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RESEARCH PAPER

Spatio-seasonal variations in water quality status of Migori River in Kenya and associated household health risk implications: an application of a multidimensional water quality index approach

Stephen Balaka Opiyo, Godwin Opinde and Sammy Letema

Department of Spatial and Environmental Planning, Kenyatta University, Nairobi, Kenya

ABSTRACT

Water quality monitoring is imperative in providing the objective evidence required to make sound decisions about water quality management. This study aimed to examine the water quality status of the Migori River by determining spatio-seasonal variations in water quality parameters, along with associated influencing factors and potential health risks. Therefore, eighteen physico-chemical and bacteriological variables were sampled and analyzed monthly for six months covering the wet and dry seasons from the upstream, midstream, and downstream stations, and a health risk survey was conducted with 90 watershed households. ANOVA and T-test were used to test for the significant spatial and seasonal variations ($p < 0.05$), respectively; whereas Pearson's correlation was used to identify relationships between parameters. Hierarchical Cluster Analysis (HCA) and Principal Component Analysis (PCA) were used to find various spatial patterns in the river water quality datasets, while the Canadian Council of Ministries of the Environment Water Quality Index (CCME-WQI) showed the suitability status of the river water quality. The assessed variables showed significant seasonal variability but no significant spatial differences in the river. HCA generated 3 clusters suggesting that water quality deteriorated downstream from the upstream of the watershed. The PCA extracted four PCs explaining 80.5% of the total variance, which suggested that the variations in water quality are attributed to point and nonpoint sources of pollution. While most of the physico-chemical variables were within maximum permissible limits, the bacteriological levels exceeded the prescribed standards. The index ranked the river's water condition between 'poor' to 'marginal'; upstream has better water condition that gradually decreases toward the downstream, and water quality is better in the wet season than the dry season. The study revealed that the water of the Migori River is polluted and potentially hazardous for human usage, and thus suitable pollution control measures are urgently needed to safeguard public health.

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Water quality; CCME water quality index; hierarchical clustering analysis; principal component analysis; Migori River

1. Introduction

Freshwater is vital in numerous aspects of human life (Gorme et al., 2010), and it is generally regarded as a fundamental input to human production and a powerful instrument for socio-economic development in society (Reza & Singh, 2010). Regrettably, the continuous availability of clean and safe freshwater for human consumption, in many countries around the world is currently threatened by pollution of freshwater sources (Mohemmad et al., 2011). This pollution is majorly caused by anthropogenic activities such as industrial effluents, wastewater disposal, and agricultural activities, (Al-Ridah et al., 2020; Gyamfi et al., 2013). Water pollution has grave implications on public health since it causes and spreads the majority of human diseases (Adelagun et al., 2021). It is estimated that about 80% of all diseases which cause deaths in the developing world are directly linked to poor drinking water quality (Ahaneku & Animashaun, 2013). Research also shows that over 6 million children in the world perish annually as a result of water-borne diseases (WHO, 2021). Due to these reasons, the deterioration of water quality has attracted global attention and is now considered a significant global environmental concern (Breabăn et al., 2012).

To safeguard public health, scholars and policy-makers agree that water quality monitoring is essential in providing the objective evidence required to make sound decisions about water quality management in the short term and long term (Al-Mashagbah, 2015). Water quality monitoring is vital since it informs watershed managers and policy-makers of the extent and major causes of pollution, and thus offers an initial step towards remedial approaches (Duan et al., 2016). Water quality is generally defined as the chemical, physical and biological characteristics of water with respect to its suitability for a designated use (Adelagun et al., 2021). These characteristics constitute the parameters for assessing the condition of the water because they usually undergo changes induced by human activities within the catchment area (Sun et al., 2016), and by the combined actions of interacting natural processes such as geomorphological configuration, hydrological conditions (Michalika, 2008), climatic conditions (Reza & Singh, 2010), and weathering processes (Yang & Wang, 2010).

