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Changes in water quality parameters along Thika river sub-catchment, Upper Tana, Kenya

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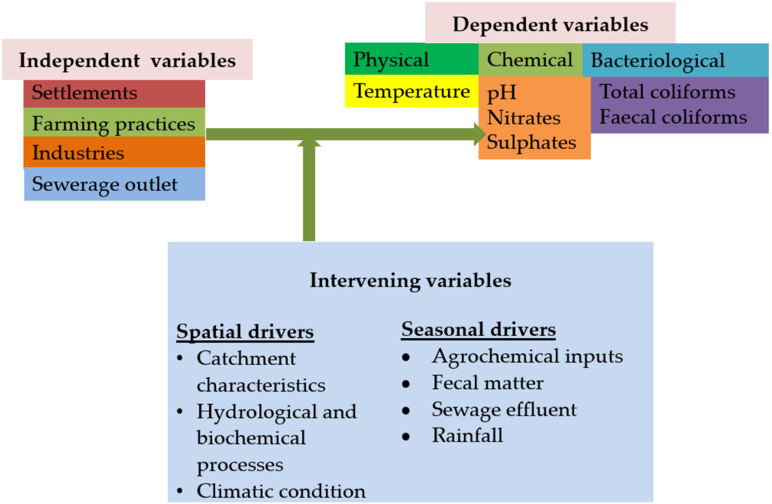
GRAPHICAL ABSTRACT



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ABSTRACT

Surface water pollution is a challenge due to effluent discharge from land-based factors like agro-based sectors, settlements, and poor sanitation. The research investigated the spatial and seasonal variation of physico-chemical and biological water quality due to land use changes along the Thika River sub-catchment, Upper Tana, Kenya. The study applied purposive sampling technique from the different zones within the catchment during the dry and wet season of 2021. The samples were tested for physico-chemical and microbial contaminants. R-studio was used to calculate the mean values and t-test performed at a 95% confidence interval to determine variation of the parameters in the two seasons and mean levels compared to the Kenya Bureau of Standards (KEBS) 2010 and the World Health Organization (WHO) acceptable quality for drinking water. There was significant variation in sulphate and nitrate concentration, total coliform and fecal coliform and no significant variations in physical parameters throughout the seasons. The total coliform and fecal coliform exceeded KEBS and WHO limits.

1. Introduction

Anthropogenic and climatic stressors significantly affect surface water resources globally. Lack of access to safe drinking water affects about 20% of the global population causing 3 million and a billion waterborne related deaths and illnesses, respectively (David, John, and Bonface, 2017).

Developing countries in sub-Saharan Africa have the lowest access to drinking water and rural areas are mostly affected due to poor sanitation and inefficient waste management systems (Bwire *et al*., 2020). About three-quarters of the cities in Sub-Saharan Africa draw about half of the public water supply from surface water sources (United Nations World Water Assessment Programme, 2015). These are mostly from rural landscapes that are affected by unplanned development and poor land management practices (TNC, 2016). Africa's urban population is likely to double in the next 20 years implying that one out of five (5) people in cities that rely on surface water supply will face water scarcity (Ondigo, Kebwaro, and Kayoo, 2018).

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Scarcity of freshwater is widespread challenge in Kenya considering the present supply of 400m^3 compared to global benchmark of 1000m^3 per capita renewable freshwater supplies (Njuguna *et al.,* 2020). Ondingo *et al*. (2018) noted that only 56% of the population have access to clean water, but contaminants from point pollution reaches alarming levels during dry seasons because the streamflow is extremely low (Kithiia, 2007). Insufficient sanitation and industrial contamination of the freshwater sources means that only a fraction of freshwater is accessible (Onywere *et al*., 2007). Discharge of untreated or inadequately treated wastewater and agrochemicals into rivers cause contamination (Githinji, Mwaura, and Wamalwa, 2019). The Tana River Basin contributes 33.5% and 23.8% of surface water and groundwater in Kenya respectively (Njuguna *et al*., 2020). The catchment provides close to 90% of water to Nairobi and the surrounding settlements through Thika and Githika rivers (Sang and Maina, 2018). Land occupied by settlements and farms increased 26.35 per cent and 32.57 percent respectively and at the same time bare land, water resources and vegetation decreased by 35.9 per cent, 3.13 per cent and 8.29 per cent respectively over the last three decades (Langat *et al*., 2021). Specifically, up to 5 million people reside in Upper Tana catchment; 98% of inhabitants grow both cash and subsistence crops (TNC, 2015: Njogu and Kitheka, 2017).

The river also traverses through settlements, commercial and small-scale farms that increase vulnerability to pollution from surface run-off. The pursuit of Sustainable Development Goal (SDG) six (6) target on leaving no one behind in sanitation and water access demonstrate that demand for freshwater will continue to increase due to ever-increasing population and growing lifestyles and consumption patterns (Sila, 2019). Therefore, to understand the nexus between water quality and land use effects, the study examined the spatial variation of physico-chemical and microbial water quality parameters and seasonal variations in physico-chemical and microbial water quality of water in Thika river sub-catchment. This study recommends further research on land use change trend in the region and how it has affected quality and quantity of surface and ground water.

2. Methodology

2.1. Area of study

Thika river sub-catchment in the Upper Tana Basin spans an average of 839 km^2. It is located between longitude 36.60º and 37.60º E and latitude 0.58º and 1.17º S as per Fig. 1. The watershed is situated in the southeastern edges of the Aberdare Mountain Ranges/Escarpment and adjacent to Gatare Forest. The predominant soil types in the region are histols and nitisols (Benedict, Khaldoon, and Omondi, 2018). The upper area covers the main catchment including the Aberdares forest reserve, Nyayo Tea Zone, and the influential river zones. Upstream area (Ndiara sampling station) was close to Aberdares Forest and characterized by large cash crop farms, mostly coffee and tea plantations, the Ndiara Shopping center, and coffee factory. The built area included homes and other settlement structures.

The mid-stream is characterized by steep topography and smallholder farms. It consists of settlement areas, and tea growing farms. Midstream area (Kimotho sampling station) had large tea plantations, the K24 tea collection center, built areas/homes, and Kimotho Primary School. Residents of Kimotho practiced small-scale farming, extending to the riverbanks. The lower section is where the water is dammed to contain the main water mass and it borders settlements and small farms. Downstream area of the sub-catchment (Wanyaga sampling station) was characterized by mixed land use namely Wanyaga shopping center, a dispensary, settlements, smallholder subsistence farms, eucalyptus plantations, Wanyaga primary school, and bare soil. Thika River Catchment experiences a bimodal rainfall pattern with an average of between 2000 - 2500 millimeters per year (Benedict, Khaldoon, and Omondi, 2018). March to May is typically occasioned by long rains while short rain season occur from October to May. The average minimum temperature and maximum temperatures are 12ºC and 25ºC respectively (Benedict, Khaldoon, and Omondi, 2018).

