Original Research Article

Assessment of Selected Water Quality Parameters in Olomodoi/Okame/Ndambuk River, Busia County, Kenya

Comment [N1]: Title should be attractive and detailed. See my suggestion below "Assessment of Water Quality and Heavy Metal Pollution in different rivers at Busia County, Kenya"

Abstract

Climate change is one of the main environmental challenges that the world is currently grappling with. Climate change manifests itself through water; in form of water scarcity (drought) or excess water (floods). Floods lead to water pollution via surface runoff which deposits pollutants into water sources. Water can also be polluted by poor agricultural practices, poor solid and liquid waste disposal, oil spillage in Lakes and Oceans as well as through aerosol deposition during windy and rainy seasons. The objective of this research study is to assess the levels of selected physico – chemical parameters of water in Ndambuk/Alupe River in Busia County, Kenya, during both the dry and wet seasons. Grab water samples were collected at seven different points along the riverand the quality determined through the assessment of physical and chemical parameters. The physical parameters that were determined include: pH, turbidity, temperature, total dissolved solids (TDS) and electrical conductivity. These were determined on site during the sampling process using portable meters as per the American Water Works Association (AWWA) standard methods for analysis of water and wastewater. The chemical parameters that were determined included heavy metals such as lead, cadmium, copper, iron, chromium, manganese, nickel, zinc and cobalt. The heavy metals were measured using Flame Atomic Absorption Spectrophotometer (FAAS) in line with the AWWA standard methods. Data analysis was carried out using Statistical Package for Social Sciences (SPSS). Turbidity was above the WHO recommended limit of 5 NTU in all the sampling points during both the dry and wet seasons. pH was above the WHO recommended limit of 6.5 – 8.5 at sampling points 5, 6 and 7 during both seasons and this can be attributed to mining activities alongthe Kenya – Uganda border.Lead, Cadmium, Cobalt, Nickel and Iron were above the WHO recommended limits in all the sampling points during both the dry and wet seasons. However, Chromium recorded concentrations below the WHO limits at sampling points 1,2 and 4 during the dry season and at sampling point 2 during the wet season.The strong correlation between the heavy metals points to the presence of metal – metal complexes in solution form. The strong correlation between the metals, electrical conductivity, total dissolved solids and turbidity points to increased anthropogenic activities, especially agricultural and mining practices downstream. This study recommends proper agricultural practices that will curb soil erosion as well as regulated mining activities, especially along the Kenya – Uganda border.

Comment [N2]: This section not necessary in abstract should move into Intro.
Why you're using the world climate change, this is very long phenomena but your study is very short span of time i.e., only two seasons. You should focus on regional factors which are more reliable impacts to thewater quality significantly.

Key words: Heavy Metals, Lead, Cadmium, Cobalt, Nickel, Iron,Water Pollution, River Olomodoi/Okame/Ndambuk,Climate change.

Comment [N3]: Keywords should be maximum 5-7. See my suggestion below "Anthropogenic, Heavy Metals, mining, water pollution, River flows"

UNDER PEER REVIEW

1. INTRODUCTION

Climate change has severely affected water availability since water is the main medium through which climate change manifests itself. This has led to a significant decrease in the amount of water available for both domestic and agricultural use in most parts of the world. In addition to the effects of climate change, rapid urbanization and technology change has also affected water quality and quantity (Kilonzo *et.al.,* 2019).Water is crucial for sustenance of life on earth, as all living organisms depend on water either directly or indirectly.Over 70% of planet earth is covered with water in form of oceans and seas and access to clean, safe and affordable water services is not only key to economic growth but also vital to the growth and well-being of all living organisms.However, in most third world nations, water quality has always been the main point of concernas the quality of water has been severely affected courtesy of both natural and anthropogenic causes (Nzeve and Matata, 2021). According to the Kenyan Water Act 2016, water is a basic human right that is enshrined in the Kenyan constitution and every person has the right to access clean and safe water irrespective of their race, place of origin or creed. For this to be realized, both the government and civil society organizations should work hand in hand to prioritize investment areas; strengthen organizational processes and strengthen governance of Water Sanitation and Hygiene (WASH) and Water Resources Management (WRM) sectors (Kewasnet, 2019).Currently over 47% of the global population reside in areas of severe water scarcity and this figure is expected to rise if appropriate measures are not put in place to arrest the situation. Water quality is affected by a wide range of factors, top of the list being climate change, industrialization, poor agricultural practices and population increase which puts pressure on the available water resources. Industries discharge effluents that are high in both chemical and biological oxygen demand; suspended solids and dyes (Mumbi and Watanabe; 2020).For water to be considered safe for human consumption, it should be assessed to determine its suitability. Water can only be considered safe for both domestic and human consumption if it satisfies the Water Quality Index (WQI) which considers the physico – chemical and microbiological parameters of water. These parameters includeturbidity, pH, total dissolved solids, heavy metals and anions as well as microorganisms such as *E. coli* (Baloïtcha*et.al.,* 2022).The presence of extensive anthropogenic activities along the Ndambuk/Alupe River is indicative of the level of pollution in the River. The rise in population of Busia town has placed a sharp demand on residential houses, leading to increased discharge of liquid waste into the River. The situation has been further worsened by poor sewer coverage in Busia town leading to discharge of raw sewage into the river. As the River flows downstream from Busia town to neighbouring Uganda, maize, millet and sugarcane plantations dominate the entire stretch (Ondoo*et.al.* 2019). The situation is worsened by the presence of artisan gold mining plants along the river which discharge a wide range of toxic heavy metals ranging from lead, arsenic to mercury courtesy of poor mining activities and lack of effective water pollution control measures. Artisan mining includes simple enough processes such as the scrapping away of topsoil to complex practices such as digging deep underground trenches in a bid to extract minerals (Dzoro*et al.*, 2023). Most of the artisan gold miners in most parts of Africa usually employ primitive mining techniques, use very low-quality ores and with limited ore production account for over 37.7% of some of the most toxic heavy metals emissions into the atmosphere and water sources (Schwartz *et.al.*, 2023).

Comment [N4]: What was research gap have you conveyed to the scientific society?
With this mind, should write a brief outline of your scope of study and its significance

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2. MATERIALS AND METHODS

2.1 Study Area

Busia is one of the 47 Counties in the Republic of Kenya. It is located 0° 29’ 45” N and 34° 7’ 59” E (Mindat, 2023). The County has an area of 1,696 $km^2$with a population of 893,681 and a population density of 526.8 km^2 as per the August 2019 census. The Annual population change, from 2009 to 2019 is 1.9% (Busia population, 2023). Busia has a tropical rainforest climate. The average temperatures range from 16 – 31 °C. The County experiences dry and wet seasons. The dry season starts from January to March with an average temperature of 31 °C, with the month of February being the hottest. The cold season lasts for about 5 months, from April to September with an average temperature of 27 °C. The coldest month is August with an average temperature of about 16 °C (Busia climate, 2023). The Ndambuk/Alupe River originates from Samia hills in Busia County and flows through Korinda and Amerikwai areas down through Alupe and Adungosi sub – locations before crossing the border into neighbouring Uganda. The first zone (upstream) mainly comprises of agricultural areas with the major crops under cultivation being maize, millet, sorghum and sugarcane plantations. The second zone (downstream) comprise of gold mining zones along the Kenya – Uganda border, while the third zone (downstream) comprise mainly of agricultural land with maize, sugarcane and millet being the major crops under cultivation. The river also acts as the main source of water for bothdomestic and agricultural use, with activities such as watering of animals, laundry and bathing being the most common on the Riverbanks. The section of the river under study was from Amerikwai in Kenya to Omanye.Fig. 1 shows the map of Ndambuk/Alupe River with the sampling points clearly indicated.

