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Comparative Assessment of Heavy Metal Loading from Sewage Effluents and Inlet Rivers in the Winam Gulf of Lake Victoria, Kenya

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ABSTRACT: Lake Victoria is an important source of fish for domestic, regional and global market. Recently, the lake has experienced severe pollution from wastewater and industry. Winam Gulf, located on the eastern side of Lake Victoria Kenya is currently under pollution threat from multiclass pollutants including heavy metals, potentially harming human health and aquatic biodiversity. Therefore, the objective of this paper was to investigate the comparative analysis of heavy metal loading from sewage effluents and Inlet Rivers in the Winam Gulf of Lake Victoria, Kenya using appropriate standard methods. Data obtained show that Nickel average concentration 0.255 mg/l exceeding 0.07mg/l WHO acceptable standards; Lead average concentration 0.048 mg/l exceeding 0.01 mg/l WHO acceptable standard; Cadmium average concentration 0.037mg/l exceeding 0.003mg/l WHO acceptable standard. Among the rivers sampled, River Kisat showed higher concentrations of all the heavy metals analyzed than River Nyando. Heavy metal concentration of the sediment and water samples collected from the different sites were significantly different ($p \leq 0.05$). In conclusion, the concentrations of Nickel, Lead, and Cadmium in water samples exceeded WHO standards, especially in River Kisat. The study recommends that there is need to conduct routine assessment of the levels of heavy metals within the gulf, stricter enforcement of regulations governing waste water treatment and discharge and improved efficiency of wastewater treatment plants.

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Heavy metals are elements with a density greater than 5gms/cm^3 including such as Hg, Cr, Cd, Pb, As, Ni, Zn, and Cu (Jadaa and Mohammed, 2023). Available literature reports on diverse sources of heavy metals in aquatic ecosystems, including landfill runoff, volcanic eruptions, soil and rock weathering, waste waters, agricultural runoff, illegal mining activities, and industrial effluents, among others (Alengebawy *et al.*,

