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Assessment of Key Point Sources of Heavy Metals (Lead, Cadmium and Chromium): A Case of River Sosiani

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Abstract The objective of the study was to establish the key point sources of heavy metals (lead, cadmium and chromium) to River Sosiani. This study was a scientific design involving sample collection, preparation and laboratory work to determine Pb, Cd and Cr concentrations in wastewater from point sources. The units of analysis used study were wastewater samples sampled from nine sampling locations (WW_1 – WW_9) in the Sosiani catchment. Data for wastewater was obtained using AAS to determine the concentrations levels of the heavy metals lead, cadmium and chromium. Data analysis was done using the statistical program for social sciences (SPSS) version 23. The results show that wastewater from solid waste dumpsite (WW_6), MTRH (WW_5) and steel mills (WW_7) had higher values of lead during both the wet and dry seasons which were above the WHO thresholds of 1.0. All sites had lead values above the NEMA thresholds for both wet and dry seasons. WW_6 also had the highest values for all the heavy metals (Pb, Cd and Cr) in both seasons. Regarding Cadmium, the values for all sites and during both the dry and wet seasons was below the NEMA thresholds of 0.1 but were ≤ the world Health Organizations thresholds of 0.03. All sites had a mixed trend for chromium values during both seasons. They fluctuated above and below the thresholds of NEMA and WHO standards. It is also noted that generally, all the wastewater sites registered higher concentrations in heavy metals during the wet season as opposed to the dry season. These sites require mandatory measures to ensure that the discharge of wastewater into the environment meets the recommended effluent standards. Some of the measures include, improved Technology in designing the wastewater treatment Works that can remove all the macro and micro heavy metals. The sewer system and drainage lines should also be improved on so as to reduce flooding and raw wastewater flow into the river.

Keywords: *wastewater, lead, chromium, cadmium, heavy metals, pollution, river Sosiani*

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1. Background

The human population suffers exposure to heavy metals by skin contact, food ingestion [1,2,3], drinking water, inhalation of air containing chemicals [4] and exposure to contaminated soil [5,6,7]. Heavy metal exposure may also happen when heavy metals from the rocks concentrate in soil, water, air, and are eventually taken up by plants and ingested by humans or animals [8,9,10]. These exposure mechanisms occur through physicochemical adsorption, biological uptake, and deposition of metal-enriched particulate matter on sediments [11]. Chromium exposure results due to exposure to wood treated with copper dichromate and leather tanned with chromic sulphate [12], from chromate production, stainless-steel production, chrome plating [9,10], and working in tanning industries [13]. On the other hand cadmium exposure is as a result of using cadmium rich phosphate fertilisers, eating contaminated food and cigarette smoking [9,10].

The monitoring of heavy metal pollution in Kenya should be a priority area of research since heavy metal concentrations in aquatic ecosystems affect water quality and the fish industry [14]; Unlike other pollutants e.g. petroleum hydrocarbons and litter which visibly build up in the environment, trace metals accumulate unnoticed to toxic levels [15]. Several studies have been carried out on heavy metals concentrations of water, sediments and microalgae in Kenyan water bodies [16,17]. For instance, in the Kenyan portion of the Lake Victoria basin (i.e. Rivers Nzoia, Nyamasaria, Sondu-Miriu, Sio, Nyando, Gucha and Yala), results indicated high heavy metal accumulation exceeding background concentrations in the sediment samples and fish parasites, with a conclusion that the Lake Victoria basin had significant basal metals contamination levels [14,16,18,19] which was attributed to agricultural and industrial activities taking place in the Lake Victoria catchments.

The vulnerability of aquatic ecosystems to heavy metal contamination has been recognized as a serious pollution problem because of heavy metal effects on the ecosystems of most countries [20,21,22]. The World Health Organization (WHO) estimates that a quarter of the diseases facing mankind today is due to prolonged exposure to environmental pollution, this implies that the general belief that wastes are hazardous to health cannot be overemphasized [23]. According to [24] and [25], heavy metals are dangerous since they bio-accumulate in biological organism over time, resulting in high concentrations. High heavy metal concentrations have toxic effects which include; competition for sites with essential metabolites, replacement of essential ions, reactions with –SH groups, damage to cell membranes and reactions with the phosphates groups [23]. [26] reported that the bioaccumulation of heavy metals in the fish from Athi River tributaries were higher than the WHO limits, therefore posing potential risk for inhabitants that depended on the river. The study therefore, sought to fill exiting knowledge gaps in the study area. Past studies were done in different geographical regions and differently [26]. Therefore, the researcher found it necessary to conduct this study. The objective of the study was to determine key point sources of heavy metals (Pb, Cd and Cr) to River Sosiani.

