Concentration, partitioning and enrichment of heavy metals in water, soil and sediments in River Kapsabet micro-watershed scale, Kenya

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Abstract

In upstream riverine environment with considerable human activities, heavy metals may be released into the environment. In this study, we quantified the concentration and distribution of heavy metal (Pb, Cu, Zn and, Fe) in water, soils and sediments and characterized their spatial and temporal variability along a gradient of agricultural activities within Kapsabet River, Kenya. Heavy metals were determined by Atomic Absorption Spectrophotometer (AAS) after digestion procedures. In water, the means and ranges in concentration were (µg/L): 0.24 (0.01-0.75) Pb, 0.07 (0.02-0.21) Cu, 2.78 (0.17-3.41) Fe and 0.32 (0.02-1.22) Zn. In the soil, means and ranges (µg/g) were: 0.39 (0.11-1.42) Pb, 0.04 (0.00-0.22) Cu, 13.11 (0.43-19.14) Fe, 0.87 (0.39-2.14) Zn while in the sediments, the means and ranges in concentration (µg/g) were: 1.05 (0.51-3.81) Pb, 0.56 (0.29-0.82) Cu, 28.11 (9.22-42.14) Fe, 1.87 (0.34-3.14) Zn. There was significant ($p < 0.05$) spatial distribution of metals along the river profile. In both water and sediments, site 3 and 4 contained significantly ($p < 0.05$) the highest concentrations of Pb, Fe and Zn associated with anthropogenic pollution. Enrichment factors and geoaccumulation indices indicate that there are moderate to high degree of anthropogenic influences in sites 3 and 4 while Cu was moderately elevated in site 1. These results suggest anthropogenic influence on the heavy metal concentrations in River Kapsabet at micro-watershed scale that have unknown toxicological and epidemiological consequences to the local community members. Thus it is recommended that a stricter policy aimed at curbing the disposal of effluents associated with heavy metals into the aquatic environment.

Key word: Heavy metals, Metal partitioning, River Kapsabet Sediment, Water

1. Introduction

Rivers play a significant role within a landscape as they are at the receiving end of all the human activities within their catchments. Therefore, the character of streams and rivers reflect an integration of physical and biological processes occurring in the catchment. Landscape form and composition play a major role in regulating stream chemistry. Human activities are responsible for fundamental changes to riparian of stream catchments around the world and may influence stream water chemistry (Maasdam and Smith, 1994), discharge (Gustard and Wesselink, 1993). Yet in the last decades, industrialization, urbanization and exponential population growth have become critical to these waterbodies.

The human activities including indiscriminate use of inorganic fertilizers during agriculture, disposal of waste products such as detergents and discharge of pollutants from the mining zones, transport of nutrients and pesticides have resulted in changes in water quality of rivers resulting in increased the levels of pollutants into recipient water bodies (Geoffrey, 2011). Since the internal ecosystems of the water bodies in rivers are intimately tied to the physical, chemical and biological processes within the entire watershed, health status of rivers often depict the cumulative effects of the water quality changes originating from the catchment areas (Datta and Jana, 2002).

Metal pollution is ubiquitous in the global environment and has drawn increasing attention due to a dramatic increase in anthropogenic heavy metals to the ecosystem through air, water and soils (Fang *et al*., 2000; Adamo *et al*., 2002; Lin and Kuo-Ming, 2003; Wilson and Pyatt, 2007; Khan *et al*., 2008; Hang *et al*., 2009). The problem has been aggravated by discharge of substances in the aquatic environments (Chen *et al*., 1997; Chan *et al*., 2001; Chen *et al*., 2006; Ruiz, 2001; Santschi *et al*., 2001; Lin *et al*., 2002). For many years, Africa was considered safe from heavy metal pollution (Biney *et al*., 1994). However, rapid population growth and high urbanization rates have resulted in a recent expansion of cities in the absence of proper planning and without adequate waste disposal facilities (JICA, 2002) and as such increased reports of adverse changes in water quality and increasing concentrations of toxic metals are reported and may not be further ignored by the environmental managers. To get a true reflection of what happens within the catchment of a river basin either through point- or non-point sources of pollution, studies of spatial and temporal changes in water quality and concentration of the heavy metals are vital.

There are numerous studies that have been conducted in Kenya. Based on these studied, ominous signs of water quality changes and increased metal pollution have been documented due to agriculture, urbanization, human settlement, motor vehicle wastes and industrial activities (Wandiga, 1981; Wandiga *et al.*, 1983; Wandiga and Onyari, 1987; Onyari and Wandiga, 1989; Onyari *et al.*, 1991; Mwamburi and Oloo, 1997; Mwamburi, 2003; Raburu, 2003; Were *et al.*, 2008; Raburu *et al.*, 2009). Yet, most of these studies have been conducted in large basins and rivers in Kenya, ignoring the potential of water quality and heavy metals problems in the upstream waterbodies, which have continued to be exposed to myriads of anthropogenic activities. As a case in point, numerous reports (e.g. Osano *et al.*, 2004) indicated that chemical fertilizers are used extensively in agriculture, in order to improve yield and productivity of agricultural products in most of the upland streams.