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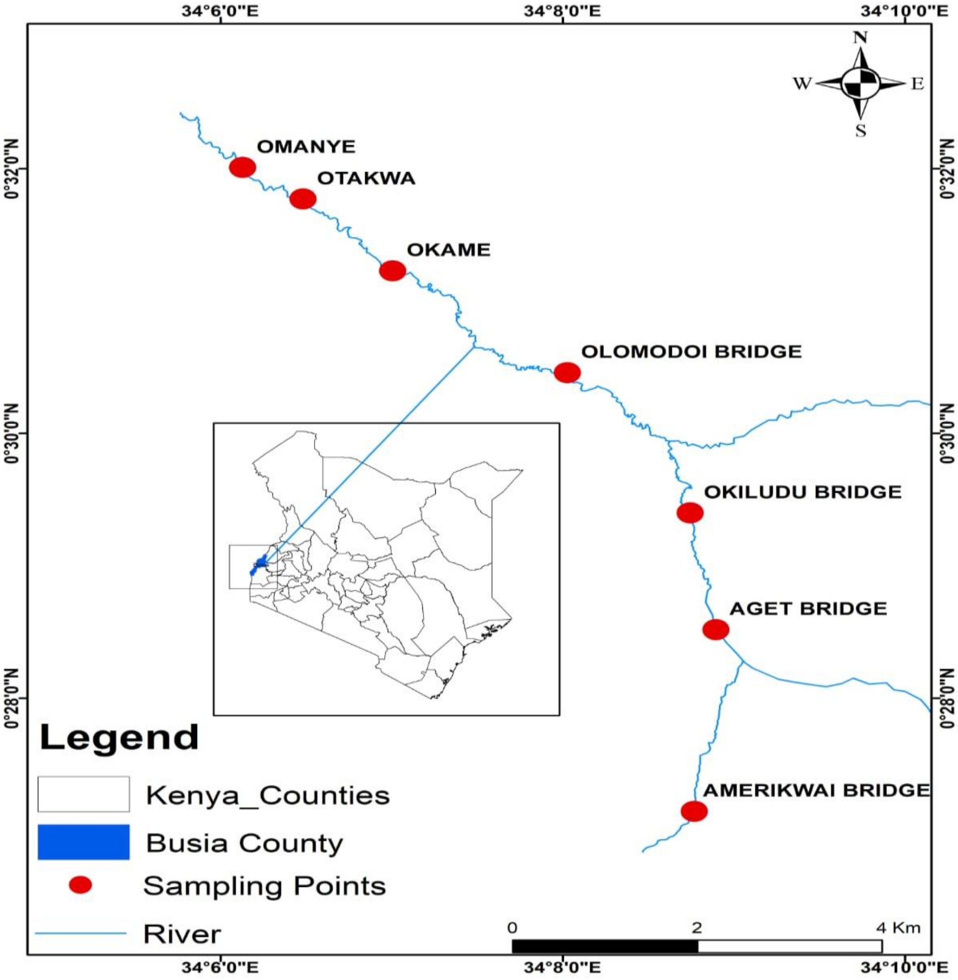

Figure 1: Sampling points along the Olomodoi/Okame/Ndambuk River

2.2 Sampling Method

The identification of sampling points was carried out prior to sampling. The GPS coordinates of the sampling locations were taken to ensure that water samples were collected at the exact location for both the dry (February 2023) and wet seasons (May 2023). ~~Water samples were collected in February 2023 (dry season) and May 2023 (wet season).~~ The dry season is between January to March and is characterized by absence of rainfall and temperatures of up to 31°C whereas the wet season is characterized by plenty of rainfall, up to 1200 mm and temperatures as low as 16°C. The wet season persists ~~lasts~~ between April and September. Random sampling method was used to collect 500 mL grab water samples in polyethylene bottles prewashed with 10% nitric acid and rinsed with distilled water (Ondoo*et.al*, 2019).

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"The surface water samples were collected 500 mL by using precleaned polyethylene bottles and transported to the lab for further analysis."

Table 1: Sampling Stations and Description Codes

Station Code	GPS Coordinates	Description
S1	[0.4473178; 34.14581]	Amerikwai bridge near Busia town
S2	[0.475463; 34.148456]	Aget bridge next to maize plantation
S3	[0.489743; 34.145468]	Okiludu bridge next to maize and sugarcane plantation
S4	[0.507436; 34.133754]	Olomodoi bridge next to sugarcane and millet plantation
S5	[0.52013; 34.1166880]	Okame, next to a mining site
S6	[0.529254;34.107975]	Otakwa, next to maize plantation
S7	[0.533175; 34.102220]	Omanye, next to maize and sorghum plantation

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*S = Sampling Point

2.3 Preparation of Standards

Serial dilution was carried out for the different stock solutions of the various metals under study, where 1000ppm stock solutions were diluted to 100ppm solutions which were then diluted further to 10ppm standards. The 10ppm metal standards were then diluted to obtain working standards of 0.1ppm, 0.2ppm, 0.4ppm, 0.8ppm, 1.6ppm, 3.2ppm and 6.4ppm. These working standards were used to prepare the calibration curves for the different heavy metals under study. The concentrations of the different heavy metals under study were determined from the calibration curves at their respective analytical lines. Both the standard and samples were treated in a similar manner in order to minimize matrix effect (APHA, 2005).

2.4 Determination of Physical Parameters

The physical parameters that were measured include: temperature, turbidity, electrical conductivity, total dissolved solids and pH. These parameters were measured on site during sampling, using ISOLAB Laborgerate GmbH portable meter. Turbidity was measured using SGZ – B portable turbidimeter. The physical parameters were determined in accordance with the American Public Health Association method for analysis of water and waste water (APHA, 2005).

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"In-situ parameters like temperature, turbidity, electrical conductivity, total dissolved solids and pH were measured on site during sampling, using ISOLAB Laborgerate GmbH portable meter."

2.5 Determination of Heavy Metals

The chemical parameters that were determined were heavy metals such as Lead (Pb), Cadmium (Cd), Chromium (Cr), Iron (Fe), Cobalt (Co), Copper (Cu), Nickel (Ni) and Zinc (Zn). 500 mL of grab water samples were collected for both the dry and wet season, after which 2.5 mL of 65% nitric acid were added then the samples transported to the laboratory and stored at a temperature of 4°C to prevent precipitation of analyte on the walls of the container. Sample digestion was carried out using nitric acid, where 5 mL of 65% nitric acid was added to 100 mL of water sample in a conical flask and then heated on a hot plate until the volume reduced to 10 mL. This was then filled to the 100 mL mark using deionized water. The levels of heavy metals in the water samples were determined using Shimadzu AA 7100 Atomic Absorption Spectrophotometer (APHA, 2005).

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3. RESULTS AND DISCUSSION

3.1 Physico – Chemical Parameters

3.1.1 pH

The pH of water ranged between 7.26±0.02and 8.85±0.02during the dry season to 7.00±0.01 and 9.53±0.01during the wet season. There was no significant difference between the dry and the wet season as per the paired t – test, with a $T_{calculated}$ value of 0.393 against a $T_{critical}$ value of 2.45 at $P = 0.05$~~$P = .05$~~ level of significance. There was however a significant difference in spatial variation during both the dry and wet seasons as per one way ANOVA, with an $F_{calculated}$ value of 5791.06 against an $F_{critical}$ value of 2.85 during the dry season and $F_{calculated}$= 33,133.92 against $F_{critical}$value of 2.85 during the wet season both at $P = 0.05$ level of significance (Could we attribute this to any factors?). Most of the sampling points recorded pH values that were within the WHO permissible limits of 6.5 – 8.5, except sampling points 5, 6 and 7 during both the dry and wet seasons. The highly alkaline conditions of water downstream can be attributed to increased anthropogenic activities such as the use of pesticides in farming and increased and unregulated mining activities along the Kenya – Uganda border with wastewaterdischarge into the river from sampling point 5. Similar high pH values beyond the WHO limits of 6.5 – 8.5 were reported in the assessment of water quality in Molo water basin in Kenya (Chebet *et.al*, 2020).

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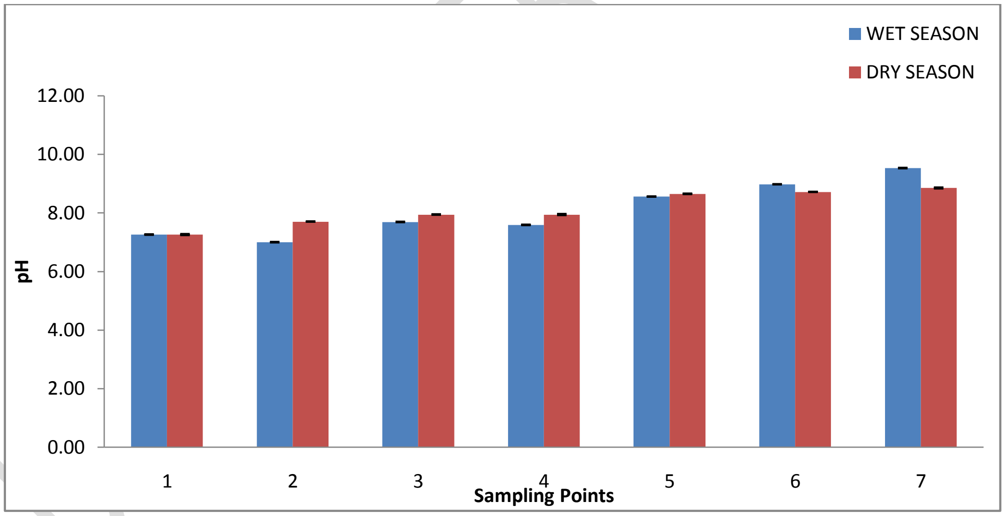

Fig. 2. Bar graph showing seasonal variations in pH

Comment [N8]: I suggest to use the box plot for all the parameters. Must merge the figures 2-6 as a single image. See this paper (https://doi.org/10.1016/j.oceano.2022.07.002) for your reference.

