<u>Original</u>	Research	Article

Assessment of Anions and Heavy Metals in Sediments from River Sio, Busia County, Kenya.

5 ABSTRACT

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Agricultural activities, discharge of raw sewage into farms and the rise in urbanization have 6 greatly contributed to soil pollution. During the rainy season, surface runoff from farms find their 7 8 way into water bodies and deposits these contaminants into Rivers and Lakes which poses a 9 threat to both aguatic and terrestrial organisms that depend on that water source. The objective 10 of this research was to determine the level of anions and heavy metals from sediments in River Sio, Busia County, Kenya. Five sediment samples were taken from five sampling points and the 11 levels of anions and heavy metals in them determined. Anions were determined using 12 Shimadzu 1800 UV/visible spectrophotometer while heavy metals were determined using 13 Shimadzu 6200 flame atomic absorption spectrophotometer (AAS). Copper, lead and nickel 14 15 were above the allowed WHO limits while cadmium was below detection limit. The levels of nitrates, phosphates and chlorides were higher during the wet season due to surface runoff that 16 carried these nutrients from the farms and deposited them on the bottom of the River. The 17 levels of heavy metals were high during the dry season due to evaporation of water from the 18 River, leading to an increase in the analyte concentration during the dry season. High levels of 19 20 copper and nickel in the sediments points to the use of herbicides and pesticides in farming and washing of vehicles and motorcycles on the banks of the River. According to I_{deo} nickel showed 21 moderate pollution during the dry season. The contamination factor for lead was very high 22 23 during the dry season, while pollution load index confirmed pollution due to anthropogenic 24 activities in sampling sites 1 - 4 during the dry season and no pollution due to anthropogenic 25 activities during the wet season. The study recommends reduced use of inorganic fertilizers in 26 order to save the River from the danger of eutrophication. Excessive use of agrochemicals such 27 as herbicides and pesticides should be discouraged. In addition, pesticide leaching and the level of microbes in soil and sediments should be considered for further research. 28

Key words: River Sio; heavy metals; sediments; anions; UV/visible spectrophotometer; Atomic Absorption Spectrophotometer.

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41 **1.0 INTRODUCTION**

42 Soil is defined as the weathered superficial layer of the earth's crust that is made up of decomposed 43 and partly decomposed parent rock material with associated organic matter at various stages of 44 decomposition [1]. The yield and growth of crops is to a great extent affected by the availability of 45 essential mineral nutrients [2]. These nutrients can be applied to plants in the form of 46 inorganic/chemical fertilizers in order to overcome nutrient deficiencies and imbalances. Nitrogen, 47 sulphur and phosphorus are major soil elements that control soil fertility and crop yield [3]. Soil is the 48 natural medium in which the roots of most terrestrial plants grow and are firmly anchored, and from 49 which plants absorb water and mineral salts essential for proper growth and development. Soil that is 50 fertile can be defined as that which contains all the essential mineral salts needed by plants for proper 51 growth and development. The composition of soil includes humus, mineral salts, microorganisms, 52 water and air [4]. The chemical composition of soil depends on the materials that were initially present 53 when it formed and by the process it has undergone in the course of its formation. The chemical 54 composition of soil is determined by the inorganic matter and humus that make up the soil [5]. Toxic metals occur naturally in the environment, but human activities such as industrial and mining 55 56 processes are to blame for wider spread of these toxic elements [6]. Lead and cadmium are non-57 essential elements which are toxic to both plants and animals while copper and zinc are involved in 58 essential metabolic processes, such as enzyme co-factors, in plants and animals [7]. Once ingested, 59 lead interacts with calcium in the nervous system to impair cognitive development, especially in 60 children. On the other hand, cadmium interacts with calcium in the skeletal system to produce Lead replaces zinc on heme enzymes and cadmium replaces zinc on 61 osteodystrophies. 62 metallotheonein [8]. There are different ways in which heavy metals get into the environment. These include industrial, agricultural and household waste waters, atmospheric deposits or through the 63 64 extraction of natural resources (mining). Heavy metals mainly accumulate on soil surfaces and in the upper layer of sediments in water bodies such as Lakes and Rivers. When heavy metals mix with 65 66 substances present in the sediments, they change their characteristics. When heavy metals combine 67 with organic substances present in sediments, it leads to the formation of a buffer that stores the 68 heavy metals for a much longer period of time [9, 10]. The extent to which heavy metals accumulate on the surface of sediments mainly depends on the emission sources and the distance between the 69 70 emission source and the polluted water body. The amount of heavy metals in sediments from Rivers 71 and Lakes will depend on the nature of human settlement and industrial emissions and discharges in 72 the neighborhood [10, 11]. High concentration of heavy metals on soil surface has an adverse effect 73 on the microorganisms present in the soil as well as human beings. The illness rate of adults and 74 teenagers as a result of diseases caused by heavy metals was found to be 1.4 - 4.5 times and that of 75 children under the age of 14 years was found to be 1.5 - 3.9 times higher in areas contaminated with 76 heavy metals [12, 13]. Therefore similar assumptions can be made regarding the accumulation of 77 heavy metals in bottom sediments and water bodies. There are extensive anthropogenic activities 78 along River Sio which lead to pollution of the river. There are maize, sugarcane, millet and sorghum 79 farms located upstream of River Sio. The increase in population of Busia County with poor or no 80 sewer systems has also led to an increase in wastes that are dumped in the river hence leading to an increase in the level of pollutants in the river. In terms of land use along river Sio, small scale farming 81 82 accounts for 24.2 %, wet land patches account for 40 %, bush land patches account for 32 % and grassland patches account for 15.1 %. Soils in the area are dominated by volcanic ash soils while at 83 the lower elevations soils are derived from metamorphic rocks, mainly gneiss, bounded gneist and 84 schist, resulting from fertile clay soils as well as poorer leached clay soils [14]. Both point and non-85 86 point sources have contributed to pollution of both sediments and water in River Sio. It is therefore 87 necessary to determine the extent to which the River has been polluted by pollutants from these The aim of this research was to determine the levels of heavy metals and anions in 88 sources. 89 sediments in River Sio, Busia County, Kenya.

92 2.0 MATERIALS AND METHODS

93 2.1 Study Area

River Sio is among the rivers in the Malaba-Malakisi catchment situated in the western part of Kenya. River Sio originates from Kaujai and Luucho Hills in Bungoma County at an altitude of 1800m and flows through Busia County into Berkeley Bay and drains into Lake Victoria in Uganda at an altitude of 1134m.The River flows through valleys as it cuts through forests, maize and sugarcane plantations into the lower densely populated and agricultural section of the catchment. Figures 1 and 2 show digitized maps of River Sio, with the counties through which the river traverses marked in light green while River Sio is marked in blue.

