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# Determination of some heavy metal levels in water and sediments from River Riana in Kisii County, Kenya.

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## ABSTRACT

In this paper, we determined the heavy metal concentrations in water and sediments in surface water and sediments from the River Riana in Kisii County, Kenya for the period of January to June 2021.Water and sediment samples were collected and the concentrations of Pb, Cr, Ni, Mn. Cu and Zn analyzed. The analysis of heavy metal was carried out using the inductively coupled- plasma atomic emission spectrometer (Shimadzu ICPE-9000) after nitric acid digestion of both water and sediments. The data obtained was analyzed using Statistical Package for Social Scientists (SPSS version 26) and Microsoft Excel spreadsheets and significant differences were accepted at $p \leq 0.05$. A compliance study conducted for the water samples to determine the level of water pollution using the Kenya Bureau of Standards (KEBS) and the World Health Organization (WHO) recommended limits for natural drinking water. Similarly, the WHO sediment quality guidelines (SQGs) for fresh water sediments was used to determine the quality of the sediment samples from the river to determine the possible toxic impacts on the aquatic ecosystem. The mean ranges for the selected water physico-chemical parameters were determined for: pH (6.35-8.85), temperature (19.46-22.86$^0$C); electrical conductivity (85-294µS/cm), dissolved oxygen (4.30-7.32mg/l), total dissolved solids (86-426mg/l) and turbidity (109-251NTU). The mean concentrations of heavy metals (ppm) in surface water for Pb (0.031-0.196), Cr (<0.001-0.009)), Ni (0.014-0.321), Mn (0.131-0.351). Cu (0.114-0.370) and Zn (0.132-0.326). The heavy metal sediment mean concentrations (ppm) for Pb (0.041-8.74), Cr (0.001-1.31), Mn (276-692), Cu (1.35-9.74) and Zn (6.37-15.67). The investigation revealed that water physico-chemical parameters complied with the WHO and KEBS drinking water quality guidelines by both except for turbidity. The heavy metals Cr, Cu and Zn were within the WHO and KEBS drinking water quality standards while the Pb and Mn concentrations in water exceeded the recommended limits. The Ni concentrations exceeded the KEBS drinking water recommend limit. All the heavy metals complied with WHO SQGs. The River Riana was contaminated by the investigated heavy metals with the potential of heavy accumulation in sediments and metal toxicity the river. To mitigate against negative impacts regular assessment of the water and sediments was proposed.

Keywords: Heavy metals, recommended limits, physico-chemical parameters, sediment quality guidelines (SQGs), WHO and KEBS.

## Introduction

Rapid urbanization and industrialization in the last decade have triggered serious concerns for the safety of the environment as the quest for improved livelihoods and energy have resulted in anthropogenic campaigns which have led to the release of chemical pollutants including heavy metals into virtually all environmental matrices (Ezemonye *et al*.,2019). This is because heavy metals are highly hazardous contaminants due to their persistence, toxicity and bioaccumulation in the various segments of the environment (Gashkina *et al*., 2020). Elevated concentrations of heavy metals in water and sediments may be biomagnified along the aquatic food chains eventually affecting human health through the consumption of metal contaminated water or fish from such water (Nyingi *et al.*, 2016). Their presence in water even at low concentrations poses significant environmental concern. However, heavy metals have acceptable recommended limits in water for example Pb (0.01mg/l), Ni (0.07mg/l), Cr (0.005mg/l), Mn (0.4mg/l), Zn (3.0mg/l) and Cu (2.0mg/l). Toxicity is realized when the heavy metal levels are higher than the recommended limits which are different for individual elements in drinking water ( Omoko *et al*., 2013. WHO, 2011Muiruri, 2013).

High levels of heavy metals in fresh water makes them unsuitable for human consumption, livestock watering, and irrigation because heavy metals are highly hazardous contaminants due to their persistence, toxicity and bioaccumulation in water, sediment, air and biota. Heavy metals are elements with densities of more than 5g/cm3, and atomic mass higher than 20 are considered heavy metals (Edokpayi et al. 2017; Muhammad *et al*., 2019; Li *et al.* 2019). Toxic metals which pose hazardous effects include are copper (Cu), chromium (Cr), zinc (Zn), cadmium (Cd), arsenic (As), cobalt (Co), mercury (Hg) and lead (Pb) and are dangerous as the tend to bioaccumulate in food chains and can be harmful to humans and animals (Kim and Lee, 2017;Kanamarlapudi *et al.*, 2018; Bedassa *et al*., 2020). Heavy metals are classified as essential and non-essential or toxic metals depending on their toxicity and nutritional value. Cu, Mn, Fe, Zn, Co are needed in minute quantities for the normal function and survival of living beings (Muhammad *et al*., 2019). Thus heavy metals raise serious concerns over the potential health effects on humans due to cell function loss, cellular changes, carcinogenesis, and neurotoxicity (Muhammad *et al*., 2022). Among the different environmental contaminants, heavy metals are of greater concern due to their toxicity to living organisms including marine life and are a unique class of naturally occurring elements which are persistent and non- biodegradable; their occurrence in waters and biota indicate the presence of natural and or anthropogenic sources (Kanamarlapudi *et al.*, 2018; Qadir *et al.*, 2008).

Heavy metals cannot be broken down and are non-biodegradable, so when they enter the human body, they pose serious hazardous impacts. They are considered toxic and dangerous when bioaccumulate into the human body and cause biological and physiological complications. There are various mechanisms of intoxication in the human body by heavy metals which can be acute or chronic. The toxicity of metals depend on dosage and exposure time that is chronic or acute exposure (Muhammad *et al*. 2022). Toxicity may occur along the food chain when the contaminated species or substance is consumed (Hang *et al.*, 2004,). These toxic metals including As, Pb and Cd are hazardous because they can cause severe health problems in minute quantiles. Health problems resulting from these metals include stomach disease, anorexia, heart disease, hypertension and cancer (Qian *et al*., 2020).

Most, heavy metals are released into the environment mainly from anthropogenic activities which include metal production, agricultural activities, transportation, mining and smelting operations, industrial and urban development among others and fertilizers have released specific quantities of heavy metals which have poisoned the land and the soil. (Moywaywa *et al.*, 2022, Chaoua *et al.* 2019). Heavy metals such as, Cd, As, Cu, Ni and Zn are common pollutants and come from different anthropogenic source (Yahya *et al.*, 2018). They are also as a result of geochemical processes such as volcanic eruptions. The continued steady growth in human population has as seen more release of heavy metals into water bodies as humans continue participating in activities that trigger more release of the concerned metals (Storelli *et al*. 2008). Heavy metals oceans due to riverine influx atmospheric deposition and anthropogenic activities. This is because anthropogenic contribution to toxins such as heavy metals have grown in the aquatic ecosystem and settle in the underlying sediments causing significant habitat contamination. These heavy metals have potentially toxic effects and accumulation into biota exposed to the sediments (Muhammad *et al*. 2022).

More attention should be given to the monitoring of heavy metals due to their inherent bioaccumulation and biomagnification potential and their long term persistence in the environmental compartments (Koki *et al*., 2011).

Thus regular quantification of heavy metals is crucial to identify temporal variations in aquatic ecosystems (Ezemonye *et al.*, 2019). The analysis of heavy metal pollution can be examined by measuring metal concentrations in water, sediments and resident organisms such as fish. Therefore measurement of heavy metals in water is very important because it is the route through which metals are flushed from a large area of land into oceans and gives an indication of degree of pollution because inside the water these heavy metals enter into the different environmental domains such as water and sediments (Beyhan *et al*., 2010,).

These heavy metals can occur as dissolved or suspended loads on water or residue in bed sediments (Sabir *et al*., 2017). Sediments in rivers do not only play important roles of influencing the pollution, they also record the history of their pollution (Akan *et al*., 2010). Sediments are one of the possible media in monitoring the health of the aquatic ecosystems. Sediments refers to particles that normally settle at the bottom of an aquatic system and are of significance in the development of aquatic ecosystems through the replenishment of nutrients, creation of benthic habitat and provision of spawning areas/ they are also important sinks and reservoirs for several contaminants such as pesticides, leached chemicals and heavy metals. They are essential in the re-introduction of pollutants in the aquatic systems when optimal conditions are provided (Õztûrk *et al*, 2009). Particulates may be produced through various means, some of these ways include land disturbing activities such as road construction, mining, farming, real estate development, water drilling, erosion and weathering. These particles may then be transported by water, wind or ice where are eventually deposited in streams, lakes, wetlands and oceans (Lalah *et al*. 2008). The heavy metal sediment recommended limits for Pb, Ni, Cr, Cu and Zn are 35mg/kg, 0.4 mg/kg, 37.5 mg/kg, 30 mg/kg and 123 mg/kg respectively but the Mn sediment limit has not been documented (WHO, 2008). Sediments are sink of a variety of pollutants, particularly heavy metals and may serve as an enriched source for benthic organisms. Sediments have higher levels of heavy metals than the water which shows that sediments act as a sink for heavy metals (Wang *et al*., 2003; Storelli, 2008). Other authors have detected contamination of sediments with heavy metals in various aquatic ecosystems around the world and in Kenya (Õztûrk *et al*, 2009, Ambedkar *et al*., 2012, Kosgey *et al*., 2015; Wasike *et al*., 2019; Moywaywa *et al*., 2022. Heavy metal distribution and bioavailability in both sediments and the overlying water column have to be considered to obtain a better understanding of the interactions between the organisms and the environment (Nzeve *et al*., 2014). Thus this study sought to determine the concentrations of some heavy metal in surface water and sediments and the levels of some selected physico-chemical water quality characteristics for water from River Riana in Kisii County, Kenya. The results obtained from this study contribute to effective monitoring and conservation of the river ecosystem sustainable human health.