3.1.2 Total Dissolved Solids

The TDS values ranged from 64.67±0.58 – 155.33±0.58 ppm during the dry season, to 83.77±0.21 – 133.11±0.58 ppm during the wet season. There was no significant difference in seasonal variation, with $T_{calculated}$ = 0.055 against a $T_{critical}$ value of 2.55 at $P = .05$. Spatial

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variations were significantly different during both the dry and wet seasons with $F_{calculated}$ = 15040.24 and $F_{critical}$ = 2.85 during the dry season and $F_{calculated}$= 20525.65 and $F_{critical}$= 2.85 at P = .05 during the wet season. All the sampling points recorded TDS values within the WHO limits of 1000 ppm during both the dry and wet seasons. The high TDS levels at sampling point 1 can be attributed to the dumping of liquid wastes such as raw sewage from Busia town by surface runoff. The increase in TDS downstream, especially at sampling points 5, 6 and 7 is linked to increased anthropogenic activities as the river flows towards areas with increased agricultural and mining activities. The TDS values obtained from this study were much higher that the values obtained in the analysis of physicochemical parameters of water and sediments collected from Rawal dam in Islamabad, Pakistan (Msood*et al.*, 2015).

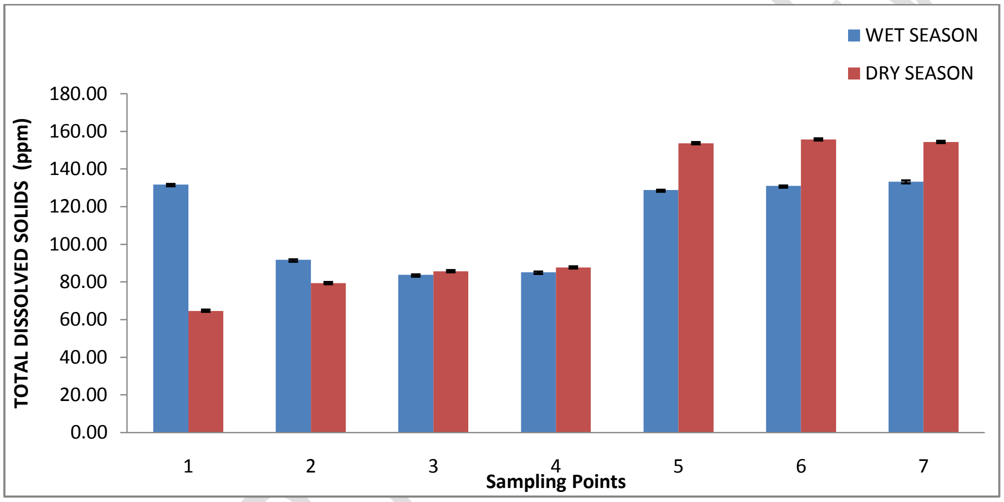

Fig. 3. Bar graph showing seasonal variations in total dissolved solids

3.1.3 Electrical Conductivity

The range for electrical conductivity values was from 129.33±0.58 – 314.67±2.52µs/cm during the dry season to 130.00±0.10 – 202.00±1.00µs/cm during the wet season. The seasonal variations were not significantly different with $T_{calculated}$ = 2.06 < $T_{critical}$ = 2.45 at *P* = 0.05~~*P* = .05~~ level of significance. Spatial variations were however significantly different with $F_{calculated}$ = 13,707.31 > $F_{critical}$ = 2.85 during the dry season and $F_{calculated}$ = 9,307.02 > $F_{critical}$ = 2.85 during the wet season, at *P* = 0.05~~*P* = .05~~ level of significance. The high levels of electrical conductivity during the dry season can be attributed to evaporation of water due to high temperatures, leading to an increase in the concentration of dissolved salts hence the high levels of electrical conductivity. The slightly high levels of electrical conductivity at sampling point 1 during the wet season can be linked to surface runoff carrying waste rich in dissolved salts, such as raw sewage and waste from garages from Busia town into the river. Electrical conductivity was within the WHO permissible levels of 500 – 5000 ppm during both seasons. The electrical

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conductivity values obtained from this study were much lower that the values obtained during the determination of the physicochemical parameters in wastewater in Bilaspur city, India (Jingxi*et al.*, 2020).

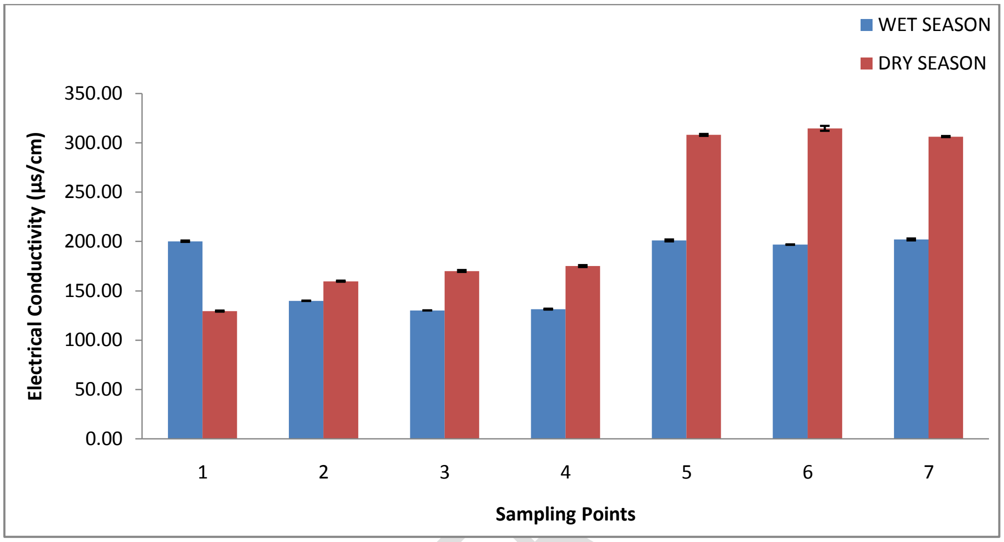

Fig. 4. Bar graph showing seasonal variations in electrical conductivity

3.1.4 Temperature

Water temperatures ranged from 24.83±0.21 –31.23±0.06 °C during the dry season, to 23.80±0.10 – 26.73±0.06 °C during the wet season. As per the paired t – test, $T_{calculated} = 3.57 > T_{critical} = 2.45$ at $P = 0.05$~~$P = .05$~~ significance level, implying significant difference in seasonal variations. Spatial variations were significantly different during both the dry and wet seasons with $F_{calculated} = 1009.13$ and 411.27 during the dry and wet seasons respectively against $F_{critical}$ value of 2.85 at $P = 0.05$~~$P = .05$~~ significance level. The slight rise in temperature during the dry season is due to increase the concentration of dissolved solids as these particles absorb heat leading to temperature rise in the river. The slight increase in temperature downstream during both seasons may be due to increased anthropogenic activities downstream as more solids find their way into water and dissolve in it, translating to an increase in temperatures. Similar temperature range for water was recorded during the assessment of water quality in Molo water basin in Kenya (Chebet *et.al.*, 2020).