Water quality assessment usually involves sampling, analysis, and measurement of the physicochemical and biological parameters at temporal scales, and at times spatial scales (Duan et al., 2013). The water quality assessment reports are often characterized by large datasets (Bilgin, 2018), thus disseminating vital information regarding water quality to the general public and policy-makers is a

CONTACT Stephen Balaka Opiyo stevebalaka@gmail.com

challenge for water quality experts (John-Mark, 2006). To address this problem, scientists came up with the water quality index (WQI) which comprehensively summarizes an enormous amount of water quality data into a single numerical value (Reza & Singh, 2010; Tyagi et al., 2013) used for categorizing the water quality status on a relative scale ranging from very poor to excellent (Gyamfi et al., 2013), hence providing a simplistic description of the quality of water as clean or polluted (Al-Mashagbah, 2015). This non-technical categorization of the quality of water is easily understood by professionals, decision-makers, and the general public alike (Okab, 2015). Besides WQI, multivariate statistical techniques such as cluster analysis (CA), discriminate analysis (DA) and principal component analysis (PCA) has recently gained popularity for better assessment and understanding of river water quality (Mena-Rivera et al., 2017). These techniques have been widely over the years used by researchers to evaluate the spatio-temporal variations in water quality as well as to identify possible pollution sources (Mena-Rivera et al., 2017; Sharma et al., 2015).

This current study generally applied a combination of a multidimensional WQI, multivariate statistical techniques, and health risk survey in assessing the water quality and suitability of Migori River of the Migori River sub-basin, which is among the largest of the six sub-basins within the Lake Victoria basin in Kenya. More specifically, the study aimed to (i) assess the spatio-seasonal variations of the physicochemical and bacteriological properties of the river water, (ii) establish the factors and sources influencing spatio-seasonal variations in river water quality through multivariate statistical techniques, (iii) determine the river water quality based on the Canadian Council of Ministries of the Environment Water Quality Index (CCME-WQI) in order to assess the suitability of the river water for drinking purposes, and (iv) assess the potential public health risk associated with river water usage.

2. Materials and methods

2.1. Study area and sampling stations

The paper is based on a study conducted in the Migori River which is located in the Migori River Watershed in Migori County, Kenya (Figure 1). The river originates from Chepalungu Forest in Emuria-Dikiri Sub-county of Narok County, from where it flows 70 km through Migori County to Lake Victoria. The entire catchment for the Migori River is situated at an altitude of approximately 1500 metres above sea level. It enjoys an inland equatorial climate which is heavily influenced by its proximity to Lake Victoria and hence receives mean annual rainfall in the range of 700 mm to 1800mm with two wet seasons (Mar-May and Sep-Nov) and two dry seasons (Dec-Feb and Jun-Aug). Average temperatures in the area range from 13^0C to 24^0C depending on the seasons. Due to these climatic conditions, the major crops cultivated in the area include maize, beans, vegetables, tobacco, coffee, sugarcane, and groundnuts. Agricultural production is limited by the occasional drought and flood conditions. In some areas, the waters of the Migori River are harvested for irrigation purposes to support crop production during droughts.

The Migori River watershed is divided into six agro-ecological areas, ranging from Upper Midland (UM) 1–3 to Lower Midland (LM) 1–5 (Odumo et al., 2011). In the Migori River watershed, there exist three predominant communities which are distributed along the length of the Migori River, the Maasai community (agro-pastoralism) is found upstream, the Kuria community (farming) lives in the midstream, and finally, the Luo community (farming, artisanal mining, and fishing) is located downstream. The choice of the Migori River was based on its significant socio-economic and ecological value. The river is a major source of water supply to almost a million people living in the region, caters to the fishing needs of the local communities, and is a major inflow to Lake Victoria. For water quality analysis, a total of six sampling stations along the river were purposively selected representing the upstream (ST1 and ST2), the midstream (ST3 and ST4), and the downstream (ST5 and ST6) sections (Figure 1).

2.2. Sampling procedure and analysis

The water quality of the Migori River was studied monthly for six months (Sep 2021-Feb 2022). Sampling was carried out in the river at the six pre-defined stations (Figure 1) during both the wet season (Sep 2021 to Nov 2021) and the dry season (Dec 2021 to Feb 2022). Sampling occurred between 9 am and 12.00 pm. At each sampling station, triplicate *in-situ* measurements of Dissolved Oxygen concentration (mgL^{-1}), Temperature (°C), Conductivity (μScm^{-1}), pH, Salinity (ppt), TDS (mgL^{-1}), and Turbidity (NTU) were determined on-site using a handheld Hanna Instruments® Multiparameter Probe (YSI Professional Plus model). Three water samples were then collected at each station, at about 10 cm depth from the right, middle and left banks of the river, using 500 ml plastic bottles that had been acid-washed (HCL) and rinsed in distilled water. The collected water samples were then labelled, stored in a cooler box at 4°C, and transferred to the laboratory at Kenya Marine and Fisheries Research Institute (KMFRI) in Kisumu within five hours of collection. All the samples were then analyzed in the laboratory following the APHA (2017) Standard Methods for the Examination of Water and Wastewater (Table 1).

