche instabilis,* which was so vulnerable 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. *Ishnura elegans* can be an appropriate species for monitoring metal bio-availability and contamination in Sosian River. There were seasonal pollutant variations with a consequential macro-invertebrate change downstream for at least three seasons.

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