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Analysis of Spatial and Temporal Levels of Heavy Metals in Water, Sediments and Fish in Sosiani River

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Abstract The objective of the study was to examine spatial and temporal levels of heavy metals in water, sediments and fish in Sosiani River. This study was an experimental design approach in which a scientific analysis was done involving sample collection, preparation and laboratory work to determine Pb, Cd and Cr concentrations in fish water and sediments. The main Sosiani river flows from the Keiyo escarpment at the far South East through Uasin Gishu plateau to Turbo which is in the North West. The units of analysis used in the study included two species of fish, water and sediment; whereby water and sediment were sampled from eleven sampling locations (SR_0 – SR_{10}) and fish from ten sampling points (SR_1 – SR_{10}) along river Sosiani catchment. Sample analysis was done using Atomic Absorption Spectrometry. Data analysis was done using the statistical program for social sciences (SPSS) version 23. Inferential (ANOVA), regression and descriptive statistics were used to analyse data. Spatial and temporal levels of heavy metals in water, sediments and fish were the outcomes. In the upper Sosiani, SR_3 (Chepkorio) registered the highest lead levels in the wet season of 0.127 mg/l. In both dry and wet seasons, and in all the sites, lead values in water were above the NEMA and WHO thresholds of 0.01 mg/l. In the analysis of cadmium concentrations, it was observed that in wet season water had all 50% of the sites above the NEMA and WHO thresholds while all the sites were had values below the limits during the dry season. Cr in water was high for 90% of the sites. Sediment had the highest lead values of 1.744mg/l. Barbus (*Barbusbarbus*) fish had high lead, cadmium and Cr values in both wet and dry seasons. In both seasons, catfish (*Clariusgariapinus*) had low values of lead and cadmium below the NEMA and WHO limits for most of the sites but high levels of Chromium. Spatial and temporal variations in heavy metal concentration were observed between the water, sediment and the two species of fish within the catchment. This study recommended mandatory measures (enforcement) to control the increased heavy metal concentration downstream the basin.

Keywords: *spatial, temporal, heavy metals, river sosiani catchment*

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1. Background

The accumulation of heavy metals in aquatic habitats and their persistence in the environment has been attracting increasing attention from researchers and policymakers worldwide. This attention is attributed to heavy metal toxicity [1,2,3]. Despite measures to reduce trace metal input into oceans, rivers and estuaries, heavy metal accumulation in the different aquatic systems is still being reported [2,4,5]. Fish has been recognized as a good bio-accumulator of organic and inorganic pollutants especially trace metals which are then passed onto higher organisms through food, and bio-accumulate over a period of time, and this bioaccumulation increases with water temperature [6]. Trace metals from natural and anthropogenic sources access aquatic system and get distributed in the water body, suspended solids, and benthic sediments during the course of their transportation.

Substantial data indicates that water acidification directly affects metal bio-concentration rates by the fish. An analysis of heavy metal levels data in fish from a number of lakes indicates that cadmium and lead concentrations are considerably higher in the fish from acidified lakes. Water hardness (mainly calcium concentration) considerably affects up- take of metals across the gill epithelium [7,8]. A study by [9] found that animals that graze on contaminated plants and drink from polluted waters, as well as marine lives that breed in heavy metal polluted waters bio-accumulate metals in their tissues and milk if lactating. Calculations based on soil, plant and faecal analyses also show that from 9% to 90% of the metal intake into cattle on contaminated land is due to ingested soil [10]. This situation is more worrisome in the developing countries where research efforts towards monitoring the environment have not been given the desired attention by the stakeholders, and yet the wastewater that goes into the water resources is not adequately treated to the stipulated WHO standards [11].

The distribution of metals between sediment and water column and between biological species such as fish and water column can be characterized by sediment-water or fish-water quotient index [12,13,14,15,16]. Increasingly vulnerable environmental conditions such as diminished biodiversity, soil degradation or growing water scarcity can bring about metal accumulation for people dependent on the marine environments for their livelihoods and also increases people's exposure to health risks [3]. Lack of preparedness for pollution of the environment is bound to have profound social and economic consequences for populations who depend on the ecosystems for their livelihoods, including food due to poverty and food insecurity.

1.1. Variations in Heavy Metal Concentration along Rivers

Generally, the general flow of a river emanates from the highlands to the low lying areas, and rivers constitute of tributaries that coalesce and contribute to the final river flow volume [17]. A difference in gradient is the major cause of river flow and thus higher gradients result in higher river flow velocities [18]. Another factor which determines river flow velocities is rainfall intensity [19] and river morphology [20] whereby river flow velocities have been found to be influenced by morphological attributes including, wide river banks, river bends, presence of rapids and deep river beds.

These changes in river flow velocities also influence the water quality within the rivers [21]; for instance, in low pH areas, the possibility of sedimentation is diminished as a result of rapid mixing of the liquid and solid material within the water body [22], while in low flow areas the level of sedimentation increases, as low flows encourage particle settlement [23]. Such differences in sedimentation levels also have a profound effect on the water quality and it is common to see pronounced water quality variations as rivers flow downstream [24]. Moreover, water flow injection points can also be from runoff during periods of heavy precipitation or human activity [25], which also contribute to the overall river water quality. In their work, [26] evaluated Pb, Cd, Cr and Zn concentrations along river Sosiani and found concentrations of 0.0405mgl^{-1}, 0.137mgl^{-1} and 0.0626mgl^{-1} for Pb, Cd and Cr, respectively. Despite this, they did not perform any heavy metal prediction analysis to determine the rate of variation in heavy metal concentration along the river.

1.2. Influence of Seasonal Changes on Heavy Metal Concentrations within Rivers

The volume of water flow in rivers is a function of seasons; during the periods of heavy precipitation, there is high volume water flow from upper zones of river catchments, whereas during dry periods, the volumes are comparatively lower. These flow, referred to as runoff flows dislodge and wash away material that includes soil, vegetative material, animal waste and human activity materials. These washed down materials may contain heavy metals which are as a result of anthropogenic and non-anthropogenic activities within the catchments [27], and increase with precipitation [21]. Moreover, the rate and volume of wash-down is also dependent on the geology and topography of the areas sourcing the pollutants, and should there be high rainfall, these factors increase wash-down. This is manifested from phenomena like soil erodibility, water flow velocities, and water infiltration and percolation rates, among other phenomena which are indicators of the aforementioned factors and distinctly influence the water and sediment quality of the rivers in specified catchments [28]. Consequently, an evaluation of the effect of precipitation on river water quality variations due to morphological characteristics of the catchments is of paramount importance [21]. Such variations in heavy metal concentrations can be evaluated with respect to the water [29] and sediment quality [30,31]. An analysis of the water quality determines assists in determination of the potability of the water within such catchments while sediment analysis gives indicators of possible pollution pathways to the flora and fauna inherent in these catchments [32]. Despite a number of studies to determine variations in heavy metal concentrations within Kenyan rivers for instance Nairobi [33] and Sosiani [31,34] rivers, no information on the effect of seasonal changes on heavy metal concentrations within the river Sosiani is available.

2. Methods

The study was conducted in Sosiani River catchment which is defined by Longitude 035° 00' 00''E, 035° 35'.00''E and also latitude 00°18'00''N, 00°37' 00''N within the Altitude range of 2,819m above sea level and 1,644m above sea level. The upper limits of the catchment are in the Keiyo escarpment while the lowest part of the catchment is Turbo forest at the confluence of Sergoit and Sosiani rivers. The middle part of the area is constituted of the Eldoret Municipality. The entire river system is approximately 67 km long and 654 km^2 basin area. It is one of the major tributaries of the Kipkaren river system. It traverses two counties i.e. Keiyo/Marakwet and Uasin Gishu [4,35]. Upper Sosiani is characterized by the Keiyo escarpment which is part of the Great Rift Valley and Kerio Valley basin. The coordinates of sampling stations in the different zones were recorded using Global Positioning System (GPS).

2.1. Research Design

This study was an experimental design approach in which a scientific analysis was done involving sample collection, preparation and laboratory analysis to determine Pb, Cd and Cr in water, two species of fish (catfish and barbus) and sediment from Sosiani Catchment.

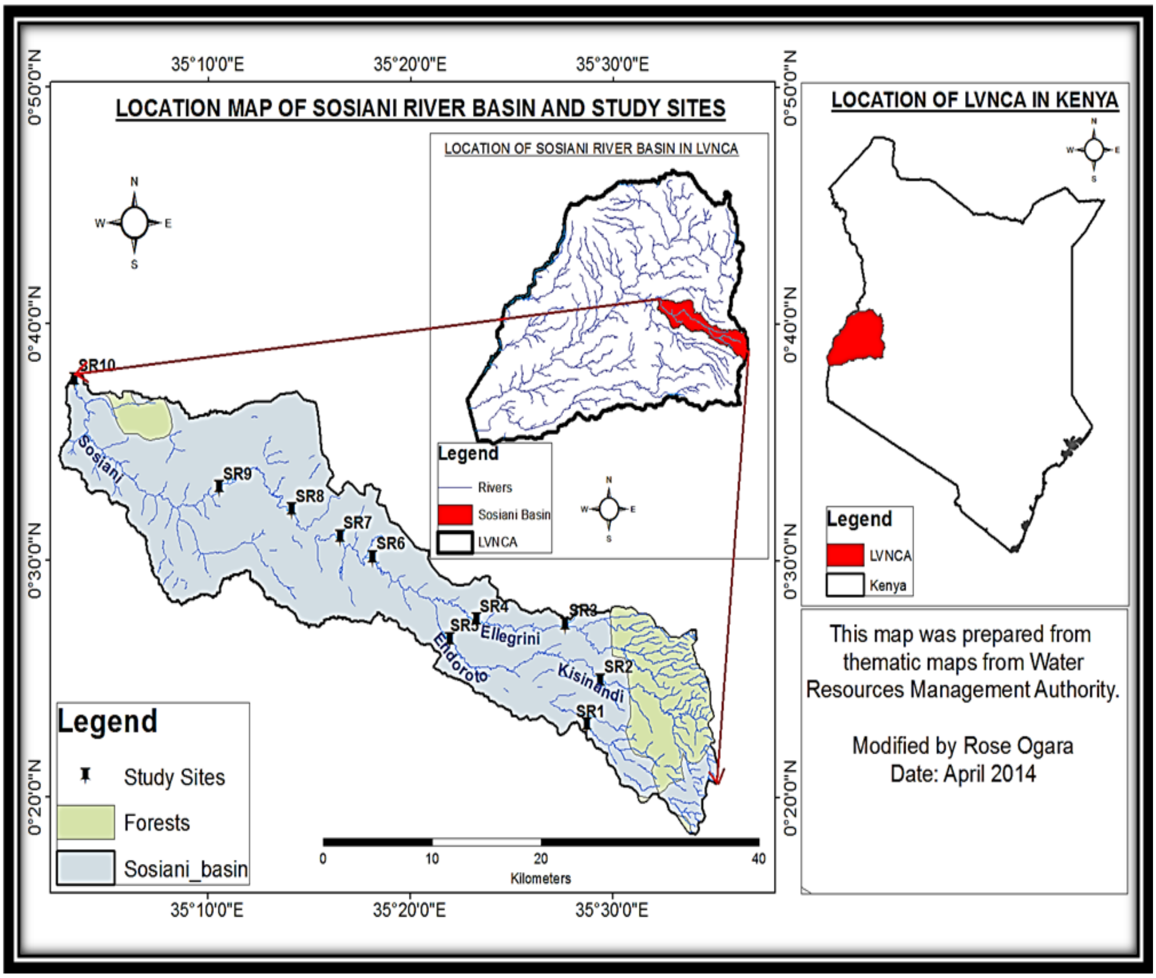

Figure 1. Map of River Sosiani showing the sampling sites [36]

2.2. Study Setting

The main land use in the Sosiani basin can be classified into five categories; indigenous and exotic forest; [37], urban and rural settlements, large scale commercial farming [38], subsistence farming [39,40] and isolated cases of quarry mining. Crops mainly cultivated in the catchment through conventional agriculture or irrigation includes maize, beans, passion fruits, vegetables, and potatoes. The catchment also has intensive floriculture, mainly through irrigation in green houses. Livestock rearing is another major land use activity in Sosiani sub catchment and is mainly in the upper and lower sub-catchments. Quarrying is also undertaken in the area at minor scale and it affects the drainage system of the area by acting as pools for stagnant water. The hydrology of the sub catchment is influenced by the topography of the area. The main Sosiani river flows from the Keiyo escarpment at the far South East through Uasin Gishu plateau to Turbo which is in the North west; The main tributaries to Sosiani river are-: Nundoroto, Kipsenende, Ellegirine and Lemook(Chepkorio). The groundwater flow direction is influenced by the topographical expression which is equally defined by the direction of the surface water flow. Monitoring of river flows are carried out at three regular gauging stations namely: - 1CB05 Sosiani, 1CB08 Nundoroto and 1CB09 Ellegirine rivers [41].

Table 1

Water				
Sampling station	Station Name	GPS coordinates	Immediate upstream station	Description
SR_0	Control point (Chepsamo)	N:00.39430, E:035.56030	Nil	Altitude:2830 m
SR_1.	Kaptagat	N:00.3840, E:035.47968	Nil	Altitude:2411 m
SR_2.	Ellegerine	N:00.411680,E:035.49073	SR_3	Altitude:2438 m
SR_3.	Chepkorio	N:00.386470, E:035.550400	Nil	Altitude:2775 m
SR_4.	Naiberi	N:00.45425, E:035.38858	Nil	Altitude:2222 m
SR_5.	Nundoroto	N:00.44058,E:035.3667	SR_2, SR_1	Altitude:2205 m
SR_6.	Nairobi-Nakuru Bridge	N:00.49841, E:035.30273	SR_5	Altitude:2093 m
SR_7.	Kapsabet Bridge	N:00.51287, E:035.27545	SR_6	Altitude:2076 m
SR_8.	Eldowas Sewerage Works	N:00.531540, E:035.23652	SR_7	Altitude:1997 m
SR_9.	Kengen	N:00.55198, E:035.18030	SR_8	Altitude:1954 m
SR_{10}.	Sosiani-Sergoit	N:00.629730,E:035.05053	SR_9	Altitude:1793 m

Table 2. Sampling Strategy of the study

Study Population Units	Sampling Method	Sample Size
Water	Stratified Random	60, 6 from sites SR_0, SR_2, SR_3, SR_4, SR_5, SR_6, SR_7, SR_8, SR_9 and SR_{10}
Sediment	Stratified Random	60, 6from sites SR_0 to SR_{10}
Fish	Stratified Random	120,12 from sites SR_1 to SR_{10}

2.3. Unit of Analysis

The units of analysis used in the study included two species of fish (catfish and barbus), water and sediment; whereby water and sediment were sampled from eleven sampling locations (SR_0 – SR_{10}) and fish from ten sampling points (SR_1 – SR_{10}) along river Sosiani. Random sampling method was used to obtain data on water quality, and heavy metal concentration in water, sediments and fish.

