WATER QUALITY PROFILE OF RIVERS NAVIGATING URBAN AREAS: CASE STUDY OF THE NAIROBI RIVER IN KENYA

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Abstract

This study analyses the spatial and temporal water quality variations, effect of settlement and effluent pollutants discharge, from industries in the Nairobi River, Nairobi Kenya. The Nairobi River is used for many anthropogenic purposes including small scale irrigation, industrial supply and domestic water supply. Sampling of this body was conducted during the wet and dry weather of May 2019 and July 2019 respectively. Water samples at different sampling locations were collected and analysed in The Technical University of Kenya-Organic/Inorganic Chemistry Laboratory. Physio-chemical parameters of the water i.e. pH, Temperature, Total Suspended Solids (TSS), Electrical Conductivity/Salinity (EC), Biological Oxygen Demand (BOD), Turbidity, Total Nitrogen and Total Phosphorus were analysed. Results obtained were subjected toone-way analysis of variance(ANOVA). Results were then checked against World Health Organisation (WHO)and NEMA- Kenya published standards and it was found that most parameters failed to meet the drinking water quality criterions. These include pH, Turbidity, TSS, EC, Total Nitrogen and Total Phosphorus which were found to have exceeded the maximum allowable limits by 4.6 %, 1275%, 504.2%, 12.2%, 72.35%, 25% respectively. This study recommends positive behavioural changes for the human settlements and Industries along this surface water body in order to maintain good water quality including improved infrastructure for waste management and various policy implementations that can be undertaken to avert any impending problems related to pollution of the Nairobi River.

Keywords: Nairobi River, Water Quality, Physio-chemical, Parameters, Policies

1. Introduction

Rivers are a major source of water used for human consumption, agriculture and industrial processes. Deterioration of river water quality is due to natural processes and anthropogenic activities through the disposal of industrial and domestic wastewater as well as surface run-off into the rivers. Rapid economic and social development in Kenya over the recent years has contributed heavily to river and other aquatic pollutions. Among other pollutions, water and environmental pollution remains a threat to human health, and therefore a major impediment to sustainable development.

Many rivers in Kenya and other sub-Saharan countries in Africa are heavily polluted due to human activities. The rapid development of industries has increased the quantity of industrial wastewater that end up in these rivers over the years since independence. Like any other third world country, Kenya still has poor infrastructural development and inferior technologies in handling waste managements and industrial effluent. Many industries discharge toxic and harmful wastes into the rivers. The pollutants are characterized by complex compounds which remain active for a long period making it impossible to reverse their effects. These industries are at infant stages as observed in the Jua Kali industry and therefore cannot afford the enormous investment required for pollution control and other mitigation measures. This causes an accelerated water quality change that impact negatively to the environment which in turn poses a key challenge that the country has to commit to handle through research, infrastructural development and policy framework formulation, (Karanja *et al.*,2014).On the other hand, increased anthropogenic activities combined with existing land use practices can increase pollutant loadings such as nutrients and microbes, into water bodies that then affect public health. Rainfallcan further accelerate pollutant load of the river water due to entry of storm water runoff from urban areas as well as from agricultural a activities. common practices in agriculture such as manure or fertilizers use and livestock grazing near the water bodies as witnessed along the Kiambiu areas increase pollutants levels in the water body. Although the entry of pathogenic organisms is a major concern, high nutrient loads can cause enrichment of water resources resulting in eutrophication. It has been reported that inflow rivers are the major contributors to eutrophication and algal blooming in the Nairobi river (Njuguna, 1979).

The main objective of the study reported here was to provide a comprehensive assessment of the Nairobi River water quality and estimate its relative level of safety in relation to internationally recognized standards for domestic water use, its pollution hotspots based on physio-chemical and nutrient concentration data through the application of multivaryable statistical approaches. The results obtained in this study identify pollution hotspots within the river for further monitoring and better management.