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^2basin area. It is one of the major tributaries of the Kipkaren river system. It traverses two counties i.e. Keiyo/Marakwet and Uasin Gishu [27,28]. 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) as shown in Figure 1.

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 wastewater from Sosiani Catchment.

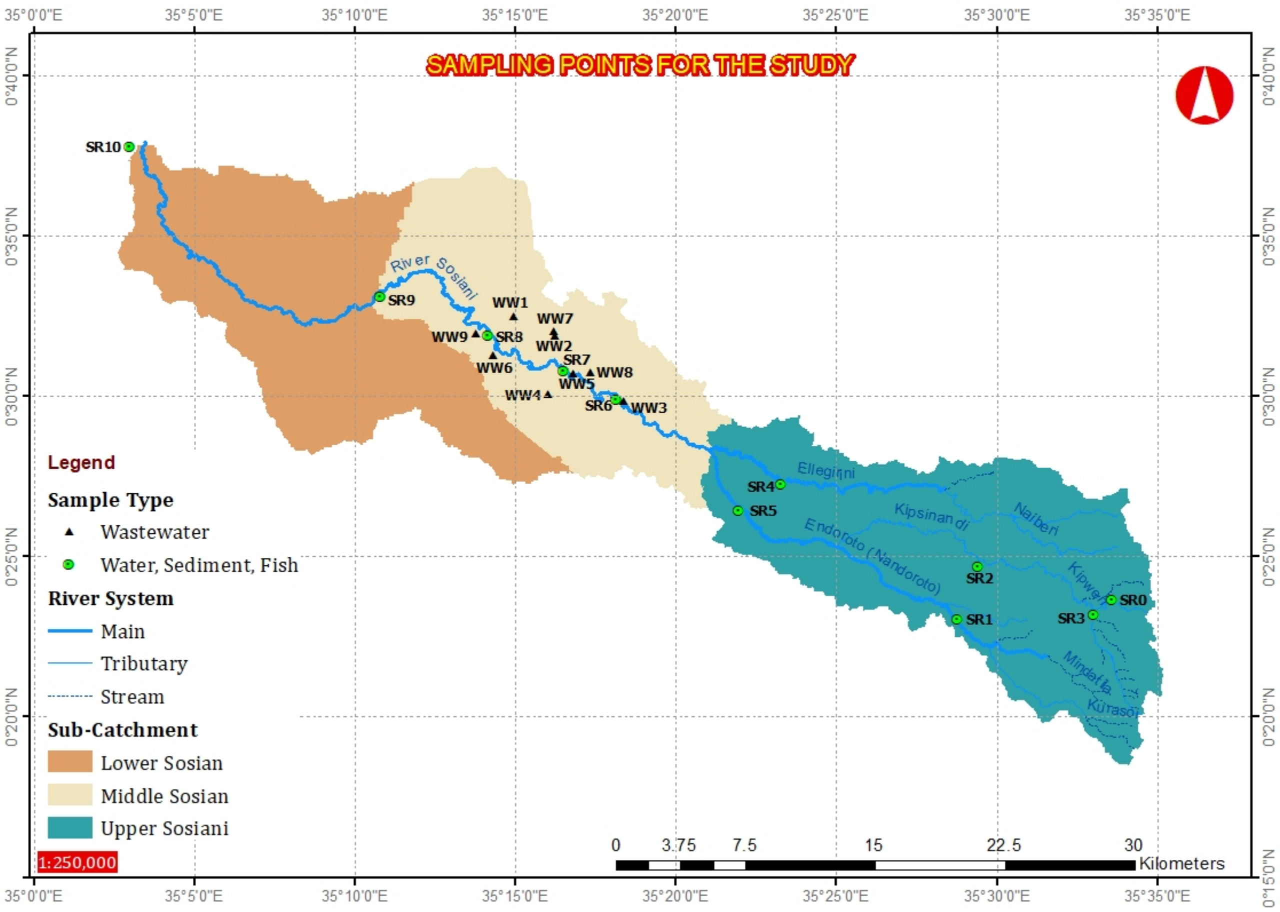

Figure 1.