Kapsabet in the Rift Valley Province in Kenya is an agricultural rural area and information available in grey literature indicates that there is extensive use of chemical fertilizers in the catchment and livestock production. Yet there is lack of studies on how these activities continue to affect the quality of water in the recipient Kapsabet River. For this, the current study was therefore undertaken to document the water quality along an upstream Kapsabet River through an analysis of the heavy metal content and distribution in riverine water, soils and sediments.

2. Materials and methods

2.1 Study area and sampling sites

The study area was at Kapsabet River which is within Kapsabet town. There is ongoing construction of water treatment plant for Kapsabet municipality along this river. Water from this river is meant to serve the residents of the rapidly growing Kapsabet town. It is bounded by the latitudes; 34° - 36° E, longitude; 0°03'- 1°15'N and lies between 1134-2700 m above sea level with average slope of 4 per 1000. The region receives an average of 1350 mm/year of rain and is an important cereal and tea farming region of Kenya producing (Osano *et al*, 2002). Potential major sources of pollution for the Kapsabet River basin are the agricultural chemicals, urban effluents. The main socio-economic activities in the study area include industrial activities such as tea factory, agrochemicals and agriculture, the latter being practiced on both sides of the riverine wetlands of Kapsabet River. To increase production from the farms, commercial fertilizers and organic manure are used. Some of these additional products may contain metals such as Zn, Pb, Fe and others that may be a health hazard in the environment.

Four sampling sites were selected for this study based in the anthropogenic gradients of the catchment. The sites were S1, S2, S3 and S4 and their description are as provided. S_1; this is the remote point upstream Kapsabet River before the river enters the town. This point is expected to be the control point of this research since there will be no contributions from the runoff from the town and farming activities within town. S_2; this is a point closer to Eldoret –Kapsabet route and an entrance point of water into town. It will assist in monitoring of lead metal contamination from exhaust fumes and runoff from farms. The difference between S_1 and S2 shows pollution from the runoffs from the Eldoret –Kapsabet route, surrounding farms and town. S_3; this is a point where water leaves the town. It assisted in evaluating progressive contribution of runoffs from the town and farms around. S_4; this is a point which is approximately 300 M downstream after the river water has left the town. The difference between S_1 and S_4 will provide total contribution of town runoff and soil erosion to the river water.

2.2 Sample collection and analysis

2.2.1 Water sampling

Fieldwork consisted of collecting water samples at three pre-determined sites at each of the sampling stations. The river water samples were obtained using the Grab Technique using half litre metal free Van Dorn bottle. All water samples were drawn from about half meter (0.5 m) below the water surface at each of the two opposite sides of Kapsabet River. This depth was considered to represent a homogeneous water layer, free from riverbed sediment or atmospheric air interference. A total of 20 water samples were collected for this study, with 5 samples from each of the four sampling sites. The samples were then transferred poured into pre-washed half litre polythelene bottles. The bottles had been pre-washed by soaking in nitric and sulphuric acids solution of 1:1 volume ratio, washed in about 2L of tap water and rinsed three times in distilled water and dried prior to field work. While in the field the sampling bottles were rinsed several times with river water. Water samples were acidified to pH 2 with concentrated nitric acid according to APHA (1998). This treatment was necessary so as to prevent loss of ions, which are normally adsorbed on the walls of the sampling container. After the preliminary treatment, the samples were placed into an ice box and transported to laboratory for temporary storage in a refrigerator at 4°C before analysis.

2.2.2 Sediment sampling and analysis

A pre-cleaned Ekman Grab Sampler was used to collect the river bottom sediments. A total of 5 grab sediment samples (up to 10 cm depth) were collected from the four sites. They were then transferred to acid rinsed polypropylene bottles. All samples were collected in triplicate.

The depth of water at each sediment-sampling site was measured using a meter rule. The wet sediment samples were kept separately in appropriately marked black polythene bags and transported to the laboratory for chemical analyses.

2.2.3 Sampling of Soil

Within each of the sampling sites, four (4), an auger sampler was used to scoop soil in the organo-mineral layer (0 – 25 cm) at each sampling point. The soil was then kept in black polythene bags, labeled and placed in an ice box and transported to the laboratory for chemical analyses.