2.0*MATERIALS AND METHODS*

2.1 Study Area

This study was carried out in the Nairobi River, one of the rivers that serves as a tributary of the Tana river which drains into the Indian Ocean. Nairobi City where this river flows through stands at 1700 m above sea level with coordinates 1.2921° S, 36.8219° E. The Nairobi river Basin receives about 1,100 mm of rainfall with mean average temperatures of 17°C. (Foeken and Mwangi, 2000)

The Nairobi River emanates 20 kilometres west of Nairobi city in the southern extremity of the Aberdares (elevation 2074 m) and passes through the city receiving sewage, industrial effluent and urban runoff, (Njuguna, 1979). Nairobi River is heavy with both human and industrial waste. Garbage from surrounding markets including the Grogon and Gikomba Markets and informal settlements along the river bank (Kamukunji and Kiambiu) is being dumped into the river, thus compounding the pollution menace, (Ngumba*et al.*, 2016).

The following are details of water sample collection points;

a) Sampling point 1: Kariokor Bridge
Elevation: 1746m   Bearing: 1^0 16'02.71" S, $36^0$46'28.24" N
Flow characteristics: Fast flowing due to high gradient
Colour: Clear
Odour: Odourless
Main activities: Fetching water for watering plants and domestic use

b) Sampling point 2: Gikomba Bridge
Elevation: 1659m   Bearing: 1^0 16'44.22" S, $36^0$49'19.87" N
Flow characteristics: Moderate flow
Color: light Brown
Odour: Slight Odour
Main activities: Fetching water for car and cloth washing, Bathing directly into the water.

c) Sampling point 3: ShauriMoyo Bridge
Elevation: 1641m   Bearing: 1^0 17'13.53" S, $36^0$50'40.58" N
Flow characteristics: Slow flowing
Colour: Turbid
Odour: Heavy Smell
Main activities: washing clothes, washing of motorcycles, vegetable farming along the river.

d) Sampling point 4: Kariobangi Bridge
Elevation: 1604m   Bearing: 1^0 15'51.94" S, $36^0$52'46.03" N
Flow characteristics: Slow flow
Colour: Dark Grey and green patches of algae
Odour: Heavy Foul smell
Main activities: Disposal of solid wastes, cultivation of vegetable, Sheep farming.

2.2 Sample Preparation and Analysis

The approach of this study was to sample points along the river and establish how various water parameters change as the river flows through the City. The methodology involved; The Collection of Water Samples and Laboratory Experimentation on the samples collected. Water samples from each sampling point mentioned above were collected during the Dry and Wet Seasons of May and July respectively. Two sample from each sampling point was taken into a 500 ml bottles made of borosilicate glass that had initially been rinsed with deionised water and dilute hydrochloric acid. While collecting samples, the river water was used to wash these bottles again before collection. All bottles were filled and lids closed below the water surface during collection. All samples were then clearly labelled by the site of collection and dated.Ideal collection points were locations of lamina flow avoiding rapids and areas with fast water currents.

2.3Water Quality Analysis

In Kenya, Water quality is regulated by the Kenya Bureau of Standards (KEBS) and the National Environmental Management Authority (NEMA). pH, Temperature, Electrical Conductivity, Turbidity, *Kjeldahl* Nitrogen and Total Phosphorus concentrations in the samples were determined by the use of a calibrated electronic meters. pH and Temperature were measured on-site with pH 3310 SET 3 handheld meter instruments(WTW, 82262 Weilheim, Germany) and Conductivity was measured using a Cond 3310 SET 1instrument(WTW, 82362 Weilheim, Germany). 5-day Dissolved Oxygen values were tested at the CSI International Laboratory ltd-Kenya. This was then used to calculate the BOD_5. Total Phosphorus was determined using the molybdenum blue method. Total Nitrogen was determined by use of the uv-visible spectrophotometry method in which a standard curve was obtained by plotting the resulting absorbance vs. concentration and obtaining the concentration of the samples. Calibration curve was prepared by running different concentrations of the standard solutions. For all parameters, average values of three replicates were taken for each determination. Data obtained were subjected" to statistical analysis.