## Materials and Methods

### Study area

The section of the river Riana in Kisii Counties between at an altitude of 1500m to 1800m above sea level The study The sampling sites were S1 (Nyamataro Bridge), S2 (Nyagwekoa Bridge) and S3 (Riana Bridge) whose geographical coordinates were S1 (S00°39.622’, E34°45.043`), S2 (S00°39.503`, E034°43.101`), S3 (S00°39.496`, E34°40.097`) respectively (Figure 1).

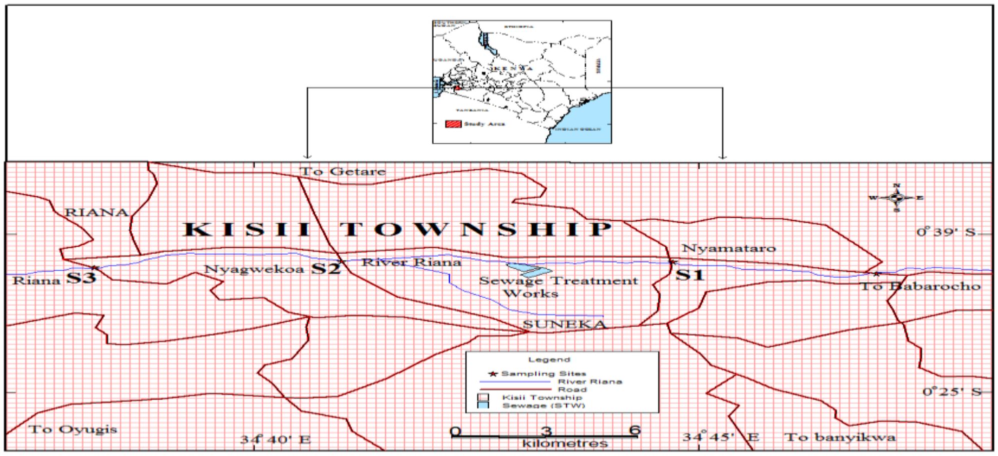

Fig 1: Location of the sampling sites

## Sample Collection

Water and sediment samples were collected monthly for a period of six months between January 2021 and June of 2021 from the River Riana in Kisii County of Kenya. Sample collection was done to include the dry months of January to March and wet months of April to June respectively. Three sampling sites were selected based on the degree of human activities in the adjacent area and the feasibility of obtaining desired samples. During each sampling period samples were collected in the morning, mid-day and in the evening, thus triplicate samples from each site of the river were collected. Water and sediment samples were collected according to the method described (Ambedkar *et al*., 2012). The water samples were collected by grab sampling method using 1L polyethylene bottles that were pre-conditioned with 5% nitric acid and rinsed thoroughly with distilled deionized water. At each sampling site, the polyethylene sampling bottles were rinsed at least three times before sampling. The pre-cleaned polyethylene sampling bottles were immersed about 10cm below the water surface. The samples were acidified with concentrated nitric acid, placed in an ice-bath and transported to the laboratory for analysis. The samples were filtered through a 0.42µm micropore membrane filter and kept at $4^oC$ until analysis. Triplicate submerged sediment samples at least 30cm below the water level were collected using a grab sampler and stored in plastic bags. All the samples were stored in the cool box at $4^0C$ for transportation to the laboratory. The samples were packed in polyethylene bags and stored below $-20^0C$ before processing for heavy metal analysis. Sediments were treated consequently digested as described by Kosgey *et al.,* (2015). The concentrations heavy metals in water and sediments were determined in triplicates using the Inductively Coupled Plasma Emission spectrometer-Shimadzu ICPE-9000 (Omoko *et al*. 2015). The mean concentrations and ranges of heavy metals for the study period in water were summarized in Table 2 and 3.

## Determination of heavy metals in water samples

Digestion of water samples for metal analysis was done in triplicates using concentrated nitric acid (AG) as reported by Zhuang (2007). 5ml of concentrated nitric acid was added to 50ml of the water sample in 100ml beaker and then heated on a hot plate ($100\ ^oC$) to boil until the volume reduced to 20ml. Another 50ml of concentrated nitric acid was added and then heated for 10 minutes and allowed to cool. About 5ml of concentrated nitric acid was used to rinse the sides of the beaker and the solution filtered using 0.42µm filter paper into a 50ml volumetric flask and topped up to the mark using distilled water. A blank solution was similarly prepared.

## Digestion and determination of heavy metals in sediments

The sediment preparation and digestion was done according to the method described [29]. Sediment samples were dried in an oven at $80^o$ C for 24 hours, ground using mortar and pestle to increase the surface area for extraction of the heavy metals from the sediment samples. The ground samples were sieved using a sieve of mesh size 72nm. Accurately weighed 0.5g of each dried sample was placed in a clean Kjedahl flask to which 10ml of the aqua-raga solution (a mixture of concentrated $HNO_3$ with HCl in the ratio of 1:3) was added. The samples were digested using an electric digester with a glass fume exhaust for a period of 2-3 hours. The solutions were filtered using the normal filter paper (0.42µm Whatman filter paper). Each of the resulting filtrate was diluted to 100ml using distilled water in acid-cleaned volumetric flasks.

## Data Analysis

Descriptive statistics, using Statistical Package for Social Scientists (SPSS version 26) and Microsoft Excel spreadsheets

## Results and Discussion

### Physico- chemical parameters

The physical, chemical and biological contents determine the quality of water. Water quality guidelines provide basic information about the water quality parameters and ecological relevant toxicology threshold values to predict specific water uses (Bedassa, 2020). The means and ranges obtained for some physico-chemical water quality paramours (Table 1) for the River Riana, during the study period were discussed.

Table 1: Monthly average levels and ranges of water physico-chemical parameters in River Riana

| | Sampling months± | | | | | |
|---|---|---|---|---|---|---|
| Physio-chemical parameter | January | February | March | April | May | June |
| pH | 7.42±0.28 | 7.66±1.11 | 7.56±0.016 | 7.50±0.11 | 7.43±0.055 | 6.92±0.13 |
| Range | (6.45-8.35) | (6.66-8.45) | (6.80-7.880) | (7.35-7.60) | (7.35-7.48) | (6.88-7.10) |
| Temperature (°C) | 21.23±1.30 | 21.22±1.67 | 22.74±0.914 | 23.28±0.002 | 22.31±0.458 | 22.71±1.31 |
| Range | (19.46-22.54) | (19.65-23.56) | (21.85-24.00) | (21.55-24.95) | (22.50-22.86) | (20.68-23.45) |
| EC (μS/cm) | 172±49.5 | 171.33±60.33 | 171.33±22.16 | 177.00±77.98 | 177.00±92.32 | 153.00±93.088 |
| Range | (117-237) | (120-256) | (116-265) | (107-286) | (113-294) | (85-280) |
| DO (mg/l) | 6.14±1.00 | 5.84± 0.73 | 5.88±1.18 | 5.37±0.70 | 6.19±0.53 | 5.77±1.05 |
| Range | (5.21-7.53) | (4.32-6.87) | (5.66-7.32) | (4.44- 6.12) | (5.77- 6.85) | (4.30-6.78) |
| TDS (mg/l) | 184.62±98.23 | 193. 4±25.05 | 121.67±10.84 | 138.39±84.39 | 122.02±0.421 | 235.0±131.31 |
| Range | (114-325) | (128-323) | (86-324) | (87-234) | (127-128) | (137- 422) |
| Turbidity (NTU) | 132.00±13.67 | 143.67±35.30 | 205.00 ±33.56 | 219.67±1.81 | 160.00±35.26 | 179.00±0.050 |
| Range | (120-154) | (117-190) | (172-251) | (217-220) | (122-207) | (109-223) |

### Turbidity

The turbidity determined level in the River Riana was in the range 109 to 251 NTU and the monthly mean concentrations in the river for all the months of the study period exceeded the recommended limit of < 1NTU and 25 NTU by WHO (2011) and KEBS (2015) respectively Thus water from the Rian River was unsuitable for domestic uses and human consumption. High turbidity (100 NTU and above) reduces light penetration into water column which have direct negative effect on photosynthesis. Other organisms high in aquatic food chain which depend on photosynthetic plants for survival also suffer some negative effects resulting from insufficient food. The consequences may be migration of motile or mass mortality and in severe cases extinction. The clarity of water is determined by its turbidity values (Ndimele and Kumolu-Johnson. 2012). The mean turbidity values obtained in this study were higher than those observed by Mwamburi (2013) in Lake Victoria 6.9 NTU to 56.1 NTU. Comparable to current study by Nzeve (2015) observed turbidity in the range of 6.13NTU to 169.67NTU for water samples from Masinga Dam. Similarly, comparable results to this study were obtained by Mwamburi (2013) who recorded turbidity values in the range in 30 NTU to 120 NTU for water samples from Lake Naivasha. Ouma and Mwamburi (2014) obtained mean turbidity value of 43.3NTU for water samples obtained from in Lake Baringo and the high turbidity contributed to a reduction of both light penetration and the aesthetic value of water in the river and this could affect aquatic organisms such as fish and algae. The observed turbidity in the study area was attributed to surface run-offs from adjacent farms, solid waste dumping in open dumps adjacent to the river, commercial activities in the surrounding urban areas and sewage contamination. Edokpayi *et al.*, (2016) recorded higher turbidity values than the present study for surface water for in Mvudi River, South Africa and which exceeded the WHO (2011) recommended value of <1NTU. Previous studies have noted that higher levels of turbidity are associated with disease causing bacteria (Patil, 2012).