2.3 Metal Analysis

Water samples were digested as a pre-requirement for spectrophotometer analysis so as to avoid interference from complexing organic matter (FAO, 1975). A combination of sulphuric acid and nitric acid digestion was used in this study (APHA, 1998). Samples were digested and concentrated on a hot plate from 100 ml to 25 ml for 3 hours. After digestion, the samples were cooled and then 2 ml of 30% hydrogen peroxide (H_2O_2) was added to each sample to oxidize any resistant organic matter (Reynolds and Thompson, 1970; Achoka 1998, Onyari *et al*., 1991). After cooling to room temperature the digested samples were filtered into 125 ml polyethylene bottles through 0.45 µm nucleopore filter paper over a vacuum pump. The concentration of metals in a sample was determined by an Atomic Absorption Spectrophotometer Varian model AA 10/20. Prior to reading of the concentration of metals in the samples, at least two calibration standards were prepared for each metal. Each blank consisted of a mixture of 10 ml nitric acid, 10 ml sulphuric acid, 2 ml of 30% $H_2 O_2$ and 25 ml of distilled water. Wet oxidation, which is normally carried out by digesting samples in mixtures of concentrated nitric acid and sulphuric acid of 1:1 v/v ratio (FAO, 1975; Han *et* *al*., 1994) was used to digest the sediments collected from Kapsabet River. A portion of the sediments from each site was put into different crucibles. Each of these crucibles had been dried in an oven and pre-weighed. The sediment samples were oven dried at 105°C for 24 hours in order to determine their dry weight (Han *et al*., 1994). A sub-sample of the cooled sediment was homogenized and sieved. Two grams of each set of the sieved sediment was then digested for one hour on a hot plate. Then 2 ml of 30% hydrogen peroxide (H_2O_2) was added to cooled samples and warmed to complete the digestion. The samples were cooled again to room temperature, filtered using 0.45 μm nucleopore filter. The volume of the resultant filtrate was made up to 50 ml mark in conical flask with deionized water. The filtrate was then analyzed for the five metals in the same way as in the case of the water samples. The reading of the concentrate of metals in the dissolved and total solids materials were done with the help of the AAS at the laboratory.

For soils and sediments, the samples were dried at low temperature (30^oC) to prevent element volatilization then digested before analysis. A sample of 1.250 g of air-dried ground soil was transferred to a distillation tube and 50 ml of deionised water added followed by a mixture of 50 ml conc. HNO_3 and HCl in the ratio of 3:1. The contents of the tube were digested at a temperature of 250°C for 1 hour. After desiccation, 5 ml HNO_3 was added to the mixture and concentrated to 5 ml. After cooling, 1 ml of 30% H_2O_2 was added and the mixture heated for 15 minutes. This procedure was repeated once, then 3 ml of H_2O_2 added and the mixture heated for 15 minutes to complete the digestion of organic matter. Finally, 10 ml of water and 5 ml HCl were added and the mixture heated to boiling. The mixture was then cooled and transferred to a 50 ml volumetric flask, filled to the mark, marked and let to settle for at least 15 hours. Flame Atomic Absorption Spectrophotometer analyzed the resultant supernatant for total Zn, Pb, Cu, and Cd.

The concentrations were calculated as µg/g dry weight. The quality of the analytical process was controlled by the analysis of IAEA MA-A-3/TM certified standard reference material of river sediment. The accuracy of the measured and certified values of the reference materials (N = 3) was: Pb 99.2 ± 0.5%; Cu 96.4 ± 3.2%; Fe 98.1 ± 2.4%; Zn 101 ± 1.1%. The detection limits were 0.01 (Pb), 0.02 (Cu), 0.02 (Fe), and 0.15 (Zn).

2.4 Data analysis

All data collected were entered, organized and managed using EXCEL spreadsheet for Windows XP. Statistical analyses were performed with either a version of STATISTICA 6.0 (StatSoft, 2001) or GenStat 4.24 Release. Data collected were subjected to apriori test to determine the homoscedasticity (Michael and Douglas, 2004) before subjecting them to statistical analysis. The normality of the data distribution was checked by means of skewness and Kurtosis when performing analysis of variance. However, before conducting t-test, Levene's test on homogeneity of variance was conducted. Data on heavy metals such as Pb, Zn, Cu, and Fe in water, soils and sediments were calculated as means (± S.D) for each site on each sampling occasion. Spatial differences in the concentrations of metals in water, soils and sediments were determined by One-Way ANOVA Where significant differences were discerned among attributes analyzed by ANOVA, Duncans Multiples Range test (DMRT) was used to discriminate between the means (Michael and Douglas, 2004). Anthropogenic pollution was determined by the Enrichment factor (EF). EF was defined as: $\mathrm{EF} = \frac{\left(\frac{X}{Al}\right)_{\mathrm{sediment}}}{\left(\frac{X}{Al}\right)_{\mathrm{crust}}}$, where $\left(\frac{X}{Al}\right)$ is the ratio of the heavy metal (X) to the Al. EF values were interpreted as suggested by Birth (2003) for the metal studied with respect to the crustal averages (Alloway, 1990). EF < 1 indicates no enrichment, EF 1-3 is minor enrichment, EF =

3-5 is moderate enrichment, EF = 5-10 is moderately severe enrichment, EF = 10-25 is severe enrichment, EF = 25-50 is very severe, and EF > 50 is extremely severe enrichment.