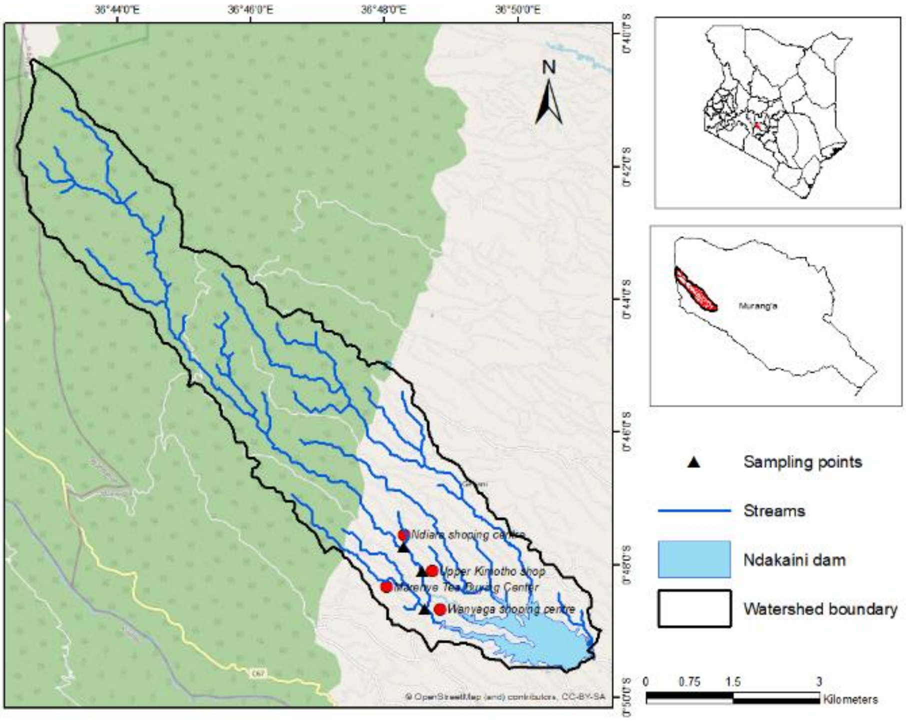

Fig. 1. Map of study area, Thika river sub-catchment (Source: topographic sheet for Mangu (134/4) and google maps satellite image 2021).

2.2. Study design

The study adopted both field survey and laboratory-based procedures summarized in Table 1 to generate quantities of physico-chemical and microbial parameters to determine the influence of the human activities both in dry and wet seasons. The study area was zoned into upstream, midstream, and downstream.

2.3. Study design

Purposive sampling was utilized to take water samples in upstream (near Thika Valley/Ndiara), midstream (Kimotho) and downstream (Wanyaga) as shown in Fig. 1. Sampling was undertaken in wet and dry seasons to examine the physico-chemical and microbial variations along the river. Sample collection for wet and dry season was conducted in July and December 2021 respectively following the standard guidelines described by the American Water Works Association (AWWA) 2014. A total of thirty-six (36) composite water samples were collected in clean bottles using water sampler and stored in cooler box for transportation to the laboratory. In each sampling session, compositing included collecting three (3) water samples into a clean bucket, mixing, and then taking about 500 ml of each sample for laboratory analysis. Both seasons were sampled in the morning specifically between 9 – 11 A.M.

2.4. Laboratory analysis

500 ml plastic bottles for sample collection were cleaned with dilute hydrochloric acid and thereafter dipped in distilled water two times. Before sample collection, the plastic bottles were cleaned three times with water from the corresponding station. To stop the analytes from vaporizing and degrading, bottles containing water samples were corked, kept in a cool box with ice, and transported to the lab. There, they were kept in a refrigerator at a temperature below 10°C. The American Public Health Association (APHA), 2005, and the American Water Works Association (AWWA), 2014 protocols were used to analyze the chemical and biological parameters. In order to prepare solutions and rinse all equipment after testing each sample, distilled water was used. All the equipment were calibrated according to the manufacturer's instructions before analysis. The field and laboratory analysis for each parameter are as per Table 1.

Table 1. Summary of field and laboratory analysis methods.

Water quality parameter	Method
Nitrates	UV-visible spectrophotometer
Sulphates	UV-visible spectrophotometer
Total coliform and faecal coliform	Defined substrate technology/ Colilert test
Turbidity	In situ (Turbidity meter)
pH	In situ (portable electronic pH meter)
Temperature	Insitu
Total suspended solids (TSS)	RGS

*RGS – River Gauging Station data

Water quality parameters were analyzed with reference to guidelines for drinking water quality by the World Health Organization (WHO) and Kenya Bureau of Standards (KEBS) vis-à-vis land uses shown in Table 2.

2.5. Statistical data analysis

The samples were collected from an area characterized by homogeneity of variance. Therefore, the collected data was analyzed using R and R studio; a programing statistical software for data analysis version 4.2.1. Analysis of variance (ANOVA) was utilized to assess differences of the physio-chemical parameters. The significance of difference was checked against an alpha value of 0.05. The measure of significance was the t-test probability value against a value of 0.05 which translates 95 % confidence. The significance was established and recorded in terms of the p value. The physico-chemical parameters included temperature, pH, turbidity, total suspended solids, nitrates, and sulphates taken during different seasons and stations or points. Differences in the physico-chemical parameters in seasons and stations were determined and recorded in terms of their means and standard errors; bar charts/graphs were used to visually display the differences of the parameters in the different sampling stations and seasons.

Table 2. Summary of drinking water quality standards by KEBS and WHO.

Parameter	Unit	KEBS	WHO
pH	pH scale	6.5-8.56	6.5-8.5
Turbidity	NTU	5 max	5 Max
Temperature	°C	12-25	12-25
Sulphate	Mg/l	400	250
Nitrates	Mg/l	10	50
TSS	Mg/l	0	0
Fecal coliform	CFU/ mL	Null/100ml	Null
Total coliform	CFU/ mL	100	Null

Source: Cotruvo (2017); KEBS

3. Results and discussion

3.1. Spatial variation of physico-chemical and microbial paramters

Summaries of range, mean values and standard deviation of variables measured in Thika sub-Catchment water samples collected at three different sub-stations; Thika Valley/Ndiara, Kimotho and Wanyaga were collected, analyzed, and documented to achieve this objective. The laboratory analysis of the water samples indicated significant statistical findings based on characteristics of stations or space variations along the Thika river sub-catchment.

3.1.1. Temperature

The temperature values were upstream 14.93 ± 0.43, midstream 14.97±0.34 and downstream 14.27±0.19. The values were determined to be within acceptable limits for drinking water standards of 12 – 25 °C by both the WHO and KEBS. There was no significant variation (p value = 4) as shown in Table 3.