101 **2.2 Sampling and Analytical Procedures**

102 Sampling was done during the dry season in January 2018 and during the wet season in May 2018. The choice of sampling site was based on where significant land change use had occurred [15]. Global 103 104 positioning system (GPS) was used to mark the sampling points during both the dry and wet seasons in order to ensure the collection of samples at the same exact point during both seasons, thereby ensuring 105 106 consistency in sample collection during sampling. The sediments were collected using a grab sampler (scoop and trowel) at a depth of 15cm [16]. Sediments were collected in containers made of 107 108 Teflon/stainless steel to avoid contamination. Parts of the sediment in direct contact with the sampler 109 were scrapped off to minimize contamination [17]. The samples were analyzed for various chemical 110 parameters during both the wet and dry seasons to study the variations in seasons of different parameters as discussed in the Environmental Protection Agency (EPA) method for the analysis of soil 111 112 and sediments [16].

Eleven chemical parameters were determined as per the methods described in table 2. The reagents used were of analytical grade and distilled de-ionized water was used to avoid sample contamination.

115 Anions were determined using Shimadzu 1800 UV/visible spectrophotometer while heavy metals in

sediments were determined using Shimadzu 6200 flame Atomic Absorption Spectrophotometer.

117 **2.2.1** Analysis of Sediments for Heavy Metals

One gram of sample was placed in 250 mL flask for digestion. The sample was heated to 95 °C with 10 mL of 50% nitric acid without boiling. After cooling the sample was refluxed with repeated additions of 65% nitric acid until no brown fumes were given off by the sample. The solution was allowed to evaporate until the volume reduced to 5 mL. After cooling, 10% of 30 mL hydrogen peroxide was added. The mixture was refluxed with 10 mL of 37% hydrochloric acid at 95 °C for 15 minutes. The digestate obtained was filtered using a Whatman no. 1 filter paper and diluted to 100 mL with deionized water [16].

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125 **2.2.2 Analysis of Sediments for nitrates**

126 A digestion mixture was prepared by making a mixture of 25g of phenol in 250 mL of concentrated 127 sulphuric acid. 1g of sediment sample was weighed and placed in a glass conical flask and then 50 mL of the digestion mixture was added and the contents were left to stand for 6hours. 25 mL of the digest was 128 129 placed in crucible and evaporated to dryness on a hotplate and 3mL of phenol disulphonic acid was 130 added and swirled gently and left to stand for 10 minutes. 15 mL of distilled water was added and stirred 131 with a glass rod. And on cooling 3 drops of para nitro-phenol indicator was added and ammonia solution added until intense yellow colour was observed. The sample volume was then diluted to 100mL and left 132 to stand for 30 minutes and measurements were done at 420nm using a Shimadzu 1800 UV/visible 133 134 spectrophotometer [18].

135**2.2.3 Analysis of Sediments for Phosphates**

136 One gram of the sediment sample was weighed and placed in a 250 mL conical flask and then 50 mL of

- aqua regia (HCl and HNO₃ in the ratio of 3:1) was added and shaken for 30 minutes in the mechanical
- shaker then left to digest for 6 hours. The digest was then filtered using a porous filter paper Whatman

No. 42. 10 mL of the filtered sample was then placed in a boiling tube and 3 drops of the nitro-phenol indicator was added. 6N ammonia solution was then added and decolorized using 1N HNO₃ and 5 mL of vanadomolybdate and the volume was made up to 50 mL in a volumetric flasks using distilled water. The concentration of the samples was then read after 30 minutes at 400 nm using a Shimadzu 1800 UV/visible spectrophotometer [18].

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146 **2.2.4 Analysis of Sediments for Sulphates**

One gram of the dried sediment sample was weighed and placed in a plastic bottle and 100 mL of distilled water was added and the contents shaken for 1 hour in a mechanical shaker. A volume of 50 mL of the sample was put into 250 mL volumetric flask and topped up to the mark. The sample was then diluted 50 times and a volume of 5 mL of the conditioning agent (30 mL HCl, 100 mL ethanol, 75g sodium chloride and 50 mL glycerol) was added followed by 5 mL barium chloride solution and a measurement was read at 420 nm using a Shimadzu 1800 UV/visible spectrophotometer [18].

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154 2.2.4 Analysis of Sediments for Chlorides

The analysis of chlorides was based on the precipitation and titration in which from the burette, silver nitrate solution was released to the chloride ions and indicator containing soil sample extracted with water. 1g of the sediment sample was weighed with 25 mL of water and placed in a 50 mL plastic bottle and shaken for 1 hour and then filtered. The silver ions reacted with chloride ions and chromate ions to form white precipitate of silver chloride and red precipitate of silver chromate.

160 25mL of the distilled water was placed in a conical flask and 3-4 drops of potassium chromate solution 161 added. Standard silver nitrate solution was added slowly from the burette while shaking the solution. At 162 the end point, light yellow colour started changing to red and the red colour persisted. The titration was 163 repeated until a concord volume V₁ was obtained. 25 mL of the extracted sediment sample was placed 164 in a conical flask and 3-4 drops of potassium chromate solution added. Silver nitrate solution was added 165 slowly from the burette and the solution shaken well. At the end point, light yellow colour started changing 166 to red colour and red colour persisted. This was repeated until a concordant V₂ was obtained [19].

167 **2.3 Statistical methods**

Statistical Package for Social Sciences (SPSS) was used for analysis of data. Each parameter was determined three times and the data reported as mean \pm standard deviation to show precision of the results obtained. Two tailed paired t-test was done to show seasonal variation of the different parameters under study, at 95% confidence level (p = 0.05). Spatial variation for both the wet and dry seasons were performed using one way analysis of variance (ANOVA) at 95% confidence level (p = 0.05). A probability test of p < 0.05 was considered to be statistically significant for both the paired t-test and one way ANOVA. Pollution indices such as the geoaccumulation index, contamination factor, pollution load index

and enrichment factor were used to assess the level of contamination by heavy metals in sediments.



178 Fig. 1: Map of River Sio Showing Sampling Points

180 2.4 Pollution Indices

181 The measured concentrations of heavy metals in sediments were used to calculate the following pollution

182 indices: geo accumulation index, enrichment factor, contamination factor and pollution load index. The

183 background values used to determine geo accumulation index, enrichment factor and contamination

184 factor were from Taylor and Mc Lennan (1995) [20].