2.3. Household health risk assessment

A descriptive cross-sectional survey was conducted in June 2022 among 114 purposively selected households in the Migori River watershed (38 households per each stream section), using a short interviewer-administered semi-structured questionnaire designed to get information concerning perceived water pollution status, indicators, and causes, as well as health implications. The households chosen for the survey were those within 2-5 km from the river as they are the ones who would have easy frequent access to the river for water collection. During the survey, the questionnaires were only administered to adult female members of the selected households as households in Kenya culturally rely on children or women of child-bearing age (or both) for water collection.

2.4. Data analyses

2.4.1. Statistical analyses

The datasets for the water quality parameters analyzed were analyzed using SPSS version 24.0. The datasets were first

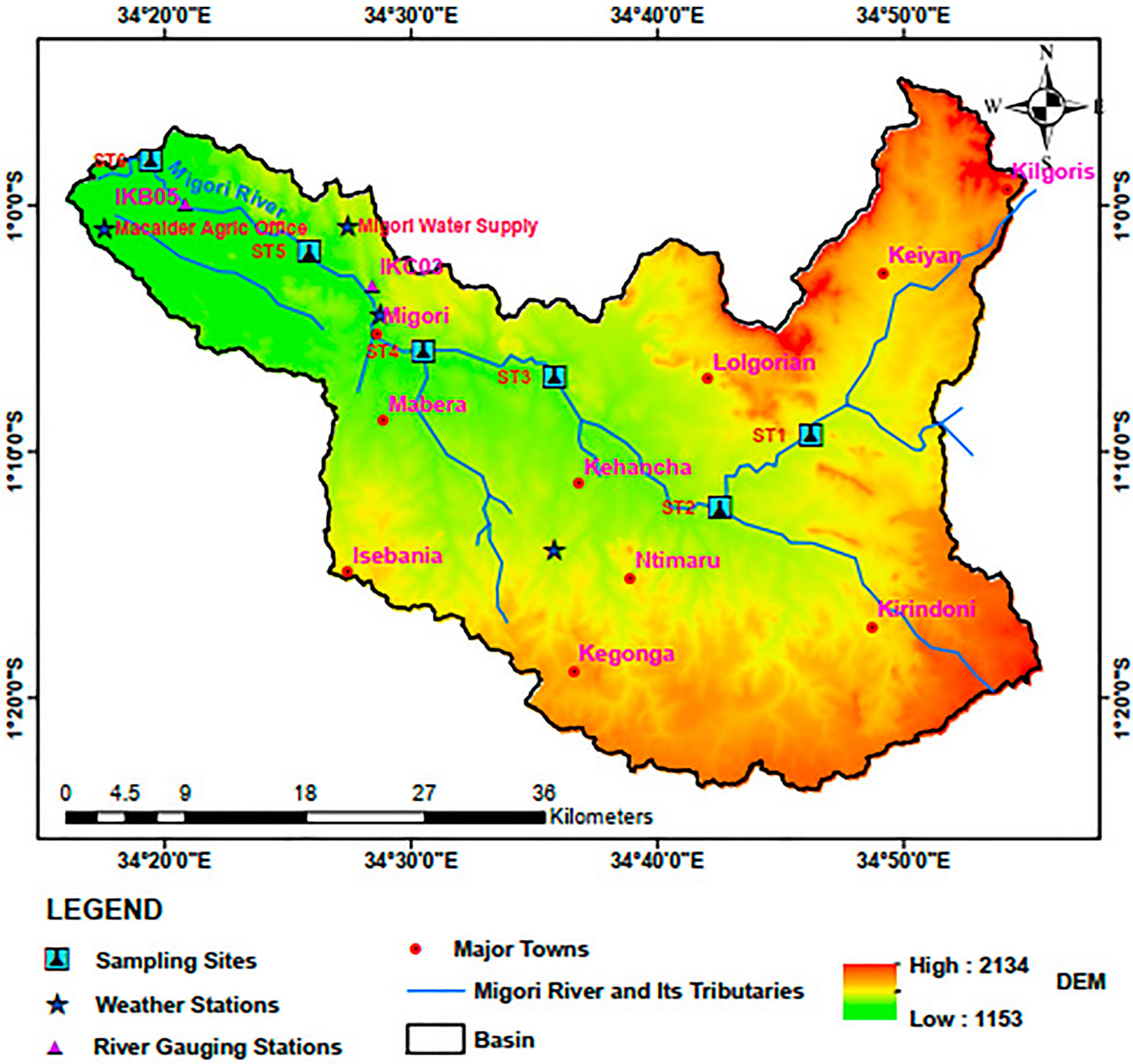

Figure 1. Distribution of sampling stations along the Migori River.