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2021). The non-degradable nature of these elements allows them to persist in both organisms and the environment, preventing their transformation into less hazardous substances (Anderson *et al*., 2022; Ramezani *et al*., 2021). The toxicological and biological effects of heavy metals like lead, mercury, cadmium, chromium, and arsenic have been thoroughly studied in recent years (Raj and Krishnan, 2023; Tolkou *et al*., 2023). Even at low concentrations, these metals have been demonstrated to cause a variety of biochemical and physiological changes in living things, such as the suppression of protein and enzyme functioning, lipid degradation, and DNA damage (Sun *et al*., 2022). Moreover, isolated studies have shown that in aquatic environments, the presence of heavy metals can cause health problems since these contaminants can build up and find their way into the human food chain (Zaynab *et al*., 2022). Other studies detected levels of heavy metals like arsenic lead and chromium having a negative impact on both aquatic ecosystem and human health (Nielsen *et al*., 2020; Roy *et al*., 2022). Globally, numerous studies have documented heavy metal contamination in aquatic ecosystems, including rivers and lakes (Afzaal *et al*., 2022; Saidon *et al*., 2024). Within the aquatic habitats, heavy metals and their associated complexes undergo dynamic chemical interactions that moderate their degradation, speciation and intermedia transfer (Ekperusi *et al*., 2019). However, due to their non-biodegradability and significant stability in aqueous media, the presence of these contaminants within the water medium can pose long-term effects to primary producer and other organisms at the top of the trophic structure (Jeong *et al*., 2023) . Lake Victoria, the second largest freshwater lake in the world after Lake Superior, has been a known ecological powerhouse of biodiversity (Elder, 2024). The substantial ecological and economic significance of Lake Victoria has generated considerable interest for many decades (Githaiga *et al.*, 2021; Outa *et al.*, 2020). From the beginning of the 21st century, Lake Victoria has attracted the attention of many researchers due to the continued deterioration of its water quality as a result of anthropogenic and natural processes ranging from water pollution, overexploitation, habitat degradation to climate change (Aura *et al*., 2024; Baguma *et al.*, 2022). The lake ecosystem faces severe threats from numerous forms of pollution including heavy metal contamination, pharmaceutical residues, pesticide runoff, microplastics, and nutrients loading that causes eutrophication (Hampton *et al*., 2018; Jenny *et al.*, 2020). Studies on the ecosystem have revealed the presence of heavy metal contaminants, such as lead, cadmium, copper, mercury, chromium, arsenic, and nickel (Mongi and Chove, 2020; Santhappan *et al*., 2024). For example, reports have shown the decline of nile perch species of fish populations affected by habitat degradation and accumulation of toxic metals such as lead and mercury (Mulenga *et al.*, 2024; Nantongo, 2021). Other studies have also documented effects to diversity in and population dynamics of macroinvertebrates within the lake (Achieng *et al.*, 2020; Natugonza *et al.*, 2021). This trajectory has posed a growing threat to human life and aquatic biota in the lake and its catchment (Belykh *et al*., 2023; Egessa *et al*., 2020). The Winam Gulf, a shallow inlet linked to the main lake through the Rusinga Channel of northern end of Lake Victoria traverses Kisumu, Busia and Homa Bay counties in Kenya. It is a vital ecosystem that significantly affects the local environment and economy (Awange, 2020; Humphrey *et al*., 2022). The Gulf is surrounded by agricultural, industrial, and residential catchments (Nyilitya *et al.*, 2021). which are potential sources of contaminants including microplastics, multiclass pharmaceutical residues, heavy metals and agrochemical residues (Khatiebi *et al*., 2023; Mbeche, 2021). Previous studies carried out in the Gulf have revealed the concentrations of heavy metals present in water, sediment and biota (Matindi *et al*., 2022; Mongare *et al*., 2023). However, there is paucity of data on the actual sources of heavy metals deposited within the Gulf. The specific loading contributions of Inlet Rivers, sewerage effluents, agricultural run-offs on heavy metal levels in the gulf still remains poorly understood. Therefore, the objective of this paper was to investigate the comparative analysis of heavy metal loading from sewage effluents and Inlet Rivers in the Winam Gulf of Lake Victoria, Kenya.

MATERIALS AND METHODS

Study Area: The Winam Gulf, previously referred to as Kavirondo Gulf, Nyanza Gulf, or Lake Nyanza Gulf, is a shallow inlet that is linked to the main lake through the Rusinga Channel, which is 4.8 kilometers wide. It is a prominent geographical feature extending from the northeastern part of Lake Victoria into the western part Kenya. The gulf is partially concealed from the main body of Lake Victoria by several islands such as the Maboko, Rusinga, and Ndere Islands (Misiko *et al.*, 2023) .The gulf has an average width of 25 kilometers and stretches for a distance of 40 miles from Kisumu to the channel. It is bordered by several towns, with Kisumu being the largest city on the Kenyan shores of Lake Victoria. Notable bays within the gulf include Naya Bay, Nyakach Bay, Osodo Bay, Kendu Bay, Homa Bay, Ruri Bay, Mirunda Bay, Asembo Bay, and Olambwe Bay. The Winam Gulf has a population of 397,957 according to the Kenya Population and Housing Census (KPHC, 2019). Kisumu city, situated on the northeastern shore of the

Winam Gulf, is the third-largest city in Kenya. The gulf is home to small-scale agricultural markets, fishing activities, and small-scale industries including tourism, food processing, oil refining, plastics, furniture, and cement production. The area also features various commercial establishments, educational institutions and healthcare and research facilities that accommodate a large population of people. Major rivers draining the Gulf drain agricultural landscapes, thus loading pesticide residues into the lake (ODARO, 2023; Zong *et al*., 2023). Within the lake, several species have been reported to deteriorate due to degraded water quality (Orina *et al.*, 2020; Paul *et al.,* 2024). This study was conducted on the Eastern side of the Winam Gulf within Kisumu County.