185 2.4.1 Geo accumulation index

186 In order to determine the extent of pollution in sediments, geo accumulation index was calculated for each

element. Defined by Muller (1979) geo accumulation index determines metal contamination in sediments
 by the concentration of metals in samples with background concentration levels. I_{aeo} is calculated as

189 shown:

$$I_{geo} = log_2 \frac{C_i}{1.5 C_b}$$

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Where: C_i is the concentration of the metal of interest in sediments, C_b is the geo chemical background concentration of the element of interest while 1.5 is introduced into the equation to account for environmental variations in the background values. Muller (1981) distinguished seven categories of geo accumulation indexes as shown in table 1 below [21].

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5 **Table 1: geoaccumulation indexes classes by Muller (1981)**

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value	<mark>Class</mark>	Sediment Quality
<mark>≤ 0</mark>	<mark>0</mark>	Unpolluted
<mark>0 - 1</mark>	<mark>1</mark>	Unpolluted to moderately polluted
<mark>1 to 2</mark>	<mark>2</mark>	Moderately polluted
<mark>2 to 3</mark>	<mark>3</mark>	Moderately to strongly polluted
<mark>3 to 4</mark>	<mark>4</mark>	Strongly polluted
<mark>4 to 5</mark>	<mark>5</mark>	Strongly polluted to extremely polluted
<mark>> 5</mark>	<mark>6</mark>	Extremely polluted

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208 2.4.2 Contamination Factor

- 209 Defined by Hakanson (1980), the contamination factor is used to evaluate the contamination of sediments
- 210 in a given location. It is calculated as shown below:

$$C_f^i = \frac{C_{0-n}^i}{C_b^i}$$

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Where: $C_0^i - n$ is the mean concentration of the element of interest while C_b^i is the background concentration of the element of interest [22].

214 **2.4.3. Enrichment Factor**

- Proposed by Simex and Helz (1981), it is used to assess the level of metals in sediments compared to the pre-industrial era. Enrichment factor normalizes the concentration of metals as a ratio to the concentration of another metal in the sediment [23]. In this study, iron was used as the reference element.
- 218 Enrichment factor is expressed as:

219 $EF = (C_x/C_{Fe})_{sample} / (C_x/C_{Fe})_{background}$

- 220 Where: $(C_x/C_{Fe})_{sample}$ is the concentration of the metal and iron in the sample, while $(C_x \text{ and } C_{Fe})_{background}$ 221 is the concentration of the metal under study and iron in the background respectively.
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- 225 2.4.4. Pollution Load Index
- 226 Pollution load index is defined by the formula:

$$PLI = \left(C_{f1} \times C_{f2} \times \dots \times C_{fn}\right)^{1/n}$$

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Where: C_{f1} , C_{f2} and C_{fn} is the contamination factor of element 1, 2 and the nth element respectively and n

is the total number of elements. Pollution load index measures the level of pollution in sediments [22].

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Table 2: Description of sampling sites and their codes

Station	Description
S1	River Sio at Malomba bridge, next to sugarcane and maize plantations
S2	River Sio at Musoma bridge, where Western sugar company abstracts water for cooling engines
S3	River Sio at Busibwabo, next to Busia sugar company
S4	River Sio at Mundika bridge, where the River crosses Busia town next to Busia water company treating plant
S5	River Sio few kilometers from Busia town, downstream next to maize plantations
*C - Ctotic	

233 *S = Station

235 3.0 RESULTS AND DISCUSSION

236 3.1 Nitrates

The concentration of nitrates in the sediments ranged from 7.42±0.72 g/kg to 27.09±0.10 g/kg during the 237 dry season and 20.80±0.14 g/kg to 51.26±0.80 g/kg during the wet season. Seasonal variations were 238 found to be significantly different at 95% confidence level with T _{calc} = 6.13 > T _{crit} = 2.78 at *P* = .05. 239 240 Spatial variations were also found to be statistically significant at 95% confidence level (P = .05). The 241 high concentration of nitrates during the wet season can be attributed to surface run-off carrying manure, fertilizers and domestic waste from the sugarcane and maize plantations and residential houses located 242 at the banks of the river. The observed increase in the concentration of nitrates downstream during the 243 dry season can be linked to disposal of domestic waste into the river as the river flows through the 244 densely populated region of Busia town. 245

246 3.2 Phosphates

247 The concentration of phosphates was found to be in the range of 1.30±0.00 g/kg to 4.11±0.00 g/kg during the dry season and 5.48±0.01 g/kg to 11.33±0.04 g/kg during the wet season. Seasonal variations were 248 statistically different as per the paired t-test, with T _{calc} = 5.43 > T _{crit} = 2.78 at P = .05. One way ANOVA 249 found the spatial variations to be statistically significant during both the wet and dry seasons at P = .05. 250 251 The high concentration of phosphates during the wet season can be attributed to surface runoff which carries phosphate based fertilizers into the river, in addition to domestic waste and raw sewage that is 252 253 discharged into the river courtesy of poor sanitation and sewerage systems. The increase in the 254 concentration of phosphates at sampling station 2 during both the wet and dry seasons and sampling 255 station 5 during the wet season can be attributed to change in land use, since these are areas with 256 sugarcane, millet and maize plantations hence they discharge more phosphates into the river due to 257 surface runoff from phosphorus based fertilizers during the wet season. There are a lot of human activities like washing of clothes and bathing which leads to more phosphates finding their way into the 258 259 river due to the use of soaps and detergents during these cleaning processes.





3.3 Sulphates

Sulphate concentration in sediments ranged from 3.55 ± 0.20 g/kg to 6.66 ± 0.19 g/kg during the dry season and 1.26 ± 0.09 g/kg and 12.13 ± 0.23 g/kg during the wet season. There was no significant difference in seasonal variations according to paired t-test. T_{calc} = $0.18 < T_{crit} = 2.78$ at P = .05. Spatial variations were found to be significantly different for both the wet and dry seasons at P = .05 as per one way ANOVA.

3.4 Chlorides

The range of chloride concentration in sediments was from 5.76 ± 0.07 g/kg to 13.60 ± 0.27 during the dry season and 9.99 ± 1.13 g/kg to 20.41 ± 0.94 g/kg during the wet season. Paired t-test revealed significant difference in seasonal variation, with T _{calc} = 2.89 > T _{crit} = 2.78 at *P* = .05. One way ANOVA revealed spatial variations to be significantly different during both the wet and dry seasons at *P* = .05. The rise in chloride ions concentration during the wet season can be linked to surface run-off from anthropogenic sources like raw sewage, animal waste and chloride based inorganic fertilizers such as potassium chloride and ammonium chloride.