2.4. Data Collection

2.4.1. Water

The water samples were collected in a 100 ml pre acid-washed polypropylene bottle and 1 ml of concentrated HNO_3 was added to the sample to stop any microbial activity [42]. This was done from eleven sites (SR_1 to SR_{10}; SR_0 being the control sampling location) along river Sosiani (in river Sosiani catchment) during Dry (Oct – Dec 2017) and the Wet (March - May, 2018) seasons in triplicate. The samples were collected from the mid depth in the mid-section of the river channel by holding the sampling bottle firmly and plunging the neck down wards. The bottle was then turned until the neck pointed upward with the mouth directed towards the current [43]. This was due to the fact that side waters move slower than the mid waters of the river implying that placing the bottle facing against the flow gives the most current sample. The samples were then transported to the laboratory under controlled temperatures.At the laboratory, both water and the wastewater samples were filtered through a 0.45µm pore membrane filter and kept at 4°C until analysis. During the analysis, 50ml representative water and wastewater samples were extracted from the filtrate, each sample was digested with concentrated HNO_3 and conc. HCl (1:3) at 80°C until the solution became transparent [44].They were then reconstituted to 50ml using deionized water. The samples were mixed thoroughly by shaking and then analysed for Pb, Cd and Cr levels by directly aspiring the sample into the AAS (Model 2380, Perkin Elmer, Inc. Norwalk, USA), having a specific lamp for the particular metal and using appropriate standards.

2.4.2. Sediment

Sediment samples were collected from 11 locations (SR_0 to SR_{10}; SR_0 being the control sampling location) during the Dry (Oct – Dec 2017) and the Wet (March - May, 2018) seasons. The samples were obtained using a grab sampler and weighed into 100g and put in polythene papers then transported to the laboratory under controlled storage temperatures. In the laboratory, the sediment samples were air dried for seven days to constant weights, sieved using a 2mm sieve to remove the pebbles, pulverized into fine powders using laboratory mortar and pestle then measured into 20g portions and stored in polythene bags below -20°C prior to analysis [45]. Digestion was done before analysis to reduce organic matter interference and to convert metal to a form that could be analysed by Atomic Absorption Spectroscopy [15]. The prepared sediment samples in amount of 2.0g were mixed with 6.5 mL of $HNO_3$and 2.6 mL HF (5:2) and digested for 30 min at 80°C. The digested solution was placed to an evaporation dish and the excess acid was removed by heating on the hot plate. The dry solid samples were then dissolved in 50 ml of deionized water and filtered through 0.45 µm membrane filters for the analysis of metals [46]. After dilution, the solution was stored in clean labelled plastic containers until analysis. Stock and working solutions were prepared and thePb, Cd and Cr levels in the filtrate determined using Atomic Absorption Spectrometer (AAS) [45] by an AAS (Model 2380, Perkin Elmer, Inc. Norwalk, USA), having a specific lamp for the particular metal and appropriate standards.

2.4.3. Fish

Fish sampling was done alongside the water and sediment samples with the help of local fishermen using nets and hooks. The samples were collected from the ten sites (SR_1 – SR_{10}) during the dry and wet seasons, the Dry (Oct – Dec 2017) and the Wet (March - May, 2018) seasons. These were done 3 times in each season. The fish were collected and catfish (*Clariasgariepinus)* and barbus (*Barbusbarbus)* species identified, weighed and separated from the rest with the aid of the Fisheries Department Uasin Gishu County. Fish of the same weight were wrapped in aluminium foil and transported to the laboratory under controlled storage conditions where the non-edible parts were removed and the whole fish sun dried to a constant weight for 7 days [47]. After drying, the fish were weighed again to ensure same weight for both species and outliers removed. Each species was then homogenized using a blender and 2.0 g dry weight of each homogenate fish sample was then digested by weighing into digestion tubes into which 10 ml of aqua regia (HNO_3: HCl in the ratio 1:3) and 1 ml $HClO_4$ acid was added, followed by heating in water bath at 80°C for 3 hours to ensure complete digestion (no more production of brown fumes) and a transparent solution was obtained. These transparent solutions were filtered through Whatman number 42 filter paper and diluted to 50 ml with distilled water. The solution was stored in clean labelled plastic containers until analysis. The concentrations of Pb, Cd and Cr in the filtrate were determined by using anAtomic Absorption Spectrometer (AAS) (Model 2380, Perkin Elmer, Inc. Norwalk, CT, USA), fitted with a specific lamp of particular metal using appropriate standards from stock solutions [2].

2.5. Analytical Instruments

The validity of the (Atomic Absorption Spectrometer) AAS was determined by relating the standard solutions of the metals to be measured against absorbance of the same solutions. This was achieved by establishing analytical figures for determination of sample Pb, Cd and Cr using the linearity test. According to [48], the linearity test involves a regression plot of absorbance values of standard solutions of Pb, Cd and Cr (y-axis) versus respective concentration of the same metal standard solutions (x-axis). For this study, the concentration ranges used were 0.200 – 1.00 mg/l. The results showed the existence of a linear relationship for the regression equations with an R^2 value of 0.99.All reagents used were of analytical grade and reference materials used in verification were prepared and the blank and standards were run after five determinations to calibrate the instrument. All glassware and plastics used for the experiments were previously soaked in 10 % HCl (v/v) and were rinsed with distilled water. Other quality assurance and control procedures for the laboratory included analysis in triplicates for the samples, standards and blanks [45].

2.6. Data Analysis

Data analysis was done using the statistical program for social sciences (SPSS) version 23. Inferential and descriptive statistics were used to analyze data. In this study association between the study variables was assessed by a two-tailed probability value of $p<0.05$ for significance. The researcher conducted analyses of normality, for the outcome variable, prior to hypothesis testing by examining kurtosis and skewness of the data. In order to test and identify possible outliers in the data, graphical assessment visuals, including scatter and box plots were used. Elimination of observed outliers was based on a case by case basis, dependent on standard deviations, and on normality and homogeneity of variance assessments. Normality was assessed using examination of the histograms by seeing how they related or deviate against a normal bell curve distribution and observing the levels of kurtosis and skewness present. Univariate analysis was used to describe the distribution of each of the variables in the study objective. One-way analysis of variance (ANOVA) and regression at 0.05 level of significance were used in the analysis.

3. Results & Discussion

3.1. Sosiani River Water Characteristics

Preliminary analysis of typical water parameters was conducted to determine the physical and chemical properties of the Sosiani river water. This analysis was done on samples from each of the ten sampling sites. The parameters analyzed included discharge, Dissolved oxygen (DO), Temperature, pH, conductivity, Total Dissolved Solids (TDS), salinity, nitrates, nitrites, total phosphates, Total Suspended Solids (TSS) and quantity of sediments. The results from the measurements are as presented in Table 3 and 4 The results indicate a reducing trend in dissolved oxygen downstream from SR_0 to SR_{10} which could be indicative of increased BOD due to increased pollution. A look at the other water parameters shows that the pH ranged from 5.28 to 7.55, implying slight acidity within the waters due to pollution in the wet season. In the dry season, the pH ranged from 5.18 to 9.32. The TDS ranged between 17.00 and 70.20mgl^{-1} between 17.63 and 64.19mgl^{-1} during the wet and dry seasons respectively which was well below the NEMA criteria of 1200mgl^{-1} which meant that the levels of dissolved solids within the waters increased with pollution, they were well below critical levels. This phenomenon is also true for the nitrates whose values ranged between 0.05 and 4.30mgl^{-1}, and 3.00 and 10.70mgl^{-1}, for the wet and dry seasons respectively. The nitrates in the river increased downstream and across the seasons. Decrease of dissolved oxygen in water is also an indicator of pollution. In this study, the DO ranged between 5.8 and 8.81mgl^{-1} and 6.28 and 9.21mgl^{-1} during the wet and dry seasons respectively.

3.2. Heavy Metal Concentration in Water

3.2.1. Spatial Variations in Heavy Metal Concentration

Table 4 and Table 5 show the variations in the levels of heavy metals in water within the River Sosiani upper, middle and lower catchments during the wet and dry seasons (Temporal variation), respectively, while Figure 2 and Figure 3 show the spatial distribution of the concentrations of the heavy metals in water. From the data it was observed that each of the metals showed a variation in concentration with respect to each of the sampling sites. This phenomenon is as discussed hereinafter;

Lead

In the upper Sosiani, SR_3 (Chepkorio) registered the highest lead levels of 0.127 mgl^{-1} (wet season), significantly different (F (9, 20) = 175.20, p= 0.00) atp< 0.05 from other sites within the catchment. Downstream to SR_3 is SR_2 (Ellegerine) whose Pb levels were lower at 0.039 mgl^{-1} (wet season) compared to SR_3. Despite these two sampling sites being in the same tributary, the lower levels at SR_2 can be attributed to heavy metal motility as the waters of the river progressed downstream resulting in lower Pb concentrations. SR_1 (Kipsenende River at Kaptagat) had Pb values of 0.058 mgl^{-1} (wet season). These higher Pb concentrations comparative to SR_2 can be ascribed to non-point sources prevalent in the region. Sampling points SR_4 (Naiber) and SR_5 (Nundoroto) had Pb concentration readings of 0.045, and 0.040 mgl^{-1}, respectively, for the wet season. Noting that SR_4 is on a different tributary (Naiber river), the intermediate Pb concentration implies moderate Pb contamination sources compared to SR_3, but higher compared to SR_1. It is observed that SR_5 (Nundoroto) had lower concentrations than SR_1, SR_2 and SR_3 despite being downstream to these stations, an evidence of Pb motility as the stream flow progresses downstream.

Table 3. Average Wet season Physical characteristics of water from each of the 10 sampling sites plus control site

Sampling station and name	DO (mgl^{-1})	Temp (°C)	pH	Conductivity (µs/cm)	TDS ($mg\ l^{-1}$)	Salinity	Nitrates ($mg\ l^{-1}$)	Nitrites ($mg\ l^{-1}$)	Total Phosphates ($mg\ l^{-1}$)	TSS ($mg\ l^{-1}$)	Discharge (m^3s^{-1})	Sediment (ton/day)
SR_0: Control point (Chepsamo)	8.81	15.11	7.32	33.58	17.00	23.65	0.04	0.36	0.01	0.20	0.83	0.32
SR_1: Kaptagat	8.02	15.20	7.42	49.20	28.30	39.64	4.21	0.43	0.03	2.00	0.89	0.76
SR_2: Ellegerine	8.30	15.60	7.48	38.61	22.40	30.10	4.10	0.44	0.30	5.50	0.92	0.82
SR_3: Chepkorio	8.31	15.25	7.42	34.01	18.25	26.90	4.05	0.38	0.12	6.60	0.94	0.94
SR_4: Naiberi	7.51	17.20	7.44	40.38	23.32	30.97	4.05	0.37	0.04	5.00	0.95	0.96
SR_5: Nundoroto	8.34	17.15	7.53	49.52	29.28	38.83	5.26	0.63	0.03	7.00	2.10	2.13
SR_6: Nairobi-Nakuru Bridge	5.83	19.60	6.63	48.22	39.18	38.27	8.15	0.58	0.05	8.50	2.81	2.19
SR_7: Kapsabet Bridge	5.34	19.63	6.54	56.29	46.22	45.22	7.15	0.59	0.04	10.00	2.86	2.38
SR_8: Eldowas Sewerage Works	5.28	21.28	5.28	90.72	70.20	65.00	10.70	1.01	0.15	12.55	2.91	5.62
SR_9: Kengen	7.60	19.56	6.94	54.22	50.64	76.12	4.30	0.37	0.50	7.00	2.98	3.60
SR_{10}: Sosiani-Sergoit	7.82	18.32	7.55	56.34	52.20	72.90	3.00	0.13	0.24	8.00	3.43	2.94
NEMA criteria*	NG	Amb±3	7.50	NG	1200	NG	10	3.00	NG	30.00	NA	NA

Amb: Ambient temperature
DO: Dissolved Oxygen (mgl^{-1})
NA: Not Applicable
NG: Not Given
TDS: Total Dissolved Solids (mgl^{-1})
TSS: Total Suspended Solids (mgl^{-1}).