2.2. Study Setting

The main land use in the Sosiani basin can be classified into five categories; indigenous and exotic forest; [29], urban and rural settlements, large scale commercial farming [30], subsistence farming [31,32] 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 [33].

2.3. Unit of Analysis

The units of analysis used in the scientific phase of the study were wastewater sampled from nine sampling locations (WW_1 – WW_9) in the Sosiani catchment. Stratified Random sampling method was used to obtain data the samples.

2.4. Data Collection

2.4.1. Wastewater

500ml grab wastewater samples were collected in pre acid - washed polypropylene bottle and 1 ml of concentrated HNO_3 was added to the sample to stop any microbial activity [34],labelled, stored under controlled temperature conditions before transporting to the laboratory. This was done from each of the nine wastewater sampling locations (WW_1 to WW_9 as indicated in Table 1 and Table 2, during the Dry (Oct – Dec 2017) and the Wet (March-May, 2018) seasons 3 times (triplicate) in each season respectively. Sampling was done six times per the nine sites during the two seasons resulting to fifty four no. of samples. The grab samples were deemed to be representatives of the site conditions at the time of sampling and provide more information on sample variability. At the laboratory, the wastewater samples were filtered through a 0.45µm pore membrane filter and kept at 4°C until analysis. During the analysis, 50ml representative wastewater samples were extracted from the filtrate, digested with 10 ml of concentrated HNO_3 and HCl at a ratio of 1:3 at 80°C until the solution became transparent. The wastewater sample was then 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, CT, USA), fitted with a specific lamp of particular metal using appropriate standards. In each case, the water temperature and pH were measured in-situ [34].

2.4.2. 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 [35], 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 within 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 [22]. AAS was used to generate data.

2.5. 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. Descriptive analysis of data was done using the mean, frequencies and percentages. 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) at 0.05 level of significance was used in the analysis.

2.6. Ethical Considerations

All aspects of academic writing call for adherence to right researcher behavior during conduction and dissemination of research findings, thus calling for the need to conduct research exercises based on laid down ethical principles [36]. Permission was thus sought from the MMUST bioethics committee before commencement of the data collection procedures. Once the approvals had been obtained, a research permit from National Commission for Science, Technology and Innovation (NACOSTI) was sought. During the study, four research assistants were trained in research ethics, and used. The study involved procedural data collection from nine sites that is WW_1 to WW_9.

3. Results & Discussion

The reliability of the heavy metal data was ascertained by a plot of concentration versus absorbance for standards [35]. This was done to precede each of the different samples analysed, wastewater $WW_1 – WW_9$. It is seen that, standards subsequently used in analysis of wastewater samples, the R^2 value for mean concentration versus mean absorbance was 0.994, 0.996 and 0.994 for Pb, Cd and Cr, respectively, for the respective indicated response equations y = 0.168x, y = 0.370x and y = 3.786. These results signify a high degree of reliability in wastewater heavy metal data.

3.1. Sources of Heavy Metals in the Mid Catchment

The research did not dwell on the point sources of heavy metal pollution within the upper part of the Sosiani catchment. These have been addressed by earlier researchers. This was based on the fact that the predominant activity in this region is agriculture hence the major point sources are the flower farms. The source of Kipsenende River and the Ellegerine River in Kaptagat forest are deemed to be the control area for the study hence sampling was done at locations within the river (sampling locations SR1 to SR10) as opposed to wastewater sources, which was done in the mid catchment. The mid catchment of the Sosiani River is the most industrialized and urbanized section. This is where the county headquarters, Eldoret is located and is also home to many industries and service amenities. These are the facilities that provided data for point sources of heavy metal pollution as indicated by WW_1 (Raiply) to WW_9 (Eldowas effluent). The Table 1 and Table 2 show the variations in the levels of heavy metals within the River Sosiani middle catchments during the wet and dry seasons, respectively.