Table 3. Spatial variation of temperature.

Temperature	Downstream N=12	Midstream N=12	Upstream N=12	p-value
Mean (SD) ± std. error	14.27 (0.64) ± 0.19	14.97 (1.18) ± 0.34	14.93 (1.48) ± 0.43	0.4
Range	12.79 – 15.00	13.27 – 16.90	13.75 – 18.33	

Variation in surface water temperature was influenced by persistence of human alteration of natural system and disturbances, through deforestation, discharge of wastewater and damming. The slightly high temperature recorded in midstream could be linked to impact of mixed development activities like wastewater and storm water and agricultural runoff.

The findings were consistent Wilson Michieka and Mwendwa (2021) finding that inflow of storm water and wastewater alter the temperature characteristics of the riverine water. Shah and Joshi (2017) emphasized that coagulation is dependent on temperature and that it affects every aspect of the chemical characteristics, treatment, and the delivery of potable water. In addition, the solubility of oxygen in water decreases with an increase in temperature thereby affecting metabolic rate, reproduction and growth of bacteria that breaks down organic matter (Shah and Joshi, 2017). The level of biological activities and biodegradation increases with rise in temperature thereby affecting oxygen demand. Equally, rates of chemical reactions, especially on chemical treatment plants decrease with decreasing temperature.

3.1.2. pH value

There was a stable upstream to downstream pH trend. The pH reduced slightly downstream namely upstream 6.82±0.13, Midstream 6.23±0.18, and Downstream 6.16±0.15 all within KEBs and WHO permissible range of 6.5 to 8.5. There was significant variation (P value = 0.009) in the average values as shown in Table 4.

Table 4. Average spatial variation of pH in Thika sub-catchment.

pH	Downstream, N = 12	Midstream, N = 12	Upstream, N = 12	p-value
Mean (SD) ± std. error	6.16 (0.53) ± 0.15	6.23 (0.61) ± 0.18	6.82 (0.46) ± 0.13	0.009
Range	5.47 – 7.05	4.71 – 7.07	5.77 – 7.51	

It was discovered that human activities greatly influenced the pH quality. The downstream and midstream sections of the river were slightly acidic with range of 5.47-7.05 and 4.71-7.07, respectively. This suggests that human activities and the inexistence of proper sanitation facilities, to a large extent enhance leakage of human and animal wastes into the river. The situation in the downstream could be attributed to the accumulation of nutrients runoff from the cash crop farms, the industries and the surrounding populations. The downstream section comprised settlements, but with no structured sanitation and sludge management and treatment system. The upstream section had a relatively stable and low pH value considering that it is close to the Aberdares forest, and the area has minimal disturbance or runoff.

These findings are consistent with Abowei (2010) findings that lower pH values are attributed to the outcome of human activities, for example, decay of domestic and industrial waste litter contributes to the acidic nature of water. Equally, Njue *et al.,* (2016) indicated that variation in mean pH between midstream and downstream is often influenced by land use, soil and other activities that influence composition of major ions in water bodies. The variation is also affected by quantity decomposing organic matter, declining vegetation cover and oxidation of soil organic matter due to continuous cultivation along riverbanks.

3.1.3. Total suspended solids (TSS)

The average concentration of TSS are shown in Table 7, all these values were above the recommended KEBs and WHO values of zero (0) Mg/l. There was no statistically significant variation in the average values of TSS at the different stations (p value = 0.018) as shown in Table 5. The quantity of total suspended solids depends on the rate of infiltrations, stream flow, and related phenomena like erosion and surface run off. The potential key drivers for the elevated TSS comprised human activities like smallholder agriculture along the riverbanks and large-scale commercial farming in coffee and tea plantations. These establishments potentially loosen the soil making it susceptible to run-off and nutrient leach to the river. In addition, human activities alter the natural stream flow components like dissolved and suspended content of the water along the river profiles.

Table 5. Average values of TSS.

Total suspended solids	**Downstream, N = 12**	**Midstream, N = 12**	**Upstream, N = 12**	**p-value**
Mean (SD) ± std.error	20 (30) ± 9	22 (9) ± 3	12 (9) ± 3	0.018
Range	3 – 112	10 – 43	4 – 30	

High TSS increases water temperature and decrease natural dissolved oxygen level in water. In addition, TSS in drinking water can affect human health, depending on nature of suspended particles, for example, algae and bacteria are often linked with occurrence of gastrointestinal complications (Ogendi *et al*., 2015). Other particles like sand and silt clog pipes, plumbing fittings, and water-based appliances and cause siltation of the dam/reservoir.

The results resonated with previous findings that average variations in total suspended solids are often caused by natural events, including presence of algae, silts, and sediments. Noori *et al.* (2010) pointed out that TSS originate from the chemical, biological and physical characteristics of rivers comprising microorganisms, silt, and fine inorganic and organic matters and algae. High levels are often detected in areas with increased human activities like industries, domestic waste, agricultural practices (Mekuria, Kassegne, and Asfaw, 2021). Ogendi *et al*. (2015) found out that spatial differences in TSS are attributed to human activities which in his study included re-suspension of silt from dumped construction sites soils, leaked sewage materials and course and fine organic particulate matter from the organic wastes. Equally, Ly, Metternicht, and Marshall (2020) found out that TSS decreased as a river traversed from the upper part of a basin due to associated land use changes. An increase in TSS can disrupt the natural processes of self-purification in river water.

3.1.4 Nitrates

Concentration of nitrates in upstream area was 11.13±3.1 mg/L, midstream area 5.54±0.21 mg/L, and downstream area 6.37±0.55 mg/l as portrayed in Fig. 2. The nitrate levels were within the permissible WHO and KEBs standards of less than 10 mg nitrates N/L. However, slightly higher levels above the permissible KEBs and WHO standards were observed in the upstream. There were no statistically significant changes in the concentration of nitrates (p value=0.5).

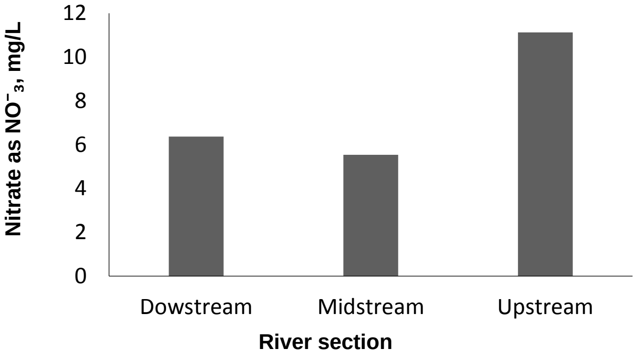

Fig. 2. Spatial variation of nitrates concentration.

