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Heavy Metal Concentration Levels In Surface Waters Of Lake Turkana And River Turkwel, Kenya

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Abstract
Heavy metal contamination in surface waters is a significant global concern, particularly because people often settle near accessible water sources like lakes. This study examined the concentrations of heavy metals in water from selected locations along the shores of Lake Turkana and Turkwel River using Microwave Plasma Atomic Emission Spectroscopy (MPAES). In Lake Turkana, *arsenic had the highest overall average concentration (0.756 mg/l) while Cd had the lowest (0.013mg/l) while in River Turkwel Zn had the highest average concentration (0.847 mg/l) with Cr being lowest (0.012mg/l). The Metal Contamination Index (MCI) in both the Lake and the River water was 0.001, while the corresponding Heavy metal Evaluation Indices (HEI) were 94.171 and 93.626 respectively. Concentrations of Cd, Ni, As, Pb and Cr were higher in the current study compared to the WHO recommended levels for drinking water.*

Keywords: *Heavy metals, concentration, water quality, Kenya*

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I. Introduction

As global demand for safe water increases, the quality of water resources is declining due to population growth, pollution, unplanned usage, climate change and global warming.

Human activities such as industrial, domestic and agricultural activities elevate levels of heavy metals in the environment, causing significant environmental harm, particularly in coastal areas, lakes and rivers. This disrupts aquatic ecosystems and threatens water sustainability. Contamination is assessed through analysis of water, sediment, and organisms [1]. Essential metals such as iron, cobalt, copper, zinc, manganese, and molybdenum play crucial roles in the human body but can become toxic when present in high concentrations [2]. In contrast, metals like lead, mercury, and cadmium are harmful even at low levels. For example, long-term exposure to cadmium can cause poisoning, affecting the lungs and kidneys, while short-term exposure leads to respiratory issues, headaches and irritation. Lead exposure has been linked to neurological conditions, including Alzheimer's disease, Parkinson's disease and amyotrophic lateral sclerosis [3]. Lead poisoning disrupts normal nervous system function, with long-term exposure harming the kidneys and brain [4]. Prolonged zinc toxicity may result in copper deficiency and nerve damage. Copper exposure negatively affects male reproductive health, reducing sperm count and motility. It is also linked to obesity [5]. Cadmium affects the vascular endothelium, triggering the release of anti-thrombolytic substances and promoting inflammation [6]. Excessive zinc can lead to anorexia, vomiting and diarrhea. Levels more than 0.05 mg/L of chromium (VI) in drinking water may cause diarrhoea, vomiting, abdominal pain, indigestion, convulsions, and liver and kidney damage [7]. Excessive arsenic exposure through drinking water can lead to skin issues, vascular diseases like arteriosclerosis, peripheral vascular disease and ischemic heart disease (ISHD). It can also cause kidney damage, neurological effects, cardiovascular and chronic lung diseases, respiratory problems, cerebrovascular disease, reproductive issues and cancers of the skin, lungs, liver, kidney and bladder [7].

As livelihoods in Turkana County shift from pastoralism to agro-pastoralism, the demand for water, both for domestic and agricultural use, is increasingly concentrated in settlements along the main rivers and shores of Lake Turkana. Key water sources include hand-dug shallow wells, direct access to rivers, and piped water from boreholes and river abstractions. The aim of this study was to examine the concentrations of heavy metals in water from selected locations along the shores of Lake Turkana and River Turkwel.

II. Materials And Methods

Study area

The study was done in Turkana Central Sub-County of Turkana County (3.2072° N, 35.6970° E). The area has a population of approximately 185,305 people, with a population density of 29 people per square kilometer and an average household size of 6 individuals [8]. The town faces increasing water demand caused by the growing population, irrigation projects and industrial activities. The Lodwar Water and Sanitation Company (LOWASCO) relies on solar/electric-powered boreholes along the Turkwel River. Despite sufficient water from the aquifer, the town struggles with unreliable supply due to low pressure, pipe bursts, and leaks [9 10].