Table 4. Average Dry season Physical characteristics of water from each of the 10 sampling sites plus control site

Sampling station and name	DO (mgl^{-1})	Temp (°C)	pH	Conductivity (µs/cm)	TDS ($mg\ l^{-1}$)	Salinity	Nitrates ($mg\ l^{-1}$)	Nitrites ($mg\ l^{-1}$)	Total Phosphates ($mg\ l^{-1}$)	TSS ($mg\ l^{-1}$)	Discharge (m^3s^{-1})	Sediment (ton/day)
SR_0: Control point (Chepsamo)	9.21	17.11	9.32	30.58	17.63	23.65	0.04	0.36	0.02	0.98	0.63	0.32
SR_1: Kaptagat	8.22	17.20	8.42	49.20	28.30	39.64	0.21	0.43	0.03	2.00	0.29	0.42
SR_2: Ellegerine	8.00	17.60	8.48	48.52	22.40	30.10	0.10	0.44	0.29	4.50	0.56	0.21
SR_3: Chepkorio	8.31	18.25	8.42	49.02	18.25	26.90	0.05	0.38	0.02	6.50	0.77	0.51
SR_4: Naiberi	7.51	17.20	8.44	43.40	23.32	30.97	0.05	0.37	0.04	5.00	0.69	0.24
SR_5: Nundoroto	8.34	17.15	8.53	49.52	29.28	38.83	0.26	0.63	0.03	7.00	1.10	1.07
SR_6: Nairobi-Nakuru Bridge	7.83	20.60	6.63	57.23	39.18	38.27	0.15	0.58	0.05	8.50	1.81	2.19
SR_7: Kapsabet Bridge	7.34	20.63	6.54	58.31	46.22	45.22	0.15	0.59	0.04	10.00	1.70	2.34
SR_8: Eldowas Sewerage Works	6.28	21.28	5.18	90.35	64.19	65.00	0.70	1.01	0.15	12.55	1.91	4.69
SR_9: Kengen	8.10	19.56	8.14	60.32	50.64	76.12	4.30	0.37	0.50	7.00	2.08	3.69
SR_{10}: Sosiani-Sergoit	8.23	19.62	8.25	56.34	52.20	72.90	3.00	0.13	0.24	8.00	3.33	2.87
NEMA criteria*	NG	Amb±3	7.50	NG	1200	NG	10	3.00	NG	30.00	NA	NA

Amb: Ambient temperature
DO : Dissolved Oxygen (mgl^{-1})
NA: Not Applicable
NG: Not Given
TDS: Total Dissolved Solids (mgl^{-1})
TSS: Total Suspended Solids (mgl^{-1}).

Table 5. Wet season heavy metal concentrations in collected water samples from the River Sosiani basin

Zone	Sampling location	Heavy metal concentration(mgl^{-1})*		
		Lead	Cadmium	Chromium
Control point	SR_0: Chepsamo	0.001 (0.001)	0.001 (0.001)	0.001 (0.000)
Upstream	SR_1: Kipsenende	0.058 (0.001)	0.003 (0.001)	0.050 (0.000)
	SR_2: Ellegerine	0.039 (0.003)	0.003 (0.000)	0.090 (0.001)
	SR_3: Chepkorio	0.127 (0.006) [a]	0.001 (0.000)	0.040 (0.001)
	SR_4: Naiber	0.045 (0.001)	0.050 (0.010) [a]	0.119 (0.001) [c]
	SR_5: Nundoroto	0.040 (0.002)	0.004 (0.001)	0.080 (0.001)
Midstream	SR_6: Nairobi bridge	0.063 (0.001)	0.002 (0.000)	0.910 (0.010) [a]
	SR_7: Kisumu bridge	0.072 (0.001) [b]	0.005 (0.001)	0.903 (0.015) [a]
	SR_8: Eldowas WW	0.084 (0.001) [b]	0.006 (0.000)	0.307 (0.012) [b]
Downstream	SR_9: Kengen power	0.051 (0.002)	0.003 (0.000)	0.113 (0.012) [c]
	SR_{10}: Sosiani-Sergoit	0.057 (0.001)	0.002 (0.000)	0.100 (0.000)
Max		0.127	0.006	0.910
Min		0.039	0.001	0.040
Mean (N =30)**		0.064	0.008	0.271
Water Criteria (NEMA) ‡		0.05	0.01	0.05
Water Criteria (WHO)†		0.01	0.003	0.05

* Numbers in parentheses indicate Standard deviations (N=3)
** Overall mean (N=30)
† [49]
‡ [50]
a b Significant heavy metal concentration (Fisher's, Followed by Post-hoc B Tukey HSD atp<0.05).

Table 6. Dry season heavy metal concentrations in collected water samples from the River Sosiani basin

Zone	Sampling location	Heavy metal concentration (mgl^{-1})*		
		Lead	Cadmium	Chromium
Control	SR_0:Chepsamo	0.001 (0.001)	0.000 (0.000)	0.001 (0.000)
Upstream	SR_1: Kipsenende	0.034 (0.001)^c	0.001 (0.000)	0.157 (0.006)
	SR_2: Ellegerine	0.023 (0.001)	0.000 (0.000)	0.100 (0.000)
	SR_3: Chepkorio	0.046 (0.001)^b	0.000 (0.000)	0.410 (0.010)^c
	SR_4: Naiber	0.029 (0.004)	0.001 (0.000)	0.220 (0.020)
	SR_5: Nundoroto	0.038 (0.002)^c	0.000 (0.000)	0.117(0.015)
Midstream	SR_6: Nairobi bridge	0.036 (0.002)^c	0.000 (0.000)	1.390 (0.010)^a
	SR_7: Kisumu bridge	0.051 (0.002)^{ab}	0.002 (0.000)	0.910 (0.010)^b
	SR_8: Eldowas WW	0.031 (0.001)	0.001 (0.000)	0.313 (0.012)^c
Downstream	SR_9: Kengen power	0.023 (0.001)	0.002 (0.000)	0.010 (0.000)
	SR_{10}: Sosianisergoit	0.062 (0.002)^a	0.001 (0.000)	0.300 (0.000)
Max		0.051	0.002	1.390
Min		0.023	0.000	0.010
Mean (N =30)**		0.037	0.001	0.393
Water Criteria (NEMA)‡		0.05	0.01	0.05
Water Criteria (WHO)†		0.01	0.003	0.05

* Numbers in parentheses indicate Standard deviations (N=3)
** Overall mean (N=30)
† [49]
‡ [50]
$^{a\,b}$ Significant heavy metal concentration(Fisher's, Followed by Post-hoc B Tukey HSD atp< 0.05).

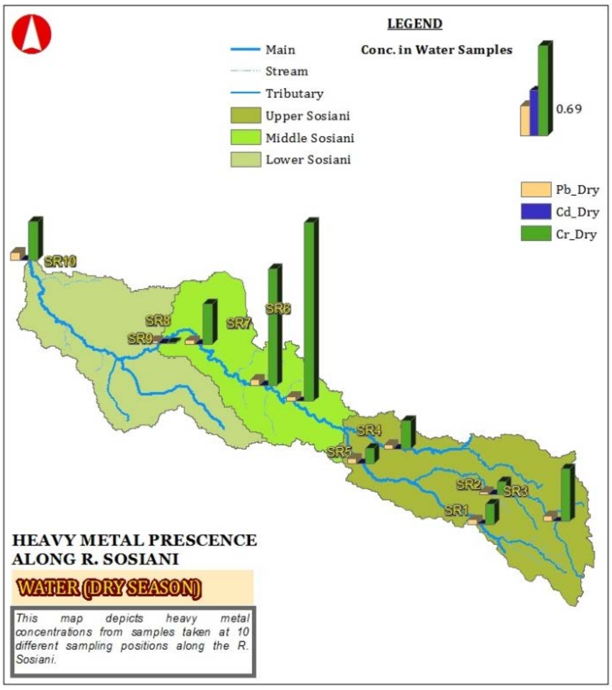

Figure 2. Spatial distribution of heavy metal concentration in the waters of River Sosiani catchment in the dry season

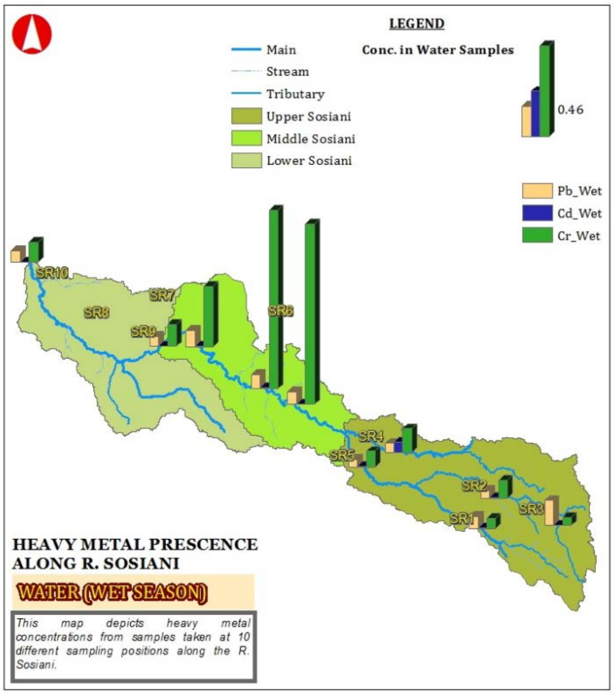

Figure 3. Spatial distribution of heavy metal concentration in the waters of River Sosiani catchment in the wet season

Finally, all the sampling locations in the upper catchment had their Pb concentrations higher compared to the control sample at Chepsamo tributary source (SR_0) with 0.001mgl^{-1}. The mid zone had all the sampling locations reporting higher Pb concentrations compared to the upper catchment, in ascending order of concentration, SR_9, SR_6, SR_7, SR_8, having Pb concentrations of 0.051, 0.063, 0.072 and 0.084mgl^{-1}, respectively, for the wet season. Pb concentrations at SR_7 (Kisumu bridge) were significantly different at $p < 0.05$ from the other sites within the zone ($F (9, 20) = 175.20$, p= 0.00). The high Pb concentration at SR_8 (Table 4) is ascribable to the presence of the Eldowas Wastewater facility (SR_8) and the solid waste dumpsite in its vicinity. A similar deduction is also applicable to SR_6 (Nairobi bridge) which receives pollutants from Zena Roses, Tipsy wood treatment, KCC and sukunanga car wash among others and SR_7 which are in the vicinity of increased urban anthropogenic activities (vehicle repair garages and car wash facilities and Munyaka stream), and frequent bursts of sewer lines and man hole blockages with SR_7 being located below the Eldoret MTRH facility and other hospitals, and SR_7 at the bridge on the main road to Nairobi. Similar correlations between commercial vehicle repair activities and Pb levels in catchment areas have also been observed by [51]. Additionally, [34,39] found lead concentration levels of 0.460 ± 0.090 ppm for water near MTRH site, implying that medical operations at this facility are possible causes of lead contamination in the river. The comparatively lower value of 0.051mgl^{-1} at SR_9 (Kengen Power Station) but higher than the NEMA thresholds is indicative of massive Pb settlement especially in the Kengen Power facility, since water flow velocities are much lower compared to the upper areas of the catchment. In the lower zone, sampling station SR_{10} (Sosiani-Sergoit confluence) registered lead concentrations of $0.062mgl^{-1}$ for the wet season. These levels are higher compared to SR_9 (Kengen power) which had $0.023mgl^{-1}$, implying a fresh injection of Pb into the river water, taking into account that the sampling station is downstream to the Eldoret Armed Forces Ordinance Factory and the presence of an old water supply which due to age could be leaching some lead into the river.

The dry season data showed Chepkorio (SR_3) registering high Pb concentrations in the upper catchment at 0.046 mgl^{-1}, significantly different at $p< 0.05$ compared to SR_1 (Kaptagat) and SR_5 (Nundoroto) which had 0.034 and $0.038mgl^{-1}$, respectively (F (9, 20) = 409.64, p= 0.00), which were in turn higher compared to SR_2 (Ellegerin) and SR_4 (Naiber) at 0.023 and 0.029 mgl^{-1}, respectively. These results suggest that there are undetermined point sources of Pb contamination in the upper catchment that warrant further scrutiny, the area around Chepkorio being the most dominant source. Upstream of Chepkorio is the control sampling point (SR_0) with Pb concentrations of $0.001mgl^{-1}$, indicating that massive Pb injection into the river between this location and Chepkorio which warrants investigation. In the mid catchment, water at SR_7 (Kisumu bridge) registered a comparatively higher Pb content compared to SR_6 (Nairobi bridge) and SR_8 (Downstream Eldowas WW) with 0.036 and $0.031mgl^{-1}$, respectively, within the same zone, but higher compared to SR_3, denoting that anthropogenic activities within the mid zone result in high Pb concentrations around SR_7. The lower zone had SR_{10} (Sosiani-Sergoit junction) registering the highest dry season Pb concentration within the Sosiani river catchment at $0.062mgl^{-1}$, attributable to the ordinance factory, old water supply within its vicinity, the bridge at Turbo, Turbo town (garages, carwash and petrol stations). Conversely, SR_9 (Kengen power) within the same sub-catchment had a lower Pb concentration of $0.023mgl^{-1}$.

Cadmium

In the analysis of Cd concentrations, it is observed that in the upper Sosiani, SR_4 (Naiber) registered the uppermost Cd levels of 0.050 mgl^{-1} in the wet season, significantly different at $p < 0.05$ from other sampling locations (F (9, 20) = 51.67, p = 0.00). This sampling site is on the Ellegerin river and downstream to SR_2 (Ellegerin), which has a Cd concentration of $0.000mgl^{-1}$. Similar trends in readings to sampling station SR_2 are observed at SR_1 (Kipsenende) with 0.003 mgl^{-1}, SR_3 (Chepkorio) with 0.000 mgl^{-1} and SR_5(Nundoroto) with 0.004 mgl^{-1}. This phenomenon indicates more sources of Cd contamination at Naiber (SR_4), compared to SR_1, SR_2, SR_3 and SR_5, which could be attributable to Cd contamination due to use of phosphate fertiliser within the region. The mid Sosiani catchment saw sampling location SR_8 (Eldowas wastewater) reporting a high wet season Cd concentration of 0.006 mgl^{-1}compared to SR_9 (Kengen power), SR_6 (Nairobi bridge) and SR_7 (Kisumu bridge), with Cd concentrations of 0.003, 0.002, and $0.005mgl^{-1}$, respectively, for the wet season. The high Cd concentration at SR_8, followed by that at SR_7, is due to heavy urban activity within the Eldoret urban centre and the Wastewater site. Conversely, the lower concentrations at SR_6 and SR_9 are due to fewer point sources of Cd at these locations compared to SR_8 and SR_7. Moreover, heavy metal settlement with river flow explains the lower values at these stations. For the lower zone, sampling station SR_{10} (Sosiani-Sergoit confluence) recorded Cd concentrations of $0.002mgl^{-1}$, which are lower compared to SR_9 (Kengen power), which implies that downstream of SR_9, point sources of Cd were lower hence lower Cd concentrations at SR_{10}.