Table 1. Wet season heavy metal concentrations in wastewater from sampling sites WW_1 to WW_9

Sampling site and name	Heavy metal concentration(mgl^{-1})*		
	Lead	Cadmium	Chromium
WW_1: Raiply	0.124(0.006)	0.002(0.000)	0.027(0.003)
WW_2: Highlands paper	0.240(0.010)	0.001(0.000)	0.089(0.002)
WW_3: Tipsy wood	0.287(0.006)	0.001(0.000)	0.140(0.010)
WW_4: Rivatex	0.297(0.015)	0.001(0.000)	0.061(0.002)
WW_5: MTRH	2.067(0.058) ^{b}	0.034(0.002) ^{a}	0.313(0.015) ^{b}
WW_6: Solid waste dumpsite	4.124(0.006) ^{a}	0.042(0.001) ^{a}	0.613(0.011) ^{a}
WW_7: Steel mill	1.047(0.006)	0.013(0.009)	0.030(0.000)
WW_8: Ken Knit	0.412(0.003)	0.001(0.000)	0.203(0.006)
WW_9: Eldowas effluent	0.630(0.001)	0.028(0.021) ^{b}	0.620(0.010) ^{a}
Minimum	0.124	0.001	0.027
Maximum	4.124	0.042	0.620
Overall mean (N= 27) **	1.025	0.014	0.233
NEMA Criteria (mgl^{-1}) †	0.1	0.1	0.05
WHO Criteria (mgl^{-1})	1.0	0.03	0.5

*Numbers in parentheses indicate Standard deviations (N=3)
** Overall mean (N= 27)
†NEMA, [37]
^{ab}Significant heavy metal concentrations (Fisher's, Followed by Post-hoc B Tukey HSDp= 0.05).

Table 2. Dry season heavy metal concentrations in wastewater from sampling sites WW_1 to WW_9

Sampling site and name	Heavy metal concentration(mgl^{-1})*		
	Lead	Cadmium	Chromium
WW_1: Raiply	0.177 (0.006)	0.002 (0.000)	0.001 (0.000)
WW_2: Highlands paper	0.347 (0.006)	0.001 (0.000)	0.008 (0.001)
WW_3: Tipsy wood	0.273 (0.015)	0.001 (0.000)	0.121 (0.001)
WW_4: Rivatex	0.390 (0.010)	0.008 (0.010)	0.011 (0.002)
WW_5: MTRH	2.297 (0.015)^{b}	0.033 (0.006)^{a}	0.250 (0.010)
WW_6: Solid waste dumpsite	3.080 (0.026)^{a}	0.035 (0.001)^{a}	0.541 (0.001)^{a}
WW_7: Steel mill	1.363 (0.032)^{c}	0.001 (0.000)	0.001 (0.000)
WW_8: Ken Knit	0.360 (0.010)	0.001 (0.000)	0.029 (0.004)
WW_9:Eldowas effluent	0.873 (0.031)	0.022 (0.002)^{b}	0.464 (0.005)^{a}
Minimum	0.177	0.001	0.001
Maximum	3.080	0.035	0.541
Overall mean (N= 27) **	1.018	0.012	0.158
NEMA Criteria†	0.1	0.1	0.05
Wastewater Criteria (mgl^{-1})	1.0	0.03	0.5

* Numbers in parentheses indicate Standard deviations (N=3)
** Overall mean (N= 27)
† NEMA, [37]
$^{a\,b}$ Significant heavy metal concentrations (Fisher's, Followed by Post-hoc B Tukey HSDp<0.05).

Table 3. Statistics of temporal variations in heavy metal concentrations from wastewater discharge 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	1.025	1.018	0.097	0.924
Cadmium	0.014	0.012	1.179	0.249
Chromium	0.233	0.158	7.150	0.000

Lead

Data obtained from wastewater analysis for lead during the wet season is as shown in Table 1, where it is noted that the wastewater from solid waste dumpsite (WW_6) (Pb = 4.124mg/l) was significantly higher at $p < 0.05$ compared to the other sampling sites ($F (8, 18) = 8504.43$, $p = 0.00$). The other sites with high lead values were MTRH (WW_5) (2.067mg/l) and Steel Mills (WW_7) (1.047 mg/l). The high figures at these locations are indicative of lead waste disposal and heavy lead usage activities, respectively in the vicinity of these sites, and imply that these facilities are major point sources of lead pollution. Raiply (WW_1), Highlands Paper (WW_2) and Tipsy Wood (WW_3) had comparatively lower lead levels in their wastewater (0.124, 0.240 and 0.287 mg/l, respectively) which mean that industrial activities in these factories pose a lesser Pb risk. The mean Pb level in the wet season was 1.025 mg/l (N = 27), which is way above the recommended Pb water criteria of 0.01 mg/l. This implies that during the wet season, the wastewater from point sources within the mid catchment of the Sosiani is heavily polluted with Pb as also evidenced by the maximum and minimum Pb concentrations of 0.124 and 4.124 mg/l, respectively.