## Electrical conductivity (EC)

Conductivity of the water is the ability to conduct electricity and it is directly related to the concentrations of ions in the water (Kinuthia *et al*. 2020); it indicates the amount of dissolved ions on water and it is a measure of the dissolved ionic components in water hence the electrical balance of water (Yilmaz, 2018; Oyem *et al*., 2014). The EC determined level in the River Riana was in the range 85 to 294 µS/cm and its monthly mean concentrations in the river for all the months of the study period were lower than the recommended limit of 1500 µS/cm and 2500 µS/cm respectively (WHO, 2011; KEBS, 2015). Studies on the physico-chemical parameters recorded EC for wastewater from open drainage channels in Nairobi, Kenya in the range 770 to 1074 µS/cm for the four sites which were below the WHO (2011) recommended limit (Kinuthia *et al*., 2020, Mbui *et al.* (2016). Kosgey *et al.*, (2013) recorded EC for the Athi River in the range155 to 206 µS/cm which was also below the WHO (2011) recommended limit of 1500 µS/cm for drinking water. Ondiere *et al.*, (2017) recorded EC values in the range 141µS/cm to 8120 µS/cm for Lake Elmentaita which was higher than the WHO recommended limit in some sites. Edokpayi *et al.,* (2016) recorded lower EC levels of surface water in Mvudi River, South Africa in the range 10.5 µS/cm to 16.1 µS/cm which complied with WHO (2011) recommended limit for that river. Both EC and turbidity are important parameters used in measuring the quality of water post-treatment (Kinuthia *et al*., 2020).

## pH

Speciation and bioavailability of heavy metals in the aquatic ecosystems are strongly dependent on pH. Low pH values <5 usually increase the toxicity of metals. The average pH values determined in the study varied between 6.92 and 7.66 (Table1) which was within the WHO and KEBS recommended limit for drinking water 6.5 to 8.5 (KEBS, 2015). The determined pH level in the River Riana was in the range 6.45 to 8.45 units and the monthly mean pH of the river for all the months of the study period were within the recommended range 6.5 to 8.5 by the WHO (2011) and 6.5 to 9.5 by USEPA (2006) respectively. Thus the water from the river was suitable for portable uses and human consumption with respect to pH. Other authors have investigated pH of other water bodies while investigating heavy metal concentration in aquatic ecosystems. Bedassa (2020) determined the pH of Lake Hawassa, Ethiopia and recoded a pH range from 8.64 to 8.75 and exposed that it exceeded WHO recommended limits. Studies by Edokpayi *et al.*, (2016) recorded pH levels of surface water in Mvudi River, South Africa in the range 7.2 to 7.7 units where the pH complied with WHO and DWAF recommended limits in the range of 6.5 to 9.5 units. Chebet *et al.*, (2020) recorded water quality physico-chemical water quality parameters for River Molo, Kenya with pH in the range 7.90 to 9.66; which was above the WHO recommended value for drinking water. Other authors have reported pH for wastewater from open drainage channels in Nairobi, Kenya in the range7.28 to 8.78 units which exceeded WHO recommended limit of 6.0 to 8,5 but was within the KEBS limit of 6.0 to 9.5 units (Kinuthia *et al*., 2020)**.**

## Temperature

The observed temperature in the River Riana was in the range 19.46 to 24.45 $^{o}$C while the monthly mean concentrations in the river for all the months of the study period were within the WHO and KEBS recommended limits respectively. Temperature is an important water parameter and microbial degradative activities in the waste water are dependent on temperature, pH, presence of organic matter and types of microbes. Elevated temperatures in waste water tends support increased biodegradative reactions in presence of organic substances (Kinuthia *et al*., 2020, Chebet 2020). The monthly temperature range recorded in the current study (19.45-24.45 $^{o}$C) was within the mean monthly temperature range 21.03 to 30.50 $^{o}$C recorded for Masinga Dam (Nzeve *et al.* 2015) which was within the acceptable limit for warm water fish species in Masinga reservoir. Equally, Mutuku *et al.*, (2014) recorded temperature for rivers within the Lake Victoria basin in the range 21.4$^{0}$C to 26.5 $^{o}$C) which was also within the WHO acceptable limits for drinking water. Chebet *et al.*, (2020) recorded water temperature for River Molo, Kenya with temperature in the range 14.02$^{o}$C to 31.5$^{o}$C temperature which complied with the WHO recommended values for drinking water. Thus water from the River Riana was within the WHO acceptable limit for drinking water.

### Dissolved Oxygen (DO)

DO in surface water comes from air or is produced in photosynthetic phytoplanktons and other plants within a water body and is essential for almost all aquatic life and its concentration in a water body provides a broad indication of water quality. DO in natural water is strongly influenced by water temperature. Studies by Bedassa (2020) determined the DO variations of Lake Hawassa, Ethiopia and recoded DO in the range 5.20mg/l to 8.43mg/l which was within the range of recommended limits by WHO and USEPA. The quality of freshwater for fish should not allow accumulation of pollutants especially heavy metals in fish to such an extent that they are potentially harmful (Alabaster and Llyod, 2013). Mutuku *et al.*, (2014) recorded DO in the range 0.7mg/l to 10.2mg/l for rivers within the Lake Victoria basin.

### Total dissolved solids (TDS)

TDS in water depends upon the dissolved concentrations of magnesium, calcium, sodium, potassium and bicarbonate, carbonate, chloride, sulphate and nitrate ions (Muhammad and Ahmad, 2020) The determined TDS level in the River Riana was in the range 86 to 433 mg/l and the monthly mean concentrations in the river for all the months of the study period were lower than the recommended limit of 1000 and 1500 mg/l respectively (WHO, 2011; KEBS, 2015). Other authors have investigated TDS in aquatic ecosystems including Ondiere *et al.*, *(*2017) who recorded higher TDS in the range of 70 to 4210mg/l for Lake Elmentaita which exceeded the results obtained in the present study and above the WHO (2011) and KEBS (2015) recommended values in some sites of the study area. Chebet *et al.*, (2020) recorded close TDS results for River Molo, Kenya in the range 69mg/l to 822mg/l which were within the KEBS recommended values for drinking water in some sites. Drinking water is significantly affected if its TDS value is equal or greater than1000mg/l (WHO, 2011). Analogous studies in TDS in various tropical water bodies have been reported. Kosgey (2013) recorded TDS in the range109 mg/l to 136mg/l for the Athi River. Parallel studies by Masime *et al.*, (2022) determined higher TDS values than the current study in the range of 43mg/l to 1085 for rivers within the Athi River Basin area in Kenya. Mutuku *et al.*, (2014) recorded TDS in the range 1.0mg/l to 244mg/l for rivers within the Lake Victoria Basin. Chebet *et al.*, (2020) recorded higher TDS comparable with the present study in the range 69mg/l to 822mg/l for River Molo; which was above the WHO (2011) recommended value of 250mgl for drinking water. Mbuthia (2015) recorded TDS values range 369.5±1.04 mg/l to 375±1.07 mg/l which exceeded those from the current study but lower the recommended limits. TDS is not a health hazard although high levels may indicate hard water which may lead to scale build up in pipes and aesthetic problems such as salty and bitter taste in water (Mbui *et al.*, 2016). The observed TDS were attributed to sewage contamination, runoff leachate from urban centres and agricultural wastes into the River Riana. It has been further indicated that TDS refers to the sum total of all components dissolved in water which include $K^+$, $Na^+$, $Mg^{2+}$, $SO_4^{2-}$, $Cl^-$, $PO_4^{3-}$ and $H_2SiO_4^{2-}$ (WHO, 2011).

### Heavy metals in water

The results of the heavy metal concentrations reported during this study and the heavy metal monthly means and ranges. In water (Table 2)

Table 2
Mean heavy metal monthly concentration and ranges (ppm) in River Riana water.

| | Sampling months | | | | | |
|---|---|---|---|---|---|---|
| Heavy metals concentrations (ppm) | January | February | March | April | May | June |
| Pb | 0.073±0.026 | 0.063±0.000 | 0.067±0.016 | 0.070±0.017 | 0.043±0.055 | 0.035±0.013 |
| Range | (0.035-0.106) | (0.041-0.195) | (0.068-0.089) | (0.048-0.089) | (0.031-052) | (0.018-0.050) |
| Cr | 0.008±0.001 | 0.007±0.002 | 0.006±0.001 | 0.004±0.002 | 0.003±0.002 | 0.003±0.002 |
| Range | (0.007-0.008) | (0.004-0.009) | (0.004-0.007) | (<0.001-0.008) | (<0.001-0.006) | (0.001-0.003) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Ni | 0.050±0.006 | 0.128±0.135 | 0.102±0.019 | 0.014±0.000 | 0.025±0.006 | 0.022±0.006 |
| Range | (0.031-0.112) | (0.026-0.320) | (0.024-0.254) | (0.014-0.041) | (0.017-0.056) | (0.014-0.018) |
| Mn | 0.238±0.041 | 0.251±0.040 | 0.287±0.055 | 0.163±0.024 | 0.161±0.013 | 0.158±0.025 |
| Range | (0.176-0.277) | (0.211-0.300) | (0.210-0.351) | (0.131-0.190) | (0.156-0.184) | (0.122-0.189) |
| Cu | 0.198±0.078 | 0.252±0.089 | 0.217±0.078 | 0.188±0.051 | 0.159±0.002 | 0.186±0.070 |
| Range | (0.114-0.315) | (0.205-0.370) | (0.119-0.321) | (0.125-0.251) | (0.073-0.288) | (0.130-0.226) |
| Zn | 0.242±0.082 | 0.258±0.050 | 0.257±0.030 | 0.199±0.066 | 0.168±0.080 | 0.166±0.050 |
| Range | (0.132-0.326) | (0.147-0.262) | (0.179-0.309) | 0.084-0.226 | 0.104-0.212 | 0.084-0.236 |