During the dry season, SR_4 (Naiber) registered uppermost Cd levels of 0.001 mgl^{-1}within the upper Sosiani. It was observed that the only other sampling location with similar concentrations was SR_1 (Kaptagat forest site 1), otherwise, the remaining locations of SR_2, SR_3 and SR_5had Cd concentrations of $0.000mgl^{-1}$. This phenomenon shows higher traces of Cd contamination at Naiber and Kaptagat forest, compared to the other locations within the catchment, however, the concentration levels are below the threshold WHO concentrations [49]. Within the same season, the mid catchment had sampling location SR_7 (Kisumu bridge) reporting Cd concentration of $0.002mgl^{-1}$and SR_6 (Nairobi bridge), and SR_8 (Kisumu bridge), having Cd concentrations of 0.000 and $0.001mgl^{-1}$, respectively. The Cd concentration at SR_7 is due to heavy urban activity within the Eldoret urban centre and the Wastewater site, a situation also acknowledged and observed by [34]. Conversely, the lower concentrations at SR_6 and SR_8 are due to fewer point sources of Cd at these locations; moreover, heavy metal settlement with river flow explains the lower values at these stations. For the lower zone, sampling station SR_{10} (Sosiani Sergoit confluence) recorded Cd concentrations of $0.001mgl^{-1}$, which were lower compared to SR_9 (Kengen power) with $0.002mgl^{-1}$, which implies that downstream of SR_9, point sources of Cd were lower hence lower Cd concentrations at SR_{10}.

Chromium

In the upper Sosiani, SR_4 (Naiber) registered the highest Cr levels of 0.119 mgl^{-1} in the wet season (Table 4); A high value indicative of possible non-point Cr pollutant sources. Upstream to SR_4 is SR_2 whose Cr readings were lower at $0.090mgl^{-1}$. The lower levels at SR_2 can be attributed to lower point Cr sources. SR_1 (Kipsenende River at Kaptagat) had Cr values of $0.050mgl^{-1}$, while SR_3 and SR_5 had Cr concentration readings of 0.040and 0.080 mgl^{-1}, respectively, which indicate less non-point Cr sources. The mid catchment had sampling locations SR_6 and SR_7 reporting higher Cr concentrations of $0.910mgl^{-1}$, and $0.903mgl^{-1}$, respectively significantly higher (F (9, 20) = 5064.43, p = 0.00) at $p< 0.05$ compared to the remaining sites. Conversely, SR_8 and SR_9 registered Cr readings of 0.307, and $0.313mgl^{-1}$, respectively. The high Cr concentration at SR_6 and SR_7 is due to its proximity to Tipsy, the two bridges (Nairobi and Kisumu) and other high urban anthropogenic activities, leading to Cr contamination. a fact also observed by Karadede, Oymak and Ünlü, (2004) in another study. The comparatively lower SR_9 (Kengen Power Station) is indicative of mass heavy metal settlement after SR_7, since additionally, it is worth noting that despite the presence of Eldowas at SR_8, the Cr levels at this sampling site were lower than at SR_6 and SR_7. At sampling station SR_{10} (Sosiani-Sergoit confluence) the lower catchment registered Cr concentrations of 0.100mgl^{-1} for the wet season. This level is lower compared to SR_9 at 0.113 mgl^{-1}, implying further settlement of Cr as the river Sosiani flows downstream.

During the dry season, the upper Sosiani, SR_4 (Naiber) registered the highest Cr levels of 0.220 mgl^{-1} (Table 5); this high value is also suggestive of possible non-point Cr pollutant sources. On the other hand, Ellegerin (SR_2) which is upstream to SR_4 with Cr concentration readings of 0.100mgl^{-1}during the dry season can attribute this concentration to lower point Cr sources. The other site, SR_1 (Kipsenende River at Kaptagat) had Cr concentration of 0.157mgl^{-1}, while SR_3 (Chepkorio) and SR_5 (Nundoroto) had Cr concentrations of 0.410mgl^{-1}, and 0.117mgl^{-1}respectively, which also indicate less non-point Cr sources. It should be noted that concentrations at SR_3 were significantly different at $p< 0.05$ from the other sites within the upper Zone. In the mid catchment, sampling locations SR_6 (Nairobi bridge) and SR_7 (Kisumu bridge) reported higher Cr concentrations of 1.390mgl^{-1} and 0.910mgl^{-1}, respectively with SR_6 being significantly higher ($F (9, 20) = 5845.11$, $p = 0.00$) at $p< 0.05$. On the other hand, SR_8 and SR_9 registered Cr readings of 0.313 and 0.010mgl^{-1}, respectively. The high Cr concentration at SR_6 and SR_7 is due to its proximity to high urban anthropogenic activity, leading to Cr contamination. a fact also observed by Karadede, Oymak and Ünlü, (2004) in another study. The comparatively lower SR_9(Kengen Power Station) is indicative of mass heavy metal settlement after SR_7, since additionally, It is worth noting that despite the presence of Eldowas and the solid waste dumpsite at SR_8, the Cr levels at this sampling site were lower than at SR_6 and SR_7. At sampling station SR_{10} (Sosiani-Sergoit confluence) the lower catchment registered a Cr concentration of 0.300 mgl^{-1} which was higher compared to SR_9, (Kengen power) with 0.010 mgl^{-1} implying further injection of Cr as the river Sosiani flows downstream.

3.2.2. Temporal Variations in Heavy Metal Concentration

Lead

Table 7 presents the statistics of heavy metal concentration variations in the water in River Sosiani catchment during the dry and wet seasons, respectively ($p< 0.05$); a general difference was observed in Pb, Cd and Cr concentrations as the seasons changed. This difference was based on data obtained from the individual sampling sites SR_1 to SR_{10}.

Table 7. Statistics of temporal variations in heavy metal concentrations in river water at sampling sites within River Sosiani

Heavy metal	Mean wet season concentration (mgl^{-1})	Mean dry season concentration (mgl^{-1})	t value (p< 0.05)	Significance
Lead	0.064	0.037	6.047	0.000*
Cadmium	0.008	0.001	2.665	0.012
Chromium	0.271	0.393	3.808	0.001

*Highly significant at p < 0.05.

An analysis of the temporal variation of Pb concentrations within the catchment water indicated that generally the sampling stations SR_1, to SR_9 reported higher Pb levels were significantly different ($t(29) = 6.047$, $p= 0.00$) during the wet season compared to the dry season, with mean concentrations of 0.064 and 0.037 mgl^{-1}, respectively. At sampling station SR_{10} however, there was a reversal of the phenomenon whereby the water Pb concentration in the wet season was lower at0.057 mgl^{-1} compared to the dry season at 0.062mgl^{-1} (Table 5 and Table 6). This deviation did little to change the statistics, and a possible explanation for this reversal is Pb contamination from the armed forces ordnance factory upstream Sergoit River, Pb being a raw material in ordnance manufacture, thus Pb levels were consistently high despite the seasons. The concentrations obtained in the study are comparatively lower than those of 1.890 ± 0.000 ppm through earlier studies by [45], which can be explained by concentration transformations in the river due to changes in the physical and regulatory environment resulting from the ban of leaded petroleum products, and conservation efforts of River Sosiani. Despite this, the Pb concentrations obtained are above the WHO tolerable drinking water Pb levels of 0.01mgl^{-1} [49].

Cadmium

An analysis of the temporal variation in Cd concentration is as presented in Table 7. It indicates that all the sites SR_1 to SR_{10} had consistently and significantly higher Cd concentration ($t (29) = 2.665$, $p = 0.012$) in the wet season compared to the dry season, with mean concentrations of 0.008 and 0.001 mgl^{-1}, respectively. For instance, a site like Naiber (SR_4) had a wet season Cd concentration of 0.050mgl^{-1} which is twice the Cd concentration observed from the same site in the dry season, a phenomenon indicative of high Cd weathering within this site. In many instances, Cd concentration seemed to arise naturally and was less determined by anthropogenic activities, a phenomenon supported by Amadi [29] who attributed Cd concentration in River Sosiani at Kipsenende to natural abundance.

Chromium

Temporal variations of Cr concentration indicated the dry season having higher concentrations at all the sampling sites when compared to the wet season with a dry season mean concentration of 0.393mgl^{-1}, which was higher than 0.271mgl^{-1} observed for the wet season. Additionally, dry season concentrations were significantly different ($t (29) = 3.808$, $p= 0.001$) compared to the wet season, indicative of higher Cr to water concentration in the dry season compared to the wet season. This means that most of the sources of Cr are point sources.

3.3. Heavy Metal Concentration in Sediments

3.3.1. Spatial Variations in Heavy Metal Concentration

Table 8 and Table 9 show the variations in the levels of heavy metals in sediment within the River Sosiani upper, middle and lower catchments during the wet and dry seasons (Temporal variation), respectively, while Figure 4 and Figure 5 show the spatial distribution of the concentrations of the heavy metals in sediment. From the data it was observed that each of the metals showed a variation in concentration with respect to each of the sampling sites. This phenomenon is as discussed hereinafter;

Lead

In the upper Sosiani, SR_3 (Chepkorio) registered the highest sediment Pb levels of 0.810mgkg^{-1} (wet season), it was followed by SR_1, $SR_2$and $SR_5$with 0.682, 0.611 and 0.609 mgkg^{-1}, respectively (Table 8). In the same zone, sediments from SR_4 registered the lowest Pb concentration of 0.300mgkg^{-1}. The concentration at SR_3 was significantly different (F (9, 20) = 9264.39, p = 0.00) at $p < 0.05$ from SR_1, SR_2 and SR_5. The data implies that Chepkorio is a location with heavy metal pollution, and similar evidence has been adduced by the water heavy metal data (Table 8 and Table 9). The mid catchment had all the sampling locations SR_6, SR_7 and SR_8 with Pb concentrations of 1.093, 1.314 and 1.313mgkg^{-1}, respectively, which were greater, compared to the upstream data. The comparatively higher values show higher Pb contamination in the midstream region as a result of anthropogenic activities. In the lower catchment, sampling station SR_{10} (Sosiani-Sergoit confluence) registered Pb concentrations of 1.744mgkg^{-1} wet season, which was significantly higher (F (9, 20) = 9264.39, p = 0.00) at $p<0.05$ compared to SR_9 at 1.303mgkg^{-1}. These higher levels compared to SR_9, also implicate new injection of Pb into the river water, taking into account that the sampling station is downstream to the Eldoret Armed Forces Ordinance Factory, turbo town and the old water supply with Pb pipes a fact also observed during analysis of the water samples.

Table 8. Wet season heavy metal concentrations in Sediment Samples from sampling sites in river Sosiani

Zone	Sampling location	Heavy metal concentrations (mgkg^{-1}) *		
		Lead	Cadmium	Chromium
Control	SR_0: Chepsamo	0.001(0.001)	0.000 (0.000)	0.001 (0.000)
Upstream	SR_1: Kipsenende	0.682(0.003) ^{c}	0.008 (0.000) ^{a}	0.127 (0.001)
	SR_2: Ellegerine	0.611(0.002) ^{d}	0.006 (0.000) ^{a}	0.188 (0.052) ^{d}
	SR_3Chepkorio	0.810(0.010) ^{c}	0.007 (0.001) ^{a}	0.222 (0.002) ^{d}
	SR_4: Naiber	0.300(0.000)	0.002 (0.000)	0.220 (0.000) ^{d}
	SR_5: Nundoroto	0.609(0.010) ^{d}	0.001 (0.000)	0.525 (0.001) ^{b}
Midstream	SR_6: Nairobi bridge	1.093(0.031) ^{bc}	0.009 (0.001) ^{a}	0.527 (0.001) ^{b}
	SR_7: Kisumu bridge	1.314 (0.012) ^{b}	0.007 (0.000) ^{a}	0.408 (0.002) ^{c}
	SR_8: Eldowas WW	1.313 (0.006) ^{b}	0.004 (0.001)	0.661 (0.001) ^{a}
Downstream	SR_9: Kengen power	1.303 (0.006) ^{b}	0.002 (0.000)	0.417 (0.001) ^{c}
	SR_{10}: Sosiani sergoit	1.744 (0.002) ^{a}	0.002 (0.000)	0.430 (0.000) ^{c}
Maximum		1.744	0.009	0.661
Minimum		0.300	0.001	0.127
Mean (N=30)**		0.978	0.005	0.373
Criteria (WHO) †		0.010	0.003	0.050

* Numbers in parentheses indicate Standard deviations (N=3)
** Overall mean (N=30)
† Sediment criteria obtained as equivalent to water quality criteria [49]
a b Significant heavy metal concentration(Fisher's, Followed by Post-hoc B Tukey HSD at p< 0.05).

Table 9. Dry season total heavy metal concentrations (mg/kg) in Sediment Samples from sampling sites in river Sosiani

Zone	Sampling location	Heavy metal concentrations (mgkg^{-1}) *		
		Lead	Cadmium	Chromium
Control	SR_0: Chepsamo	0.001 (0.001)	0.000 (0.000)	0.001 (0.000)
Upstream	SR_1: Kipsenende	0.200 (0.000) ^{d}	0.010 (0.000)	0.070 (0.000)
	SR_2: Ellegerine	0.106 (0.012) ^{e}	0.002 (0.001) ^{c}	0.395 (0.005) ^{a}
	SR_3 Chepkorio	0.342 (0.016) ^{c}	0.010 (0.000) ^{a}	0.092 (0.002)
	SR_4 Naiber	0.001 (0.001)	0.001 (0.001)	0.140 (0.000) ^{c}
	SR_5 Nundoroto	1.460 (0.020) ^{a}	0.001 (0.001)	0.262 (0.002) ^{b}
Midstream	SR_6 Nairobi bridge	0.211 (0.001) ^{d}	0.001 (0.001)	0.122 (0.002) ^{c}
	SR_7 Kisumu bridge	1.333 (0.006) ^{a}	0.008 (0.002) ^{a}	0.282 (0.002) ^{b}
	SR_8 Eldowas WW	0.203 (0.006)	0.005 (0.002) ^{b}	0.341 (0.001) ^{a}
Downstream	SR_9 Kengen power	0.200 (0.000)	0.001 (0.000)	0.251 (0.002) ^{b}
	SR_{10} Sosianisergoit	0.521 (0.002) ^{b}	0.002 (0.001) ^{c}	0.162 (0.002) ^{c}
Maximum		1.460	0.008	0.395
Minimum		0.001	0.001	0.070
Mean (N=30)**		0.458	0.004	0.212
Sediment Criteria (WHO) †		0.010	0.003	0.050

* Numbers in parentheses indicate Standard deviations (N=3)
** Overall mean (N=30)
† Sediment criteria obtained as equivalent to water quality criteria [49]
a b Significant heavy metal concentrations (Fisher's, Followed by Post-hoc B Tukey HSD, p< 0.05).