Lake Turkana is located in Lake Turkana Basin, situated in the northern part of Kenya's Rift Valley, covering about 6405 km², lying between longitudes 35° 45' E and 36° 48' E and latitudes 2° 25' N and 4° 38' N. The lake borders Turkana and Marsabit Counties, with a 240 km shoreline and a maximum depth of 120 meters. The area's geology consists of granite, tuffs, gneisses, and limestone, encircled by volcanic peaks such as Mt. Nyiru, and the Kulal and Longipi volcanic complexes. Its geology is influenced by volcanic activity and sediment deposits from the Omo, Kerio, and Turkwel Rivers [11].

Lake Turkana is situated in an arid and semi-arid region (ASAL) with a hot climate. Areas near the Lake receive as little as 50 mm per year, while the western regions, due to higher elevations, generally receive over 450 mm annually [10]. The Lake which is a saline body of water, is a significant landmark and offers fishing opportunities to locals. A cartographic representation of the study area showing the sampling locations is shown in Figure 1.

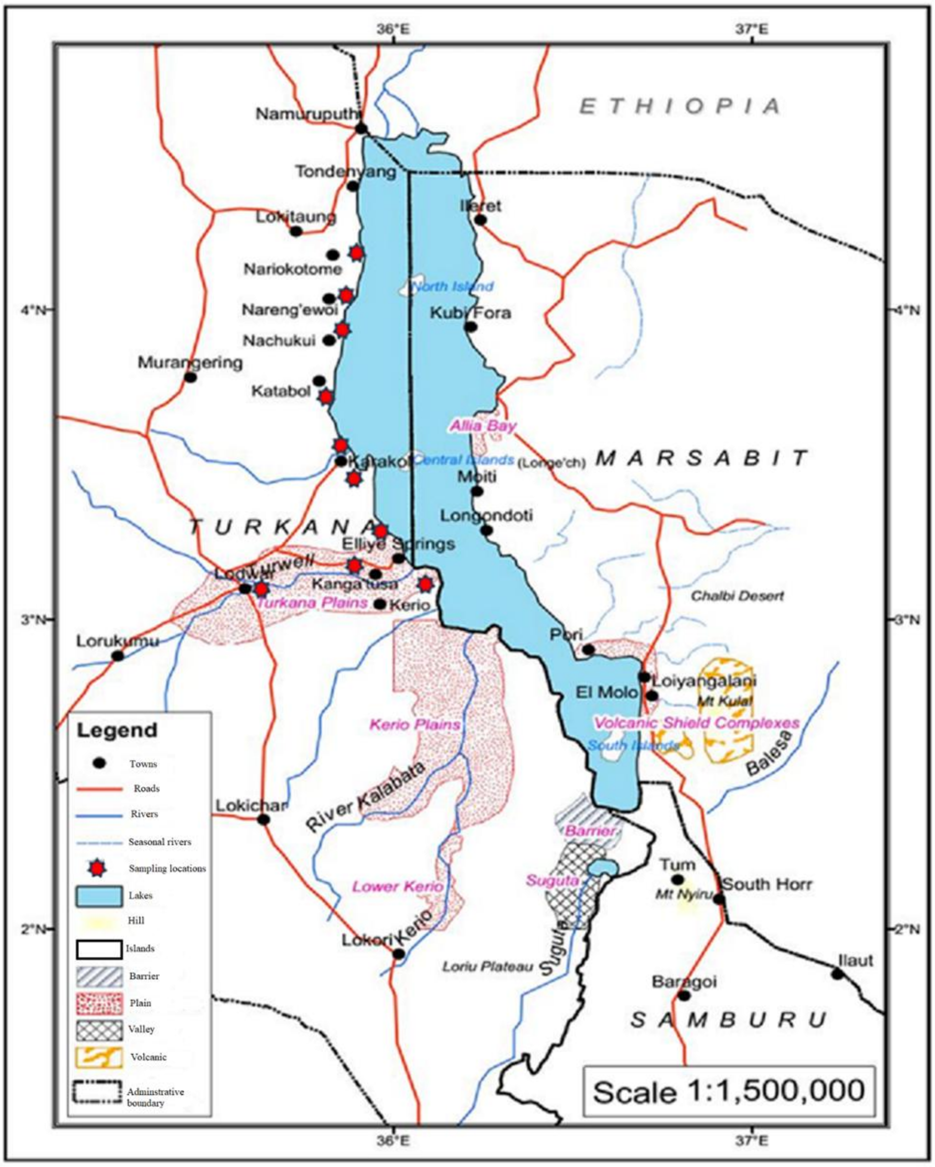

Figure 1: A cartographic representation of the Lake Turkana basin displaying sampling locations.

