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Concentration Levels of Iron (Fe), Copper (Cu), Lead (Pb), Cadmium (Cd), Chromium (Cr) and Selected Nutrients in Water of Motoine River Channel, Kibera, Kenya

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Authors' contributions

This work was carried out in collaboration between all authors. Author SMM designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors AOO, AMS and AOY supervised the work done by author SMM. Author SMM managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The need for clean and safe consumable water is of paramount importance to any society since water is a crucial substance for the sustenance of life. Kibera slum is one of the leading slums in the world with a high population, leading to poor levels of sanitation and inadequate clean water supply. Consequently, the residents have to seek for alternative water supply. Motoine River flows through the slum, and thus acts as an alternative source of water. This study determined the concentration levels of heavy metals (Pb, Fe, Cu, Cr and Cd) and nutrients (nitrates, nitrites and phosphates) in Motoine River, Kibera in September 2014 and compared the variations downstream. The metals were determined using Atomic Absorption Spectroscopy (AAS) while the nutrients were determined using UV/Visible spectroscopy. Concentration levels of Cu, Cd and Cr were found to be lower than

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the Environmental Protection Agency (EPA) values for maximum contaminant level (MCL) while those of Fe, Pb and the nutrients were higher than EPA's MCL values. Cd had the lowest concentration and was below the detection limit of the instrument used. Nitrates were found to be of the highest concentration at 16.4959 ± 2.4432 parts per million (ppm). The high concentration of nutrients in the water could be due to domestic waste and effluent disposal into the river and agricultural runoffs while that of metal ions could be due to waste from informal jua kali industries and erosion of natural deposits. The efforts by the government to rehabilitate and clean rivers within Nairobi should be extended to include Motoine River.

Keywords: Motoine River; nutrients; metals; UV/visible; atomic absorption spectroscopy.

1. INTRODUCTION

Water is essential to the survival of life on the planet. It covers about 70% of the Earth's surface and the properties of this liquid and its vapour control the climatic conditions that make life possible on earth [1]. In addition, water's solvent properties control the chemical weathering of rocks, the transfer of nutrients to plants and the transfer of chemicals inside organisms. Of all water within the surface zone of the earth, 97% is in the oceans, about 2% is in ice caps and glaciers, and only 0.6% is fresh water of direct use to humans [2].

Water is utilised for cleaning, farming, construction, transport and many other things. Water generally supports life on earth and for that reason, its importance and uses cannot be stated exhaustively. Therefore, the quality of water in any human settlement remains to be of critical concern. Water pollution occurs when pollutants are directly or indirectly discharged into water bodies without adequate treatment to remove harmful compounds. A worst case scenario was observed in slums where water is scarce, and consumption of contaminated water is the norm. It should, however, be noted that water pollution is not solely a third world problem, on the contrary, it is a major global problem which requires ongoing evaluation and revision of water resource policy. Water pollution has been mentioned as a leading cause of diseases and deaths [3,4]. Therefore, we cannot ignore the fact that the problem is worse in informal settlement and slums all around the world.

Kibera slum in Kenya, for example, is the biggest urban slum in Africa and one of the biggest in the world [5]. The living conditions in Kibera slums are deplorable to most of the residents unable to access basic services such as electricity, sanitation and clean water [6]. This being an informal settlement facing rapid population growth, it is not easy for the government to regulate water provision in the area. Other factors that make the water problem altogether worse water rationing in Nairobi City, poor infrastructure, vandalism and human economic activities at various points along the river [7].

Motoine River rises from Riu Swamp and is heavily used in the settled Dagoretti area [8]. As the river flows eastwards, farmers in the valley use its water for irrigation, agriculture and other domestic uses. The water colour in this section of the river is mainly red due to the soil characteristic of the area. Other polluting activities include dairy farming and abattoirs. Motoine River starts receiving agrochemical pollution right from its water headwater in the Dagoretti area and picks other forms of pollution as it flows through the Ngong Forest and the Kibera area [9]. Due to lack of a waste management mechanism for Kibera slum, Motoine River system has become a natural receptacle for all the uncollected waste emanating from the area.