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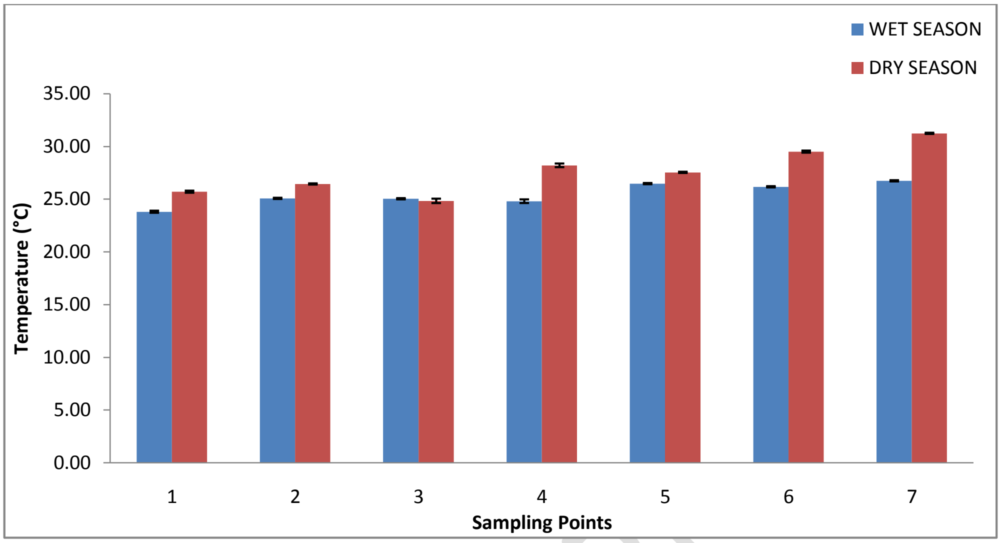

Fig. 5. Bar graph showing seasonal variations in temperature

3.1.5 Turbidity

The values for turbidity were 30.8±0.40 – 96.63±0.55 NTU during the dry season and212.90±0.66 – 576.9±0.38 NTU during the wet season. Seasonal variation was statistically significant with $T_{calculated} = 5.11 > T_{critical} = 2.45$ at $P = .05$ level of significance. Spatial variations were also statistically significant, with $F_{calculated}$ = 10,274.56 and 202,750.3during both the dry and wet seasons respectively > $F_{critical}$ = 2.85 at$P = 0.05$~~$P = .05$~~ significance level. The high turbidity levels during the wet season are due to surface runoff carrying suspended particles/solids into the river. The steady increase in turbidity levels downstream during the wet season can be attributed to increased anthropogenic activities downstream, as the river flows through the heavily cultivated and mined section of the catchment. All the sampling points recorded turbidity levels way above the WHO recommended levels of 5.0 NTU during both the dry and wet seasons. Similar turbidity patterns were recorded during the formulation of water quality assessment index for the Chania River in Kiambu County, Kenya (Robert, Onyari and Mbaka, 2020).

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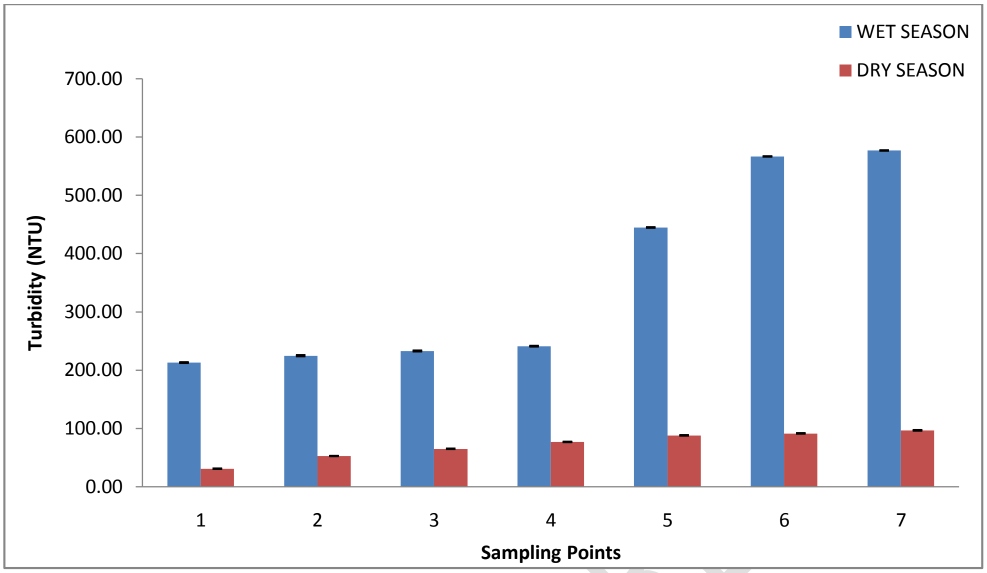

Fig. 6. Bar graph showing seasonal variations in turbidity

3.2 Heavy Metals

3.2.1 Copper

The concentration of Cu in water was 0.030±0.003 – 0.180±0.002mg/l during the dry season to 0.121±0.002 – 0.181±0.003 mg/l during the wet season. Seasonal variation revealed no significant difference between the dry and wet season as $T_{calculated} = 0.78$, < $T_{critical} = 2.45$ at $P = 0.05$ level of significance. Spatial variations revealed significant difference, with $F_{calculated}$ = 2052.62 and 336.71 for dry and wet seasons respectively, against F critical = 2.85 at $P = 0.05$ confidence level. The high concentration of copper at sampling point 1 during the wet season can be attributed to surface run off carrying pollutants rich in copper from residential houses as well as garages and untreated sewage from Busia town. The high levels of copper at sampling point 2 during the wet season can be linked to the tributary that joins the river just before sampling point 2. This tributary carries waste rich in copper from other parts of the catchment and dumps the waste into the river, leading to a rise in the concentration of copper at this sampling point. All the seven sampling points recorded copper levels within the WHO limits of 1.0 – 2.0 mg/l, indicating no pollution from copper. The concentrations of copper obtained from this study were much lower than those obtained from the evaluation of the quality of water used for irrigation in the states of Osun and Ondo in the federal republic of Nigeria (Olubanjo& Alando, 2018).

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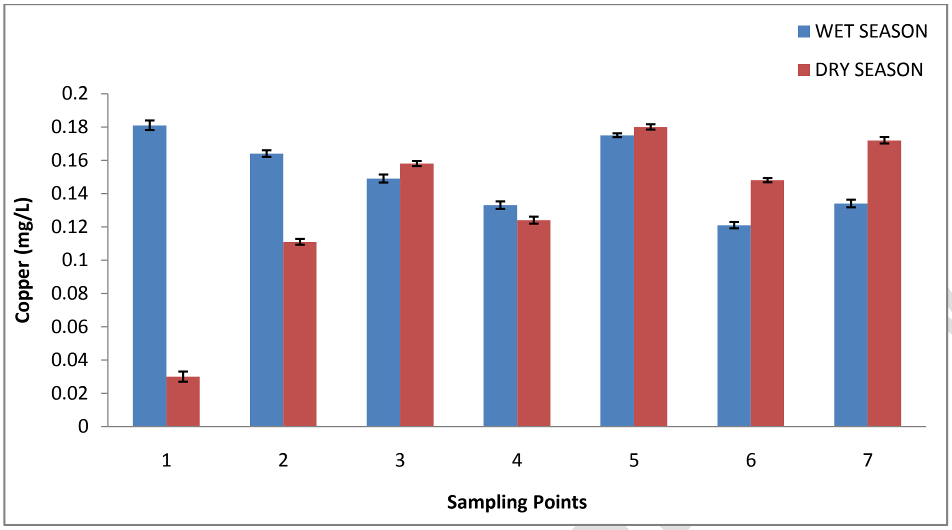

Fig. 7. Bar graph showing seasonal variations in copper

Comment [N9]: Here also I am suggesting you to please use the box plot for all the heavy metal results. Must merge the figures 7-14 as a single image. Find the paper link below for your reference(https://doi.org/10.1016/j.oceano.2022.07.002).

3.2.2 Zinc

Zinc levels ranged from 0.014±0.001 – 0.101±0.003 mg/l during the dry season, to 0.014±0.001 – 0.069±0.002 mg/l during the wet season. There was statistical difference in seasonal variations with $T_{calculated} = 7.44$, $< T_{critical} = 2.45$ at $P = 0.05$~~$P = .05$~~ confidence level. One way ANOVA revealed spatial difference to be statistically significant with $F_{calculated} = 818.28$ and 247.47 for dry and wet season respectively against $F_{critical}$ value of 2.85 at $P = 0.05$~~$P = .05$~~ level of significance.Sampling point 2 recorded the highest levels of Zn during the dry season, and this may be linked to the tributary joining the river at this point and is responsible for dumping waste rich in Zn from other parts of the catchment. The high levels of Zn at sampling point 5 and 6 during the dry season may be linked to wastewater rich in Zn that is discharged into the river from the mining site. High levels of Zn during the wet season may be linked to surface runoff carrying pollutants rich in Zn from pesticides and fertilizers used in farming. All the sampling points recorded Zn levels below the WHO limits of 3.0 mg/l, indicating no pollution from Zn. Similar concentrations for Zn in water were reported during the assessment of heavy metal contamination in surface water of Masinga reservoir, Kenya (Nzeve*et.al*, 2015).