Table 3: Paired t-test showing seasonal variations in sediments at 95% confidence level (P = 0.05)								
Parameter	Seasonal variation (T critical = 2.78, P = 0.05, df = 4)							
	T calculated	Significance						
Nitrates	6.13	0.004						
Phosphates	5.43	0.006						
Sulphates	0.18	0.863						
Chlorides	2.89	0.045						
Manganese	2.31	0.082						
Lead	6.99	0.002						
Copper	2.23	0.089						
Nickel	4.69	0.009						
Chromium	0.47	0.663						
Cobalt	3.53	0.024						
Zinc	1.73	0.158						
Iron	1.41	0.230						

* Bolded values show significant variation, *df = degrees of freedom

Table 4: One - way ANOVA showing spatial variations in sediments at 95% confidence level (P = 0.05)

Parameter	Spatial Variation (df = 4, F critical= 4.76, P = 0.05)							
	Wet Season		Dry Season					
	F calculated	Sig.	F calculated	Sig.				
NITRATES	824.92	0.000	584.53	0.000				
PHOSPHATES	45458.13	0.000	702343.10	0.000				
SULPHATES	2075.11	0.000	97.49	0.000				
CHLORIDES	68.57	0.000	1577.05	0.000				
MANGANESE	5176.18	0.000	1264.13	0.000				
LEAD	59.74	0.000	27.14	0.000				
COPPER	1425.30	0.000	559.18	0.000				
NICKEL	19.72	0.000	25.91	0.000				
CHROMIUM	31.37	0.000	12.09	0.001				
ZINC	291.43	0.000	260.83	0.000				
COBALT	80.76	0.000	21.35	0.000				
IRON	374.56	0.000	220.69	0.000				

*df = degrees of freedom * Bolded values shows spatial significance

3.5 Heavy Metals

Heavy metals are released in huge amounts into ground water, soil and the biosphere by human activities such as mining, agriculture and transportation. The accumulation of heavy metals in plants leads to the contamination of food via the soil-root interface. Heavy metals like cadmium, lead and nickel are not essential to the growth and development of plants but they are readily taken up and accumulated by plants in toxic forms. There is a significant risk posed to humans and wildlife when they feed on crop products irrigated with waste water and grown in soil that has been contaminated by heavy metals. The concentration of heavy metals in soil is directly linked to metal bioavailability in plants. Research has proven that the use of waste water contaminated with heavy metals for irrigation over long period of time leads to an increase in the concentration of heavy metals in soil above the recommended limits. An increase in the concentration of heavy metals in soil leads to an increase in the uptake of heavy metals by plants depending on the type of soil, the growth stage in which the plant is in and the plant species [24].

The most common sources of heavy metals in the environment are anthropogenic sources such as metal smelting processes, mining, steel and iron industry, automobiles, chemical and metallurgical industries, fertilizers as well as domestic activities [25]. The negative effects that heavy metals have on the soil ecology, agricultural product quality and ground water quality are closely related to the biological availability of heavy metals, which are in turn controlled by metal ion speciation present in the soil. Hence the determination of free metal ion in the soil is key in monitoring heavy metal pollution. The free metal ion concentration depends on both the total content of heavy metals in soil and the metallic species that is present in the soil. Metals also occur naturally in small amounts and may enter the aquatic system via leaching of rocks, airborne dust and forest fires. Since heavy metals cannot be degraded, they continuously get deposited and incorporated in water hence leading to heavy metal pollution in water bodies [26].

3.5.1 Cadmium

Cadmium is primarily found in surface water as a pollutant from industries such as the electroplating industry. Potential damage from cadmium may take the form of anemia, retarded growth and increased hypertension [28]. The levels of cadmium in all the limit of detection during stations were found to be below the both the dry and wet seasons.

298	Table 5: Correlation coefficient ma	atrix for sediment	parameters durir	ng the dry season
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	NO₃⁻	PO4 ³⁻	SO4 ²⁻	CI⁻	Mn	Cu	Ni	Cr	Zn	Со	Fe	Pb
NO₃⁻	1.00											
PO4 ³⁻	-0.14	1.00							(
SO4 ²⁻	-0.47	0.27	1.00									
Cl⁻	-0.56	-0.07	0.52	1.00								
Mn	-0.37	0.85	0.73	0.16	1.00							
Cu	-0.35	0.79	-0.06	0.20	0.50	1.00						
Ni	-0.34	0.47	-0.47	-0.15	0.09	0.81	1.00					
Cr	-0.69	0.22	-0.22	0.33	0.03	0.71	0.85	1.00				
Zn	-0.39	0.89	0.55	-0.06	0.95	0.55	0.29	0.14	1.00			
Со	0.26	0.75	0.51	-0.10	0.79	0.26	-0.21	-0.45	0.70	1.00		
Fe	-0.30	0.22	0.83	0.81	0.54	0.10	-0.45	-0.13	0.27	0.46	1.00	
Pb	-0.39	0.07	-0.15	-0.53	0.07	0.03	0.46	0.32	0.33	-0.28	-0.63	1.00
Bolded va	lues show s	ignificant c	orrelation									

(D).

Bolded values show significant correlation 299

Table 6: Correlation coefficient matrix for sediment parameters during the wet season 300

	NO₃⁻	PO4 ³⁻	SO4 ²⁻	CI⁻	Mn	Cu	Ni	Cr	Zn	Со	Fe	Pb
NO₃⁻	1.00											
PO4 ³⁻	0.38	1.00										
SO4 ²⁻	0.76	0.83	1.00									
Cl⁻	-0.47	-0.14	-0.32	1.00								
Mn	-0.32	0.38	-0.14	0.26	1.00							
Cu	0.43	0.63	0.42	0.07	0.70	1.00						
Ni	0.66	0.92	0.98	-0.20	0.06	0.55	1.00					
Cr	-0.48	-0.18	-0.59	0.52	0.81	0.46	-0.42	1.00				
Zn	-0.14	-0.03	-0.31	0.57	0.73	0.68	-0.16	0.91	1.00			
Со	-0.67	-0.01	-0.55	0.33	0.89	0.34	-0.36	0.88	0.66	1.00		
Fe	-0.31	0.27	-0.07	0.86	0.64	0.52	0.12	0.67	0.76	0.53	1.00	
Pb	-0.32	0.40	-0.10	0.47	0.97	0.72	0.11	0.82	0.80	0.84	0.81	1.00

Bolded values show significant correlation 301









316 3.5.2 Iron

The concentration of iron in the sediments was between 2391.67±18.92 mg/kg to 3298.50±37.51 mg/kg during 317 318 the dry season and 2680.33±47.04 mg/kg to 3861.83±36.06 mg/kg during the wet season. There was no 319 significant difference between the dry and wet seasons as per the paired t-test, with T calc = 1.41 < T crit = 2.78 at 320 P = .05. However, spatial variations were statistically significant at P = .05. The slightly high levels of iron during 321 the wet season can be attributed to surface run off that carried compounds of iron from garages, car wash and 322 fertilizers from the trading centers close to the River and the maize and sugarcane plantations respectively. The 323 level of iron in the sediments was below the WHO recommended levels of 50,000 mg/kg in all the sampling 324 stations during both the wet and dry seasons, which indicated no pollution from iron.