Sample Collection and Preparation

Purposive sampling method was used to collect 30 water samples from different sites along the shores of Lake Turkana and the Turkwel River. 8 sampling locations were selected along the shores of Lake Turkana and 2 along the Turkwel River as indicated in Figure 1. Sampling along the shores of the Turkwel River was done at two locations, typically one upstream and the other downstream to establish whether the River has consistent hydrological and chemical properties between the two locations that are about 50 km apart. For each sampling location, three sampling sites that were between 30 and 50 m apart were selected. Surface water samples were collected into pre-cleaned 500 ml plastic bottles that were filled to the brim. A label detailing the sample information was affixed to the bottle.

The samples were first weighed and transformed into a solution through appropriate dilution using distilled water. Precisely 0.5 liters of each sample was carefully measured into a clean digestion flask and mixed with 9ml of concentrated nitric acid and 3ml of concentrated hydrochloric acid. The sample was heated during the digestion process until all the brownish fumes (nitrogenous compounds) were completely expelled out. Afterwards, the sample was cooled to room temperature and diluted with distilled water to approximately 100 ml. Next, the mixture was filtered through Whatman filter papers No. 42 into to 100 mL volumetric flasks after which they were filtered through filters of pore size 0.22µm into plastic reagent bottles and subsequently used for atomic emission spectrometry. A series of calibration standards were prepared by diluting high-purity elemental standards in a matrix similar to the sample matrix [12].

Elemental analysis

The concentrations of zinc, barium, cadmium, lead, copper, arsenic, nickel and chromium in the samples were determined using an Agilent 4210 Microwave Plasma Atomic Emission Spectrometer (MP-AES). To evaluate the effectiveness of the MP-AES techniques and the experimental procedures, quality control tests were conducted. A pre-digested sample was spiked with 5 mg/l, prepared by serial dilution of a 1000 mg/l stock standard solution, ensuring quality assurance [13]. Thereafter, the concentrations of the eight elements were determined using an eight-point calibration curve of a multi-element standard in emission mode.

Evaluation of Water Quality

Water quality was determined by evaluating the Heavy Metal Contamination Index (MCI) used to assess the overall level of heavy metal contamination in water [4]. It combines the concentration of various metals in water with their toxicity to create an overall pollution index.

The MCI was determined using Equation 1 [4].

$$\mathrm{MCI} = (\mathrm{C_{Zn}} \times \mathrm{C_{Pb}} \times \mathrm{C_{Cu}} \times \mathrm{C_{Cd}} \times \mathrm{C_{Cr}} \times \mathrm{C_{Ba}} \times \mathrm{C_{As}} \times \mathrm{C_{Ni}})^{1/3} \qquad (1)$$

Where C_{Zn}, C_{Pb}, C_{Cu}, C_{Cd}, C_{Cr}, C_{Ba}, C_{As} and C_{Ni} are the concentrations of metals of interest in mg/l.

Based on the mean MCI values obtained, the water can be categorized as good quality water having low metal pollution if the MCI value falls within the range of 0 to 1. If $1 < \mathrm{MCI} \leq 5$, the metal pollution of the water is moderate and have some negative impact on the ecosystem and when $\mathrm{MCI} > 5$, the metal pollution in the water is high, hence can harm both aquatic life and humans [4].

The Heavy metal evaluation index (HEI) was calculated using Equation 2

$$\mathrm{HEI} = \sum \frac{\mathrm{C_i}}{\mathrm{MAC}} \qquad (2)$$

Where C_i is the concentration of heavy metals and MAC is the maximum permissible concentration of the heavy metal in drinking water. The water is classified as highly polluted when the average HEI value exceeds 10 [2].

III. Results And Discussions

Heavy Metal Concentration in the Water Samples

Table 1 presents the concentrations of heavy metals (Zn, Cd, Ba, Cu, Ni, As, Pb, Cr) in water samples from different locations. The data highlights the variability in concentrations across the sampling sites, providing insights into regional water quality and potential environmental concerns. Some values were recorded as < 0.01, indicating that the specific elements in certain samples were below the detection limit of the MP-AES equipment.