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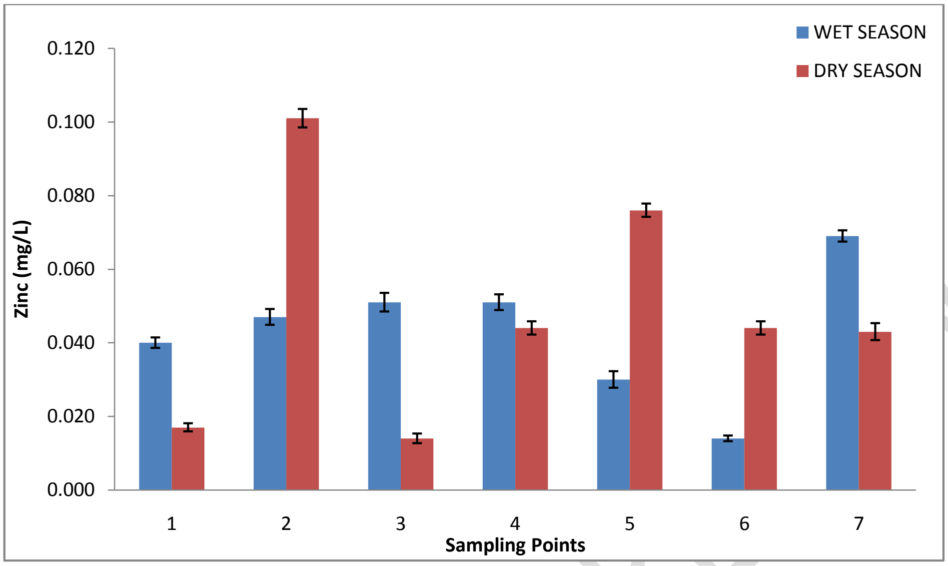

Fig. 8. Bar graph showing seasonal variations in zinc

3.2.3 Lead

Lead levels in water were from0.439±0.033 – 0.786±0.008 mg/l during the dry season to 0.288±0.016 – 0.625±0.012 mg/l during the wet season. There was significant difference in seasonal variation as per paired t – test, with $T_{calculated} = 3.32, > T_{critical} = 2.45$ at $P = 0.05$ confidence level. Spatial variations were also significantly different with $F_{calculated} = 9.99$ and 326.22 during the dry and wet seasons respectively against an $F_{critical}$ value of 2.85 at $P = .05$ confidence level. The increase in the level of Pb upstream during both the dry and wet season can be attributed to increased anthropogenic activities which lead to pollutants rich in Pb finding their way into the river. They include discharge of raw sewage into the river, airborne deposition of Pb from automobiles, pollutants from garages and workshops located close to the catchment, leaching of Pb from Pb – rich rocks at the riverbed as well as the discharge of wastewater rich in Pbat the mining site. All the seven sampling points recorded Pb levels that were way above the WHO limit of 0.01 mg/l during both the dry and wet seasons, indicating pollution from Pb.

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Correct the error in the entire MS

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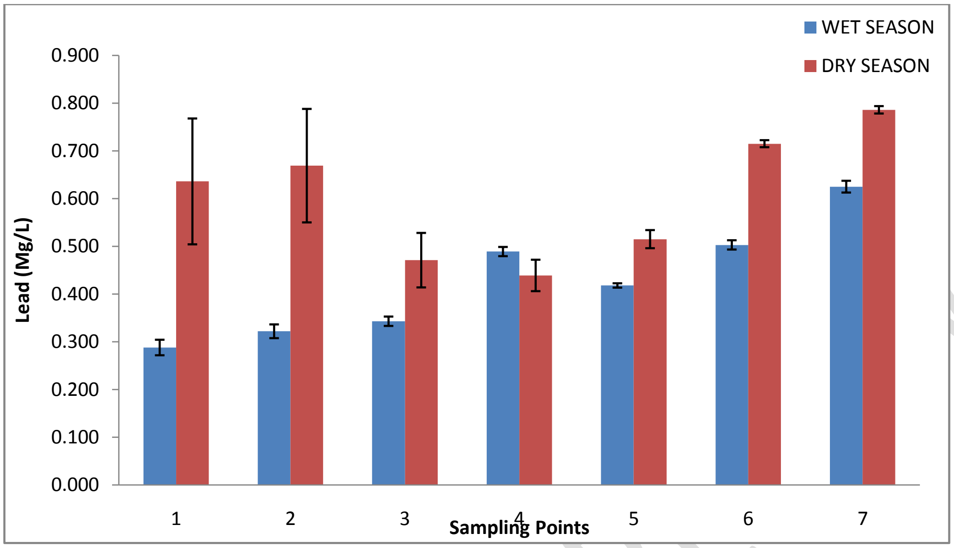

Fig. 9. Bar graph showing seasonal variations in lead

3.2.4 Chromium

The levels of Cr ranged from 0.023±0.002 – 0.915±0.010 mg/l during the dry season to 0.036±0.002 – 0.894±0.012 mg/l during the wet season. There was no significant difference in seasonal variations, with $T_{calculated} = 2.17 < T_{critical} = 2.45$ at $P = 0.05$ confidence level. Spatial variations were statistically significant, with $F_{calculated} = 1735.99$ and 5612.39 during the dry and wet seasons respectively whereas $F_{critical}$ was 2.85 at $P = 0.05$ level of significance. The high levels of Cr in most of the sampling points during the wet season can be attributed to surface run off carrying pollutants rich in Cr into the river. These pollutants originate from paint, wood preservatives, workshops and garages as well as from pesticides given that chromium VI is used to manufacture pesticides. The steady increase in the concentration of Cr downstream is indicative of increased anthropogenic activities downstream. The use of Cr rich pesticides in farming and mining activities downstream account for the steady increase in Cr levels downstream. The washing of motorcycles and vehicles in the river can also be associated with the high levels of Cr above the WHO limits given that most of these motorcycles are made from chromium plated metal parts which eventually find way into water sources. All the sampling points recorded Cr levels above the WHO limit of 0.05 mg/l except for sampling points 1,2 and 4 during the dry season and sampling point 2 during the wet season. The levels of Cr obtained from this study are way higher than those obtained by Tomno*et.al* during the determination of heavy metal contamination of water, soil and vegetables in urban streams in Machakos municipality, Kenya (Tomno*et.al*., 2020).

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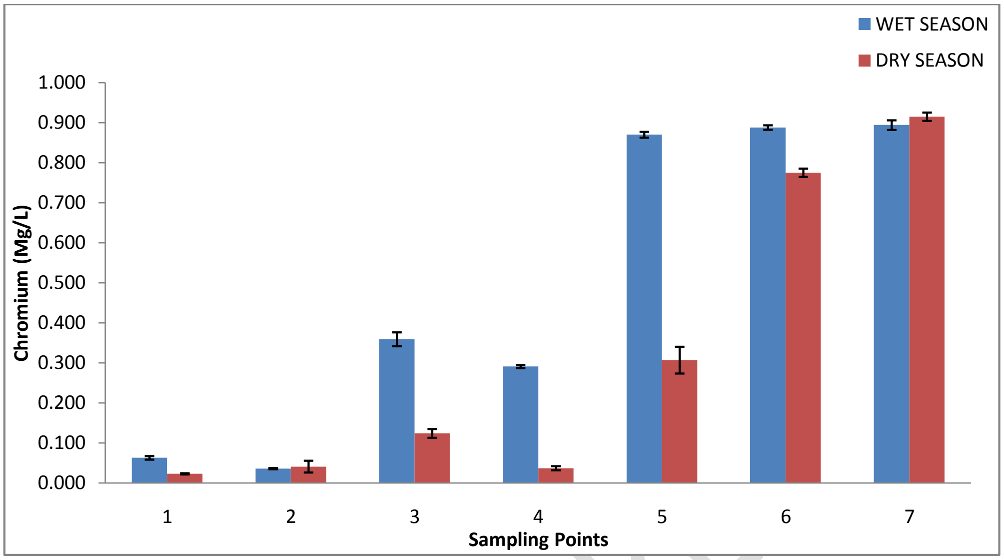

Fig. 10. Bar graph showing seasonal variations in chromium

3.2.5 Cobalt

The reported levels of cobalt were 0.652±0.032 – 1.601±0.131 during the dry season to 0.261±0.030 – 0.535±0.028 during the wet season. Significant differences were reported for seasonal variations, with $T_{calculated} = 7.04 > T_{critical} = 2.45$ at $P = .05$ level of significance. Spatial variations were equally significantly different at $P = .05$ confidence level. All the sampling points recorded Cot concentrations above the WHO limit of 0.05 mg/l during both the dry and wet seasons. During the dry season, the elevated levels of Co (Cobalt) in the water samples could be linked to water evaporation from the river, resulting in a higher concentration of the analyte. However, this effect seems to be counteracted during the wet season, as dilution occurs, leading to lower Co concentrations in the water during this period.~~The high levels of Co during the dry season may be attributed to evaporation of water from the river during the dry season, leading to increased analyte concentration. But this is offset during the wet season by dilution which accounts for the low concentration of Co in water during the wet season.~~Cobalt levels downstream during the wet season remained constant. However, the steady increase in Co levels downstream during the dry season is indicative of increased anthropogenic activities such as farming; where cobalt sulphate heptahydrate fertilizer, which consists of 21% cobalt is used by farmersas well as unregulated mining activities across the Kenya – Uganda border. Similar seasonal variations in the concentration of cobalt were recorded in the study involving seasonal variations of heavy metals in water at Port Said, Egypt (Nabil *et al.*, 2018).