Contrary to a common misconception, man is not the sole culprit in bringing about pollution in the environment. Certain natural events result in effects identical to those produced by human interference in the system. These natural events can also be classified as pollution. Such events include Natural oil seepages and high levels of toxic metals in soils due to weathering of mineral deposits [1]. Consumption of contaminated water poses a health risk and can result in a myriad of health problems in both human and aquatic life [10]. For example, Pb affects the nervous system, kidney and haematopoietic system. Anaemia is an early manifestation of acute or chronic Pb intoxication which is usually a result of shortened erythrocyte life span and impairment of heme synthesis [11] while cadmium causes a reduction in the iron content of both animals and plants leading to reduced growth. Absorption of cadmium from the gastrointestinal tract is increased if there is a deficiency in calcium and iron [12].

On the other hand, nitrogen and phosphorus are nutrients that are natural parts of aquatic ecosystems. They support the growth of algae and aquatic plants, which provide food and habitat for fish, shellfish and smaller organisms that live in water [13]. Nitrate is found at low levels from naturally occurring sources, but high levels usually indicate human-caused contamination. Possible sources of nitrates in groundwater include runoff from fertilisers, septic tanks leakages, sewage and erosion of natural deposits. Both nitrite and nitrate cause shortness of breath and blue-baby syndrome in infants below the age of six months [13]. Phosphorous occurs in waters and wastewaters as orthophosphates, condensed phosphates and organically bound phosphates [14]. Domestic wastewater is relatively rich in phosphorous compounds mainly because of detergents. Most heavy duty synthetic detergent formulations designed for household market contain large amounts of polyphosphates [14].

Kibera slum is facing water supply challenges thus the residents are likely to use water from Motoine River for domestic purposes. However, there is limited information regarding the water quality of Motoine River. Therefore, this study was carried out to determine the levels of selected metals and nutrients (Fe, Cu, Pb, Cd, Cr, nitrates, phosphates and nitrites) in water from Motoine River, Kibera, Nairobi, Kenya.

2. MATERIALS AND METHODS

2.1 Sampling

Nine samples were collected along Motoine river, three from each of the three sampling points, that is upstream, downstream and mid-stream (Fig. 1) and they were preserved with 2 mL concentrated nitric acid per 250 mL of sample in accordance to EPA guidelines of pH below 2 [15]. Before sampling was done, the pre-cleaned sample containers were flushed with water from the sampling site before collecting the water samples. The sample containers were dipped into the water with the bottle opening slightly (about 1 cm) below the water surface and the water allowed to flow into the bottle before closing the bottle [16].

2.2 Sample Preparation and Analysis

2.2.1 Metals

For the heavy metal analysis, the samples were first digested by aqua regia before analysis by the FAAS. For the metals, standards were prepared from analytical reagent grade salts (lead nitrate, iron (III) chloride, copper (II) nitrate, copper (II) nitrate, chromium (III) nitrate, and cadmium nitrate) and the concentration of Pb, Fe, Cu, Cr and Cd were determined using Flame atomic absorption spectrophotometer (Shimadzu AA-6200) [16].

2.2.2 Nutrients

Phosphates were determined using the combined reagent, and the intensity of blue coloured complex was measured at 830 nm, nitrates were determined at 210 nm and 275 nm so that:

$$\text{Actual Absorbance } A = A_{(210)} + 4A_{(275)}$$

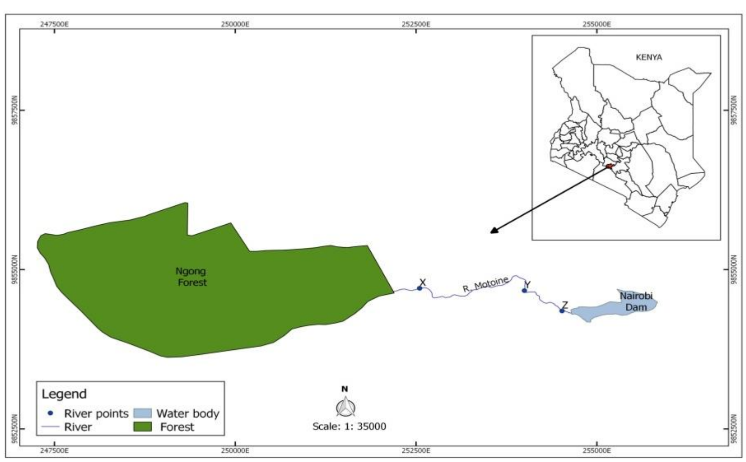

Fig. 1. A map showing the three sampling points on Motoine River

While nitrites were determined using N-(-1-Naphthyl)-ethylenediamine dihydrochloride and sulphanilic acid solution at 550 nm. The phosphates, nitrates and nitrites were analysed using a UV-Visible spectrophotometer (Shimadzu 1800) [17]. The reagents used were of the analar grade.

2.3 Statistical Analysis

The concentrations of the metal and nutrients were analysed were determined in triplicate and the data represented in tables as a mean± standard deviation. IBM SPSS v23 was used for the statistical analysis.

3. RESULTS AND DISCUSSION

3.1 Metals

From the data obtained in this study, there was a variation in the concentration levels of both the metal ions and the nutrients analysed. For the metal ions, Fe had the highest average concentration (0.3230 +0.0645 mg/L) followed by copper (0.3343 +0.0527 mg/L) then lead (0.0973 +0.0067 mg/L) and finally chromium (0.0581 +0.0001 mg/L) as shown in Table 1. The concentration levels of Cd were below the detection limit of the instrument used. The above trend can be explained probably by the fact that Pb and Fe based products are generally more common than Cd and Cr products. Use of Fe and Pb containing products is more pronounced than Cd and Cr containing products. Of significance is that the concentration levels of Fe, and Pb were found to be higher than the EPA maximum contaminant levels (MCL) while those of Cr, Cd and Cu were lower. The EPA MCL for the metals are Pb – 0.015 mg/L, Fe – 0.3 mg/L, Cr – 0.1 mg/L, Cd – 0.005 mg/L, and Cu – 1.3 mg/L [18].

The concentration of Pb, Fe and Cu increased downstream (Fig. 2). This could be explained by the fact that dumping of solid waste (including metals) and effluents is pronounced at both mid-stream and downstream [19] as one approaches Kibera slum. Also, as the river flows through the slum it is likely that there is an increased disturbance of the river bed, a factor that will also lead to increase in the concentration levels of the elements [20]. The concentration of Fe was found to increase downstream as one approached Kibera slum. This was probably due to an increase in dumping [13,21] and a decrease in vegetation [22]. The concentration of Cr was found to be higher upstream than mid-stream. It is possible that some of the Cr were lost due to sedimentation [23]. Down the river, the concentration of Cr rose again so that it was lower midstream than at downstream which could be as a result of increased waste disposal into the river [13]. Cd was below the detection limit which is a probable indicator of limited cadmium pollution in the river and the region by extension. The increase in the concentration of the metals downstream could also be to increase in domestic effluents being discharged into the river [22,24] especially due to the presence of jua kali shades within the slum.

3.2 Nutrients

The concentration of the nutrients was found to be much higher than that of the metals with that of phosphates being highest (17.7752 ±1.8653 mg/L) followed by nitrates (16.4959 ± 2.4432 mg/L) and finally nitrites (5.7600 ± 4.0394 mg/L) as in Table 2. The comparatively much lower concentration of nitrites can probably be explained by the fact that nitrites are not very stable in the environment [25] and consequently most of them are converted to nitrates.

The obvious improper and unregulated disposal of domestic effluent and human waste from the Kibera slums into Motoine River can be used to explain why the concentrations of phosphates, nitrites and nitrates were much higher than the EPA standards for maximum contamination level of 1 ppm, 1 ppm and 10 ppm respectively [13]. The human activities alongside the river and the

Table 1. Concentration level of metals in water samples from Motoine River, September 2014