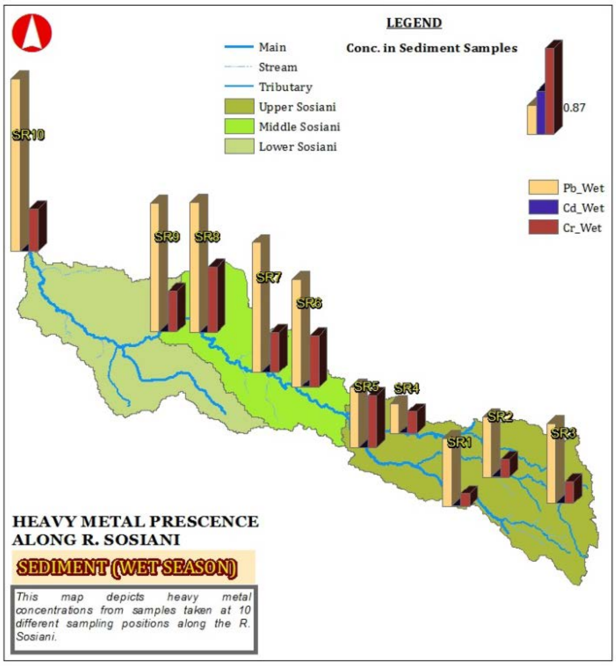

Figure 4. Spatial distribution of heavy metal concentration in sediment during the wet season

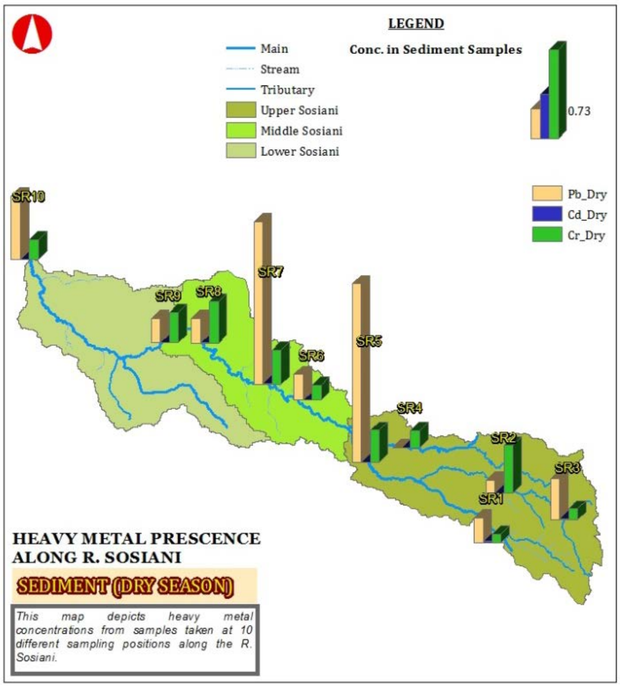

Figure 5. Spatial distribution of heavy metal concentration in sediment during the dry season

The data obtained from analysis of sediment concentration during the dry season is presented in Table 9. It is evident that SR_5 had the highest Pb concentration of 1.460 mg kg^{-1}; this was followed by SR_3 and SR_1 with 0.342 $mgkg^{-1}$ and 0.200 $mgkg^{-1}$, respectively. The concentration at SR_5 was significantly different (F (9, 20) = 4333.19, p = 0.00) at p< 0.05from SR_3, and SR_1. The Pb concentration at SR_4 was 0.001 $mgkg^{-1}$, which was rather curious taking into account that the reported concentration was equal to the control concentration; it denotes that activities producing Pb based contaminants are less in Naiber area compared to the other regions, Naiber being on a separate tributary. Within the mid catchment, SR_7 had a high Pb concentration of 1.333 $mgkg^{-1}$, significantly different (F (9, 20) = 4333.19, p = 0.00) at p < 0.05 from SR_6 and SR_8 with 0.211 and 0.203$mgkg^{-1}$, respectively. These comparatively higher concentrations show Pb contamination in the urban area. However, it should be noted that SR_3 in the upper catchment had a higher Pb concentration than SR_6, SR_7 and SR_8 despite its location. This means that Pb contamination during the dry season was not dependent on the catchment stage. The lower zone saw SR_9 and SR_{10} having sediment Pb concentrations of 0.200 and 0.521 $mgkg^{-1}$, respectively. The latter concentration can be attributed to possible Pb contamination from the wastewater and runoff are discharged through the Sosiani Sergoit confluence and Pb accumulation from both Eldoret and Turbo towns.

Cadmium

The Table 9 shows the spatial variation of heavy metal concentration in the upper, middle and lower Sosiani catchments during the wet season. Cd concentrations, show that in the upper Sosiani, sediments from SR_1, SR_2 and SR_3 registered the uppermost Cd levels of 0.008, 0.006 and 0.007$mgkg^{-1}$, respectively, which at p < 0.05 were significantly higher (F (9, 20) = 5.827, p = 0.00) compared to SR_4 and SR_5 with 0.002 and 0.001$mgkg^{-1}$, respectively. These high Cd concentrations indicate that the upper catchment has sources of Cd pollution that merit further investigation and possible mitigation, a possible causative factor being the use of DAP (Di-ammonium Phosphate) fertiliser.

In the mid zone, SR_6 and SR_7 had sediment Cd concentrations of 0.009 and 0.007$mgkg^{-1}$, respectively, which were comparable to concentrations at SR_1, SR_2 and SR_3. These concentrations are evidence of heightened urbanization and human activities with associated Cd contamination of the environment. For the lower zone, sampling station SR_{10} and SR_9 both recorded cadmium concentrations of 0.002$mgkg^{-1}$. These levels are lower compared to the upstream concentrations, which imply that downstream of SR_8. point sources of Cd were few.

In the dry season, SR_3 (Chepkorio) and SR_1 (Kaptagat site 1) had the highest Cd concentration, reporting a value of 0.010 $mgkg^{-1}$, which was significantly different (F (9, 20) = 253.52, p = 0.00) at p < 0.05 from all the other sampling stations within the zone where sediments SR_2, SR_4 and SR_5 had Cd levels of 0.002, 0.001 and 0.001 $mgkg^{-1}$, respectively. The mid zone however had its sampling sites SR_7 and SR_8 registering comparatively higher Cd concentrations at 0.008 and 0.005 $mgkg^{-1}$, respectively, significantly higher (F (9, 20) = 253.52, p = 0.00) at p < 0.05 than SR_6 which had 0.001 $mgkg^{-1}$, respectively, showing that in the dry season anthropogenic sources of Cd are critical in the urban area. Conversely, the lower catchment saw its sampling stations SR_9 and SR_{10} having Cd concentrations of 0.001 and 0.002$mgkg^{-1}$, respectively, which were lower than the prescribed criteria.

Chromium

In the upper Sosiani, SR_5 registered the highest Cr sediment levels of 0.525$mgkg^{-1}$ in the wet season (Table 8), which is a high value indicative of possible non-point source of Cr pollutants. The other stations including SR_4, SR_3 and SR_2 had sediment Cr concentrations of 0.220, 0.222 and 0.188$mgkg^{-1}$, respectively, which at $p < 0.05$ were significantly lower ($F (9, 20) = 5.827$, $p = 0.00$) than SR_5 readings but higher than SR_1 with 0.127. This implies that there was possible downstream accumulation of Cr at SR_5 coupled with undocumented non-point sources within the vicinity of this sampling station. The mid-stream saw all the sampling stations registering comparatively higher sediment Cr concentrations within the entire catchment; SR_6 SR_7 and SR_8 had Cr concentrations of 0.527, 0.408 and 0.661mgkg^{-1}, respectively, with SR_8 being significantly higher ($F (9, 20) = 5.827$, $p = 0.00$) at $p < 0.05$ compared to SR_5, which in turn was significantly different. In the lower Sosiani catchment, sediment samples from SR_9 and SR_{10} registered chromium concentrations of 0.417 and 0.430mgkg^{-1}, respectively. The comparatively lower SR_9 (Kengen Power Station) is indicative of mass heavy metal settlement after SR_7, since additionally, It is worth noting that despite the presence of Eldowas at SR_8, the chromium levels at this sampling site were lower than at SR_6 and SR_7.

The data obtained from sediment concentration analysis during the dry season is presented in Table 9. From the Table, SR_2 had the highest sediment chromium concentration of 0.395 mgkg^{-1}; this was followed by SR_5 and SR_4 with 0.262 and 0.140 mgkg^{-1}, respectively. The concentration at SR_2 was significantly higher ($F (9, 20) = 253.52$, $p = 0.00$) at $p < 0.05$ compared to SR_5 and SR_4. The Cr concentrations from sediments at SR_1 and SR_3 was 0.070 and 0.092 mgkg^{-1}, respectively which was higher than the control sample concentration, but lower compared to the other upstream sites. Within the mid catchment, SR_8 had a high Cr concentration of 0.341 mgkg^{-1}, which at $p < 0.05$ were significantly higher ($F (9, 20) = 253.52$, $p = 0.00$) than SR_7 and SR_6 with 0.282 and 0.122mgkg^{-1}, respectively. These comparatively higher concentrations are indicative of higher Cr contamination in the urban area. It should be noted that SR_2 in the upper catchment had a higher Pb concentration than SR_6 and SR_7, despite its location, implying the independence of Cr contamination on the river stage, hence could be attributable to local geology. The lower zone had SR_9 and SR_{10} having sediment Cr concentrations of 0.251 and 0.162 mgkg^{-1}, respectively, the SR_9 concentration being higher than that at SR_{10}.

The presence of heavy metals in the environment is from natural or anthropogenic sources, but their concentrations are elevated rapidly through waste disposal and smelter stacks. Hence, distribution of heavy metals in sediments provides evidence of the impact of anthropogenic activities on aquatic ecosystems. Heavy metals are identifiable in sediments samples due to the nature of the sample which has both dissolved and non-dissolvable particulate matter. Additionally, the behaviour of heavy metals in water is a function of the water chemistry, substrate sediment composition and the suspended sediment composition. Thus, during their transportation within rivers, these trace metals undergo changes in their speciation due to dissolution, sorption, precipitation, and complexation phenomena [32].

Dissolved particulate matter in the water regularly mixes while depositing the heavy metal in the solid particles in the river bed. This elevates heavy metal concentration, especially during the rainy season which is traceable to runoff whereby secondary particles with heavy metals concentrations are washed up and drain into the rivers thereby elevating the heavy metal concentrations [52]. Also, during the rainy season, the intense activity in the industrial and agriculture sectors inevitably leads to elevated levels of heavy metals in natural waters (Karadede, Oymak and Ünlü, 2004). Another issue that lead to increased heavy metals concentration levels arises from the management of waste in urban environments such as municipal waste from public places, and industrial waste from manufacturing firms and industrial plants (Ndwiga, 2016).This mix up in the waste will also elevate the concentration of heavy metals in the environment in cases where waste disposal, handling and management are not coping with the production systems that generate the same waste.

3.3.2. Temporal Variations in Heavy Metal Concentration

Table 10 presents the statistics of heavy metal concentration variations in the River Sosiani catchment during the dry and wet seasons, respectively ($p < 0.05$); A general difference was observed in Pb, Cd and Cr concentrations as the seasons changed. This difference was based on data obtained from the individual sampling locations SR_1 to SR_{10}. An analysis of the temporal variation of Pb concentrations within the catchment sediments indicated that with the exception of SR_5 and SR_7, the sampling stations SR_1 to SR_{10} reported significantly higher ($t (29) = 4.711$, $p = 0.000$) Pb levels during the wet season compared to the dry season, with mean concentrations of 0.978 mgkg^{-1} ($N = 10$) and 0.458mgkg^{-1} ($N = 10$), respectively. Moreover, the Pb concentrations obtained in both seasons are above the WHO tolerable drinking water Pb levels of 0.01mgl^{-1} [49].

In respect to Cd, analysis of the temporal variation in Cd concentration is as presented in Table 10. It indicates that all the sites from SR_1 to SR_{10} with the exception of SR_3 and SR_7, had higher Cd concentration in the wet season compared to the dry season, with mean concentrations of 0.005mgkg^{-1}) and 0.004mgkg^{-1} respectively, a difference which was not significant ($t (29) = 1.427$, $p = 0.164$).

A site like SR_6 had a wet season sediment Cd concentration of 0.009mgkg^{-1}, nine times the Cd concentration observed from the same site in the dry season, a phenomenon indicative of high Cd accumulation within the sediments at this site.

Table 10. Statistics of temporal variations in heavy metal concentrations in sediments from sampling locations within River Sosiani

Heavy metal	Mean wet season concentration (mgkg^{-1})	Mean dry season concentration(mgkg^{-1})	t value ($p < 0.05$)	Significance
Lead	0.978	0.458	4.711	0.000*
Cadmium	0.005	0.004	1.427	0.164
Chromium	0.373	0.212	10.019	0.000*

*Highly significant at $p < 0.05$.

Temporal variations of Cr concentration 10 indicated all the sampling sites except SR_2 having higher concentrations in the wet season as compared to the dry season, with mean concentration of 0.373 $mgkg^{-1}$ and 0.212 $mgkg^{-1}$ for the wet season and dry season, respectively. Additionally, wet season concentrations were significantly higher ($t(29) = 10.019$, $p = 0.000$) compared to the dry season, indicative of higher Cr to sediment concentration in the wet season compared to the dry season.

The distribution of heavy metals in sediments can provide an evidence of the anthropogenic impact on aquatic ecosystems. This phenomenon identified in the sediment's samples arises because of the nature of the sample which has both dissolved and non-dissolvable particulate matter. The dissolved particulate matter is in the water regularly mixes while depositing the heavy metal in the solid particles in the river bed. Thus, this would cause the elevation of heavy metal concentration during the rainy season which is traceable to runoff that drains the mix of rain water and solid particles into the rivers. During the rain seasons, the secondary particles containing the heavy metals concentrations are washed up and drain into the rivers thereby elevating the concentrations of heavy metals [52].