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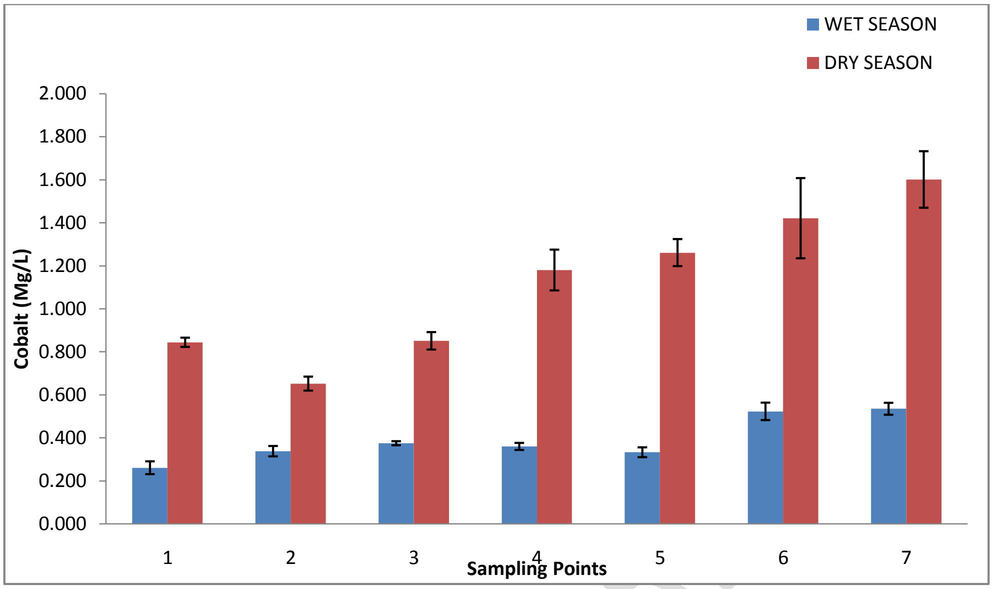

Fig. 11. Bar graph showing seasonal variations in cobalt

3.2.6 Nickel

The reported levels of Ni in water were 0.324±0.027 – 0.960±0.038 mg/l during the dry season, ~~to~~ whereas it was0.165±0.009 – 0.766±0.023 mg/l during the wet season. There was no significant difference between the dry and the wet season, with $T_{calculated} = 1.38 < T_{critical} = 2.25$ at $P = .05$ level of confidence. The spatial variations were significantly different, with $F_{calculated}$ = 121.81 and 331.45 for both dry and wet season against $F_{critical}$ value of 2.85 at $P = 0.05$ level of confidence. All the sampling points registered nickel levels above the WHO recommended limit of 0.07 mg/l for both the dry and wet seasons. The high nickel levels during the dry season at sampling points 1 – 5 can be attributed to evaporation of water, leading to an increase in analyte concentration. But this is quickly reversed during the wet season due to dilution by rainwater leading to low nickel concentrations. The high levels of nickel at sampling points 5 and 6 during the wet season can be linked to surface runoff carrying nickel rich pollutants such as raw sewage that is discharged into the river as the river flows through densely populated and highly agricultural areas, since nickel can be excreted in human faeces. A similar seasonal variation in the concentration of nickel in river water was reported during the physicochemical analysis of water in river Okoro in the federal republic of Nigeria (Ukpatu*et al.*, 2018).

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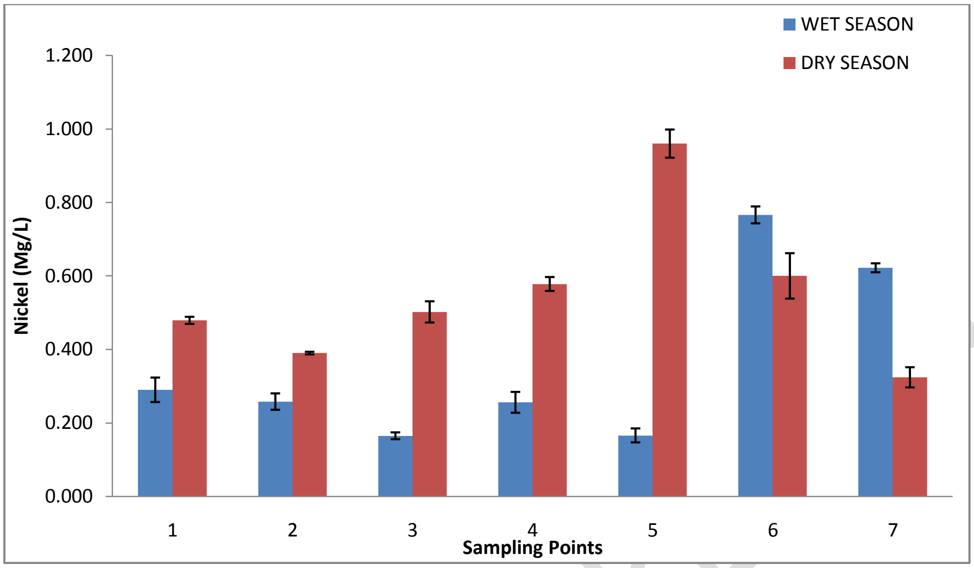

Fig. 12. Bar graph showing seasonal variations in nickel

3.2.7 Iron

Reported levels of iron were 1.677±0.190 – 8.179±0.241 mg/l during the dry season, to 5.271±0.354 – 15.250±0.393 mg/l during the wet season.Paired t – test revealed significant differences between dry and wet seasons, with $T_{calculated}$ = 4.54, > $T_{critical}$ = 2.45 at *P* = .05 confidence level. There were significant differences in spatial variations, with $F_{calculated}$ = 422.76 and 168.93 for dry and wet seasons respectively against $F_{critical}$ = 2.85 at *P* = .05 level of significance. All the sampling stations recorded iron concentrations way above the WHO recommended values of 0.3 mg/l during both seasons. The high concentration of iron during the wet season can be linked to surface runoff rich in iron pollutants, mainly from rusted scrap metal, inorganic fertilizers used in farming, untreated sewage, workshops and garages and paints from construction sites located downstream. The steady increase in the concentration of iron from sampling points 4 – 7 during the wet season and sampling points 3 – 6 during the dry season is indicative of increased anthropogenic activities downstream, contributing to further pollution of the river.

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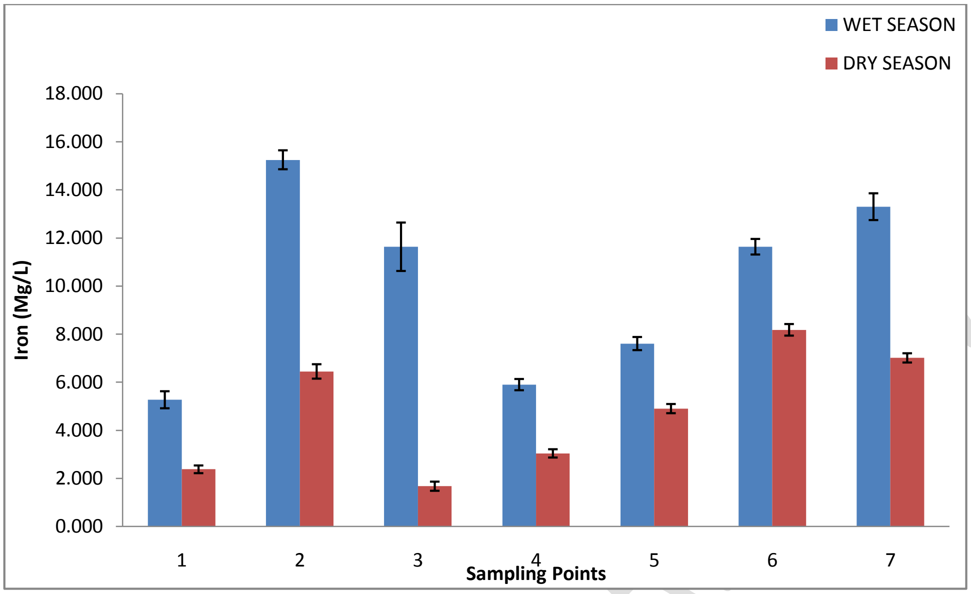