The I_{geo} values for the metal studied were calculated using the Muller's (1979) expression $I_{geo} = \mathrm{Log}_2\left(\frac{C_n}{1.5B_n}\right)$, where C_n is the measured content of element "n" and B_n is the background content of species in the average shale. Based on Muller geoaccumulation index and borrowing from the work by Chen *et al.* (2006), contamination level with respect to each metal can be used to classify sites as: 0 = None, 1 = None to medium, 2 = Moderate, 3 = Moderately to strong, 4 = Strongly polluted, 5 = Strong to very strong and 6 Very strong. Significance was declared at $p < 0.05$ for all analysis. Mean differences in the heavy metals among sites were analyzed using a one-way ANOVA. Spatial and temporal variations in heavy metals concentration was examined by Two-Way ANOVA.

3. Results

The mean elemental heavy metal content obtained in water, soils and sediment are summarized in Fig. 1. In water, the means and ranges in concentration were (μg/L): 0.24 (0.01-0.75) Pb, 0.07 (0.02-0.21) Cu, 2.78 (0.17-3.41) Fe and 0.32 (0.02-1.22) Zn. In the soil, means and ranges (μg/g) were: 0.39 (0.11-1.42) Pb, 0.04 (0.00-0.22) Cu, 13.11 (0.43-19.14) Fe, 0.87 (0.39-2.14) Zn while in the sediments, the means and ranges in concentration (μg/g) were: 1.05 (0.51-3.81) Pb, 0.56 (0.29-0.82) Cu, 28.11 (9.22-42.14) Fe, 1.87 (0.34-3.14) Zn All the four metals investigated displayed significant ($p < 0.05$) differences among the sampling sites. Concentration of Pb, Fe and Zn increased along the river profile to be highest in sites S3 and S4. However, the concentration of Cu tended to decrease from the upstream to the downstream.

The spatial and temporal variations of all the metals among the four sampling sites are shown in Table 1. There were significant spatio-temporal variations (ANOVA; $p < 0.05$) in the concentration of metals in water soils and sediments with all dry seasons having the highest concentration of all the metals in all the media. In the three media, there was a systematic increase in the concentration of metals along the sites except Cu from site S1 to S4 both in the dry and rainy season

Table 3 presents the mean EF values of the metals studied with respect to crust average (Alloway, 1990). High EF values (e.g., > 16 for Pb) were found in station 3 and 4; station 3 and 4 also had high Fe and Zn enrichment while Cu was high in site 1. Based on I_{geo} data and Muller's geo-accumulation indexes, the contamination level, sediments in River Kapsabet had moderate to strong pollution of Pb and Fe and Zn in site 3 and 4 while Cu pollution was in site 1.

4. Discussion

The problem of toxic metals in water bodies has necessitated a substantive research on concentration of metals in the aquatic systems. Mainly because elevated concentration of the heavy metals than threshold background levels, will adversely affect the environment and the living biota. The aim of this study was to quantify the concentrations of four heavy metals, along a concentration of anthropogenic effluent discharge. This is mainly because previous studies have indicated that levels of heavy metals are highly dependent on the anthropogenic inputs through the industrial activities. Hence, in addition to geological weathering, industrial processes and domestic effluents also significantly contribute to the background concentration of metals in natural water systems (Allard *et al.*, 1987). This study demonstrated gradient specific differences in the metal concentration characterized by undisturbed sites, agricultural effluents, and municipal effluents in a micro-watershed scale.

In comparison to areas where there are less human activities, the concentrations of the metals in most of the studied sites were high. Spatial distribution of heavy metals in the soils showed consistent patterns of variations for all the metals among the four stations. All the four metals investigated displayed significant ($p < 0.05$) differences among the sampling sites. Concentration of Pb, Fe and Zn increased along the river profile to be highest in sites S3 and S4 while the concentration of Cu decreased from the upstream to the downstream. The concentration of Pb, Fe and Zn in sites S3 and S4, which are all located near Kapsabet Town could be attributed to the enrichment of soils and water with the industrial discharge such as Chebut tea industry in addition to the urban effluent discharge from the area, which are similar to reported findings by Chen *et al*. (2005) and Adamo *et al*. (2005). The industrial discharge from the factory may contain traces of metals at low concentration(s), yet, continued deposition of effluents over the soil surface has been observed which increase the overall metals in the soils to levels that are beyond the threshold metal concentration. Accumulated metal deposition from the time the factory was built can cause immense problems of heavy metals in the soils surrounding the factory. The soils of this region are reported to be ultisols which are liable to accumulate metals at higher concentration than other soils found in Lake Victoria Basin (Mwamburi and Oloo, 1997; Mwamburi, 2003; Lalah et al., 2008; Ochieng and Wandiga, 2012; Oyoo-Okoth et al., 2010a,b,c; Oyoo-Okoth et al., 2012). The decrease in the concentration of Cu may be associated with reduced geological contribution to Cu enrichment since Cu is normally found to be rich in areas that have low relative disturbances and may therefore be washed into the surrounding environment. This residual fraction contains naturally occurring minerals which may hold trace metals within their crystalline matrix; extractable copper is mainly associated with oxidizable phase, where it is likely to occur as organically complexed metal species. This behavior may be attributed to the high affinity of copper to humic substances, which are a fraction of natural organic matter and chemically very active in complexing such metals (Pempkowiase *et al*., 1999).