2.4 Analytical Quality Assurance

Appropriate quality assurance procedures and precautions were taken to ensure the authenticity of the results. Samples were carefully handled to avoid cross-contamination. Glassware's were properly cleaned and deionized water was used throughout the study. All the reagents used in the determination of turbidity, Total Nitrates and Total Phosphates were of analytical grade. In order to check the reliability of the analytical method employed for water quality determination, two samples were to confirm every result and average sample result obtained.

3. STATISTICAL ANALYSIS

The variations in physio-chemical and nutrient parameters across the sampling locations (spatial) and seasons were analysed by one-way analysis of variance(ANOVA). Only the data which was available for both wet and dry weather periods were used for statistical analysis. Physio-chemical and nutrient properties collected from all four locations during the two seasons were used for further statistical analyses to obtain average seasonal values and cumulative average values.

4. *EXPERIMENTATION RESULTS*

4.1. Sample Parameter Concentration

Result obtained from the determination of the properties of each parameter across the different sampling points along the Nairobi River Basin as it flows through the cities light industries and markets in Nairobi County, Kenya are as shown in Table 1. Table 2 shows the Average and cumulative average values of obtained from both the wet and dry weather values in Table 1.

Table 1: Results Obtained from Analysed Water Samples

Date	Sample Station	Temp °C	pH	EC (µs/cm)	BOD (mg/l)	Turb (NTU)	TSS (mg/l)	Total Nitrogen (mg/l)	Total Phosphorus (mg/l)
23/05/2019 (Wet weather Sampling)	1	18.87	6.9	765	4.23	89	270	0.956	0.1820
	2	19.25	6.5	975	4.57	45	230	1.095	0.5580
	3	19.20	6.1	1261	4.90	50	197	1.952	0.9670
	4	19.55	5.9	1683	5.43	52	180	2.001	1.0910
06/07/2019 (Dry Weather Sampling)	1	19.02	6.2	783	3.12	31	190	1.813	0.1580
	2	21.25	6.5	842	4.15	49	150	2.095	1.3696
	3	22.30	5.1	1095	4.65	54	158	2.943	1.5921
	4	22.45	5.9	1551	4.98	70	75	3.447	2.5156

Table 2: Average of Wet and Dry Season Water Samples Analysed Parameters

Weather Condition	Sample Station	Temp °C	pH	EC (µs/cm)	BOD (mg/l)	Turb (NTU)	TSS (mg/l)	Total Nitrogen (mg/l)	Total Phosphorus (mg/l)
Average Wet and Dry Weather Condition	1	18.95	6.6	774.0	3.67	60	230.0	1.3845	0.1700
	2	20.25	6.5	908.5	4.30	47	190.0	1.5950	0.9638
	3	20.75	5.6	1178.0	4.77	52	177.5	2.4475	1.2796
	4	21.00	6.0	1617.0	5.20	61	127.5	2.7240	1.8033
Cumulative Average		20.24	6.2	1119.4	4.49	55	181.25	2.0378	1.0542

5.*DISCUSIONS*

During the wet weather of May, lower temperature values (< 20°C) were observed as seen in Table 1. This season was characterised by cloudy conditions hence the amount of solar radiation penetrating such atmospheric conditions is limited. The wet weather to dry weather fluctuation stood at 0.79% decrease for point 1 and further reduced at 9.4%, 13.9%, and 12% for point 2, 3 and 4 respectively. High temperatures in the river is responsible for the destruction of aquatic communities. It also interferes with the water purification process that break down organic matter. Temperature is a highly non-linear parameter in space and time, therefore minimal standards are applied for domestic use.

The pH of the river water obtained is found to be between 5.9 to 6.9 (< 8.5) confirming the that the river water is acidic. At point 1, the average river water pH value stands at 6.6. The increase in pH values at point 2 and 4 was attributed to intensive washing of clothes and vehicles directly into the river as detergents are usually alkaline. Most detergents are usually made of sodium hydroxide (an alkali) and alcohols. This neutralises the acidity raising the pH at these points. From the field observations, it was noted that most of the washing was carried out just before point 2 and 4, i.e. Grogon market sampling point and the Kiambiu Slums sampling station. The wet season recorded slightly higher values of pH as compared to the dry season for sampling points 1 and 2. During wet season, there is increased surface run off into the river. This runoff may contain dissolved alkalis increasing the pH of the river water.Significant statistical differences inpH were observed ($p < 0.5$) with little spatial variation was observed.