analyzed descriptively to generate mean and standard error values for the various stream sections and seasons. One-way ANOVA was then used to test for significant spatial variations at a *p-value* of ≤0.05 whereas the t-test was used to test for significant seasonal variations at a *p-value* of ≤0.05. Pearson's correlation analysis was used to identify relationships between various water quality parameters ($p < 0.05$) (Shil et al., 2019). Multivariate statistical techniques were used to find various spatial patterns in the river water quality datasets. The hierarchical cluster analysis (HCA) was used to organize sampling stations into similar groups considering similarities in water quality, with Ward's method of association and squared Euclidean distance as a measure of similarity considered to graphically summarize the clustering processes in a dendrogram (Mena-Rivera et al., 2017). The PCA based on the correlation coefficient matrix was used to identify the key parameters that explain the variations in the water quality data (Di Rienzo et al., 2015), as well as possible sources of pollution in the river water (Tusher et al., 2021). PCA is a data reduction procedure that converts the original variables into a new subset of uncorrelated variables, known as principal components, which explains the variations in the original data.

Table 1. Studied parameters and their respective standard analytical methods.

Water Quality Parameter	Analytical Method as per APHA (2017)
Biochemical Oxygen Demand (mgL^{-1})	5-day test
Total Hardness (mgL^{-1})	Ethylene-diamine Tetra-acetic acid (EDTA) Titrimetric Method
Nitrite-nitrogen (μgL^{-1})	Diazotization
Total Nitrogen (μgL^{-1})	Persulphate Digestion
Nitrate-Nitrogen (μgL^{-1})	Cadmium Reduction
Ammonia-Nitrogen (μgL^{-1})	Nessierization spectrophotometric (Nessler)
Total alkalinity (mgL^{-1})	Sulphuric Acid Titration
Total phosphorous (μgL^{-1})	Acid Persulphate Digestion
Soluble Reactive Phosphate (μgL^{-1})	Ascorbic Acid
Silicates (μgL^{-1})	Ammonium Molybdate
Fecal Coliform (cfu $100ml^{-1}$)	Multiple tube fermentation technique

2.4.2. Calculation of CCME-water quality index

Following the procedure outlined in CCME (2017) manual, the physicochemical variables to be used in WQI calculation together with their established water quality guidelines (referred to as objectives) were first selected and appropriately arranged in an Excel file. The CCME-WQI values for the various river sections and seasons were obtained by the comparison of the selected physicochemical variables against their established NEMA (2017) guidelines following the procedure outlined in CCME (2017) using equation 1.

$$\text{CCME} - \text{WQI} = 100 - \left\{\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right\} \quad (1)$$

Where the index equation comprises three components:

I. F_1 (*Scope*) – represents the percentage of physicochemical variables for which at least one measure doesn't comply with the prescribed water quality limits.

$$F_1 = \left\{\frac{\textit{Number of failed variables}}{\textit{Total number of variables}}\right\} \text{X } 100 \quad (2)$$

II. F_2 (*Frequency*) – represents the percentage of individual tests (measurements) that do not comply with their prescribed water quality limits.

$$F_2 = \left\{\frac{\textit{Number of failed tests}}{\textit{Total number of tests}}\right\} \text{X } 100 \quad (3)$$

III. F3 (*Amplitude*) – represents the quantity by which failed test values do not comply with their prescribed water quality limits. This is computed in three steps:
   a. Computation of Excursion. The excursion refers to the number of times by which an individual concentration is greater than (or less than, when the water quality guideline is a minimum) the set guideline. When the water quality guideline must not be exceeded, it is calculated using:

$$\textit{Excursions}_i = \left\{\frac{\textit{Failed Test Value}_i}{\textit{Objective}_j}\right\} - 1 \quad (4a)$$