This finding suggests that even though several industrial effluents can be deposited in the environment by human activities that spread in the spatial scale within these areas, there are fewer threats from the Pb contamination of water among the sampled sites. The low levels of most metals in water could also be ascribed to dilution and sedimentation in the river. In comparison to WHO (WHO, 1996) guidelines for Pb in drinking water, the water of Kapsabet River is therefore safe for drinking and other domestic uses. The mean concentration of copper in Kapsabet River water among all the stations was established to be below 0.01 mg/L. However, highly elevated levels occurred in Kapsabet, which was in excess of 0.03 mg/L. Metals in fluvial hydro-ecosystems are derived from a variety of natural and anthropogenic sources. Since they are not subject to degradation process, they tend to accumulate in the bottom sediments where they can be taken up by aquatic biota. Sediments are increasingly recognized as carriers and possible sources of contaminants in an aquatic system (Borrego *et al.*, 2002). It is now well known that the total concentrations of trace metals in sediments in the bottom sediment can predict their bioavailability and toxicity (Di Toro *et al.*, 2005; Luoma and Rainbow, 2008). Metal bioavailability and toxicity may be reflected in their partitioning in different spatial environments of the bottom river sediments at the sediment-water interface (Chen *et al.*, 2005; Warren *et al.*, 1998; Pacyna, 2005). Results showing the metal concentrations in soils of Kapsabet River during the study period are shown in Figure 4.8. However, the levels of metals were not high enough in comparison to other areas of the world such as Pb levels of 44-128 mg/kg in sediments in Montevideo, Uruguay (Muniz *et al.*, 2004), 24-1920 mg/kg in Ventspil, Lativia (Muller-Karulis *et al.*, 2003) and 3-44 mg/kg in Elizabeth South Africa (Fatoki and Mathabatha, 2001). The low levels of Pb could also be ascribed to dilution and depuration in natural waters. Besides the input from natural and anthropogenic sources, Pb distribution in sediments could also be affected by factors such as sediment chemical composition and diagenesis (Salomons and

Fŏrstner, 1994). Clark (1998) presented a model that recognized the development of oxidation and reduction horizons, water table fluctuations, and bioturbation as major factors controlling the Pb behavior within sediments.

Soils are composed of a combination of lithogenic and biogenic components such as mineral grains, organic matter, iron and manganese oxides, sulphides and carbonates (Elliot *et al*., 1986). The heavy metals attach to any of these phases in proportions, which depend on the physico-chemical conditions prevailing in the sediments and associated waters. The addition of fertilizers, chemicals and other substances containing heavy metals to boost agricultural production has often elevated the levels of heavy metals in the soils, which in addition to discharge from industrial sources are likely to elevate the metals concentration in the environment (Adamo *et al*., 2002; Berthet *et al.,* 2003; Islam *et al*., 2005; Were *et al*., 2008). Levels of heavy metals in soils can help in determination of the safety in the use of the agricultural soils within the areas and to the eventual consumers of products from the soils. Though there are no recommended level of heavy metals in the soil, higher threshold values of heavy metals provides evidence of perturbations in the soils due to heavy metals contaminations. Spatial distribution of heavy metals in the soils showed consistent patterns of variations for all the metals among the four stations. All the four metals investigated displayed significant ($p < 0.05$) differences among the sampling sites. Concentration of Pb, Fe and Zn increased along the river profile to be highest in sites S3 and S4. However, the concentration of Cu decreases from the upstream to the downstream. As in the case of soil, the concentration of Pb, Fe and Zn in sites S3 and S4, which are all located near Kapsabet Town could be attributed to the enrichment of soils and water with the industrial discharge such as Chebut tea industry. The industrial discharge from the factory may contain traces of metals at low concentration(s), which if continuously deposited on the soils will increase the concentration of these metals in the soils. The soils of this region are reported to be ultisols which are liable to accumulate metals at higher concentration than other soils found in Lake Victoria Basin. The decrease in the concentration of Cu may be associated with reduced geological contribution to Cu enrichment to the soils since Cu is normally found to be rich in areas that have low relative disturbances and may therefore be washed into the surrounding environment. This behavior may be attributed to the high affinity of copper to humic substances, which are a fraction of natural organic matter and chemically very active in complexing such metals (Pempkowiase *et al*., 1999).

Because of the reactivity of metals with organic compounds (Alloway, 1990), there could be a tendency of the effluents to react with any metal from the geological basins such as Zn. Absence of such organic compounds, could have resulted in increased Zn concentration from the geological sources. Although Kapsabet station reported similarly higher concentrations of Zn in Kapsabet River water, this was however related to heavy fertilizer use in the agricultural farms in the close vicinity for sugarcane production rather than from the factory. Thus the presence of metals in a riverine environment may be attributed to numerous non-point sources of pollutants rather than predictable effluents discharge from the industries in close proximity of the river profile. This finding is in agreement with similar findings in other aquatic environments (Machiwa, 1992; Mpendazoe *et al*., 1993; Mahimairaja *et al*., 2005; Mbagwu *et al*., 2004; Mandal *et al*., 1998).