### Lead (Pb) concentrations in water (ppm)

The monthly Pb concentration in the River Riana were in the range of (0.018-0.195ppm) and the Pb mean monthly concentrations for all the months of the study period was higher the recommended limit of 0.01mg/l recommended limit (WHO, 2011; KEBS, 2015). The determined Pb concentration equally exceeded 0.05mg/l recommended limit (USEPA, 2006) except during the month of June 2021 when the Pb concentration was in the range (0.018-0.050ppm). The observed Pb concentration exceeded Pb concentration (0.0003- 0.019 mg/l) and (0.001-0.013 mg/l) in water from Avsar Dam Lake in Turkey and Nzhelele River, South Africa respectively (Õztûrk *et al*., 2009; Edokpayi *et al*., 2017). Reported Pb concentrations in water bodies in Kenya include Pb range from (0.57±0.09- 3.36±1.15 mg/l) and (0.004-0.047mg/l) for water from river Kuywa Bungoma and Athi-Galana-Sabaki tributaries respectively (Wasike *et al*., 2019; Muiruri *et al*. 2013); Pb mean concentration of 0.1mg/l for water samples from Nairobi River (Mbui *et al*., 2016) and were all higher than the recommended limit of 0.01mg (WHO, 2011; KEBS. 2015). Higher Pb amounts in the range 0.025mg/l to 0.563 mg/l for five Rift Valley lakes Ochieng *et al*., 2007) have been reported. The Pb concentration in the water was attributed to surface runoff from garages and motor washing points, batteries, electrical pigments, glass and paints (Fifield and Hainess, 2000) application of agrochemicals including pesticides, insecticides and fertilizers, sewage contamination, urban and industrial wastes (Awofolu, 2005). Thus the water from the River Riana was unsuitable for domestic use and human consumption. The mean variation of Pb concentration at different sites along the river throughout the study period showed that Pb concentration increased from S2<S1<S3 (fig 2).

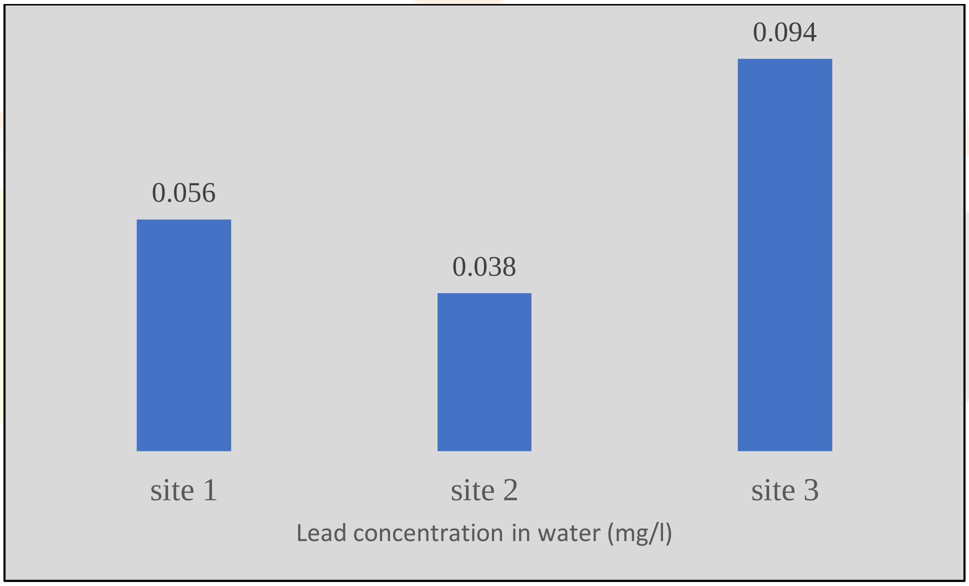

Fig 2: Mean lead concentration in water at different sites

### Chromium (Cr) concentrations in water (ppm)

The Cr concentration in the River Riana ranged between <0.001 to 0.008ppm while the Cr monthly average concentrations for all the months of the study period was lower than the recommended limit of 0.05mg/l by (WHO, 2011; KEBS, 2015). Thus, water from the River Riana was thus suitable for domestic uses and human consumption with regard to Cr level in the river. The contamination of the river with Cr was attributed to sewage pollution, contamination with fossil fuels, pesticides, fertilizers and discharges from untreated urban and industrial wastes (Awofolu *et al*., 2005). The observed Cr concentration closely related Cr concentration in the range of (0.001- 0.012 mg/l) in water from Avsar Dam Lake in Turkey but was exceeded by Cr level (0.045-0.0.346 mg/l) observed in Nzhelele River, South Africa (Õztûrk *et al*., 2009; Edokpayi *et al*., 2017). The current study was in agreement with other studies including Cr concentration (0.02 mg/l) in Nairobi River (Mbui *et al*., 2016); Masinga Dam with Cr concentration (0.006±0.004 mg/l) at Riakanau site (Nzeve *et al*., 2015). The present study compared closely with Cr concentrations in the range (ND- 0.068mg/l) in the Athi-Galana-Sabaki tributaries, Kenya (Muiruri *et al.* 2013). The observed Cr concentration in the river water was attributed pesticides and fungicides, solid wastes, wood preservatives, pigments and fertilizers (Muiruri *et al.* 2013; Nzeve *et al*., 2015, Fifield and Hainess, 2000). The variation of mean Cr concentration at different sites along the river throughout the study period showed that Ct concentration increased from S2<S3<S1 (fig 3).

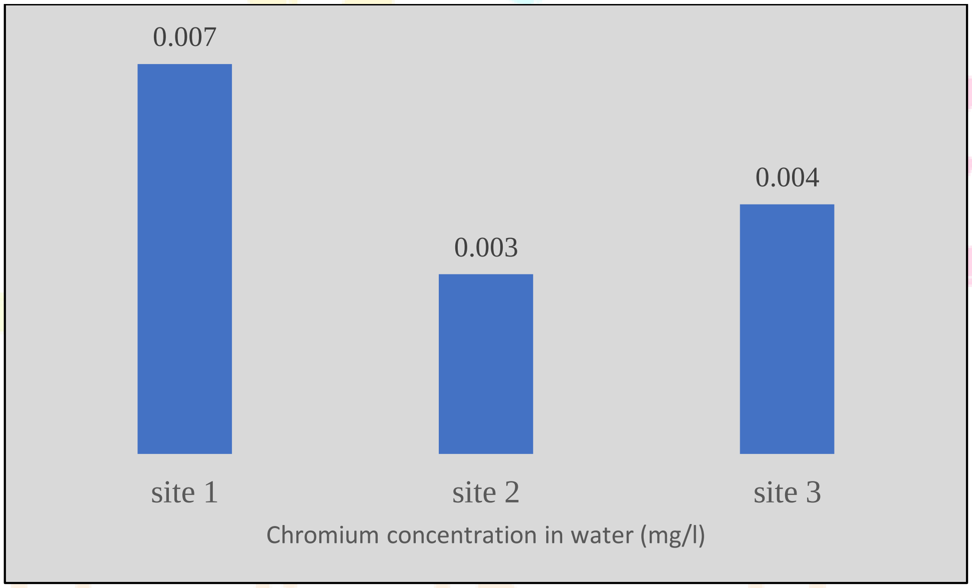

Fig. 3. Mean chromium concentration in River Riana at different sites

Nickel (Ni) concentration in water (ppm)

The range of Ni concentration (0.014-0.254ppm) in the River Riana and its monthly average concentrations in water for all the months of the study period exceeded the recommended limit of 0.07mg/l (WHO, 2011) except for February 2021 with a mean concentration (0.063±0.00mg/l). However, the monthly Ni mean for all the months were lower than KEBS recommended limit of 0.2mg/l (2015). Thus the water from the River Riana was safe from domestic uses and human consumption according to the KEBS standards. Related studies in Lake Hayq, Ethiopia recorded Ni mean concentration (0.018mg/l), lower than the permissible limit of 0.07mg/l for Ni in drinking water. (Tibebe *et al*., 2019). Lower Ni concentration ranging from (0.0004- 0.014mg/l) in water from Avsar Dam Lake, Turkey (Õztûrk *et al.* 2009) and higher Ni concentrations (0.201-1.77mg/l) for River Tyume in South Africa (Awofolu, 2005) have been reported. Related studies in Kenya have reported dissolved Ni concentrations (nd-54.1 µ/l) in water from Winam Gulf; (Lalah *et al*., 2008); Ni concentrations ranging from (0.007-0.062mg/l) in water for Athi-Galana- Sabaki tributaries (Muiruri *et al.* 2013); Ni concentration (<15-77µg/l) in water for River Thika (Moywaywa *et al*., 2022). The presence of Ni was attributed to solid wastes fertilizers, battery and electrical pigments, paints, alloys and catalysts (Fifield and Hainess, 2000) The variation of mean Ni concentration at different sites along the river throughout the study period showed that Ni concentration increased from S1<S2<S3 (fig 4).