Fig. 13. Bar graph showing seasonal variations in iron

3.2.8 Cadmium

Cadmium levels in water showed significant seasonal variations, ranging from 0.215 ± 0.004 – 0.427 ± 0.004 mg/l during the dry season to 0.073 ± 0.003 – 0.192 ± 0.002 during the wet season. The observed differences were highly significant, with a calculated T-value of 9.03, exceeding the critical T-value of 2.45 at a confidence level of P = 0.05.Additionally, spatial variations in Cadmium levels were also found to be significantly different based on a one-way ANOVA test. The F-calculated values were 201.17 and 248.44 during the dry and wet seasons, respectively, with an F-critical value of 2.85 at a confidence level of P = 0.05.Notably, all the sampling points recorded Cadmium levels well above the WHO limit of 0.003 mg/l during both the dry and wet seasons. This indicates a concerning level of Cadmium contamination in the water.~~Cadmium levels in water were 0.215±0.004 – 0.427±0.004 mg/l during the dry season, to 0.073±0.003 – 0.192±0.002 during the wet season. Seasonal variations were significantly different with $T_{calculated}$ = 9.03, > $T_{critical}$ = 2.45 at *P* = .05 confidence level. Spatial variations were significantly different as per one way ANOVA, with $F_{calculated}$ = 201.17 and 248.44 during the dry and wet seasons respectively with an $F_{critical}$ value of 2.85 at *P* = .05 level of confidence.All the sampling points registered Cadmium levels way above the WHO limit of 0.003 mg/l during both the dry and wet seasons.~~These high levels of Cadmium above the WHO permissible limits can be attributed to weathering of rocks rich in Cadmium, dumping of both liquid and solid waste into the river, especially Cadmium – rich wastes such as dry cell batteries, pigments and paints, pesticides used in farming as well as plastic and iron waste given that Cadmium finds wide spread use in the manufacture of plastics and also in iron and steel plating (Greenfacts, 2018). The high levels of Cadmium during the dry season can be linked to

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evaporation of water leading to high concentration of the analyte. This is however quickly reversed during the wet season by dilution from rainwater. Very high concentrations of Cadmium at sampling points 6 and 7 during both the dry and wet seasons can be because ofCadmium – rich wastewater from the mining site that finds its way into the river. The concentrations of Cadmium obtained from this study were slightly higher than those obtained during the determination of heavy metals in vegetables irrigated using wastewater(Mohsin *et al.*, 2019).

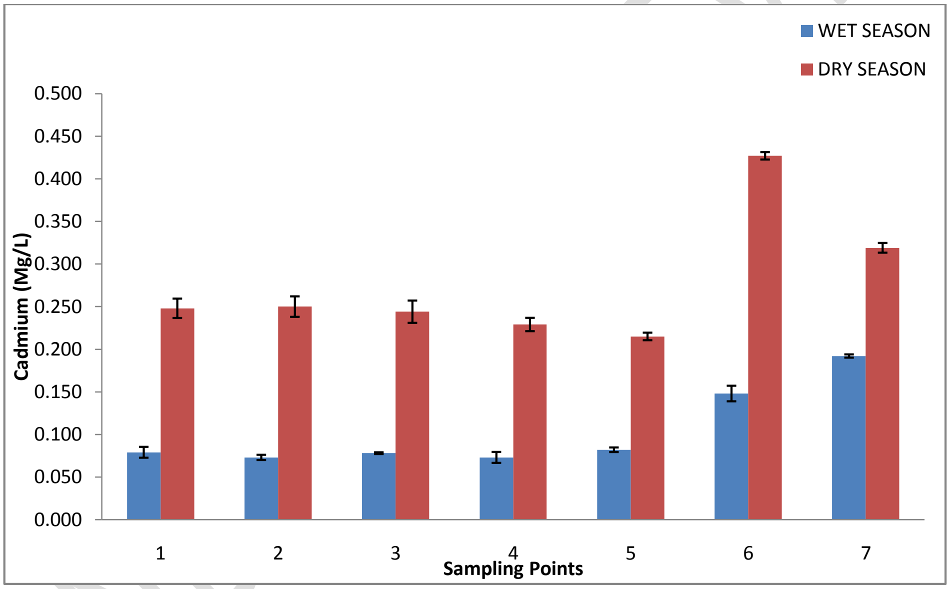

Fig. 14. Bar graph showing seasonal variations in cadmium

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Table 2: Concentration of physical parameters in water during dry and wet seasons

PARAMETER	SEASON	S1	S2	S3	S4	S5	S6	S7	WHO	KEBS
pH	**DRY**	7.26±0.02	7.70±0.01	7.67±0.01	7.94±0.02	**8.65±0.01**	**8.72±0.01**	**8.85±0.02**	6.5 - 8.5	6.5 - 8.5
	WET	7.26±0.01	7.00±0.01	7.69±0.01	7.59±0.01	**8.56±0.01**	**8.98±0.01**	**9.53±0.01**		
TDS (ppm)	**DRY**	64.67±0.58	79.33±0.58	85.67±0.58	87.67±0.58	153.67±0.58	154.33±0.58	154.33±0.58	1000	1500
	WET	131.8±0.20	91.70±0.26	83.77±0.21	85.20±0.26	128.87±0.06	131.03±0.15	133.11±0.58		
Turbidity (NTU)	**DRY**	**30.8±0.40**	**52.57±0.21**	**64.93±0.35**	**76.77±0.35**	**88.00±0.46**	**91.40±0.44**	**96.63±0.55**	5	5
	WET	**212.90±0.66**	**224.77±1.00**	**232.83±0.78**	**241.03±0.60**	**444.77±0.50**	**566.67±0.31**	**576.9±0.38**		
Electrical Conductivity(µs/cm)	**DRY**	129.33±0.58	159.67±0.58	170.00±1.00	175.00±1.00	308.00±1.00	314.67±2.52	306.33±0.58	500 - 5000	1000
	WET	200.20±0.72	139.77±0.21	130.00±0.10	131.33±0.47	201.00±1.00	196.77±0.25	202.00±1.00		
Temperature (°C)	**DRY**	25.70±0.10	26.43±0.06	24.83±0.21	28.20±0.17	27.53±0.06	29.50±0.10	31.23±0.06		
	WET	23.80±0.10	25.07±0.06	25.03±0.06	24.80±0.17	26.47±0.06	26.17±0.06	26.73±0.06		

* Bolded values indicate parameters whose concentration is above the who limits

KEBS = Kenya Bureau of Standards

S = Sampling point

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Table 3: Concentration of metal ions in water during dry and wet seasons

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Parameter	**Season**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S6**	**WHO**	**KEBS**
Copper mg/L	DRY	0.030±0.003	0.111±0.002	0.158±0.002	0.124±0.002	0.180±0.002	0.148±0.001	0.172±0.002	1.0 - 2.0	0.1
	WET	0.181±0.003	0.164±0.002	0.149±0.002	0.133±0.002	0.175±0.001	0.121±0.002	0.134±0.002		
Zinc mg/L	DRY	0.017±0.001	0.101±0.003	0.014±0.001	0.044±0.002	0.076±0.002	0.044±0.002	0.043±0.002	3.0	5.0
	WET	0.040±0.001	0.047±0.002	0.051±0.003	0.051±0.002	0.030±0.002	0.014±0.001	0.069±0.002		
Lead mg/L	DRY	**0.636±0.132**	**0.669±0.119**	**0.471±0.057**	**0.439±0.033**	**0.515±0.019**	**0.715±0.007**	**0.786±0.008**	0.01	0.05
	WET	**0.288±0.016**	**0.322±0.014**	**0.343±0.010**	**0.489±0.010**	**0.418±0.005**	**0.503±0.010**	**0.625±0.012**		
Cadmium mg/L	DRY	**0.248±0.011**	**0.250±0.012**	**0.244±0.013**	**0.229±0.008**	**0.215±0.004**	**0.427±0.004**	**0.319±0.006**	0.003	0.005
	WET	**0.079±0.006**	**0.073±0.003**	**0.078±0.001**	**0.073±0.006**	**0.082±0.003**	**0.148±0.009**	**0.192±0.002**		
Chromium mg/L	DRY	0.023±0.002	0.041±0.015	**0.124±0.011**	0.037±0.005	**0.307±0.033**	**0.775±0.010**	**0.915±0.010**	0.05	0.05
	WET	**0.063±0.005**	0.036±0.002	**0.359±0.017**	**0.291±0.004**	**0.870±0.007**	**0.888±0.006**	**0.894±0.012**		
Cobalt mg/L	DRY	**0.844±0.021**	**0.652±0.032**	**0.851±0.041**	**1.180±0.095**	**1.261±0.063**	**1.421±0.186**	**1.601±0.131**	0.05	0.05
	WET	**0.261±0.030**	**0.338±0.024**	**0.375±0.009**	**0.360±0.016**	**0.333±0.023**	**0.523±0.041**	**0.535±0.028**		
Nickel mg/L	DRY	**0.479±0.010**	**0.390±0.004**	**0.502±0.029**	**0.578±0.019**	**0.960±0.038**	**0.600±0.062**	**0.324±0.027**	0.07	0.05
	WET	**0.290±0.033**	**0.258±0.022**	**0.165±0.009**	**0.256±0.028**	**0.166±0.019**	**0.766±0.023**	**0.622±0.012**		
Iron mg/L	DRY	**2.380±0.160**	**6.449±0.300**	**1.677±0.190**	**3.042±0.172**	**4.904±0.191**	**8.179±0.241**	**7.012±0.192**	0.3	0.3
	WET	**5.271±0.354**	**15.250±0.393**	**11.633±1.006**	**5.901±0.233**	**7.608±0.273**	**11.634±0.323**	**13.299±0.557**		