Nitrates originate from both natural and human sources. However, high levels are often recorded in streams adjacent to agricultural activities and mostly associated with over application of nitrogen-based fertilizers and animal manure. Nitrate is highly soluble and excess components.

The values were reflective of the activities including tea and coffee plantation where farmers regularly apply fertilizers. Nitrogenous fertilizers are often used in large farms to enhance productivity as witnessed in the large-scale farming of tea and coffee in the Thika Valley. Excess nitrates can accelerate eutrophication and changes in aquatic flora and fauna which in turn affects temperature, and dissolved oxygen. This can present a serious public health especially for infants as it is a risk factor for methemoglobinemia or blue baby syndrome.

The study results were similar Nyilitya *et al.* (2021) findings that discharge in the Nyando Basin varied spatially because of the intensive land use patterns. Ontumbi, Obando, and Ondieki (2015) identified that nutrient levels were low in areas with low crop cultivation. Agriculture is one of the single largest of nitrogen to surface water. Nitrate concentrations increase as the land use devoted to agriculture increases.

3.1.5. Sulphates

The concentration of sulphates in the upstream was 215 mg/l, midstream 282 mg/l and downstream 286 mg/l as shown in figure 3 compared to permissible standards by KEBS and WHO of 400mg/l and 250 mg/l respectively.

There was no significant variation in the concentration of sulphates along the river profile (p value = 0.4). This implied that the populations living within this sub-catchment engage in agriculture in almost every segment of the region. While the upstream engage in large scale farming, water from these areas moves with dissolved Sulphate ions downstream, spreading the pollutants to other parts of the river. In return, the water becomes evenly polluted over time across all stations.

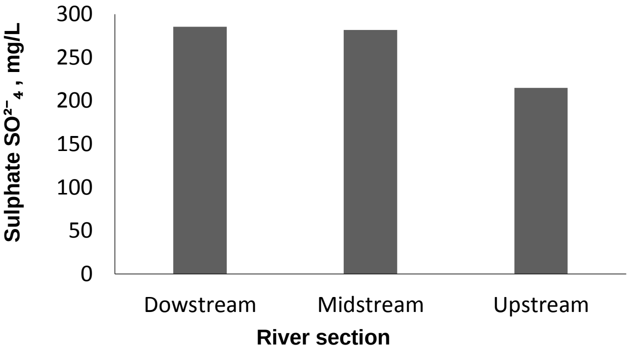

Fig. 3. Average concentration of sulphates.

The variation in concentration of sulphates in surface water is a common occurrence in rivers that traverse agricultural fields and settlements. Run-off transport dissolved Sulphate ions downstream, spreading the pollutants to other parts of the river. In return, the water becomes evenly polluted over time across all stations.

The findings were similar to Ondoo *et al.* (2019) study that agricultural activities contribute more nutrients to the surface water. Water quality variance is also dependent on the background, morphology and human related contagion including domestic wastewater, agricultural runoff, or industrial wastes. Equally, Kambwiri *et al.* (2014) found out that concentration of sulphates along the Ruo River was affected by land uses, with significant variances between estate farmer's land use and the rest of the sections. This can be attributed to higher application rates of sulphate rich fertilizers like ammonium sulphate, single super phosphate, muriate of potash. Even though the research did not capture the types of fertilizers applied in the area, it was assumed that sulphate rich fertilizers are often applied in smallholder farming as witnessed in many parts of downstream stations. Therefore, there is need for improving environmental knowledge of host communities and engage them to design interventions to address contamination (Dehghan, Karami, and Yazdanbakhsh, 2021).

3.1.6. Total coliform

There was relatively similar pattern or near similar levels in total coliforms in the upstream, midstream, and downstream as shown in Fig. 4.

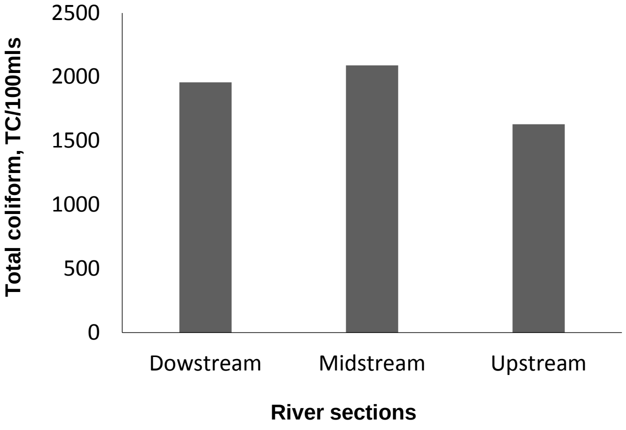

Fig. 4. Average concentration of total coliform in water.

The amount of total coliform was recorded as 1,959 (835) ± 241 for downstream, 2,089 (603) ± 174 for midstream and 1,630 (870) ± 251 for the upstream. These values surpassed permissible standards by KEBs 100 CFU/ml and WHO of zero CFU/ml. However, there was no statistically significant variation in the average concentration of total coliform (p value= 0.3). These findings indicated that the river was evenly contaminated across the river profile.

These visible differences indicated the impacts of anthropogenic activities, specifically, lack of a functioning and efficient wastewater, sludge, sewage wastes and other organic wastes. Moreover, WHO recognizes that animal and human wastes have the greatest risk in water contamination, with high infectivity rates when consumed in contaminated water. Nouri and Montazer Faraj (2022) also noted that microbial parameters can enter surface water through fecal matter and can cause significant risk to human health.

3.1.7. Fecal coliform

Fig. 5 shows that the highest concentrations of feacal coliform were recorded in the downstream compared to the midstream and upstream. The average concentration of faecal coliform was recorded as 315 (523) ± 151 at the downstream region, 99 (104) ± 30 midstream and 104 (63) ± 18 the upstream areas as shown in Table 3 and depicted in Fig. 5.

However, there were no significant variations in the amount of fecal coli in all sampled stations (p value = 0.3). Catchment characteristics have a direct influence on the indicator bacterial counts including total coliform and fecal coliform. The protected land upstream had the least contamination compared to sections of the river that traversed agricultural land and built-up environment. A similar trend was observed in the Thika River study indicating that surface run-off is a carrier of sediments, agricultural waste and bacteria that cause undesirable impact on the water quality.

This is consistent with Ibekwe, Ma, and Murinda (2016) findings that the occurrence of the microbial bacteria increases near an urban environment or an area with large population with no effecting sewage treatment. A study by Waithaka, Murimi and Obiero (2020) found out that concentration of microbial contaminants in River Ruiru were attributed to discharge of raw sewage and run-off farm agricultural land, built areas and storm water. According to Ontumbi, Obando, and Ondieki (2015) microbiological contamination in the Sosiani river was caused byland use activities and development in the watershed.