3.4. Heavy Metal Concentration in Fish

3.4.1. Barbusbarbus

Spatial variations in heavy metal concentration

The Table 11 and Table 12 show the levels of heavy metals within *Barbusbarbus* fish obtained from the upper, middle and lower catchments of River Sosiani during the wet and dry seasons (temporal variations), respectively while Figure 6 and Figure 7 show the spatial distributions of the concentrations of heavy metals in fish. From the Tables, the information on respective heavy metal contamination levels can be adduced.

Lead

In the upper Sosiani, *Barbusbarbus* fish from SR_3 (Chepkorio) registered the highest Pb levels of 0.977$mgkg^{-1}$ (wet season); this was followed by SR_5 and SR_4 with 0.827 and 0.817 $mgkg^{-1}$, respectively (Table 11), with SR_3 being significantly higher ($F(9, 20) = 40.42$, $p = 0.00$) at $p < 0.05$ than SR_5 and SR_4.

In the same sub catchment, fish from SR_2 and SR_1 had Pb concentrations of 0.267 and 0.063$mgkg^{-1}$, respectively. The results reinforce the fact that Chepkorio (SR_3) has a major source of Pb pollution despite not being counted amongst the point pollutants within the catchment, a phenomenon reinforced by evidence from the water (Table 5 and Table 6) and sediment (Table 8 and Table 9) data. The mid catchment had sampling locations SR_7 and SR_8 with Pb concentrations of 1.030 and 1.027$mgkg^{-1}$, respectively, and SR_6 whose fish Pb concentrations were 0.217$mgkg^{-1}$, a value that was significantly the lowest along the whole catchment. The comparatively higher values at SR_7 and SR_8 show higher Pb contamination in the midstream region as a result of anthropogenic activities. However, the low Pb concentration at SR_6 can be adduced to its distance from SR_5, this long distance results in Pb deposition within the sediments along the river between SR_5 and SR_6 resulting in lower water concentrations, thus depriving the *Barbusbarbus* fish since they are water feeders. In the lower catchment, *Barbusbarbus* from sampling station SR_9 registered Pb concentrations of 1.230$mgkg^{-1}$ (wet season), which was significantly higher ($F(9, 20) = 40.42$, $p = 0.00$) at $p < 0.05$ compared to SR_{10} at 1.013$mgkg^{-1}$. These lower levels compared to SR_9, also implicate new injection of Pb into the river water, taking into account that the sampling station is downstream to the Eldoret Armed Forces Ordinance Factory, a fact also observed during analysis of the water samples.

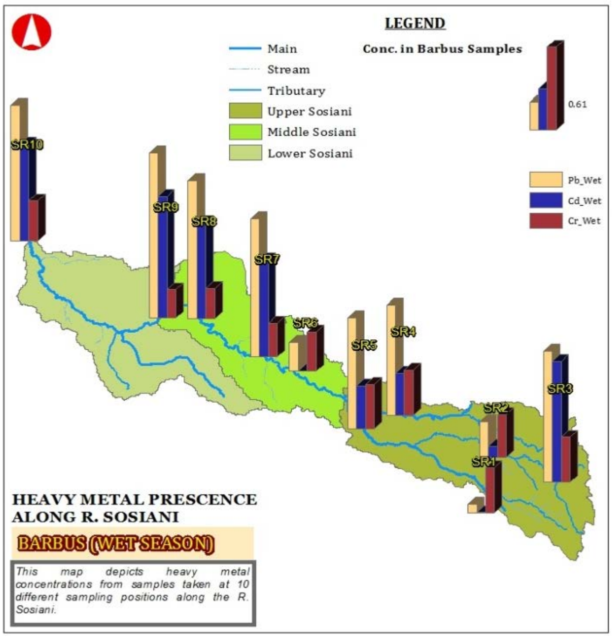

Figure 6. Spatial distribution of heavy metal concentration in *Barbusbarbus* during the wet season

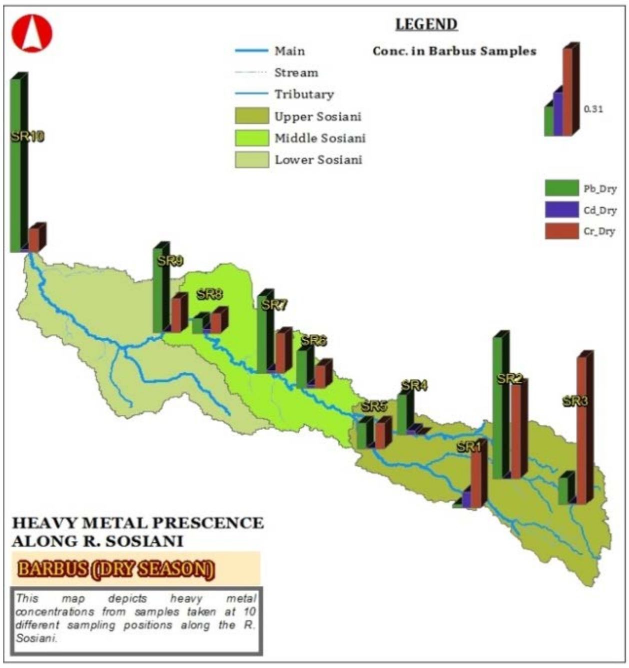

Figure 7. Spatial distribution of heavy metal concentration in *Barbusbarbus* during the dry season

Table 11. Wet season heavy metal concentrations in *Barbusbarbus* fish samples from river Sosiani

Tributary	Sampling location	Heavy metal concentrations (mgkg^{-1})		
		Lead	Cadmium	Chromium
Control	SR_0	Nil	Nil	Nil
Upstream	SR_1: Kipsenende	0.063 (0.003) [c]	0.001(0.000) [e]	0.333(0.006) [a]
	SR_2: Ellegerine	0.267 (0.003) [d]	0.082 (0.001) [e]	0.320(0.010) [a]
	SR_3: Chepkorio	0.977 (0.006) [b]	0.902 (0.001) [a]	0.337(0.015) [a]
	SR_4: Naiber	0.817 (0.012) [c]	0.310 (0.010) [c]	0.337(0.006) [a]
	SR_5: Nundoroto	0.827 (0.025) [c]	0.317 (0.015) [c]	0.330(0.010) [a]
Midstream	SR_6: Nairobi bridge	0.217 (0.021) [d]	0.001 (0.000) [d]	0.293(0.006) [ab]
	$SR_{7\ Kisumu}$ bridge	1.030 (0.010) [b]	0.723 (0.006) [b]	0.250(0.010) [b]
	SR_8 Eldowas WW	1.027 (0.025) [b]	0.713 (0.012) [b]	0.227(0.006) [b]
Downstream	SR_9 Kengen power	1.230 (0.010) [a]	0.907 (0.006) [a]	0.213(0.012) [b]
	SR_{10}Sosiani sergoit	1.013 (0.023) [b]	0.720 (0.020) [b]	0.300(0.000) [ab]
Maximum		1.230	0.907	0.337
Minimum		0.063	0.001	0.213
Mean (N=30)		0.745	0.294	0.468
Admissible limit		0.30[†]	0.050[‡]	0.10

* Numbers in parentheses indicate Standard deviations (N=3)
** Overall mean (N=30)
[†] [53]
[‡] [54]
[a b] Significant heavy metal concentration(Fisher's, Followed by Post-hoc B Tukey HSD p< 0.05).

Table 12. Dry season heavy metal concentrations in *Barbusbarbus* fish samples from river Sosiani

Tributary	**Sampling location**	**Heavy metal concentrations (mgkg^{-1})**		
		Lead	**Cadmium**	**Chromium**
Upstream	SR_1: Kipsenende	0.011 (0.001)	0.056 (0.001) [a]	0.220 (0.001) [c]
	SR_2: Ellegerine	0.500 (0.000) [b]	0.001 (0.001)	0.331 (0.001) [b]
	SR_3: Chepkorio	0.097 (0.006) [d]	0.004 (0.001)	0.523 (0.006) [a]
	SR_4: Naiber	0.140 (0.001) [d]	0.013 (0.000) [b]	0.000 (0.000)
	SR_5: Nundoroto	0.091 (0.001) [d]	0.001 (0.000)	0.092 (0.002)
Midstream	SR_6: Nairobi bridge	0.133 (0.006) [d]	0.013 (0.002) [b]	0.082 (0.002)
	SR_7Kisumu bridge	0.276 (0.035) [c]	0.011 (0.001)	0.141 (0.001)
	SR_8Eldowas WW	0.052 (0.002)	0.015 (0.001) [b]	0.071 (0.002)
Downstream	SR_9Kengen power	0.300 (0.000) [c]	0.005 (0.001)	0.121 (0.002)
	SR_{10}Sosiani sergoit	0.613 (0.015) [a]	0.009 (0.001)	0.082 (0.002)
Maximum		0.500	0.056	0.523
Minimum		0.011	0.001	0.000
Mean (N=30)		0.221	0.013	0.166
Admissible limit		0.30[†]	0.050[†]	0.10[‡]

* Numbers in parentheses indicate Standard deviations (N=3)
** Overall mean (N=30)
[†] [53]
[‡] [54]
[a b] Significant heavy metal concentration(Fisher's, Followed by Post-hoc B Tukey HSDp= 0.05).

During the dry season, from the data presented in Table 12, it is evident that apart from SR_2 with Pb concentration 0.500mgkg^{-1}, all *Barbusbarbus* fish from the other sampling locations had Pb concentrations lower than the wet season concentrations. Moreover the SR_2 concentration was the highest in the upper catchment and at $p < 0.05$ significantly higher ($F (9, 20) = 9.32$, $p = 0.00$) than SR_1, SR_3, SR_4 and SR_5 with 0.011, 0.097, 0.140 and 0.091mgkg^{-1}, respectively. In the mid catchment, the fish obtained from sampling locations SR_6, SR_7 and SR_8 had Pb concentration of 0.133, 0.276 and 0.052mgkg^{-1}, respectively. The lower catchment of the Sosiani basin had fish from SR_9 and SR_{10} having Pb concentrations of 0.300 and 0.613 mgkg^{-1}, respectively, whereby the concentration at SR_{10} was at $p < 0.05$, the highest ($F (9, 20) = 9.32$, $p = 0.00$) in the whole basin.

Cadmium

The Table 11 shows the disparities in Cd concentration from *Barbusbarbus* fish collected in the upper, middle and lower Sosiani catchments during the wet season. The concentrations, show that in the upper Sosiani, *Barbus* fish from SR_3 registered the uppermost Cd levels at 0.902mgkg^{-1}, which was at $p < 0.05$ significantly higher ($F (9, 20) = 4292.21$, $p = 0.00$) compared to SR_4 and SR_5 which had 0.310 and 0.317 mgkg^{-1}, respectively. These two sites also had their fish Cd concentrations higher than SR_1 and SR_2, which had Cd concentrations of 0.001 and 0.082mgkg^{-1}, respectively. These high Cd concentrations indicate fish ingestion of cadmium-based compounds within the waters at respective sampling locations. In the mid catchment, fish from SR_7 and SR_8 had Cd concentrations of 0.723 and 0.713mgkg^{-1}, respectively, which were higher when compared to concentrations in the upper catchment, signifying presence of Cd in the eaters therein. These SR_7 and SR_8 concentrations were higher compared to SR_6 (0.001mgkg^{-1}), and are also evidence of heightened anthropogenic activities with associated Cd contamination of the environment. A look at the lower catchment of the Sosiani shows that fish from SR_9 and SR_{10} had Cd concentrations of 0.907 and 0.720mgkg^{-1}, respectively. It should be noted that the concentration at SR_9 was the highest in the entire catchment, implying that the feeding locations for fish at this sampling location have heavy Cd pollution.

A different trend is observed during the dry season (Table 12) whereby fish from all sites had lower Cd concentrations compared to the wet season. For instance in the upper catchment, fish from SR_1 had the highest Cd concentration at 0.056mgkg^{-1}, significantly higher (F (9, 20) = 1006.79, p = 0.00) at $p< 0.05$ compared to SR_4, SR_3, SR_2 and SR_5, having Cd concentrations of 0.013, 0.004, 0.001 and 0.001mgkg^{-1}, respectively. It indicates that despite the presence of Cd within the eaters at these sampling sites is lower, attributable to less runoff during the dry season.

The trend persists in the mid catchment whereby fish from SR_6, SR_7 and SR_8 had Cd concentrations of 0.013, 0.011 and 0.015 mgkg^{-1}, respectively, concentrations which despite being lower than those for the same sampling sites during the wet season, showed that fish from this sub-catchment had at $p < 0.05$, significantly the highest (F (9, 20) = 1006.79, p = 0.00) dry season cadmium concentrations in the whole basin. The lower catchment had its fish with cadmium levels of 0.005 and 0.009 mgkg^{-1} for sites SR_9 and SR_{10}, respectively, The lower concentrations are indicative of reduced intensity of anthropogenic activities downstream.

Chromium

Data for *Barbusbarbus* Cr concentrations in the dry and wet seasons are as presented in Table 12 and Table 11, respectively. During the wet season (Table 11), all the sampling locations in the upper Sosiani, i.e. SR_1, SR_2, SR_3, SR_4, and SR_5 had Cr concentrations of 0.333, 0.320, 0.337, 0.337 and 0.330 mgkg^{-1} respectively, an indication that feeding sites for the fish in this part of the Sosiani had almost equal Cr concentrations. The mid Sosiani saw fish from all the sampling stations registering comparatively lower Cr concentrations whereby SR_6 SR_7 and SR_8 had Cr concentrations of 0.293, 0.250 and 0.227mgkg^{-1}, respectively, which were significantly lower (F (9, 20) = 74.72, p = 0.00) at $p <0.05$ compared to the upper catchment. In the lower Sosiani catchment, *Barbusbarbus* fish samples from SR_9 and SR_{10} registered chromium concentrations of 0.213 and 0.308 mgkg^{-1}, respectively, with SR_9 being marginally lower (F (9, 20) = 74.72, p = 0.00 at $p< 0.05$ than SR_{10}, the latter not being significantly different from upstream concentrations. The lower SR_9 (Kengen Power Station) is indicative of mass heavy metal settlement after SR_7, hence a dilution of the available Cr within the waters, rendering the fish with less aquatic Cr sources.