The results show considerable variation in the concentrations of the elements across the locations. Zinc (Zn) and arsenic (As) exhibit relatively higher concentrations, particularly in the Eliye, Kang'atosa and Lodwar locations, while other elements like cadmium (Cd) and chromium (Cr) show more consistent and lower levels. lead (Pb) and nickel (Ni) concentrations varied, with some samples showing significant differences. The variability in concentrations likely reflects local environmental factors, pollution sources and water quality conditions specific to each sampling site.

Table 1: Concentrations of heavy metals in water samples across various sampling locations (mg/l)

		Concentration (mg/L)							
Sampling location	Sampe ID	Zn	Cd	Ba	Cu	Ni	As	Pb	Cr
NARIOKOTOME	NARI 1	0.04	0.01	0.08	0.02	0.03	0.48	0.03	0.01
	NARI 2	0.08	0.01	0.18	0.01	0.03	0.62	0.05	0.01
	NARI 3	0.12	0.02	0.01	0.01	0.02	0.59	0.02	0.02
KERIO	KERIO 1	0.33	0.01	0.17	0.03	0.05	0.86	<0.01	<0.01
	KERIO 2	0.23	0.01	0.09	0.02	<0.01	0.9	0.02	<0.01
	KERIO 3	0.11	0.02	0.16	0.02	0.04	1.09	0.01	<0.01
ELIYE	ELIYE 1	4.58	0.01	0.08	0.13	0.01	1.13	0.02	0.12
	ELIYE 2	3.81	0.011	<0.01	0.04	0.01	1.11	0.01	0.08
	ELIYE 3	1.94	<0.01	0.09	0.1	0.01	1.2	0.01	0.09
KANG'ATOSA	KANG 1	0.6	0.03	0.16	0.04	0.01	0.93	0.02	0.01
	KANG 2	1.24	0.01	0.06	0.02	0.02	0.92	0.03	0.02
	KANG 3	0.8	0.03	0.08	0.02	0.02	0.78	0.04	0.01
KALOKOL	KALO 1	0.12	0.02	0.09	0.06	0.01	0.84	0.03	0.01
	KALO 2	0.11	0.01	0.1	0.02	0.012	0.51	<0.01	<0.01
	KALO 3	0.03	0.01	0.07	0.04	0.01	0.38	0.03	<0.01
KATABOI	KATA 1	0.05	0.01	0.12	0.02	0.01	0.28	<0.01	<0.01
	KATA 2	0.06	0.01	0.18	0.01	0.59	0.46	0.01	<0.01
	KATA 3	0.02	0.01	0.13	0.02	0.02	0.42	0.01	<0.01
LODWAR	LODW 1	0.35	0.03	0.63	0.01	0.03	0.39	0.32	0.01
	LODW 2	1.88	0.01	0.15	0.02	<0.01	0.54	<0.01	<0.01
	LODW 3	0.21	0.02	0.03	0.03	<0.01	0.53	0.02	0.01
NARENG'EWOI	NARE 1	0.87	0.01	0.04	0.02	<0.01	0.57	<0.01	<0.01
	NARE 2	0.41	0.01	0.12	0.04	0.01	0.47	<0.01	<0.01
	NARE 3	0.04	0.01	0.08	0.04	0.01	0.65	0.02	<0.01
LONG'ECH	LONG 1	0.12	0.01	0.15	0.05	<0.01	0.6	<0.01	0.01
	LONG 2	0.12	0.01	0.18	0.08	0.02	0.67	0.01	0.01
	LONG 3	0.06	0.01	0.08	0.03	0.01	0.51	0.02	<0.01
NACHUKUI	NACH 1	0.21	0.02	0.04	0.02	<0.01	0.41	<0.01	<0.01
	NACH 2	0.06	0.01	0.02	0.02	<0.01	0.34	<0.01	<0.01
	NACH 3	0.16	0.03	0.04	0.01	<0.01	0.36	0.03	<0.01

Table 2 displays the average concentrations of selected heavy metals of Lake Turkana's surface water together with water quality indices at different sampling locations.

Nickel (Ni) had the highest range (0.008 to 1.00 mg/L), showing significant variability, followed by chromium (Cr) with a range of 0.01 to 1.00 mg/L. Arsenic (As) had the highest mean concentration at 0.756 mg/L, indicating consistent high levels across sites. The Heavy Metal Evaluation Index (HEI) ranged from 64.787 to 121.232, with an average of 94.171, suggesting varying degrees of pollution. Sites such as Kerio and Eliye had the highest HEI values.