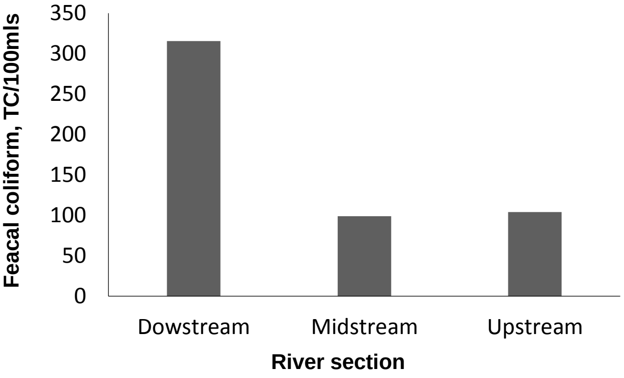

Fig. 5. Quantity of fecal coliform.

3.2. Seasonal variations of physico-chemical and microbial water quality

The section contains the summaries of range, mean and standard deviation in the quantity of physico-chemical and microbial water quality parameters along the river profile over the dry and wet season. Considering the dry season of June - July and the short rain seasons of November-December, the research focused on the temporal variations in quality across various sub-stations in the study area. Using critical value of 0.05, the research sought to test the null hypothesis, which stated there were no significant difference in seasonal variations in physico-chemical and microbial water quality parameters in Thika River sub-catchment.

3.2.1. Turbidity

The average turbidity values in dry season were 1.56±0.04 NTU and 2.48±0.19 NTU in the rainy season. The turbidity levels were within the permissible WHO and KEBS limit of 5 NTU. Lower turbidity was recorded during the dry season (June-July) than during wet seasons (Nov- Dec). Nonetheless, there were significant statistical differences in the seasonal average turbidity values during the two seasons (p value =0.001) as portrayed in Table 6.

Table 6. Seasonal variation of turbidity.

Turbidity	Dry (June - July), N = 18	Short Rains (Nov - Dec), N = 18	p-value
Mean (SD) ± std. error	1.56±0.04	2.48±0.19	0.001
Range	1.5 – 1.6	2.4 – 2.8	

High turbidity during the rainy season resulted from increased surface runoff or suspended materials and erosion and inflow contaminated surface runoff from the nearby lands into the Thika River. The suspended matter transported in river increases at onset of the rainy season but decrease as the rains prolong.

A similar trend was identified by Njue *et al.* (2016) that there was high turbidity in rainy season compared to the dry season especially in areas dominated by agricultural activities. Ondoo *et al.* (2019) also noted that elevated turbidity during wet season is caused by surface run-off from poorly managed agricultural fields in upstream section of a river. Ouma *et al.* (2016) highlighted that high levels of turbidity could be linked to high load of coliforms in the surface water.

3.2.2. Total suspended solids

The average TSS during the dry season was 14±2 mg/L and wet season 21±6 mg/L. There was insignificant differences in TSS (p value = 0.7) during dry and short rain seasons as shown in Table 7.

Table 7. Seasonal variation of TSS.

Total Dissolved Solids	Dry (June - July), N = 18	Short Rains (Nov - Dec), N = 18	p-value
Mean (SD) ± std. error	14 (9) ± 2	21 (25) ± 6	0.7
Range	3 – 35	4 – 112	

Little or no surface run off took place in dry season, hence, less loose soil particles reached the river. Short rains led to increased run-off. One of the contributing factors to this trend as observed in the Thika River sub-catchment was the influx of surface run off on bare arable land with eroded soil into the river. Also, the variations in vegetative cover in most parts of the riverbank affected the rates of TSS within the channels. Contrary to the current findings, Ngatia, Kithiia, and Voda (2023) found out that TSS for Ngong River were higher during the dry season compared to the dry season indicating the impact of industrial effluent discharges on the surface water. However, in both studies, it was evident that anthropogenic activities have an impact on water quality in both the wet season and dry season.

3.2.3. Seasonal variation of temperature

Temperature during dry season and short rains; 14.14±0.21 and 15.3±0.27 respectively as shown in Fig. 6.

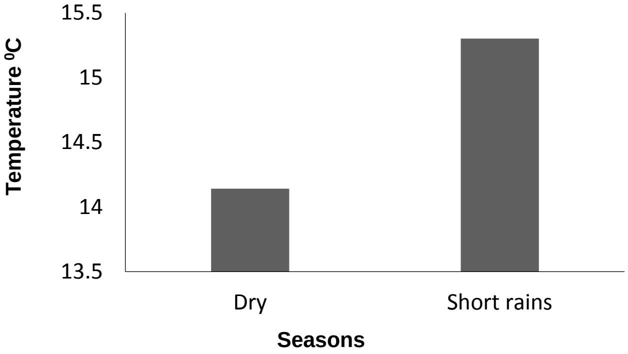

Fig. 6. Average temperature values during the dry and short rains.

However, there was no significant variation in the average temperature values (p value=0.001) between the dry and wet season. The high temperature during the wet season was due to an increase in suspended matter that absorb sunlight and in turn increase surface water temperature.

During the short rains, there was an influx in surface run off which carried materials from markets, construction sites, sewage, and other household waste alongside chemical wastes from farms and manufacturing sector. These materials had the potential to significantly alter the temperature of water based on volume and other parameters in the river channels.

Monitoring temperature was vital because estimates of water temperature are needed for effective management of water resources, including drinking water production. Higher temperatures during the high-water levels could lead to increased primary microbial activity. Besides, decomposition in tropical streams is also influenced by the water temperature, oxygen and dissolved organic carbon. Accordingly, van Vliet *et al.* (2013) outlined that changes in streamflow significantly affect water temperatures, for example warm or dry periods are associated with low river flows. Temperature is strongly affected by radiation and air temperature instead of precipitation. Higher water temperatures usually coincide with higher flows over the wet season, but even higher values can be recorded depending on the timing and location.

3.2.4. pH

The pH values during the dry season were 6.43±0.17 and in wet season were 6.37±0.12 as shown in Fig. 7. The average pH values were slightly lower than the permissible WHO and KEBS values of 6.5 and 8.5 respectively. There were no statistically significant differences of average pH values between dry season and short rainy season (p value = 0.6).

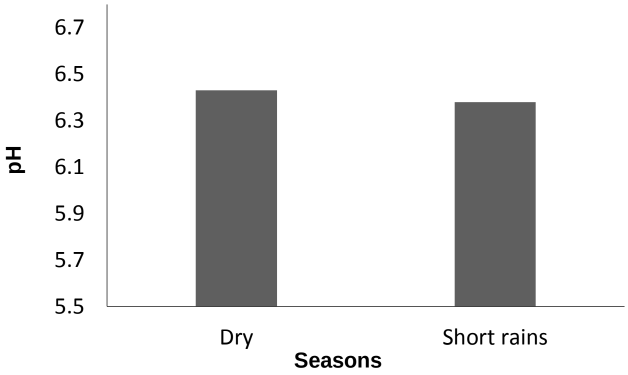

Fig. 7. Dry season and wet season average pH values.