During the dry season, as observed in Table 2, a similar trend to the wet season is observed with wastewater from the solid waste dump (WW_6) having highest lead levels at 3.080 mg/l, significantly higher at $p < 0.05$ compared to the other sampling sites ($F (8, 18) = 12178.14$, $p = 0.00$), it was followed by MTRH (WW5) with 2.297mg/l. The other sampling locations reported lower lead levels of 1.363mg/l and 0.873 mg/l at Steelmills (WW_7) and Eldowas effluent (WW_9), respectively. The remaining sites (WW_1, WW_2, WW_3, WW_4 and WW_8) had the lowest lead levels reporting 0.177, 0.347, 0.273, 0.390 and 0.360mg/l, respectively, and all the sites reporting an overall mean of 1.018mg/l. These values still exceed the recommended NEMA standards for lead in waste water and also imply that these sites are the heaviest sources of lead, indicative that the industrial activities therein are heavily lead loaded.

Chromium

The dry and wet season chromium data (Table 1 and 2 respectively) shows that in the wet season, wastewater from MTRH (WW_5) and the solid waste dump (WW_6) had chromium concentrations of 0.034 and 0.042mg/l, respectively, both of them being significantly higher ($F (8, 18) = 8309.94$, $p = 0.00$) at $p < 0.05$ compared to the other sampling sites. Relatively lower chromium levels are noticed at Steel mills (WW_7), and Eldowas Effluent (WW_8) had in their waste water 0.013 and 0.028 mg/l, respectively. The mean chromium level during the wet season was 0.014mg/l (N = 27) which is way above the recommended water criteria. During the dry season, a similar trend to the wet season is seen; whereby wastewater from MTRH (WW_5) and the solid waste dump (WW_6) had chromium concentrations of 0.033 and 0.035mg/l, respectively. From these values it is noted that the solid waste dump and MTRH are the most pertinent point sources of chromium pollution within the middle zone of the Sosiani catchment, a phenomenon which is persistent regardless of the season. Deductions for the Eldowas effluent site (WW_9) during the dry season are similar to those observed for it during the wet season despite a chromium concentration of 0.022mg/l. All the other sites with exception of WW_9 (0.022mg/l) had chromium concentrations below 0.008mg/l. These values still exceed the recommended NEMA standards for lead in waste water. Information garnered from this data shows a clear correlation between solid waste dumping and waste water chromium concentration.

Cadmium

Table 1 presents results for cadmium concentrations during the wet season from the wastewater sampling sites in the mid catchment of the Sosiani basin; the wastewater from the Eldowas effluent treatment plant (WW_9) having the highest cadmium levels at 0.620mg/l. It was closely followed by solid waste dump (WW_6) with 0.613mg/l. Both of these sites showed at $p < 0.05$, significantly higher concentrations ($F (8, 18) = 42.59$, $p = 0.00$), compared to the remaining sites. High figures at these locations reveal heavy chromium use through urban anthropogenic practices within the former Eldoret municipality, as evident in effluent quality. The other sampling sites had lower cadmium concentrations whereby MTRH (WW_5) and Ken knit (WW_8) reported higher cadmium concentrations at 0.313mg/l and 0.203mg/l respectively, compared to WW_1 (0.027mg/l), WW_2 (0.089mg/l), WW_3 (0.140mg/l), WW_4 (0.061mg/l) and WW_7 (0.030mg/l).These results mean that industrial activities in these factories make them a lesser cadmium point source compared to WW_9 and WW_6. It should be noted that the mean cadmium level in the wet season was 1.025mg/l (N = 27), way above the recommended water criteria of 0.01mg/l.

During the dry season (2), an opposite trend to the wet season is observed with waste water from the solid waste dump (WW_6) having highest lead levels at 0.541mg/l followed by Eldowas effluent (WW_9) with 0.464mg/l, both significantly higher ($F (8, 18) = 14.30$, $p= 0.00$) at $p < 0.05$ compared to the remaining sampling locations. These locations reported lower cadmium levels of 0.121mg/l and 0.250mg/l at Tipsy (WW_3) and MTRH (WW_5), respectively. The sites WW_2 (Highlands paper) and WW_8 (Ken knit) had the even lower cadmium levels at 0.008 and 0.029mg/l, respectively while sites WW_1 (Raiply) and WW_7 (Steel mill) reported cadmium levels of 0.001mg/l. Despite the mean dry season cadmium level being 0.158mg/l, it still exceeded the recommended NEMA standards for lead in waste water. From the analysis of wastewater from the industrial firms within the municipality, these firms can be considered to be the sources of heavy metal pollution and this trend is said to threaten the safety of the user of water downstream as it increases the level of risk posed by pollution. This result is also supported by Peng *et al.*, (2016) who indicated that the increasing industrialization and growth of population around the water sources tend to threaten the community water sources.