* Bolded values are those above the WHO recommended limit
KEBS = Kenya Bureau of Standards
S = sampling point

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3.3 Correlational Analysis

Comment [N11]: Why the results are described only positive correlation and why no there is no negative correlations in the described section. Consider and revise the section accordingly.

During the dry season, Cadmium was strongly correlated to Chromium (r = 0.78) and Iron (r = 0.72); Iron showed strong correlation to Lead and Chromium (r = 0.76 and 0.75 respectively); Cobalt was strongly correlated to Chromium (r = 0.86). These strong correlations are indicative of the presence of metal – metal complexes in solution form. Turbidity showed strong correlation to temperature and this is due to the fact that suspended particles absorb and retain heat from the sun hence leading to temperature rise when the water is highly turbid. TDS showed strong correlation to metals such as Copper (r = 0.75), Chromium (r = 0.87), Iron (0.70) and Cobalt (0.87). The strong correlation between TDS and these metals in evidence of dissolved metal ions in water. Turbidity showed strong correlation to metals such as Copper (r = 0.88), Chromium (r = 0.77) and Cobalt (r = 0.87).This point to the existence of suspended metal particles in water. The strong correlation between temperature and electrical conductivity (r = 0.77) is indicative of high amounts of dissolved salts whose solubility increases with increase in temperature.

During the wet season, there was a strong correlation between Cadmium and metals such as Lead, Chromium, Cobalt and Nickel (r = 0.82, 0.90, 0.87 and 0.88 respectively). Lead was strongly correlated to Chromium and Cobalt (r = 0.76 and 0.85 respectively). Chromium was strongly correlated to Cobalt (r = 0.74) while cobalt was strongly correlated to Nickel (r = 0.85). This point to the existence of metal – metal complexes in solution form. Turbidity showed strong correlation to temperature (r = 0.89) and this means that suspended particles are responsible for absorption of heat leading to a rise in water temperatures. TDS was strongly correlated to electrical conductivity (r = 1.00) indicating that dissolved solids are responsible for increased electrical conductivity in water. Turbidity was strongly correlated to pH (r = 0.97) and this is evident of the fact that suspended particles have a strong effect on the pH of water, especially downstream where turbidity is very high during the wet season, the pH increases from near neutral to alkaline. pH showed strong correlation with temperature for both the dry and wet seasons (r = 0.84 and r = 0.88 respectively). This is because of an increase in temperature leads to dissociation of water molecules into H^+ and OH^- and since pH is a measure of H^+ concentration, more of H^+ is produced leading to a shift in the pH value of water as the temperature changes. There was a strong correlation between pH and metals such as Cadmium, Lead, Chromium, Cobalt and Nickel (r = 0.88, 0.85, 0.96, 0.84 and 0.71 respectively). This correlation arises because the dissolved salts of these metals are either acidic or alkaline hence they lead to pH changes in water. The strong correlation between temperature and metals such as Lead, Chromium and Cobalt (r = 0.74, 0.91 and 0.75 respectively) points to the existence of metal salts whose solubility is influenced by change in water temperatures.

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Table 4: Correlation coefficient matrix for water quality parameters - Dry season

	Cu	Zn	Cd	Pb	Cr	Fe	Co	Ni	pH	TDS	EC	Temp	Turbidity
Cu	1.00												
Zn	0.24	1.00											
Cd	0.18	-0.13	1.00										
Pb	-0.05	0.16	0.67	1.00									
Cr	0.55	-0.04	**0.78**	0.69	1.00								
Fe	0.38	0.54	**0.72**	**0.76**	**0.75**	1.00							
Co	0.58	-0.11	0.54	0.35	**0.86**	0.53	1.00						
Ni	0.32	0.20	-0.23	-0.51	-0.11	-0.09	0.17	1.00					
pH	**0.79**	0.25	0.53	0.38	**0.86**	**0.73**	**0.89**	0.29	1.00				
TDS	**0.75**	0.20	0.55	0.39	**0.87**	**0.70**	**0.87**	0.37	**0.98**	1.00			
EC	**0.74**	0.21	0.56	0.40	**0.86**	**0.71**	**0.86**	0.38	**0.98**	**1.00**	1.00		
Temp	0.46	0.15	0.60	0.58	**0.85**	**0.74**	**0.90**	-0.10	**0.84**	**0.77**	**0.77**	1.00	
Turbidity	**0.88**	0.16	0.44	0.15	**0.77**	0.57	**0.87**	0.29	**0.95**	**0.89**	**0.89**	**0.78**	1.00

Table 5: Correlation coefficient matrix for water quality parameters - Wet season

	Cu	Zn	Cd	Pb	Cr	Fe	Co	Ni	pH	TDS	EC	Temp	Turbidity
Cu	1.00												
Zn	-0.03	1.00											
Cd	-0.60	0.16	1.00										
Pb	-0.75	0.23	**0.82**	1.00									
Cr	-0.46	-0.22	**0.72**	**0.76**	1.00								
Fe	-0.31	0.21	0.42	0.19	0.15	1.00							
Co	-0.84	0.04	**0.90**	**0.85**	**0.74**	0.54	1.00						
Ni	-0.69	-0.20	**0.87**	0.68	0.57	0.35	**0.85**	1.00					
pH	-0.53	-0.03	**0.88**	**0.85**	**0.96**	0.21	**0.84**	**0.71**	1.00				
TDS	0.10	-0.32	0.60	0.33	0.58	-0.14	0.30	0.56	0.63	1.00			
EC	0.14	-0.32	0.57	0.31	0.59	-0.16	0.27	0.52	0.63	**1.00**	1.00		
Temp	-0.42	-0.05	0.69	**0.74**	**0.91**	0.44	**0.75**	0.49	**0.88**	0.41	0.42	1.00	

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Turbidity	-0.51	-0.20	**0.87**	**0.80**	**0.94**	0.29	**0.84**	**0.78**	**0.97**	0.69	0.69	**0.89**	1.00

* Bolded values show significant correlation

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4.0 CONCLUSION AND RECOMMENDATIONS

The parameters whose levels were above the recommended WHO limits werepH, turbidity, lead, Cadmium, Chromium, Cobalt,Nickel and Iron. These high concentrations are indicative of high levels of pollution, mainly because ofanthropogenic activities. Busia County is currently grappling with poor sewerage coverage, with the old sewerage system which was put in place about four decades ago no longer able to sustain the ever-increasing population. This has led to the discharge of raw/untreated sewage into the river hence polluting the water with high turbidity, TDS as well as toxic heavy metals such as Lead, Cadmium, Arsenic, Chromium and Nickel. The second cause of water pollution in Busia County includes both large scale and artisan mining. The heavy metals which are produced while mining have led to severe pollution of the river, especially by the mining from sampling point five onwards at the Kenya – Uganda border. Poor agricultural practices such as the use of pesticides has led to further pollution of the river, as these pesticides contain high levels of heavy metals such as Lead, Arsenic, Chromium, Copper and Cadmium.

Therefore, this study recommends several measures to be put in place in order to curb both surface and ground water pollution. There is need to adopt integrated pest management so as to avoid over reliance on inorganic fertilizers; waste water from mining companies should be treated before being discharged into nearby water bodies; proper soil control measures should be adopted so as to reduce the amount of soil that is carried by surface runoff into water bodies; nitrogen fixing leguminous plants should be adopted to supplement the use of nitrogenous fertilizers such as ammonium nitrate; the County government of Busia should enact and enforce the existing environmental legislations that aim at curbing water pollution and strict penalties should be imposed on those found guilty of environmental crimes such as water, air and soil pollution.

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