Increased rainfall and crop cover during the short rains did not affect pH values because most tributaries have consistent vegetative cover along the riverbanks. Smallholder farming and clearance of riparian lands also tend to have long lasting effects on the pH variables of the rivers. Nonetheless, it was evident that Thika River sub-catchment waster was slightly acidic both in dry and wet season. The acidity could be attributed to the presence of organic acids and carbon dioxide from the biogeochemical processes that occur during composting, decay of organic wastes and subsequent leaching and run-off into the river system.

Ondoo *et al.* (2019) attributed the slight alkalinity and variation during the dry season and wet season to influx of domestic and industrial waste. Adongo *et al.* (2022) highlighted that pH is an important indicator acidity.

3.2.5. Nitrates

Average concentration of chemical parameters for the water samples during dry and short rain seasons as shown in Fig. 8. Accordingly, during the dry season, nitrates concentration was recorded to be 8.87±2.18 mg/L while during the short rains, the average concentration reduced to 6.48±0.3 as shown in Fig. 8. However, there was no significant variation in concentrations of nitrates during dry season than that of the short rainy season (p value = 0.043).

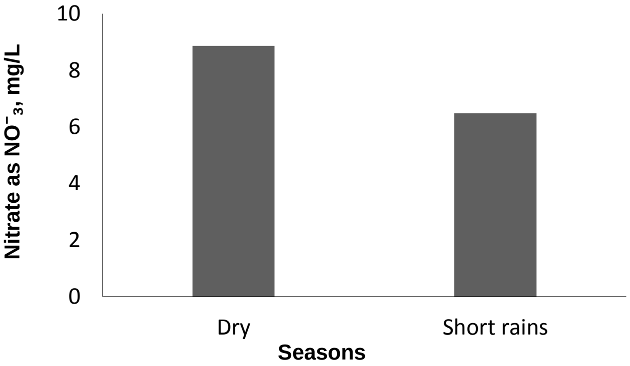

Fig. 1. Nitrate concentration during dry and short rainy season.

The average nitrate values were higher during the dry season than wet season and this could be attributed to the intensity of human activities and the surface run-off. Free range livestock and application of manure in the adjacent farms and lack of an efficient wastewater treatment system were identified as some of the risk factors for contamination. Nitrates concentrations in the range of 2.5 to 10mg/L can lead to eutrophication, blossoming of algae and might render water poisonous for human consumption (Edokpayi *et al*., 2015).

The findings were in line with Edokpayi *et al*. (2015) findings that variation in nitrates concentrations during the dry and rainy seasons are influenced by dilution, for example, the concentrations during the dry seasons are always high compared to rainy seasons due to dilution by rainfall and high-water levels. Ontumbi, Obando, and Ondieki (2015) also noted that overuse of animal manure in the riparian areas leads to an increase of nitrite and ammonia. The levels increase during the rainy season when most of materials are washed to the river. Ondoo *et al.* (2019) also attributed increase of nitrates to surface run-off rich in fertilizers, manure, and domestic wastes, as well as domestic sewage.

3.2.6. Sulphates

The average concentration of sulphates increased from 188.71±17 during dry season to 333.30±7 mg/L during short rains as shown in Fig. 9. The dry season concentration was within the WHO permissible limits of 250mg/L for drinking water, while the wet season was slightly higher than the recommended standards.

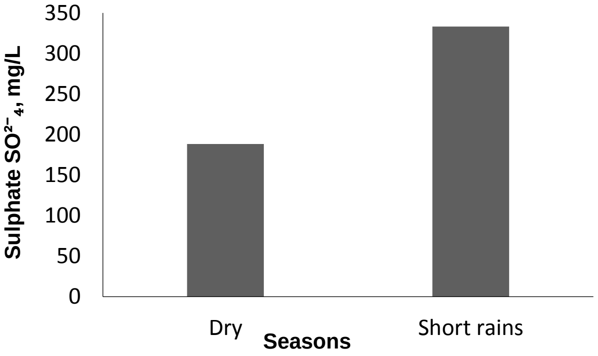

Fig. 2. Average concentration sulphates during dry and short rainy seasons.

There was a significant variation in the concentration of sulphates (P value <0.001) during the two seasons. Variation could be attributed to the fact that majority of the residents rely on rainfed agriculture. Equally, sustainable soil and water conservation practices appeared to be lacking implying that a good portion of the organic fertilizer and sulphate rich nutrients are washed away from the farms to the surface water. Sulphate ions are not fast absorbed by the plant roots and can easily be carried alongside surface run off during the short rains.

The findings are in line with Edokpayi *et al.* (2015) research that high concentration of sulphates is realized during the wet season due to increased surface runoff from adjacent agricultural fields, roads, and human settlements. In addition, Ondoo *et al*. (2019) attributed an increase in the concentration of sulphates in surface water during the wet season to surface run-off containing ammonium sulphate fertilizers and domestic wastewater contamination.

3.2.7. Total coliform

The analyzed data indicated that the average count of total coliform was 1365.28±192 during the dry season and the amount elevated to 2420±0 TC/100mls during the rainy as shown Fig. 10. There was significant variation on the concentration of total coliforms (p<0.001) during the dry season and the short rains.

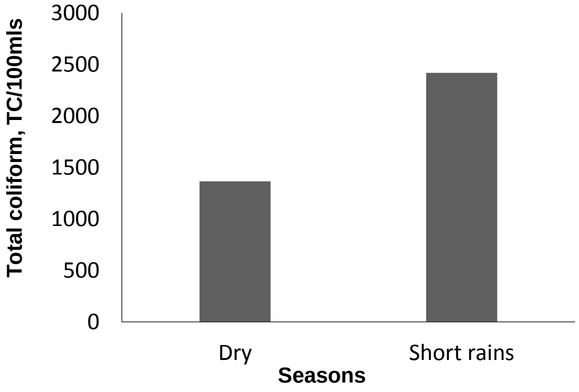

Fig. 3. The Average values of total coli form during dry and short rain seasons.

3.2.8. Fecal coliform

The study established that the concentration of fecal coli form was at 39.5±4.94 during the dry season and increased almost tenfold to record 306.06±97.11 TC/100 mls during the short rains as shown Fig. 11.

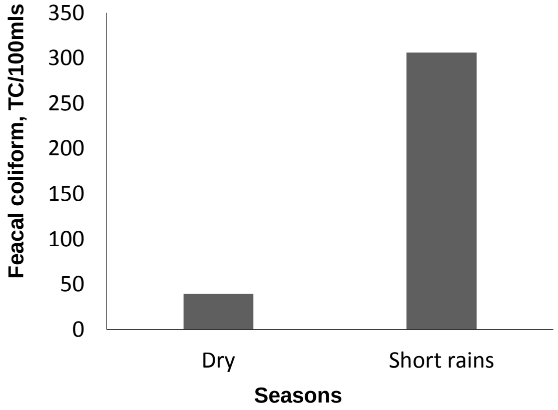

Fig. 4. Faecal coliform during dry and short rain season.