325 3.5.3 Zinc and Copper

Zinc levels in sediments ranged from 17.33 \pm 1.04 mg/kg to 52.50 \pm 3.61 mg/kg for the dry season and 35.83 \pm 0.29 mg/kg to 50.50 \pm 0.00 mg/kg during the wet season. There was no significant difference between the dry season and the wet season, since T _{calc} = 1.73 < T _{crit} = 2.78 at *P* = .05. One way ANOVA revealed a significant difference in spatial variations. The slightly high levels of zinc during the wet season can be attributed to runoff that carried dissolved zinc from garages located at the trading centers near the river and fertilizers from farms. The level of zinc in all the sampling stations was below the WHO recommended levels of 300 mg/kg for both the dry and the wet season, indicating no pollution from compounds of zinc. 333 The level of copper in sediments ranged from 61.33±2.52 mg/kg to 360.33±14.25 mg/kg during the dry season 334 and 17.00±0.00 mg/kg to 31.67±0.58 mg/kg during the wet season. Paired t-test revealed no significant 335 difference between wet season and dry season as T _{calc} = 2.23 < T _{crit} = 2.78 at P = .05. One way ANOVA 336 revealed significant difference in spatial variation at 95% confidence level. The high concentration of copper in 337 sediments during the dry season can be attributed to low volume of water in the river leading to a high 338 concentration of the metal in sediments. The concentration decreases during the wet season due to dilution 339 from the rain water, leading to a high water volume in the River which leads to low analyte concentration. 340 Sampling stations 1, 2 and 3 recorded copper levels that were above the WHO recommended limits of 100 341 mg/kg during the dry season, indicating pollution by copper. The level of copper was below the WHO recommended limit in all the sampling stations during the wet season due to dilution from rain water. 342

343 3.5.4 Manganese

344 The level of manganese in sediments ranged from 315.50±1.73 mg/kg to 723.83±8.02 mg/kg during the dry 345 season and 263.33±1.26 mg/kg to 495.00±2.65 mg/kg during the wet season. There was no significant difference between the dry and wet season, since T _{calc} = 2.31 < T _{crit} = 2.78 at P = .05. Spatial variations were 346 statistically significant at 95% confidence level. The slightly high levels during the dry season can be linked to 347 348 evaporation of water from the River, leading to an increase in concentration. However, this is offset during the 349 wet season leading to a decrease in concentration of manganese in sediments as a result of dilution from the 350 rain water. All the sampling stations recorded manganese levels that were within permissible limits of 2000 351 mg/kg by the WHO during both the dry and the wet season.

352 3.5.5 Chromium

353 The concentration of chromium in sediments was between 42.50±1.32 mg/kg to 49.00±1.73 mg/kg during the 354 dry season and 26.67±7.64 mg/kg to 64.17±2.89 mg/kg during the wet season. There was no significant 355 difference between the dry and the wet season, since T _{calc} = 0.47 < T _{crit} = 2.78 at P = .05. Spatial variations 356 were statistically significant at 95% confidence level. The slightly high concentrations of chromium at sampling 357 stations 1, 2 and 3 during the wet season is most likely due to surface runoff that carries chromium compounds 358 from wood preservatives, pesticides and fungicides and surface coatings into the River during the wet season. 359 The level of chromium in all the five sampling stations was below the WHO recommended limits of 100 mg/kg 360 during both the dry and wet seasons, indicating no pollution from chromium compounds.

361 3.5.6 Nickel

The concentration of nickel in sediments was between 133.33±11.45 mg/kg to 237.83±11.45 mg/kg during the 362 dry season and 81.83±5.97 mg/kg to 115.50±7.05 mg/kg during the wet season. Seasonal variations were 363 significantly different with T _{calc} = 4.69 > T _{crit} = 2.78 at P = .05. Spatial variations were also found to be 364 statistically significant at 95% confidence level. The high concentrations of nickel during the dry season can be 365 366 attributed to increased evaporation of water from the River leading to a higher concentration of the analyte. But 367 this was quickly offset during the rainy season, as rain water caused dilution resulting to a significant decrease in the concentration of the analyte during the wet season. All the five sampling stations recorded nickel 368 369 concentrations which were way above the WHO recommended level of 50 mg/kg. This was an indication of 370 pollution resulting from nickel and nickel related compounds.

371 3.5.7 Cobalt

The level of cobalt in sediments was between 12.50 ± 1.32 mg/kg to 20.67 ± 1.44 mg/kg during the dry season and 3.00 ± 0.87 mg/kg to 19.00 ± 1.32 mg/kg during the wet season. Variation between the dry and the wet season was significantly different with T _{calc} = 3.53 > T _{crit} = 2.78 at *P* = .05. Spatial variations were found to be significantly different as per one way ANOVA at 95% confidence level. The high levels of cobalt in the sediments during the dry season can be attributed to evaporation of River water leading to a high concentration of the analyte, which is reversed during the wet season following dilution by rain water leading to a decrease in

- the concentration of cobalt attached to the surface of sediments. Cobalt levels in all the five sampling stations
- 379 during the dry and wet seasons were below the 50 mg/kg level recommended by WHO indicating lack of
- 380 pollution by cobalt in the sediments.

381 3.58 Lead

The concentration of lead in sediments ranged from 225.50±28.23 to 486.37±65.25 during the dry season to 382 8.00±0.52 to 15.65±0.90 during the wet season. There was significant variation between the dry and wet 383 season with T_{calc} = 6.99 > T _{crit} = 2.78 at P = .05. One way ANOVA revealed statistical difference in spatial 384 variations at 95% confidence level. Water evaporation during the dry season can be linked to the high level of 385 lead in sediments during the dry season. But this is offset by dilution during the wet season, leading to 386 significant reduction in the concentration of lead. The level of lead was above the WHO recommended level of 387 100 mg/kg in all the sampling sites during the dry season and way below the WHO recommended level during 388 389 the wet season.