Sampling design and collection: Purposive sampling was used so as to obtain the maximum range of heavy metals from the sediment and water samples collected from fifteen different sites in the gulf. Sampling was carried out at the flood plains of the inlet rivers, the Kisumu wastewater treatment plant's (WWTP) effluent discharge into the lake, Kisumu industrial effluent, fish landing beachs, storm water entrance points, the Kisumu Water and Sewerage Company (KIWASCO) treatment facility. Sediment and water samples were collected from various sampling sites from the lake, KIWASCO effluent, River Kisat and River Nyando (figure 1).

Fig 1: Location of Winam Gulf in Lake Victoria, Kenya, showing the sampling sites Three replicates' samples water and sediment samples were collected from 31 sampling and placed in sterile plastic bottles (500 ml) that and transported to the laboratory in cooler boxes (4°C) within 12 hours and stored at −80°C for laboratory analysis.

Laboratory analysis of samples: The analysis of heavy metals was conducted using the Hach method technique with a spectrophotometer. Any organic debris was removed from the sediment samples, then dried, ground to a fine powder, and dissolved in distilled water. Samples of fish gills were digested in concentrated HNO_3 and H_2O_2 and diluted to 50 mL with distilled water, and filtration was done, ready for heavy metal analysis. Filtration of the samples was done to remove any suspended solids. A set of calibration standards containing precise concentrations of heavy metals, including lead, mercury, nickel, copper, cadmium, zinc, and aluminum, was prepared for analysis (Ghale Askari *et al.,* 2022). The standards covered the expected range in the samples according to the appropriate reagent of the Hach standard preparation. The digestion process for each sample of heavy metal involved weighing 0.5 gram of the sample and adding concentrated nitric acid and hydrochloric acid to a digestion vessel.

Sample digestion was performed to break down the sample matrix and release the metal for analysis. The mixture was heated to dry, and then hydrochloric acid was added until fully dissolved. The solution was transferred to a volumetric flask and diluted with distilled water to a final volume of 1 liter. The digested samples were analyzed using a spectrophotometer that was calibrated to the absorption maximum of each heavy metal being tested. Standard solutions with known concentrations were prepared to create a calibration curve by measuring their absorbance. After digestion, the samples were analyzed for their absorbance to determine the concentration of heavy metals using the calibration curve. The calibration and selection of the optimal wavelength followed the Hach method

(Maidan Dali *et al.*, 2023). The absorbance of each sample was measured and recorded, with quality control measures in place such as analyzing blank samples and conducting test replicates to assess precision and accuracy.

Data Analysis: The data was analyzed using graphpad prism software version 10. All the results were tested for normality using Shapiro –wilk test and expressed as a mean ±SD sing descriptive statistics. Two –way ANOVA was used to test the significance difference of heavy metals in lake, sediments and in fish. Post-hoc analysis was done using Dunnett's multiple comparisons test to check the significant differences in mean concentrations of heavy metals at the various sites sampled. The test data was statistically significant at $p \leq 0.05$.

RESULTS AND DISCUSSIONS

Heavy metal concentrations in water samples: The concentrations of heavy metals analyzed varied from one site to another (table 1). Within the aquatic environments, spatial variations in heavy metal concentrations are mediated by multiple factors such as geological processes, anthropogenic activities, hydrological factors, biological activities, environmental conditions, land use and management practices and seasonal changes (Hanfi *et al.*, 2020; Okereafor *et al.*, 2020) . This explains why the levels of all the heavy metals analyzed in this study varied from one site to another (table 1 and table 2).