Also, there was statistically significant variation (p value < 0.001) in the concentration of the microbial parameters in dry seasons and during short rains. These findings project fundamental information about waste management systems and hygiene standards. The influx of coliforms into the river systems indicate the presence of open defecation areas, poor sewerage management, poor handling of animal wastes and existing loopholes in wastewater managements system.

The high number of total coliform and feacal coliform during the wet season were attributable to the organic loads from the land use activities like human and animal waste and suspended matter and high-volume surface runoff from land-based activities.

The result also mirrored the Edokpayi *et al.* (2015) research that high bacterial counts are usually higher during the wet season because of the rainfall events and more common in turbid water. In addition, Waithaka, Murimi and Obiero (2020) noted that elevated concentration of microbial contaminants is common during the wet season due to surface run-off. Ontumbi, Obando, and Ondieki (2015) attributed the increase in feacal coliform for the increased surface runoff during the wet season. Rasi Nezami and Aghlmand, (2023) denoted that nutrient concentration follow the general trend of other water quality parameters, for instance, sulphate concentration increases with decreasing river discharge.

4. Conclusions

Human activities have a direct impact on quality of water in Thika River sub-catchment. The land use-water quality correlation portrays a complex relationship both in spatial and seasonal perspectives. The study revealed that key drivers of pollution encompass improper handling of wastewater and sanitation challenges and run-off from farms. Nonetheless, the study revealed that despite the empirical challenges, most of the tested parameters are within the permissible standards by KEBS and WHO for drinking water. Water pollution increased downstream with main pollutants noticed including Nitrates, coli forms and other components disposed into the streams. There is need for practical interventions to safeguard the resource considering that variations of the parameters from upstream to the downstream indicate influence of human activities. The researcher recommends awareness creation among the smallholder farmers soil water management strategies. The stakeholders should promote the protection of forest and vegetation cover to limit leaches and surface run-off and improve infrastructure for waste and wastewater management.

Author Contributions

Joanes Ooko Odero: Conceiving and designing the research; performing the data collection and analysis and interpreting the data, writing the paper.
Prof. George Lukoye Makokha and Prof. Bancy Mati: Conceiving and designing the research and interpreting the data.
Dr. Nathan Oduor Okoth: Assisting in interpreting the data and writing the paper.

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Conflict of Interest

All authors declare that they have no conflicts of interest to disclose.

Data Availability Statement

All required data have been presented.

References

Abowei, J. F. N., (2010) ‘Salinity, dissolved oxygen, ph and surface water temperature conditions in Nkoro river, Niger Delta, Nigeria’, *Advance Journal of Food Science and Technology*, 2(1), pp. 36-40. https://maxwellsci.com/print/ajfst/v2-36-40.pdf

Adongo, M. J. *et al*. (2022) ‘Seasonal variation in physicochemical properties of groundwater, a case study of Kamiti-Marengeta Subcatchment Kiambu, Kenya’, *Journal of Water Resource and Protection*, 14(2), pp. 72-85. http://dx.doi.org/10.4236/jwarp.2022.142005

Benedict, M., Khaldoon, A. and Omondi, B. (2018) ‘Uncertainty analysis and calibration of swat model for estimating impacts of conservation methods on streamflow and sediment yield in Thika River Catchment, Kenya’, *International Journal*, 3(1), pp. 1-11. http://dx.doi.org/10.18488/journal.108.2018.31.1.11

Bwire, G. *et al*. (2020) ‘The quality of drinking and domestic water from the surface water sources (Lakes, Rivers, irrigation canals and ponds) and springs in cholera prone communities of uganda: An analysis of vital physicochemical parameters’, *BMC Public Health*, 20(1), pp. 1-18. https://doi.org/10.1186/s12889-020-09186-3

Cotruvo, J.A. (2017) ‘WHO guidelines for drinking water quality: First Addendum to the Fourth Edition,’ *Journal‐American Water Works Association*, *109*(7), pp. 44-51. https://doi.org/10.5942/jawwa.2017.109.0087

David, M. M., John, W. K. and Bonface, J. (2017) 'Bacteriological and physicochemical characterization of aora loko stream water, Maseno, Kenya', *Journal of Asian Scientific Research,* 7(4), pp. 119. https://doi.org/10.18488/journal.2.2017.74.119.128

Dehghan, F., Karami, J. and Yazdanbakhsh, K. (2021) 'Predicting environmental behavior by relying on water consumption behavior based on environmental awareness, attitude and concern', *Journal of Applied Research in Water and Wastewater*, *8*(2), pp. 113-117. https://doi.org/10.22126/arww.2021.5834.1192

Edokpayi, J. N. *et al.* (2015) 'Temporal variations in physico-chemical and microbiological characteristics of Mvudi river, South Africa', *International Journal of Environmental Research and Public Health,* 12(4), pp. 4128–4140. https://doi.org/10.3390/ijerph120404128

Githinji, M. W., Mwaura, F. and Wamalwa, J. (2019) 'Land use and water pollution along the altitudinal gradient of the Likii river, Laikipia County, Kenya', *Journal of Environment Pollution and Human Health,* 7(1), pp. 39-52. https://doi.org/10.12691/jephh-7-1-6

Ibekwe, A. M., Ma, J. and Murinda, S. E. (2016) 'Bacterial community composition and structure in an urban river impacted by different pollutant sources', *Science of the Total Environment*, 566, pp. 1176-1185. https://doi.org/10.1016/j.scitotenv.2016.05.168

Kambwiri, A. M. *et al.* (2014) 'Land use impacts on water quality of rivers draining from Mulanje mountain: A case of Ruo river in the Southern Malawi', *Malawi Journal of Science and Technology*, 10(1), pp. 15-31. https://www.ajol.info/index.php/mjst/article/view/105866

Kithiia, S. M. (2007) 'An Assessment of water quality changes within the athi and nairobi river basins during the last decade', *IAHS Publication,* 314, pp. 205. https://iahs.info/uploads/dms/14040.28-205-212-314-18-Kithiia.pdf

Langat, P. K. *et al.* (2021) 'Monitoring of land use/land-cover dynamics using remote sensing: A Case of Tana River Basin, Kenya', *Geocarto International,* 36(13), pp. 1470-1488. https://doi.org/10.1080/10106049.2019.1655798

Ly, K., Metternicht, G. and Marshall, L. (2020) 'Linking changes in land cover and land use of the lower mekong basin to instream nitrate and total suspended solids variations', *Sustainability,* 12(7), pp. 2992. https://doi.org/10.3390/su12072992