Analyte	Sample Concentration (mg/L)			
	Sampling point X	Sampling point Y	Sampling point Z	Average
Pb (n=3)	0.090 ± 0.005	0.101 ± 0.007	0.101 ± 0.008	0.097 ± 0.007
Fe (n=3)	0.250 ± 0.059	0.349 ± 0.061	0.371 ± 0.073	0.323 ± 0.065
Cr (n=3)	0.020 ± 0.001	0.019 ± 0.0003	0.019 ± 0.0002	0.019 ± 0.0001
Cd (n=3)	BDL	BDL	BDL	BDL
Cu (n=3)	0.273 ± 0.049	0.365 ± 0.050	0.365 ± 0.059	0.334 ± 0.053

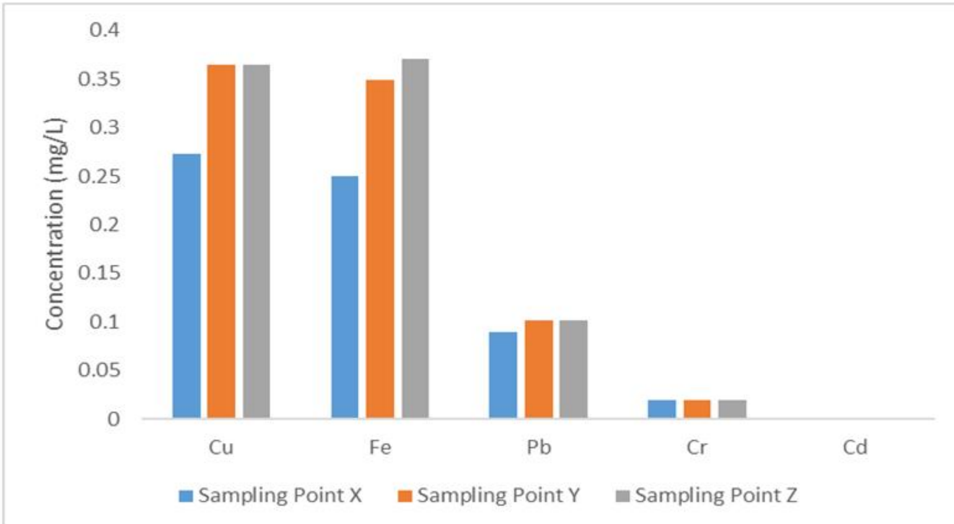

Fig. 2. Bar graph comparing the metal concentrations

Table 2. Concentration levels of various nutrients in water samples from Motoine River, September 2014

Nutrient	Sample Concentration (mg/L)			
	Sampling point X	**Sampling point Y**	**Sampling point Z**	**Average**
PO_4^{3-} (n=3)	15.906 ± 1.746	17.783 ± 1.897	19.637 ± 1.952	17.775 ± 1.865
NO_2^- (n=3)	1.615 ± 0.254	5.980 ± 1.344	9.685 ± 2.103	5.760 ± 4.039
NO_3^- (n=3)	14.133 ± 2.207	16.342 ± 2.512	19.012 ± 2.610	16.496 ± 2.443

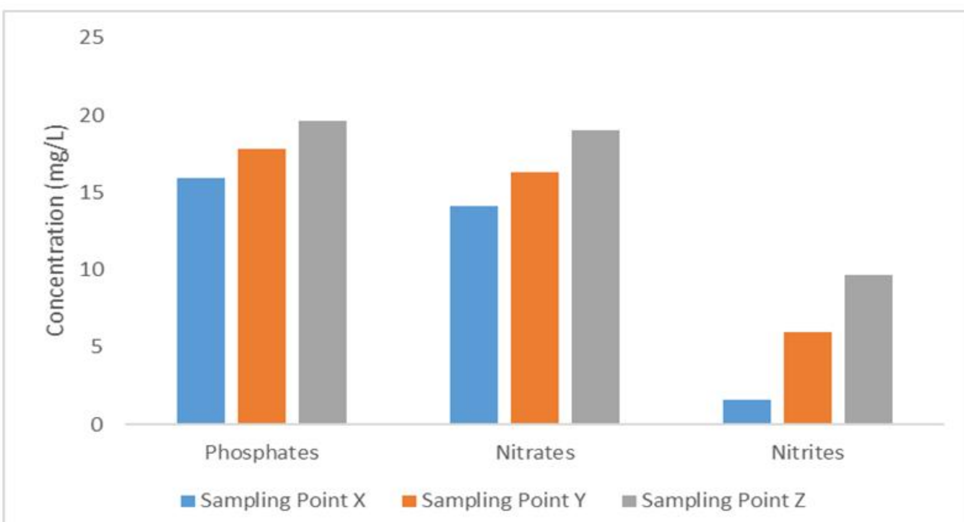

Fig. 3. Bar graph comparing the nutrients concentrations

activities of the organism within the river greatly influence the concentration of the nutrients [1]. For instance, the high concentration levels of the nutrients could be attributed to the use of phosphorus and nitrogen derived fertilisers and manures [26].