Table 2: Average concentrations of heavy metals and water quality indices across various sampling locations along shores of L. Turkana

Sampling location	Average concentration (mg/L)								Water quality Indices	
	Zn	Cd	Ba	Cu	Ni	As	Pb	Cr	MCI	HEI
NARIOKOTOME	0.080	0.013	0.130	0.013	0.027	0.563	0.033	0.013	0.000	64.787
KERIO	0.223	0.013	0.140	0.023	0.045	0.950	0.010	1.000	0.002	121.232
ELIYE	0.443	0.011	0.085	0.090	0.010	1.147	0.013	0.047	0.001	121.005
KALOKOL	0.087	0.013	0.087	0.040	0.011	0.577	0.030	0.010	0.000	65.552
KATABOI	0.043	0.010	0.143	0.017	0.008	0.478	0.010	1.000	0.000	72.469
NARENGÉWOI	0.440	0.010	0.080	0.033	0.010	0.768	0.020	1.000	0.001	102.495
LONGECH	0.100	0.010	0.137	0.053	0.015	0.984	0.015	0.010	0.000	103.890
NACHUKUI	0.143	0.020	0.033	0.019	1.000	0.579	0.030	1.000	0.003	101.938
MINIMUM	0.043	0.010	0.033	0.013	0.008	0.478	0.010	0.010	0.000	64.787
MAXIMUM	0.443	0.020	0.143	0.090	1.000	1.147	0.033	1.000	0.003	121.232
AVERAGE	0.195	0.013	0.104	0.036	0.141	0.756	0.020	0.510	0.001	94.171

Table 3 displays the average concentrations of selected heavy metals in the Turkwel River and its water quality indices at the two sampling locations. Of the metals studied in the River's water, Zn had the highest overall average concentration (0.847 mg/l) while Cr had the lowest (0.012mg/l). Kang'atosa (downstream) has higher concentrations of Zn, Cd, Cu, As and Cr while Lodwar (upstream) has higher concentrations of Ba, Ni and Pb. Kang'atosa, being downstream is likely to receive effluents from human activities such as agriculture, settlements, or industrial discharge. These can increase concentrations of metals like Zn, Cu and As. The higher presence of zinc at Kang'atosa can be attributed to use of zinc related fertilizers used in farms found in the Turkana plains and anthropogenic activities upstream. The higher concentrations of Ba and Pb at Lodwar could be due to industrial activities, discharges from car wash points and vehicle repair workshops within the town. Both locations show equal MCI (0.001), suggesting contamination intensity is similar. HEI is higher at Kang'atosa than Lodwar, indicating more heavy metal burden downstream.

Table 3: Average concentrations of heavy metals and water quality indices in the Turkwel River

Sampling location	Average concentration (mg/L)								Water quality indices	
	Zn	Cd	Ba	Cu	Ni	As	Pb	Cr	MCI	HEI
KANGÁTOSA	0.880	0.023	0.100	0.027	0.017	0.877	0.030	0.013	0.001	99.202
LODWAR	0.813	0.020	0.270	0.020	0.030	0.632	0.170	0.010	0.001	88.054
DIFFERENCE	0.067	0.003	-0.170	0.007	-0.013	0.245	-0.140	0.003	-0.001	11.148
Overall average	0.847	0.022	0.185	0.024	0.024	0.755	0.100	0.012	0.001	93.628

Overall, the average MCI in both the Lake and River's water is 0.001 a value that falls within the range of 0 to 1 hence, the water can be categorized as having low metal pollution. The corresponding HEI in the Lake and River's water are 94.171 and 93.628 respectively.

Figure 2 (a) and (b) show bar graphs of the average concentrations of heavy metals for both Lake Turkana and the Turkwel River respectively. Figure 2(a) illustrates that arsenic (As) had the highest concentration in the Lake's water while in the Turkwel River, Zn had the highest concentration followed by arsenic (As) as illustrated in Figure (b).