390 **3.6 Pollution Indices**

391 **3.6.1 Geoaccumulation Index**

392 Table 7 below shows the geoaccumulation index values for heavy metals in sediments from River Sio.

393 <mark>T</mark>	Table 7: Heavy metals geoaccumulation index
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SAMPLING SITE	<mark>SEASON</mark>	<mark>Cr</mark>	<mark>Mn</mark>	Fe	Co	Ni	<mark>Cu</mark>	<mark>Zn</mark>	<mark>Pb</mark>
<mark>S1</mark>	<mark>DRY</mark>	<mark>-1.34</mark>	<mark>-0.49</mark>	<mark>-4.48</mark>	<mark>-0.2</mark>	<mark>1.56</mark>	<mark>0.83</mark>	<mark>-0.89</mark>	<mark>4.25</mark>
	WET	<mark>-1.28</mark>	<mark>-1.18</mark>	<mark>-4.48</mark>	<mark>-1.62</mark>	<mark>0.45</mark>	<mark>-1.42</mark>	<mark>-1.13</mark>	<mark>-1.62</mark>
<mark>S2</mark>	<mark>DRY</mark>	<mark>-1.18</mark>	<mark>-0.53</mark>	<mark>-4.37</mark>	<mark>-0.25</mark>	<mark>1.99</mark>	<mark>2.59</mark>	<mark>-1.03</mark>	<mark>3.69</mark>
	<mark>WET</mark>	<mark>-0.79</mark>	<mark>-1.04</mark>	<mark>-4.03</mark>	<mark>-0.34</mark>	<mark>0.66</mark>	<mark>-0.93</mark>	<mark>-0.95</mark>	<mark>-0.70</mark>
<mark>S3</mark>	<mark>DRY</mark>	<mark>-1.18</mark>	<mark>-1.69</mark>	<mark>-4.65</mark>	<mark>-0.94</mark>	<mark>1.85</mark>	<mark>1.00</mark>	<mark>-2.48</mark>	<mark>4.19</mark>
	<mark>WET</mark>	<mark>-1.17</mark>	<mark>-1.63</mark>	<mark>-3.96</mark>	<mark>-1.74</mark>	<mark>0.70</mark>	<mark>-1.12</mark>	<mark>-0.98</mark>	<mark>-1.13</mark>
<mark>S4</mark>	<mark>DRY</mark>	<mark>-1.34</mark>	<mark>-0.91</mark>	<mark>-4.19</mark>	<mark>-0.38</mark>	<mark>1.15</mark>	<mark>0.03</mark>	<mark>-1.97</mark>	<mark>3.15</mark>
	WET	<mark>-2.06</mark>	<mark>-1.95</mark>	<mark>-4.38</mark>	<mark>-2.08</mark>	<mark>0.66</mark>	<mark>-1.82</mark>	<mark>-1.44</mark>	<mark>-1.67</mark>
<mark>S5</mark>	DRY	<mark>-1.38</mark>	<mark>-1.51</mark>	<mark>-4.61</mark>	<mark>-0.36</mark>	<mark>1.52</mark>	<mark>0.36</mark>	<mark>-2.49</mark>	<mark>3.54</mark>
	WET	<mark>-1.97</mark>	<mark>-1.66</mark>	<mark>-4.36</mark>	<mark>-3.00</mark>	<mark>0.95</mark>	<mark>-0.92</mark>	<mark>-1.23</mark>	<mark>-1.38</mark>

394

395 Cr, Mn, Fe, Co and Zn showed negative geoaccumulation index values, showing unpolluted status (class 0). 396 However, Ni showed moderate pollution in sediments during the dry season (class 2) and unpolluted to 397 moderately polluted during the wet season (class 1). The shift from class 2 to class 1 in the geoaccumulation 398 index can be attributed to dilution during the wet season. For copper, sampling stations 1, 3, 4 and 5 were 399 classified under class 1 in the geoaccumulation index showing that the levels of copper in sediments in these 400 stations vary from unpolluted to moderately polluted during the dry season. However, sampling station 2 had a 401 geoaccumulation index value of 2.59 for copper during the dry season, and is therefore classified under class 3, 402 which ranges from moderately polluted to strongly polluted. But the geoaccumulation index values for copper 403 were below 0 during the wet season, showing no pollution during the wet season. This can be attributed to 404 dilution during the wet season, leading to a decrease in the concentration of copper. Sampling sites 2, 4 and 5 405 were strongly polluted with lead whereas sampling sites 1 and 3 ranged from strongly to extremely polluted with 406 lead during the dry season. The geoaccumulation index value for lead was below zero in all the sampling sites

407 during the wet season, indicating no pollution due to lead during the wet season.

409 3.6.2 Contamination Factor

- 410 Using contamination factor, heavy metal pollution in sediments can be classified into four categories. $C_f \le 1$ =
- low, $C_f 1 3$ = moderate, $C_f 3 6$ considerable contamination while $C_f > 6$ = very high contamination. Table 8 411
- 412 shows the contamination factor for the heavy metals in River Sio.
- 413
- 414