And when the observed value must not be less than the water quality guideline:

$$\textit{Excursions}_i = \left\{\frac{\textit{Objective}_j}{\textit{Failed Test Value}_i}\right\} - 1 \quad (4b)$$

Computation of Normalized Sum of Excursions (NSE): The normalized sum of excursions is the collective amount by which individual tests are out of compliance. This is calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests (both those meeting objectives and those not meeting objectives). The NSE is computed as:

$$\text{NSE} = \left\{\frac{\sum_{i=1}^{n} \textit{Excursion}_i}{\textit{Number of tests}}\right\} \quad (4c)$$

Computation of F3 (Amplitude): The F3 is then computed by an asymptotic function that scales the normalized sum of the excursions from water quality guidelines to yield a range from 0 to 100.

$$F_3 = \left\{\frac{nse}{0.1nse + 0.01}\right\} \quad (5)$$

The CCME-WQI is finally calculated as:

$$\text{CCME} - \text{WQI} = 100 - \left\{\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right\}$$

The divisor 1.732 normalizes the resultant values to a range between 0 and 100, where 0 represents the worst water quality and 100 represent the best water quality. The resultant WQI values place water quality into five categories with the following interpretations (Table 2).

Table 2. CCME WQI categorization schema (CCME, 2017).

Rank	WQI Value	Description
Excellent	95–100	Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels; these index values can only be obtained if all measurements are within objectives virtually all of the time.
Good	80–94	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.
Fair	65–79	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.
Marginal	45–64	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.
Poor	0–44	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels.

3. Results and discussion

3.1. Spatio-seasonal variations in the physicochemical and bacteriological properties of Migori River water

The spatial and seasonal variations of monitored physicochemical and bacteriological parameters in the surface waters of the Migori River are shown in Tables 3 and 4, respectively. With an overall mean of 25.24°C, the mean water temp in the river varied between 24.84°C and 25.59°C recorded upstream and downstream, respectively. Since water temperature is regulated by the geographical location of the river and the local climatic conditions (Mathew et al., 2017), the upstream waters are cooler than the downstream waters because of variation in altitude and vegetation cover. The upstream has dense riparian vegetation which cools the passing water while the downstream has sparse vegetation exposing it to direct insolation. The mean temperature of the dry season (26.35°C) was higher than that of the wet season (24.12°C), which might be due to the dry season being characterized by reduced precipitation and less cloud cover facilitating intense insolation to directly reach the waters of the river. These findings are consistent with those of Musyimi et al. (2017). Water temperature was within the acceptable drinking water standards recommended in the NEMA (2017) and WHO (2017).

Dissolved oxygen (DO) is the concentration of oxygen in the water column (Beddle, 2008) and is influenced by the level of temperatures, photosynthetic activity, and water flow velocity which regulates the aeration, and decomposition of organic materials (Cronk & Fennessy, 2016; Musyimi et al., 2017). The mean DO varied from 7.89 mgL^{-1} registered by the upstream to 8.68 mgL^{-1} registered by the downstream. The DO level is highest downstream compared to the other two zones probably because its higher temperatures influenced greater solubility of oxygen in the water column. The mean DO for the wet season (8.49 mgL^{-1}) was slightly higher than that of the dry season (8.08 mgL^{-1}), which could be attributed to increased

Table 3. Spatial variation of water quality parameters (Mean ± S. E) in the three stream sections of Migori River compared against established standards.