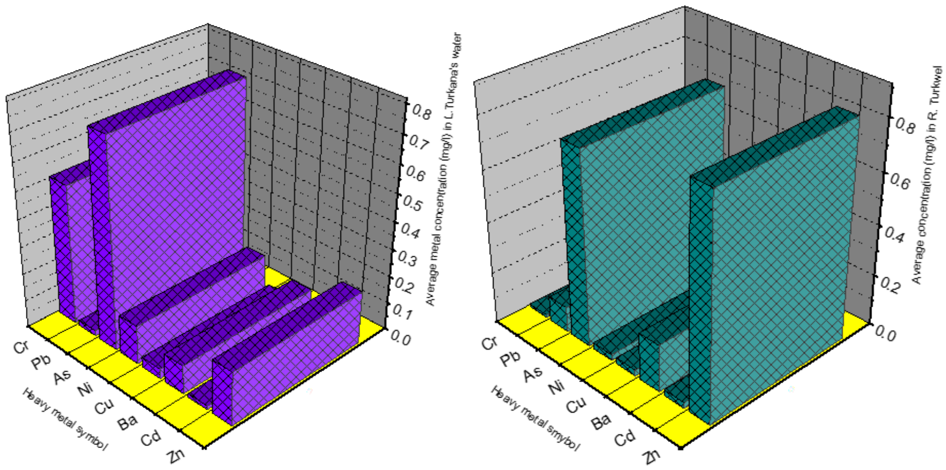

Figure 2: Heavy metal concentrations in Lake Turkana water (a) and River Turkwel (b).

The concentration of heavy metals in the current work was compared to concentrations of selected elements in studies done by other researchers in water from other lakes and one of the rivers found in the Kenyan Rift valley and results presented in Table 4 which also presents WHO recommended limits for drinking water. The findings of concentrations of cadmium and lead in water from selected sites at Lake Turkana by Munene et al are consistent with those observed in the current study. The concentrations of Pb, Cr and As were higher in Lake Turkana when compared to concentrations of corresponding elements in both Lake Elmentaita and Lake Nakuru. This is primarily due to its unique geological and hydrogeochemical characteristics, combined with the effects of evaporation in a closed basin. The concentration of Cu and Pb was found to be higher in River Sosian compared to River Turkwel in the current study. However, the concentration of Zn in River Turkwel's water was higher than that of River Sosian. The higher Zn in the Turkwel River can be from fertilizers used in farming activities found along its course that is largely through a semi-arid region. On the other hand, River Sosian flows through regions with high rainfall and therefore its water is not utilized in farming activities as much. Concentrations of Cd, Ni, As, Pb and Cr were higher in the current study compared to corresponding WHO recommended levels for drinking water.

Table 4: Comparison of heavy metals concentration with reported concentrations and WHO recommende limits for drinking water

Source	Study area	Metal concentration (mg/l)								Reference
		Zn	Cu	Pb	Cd	Cr	Ba	As	Ni	
Lake water	L. Turkana, Kenya	0.195	0.036	0.02	0.013	0.51	0.104	0.756	0.141	Present work
Lake water	L.Turkana			>0.11	>0.03	>0.03				[14]
River water	R. Turkwel, Kenya	0.847	0.024	0.1						Present work

River water	R. Sosian, Kenya	0.291	0.407	0.106						4
Lake water	L. Elmentaita, Kenya			0.014	0.003			0.010		15
Lake water	L. Nakuru, Kenya			0.012		0.005		0.002		15
Drinking water Standard limit		5	2	0.01	0.003	0.05	0.7	0.01	0.07	16

IV. Conclusion

This study assessed the concentrations of heavy metals zinc, cadmium, barium, copper, nickel, arsenic, lead, and chromium in surface water from the Turkwel River and Lake Turkana. The average Metal Contamination Indices (MCI) for both water bodies were below 1, indicating low overall metal contamination, though the Heavy Metal Evaluation Index (HEI) exceeded 10 in both cases. Furthermore, the mean concentrations of Pb, Cd, As, Ni, and Cr surpassed the World Health Organization (WHO) recommended limits for drinking water. Water treatment is therefore necessary before consumption of water from the sources. Furthermore, water infrastructural development and policy implementation by the County government of Turkana, international donors, NGOs and the community in provision of clean treated water to Turkana county's growing population is encouraged.

Conflict Of Interest

We affirm that there are no conflicts of interest related to the research conducted and presented in this study.

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