Table 3. Comparison of metal and nutrient concentration along the sampling points of Motoine River with other rivers in Nairobi City

	Point X	Y	Z	Nairobi river [30]
Pb	0.090	0.101	0.101	0.00117
Fe	0.250	0.349	0.371	0.0766
Cr	0.020	0.019	0.019	0.00147
Cd	BDL	BDL	BDL	0.00013
Cu	0.273	0.365	0.365	0.00296
PO_4^{3-}	15.906	17.783	19.637	-
NO_2^-	1.615	5.980	9.685	-
NO_3^-	14.133	16.342	19.012	0.487

It was also established that the concentration of the nutrients generally increased downstream (Fig. 3). This could probably be attributed to a decrease in vegetation downstream which implies fewer nutrients uptake by plants [24]. Additionally, with proper vegetation cover, the level of contamination of a river is likely to minimal while areas with disturbed vegetation showing elevated levels of the nutrients [27]. Also, down the river, as one approached Kibera slum, there was the increased dumping of both domestic waste and effluent [13,25] which accounted for the very high concentration of nutrients [23]. The poor sanitation facilities in Kibera slums [28] is also likely to increase the nutrient concentration due to surface runoff water finding its way to the river. Dumping of solid waste is serious at bridges and crossing points. Drainage systems within the slums have also become channels of domestic sullage from the unserviced informal settlements. These polluting outfalls have caused the water quality of Motoine to deteriorate further as it flows through Kibera into the Nairobi Dam [29].

Compared to results obtained from Nairobi River during the rainy season, the levels of the Pb, Fe, Cr and Cu at all the points sampled are generally higher. This indicates that the water from Motoine River is more polluted than Nairobi river thus poses a greater health hazard to the domestic users. Motoine River basin has been greatly invading by human activity thus the water volumes have gradually decreased. Due to increasing sources of pollution, the heavy metal loading is on the rise.

4. CONCLUSION

Due to the inadequate piped water supply in Kibera slum by the Nairobi water and sewerage company, alternative sources of water that are used by the Kibera slum residents include Motoine River. The concentration levels of the metals and nutrients were generally increasing downstream as the river flows through the slum towards Nairobi dam. For the metals, Fe had the highest concentration levels except for the upstream sample for which Cu had the highest. For the nutrients, nitrates were of the highest concentrations. Besides Cu, Cr and Cd, the concentration of the analytes was higher than the EPA MCL, which poses a threat to the residents using the water from Motoine River. Moreover, the study established that waters of Motoine River are more polluted than waters of Nairobi river. Therefore, some of the remedies that can be used to reduce the pollution include a clean-up of the river which would be very crucial in eliminating the solid waste that is present in the river bank. Establishment of stringent regulations on the use of phosphorus-based detergents and nitrogenous fertilisers would help in avoiding further increase in the phosphates and nitrates. Additionally, the prevalent poor sanitation effects in the slum area can be mitigated by adoption and encouraging the use of dry toilets that are already being used in some of the informal settlements within Nairobi. The use of dry toilets will ensure that pollution due to human waste is minimised. Furthermore, it would be beneficial if the government strengthened the implementation of various programs aimed at rehabilitating polluted rivers and adopting new ones such as payment for ecosystem services. Moreover, the ongoing recovery of riparian land will contribute significantly to the recovery of River Motoine and the Nairobi dam at large, which has been encroached. Finally, a behaviour change targeting waste disposal would greatly benefit the river. People need to be encouraged to dispose waste at designated points rather than dispose of the waste materials anywhere carelessly. This would eventually reduce the waste getting into the river.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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