The spatial and temporal variations of all the metals among the four sampling sites are shown in Table 4.4. There were significant spatio-temporal variations (ANOVA; $p < 0.05$) in the concentration of metals in water soils and sediments with all dry seasons having the highest concentration of all the metals in all the media. In the three media, there was a systematic increase in the concentration of metals along the sites except Cu from site S1 to S4 both in the dry and rainy season and this could be accounted for by systematic increase in the concentration of metals in water due to increased inputs of external contaminants into the water body from both agricultural and municipal centres. These results also signify that at each site, there is relative contribution of external sources of the studied metals that may not be easily quantified in the surrounding areas because of the non-point nature of the metal pollutants.

Anthropogenic activities have long been regarded as the main factors associated with elevated heavy metal incidences in the aquatic environment by various workers elsewhere. In this study the high EF values were associated with direct anthropogenic influences through discharge of effluents into the aquatic environment. Based on the above observations, sediments in River Kapsabet had strongly polluted by some of the metals that may have detrimental impacts.

The results in this study clearly demonstrate that anthropogenic influence the heavy metal concentrations, distribution, partitioning and enrichment in River Kapsabet Basin scale that have unknown consequences to the local community members. In light of the foregoing, it is clear that further studies on heavy metals are required within the Kapsabet Rivers as well as the rest of the Kenya riverine aquatic environment. Such studies should aim to quantify the biologically available heavy metals, and understand how bioaccumulation of a metal is related to the specific species, age, feeding habit and locality, and how all these factors interrelate at the spatial and temporal scales. Given our inability now to discriminate between contaminant effects and natural variability it is recommended that a stricter policy aimed at curbing the disposal of refuse associated with heavy metals into the aquatic environment should be instituted and enforced by the authorities responsible.

Conclusion

There were significant variations of metal concentration in water along the sampling stations, which clearly correlated well with urban effluent discharge along the industrial discharge points in the river. Most of the metals analyzed, except Cu were elevated in water along the urban and industrial discharge points. Significant variations of metals in sediments were also associated with urban and industrial discharge from the factory near the water bodies. The sediments accumulated the metals near sites of industrial discharge than at other sites farther away from the metal discharge sources.

Metal distributions in the soil were linked to discharge of effluents from various anthropogenic sources mainly the industrial sources. There were higher concentrations of metals in soils near the Kapsabet River banks.

Most of the metals that increased downstream the river were generally linked to the factory where there were direct effluent sources. Metal levels generally reduced away from the direct sources of pollutants.

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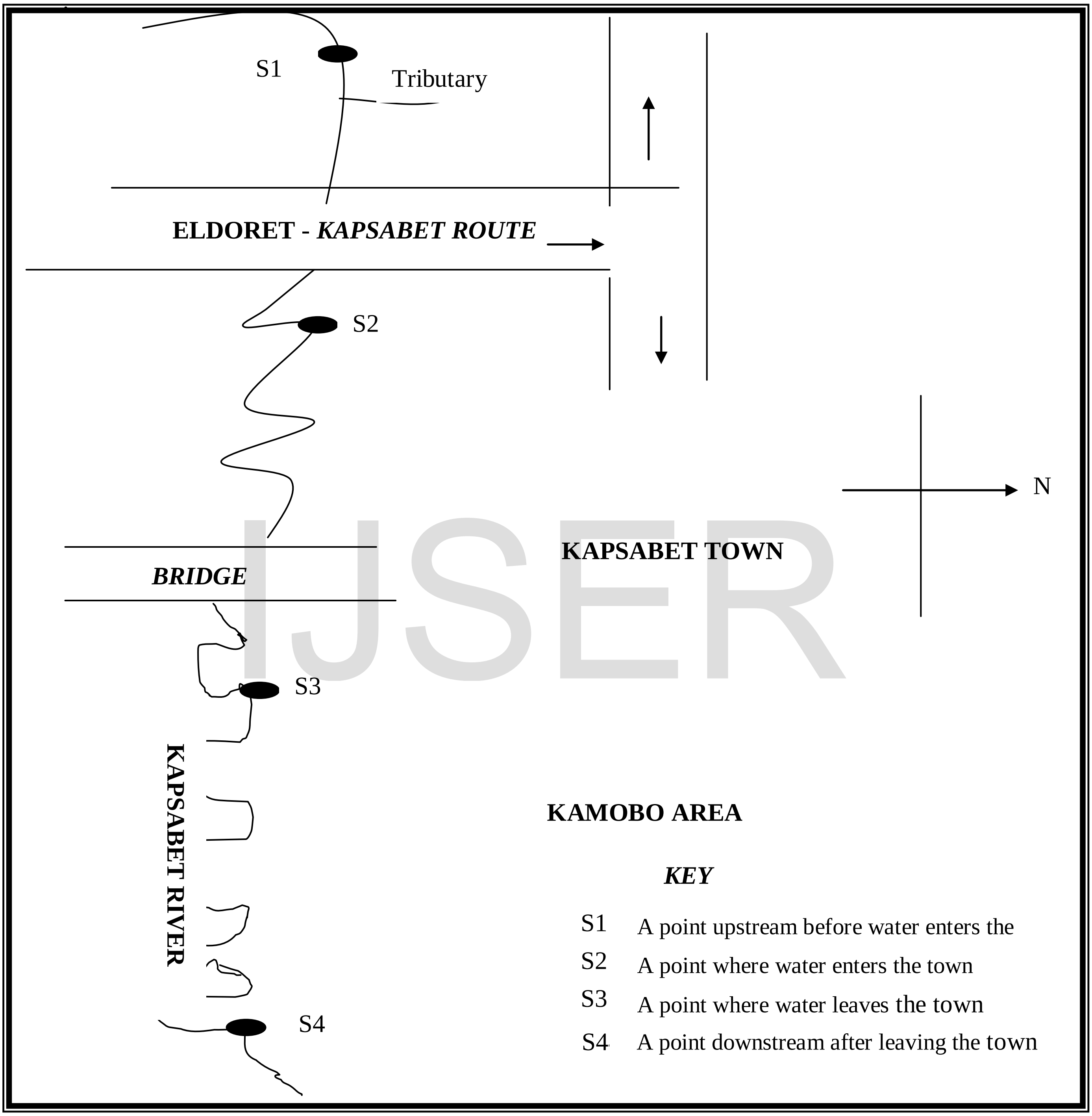
Fig. 1: Map showing the location of Kapsabet River systems.