The values for Total Suspended Solids (TSS)obtained ranged from 75 mg/l to 270 mg/l. The concentration of suspended solids (>20 mg/l) decreases downstream. This phenomenon can be attributed to increased turbulence upstream with the flow transitioning to lamina flow downstream. Point 1 values were the highest at 190 mg/l and 270 mg/l for the wet and dry weather respectively as this section is upstream where the river is in its youthful stage characterised by turbulence that erodes and carries surface runoff. The general increase in the value of TSS for the wet weather compared to dry weather can be attributed to increased erosion and surface runoff during the wet weather. Most of the solid wastes in the city markets find their way into the Nairobi River especially during the wet season increasing the number of suspended solids. High variations of values were recorded at the final sampling point downstream of the Kiambiu bridge. This is because here the flow is lamina with little or no turbulence and minimal disturbance from human activity especially during the dry season. However, storm water from the slums, drainage systems and surrounding small scale farms increased the concentration of suspended solids. Suspended solids in water are significant as they hold a lot of organic matter. If organic matter increases, putrefaction will occur and the river will become devoid of oxygen. However, suspended organic matter forms sludge banks when they settle hindering aquatic life. The Nairobi river shows little sign of harbouring aquatic life within the sample area.

The average values of Turbidity (Turb) increased from 60 NTU at to 61 NTU at point 4 (<100 NTU). This is as a result of increased solid pollutants and organic matter in the river water downstream. However, the preceding points recorded lower values during wet weather sampling as the coagulated wastes have settled due to the low lamina stream flow. The wet period showed lower turbidity opposed to the dry period except at point 1 where the river is rapid and collects a lot of suspended solids and organic load influx. However, during the dry weather, the water is nearly clear with little or no interference. This results in the huge variation of values at this point.

The average values of BOD_5 increased downstream from 3.67 mg/l at point 1 to 5.20 mg/l at sampling point 4 for the dry weather samples. This is due to increased levels of organic load downstream increasing the oxygen demand for oxidation of the organic matter.Point 1 indicated minimal values as the river water has not been interfered with by anthropogenic activities. However, organic matter in form of leaves and branches may contribute to the significant values at this point. Also, the river generally flows from the western part of the city where sanitation systems are more developed hence little organic loading. Domestic wastewater flowing by the sides drains of the roads in the city as seen at the Gikomba market and the Kiambiu slums ultimately finds its way into the river. Faecal matter as noted during the field sampling also contributes to the organic loading. The dark grey colour of the river is due to high concentrations of organic wastes. The wet weather recorded lower values of BOD_5 for all the sampling points. This was due to increased volume of river water during the wet season lowering the concentration of organic wastes due to dilution effect. The wet season was also associated with low temperatures reducing biological activity hence lower values.

The average wet and dry weather values of Electrical Conductivity(EC) increased downstream from 774 µs/cm at point 1 to 1617.0 µs/cm at sampling point 4. Sampling point 2 recorded a value of 1178µs/cm. At point 1, there is little interference due to little river encroachment hence lower discharge of ions responsible for electrical conductivity. Downstream to sampling points 2 and 3, increased human encroachment to the river increases pollution as materials containing ions are discharged into the river. Such chemical compounds could be from soaps and detergents used for washing clothes, cars as seen along the Grogon area. Discharge from failing sewer systems could introduce these chloride, nitrates and phosphates too. Additionally, contamination by chemicals from fertilizers downstream as a result of the small-scale farming activities as seen along Kiambiuareas add to inorganic matter. The wet weather has a dilution effect on the EC levels allowing ions to move freely. Hence, dry season EC levels were slightly lower than wet season EC levels.