Parameter	Water Quality Standards		Stream Overall Mean (± S.E)	Site-Specific Measurements Mean (± S.E)			ANOVA Results	
	NEMA	WHO		Upstream	Midstream	Downstream	F (2,33)	*p*-Value
Temperature (°C)	25	25	25.24 (0.28)	25.28 (0.49)[a]	24.84 (0.51)[a]	25.59 (0.41)[a]	0.58	0.57
DO (mgL^{-1})	8	7	8.28 (0.11)	7.89 (0.13)[a]	8.28 (0.09)[b]	8.68 (0.16)[c]	8.50	0.00
BOD (mgL^{-1})	5	5	14.62 (0.73)	10.80 (0.78)[a]	15.01 (0.93)[b]	18.06 (1.09)[c]	15.01	0.00
pH	6.5-8.5	6.5-8.5	8.43 (0.07)	8.16 (0.10)[a]	8.59 (0.15)[a]	8.53 (0.12)[a]	5.28	0.01
EC (µScm^{-1})	250	1500	169.55 (7.74)	176.64 (14.12)[a]	157.62 (13.58)[a]	174.40 (13.00)[a]	0.59	0.56
Salinity (mgL^{-1})	0.04	0.04	0.07 (0.01)	0.08 (0.02)[a]	0.07 (0.01)[a]	0.07 (0.1)[a]	0.30	0.74
Total Alkalinity (mgL^{-1})	500	500	53.40 (2.29)	55.18 (4.36)[a]	51.02 (3.86)[a]	53.99 (3.89)[a]	0.28	0.76
Total Hardness (mgL^{-1})	500	500	53.20 (2.12)	53.67 (3.66)[a]	50.02 (4.12)[a]	55.92 (3.30)[a]	0.64	0.53
TDS (mgL^{-1})	1500	1200	106.92 (5.24)	111.22 (10.19)[a]	101.14 (8.79)[a]	108.40 (9.27)[a]	0.30	0.74
Turb (NTU)	5	5	249.32 (31.82)	193.03 (44.18)[a]	238.47 (47.31)[a]	316.45 (69.04)[a]	1.31	0.28
TP (µgL^{-1})	2000	2000	171.53 (8.33)	156.33 (8.59)[a]	166.53 (15.41)[a]	191.74 (17.05)[a]	1.66	0.21
TN (µgL^{-1})	2000	2000	1104.58 (61.69)	1035.66 (64.35)[a]	984.8 (107.40)[a]	1293.25 (125.22)[a]	2.62	0.09
NO_3—N (µgL^{-1})	10000	10000	162.87 (16.17)	213.05 (39.54)[a]	127.47 (20.32)[a]	148.11 (12.51)[a]	2.81	0.07
NO_2—N (µgL^{-1})	3000	1000	19.05 (0.75)	19.49 (1.54)[a]	20.01 (1.28)[a]	17.67 (1.05)[a]	0.89	0.42
NH_3—N (µgL^{-1})	500	500	33.30 (3.30)	37.73 (6.33)[a]	33.63 (6.79)[a]	28.53 (3.77)[a]	0.64	0.54
SRP(µgL^{-1})	NS	NS	40.20 (3.22)	40.56 (5.53)[a]	39.92 (7.01)[a]	40.13 (4.40)[a]	0.00	1.00
SiO_2 (µgL^{-1})	NS	NS	32.37 (1.69)	33.21 (2.93)[a]	31.43 (3.23)[a]	32.47 (2.86)[a]	0.09	0.92
FC Counts (cfu/100 ml)	Nil (0)	Nil (0)	512.23 (35.90)	307.51 (36.17)[a]	596.63 (65.14)[b]	632.55 (31.28)[c]	14.59	0.00

Note: Mean values in the same row that do not share a superscript letter are significantly different ($p < 0.05$).
Key: DO: dissolved oxygen; BOD: biological oxygen demand; EC: electrical conductivity; TDS: total dissolved solids: Turb: turbidity; TP: total phosphate; TN: total nitrogen; NO_3—N: nitrate-nitrogen, NO_2—N: nitrate-nitrogen; NH_3—N: ammonia-nitrogen; SRP: soluble reactive phosphorus; FC: fecal coliforms.

atmospheric diffusion of oxygen by fast-flowing water during rainy periods, allowing greater aeration (Langat, 2009). With an overall mean of 8.28 mgL^{-1}, the DO levels recorded in the river were within the acceptable limits recommended by NEMA (2017) and the WHO (2017).

BOD signifies the amount of DO required by aerobic microbes to break down organic materials in a water sample (Woldeab et al., 2018); hence it is influenced by the same factors as DO. Since the mean BOD spatially varied between 10.80 mgL^{-1} in upstream and 18.06 mgL^{-1} downstream, the BOD levels were generally low at the upstream stations and gradually increased toward the downstream stations due to increased loading of organic matter from domestic wastes and industrial effluents downstream through runoff from the upper reaches of the river. BOD concentration of the wet season (17.34 mgL^{-1}) was higher than that of the dry season (11.91 mgL^{-1}) because high amounts of runoff during the wet season collect huge amounts of organic material and deposit them in the river (Sanchez et al., 2020). The BOD values recorded at various stations and seasons exceeded the permissible limit of 5 mgL^{-1} recommended by NEMA (2017) and WHO (2017).