Mekuria, D. M., Kassegne, A. B. and Asfaw, S. L. (2021) 'Assessing pollution profiles along little Akaki river receiving municipal and industrial wastewaters, central Ethiopia: Implications for environmental and public health safety', *Heliyon,* 7(7), pp. e07526. https://doi.org/10.1016/j.heliyon.2021.e07526

Ngatia, M., Kithiia, S. M. and Voda, M. (2023) 'Effects of anthropogenic activities on water quality within Ngong river sub-catchment, Nairobi, Kenya', *Water,* 15(4), pp. 660. https://doi.org/10.3390/w15040660

Njogu, I. N. and Kitheka, J. U. (2017) 'Assessment of the influence of rainfall and river discharge on sediment yield in the upper Tana catchment in Kenya', *Hydrology Current Research*, 8(1), pp. 263. https://doi.org/10.4172/2157-7587.1000263

Njue, N. *et al*. (2016) 'Influence of land use activities on riparian vegetation, soil and water quality: an indicator of biodiversity loss, Southwest Mau Forest, Kenya', *Open Journal of Forestry,* 6(5), pp. 373-385. http://dx.doi.org/10.4236/ojf.2016.65030

Njuguna, S. M. *et al.* (2020) 'Application of multivariate statistical analysis and water quality index in health risk assessment by domestic use of river water: Case study of Tana river in Kenya', *Process Safety and Environmental Protection*, 133, pp. 149-158. https://doi.org/10.1016/j.psep.2019.11.006

Noori, R. *et al.* (2010) 'Multivariate statistical analysis of surface water quality based on correlations and variations in the data set', *Desalination*, 260(1-3), pp. 129-136. https://doi.org/10.1016/j.desal.2010.04.053

Nouri, M. and Montazer Faraj, A. (2022) 'Monitoring and assessment of water quality in Tehran city using physicochemical and microbial indexes', *Journal of Applied Research in Water and Wastewater*, 9(2), pp. 22-25. https://doi.org/10.22126/arww.2022.7066.1229

Nyilitya, B. *et al*. (2021) 'Nitrate source apportionment in the complex Nyando Tropical river basin in Kenya', *Journal of Hydrology*, 594, pp. 125926. https://doi.org/10.1016/j.jhydrol.2020.125926

Ogendi, G. M. *et al.* (2015) 'Assessment of the microbial load of Nyanchwa-Riana and Nyakomisaro-Riana rivers, Kisii, Kenya', *International Journal of Fisheries and Aquatic Studies,* 2(6), pp. 182-192. https://www.fisheriesjournal.com/archives/2015/vol2issue6/PartC/2-6-5.pdf

Ondigo, D. A., Kebwaro, J. and Kayoo, A. M. (2018) 'Water resources and management under increasing urban demography: A Kenyan perspective, A review', *Journal of Water Resource and Protection*, 10, PP. 919. https://doi.org/10.4236/jwarp.2018.109054

Ondoo, K. O. *et al.* (2019) 'Determination of selected water quality parameters in river Sio, Busia County, Kenya', *International Research Journal of Pure and Applied Chemistry*, 18(3), pp. 1-16. https://doi.org/10.9734/IRJPAC/2019/v18i330092

Ontumbi, G., Obando, J. and Ondieki, C. (2015) 'The influence of agricultural activities on the water quality of the river Sosiani in Uasin Gishu county, Kenya', International *Journal of Research in Agricultural Sciences*, 2(1), pp. 2348-3997. https://ijras.com/administrator/components/com_jresearch/files/publications/IJRAS-194_final.pdf

Onywere, S. M. *et al.* (2007) 'Intensification of agriculture as the driving force in the degradation of Nzoia river basin: The challenges of watershed management,' *LARS*, http://ir.mksu.ac.ke/handle/123456780/4608

Ouma, S. O. *et al*. (2016) 'Seasonal variation of the physicochemical and bacteriological quality of water from five rural catchment areas of lake Victoria Basin in Kenya', *Journal of Environmental Analytical Chemistry*, 3(170), pp. 2. https://doi.org/10.4172/jreac.1000170

Rasi Nezami, S. and Aghlmand, R. (2023) 'Assessing the suitability of river water quality using water quality indices: A case study on Balikhlou river in Northwest of Iran', *Journal of Applied Research in Water and Wastewater*, 10(1), pp. 1-6. https://doi.org/10.22126/arww.2022.7574.1239

Sang, J. K. and Maina, C. W. (2018) 'Modelling the impacts of structural conservation measures on sediment and water yield in Thika-Chania Catchment, Kenya', *International Soil and Water Conservation Research*, 6(2), pp. 165-174. https://doi.org/10.1016/j.iswcr.2017.12.007

Shah, K. A. and Joshi, G. S. (2017) 'Evaluation of water quality index for River Sabarmati, Gujarat, India', Applied *Water Science,* 7, pp. 1349-1358. https://link.springer.com/article/10.1007/s13201-015-0318-7

Sila, O. N. A. (2019) 'Physico-chemical and bacteriological quality of water sources in rural settings, a Case study of Kenya, Africa', *Scientific African,* 2, pp. e00018. https://doi.org/10.1016/j.sciaf.2018.e00018

TNC (2015) *Upper Tana-Nairobi water fund business case. Version 2.* The Nature Conservancy: Nairobi, Kenya. https://www.nature.org/content/dam/tnc/nature/en/documents/Nairobi-Water-Fund-Business-Case_FINAL.pdf

TNC (2016) *Sub-Saharan Africa's urban water blueprint: securing water through water funds and other investments in ecological infrastructure.* The Nature Conservancy: Nairobi, Kenya. https://www.nature.org/content/dam/tnc/nature/en/documents/Urban_Water_Blueprint_Region_Africa_Aug2016.pdf

United Nations world water development (2015), *Water for a sustainable world* (Vol. 1). UNESCO Publishing. ePub ISBN978-92-3-100099-7

van Vliet, M. T. *et al*. (2013) 'Global river discharge and water temperature under climate change', *Global Environmental Change,* 23(2), pp. 450-464. https://doi.org/10.1016/j.gloenvcha.2012.11.002

Waithaka, A., Murimi, K. S. and Obiero, K. (2020) 'Effects of temporal rainfall variability on water quality of River Ruiru, Kiambu County, Kenya', *ChemSearch Journal*, 11(1), pp. 59-65. https://www.ajol.info/index.php/csj/article/view/197382

Wilson, M. M., Michieka, R. W. and Mwendwa, S. M. (2021) 'Assessing the influence of horticultural farming on selected water quality parameters in Maumau stream, a tributary of Nairobi river, Kenya', Heliyon, 7(12), pp. e08593. https://doi.org/10.1016/j.heliyon.2021.e08593