Total *Kjeldahl* Nitrogen (TKN) levels increased downstream on average. Point 1 had a value of 1.3845 mg/l (>1mg/l). Sampling point 1 recorded the lowest value of 1.5950 mg/l while points 3 and 4 had 2.4475 and 2.7240 mg/lrespectively. The value of point 1 upstream was low as there were no major anthropogenic activities that contribute to nitrogen concentration. Higher Nitrogen levels were recorded at sampling point 3 and sampling point 4 as the market and small-scale farming activities around these areas discharged effluent to the river.

The average values of Total Phosphorus (TP) obtained generally increased downstream from 0.1700 mg/l to 1.8033 mg/l at point 1 to point 4 respectively. Point 2 and 3 recorded 0.9638 and 1.2796 mg/l respectively. The wet weather recorded lower Total Phosphorus levels as shown in Table 1. This is due to dilution effects by the increased flow during the wet season. High phosphorus concentrations in the river water may be due to ions from natural minerals in the area i.e. river streambed with salt containing minerals since the river originates from a spring. However, increased concentration downstream was due to pollution by faecal matter or run off farms as seen in the Kiambiu where fertilizers are used, and sewerage discharge.

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Figure 1: Polluted Sections of the Nairobi River Burdened with Solid Water Pollutants

5.1 Pollution Profiles

The spatial-temporal distribution of the average water quality across the different sampling points in the study area are as shown in Figure 2 and Figure 3.

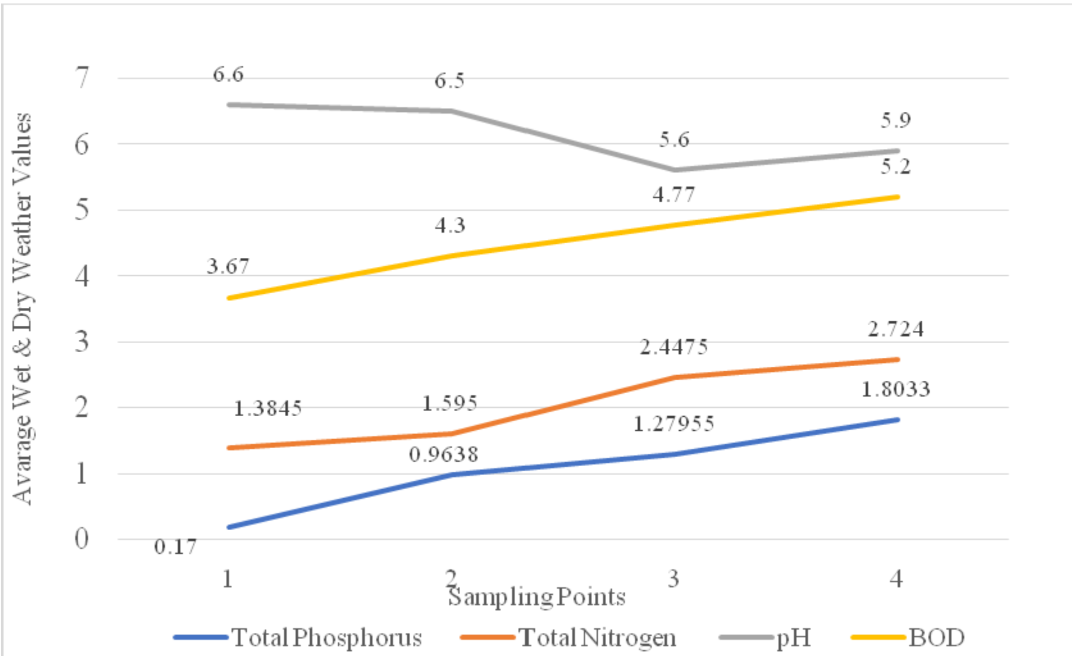

Figure 2: Spatial Distribution of the Average concentration of Total Phosphorus, Total Nitrogen, BOD and the