The data obtained from *Barbusbarbus* Cr concentration analysis during the dry season is presented in Table 12. From which, fish at SR_3 had the highest chromium concentration of 0.523 mgkg^{-1}; followed by SR_2 and SR_1 with 0.331 and 0.220 mgkg^{-1}, respectively. The concentration at SR_3 was significantly higher (F (9, 20) = 12800.29, p = 0.00) at $p <0.05$ compared to SR_2 and SR_1, which were in turn, higher compared to SR_4 and SR_5 with fish chromium concentrations of 0.000 and 0.092mgkg^{-1}, respectively. Within the mid catchment, SR_7 had a high chromium concentration of 0.141 mgkg^{-1}, significantly higher (F (9, 20) = 12800.29, p = 0.00) at $p < 0.05$ than SR_6 and SR_8 with 0.082 and 0.071mgkg^{-1}, respectively. These concentrations are indicative of high chromium contamination in the urban area, but being in the same concentration band as some upstream sites (SR_4 and SR_5); hence could also be attributable to local geology. The lower catchment had SR_9 and SR_{10} having *Barbusbarbus* chromium concentrations of 0.121 and 0.082 mgkg^{-1}, respectively.

3.4.2. Temporal Heavy Metal Concentration

The Table 12 presents the statistics of temporal heavy metal concentration variations from *Barbusbarbus* fish in the River Sosiani catchment ($p< 0.05$); a general difference was observed in Pb, Cd and Cr concentrations as the seasons changed. This difference was based on data obtained from the individual sampling locations SR_1 to SR_{10}. Analysis of the temporal variation of Pb concentrations in fish within the catchment waters indicated that with the exception of SR_5, all other sampling stations had higher Pb levels during the wet season compared to the dry season, with mean concentrations of 0.747 mgkg^{-1} (N = 10) and 0.221 mgkg^{-1} (N = 10), respectively. However t-test analysis ($p< 0.05$) indicated an insignificant difference (t (29) = 1.527, p = 0.161) between the means. With respect to Cd, analysis of the temporal variation in Cd concentration within *Barbusbarbus* fish as presented in Table 11 indicated that all the sites from SR_1 to SR_{10},with the exception of SR_1 and SR_6,had higher Cd concentration in the wet season compared to the dry season, with mean concentrations of 0.294 mgkg^{-1} and 0.013 mgkg^{-1}, respectively, with a statistical difference deemed not significant (t (29) = -0.945, p = 0.369). Temporal variations of Cr concentration (Table 12) indicated all the sampling sites except SR_2 and SR_3 having higher concentrations in the wet season as when compared to the dry season, with mean concentration of 0.468 mgkg^{-1}and 0.166 mgkg^{-1} for the wet season and dry season, respectively. Similarly, wet season concentrations were not significantly different (t (29) = 0.213, p = 0.836) compared to the dry season, indicative of a mixed trend in Cr concentration, regardless of the season. The results obtained for Cr are in tandem with those by [35] who indicated that Cd and Cr in *Barbusbarbus* fish muscle ranged between 0.0 to 0.031mg/kg (0.02 mgkg^{-1}) and 0.001 to 0.03mgkg^{-1} (0.007mgkg^{-1}) respectively. The study by [35] only focused on the fish organs, thereby the lower levels when compared to this study. The results confirm the postulate by [55] of toxic chemicals accumulation in fish inhabiting contaminated waters.

3.4.3. Catfish

Spatial variations in heavy metal concentration

The Table 14 and Table 15 show the spatial variations in levels of heavy metals within catfish caught from the upper, middle and lower catchments of river Sosiani, while Figure 8 and Figure 9 show the spatial distributions of the concentrations. From these Tables, the information on respective heavy metal contamination levels can be documented.

Lead

In the upper Sosiani, catfish from SR_5 (Nundoroto) had the highest lead levels of 0.087 $mgkg^{-1}$, which at $p < 0.05$, were not significantly higher ($F (9, 20) = 1.327$, $p = 0.285$) than SR_1, SR_2 and SR_4, having concentrations of 0.050, 0.040 and 0.050$mgkg^{-1}$, respectively (Table 14). Conversely, catfish from SR_3 (Chepkorio) had the lowest lead concentration (0.010 $mgkg^{-1}$). The mid catchment had catfish from sampling locations SR_6, SR_7, and SR_8 reporting lead concentrations of 0.043, 0.060, 0.050$mgkg^{-1}$, respectively. The high lead concentration at SR_7 is ascribable to intense urban activity in its vicinity with SR_7 being located near the Eldoret MTRH facility. A similar deduction is also applicable to SR_6 which is on the main road to Nairobi. In the lower catchment, catfish from SR_{10} (Sosiani-Sergoit confluence) registered lead concentrations of 0.324$mgkg^{-1}$ for the wet season, which was not only significantly higher than SR_9 with 0.067$mgkg^{-1}$ but also the highest in the entire catchment. These higher levels compared to SR_9, imply new injection of lead into the river water, taking into account that the sampling station is downstream to the Eldoret Armed Forces Ordinance Factory, and manifested in the catfish.

A similar trend is observed during the dry season (Table 15) whereby with the exception of SR_6 and SR_8, catfish from all sites had lower Pb concentration compared to the wet season. For example, in the upper catchment, fish from SR_5 had the highest Pb concentration at 0.060 $mgkg^{-1}$, significantly higher ($F (9, 20) = 77.03$, $p = 0.00$) at $p < 0.05$ compared to SR_4, SR_3, SR_2 and SR_1 with Pb concentrations of 0.030, 0.010, 0.030 and 0.020$mgkg^{-1}$, respectively. It indicates an increase in Pb concentration within the fish during the dry season as one approach the urban centre, attributable to less runoff during the dry season. A slightly different trend is seen in the mid catchment whereby catfish from SR_6, SR_7 and SR_8 had Pb concentrations of 0.060, 0.041 and 0.051 $mgkg^{-1}$, respectively, concentrations which with the exception of SR_7 were higher than those for the same sampling sites during the wet season, but significantly higher ($F (9, 20) = 77.03$, $p = 0.00$) at $p < 0.05$. Within the lower catchment, SR_9 and SR_{10} had catfish caught therein with Pb concentrations of 0.030 and 0.060$mgkg^{-1}$, respectively.

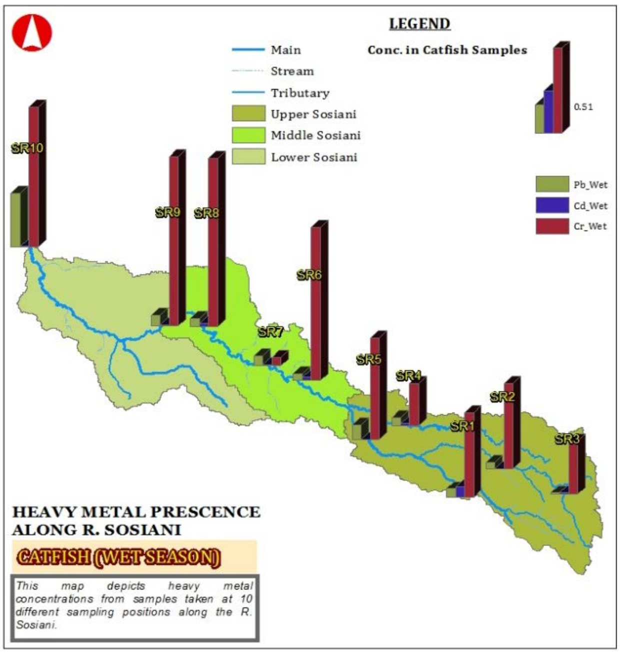

Figure 8. Spatial distribution of heavy metal concentration in catfish during the wet season

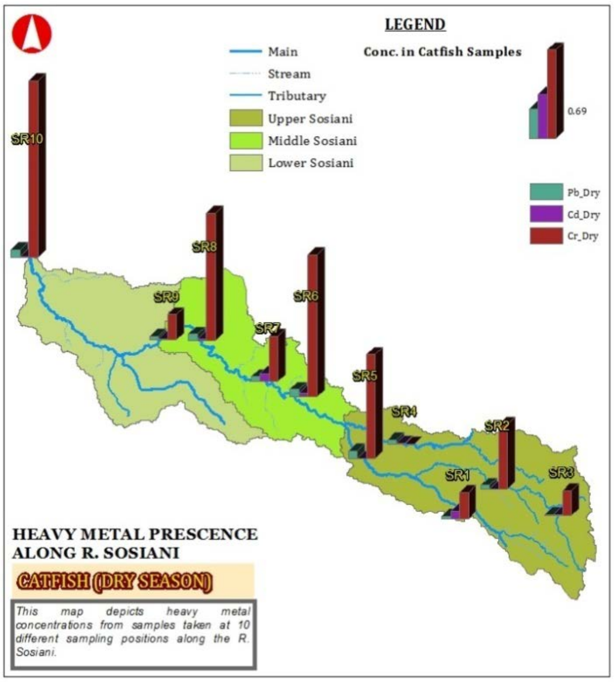

Figure 9. Spatial distribution of heavy metal concentration in catfish during the dry season

Table 13. Statistics of temporal variations in heavy metal concentrations in*Barbusbarbus* fish from sampling locations within River Sosiani

Heavy metal	Mean wet season concentration($mgkg^{-1}$)	Mean dry season concentration($mgkg^{-1}$)	t value ($p< 0.05$)	Significance
Lead	0.747	0.221	1.527	0.161
Cadmium	0.294	0.013	-0.945	0.369
Chromium	0.468	0.166	0.213	0.836

Table 14. Wet season Heavy Metal Concentrations in Catfish samples from river Sosiani

Tributary	Sampling location	Heavy metal concentrations (mgkg^{-1}) *		
		Lead	Cadmium	Chromium
Upstream	SR_1: Kipsenende	0.050 (0.010)^{c}	0.060 (0.000)^{a}	0.507(0.012)
	SR_2: Ellegerine	0.040 (0.010)^{c}	0.001 (0.000)	0.513(0.015)
	SR_3: Chepkorio	0.010 (0.000)^{d}	0.010 (0.000)^{c}	0.320(0.020)
	SR_4: Naiber	0.050 (0.010)^{c}	0.011 (0.002)^{c}	0.252(0.002)
	SR_5: Nundoroto	0.087 (0.006)^{b}	0.001 (0.000)	0.613(0.012)^{b}
Midstream	SR_6: Nairobi bridge	0.043 (0.006)^{c}	0.020 (0.002)^{b}	0.923(0.015)^{a}
	SR_7: Kisumu bridge	0.060 (0.000)^{c}	0.006 (0.001)	0.051(0.002)
	SR_8: Eldowas WW	0.050 (0.000)^{c}	0.022 (0.002)^{b}	1.013(0.015)^{a}
Downstream	SR_9: Kengen power	0.067 (0.006)^{bc}	0.009 (0.001)^{c}	1.020(0.020)^{a}
	SR_{10}: SosianiSergoit	0.324 (0.042)^{a}	0.004 (0.000)	0.843(0.000)^{ab}
Maximum		0.324	0.022	1.020
Minimum		0.010	0.001	0.051
Mean**		0.078	0.606	0.014
Admissible limit		0.30†	0.050†	0.10‡

* Numbers in parentheses indicate Standard deviations (N=3)
** Overall mean (N=30)
† [53]
‡ [54]
ab Significant heavy metal concentrations (Fisher's, Followed by Post-hoc B Tukey HSDp= 0.05).

Table 15. Dry season Heavy Metal Concentrations in Catfish samples from river Sosiani

Tributary	Sampling location	Heavy metal concentrations (mgkg^{-1})		
		Lead	Cadmium	Chromium
Upstream	SR_1: Kipsenende	0.020 (0.000)	0.057 (0.001)^{a}	0.207(0.012)
	SR_2: Ellegerine	0.030 (0.000)	0.001 (0.001)	0.510(0.010)
	SR_3Chepkorio	0.010 (0.000)	0.008 (0.000)	0.200(0.000)
	SR_4Naiber	0.030 (0.000)	0.006 (0.001)	0.000(0.000)
	SR_5Nundoroto	0.060 (0.010)^{a}	0.002 (0.002)	0.817(0.015)^{b}
Midstream	SR_6Nairobi bridge	0.060 (0.000)^{a}	0.033 (0.001)^{b}	1.117(0.015)^{a}
	SR_7Kisumu bridge	0.040 (0.000)	0.061 (0.001)^{a}	0.357(0.046)
	SR_8Eldowas WW	0.051 (0.001)^{b}	0.012 (0.001)^{c}	1.000(0.010)^{ab}
Downstream	SR_9Kengen power	0.030 (0.000)	0.013 (0.002)^{c}	0.200(0.000)
	SR_{10}Sosiani Sergoit	0.060 (0.000)^{a}	0.006 (0.000)	1.390(0.010)^{a}
Maximum		0.060	0.061	1.390
Minimum		0.010	0.001	0.000
Mean**		0.039	0.579	0.020
Admissible limit		0.30†	0.050†	0.10‡

* Numbers in parentheses indicate Standard deviations (N=3)
** Overall mean (N=30)
† [53]
‡ [54]
a b Significant heavy metal concentration(Fisher's, Followed by Post-hoc B Tukey HSDp< 0.05).

Cadmium (Cd)

Spatial variations of heavy metal concentrations within the River Sosiani upper, middle and lower catchments in the wet season show that for Cd concentrations, It is observed that catfish from the upper Sosiani, SR_1 registered the uppermost Cd levels of 0.060 mgkg^{-1}, significantly higher (F (9, 20) = 842.16, p = 0.00) at $p < 0.05$, compared to SR_5, SR_4, SR_3 and SR_2 with Cd concentrations of 0.001, 0.011, 0.010 and 0.001mgkg^{-1}, respectively. This sampling site is almost on the source of the Sosiani River and indicates sediment enrichment by Cd compounds, which is transferred to the fish. The mid catchment saw fish from SR_8 (Eldowas wastewater) reporting a high Cd concentration of 0.022mgkg^{-1} which was followed by SR_6 and SR_7 with Cd concentrations 0.020 and 0.006 0.001 mgkg^{-1}, respectively, and SR_8 and SR_9 being at $p < 0.05$, significantly higher (F (9, 20) = 842.16, p = 0.00) compared to SR_7. For the lower catchment, fish from sampling station SR_9 (Kengen) recorded a Cd concentrations of 0.009 mgkg^{-1}, which was significantly higher compared to SR_{10} that had a concentration of 0.004 mgkg^{-1}(dry season), SR_{10} being significantly higher (F (9, 20) = 842.16, p = 0.00) at $p < 0.05$ compared to SR_9. Both the downstream concentrations (SR_9 and SR_{10}) were lower than those obtained at SR_8 implying that fish downstream of the urbanised region have less exposure to Cd.