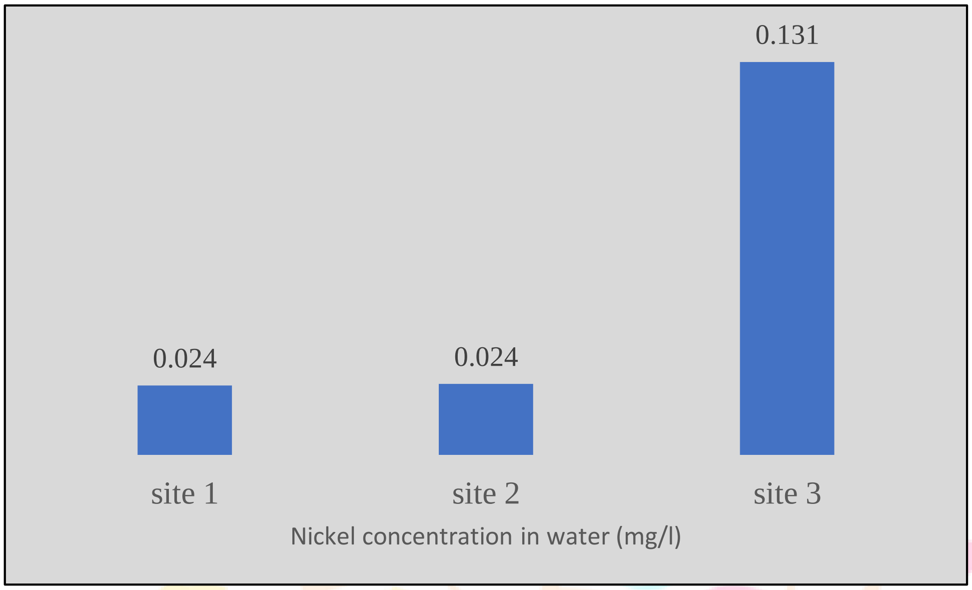

Figure 4. Mean nickel in water at different sites during study period

Manganese (Mn) concentration in water (ppm)

The Mn concentration results (Table 2) obtained during the study period ranged between (0.014-0.277ppm) where the Mn monthly mean concentrations for all the months of the study period were lower than the recommended limit of 0.4mg/l (WHO, 2011) but exceeded the KEBS recommended limit of 0.10 mg/l (KEBS, 2015). Thus, water from the River Riana was unsuitable for domestic uses and human consumption with regard to the Mn level in this water. The contamination of the river with Mn was attributed to sewage pollution, fossil fuels, pesticides, fertilizers, untreated urban and industrial wastes (Awofolu *et al.*, 2005). In related studies recorded Mn mean level (0.08± 0.006ml/l) in water samples from river Gudillam, Tamilnadu India (Ambedkar *et al*. 2012). A number of authors have reported Mn concentration in water bodies in Kenya including Masinga Dam (0.006±0.005mg/l) by (Nzeve *et al.*, 2015); higher Mn concentrations (0.533-1.087mg/l) in water samples from Athi-Galana- Sabaki tributaries (Muiruri *et al*. 2013). Winam Gulf, Lake Victoria in the range 0.05 mg/l to 3.276mg/l (Lalah *et al*, .2008); Lake Kanyaboli, Kenya (0.185-0.376mg/l) by (Ochieng *et al*, 2008); Rift Valley Lakes in the range of ( 0.50-0.282mg/l) by (Nyingi *et al*., 2016) and River Thika (53-653µg/l) by (Moywaywa *et al.*, 2022). The elevated Mn concentrations were attributed to industrial effluents and solid wastes containing pigments and batteries, sewage contamination and agro-chemicals such as fertilizers, The variation of mean Mn concentration at different sites along the river throughout the study period exposed that Mn concentration increased from S2<S3<S1 (fig 5).

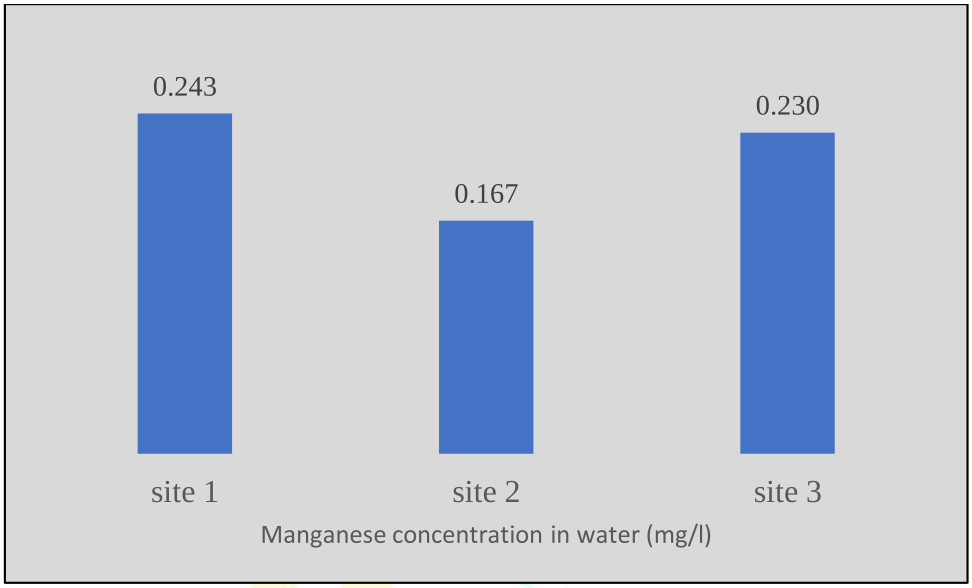

Fig 5. Mean manganese concentrations in water at different sites

Copper (Cu) concentration in water (ppm)

The Cu concentration results during this study ranged from (0.073- 0.370 ppm) and the monthly mean Cu concentrations for all the months of the study period which were lower than the recommended limits (Table 2) of 2.0mg/l and 1.0 respectively (WHO,2011; KEBS. 2015). The water from the River Riana was thus suitable for domestic uses and human consumption with regard to the Cu level in this water. However this level was lower than the Cu level (0.025-0.0.066 mg/l) observed in Nzhelele River, South Africa (Edokpayi *et al*., 2017).Similar studies reported lower mean Cu concentration (0.50± 0.025ml/l) in water samples of for river Gadilam, Tamilnadu India (Ambedkar *et al*. 2012). Authors in Kenya have reported similar Cu levels of 2.228 ppm in Nyakomisaro stream and Cu concentrations in the range of (1.10±0.12-1.92±0.14mg/l) in River Kuywa, Bungoma (Omoko *et al*., 2013; Wasike *et al*.,2020). Other studies recorded results with very close Cu concentration values in the range of (<10-343µg/l) for water in River Thika (Moywaywa *et al*., 2022), but lower Cu concentrations were reported in Masinga Dam at various sites including Riakanau (0.003±0.002 mg/l), Kathini (0.006±0.003 mg/l), Tumutumu (0.018±0.007 mg/l) and Manyatta (0.019±0.003 mg/l) by (Nzeve *et al*., 2015). The observed Cu levels in present study were attributed to surface runoffs with agrochemicals including fertilizers and pesticides, sewage discharge, urban solid waste containing pigments, alloys and paints (Ambedkar *et al*. 2012; Fifield and Hainess, 2000). Thus there is need for regular assessment and monitoring of the River Riana water to ascertain its quality and to assure both ecosystem and human health. The variation of mean Cu concentration at different sites along the river throughout the study period showed that Cu concentration increased from S2<S3<S1 (fig 6).

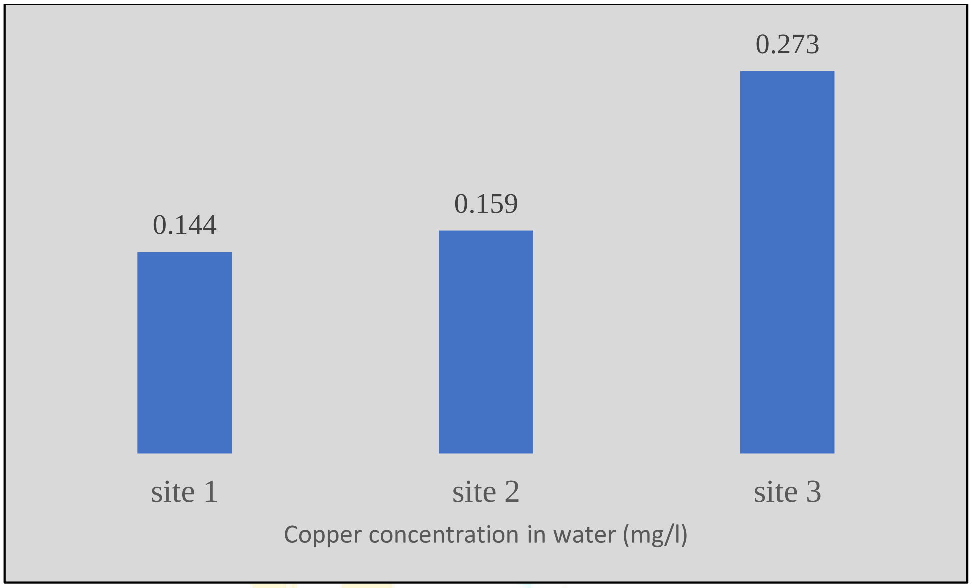

Fig 6. Copper (Cu) mean concentrations in water at different sites

Zinc (Zn) concentration in water (ppm)

The Zn concentration were presented in Table 2 with the Zn concentration ranged between (0.084-0.370 ppm ) and the Zn monthly average concentrations for all the months of the study period were lower than the recommended limits of 3.0mg/l and 5.0mg/l (WHO, 2011; KEBS, 2015). Thus, the water from the River Riana was suitable for domestic uses and human consumption with regard to the Zn level in the water. Similar studies by other authors have recorded lower mean Zn concentrations in water samples 0.10± 0.002ml/l for river Gadilam, Tamilnadu India (Ambedkar *et al*. 2012). However, related studies have recorded Zn concentration in the range (0.042-0.131mg/l) in Nzhelele River, South Africa lower than the current study (Edokpayi *et al.*, 2017).. Similar studies in Kenya aquatic ecosystems include Lake Kanyaboli (0.185-0.376mg/l) in Kenya (Ochieng *et al*., 2008) and Winam Gulf (0.025-0.2195mg/l) in Lake Victoria (Lalah *et al*., 2008). Lower Zn concentrations have also been reported in Nyakomisaro stream through Kisii town (0.141ppm) in Kenya (Omoko *et al*., 2013). Lake Baringo (0.01-0.31µ/ml) in Kenya (Nyingi *et al*., 2016) and in water from River Thika (<22-325µg/l) in Kenya (Moywaywa *et al.*, 2022). In related studies lower Zn concentrations were reported in Masinga Dam: (0.108±0.018 mg/l) at Riakamau (0.092±0.013 mg/l) at Kathini, (0.132±0.019 mg/l) at Tumutumu and (0.111±0.018 mg/l) at Mathauta sites (Nzeve *et al*., 2015). It has been noted that water contaminated with Zn could be toxic to other aquatic fauna and poisonous to human consumers (Kisamo, 2003). The Zinc concentration observed was attributed to batteries, alloys, paints, pigments, sewage and urban effluents. The variations mean Zn concentration at different sites along the river throughout the study period showed that Zn concentration increased from S2<S3<S1 as shown in figure 7.