The results show that wastewater from solid waste dumpsite (WW_6), MTRH (WW_5) and steel mills (WW_7) had higher values of lead during both the wet and dry seasons which were above the WHO thresholds of 1.0. All sites had lead values above the NEMA thresholds for both wet and dry seasons. WW_6 also had the highest values for all the heavy metals (Pb, Cd and Cr) in both seasons. Regarding Cadmium, the values for all sites and during both the dry and wet seasons was below the NEMA thresholds of 0.1 but was < the world Health Organizations thresholds of 0.03. All sites had a mixed trend for chromium values during both seasons. They fluctuated above and below the thresholds of NEMA and WHO standards. It is also noted that generally, all the wastewater sites registered higher concentrations in heavy metals during the wet season as opposed to the dry season. From the analysis of wastewater from the industrial firms within the municipality, these firms can be considered to be the sources of heavy metal pollution and this trend is said to threaten the safety of the user of water downstream as it increases the level of risk posed by Cr pollution. This result is also supported by [38] who indicated that the increasing industrialization and growth of population around the water sources tend to threaten the community water sources.

3.2. Lower Catchment

Just as in the upper catchment, the research did not identify point sources of heavy metal pollution. The data collected from this region of the catchment was based on the assumption that this region formed the cumulative pollution region, implying that heavy metal concentrations within these sub-catchments were a function of upstream pollution. From the analysis of wastewater from the industrial firms within the municipality, these firms can be considered to be the possible sources of heavy metal pollution into River Sosiani. During the wet season, the sewer lines tend to frequently block thus the man holes pour raw sewage into the environment which is subsequently carried into the river by surface runoff. This trend is said to threaten the safety of the user of water downstream as it increases the level of risk posed by pollution. This result is also supported by [38] who indicated that the increasing industrialization and growth of population around the water sources tend to threaten the community water sources.

Most urban areas in Africa are characterized by rapid and disorganized urban expansion, which when coupled with industrial developments and inadequate waste management increases the accumulation of municipal waste [23,39]. The link between urban waste and heavy metal accumulation has been extensively studied, for instance [39] observed methane and heavy metal traces within leachates from the Dandora waste dumpsite in Nairobi. These studies did not give the quantity of the risk indicators caused by poor urban waste management. In order to protect aquatic ecosystems and to preserve drinking water resources, reduction of the inputs of heavy metals in surface waters is necessary. From the various studies done which have highlighted the need to remove pollutants from the treated wastewater before discharge into aquatic ecosystem due to their negative effect on human and animal health and ecotoxicological effects, the designs and development of the WWTPs should use the most current Technology that is able to remove all the macro and micro pollutants [40].

4. Conclusion & Recommendation

The mid catchment of the Sosiani basin was found to have the largest number of point sources of heavy metals, which is attributed to its intense urban activity. From the results it is discerned that amongst the nine wastewater locations the solid waste dumpsite was the highest source of lead, cadmium and chromium during the wet season. The same is also true for the same site during the dry season. The other wastewater site with critical wastewater concentrations were the Moi Teaching and Referral Hospital (MTRH) and Eldowas Effluent Plant. Otherwise all the other wastewater locations had lower heavy metal concentrations, albeit all the heavy metal concentrations were higher than the prescribed NEMA regulations for discharge into the environment. It is also noted that generally, with the exception of all the waste water sites registered higher concentrations in heavy metals during the wet season as opposed to the dry season. This was due to the contribution of both point and non-point pollution sources during the wet season. The mid catchment have the highest number of point sources of pollution namely the effluent from waste generation sites at the factories. These sites require mandatory measures to ensure that the discharge of wastewater into the environment meets the recommended effluent standards. Some of the measures include, improved Technology in designing the wastewater treatment Works that can remove all the macro and micro heavy metals. The sewer system and drainage lines should also be improved on to reduce flooding and raw wastewater into the river.

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