											\sim
Table 8: Heavy	metals con	tamina	tion fa	ctor							
<mark>SAMPLING</mark> SITE	<mark>SEASON</mark>	<mark>Cr</mark>	<mark>Mn</mark>	<mark>Fe</mark>	<mark>Co</mark>	Ni	<mark>Cu</mark>	<mark>Zn</mark>	Pb	PLI	
<mark>S1</mark>	<mark>DRY</mark>	<mark>0.59</mark>	<mark>1.07</mark>	<mark>0.07</mark>	<mark>1.29</mark>	<mark>4.43</mark>	<mark>2.66</mark>	<mark>0.81</mark>	<mark>28.61</mark>	<mark>1.41</mark>	
	WET	<mark>0.62</mark>	<mark>0.43</mark>	<mark>0.07</mark>	<mark>0.49</mark>	<mark>2.05</mark>	<mark>0.56</mark>	<mark>0.69</mark>	<mark>0.49</mark>	<mark>0.49</mark>	
<mark>S2</mark>	<mark>DRY</mark>	<mark>0.66</mark>	<mark>1.04</mark>	<mark>0.07</mark>	<mark>1.26</mark>	<mark>5.95</mark>	<mark>9.01</mark>	<mark>0.74</mark>	<mark>19.34</mark>	<mark>1.62</mark>	
	WET	<mark>0.87</mark>	<mark>0.73</mark>	<mark>0.09</mark>	<mark>1.19</mark>	<mark>2.38</mark>	<mark>0.79</mark>	<mark>0.78</mark>	<mark>0.92</mark>	<mark>0.74</mark>	
<mark>S3</mark>	<mark>DRY</mark>	<mark>0.66</mark>	<mark>0.46</mark>	<mark>0.06</mark>	<mark>0.78</mark>	<mark>5.40</mark>	<mark>3.00</mark>	<mark>0.27</mark>	<mark>27.33</mark>	<mark>1.07</mark>	
	WET	<mark>0.67</mark>	<mark>0.49</mark>	<mark>0.10</mark>	<mark>0.45</mark>	<mark>2.44</mark>	<mark>0.69</mark>	<mark>0.76</mark>	<mark>0.69</mark>	<mark>0.58</mark>	
<mark>54</mark>	<mark>DRY</mark>	<mark>0.59</mark>	<mark>0.80</mark>	<mark>0.08</mark>	<mark>1.16</mark>	<mark>3.33</mark>	<mark>1.53</mark>	<mark>0.38</mark>	<mark>13.27</mark>	<mark>1.02</mark>	
	<mark>WET</mark>	<mark>0.36</mark>	<mark>0.39</mark>	<mark>0.07</mark>	<mark>0.35</mark>	<mark>2.38</mark>	<mark>0.43</mark>	<mark>0.55</mark>	<mark>0.47</mark>	<mark>0.42</mark>	
<mark>S5</mark>	<mark>DRY</mark>	<mark>0.57</mark>	<mark>0.53</mark>	<mark>0.06</mark>	<mark>1.17</mark>	<mark>4.30</mark>	<mark>1.93</mark>	<mark>0.27</mark>	<mark>17.42</mark>	<mark>0.98</mark>	
	WET	<mark>0.38</mark>	<mark>0.47</mark>	0.07	0.19	<mark>2.89</mark>	0.79	<mark>0.64</mark>	<mark>0.58</mark>	<mark>0.46</mark>	

415 Table 8: Heavy metals contamination factor

416 **PLI = Pollution Load Index**

417 The contamination factor for Cr, Fe and Zn were low ($C_f < 1$) during both the dry and wet seasons. The 418 contamination factor for manganese was low for both the dry and wet seasons, except for sampling sites 1 and 419 2 in which the contamination factor was > 1 during the dry season, indicating moderate contamination by 420 manganese. The contamination factor for cobalt was moderate during the dry season, ($C_f > 1$) and low during 421 the wet season ($C_f < 1$) and this can be attributed to dilution of the metals in the river water during the wet 422 season. Copper showed moderate contamination in sampling sites 1, 3, 4 and 5 while sampling site 2 showed 423 very high contamination ($C_f > 6$) of copper during the dry season. However, copper showed low contamination 424 in all the sampling sites during the wet season and this is due to dilution during the wet season, leading to low 425 concentration of copper in sediments during the wet season. Nickel had the highest contamination factor during 426 both the dry and wet seasons. During the dry season, there was considerable contamination by nickel ($C_f < 6$) 427 but showed moderate contamination during the wet season ($C_f < 3$) due to dilution during the wet season. The 428 contamination factor for lead was very high in all the sampling sites during the dry season (C_f > 6) while it was 429 moderate during the wet season ($C_f 0.42 - 0.74$). The reduction in contamination factor values witnessed during 430 the rainy season can be linked to dilution of lead in sediments by rain water.

3.6.3 Pollution Load Index 431

432 Pollution due to anthropogenic activities is indicated by a PLI > 1 while a PLI < 1 indicates no pollution [22].

Sampling site 5 showed no pollution due to human related activities during the dry season (PLI < 1). However, 433

434 all the remaining sampling sites showed pollution due to anthropogenic activities during the dry season (PLI >

435 1) while during the wet season there was no pollution due to anthropogenic activities (PLI < 1).

436 3.6.4. Enrichment Factor

- 437 The enrichment factor is divided into several classes. $E \cdot F < 1 = no$ enrichment, $E \cdot F \cdot 1 = 3 = minor enrichment$,
- E.F 3 5 = moderate enrichment, E.F 5 10 = moderately severe enrichment, E.F 10 25 = severe 438

439 enrichment, E.F 25 – 50 = very serious enrichment while E.F > 50 = extremely severe enrichment. In this study,

440 iron was used as the reference metal in calculating the enrichment factor. The enrichment factor for the different

441 heavy metals under study is given in table 9.

442

<mark>SAMPLING</mark>								
<mark>SITE</mark>	<mark>SEASON</mark>	<mark>Cr</mark>	<mark>Mn</mark>	<mark>Co</mark>	Ni	<mark>Cu</mark>	<mark>Zn</mark>	<mark>Pb</mark>
<mark>51</mark>	DRY	<mark>8.90</mark>	<mark>15.82</mark>	<mark>19.19</mark>	<mark>65.87</mark>	<mark>39.56</mark>	<mark>12.00</mark>	<mark>425.06</mark>
	<mark>WET</mark>	<mark>9.24</mark>	<mark>6.37</mark>	<mark>7.30</mark>	<mark>30.53</mark>	<mark>8.39</mark>	<mark>10.26</mark>	<mark>7.29</mark>
<mark>52</mark>	DRY	<mark>9.13</mark>	<mark>14.31</mark>	<mark>17.39</mark>	<mark>82.02</mark>	<mark>97.81</mark>	10.15	266.75
	<mark>WET</mark>	<mark>9.42</mark>	<mark>7.90</mark>	<mark>12.89</mark>	<mark>25.79</mark>	<mark>8.55</mark>	<mark>8.44</mark>	<mark>9.99</mark>
<mark>S3</mark>	DRY	<mark>11.04</mark>	<mark>7.76</mark>	<mark>13.07</mark>	<mark>90.24</mark>	<mark>50.25</mark>	<mark>4.50</mark>	<mark>457.05</mark>
	<mark>WET</mark>	<mark>6.88</mark>	<mark>5.02</mark>	<mark>4.64</mark>	<mark>25.29</mark>	7.17	<mark>7.86</mark>	<mark>7.10</mark>
<mark>S4</mark>	DRY	<mark>7.18</mark>	<mark>9.70</mark>	<mark>14.02</mark>	<mark>40.42</mark>	<mark>18.59</mark>	<mark>4.63</mark>	<mark>160.86</mark>
	<mark>WET</mark>	<mark>5.00</mark>	<mark>5.38</mark>	<mark>4.92</mark>	<mark>32.97</mark>	<mark>5.90</mark>	<mark>7.65</mark>	<mark>6.53</mark>
<mark>S5</mark>	DRY	<mark>9.36</mark>	<mark>8.56</mark>	<mark>19.02</mark>	70.01	<mark>31.44</mark>	<mark>4.35</mark>	<mark>287.39</mark>
	WET	<mark>5.23</mark>	<mark>6.48</mark>	<mark>2.56</mark>	<mark>39.43</mark>	10.81	<mark>8.76</mark>	<mark>7.90</mark>