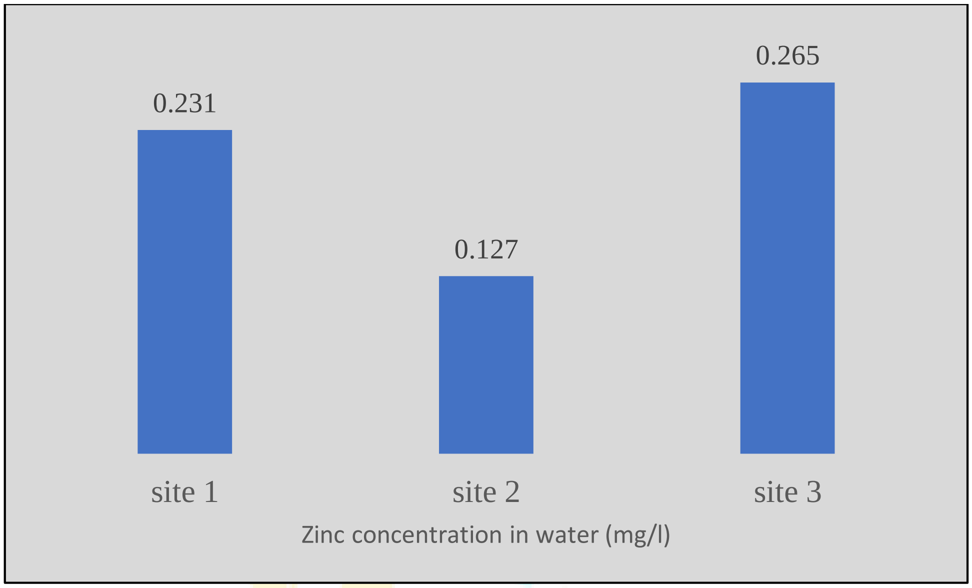

Fig 7. Mean Zinc Concentration in Water at different sites

Heavy metals in sediments

Currently, Kenya does not have sediment quality guidelines (SQGs) for heavy metal concentrations in freshwater sediments and therefore WHO (2008) SQGs for freshwater sediment were employed in this study. The determined heavy metal sediment concentration results during the study period were provided in Table 3. The WHO (2008) sediment heavy metal recommended limits for were: Pb (35mg/kg), Ni (65mg/kg), Cr (37.5 mg/kg), Zn (123 mg/kg) and Cu (30 mg/kg). Mn sediment limit concentration is not provided by WHO (2011). However, higher accumulation Mn could be directly detrimental to the health of the aquatic ecosystems and indirectly to man and sediments could be a contributing source of heavy metals in water hence constant assessment and monitoring was recommended (Awofolu *et al.*, 2005).

Lead (Pb) concentration in sediments (ppm)

The determined range in Pb concentration (0.041- 9.74 ppm) in sediments (Table 3) during this study and its monthly Pb average concentrations for all the months of the study period were lower than the WHO recommended sediment guideline of 35mg/kg (WHO, 2008). In related studies by other authors recorded Pb concentrations (1.775-4.157mg/kg) in sediments for Mvudi River in South Africa (Edokpayi *et al*., 2016) and also Pb concentrations in the range (0.248-2.71 mg/kg) was observed in Nzhelele River, South Africa (Edokpayi *et al*., 2017). Closely related to the current study, Pb concentration in the range (0.64- 6.35 mg/l) in sediments was determined for Avsar Dam Lake in Turkey (Õztûrk *et al*., 2009). Other studies have reported sediment Pb concentration for Masinga Dam, Kenya in the range (11.14-14.47 mg/kg), which exceeded results from the current study, but lower than the WHO recommended limit (Nzeve *et al*., 2014). Similarly, lower Pb sediment concentration in the range (32-177µg/l) was reported in River Thika (Moywaywa *et al*., 2022) than the current study. Higher Pb concentrations in sediments than the current study have been reported in Kenyan aquatic systems including Rift Valley Lakes in the range (10.92-38.98 mg/kg); Lake Kanyaboli (11.42-153.90 mg/kg) and of Winam Gulf in Lake Victoria (3.09-66.05 mg/kg) (Ochieng *et al*., 2007;Ochieng *et al*., 2008; Tole and Shitsama, 2013). The presence of Pb level in sediments was attributed to atmospheric deposition, solid wastes containing battery wastes, paints and pigments, pesticides and insecticides, industrial effluents, fossil fuels from transportation vehicles. The variation of Pb mean concentration in sediments at

Table 3

Heavy metals levels in sediments (ppm) during the study period

| | Sampling months | | | | | |
|---|---|---|---|---|---|---|
| Heavy metals concentrations (ppm) | January | February | March | April | May | June |
| Pb | 1.69±3.27 | 1.08±1.23 | 5.74±3.02 | 1.48±0.319 | 1.342±0.509 | 1.334±1.02 |
| Range | (1.45-3.27) | (0.041-2.63) | (1.26-8.74) | (1.00-1.76) | (0.973-206) | (0.662-2.500) |
| Cr | 0.005±0.002 | 0.46±0.055 | 0.006±0.078 | 0.065±0.078 | 0.606±0.852 | 0.084±0.118 |
| Range | (0.002-0.007) | (0.007-0.129) | (0.003-0.177) | (0.001-0.176) | (0.004-1.81) | (0.003-0.242) |
| Ni | 3.94±0.943 | 4.47±1.74 | 3.45±1.157 | 3.51±0.978 | 6.19±1.78 | 8.918±1.455 |
| Range | (2.45-4.59) | (1.48-5.48) | (1.45-4.36) | (2.13-4.33) | (3.78-6.44) | (1.780-9.740) |
| Mn | 413±141.41 | 405.3±160.61 | 368.32±153.68 | 478.00±166.36 | 467±105.85 | 452.0±140.04 |
| Range | (383-610) | (268-630) | (245—585) | (206-693) | (329-586) | (256-574) |
| Cu | 466±1.25 | 4.98±1.10 | 5.44±2.711 | 13.75±1.89 | 5.117±2.289 | 6.173±3.950 |
| Range | (4.33-6.34) | (4.77-5.94) | (2.46-9.02) | (1.35-5.45) | (3.34-8.30) | (3.330-9.740) |
| Zn | 13.88±3,371 | 10.45±3.12 | 10.083±3.84 | 6.52±2.04 | 12.303±1.75 | 10.118±1.27 |
| Range | (8.46-15.67) | (6.37-14.4) | (6.42-15.5) | (3.56-8.56) | (9.76-14.45) | (9.02-11.90) |

different sites along the river throughout the study period showed that Pb concentration increased from S2<S1<S3 (fig 8)

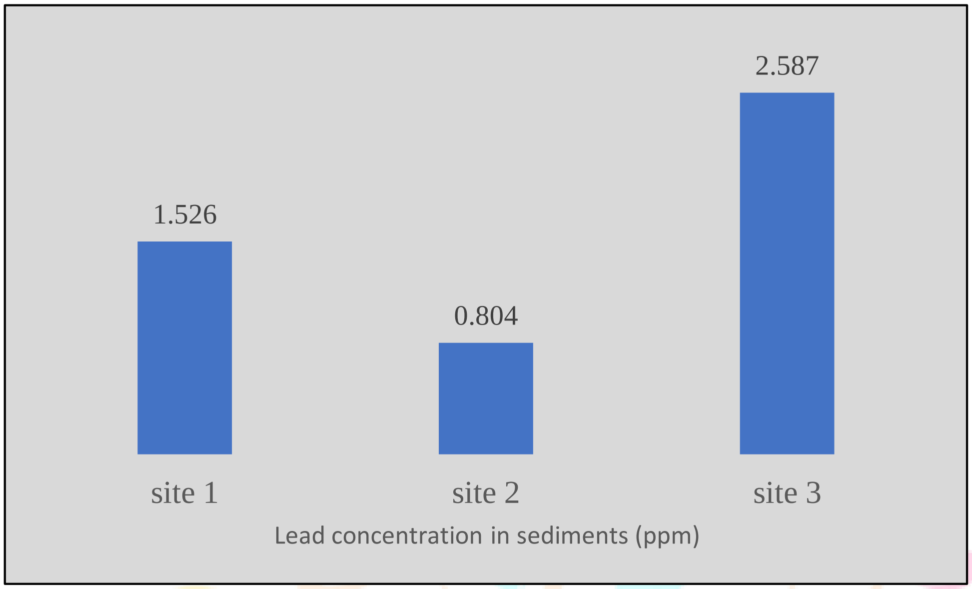

Fig 8. Variation in mean lead (Pb) concentration in sediments at different sites

Chromium (Cr) concentration in sediments (ppm)