Table 1: mean and standard error of heavy metals in water samples from the Winam Gulf and WHO standards

Sample	N	Ni	Pb	Cu	Cd	Zn	Al	Hg
The lake	134	0.238±0.005	0.033±0.002	0.002±0.020	0.001±0.067	0.025±0.126	0.026±0.017	0.00032±0.001
Kiwasco	134	0.304±0.077	0.016±0.004	0.282±0.005	0.0247±0.026	0.823±0.007	0.007±0.024	0.00051±0.001
R Nyando	134	0.204±0.033	0.007±0.102	0.121±0.001	0.097±0.001	0.049±0.013	0.004±0.042	0.00047±0.001
R. Kisat	134	0.275±0.029	0.135±0.019	0.019±0.002	0.024±0.002	0.073±0.009	0.015±0.002	0.00049±0.001
WHO STDS		0.07mg/l	0.01mg/l	2mg/l	0.003mg/l	5mg/l	0.09mg/l	0.006mg/l

Moreover, two way analysis of variance showed significant differences between the means of heavy metals analyzed heavy metals in the different water samples (F= (p<0.05).

Table 3: Analysis of variance in means of heavy metal concentration in water

Source of Variation	% of total variation	P value	P value summary	Significant	
Column Factor	18.16	<0.0001	****	Yes	
ANOVA table	SS (Type III)	DF	MS	F (DFn, DFd)	P value
Column Factor	5.481	4	1.370	F (4, 408) = 23.80	P<0.0001
Residual	23.49	408	0.05758		

Of all the heavy metals studied, the concentrations of Nickel, Lead and Cadmium concentration in water samples collected from all sites exceeded WHO acceptable standards. In most aquatic ecosystems, heavy metals are derived from both natural and anthropogenic activities (Uddin *et al.*, 2021). Naturally, weathering of rocks, natural groundwater discharge, mineral deposits, soil erosion, and volcanic activities generate heavy metal traces that end up in aquatic (Bonetto *et al.*, 2021; Ligate *et al.*, 2021). On the other hand, anthropogenic sources that have been linked with heavy metal deposition in aquatic habitats include landfills, agricultural run-offs, industrial wastes, wastewater treatment plants and mining activities (Sulistyowati *et al.*, 2023). These anthropogenic pressures, independently or cumulatively lead to elevated concentrations of heavy metals in ecosystems. This is why the concentrations of Nickel, lead, and cadmium in this study exceeded the WHO acceptable standards, a trend that concurs with other previous studies conducted elsewhere in the world such as (Ngoc *et al.*, 2020; Ngure & Kinuthia, 2020). However Copper, Aluminum and Mercury concentrations in the water samples from all sites were lower than the WHO acceptable Standards (Table1). Lake water recorded the lowest concentration of copper, cadmium, zinc and mercury compared to all sampling sites (Table1).

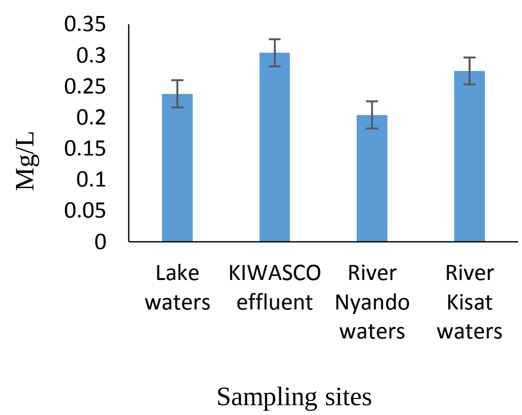

Fig 2: concentrations of nickel across sampling sites

Within the lake, various biological, physical and chemical transformations such as precipitation, dilution, complexion and adsorption takes place that may lower heavy metal concentrations in the aqueous phase in the Lake (Jamil *et al.*, 2024). This partly corroborates the lower heavy metal concentrations observed in the lake compared to the Inlet Rivers.