In the dry season (Table 15), fish caught from SR_1 had the highest Cd concentration at 0.057mgkg^{-1}, which was the highest in the sub-catchment and significantly different (F (9, 20) = 1261.31, p = 0.00) at $p < 0.05$ compared to the other sampling locations such as SR_2, SR_3, SR_4 and SR_5 with Cd concentrations of 0.001, 0.008, 0.006 and 0.002 mgkg^{-1}, respectively. Additionally, catfish caught at SR_3 and SR_4 had their Cd concentrations significantly higher (F (9, 20) = 1261.31, p = 0.00) at $p < 0.05$ than those caught at SR_2 and SR_3. Midstream of the Sosiani, catfish from SR_7 had the highest Cd concentration (0.061mgkg^{-1}) which was higher compared to SR_6 and SR_8, having 0.033 and 0.012 mgkg^{-1}, respectively. Finally, the lower catchment had catfish from SR_9 and SR_{10} having Cd concentrations of 0.013 and 0.006 mgkg^{-1}, respectively.

Chromium (Cr)

The Cr concentration data from catfish caught from the Sosiani basin during the wet and dry seasons is as presented in Table 14 and Table 15, respectively. It is observed that with regard to Cr concentration, during the wet season, catfish from the upper Sosiani sub-catchment had Cr concentrations exceeding the WHO thresholds, despite the fact that the zone was rural. For instance, at SR_5, the Cr concentration was 0.613mgkg^{-1}; a figure indicating the presence of non-point Cr pollution. It was followed by fish from SR_1 and SR_2 with Cr concentrations 0.507 and 0.51mgkg^{-1}, respectively, with SR_5 being at $p < 0.05$, significantly higher (F (9, 20) = 1707.29, p = 0.00) compared to SR_1 and SR_2. Within this upper sub-catchment, the lowest Cr concentrations were observed from catfish caught at SR_4 (0.252mgkg^{-1}). The mid catchment had sampling locations SR_6 and SR_8 reporting higher Cr concentrations of 0.923mgkg^{-1} and 1.013 mgkg^{-1}, respectively, which were significantly higher (F (9, 20) = 1707.29, p = 0.00) at $p < 0.05$ compared to fish from SR_7 having Cr concentration of 0.051mgkg^{-1}. On the other hand, within the lower catchment, fish from SR_9 and SR_{10} registered Cr concentrations of 1.020 and 0.843mgkg^{-1}, respectively, for the wet season. These concentrations were statistically not significantly different (F (9, 20) = 1707.29, p = 0.00) at p <0.05 from SR_8 and SR_6 concentrations, indicating an almost uniform Cr contamination within the mid and lower catchments of the Sosiani River.

During the dry season, a similar phenomenon to the wet was observed; for catfish from SR_5, the Cr concentration was 0.817mgkg^{-1}; similarly, indicative of non-point Cr pollution. It was followed by fish from SR_2 with Cr concentrations of 0.510 mgkg^{-1}, with SR_5 being significantly higher (F (9, 20) = 30.03, p = 0.00) at $p < 0.05$ compared to SR_2. The remaining sites SR_1, SR_3 and SR_4 had fish caught therein having Cr concentrations of 0.207, 0.200 and 0.000 mgkg^{-1}, respectively, which were significantly lower compared to SR_2 and SR_5. The mid catchment had sampling locations SR_6 and SR_8 reporting higher Cr concentrations of 1.117mgkg^{-1} and 1.000 mgkg^{-1}, respectively, which were at p <0.05 significantly higher F (9, 20) = 30.03, p = 0.00) compared to fish from SR_7 which had a Cr concentration of 0.357mgkg^{-1}. A glance at the lower sub-catchment shows that fish from SR_9 and SR_{10} had Cr concentrations 0.200 and 1.390mgkg^{-1}, respectively.

Table 16. Statistics of temporal variations in heavy metal concentrations in catfish from sampling locations within River Sosiani

Heavy metal	Mean wet season concentration (mgkg^{-1})	Mean dry season concentration (mgkg^{-1})	t value (p< 0.05)	Significance
Lead	0.078	0.039	3.916	0.004^{ns}
Cadmium	0.606	0.579	3.861	0.004^{ns}
Chromium	0.014	0.020	2.769	0.022^{ns}

^{ns} Not significant at p< 0.05.

Temporal variation in heavy metal concentrations

The Table 15 presents the temporal heavy metal concentration statistics for catfish caught from sites SR_1 to SR_{10} in the River Sosiani catchment at $p < 0.05$; a general difference was observed in Pb, Cd and Cr concentrations, with changes in seasons. Analysis of the temporal variation of Pb concentrations in catfish within the catchment waters indicated that with the exception of SR_6, all other sampling stations had higher Pb levels during the wet season compared to the dry season, with mean concentrations of 0.078 mgkg^{-1} and 0.039 mgkg^{-1}, respectively, with insignificant difference between the means (t (29) = 3.916, p = 0.004). With respect to Cd, temporal variation in Cd concentration within catfish as presented (Table 15) indicated that 60% of all the sites from SR_1 to SR_{10} (i.e. excluding SR_5, SR_6, SR_7 and SR_{10}) had higher Cd concentration in the wet season compared to the dry season, with mean concentrations of 0.606 mgkg^{-1} and 0.579 mgkg^{-1}, respectively, whereby, just like in Pb, the statistical difference was deemed not significant (t (29) = 3.861, p = 0.004). Regarding Cr concentration (Table 15), temporal variations indicated an equal distribution whereby 50% of the sampling sites (SR_1, SR_2, SR_3, SR_4 and SR_8) had higher concentrations in the wet season compared to the dry season, with total mean concentration of 0.014 mgkg^{-1}and 0.020 mgkg^{-1} for the wet season and dry season, respectively. Similarly, wet season concentrations were not significantly different (t (29) = 2.769, p = 0.004) from the dry season, indicative of a mixed trend in Cr concentration, regardless of the season. The results confirm the postulate by [55] of toxic chemicals accumulation in fish inhabiting contaminated waters. Despite measures to reduce trace metal input into oceans, rivers and estuaries, heavy metal accumulation in the different aquatic systems is still being reported [2,4,5]. This calls for more efficient WWTPs to remove both the macro and the micro chemicals from the effluent which normally varies with the nature of the chemical compound in question [56].

4. Conclusion& Recommendation

Spatial variations in heavy metal concentration were observed within the catchment; For instance a review of the spatial variation in heavy metal concentration within the sites showed that during the wet season, water at

Chepkorio had the highest Pb concentration, having 0.127mgkg^{-1}. This location was in the upper catchment which implies possible point sources of Pb contamination. Its concentration is actually higher compared to waters from river Sosiani at Eldowas wastewater having 0.084, at Kisumu bridge 0.072 and at Nairobi bridge with 0.063 mgkg^{-1}, respectively, attributable to heavy metal deposition between the upper and the mid catchment. In 2013, Amadi [45] got results of 0.77mg/l Pb in water at Kaptagat. This was very high values that exceeded both the WHO and the NEMA STDs in water. The results are also in agreement with what Jepkoech [34] found in the upper Catchment of 0.18 mg/l Pb during the wet season. The same is true for the lower catchment since the highest wet season concentration was at Sosiani River at Sergoit confluence, 0.057mgkg^{-1}. In the lower catchment, [34,45] got 0.072 at Kengen and 0.74 mgkg^{-1} at Kapsoas respectively. Both values were higher than what this study found.

Regarding Cd; similar to Pb, the upper catchment still reports high Cd concentrations with Naiber having 0.050mgkg^{-1}, while all the other sampling sites have significantly lower Cd concentrations regardless of the stage in the basin. It indicates that the assumption that the upper catchment might have lower heavy metal concentrations since it is rural is misplaced. In the study by [26] on spatial and temporal variation of heavy metals (Zn, Pb, Cd and Cr) in Sosiani River, showed high values of Cd in the catchment ranging between (0.015 – 0.67) mgkg^{-1}. Values of Cd above the recommended values by WHO and NEMA were similarly observed by a study done by [45] on Nutrient loads and heavy metals assessment along Sosiani river, Kenya.

The wet season Cr concentrations were unexpectedly high at Naiberi, which is within the upper catchment (0.119mgkg^{-1}). Other high Cr values were observed in the mid and lower catchments. It is however noted that unlike the phenomenon observed in Pb and Cd, sampling locations in the lower catchment had comparative Cr concentration with Kengen having Cr concentration of 0.113mgkg^{-1}. The dry season Cr values were higher than the wet season indicating that their sources were point as compared to wet season where the sources were both point and non-point although reduced by dilution of higher water quantity. Both the wet and dry season Cr values in this study were higher 0.04 to 0.910 and 0.01 to 1.39 respectively than those observed by Masakha [26] as 0.002 to 0.007 mg kg^{-1}. This is a clear indication of increasing Cr pollution in the catchment due to increased wood treatment sites.

A look at variations in sediment heavy metal concentrations along the catchment shows that for Pb, stations in the lower catchment had high Pb concentrations with Kengen power having 1.744mgkg^{-1}. It indicates heavy presence of Pb within sediments, this site being a reservoir. Within the mid catchment, comparatively lower Pb concentrations were observed at Kisumu Bridge and Sosiani at Eldowas Wastewater had Pb concentrations of 1.314 and 1.313mgkg^{-1}, respectively.

Regarding Cd concentrations within sediments, in the wet season, the mid catchment sites still registered low concentrations since Nairobi Bridge had 0.009mgkg^{-1}. However, some sampling locations upstream, especially Kaptagat and Chepkorio registered low Cd concentrations (0.008 and 0.006mgkg^{-1}, respectively), still indicative of the fact that there are pollutant sources upstream.

Spatial variations in Cr concentration had the upper and mid catchments having almost equal Cr concentrations with Nundoroto in the upper catchment having the highest sediment concentration of 0.525mgkg^{-1}, while downstream Eldowas wastewater and Nairobi bridge had 0.661 and 0.527mgkg^{-1}, respectively. The lower catchment had comparatively lower Cr concentrations of 0.430 and 0.417mgkg^{-1} at Sosiani Sergoit junction and Kengen power respectively.

Barbusbarbus heavy metal concentrations within the basin showed that the highest wet season concentrations were observed from fish caught in the lower catchment at Kengen power, which had Pb concentration of 1.230mgkg^{-1}. This was higher compared to the mid catchment whereby fish caught therein had Pb concentrations of 1.030 and 1.027 (Kisumu bridge and Sosiani downstream Eldowas wastewater, respectively), indicative of Pb concentrations within the waters which are the feeding media for *Barbusbarbus* fish. Curiously enough, fish from the upper catchment still registered significant Pb concentrations with Chepkorio and Nundoroto having a Pb concentration of 0.977 and 0.827mgkg^{-1}, respectively. All the sites showed Pb levels above the recommended values or the admissible limits in edible fish.

Barbusbarbus Cd concentration within the catchment showed that fish from the lower and upper catchment had high Cd concentrations; those from Kengen (lower catchment) had 0.907mgkg^{-1} while those caught from the upper catchment had 0.902mgkg^{-1} (Chepkorio). For Cr concentrations during the wet season, fish from the upper catchment registered the highest Cr concentrations exceeding 0.330mgkg^{-1} while those caught in the mid and lower catchments had 0.300 and 0.293mgkg^{-1} respectively. In a study called “Heavy Metals Pollutants and their Concentrations in Fish (Barbus species) in Sosiani River Kenya” by [35], the metals studied were: Cadmium, Chromium, Lead, Zinc, Magnesium, Calcium, Manganese and Copper and all were detected in fish tissues. Cd levels in different tissues ranged from 0.0 to 0.02 mg /kg while Cr levels ranged from 0.01 to 0.03mg/kg. The mean metal concentrations analysed by Ogindo *et al*., [35] were all lower than the recommended WHO values. This indicates increase in pollution in river Sosiani with years which are bio accumulating in the aquatic organisms including *Barbusbarbus* fish as seen in this study during both the wet and the dry season.

Finally, heavy metal concentrations in catfish caught from sampling sites within the Sosiani catchment showed that for lead, the upper catchment had catfish from Nundoroto having 0.087mgkg^{-1} which was the highest within this sub catchment, while in the mid catchment Kisumu bridge had the highest lead concentration 0.060mgkg^{-1}. However, the wet season lead concentration within the entire catchment was obtained from catfish obtained from Sosiani Sergoit junction, having 0.324mgkg^{-1}. Regarding cadmium concentrations, the upper catchment had the highest concentrations within the catchment with Kaptagat having 0.060mgkg^{-1}. This exceeded the mid and lower sub catchments, whereby the highest concentrations therein were 0.020 and 0.009 mg kg^{-1} for the site at downstream Eldowas Wastewater and Kengen power, respectively. A review of the catfish chromium concentrations within the catchment shows that the mid and lower catchments had high concentrations with at downstream Eldowas Wastewater and Kengen power having 1.013 and 1.020 $mgkg^{-1}$, respectively while in the upper catchment; chromium concentrations were comparatively lower at 0.613 $mgkg^{-1}$ at Nundoroto, which was the highest within this catchment. The causes in these cases are: the dumpsite, Eldowas Effluent, Wood treatment plants and other point and non-point sources in the catchment. The levels of heavy metals within the water, fish and sediments of the river Sosiani catchment showed spatial and temporal variation whereby in the rainy seasons there was a generally significantly higher heavy metal concentration in the wet season compared to the dry season. Additionally, there was a general trend in increased heavy metal concentration downstream the basin. However, this was also influenced by point sources in the catchment whereby there were concentration spikes.

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