The results (Table 3) indicated the determined range Cr concentration in sediments were in the range (0.001- 1.81 ppm) and its monthly Cr average concentrations for all the months of the study period were also lower than the WHO (2008) recommended sediment limit of 37.5mg/kg. However, sediments have the capacity to accumulate more heavy metals with time and mobilize them back to water and food chain (WHO, 2011). Thus the need for constant monitoring and assessment of sediments from this river was proposed to ensure ecosystem safety. Compared to the present study, very high sediment Cr mean concentration (9500 ppm) has been reported in the Wadi Hanifah, Saudi Arabia (Abdel-Baki *et al.*, 2011). Relatively higher Cr concentration in the range (9.41-19.9 mg/l) sediments than the current study determined for Avsar Dam Lake in Turkey (Ozturk *et al.*, 2009). In similar studies sediment Cr concentrations in the range (44.23- 149.52mg/kg) for Mvudi River in South Africa were recorded (Edokpayi *et al*. 2016) and also sediment Cr level in the range (7.804-51.288mg/kg) in Nzhelele River, South Africa was recorded (Edokpayi *et al*., 2017). Similarly, higher mean Cr concentrations (44.23-49.62mg/kg) in sediment samples than the recommended limit for Masinga Dam in Kenya have been reported (Nzeve *et al*., 2014). Comparable to this study lower Cr sediment concentration (2.92-5.36µg/g) dry weight was recorded for heavy metal inputs into Winam Gulf, Kenya (Lalah *et al*., 2008). Other authors have reported lower Cr sediment concentrations (0-25.89mg/kg) than the WHO recommended limit for rivers in Lake Victoria Basin have been reported (Ondiere *et al*., 2017). The observed Cr concentration in sediments in this study was attributed to pigments, fertilizers and industrial wastes containing textile wastes into the river (Fifield and Hainess, 2000). The variation of Cr mean concentration in sediments at different sampling sites along the river during the study period showed that Cr concentration increased from S2<S1<S3 (fig 9).

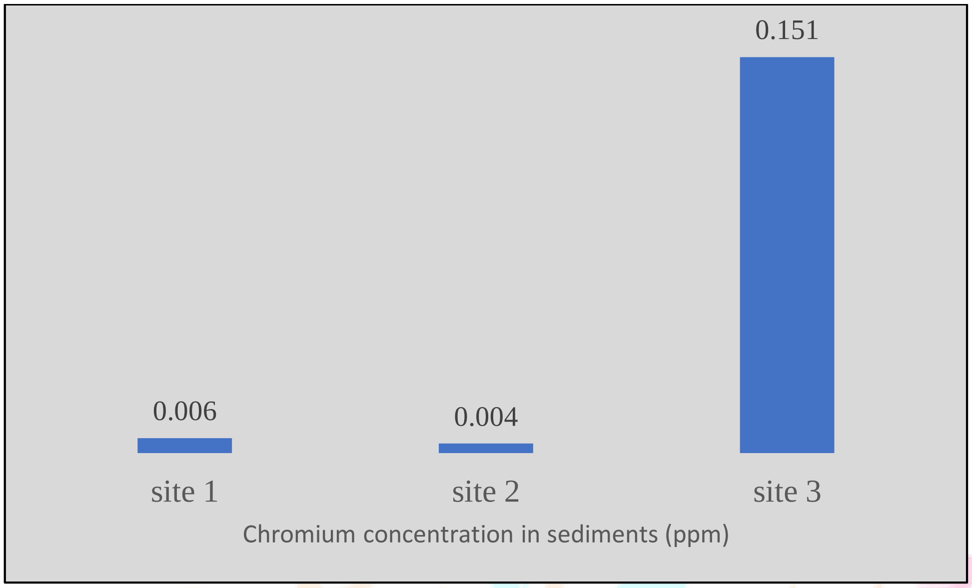

Fig 9: Mean chromium (Cr) concentration in sediments at different sites

Nickel (Ni) concentration in sediments (ppm)

The results (Table 3) specify the determined Ni concentration range (1.45-9.74 ppm) in sediments where its monthly Ni mean concentrations of the study period were lower than the WHO (2008) sediment recommended limit (65mg/kg). Although the Ni sediment concentration was lower than the recommended limit, sediments have the capacity to accumulate heavy metals gradually and mobilize them in the water and food chains (WHO, 2011), hence the need for continuous assessment the river sediments for heavy metals to ensure River Riana ecosystem safety. Other authors have reported lower sediments Ni concentrations from Athi River with a peak of 0.01912 ppm, lower than the current study (Kosgey *et al*., 2015). Relatively higher sediments Ni concentration (10.8- 39.4 mg/l) in sediments than the current study was determined for Avsar Dam Lake, Turkey (Õztûrk *et al*., 2009). Parallel studies recorded relatively lower Ni concentration in sediment at Winam Gulf where sediment Ni concentration in the range (4.33-42.99 µg/g) was recorded meaning that sediments were not Ni polluted (Lalah *et al*., 2008). Similar results with lower sediment Ni concentration (68-172µg/l) was reported in River Thika (Moywaywa *et al.*, 2022). Nickel can cause allergic reactions and certain Ni compounds may be carcinogenic. Nevertheless, Ni related health effects such as renal, cardiovascular, reproductive and immunological effects have been reported in man (Salnikow and Denkhans, 2002). The presence of Ni in sediments in this study was attributed to fertilizers, pesticides, paints batteries and electrical pigments catalysts and solid wastes (Fifield and Hainess, 2000). The mean variations of Ni mean concentration in sediments at different sites along the river throughout the study period showed that Ni concentration increased from S2<S1<S3 (fig 10).

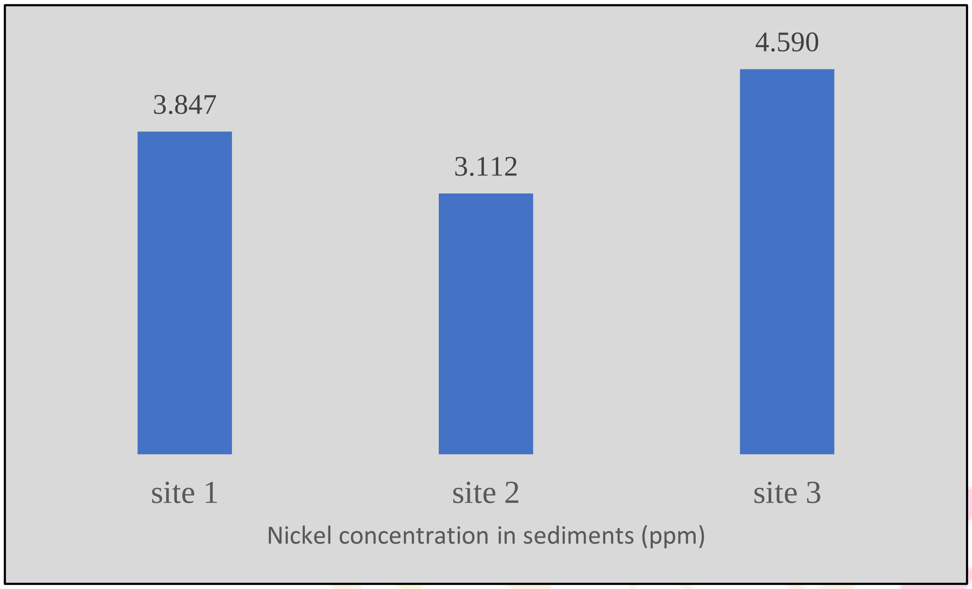

Fig 10: Mean Nickel (Ni) in sediments at different sites

Manganese (Mn) concentration in sediments (ppm)

The results (Table 3) indicate the determined mean sediment Mn concentration range (206-693 ppm). Manganese sediment limit is not documented in larger amounts (WHO, 2011). Compared to other studies, this was lower than the Mn sediments concentrations range (279-1638 mg/kg) for Mvudi River in South Africa (Edokpayi *et al*., 2016). Related studies in Kenya exposed high Mn sediment concentration that was very close to the current study in Masinga Dam in the range (259.12-642.34 mg/kg (Nzeve *et al*., 2014). Parallel studies have recorded similar high Mn concentrations in Winam Gulf, Lake Victoria in the range (133-723.7mg/kg) by (Lalah *et al*., 2008). The high concentrations of Mn in sediments in the study area was attributed to application of agrochemicals including fertilizers, sewage contamination natural geology, urban solid waste dumping on the river banks at specific points. There is need for periodic assessment of the river ecosystem including pollution of sediments with heavy metal because sediments have the capacity to accumulate heavy metals and gradually mobilize them in the water and food chains (WHO, 2011). Thus the need for periodic assessment of the river for heavy metals. The variation of Mn mean concentration in sediments at different sites along the river throughout the study period showed that Mn concentration increased from S2<S1<S3 (fig10). Very high Mn concentration at Riana market (site S3) was attributed to fertilizers and sewage contamination from Suneka Sewage Treatment works