443 **Table 9: Enrichment factor for heavy metals in sediments during dry and wet season.**

444

Cr recorded moderately severe enrichment in all the sampling sites during both the dry and wet season, except 445 for sampling site 3 which recorded severe enrichment during the dry season. There was moderately severe 446 enrichment of manganese in all the sampling sites during both seasons except in sampling sites 1 and 2 which 447 recorded severe enrichment during the dry season. The enrichment factor for cobalt was moderately severe 448 during the wet season and severe during the dry season except for sampling site 2 which recorded severe 449 enrichment during the wet season. Elevated enrichment was observed in nickel as all the sampling sites 450 451 recorded extremely severe enrichment during the dry season and very severe enrichment during the wet season. Similar levels of enrichment was observed in copper, which recorded extremely severe enrichment in 452 sampling sites 2 and 3 during the dry season, very severe enrichment in sampling sites 1 and 5 during the dry 453 454 season and severe enrichment in sampling site 4 during the dry season. During the wet season, sampling sites 455 1, 2, 3 and 4 recorded moderately severe enrichment during the wet season, whereas sampling site 5 recorded 456 severe enrichment in copper during the same season. All the sampling sites were moderately enriched with 457 zinc except sampling site 1 during both the dry and wet season and sampling site 2 during the dry season. 458 These sampling sites recorded moderately severe enrichment. The high levels of enrichment during the dry 459 season can be attributed to high concentrations of metals in sediments due to the high rate of evaporation. The 460 enrichment factor for lead was extremely severe in all the sampling sites during the dry season (E.F > 50) while the wet season witnessed moderately severe enrichment (E.F 5 - 10). The low enrichment levels during the wet 461 462 season can be linked to dilution leading to low concentration of metals in sediments.

463 3.7 CORRELATION.

464 Correlation coefficient (r) measures the joint variation between two variables, x and y. It measures the strength 465 and direction of a linear relationship between the two variables on a scatter plot. The correlation coefficient r 466 can only take values in the range $-1 \le r \le +1$. An r value of -1 describes a perfect negative correlation and an r value of + 1 indicates a perfect positive correlation while an r value of 0 indicates no linear correlation between 467 468 the values of x and y [27]. During the dry season, there was a strong correlation between manganese, copper, 469 zinc and cobalt to the phosphate anion (r = 0.85, 0.79, 0.89 and 0.75 respectively) indicating that these metals 470 in sediments exist in phosphate form. Sulphate showed strong correlation to manganese and iron (r = 0.73 and 471 0.83 respectively) indicating that manganese and iron are most likely to exist in sulphate form. Chloride showed

472 a strong correlation to iron (r = 0.81) indicating high levels of iron (II) chloride in the sediments. Manganese 473 showed strong correlation to zinc and cobalt (r = 0.95 and 0.79 respectively) indicating the presence of alloys of 474 manganese in sediments. The strong correlation of copper to nickel and chromium (r = 0.81 and 0.71) indicates 475 the presence of copper alloys in sediments. Nickel strongly correlated to chromium (r = 0.85) and zinc to cobalt 476 (r = 0.70) providing a strong evidence of alloys of these metals in sediments. During the wet season, nickel was 477 strongly correlated to phosphates and sulphates (r = 0.92 and 0.98 respectively) indicating the presence of 478 phosphates and sulphates of nickel in sediments. Manganese showed strong correlation to copper, chromium, 479 zinc and cobalt providing further evidence of alloys of these metals in sediments. Strong correlation of 480 chromium to zinc and cobalt (r = 0.91 and 0.88 respectively), lead to manganese, copper, chromium, zinc, iron and cobalt (r = 0.97, 0.72, 0.82, 0.80, 0.81 and 0.84 respectively) provides further evidence for the existence of 481 482 alloys in sediments.

483 **4.0 CONCLUSION**

484 The parameters that were above the WHO recommended levels are all the anions: nitrates, phosphates, 485 sulphates, and chlorides. Copper and nickel were the only cations that were above the WHO recommended limit. Lead and cadmium were below the limit of detection, while all the remaining cations were below the WHO 486 487 recommended limits in sediments. Elevated levels of nitrates, phosphates, sulphates and chlorides is a clear 488 indication of poor land use, as these nutrients find their way into the River courtesy of surface runoff that carries 489 nutrients from inorganic fertilizers and dumps them into the River. High levels of copper and nickel in the 490 sediments points to the use of herbicides and pesticides in farming and washing of vehicles and motorcycles on 491 the banks of the River. The release of these metals into the River poses a threat to aquatic and terrestrial forms 492 of life that depend on the River due to their high toxicity. This situation is further worsened by skyrocketing 493 levels of anions which are most likely to cause the eutrophication of river Sio, in addition to affecting the 494 physico-chemical characteristics of water from the River. According to I_{dee} nickel showed moderate pollution 495 during the dry season. The contamination factor for lead was very high during the dry season, while pollution load index confirmed pollution due to anthropogenic activities in sampling sites 1 - 4 during the dry season and 496 497 no pollution due to anthropogenic activities during the wet season.

498 In view of the above, this study recommends that excessive use of inorganic fertilizers should be discouraged in 499 order to save the River from the danger of eutrophication. Instead the use of compost and farmyard manure 500 should be encouraged since they contain very low levels of heavy metals and other water pollutants. Excessive 501 use of agrochemicals such as herbicides and pesticides should be discouraged. Farmers should instead resort 502 to the use of biological control to keep pests at bay. Both the County and National governments should enforce 503 appropriate legislations on proper solid waste management in order to prevent soil pollution. The National Environmental Management Authority (NEMA) should step in and impose heavy penalties (including jail time) 504 505 for those contravening environmental laws. In addition, pesticide leaching and the level of microbes in soil and 506 sediments should be considered for further research.

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