KEY	
S1	A point upstream before water enters the
S2	A point where water enters the town
S3	A point where water leaves the town
S4	A point downstream after leaving the town

FIGURE 1.1: Map of Study Area

Fig. 1.

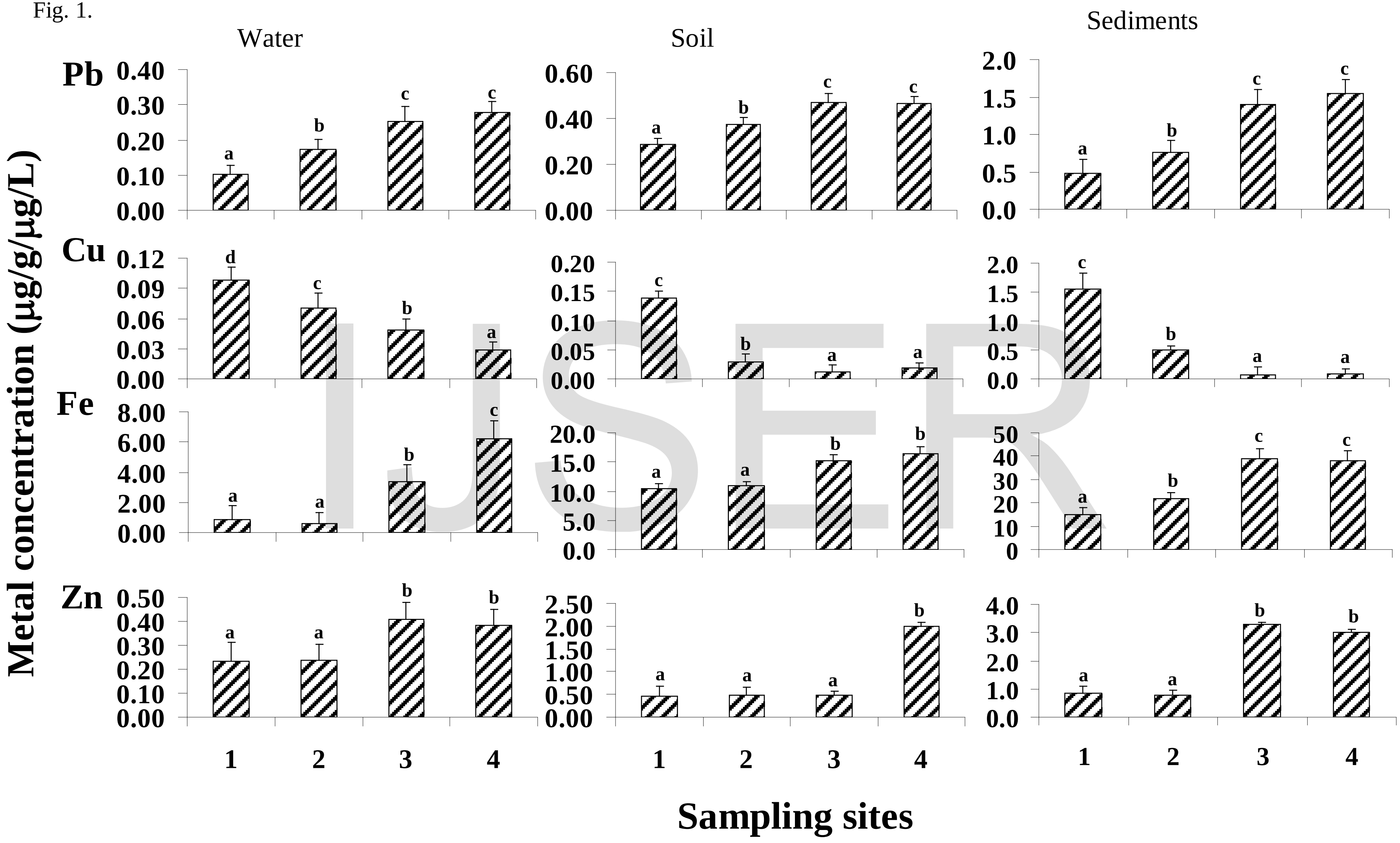

Water
Soil
Sediments
Pb
Cu
Fe
Zn
Metal concentration (µg/g/µg/L)
Sampling sites
1
2
3
4
0.00
0.10
0.20
0.30
0.40
0.60
0.12
0.09
0.06
0.03
0.15
0.05
0.50
2.00
4.00
6.00
8.00
5.0
10.0
15.0
20.0
0.0
0.5
1.0
1.5
2.0
2.50
1.50
1.00
3.0
4.0
0
10
20
30
40
50
a
b
c
d

Table 1: Heavy metals concentration in the river water (µg/L dw), and sediment (µg/g dw) from River Perkera

		S1		S2		S3		S4	
	Metal	Rainy	Dry	Rainy	Dry	Rainy	Dry	Rainy	Dry
Water	Pb	0.41 ± 0.01	0.01 ± 0.03	0.43 ± 0.03	0.09 ± 0.005	0.41 ± 0.007	0.03 ± 0.004	0.52 ± 0.01	0.04 ± 0.002
	Cu	0.17 ± 0.04	0.01 ± 0.004	0.14 ± 0.03	0.00 ± 0.006	0.08 ± 0.006	0.01 ± 0.003	0.05 ± 0.01	0.01 ± 0.004
	Fe	1.80 ± 0.16	2.58 ± 0.15	1.17 ± 0.15	1.84 ± 0.05	15.23 ± 2.32	1.73 ± 0.11	29.65 ± 3.42	1.57 ± 0.03
	Zn	0.37 ± 0.03	0.09 ± 0.002	0.33 ± 0.08	0.14 ± 0.008	0.33 ± 0.05	0.49 ± 0.04	0.43 ± 0.06	0.19 ± 0.02
Soil	Pb	0.72 ± 0.01	0.22 ± 0.01	0.71 ± 0.07	0.22 ± 0.07	0.61 ± 0.18	0.13 ± 0.04	0.44 ± 0.05	0.13 ± 0.02
	Cu	0.02 ± 0.004	0.26 ± 0.04	0.02 ± 0.004	0.04 ± 0.003	0.02 ± 0.003	0.01 ± 0.002	0.03 ± 0.006	0.01 ± 0.004