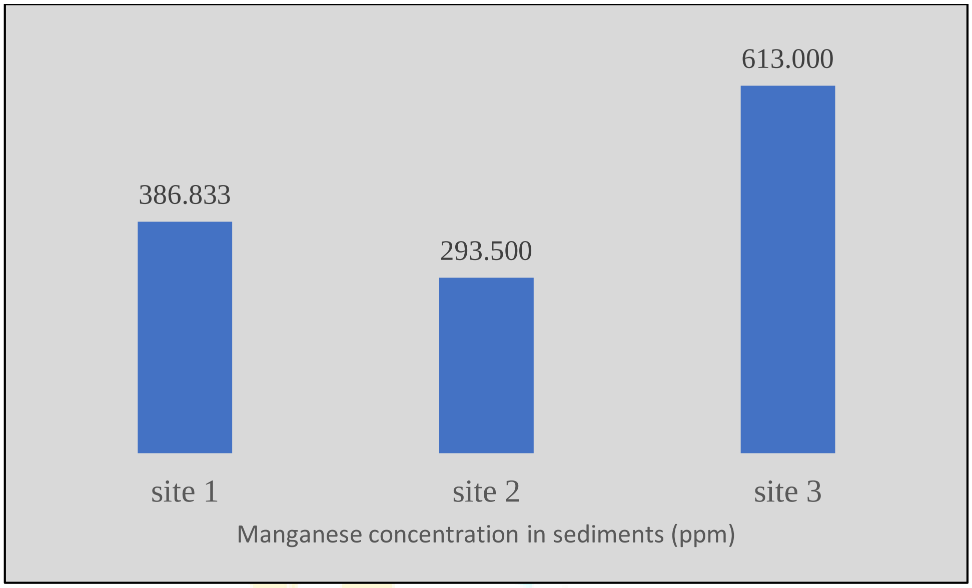

Fig 11: Variation in mean manganese (Mn) concentration in sediments at different sites

Copper (Cu) concentrations in sediments ppm

The determined range (Table 2) for sediments Cu concentration (1.35-9.74 ppm) in during the period study and the monthly Cu average concentrations for all the months of the study period were lower than the WHO recommended sediment limit of 65mg/kg (WHO, 2008). Similar studies recorded Cu concentrations (13.22- 1027mg/kg) in sediments for Mvudi River in South Africa (Edokpayi *et al*., 2016). Relatively higher Cu sediments concentrations (18.8- 38.4 mg/l) than the current study was determined for Avsar Dam Lake, Turkey (Õztûrk *et al*., 2009). Comparable results of mean Cu sediment concentrations (1.46-20.85 mg/kg) in surface sediments have been reported for the five Rift Valley Lakes in Kenya (Ochieng *et al*., 2007). Winam Gulf of Lake Victoria, Kenya (3.90-150.2 mg/kg) has been reported (Lalah *et al*., 2008); similarly in River Thika lower sediment Cu concentration (51-115µg/l) was recorded by (Moywaywa *et al*., 2022); in Lake Elmentaita in Kenya sediment Cu concentration (2.93±0.66-134.07±27.05mg/kg) was reported by (Ondiere et al., 2017); also in Masinga Dam Cu level (11.38±2.77-23.38±6.54 mg/kg) in water was determined (Nzeve *et al*. 2014). Whereas the Cu sediment concentration was lower than the recommended sediments limit in the present study, sediments have the capacity to accumulate heavy metals including Cu and mobilize them in the water and food chains (WHO, 2011). The presence of Cu in sediments in this study was attributed to batteries and electrical pigments, fertilizers, pesticides, paints catalysts and solid wastes (Fifield and Hainess, 2000). The variation of Cu mean concentration in sediments at different sites along the river throughout the study period showed that Cu concentration increased from S1<S3<S2 (fig11). Relatively high Cu concentration in

sediment at Nyamataro Bridge (site S1) was mainly attributed to anthropogenic activities including solid wastes and pesticides.

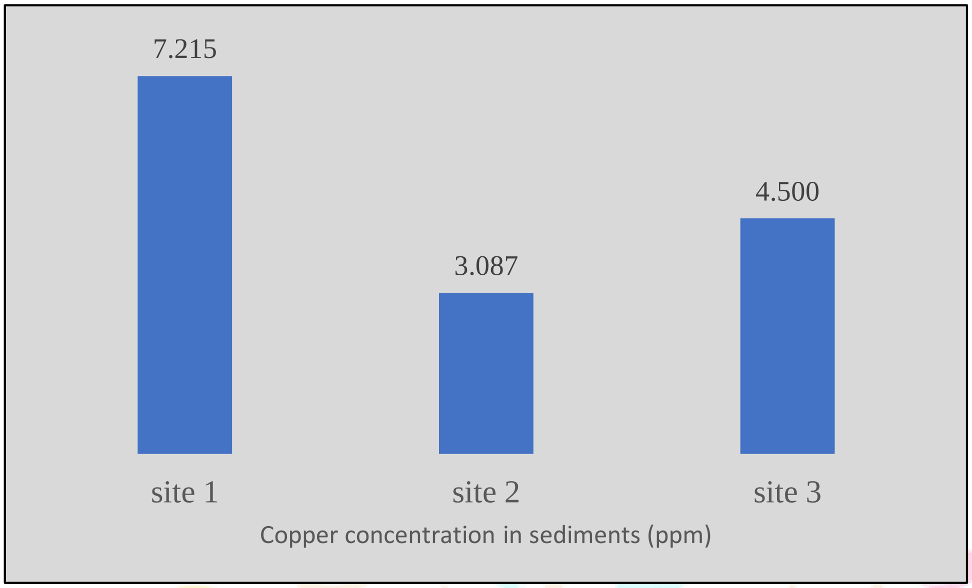

Fig 12: Mean copper (Cu) concentration in sediments at different sites

Zinc (Zn) concentrations in sediments ppm

The Table 3 expresses the determined mean Zn concentrations in the range (3.56-16.67 ppm) during this study and its mean monthly concentrations were lower than the WHO recommended sediment limit of 123mg/kg (WHO, 2008). Similar studies recorded Zn concentrations (4.481- 39.58mg/kg) in sediments for Mvudi River in South Africa (Edokpayi *et al*., 2016) and also sediment Zn level in the range (2.605-202 mg/kg) in Nzhelele River, South Africa was recorded (Edokpayi *et al*., 2017). Higher sediment Zn concentrations in the range (60.04±25.633-75.84± 27.684 mg/kg) was reported for Masinga reservoir (Nzeve *et al*., 2014). Other studies recorded higher sediment Zn levels in the range (23.39- 350.80 mg/kg) in some sites for Winam Gulf in Lake Victoria, Kenya (Tole and Shitsama, 2013),. Similar parallel studies reported lower Zn concentration (153-432µg/l) in sediments in River Thika (Moywaywa *et al*., 2022).The sources of Zn concentrations could be from a number of alloys including brass and bronze batteries, pesticides. Fertilizers, batteries, glass, electrical pigments and plastics (Akan *et al.*, 2010; Fifield and Hainess, 2000). While the Zn sediment concentration was lower than the recommended limit in this study, sediments have the capacity to accumulate heavy metals gradually and mobilize them in the water and food chains (WHO, 2011). Thus the need for sustainable assessment and monitoring of the river to maintain ecosystem and human health was suggested. The variation of Zn mean concentration in sediments at different sites along the river throughout the study period showed that Zn concentration increased from S2<S1<S3 (fig 13). The high Zn concentration at Riana market (site S3) was attributed to fertilizers and sewage contamination from Suneka Sewage Treatment works

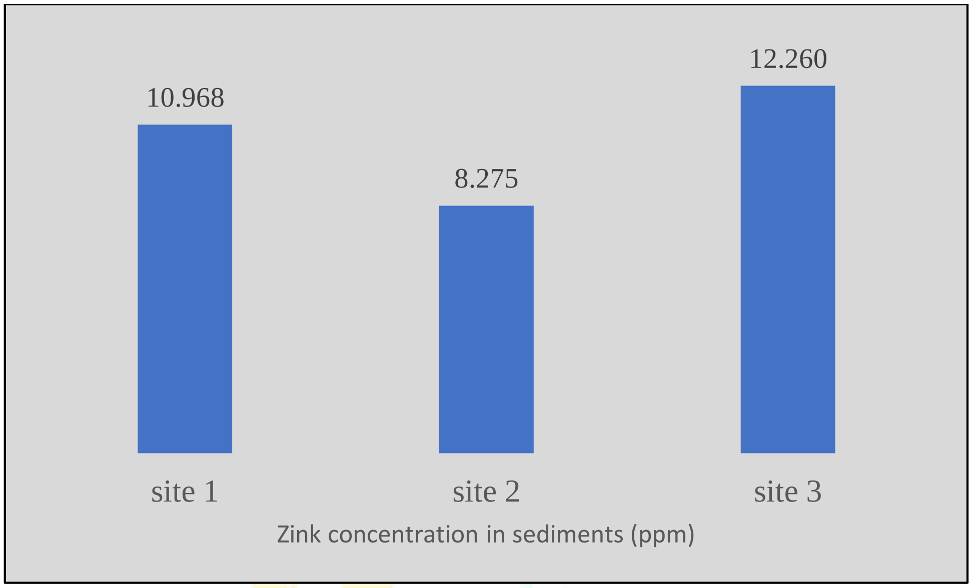

Fig 13: Mean Zinc (Zn) concentration in sediments at different sites

Conclusions and Recommendations

The study revealed presence of the investigated heavy metals in both water and sediments in River Riana. The monthly mean concentrations of heavy metals Cu and Zn were within the WHO and KEBS drinking water recommended limits. The mean monthly concentration for heavy metals Cr, Ni met the KEBS drinking water criteria in all the months of the study period. The Mn monthly average values never exceeded WHO drinking water criteria in all the months of the study period for water samples obtained from the River. The average monthly concentrations for the heavy metals in surface water for the River decreased in the order: Mn>Zn>Cu>Pb>Ni.>Cr. All the investigated heavy metals met the WHO sediment quality guidelines for the River. Thus contamination of both water and sediments was a strong indication of anthropogenic activities hence the study recommended regular monitoring and assessment of the river water and sediments to ensure sustainable environmental and human health.

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Competing interests

Authors declare that there are no known conflicts of interest associated with the work reported in this this paper.

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