Moreover, some aquatic species including fish, plants, and microorganisms absorb and assimilate heavy metals, lowering the concentration of those metals in the water (Sharma *et al*., 2024). The open lake waters therefore sometimes show lower concentration of copper, cadmium, zinc and mercury compared to other sites (Outa *et al*., 2020). The high Nickel concentration poses potential threat to humans and aquatic species. Even though heavy metals are generally considered harmful to biological systems, their levels of toxicity and potential associated ecotoxicological impacts varies from one element to another. Most of them, even at very low concentrations, can impair ecosystem functioning especially when present in levels above background concentrations. For example, Nickel, Cadmium and lead have been associated with direct harm aquatic organisms due to their chemical toxicity thus disrupting the functioning of vital biological process (Singh *et al*., 2022). In addition, Nickel is a naturally the most abundance heavy metal in the crust earth and it presence in rocks its easily released to water bodies through geological activities (Obasi and Akudinobi, 2020). Nickel is highly used in the industrial applications thus easily released to the environment through anthropogenic activities (Mishra *et al*., 2019). (Nickel was higher in the KIWASCO waters than other sites this can be attributed to the sources from industrial wastes, domestic wastes and urban runoffs and its solubility in aqueous environment thus making it mobile in water treatment plants (Ribbe *et al*., 2021). Previous studies including Aradpour *et al*., (2020); Choudhury *et al.*, (2021) have all separately reported that nickel is the most concentrated heavy metal in aquatic environments. The presence of nickel lead and cadmium concentration above WHO acceptable standards indicates a potential health hazard to human and aquatic biodiversity (Arisekar *et al.*, 2020). Their elevated concentrations can impair the respiratory, reproductive and immune system of aquatic organisms leading to reduced population sizes and biodiversity (Sharifinia *et al.*, 2020). At the microbial community level, exposure to heavy metals can alter community composition of microbes through intoxication and alteration of nutrient cycles (Shuaib *et al.*, 2021). For example, aquatic bacteria may develop antibiotic resistance through expression of antibiotic resistance genes Gupta *et al*., (2021) when exposed to high levels of Nickel and Cadmium. This can lead to the up and down regulating of specific genes involved in resistance mechanism further promoting antibiotic resistance in aquatic bacteria (Rilstone *et al.*, 2021). Comparatively, the levels of heavy metals in waters of River Kisat were higher than those of the waters of River Nyando except for copper (figure 3). Possible pollution sources like mining operations, farms, and sewage and industrial effluents are common within the Winam Gulf. River Kisat drains a peri-urban environment with poor waste management systems. Most of waste effluents therefore find their way in to the river through overland run off. This explains the high concentration of Nickel observed in sediments and water samples collected from River Kisat compared to other sampled sites.

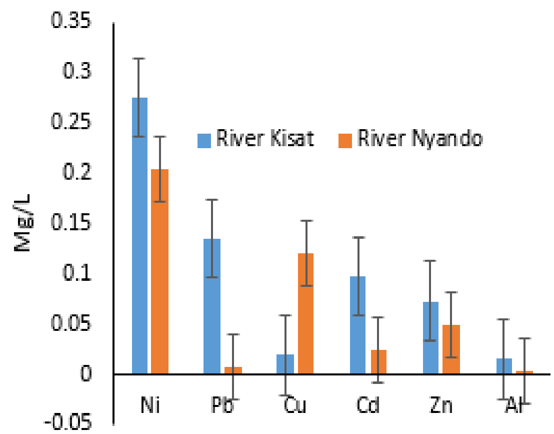

Fig 3: concentrations of heavy metals in rivers Kisat and Nyando waters

Higher concentrations of heavy metals in River Kisat waters is due to the higher industrial and domestic effluent loads the river receives within its catchment as it drains the urban area of Kisumu City. Most of the industrial plants within the city have less efficient waste treatment systems. The poorly processed industrial wastes therefore find their way in to river Kisat leading to elevated heavy metal concentration (Guo *et al.*, 2024) . Generally, in many parts of the world, rivers receiving effluents from wastewater and industrial treatment plants are characterized with high heavy metals concentration (Odhiambo *et al.*, 2023). On the other hand, high heavy metal concentration in river Nyando is attributed to the existence of agricultural activities along the upper reaches of the river course. The several sugar cane farms within the river catchment are characterized with high usage of chemical fertilizers that boost crop performance. Residues of mineral fertilizers, together with heavy metal traces are washed by surface run off, particularly during heavy rainfall events, into the river channel leading to high heavy metal concentrations. Moreover, industrial and mining activities within the watershed could also contribute to elevated heavy metal concentrations (Ogola *et al.*, 2023). In concurrence with the observed trend, previous studies have also repeated heavy metal contamination in many rivers draining their waters in to Lake Victoria (Aura *et al.*, 2024).