	Fe	13.47 ± 1.86	19.47 ± 0.04	10.75 ± 0.05	19.60 ± 3.76	2.25 ± 0.06	19.47 ± 3.32	1.45 ± 0.23	19.28 ± 4.32
	Zn	3.32 ± 0.37	0.67 ± 0.03	0.25 ± 0.04	0.71 ± 0.13	0.40 ± 0.07	0.56 ± 0.07	0.39 ± 0.009	0.52 ± 0.07
Sediment	Pb	0.79 ± 0.05	0.16 ± 0.03	0.60 ± 0.11	0.12 ± 0.03	0.75 ± 0.13	0.06 ± 0.008	0.75 ± 0.13	0.10 ± 0.06
	Cu	0.05 ± 0.006	0.14 ± 0.02	0.07 ± 0.008	0.17 ± 0.07	0.05 ± 0.006	0.09 ± 0.01	0.01 ± 0.005	0.18 ± 0.06
	Fe	22.43 ± 4.57	19.48 ± 2.98	24.08 ± 4.21	19.69 ± 3.85	20.29 ± 4.42	19.81 ± 4.55	16.95 ± 3.97	19.44 ± 5.33
	Zn	0.97 ± 0.21	0.73 ± 0.13	0.93 ± 0.23	0.63 ± 0.11	0.62 ± 0.09	0.45 ± 0.07	3.64 ± 0.76	0.88 ± 0.21

Similar lettering represents concentrations that do not differ significantly ($p > 0.05$).

Table 2. Enrichment factor and geo-accumulation index various sites in River Kapsabet

	Sampling sites				
	1	2	3	4	
(a) Enrichment factor					
Pb	1.1	4.3	4.7	**16.6**	
Cu	**15.2**	4.2	5.1	7.1	
Fe	1.3	2.4	3.1	**9.9**	
Zn	1.6	0.7	**7.1**	**6.2**	
(b) I_{geo} class[b]					
Pb	1	2	2	**4**	**5**
Cu	1	2	**3**	2	2
Fe	1	2	0	**3**	**3**
Zn	1	1	**4**	**3**	**3**

[a] Station number

[b] 0 = None, 1 = None to medium, 2 = Moderate, 3 = Moderately to strong, 4 = Strongly polluted, 5 = Strong to very strong 6 = Very strong

[c] ND Not determined

Values in bold show respective heavy metal pollution