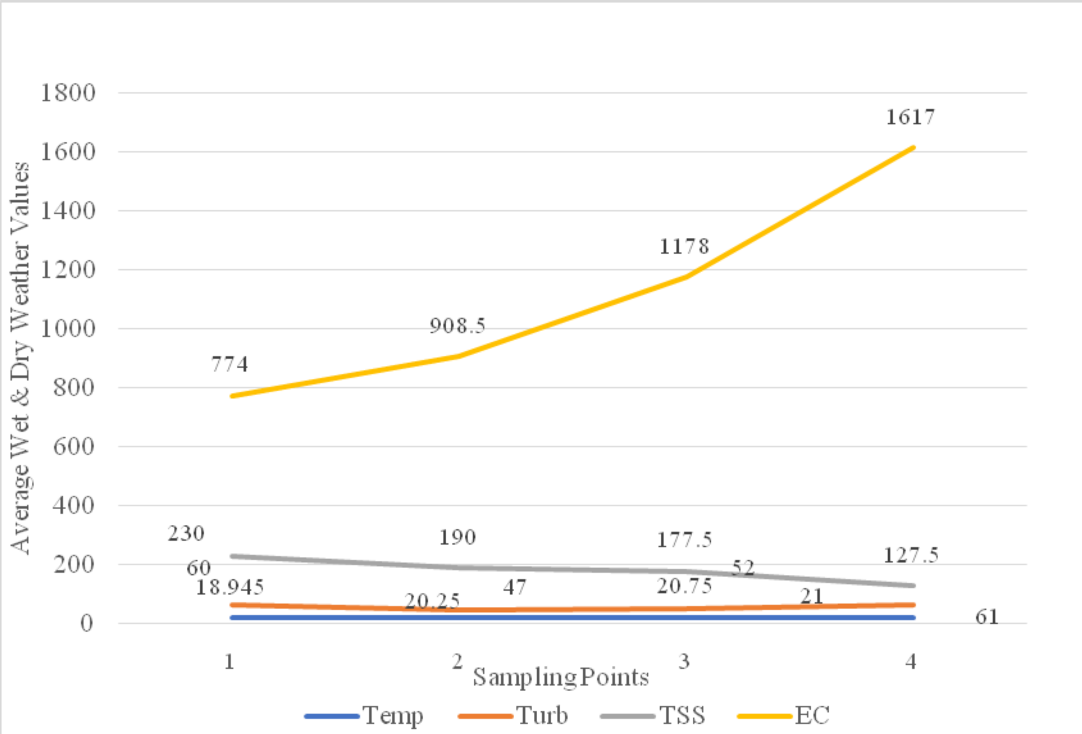

Figure 3: Spatial Distribution of the Average concentration of Temperature, Turbidity, Total Suspended Solids and Electrical Conductivity

5.0*CONCLUSION*

The study determines that the physio-chemical properties of the water samples tested generally increased as the river flows downstream. It is noted that pH, Temp, Turbidity, TSS, EC and BOD_5 are the major parameters that are responsible for pollution according to the scope of the study. These exceeded maximum allowable limits by 4.6 %, 1275%, 504.2% and 12.2% respectively. A steady increase of nutrients (Total Nitrogen and Total Phosphorus)was observed as the river flows downstream which increased by67.5% and 9.6% respectively within the study area. The market areas and small-scale farming activities within the study area significantly increased the pollution loading in the river.The nutrients quantity varies with the type of land-use, economic activities and industrial discharge where nonpoint source senter the Nairobi River. The entry of wastes into this river from nonpoint sources was observed in several locations during sampling activities. These wastes negatively affect the Nairobi River water quality. The elevated levels of nutrients contribute to eutrophication that is evident from the presence of high concentrations of Algae and floating plants evident in locations downstream.By visual inspection the colour of the river gradually changes from clear to dark grey colour accompanied by foul smell. Further research is recommended to collect a wider pool of information such as heavy metals, chloride, Nitrates, Fluoride and Bacterial analysis including more sampling points during both rainy and dry season and regular sampling over a minimum period of two years.

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