Table 3: mean and standard error of heavy metal concentrations at different sites in winam gulf and who standards

Sample	N	Ni	Pb	Cu	Cd	Zn	Al	Hg
The lake	134	0.238±0.005	0.033±0.002	0.002±0.020	0.001±0.067	0.025±0.126	0.026±0.017	0.00032±0.001
Kiwasco	134	0.304±0.077	0.016±0.004	0.282±0.005	0.0247±0.02	0.823±0.007	0.007±0.024	0.00051±0.001
R Nyando	134	0.204±0.033	0.007±0.102	0.121±0.001	0.097±0.001	0.049±0.013	0.004±0.042	0.00047±0.001
R. Kisat	134	0.275±0.029	0.135±0.019	0.019±0.002	0.024±0.002	0.073±0.009	0.015±0.002	0.00049±0.001
WHO STDS		0.07mg/l	0.01mg/l	2mg/l	0.003mg/l	5mg/l	0.09mg/l	0.006mg/l

Heavy metal concentrations in sediments: Copper, zinc, and aluminum concentration level in the Sediment samples from all the sites were within acceptable WHO standards (Table 3).

However, nickel, lead, and cadmium from the sediment samples were above the WHO acceptable standards. In aquatic ecosystems, Nickel, lead, and cadmium exhibit a strong tendency to adsorb onto sediments and the remains of organisms within the benthic column (Sani *et al.,* 2022) . This is why Nickel, lead, and cadmium concentrations from the sediment samples were above the WHO acceptable standards. The open lake concentration in sediment samples of copper, cadmium, Aluminiun and mercury was the highest compared to all sampling sites in the Gulf, which agrees with previous studies (Rezaei *et al*., 2021). Therefore, the main lake serves as a natural sink for pollutants like heavy metals, which build up in sediments (Xue *et al.,* 2023). In addition, biogeochemical activities in the lake can potentially result in the production of metals. On the other hand, microbiological activity, chemical precipitation, and particulate matter adsorption might also cause metal accumulation in sediments leading to elevated heavy metal concentrations (Lin *et al.,* 2023). Compared to river sediments, the lake's fine-grained sediments provides potential catalytic base for metal adsorption, increasing their concentration in lakes (Cui *et al.,* 2022). Sediments and benthic creatures in the lake have a higher concentration of heavy metals due to the lake's longer retention time than the rivers Nyando and Kisat (Githaiga *et al.,* 2021; Masese *et al.,* 2023).

Conclusions: In conclusion, results show that river Kisat showed higher concentrations of the analyzed heavy metals compared to River Nyando. Nickel, Lead and Cadmium concentration in water samples exceeds WHO acceptable standards and could pose a potential harm to aquatic biota and human health. Fish and other aquatic species can accumulate heavy metals including lead, mercury, cadmium, and arsenic, those possible transfer to humans through consumption. Comparatively, the concentrations of Copper, zinc and aluminum in sediment samples from all the sites were within acceptable WHO standards, posing less pollution threat. However, nickel, lead and cadmium levels in sediment samples were above the WHO acceptable standards. The open lake concentration in sediment samples of copper, cadmium, aluminum and mercury was the highest compared to all sampling sites in the Gulf. The major sources of heavy metal loading within the Winam Gulf are agricultural and industrial wastes that find their way in to the lake. To mitigate the release of heavy metals into the lake, regulatory bodies create and enforce stronger regulations for discharge industrial and domestic effluents in to water resources. Effluents dischargeable in to the water bodies should have heavy metal concentrations that ear within the accepted WHO standards.

Conflict Of Interest: The authors declare no conflict of interest.

Data Availability Statement: Data are available upon request from the corresponding author.

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