With an average pH level of 8.43, the waters of the Migori River can be described as slightly basic. This weak alkalinity comes from the carbonate-rich rocks and soils in which the river travels. The pH results were uniform throughout this study, which is an indication that there is more or less the same level of chemical disruption across the river length (Sanchez et al., 2020). The study observed a slightly higher pH during the wet season compared to the dry season which could probably be a result of increased photosynthetic activity in the wet season which depleted the CO_2 concentration in the water column and hence raised the pH slightly. It could also be attributed to increased levels of alkaline-based detergents washed off by runoff during the wet season. Every pH value observed in the river was within the maximum permissible range of 6.5-8.5 recommended by NEMA (2017) and WHO (2017).

The EC and TDS measure the salinity of river water, which also refers to any minerals, salts, metals, anions, or cations dissolved in river water (Opiyo, 2019; WHO, 2008). The EC, salinity, and TDS levels exhibited similar spatial and seasonal variability in the river because all three variables are governed by the weathering of the geological configuration of the watershed, soil type, prevailing climatic conditions, and the intensity of anthropogenic activities occurring within the catchment (Ansa-Asare & Asante, 1998; Stevenson et al., 2010). The mean values of EC ranged from 157.62 µScm^{-1} of midstream to 176.60 µScm^{-1} of upstream (overall mean of 169.55 µScm^{-1}), and salinity ranged from 0.07 mgL^{-1} of both the midstream and downstream to 0.08 mgL^{-1} of upstream (overall mean of 0.07 mgL^{-1}), while TDS varied from 101.14 mgL^{-1} of midstream to 111.22 mgL^{-1} of upstream (overall mean of 106.92 mgL^{-1}). The lack of significant spatial differences in the levels of EC, salinity, and TDS across the three sections of the river length (Table 3) implies that the erosion and weathering of dissolved minerals from the watershed are more or less uniform throughout the river length owing to the uniform geological characteristics of the watershed. The levels of EC, salinity, and TDS were higher during the dry season compared to the wet season (Table 4), because the dry season is characterized by high evaporation rates and no dilution effect whereas the wet season experiences dilution of dissolved minerals by the voluminous water brought about by the rains (Woldeab et al., 2018). Despite the similarity in spatio-seasonal variability, the levels of EC and TDS in the river were within the maximum permissible limits for drinking water while salinity exceeded it's maximum permissible limit for drinking water standards (Table 3).

The total alkalinity (TA) level is dependent on the concentration of carbonates, bicarbonates, and hydroxides in the water whereas the total hardness (TH) level is dependent on the concentration of dissolved cations (magnesium and calcium) and anions (chloride, carbonate, bicarbonate, and sulphates) in the water (USGS, 2018). The source of these ions in water is deposits of limestone or gypsum minerals (EPA, 2019). In the present study, with no significant differences among zones (Table 3), the mean values of TA oscillated around 50 mgL^{-1} across the river length with an overall mean of 53.40 mgL^{-1} whereas those of TH varied between 50.00 mgL^{-1} of upstream and 57.83 mgL^{-1} of

Table 4. Seasonal variation of water quality parameters (Mean ± S.E) in the two seasons of Migori River System in comparison with established standards.

Parameter	Water Quality Standards		Overall Sampling Period Mean (± S.E)	Season-specific Measurements Mean (± S.E)		T-test Results	
	NEMA	WHO		Wet Season	Dry Season	t (34)	*p*-value
Temperature (°C)	25	25	25.24 (0.28)	24.12 (0.39)[a]	26.35 (0.17)[b]	−5.212	0.000
DO (mgL^{-1})	8	7	8.28 (0.11)	8.49 (0.14)[a]	8.08 (0.10)[a]	2.347	0.191
BOD (mgL^{-1})	5	5	14.62 (0.73)	17.34 (0.92)[a]	11.91 (0.68)[a]	4.727	0.195
pH	6.5-8.5	6.5-8.5	8.43 (0.07)	8.54 (0.08)[a]	8.32 (0.10)[a]	1.736	0.377
EC (μScm^{-1})	250	1500	169.55 (7.74)	141.28 (11.81)[a]	197.83 (3.66)[b]	−4.574	0.000
Salinity (mgL^{-1})	0.04	0.04	0.07 (0.01)	0.06 (0.00)[a]	0.09 (0.00)[b]	−5.586	0.000
Total Alkalinity (mgL^{-1})	500	500	53.40 (2.29)	44.50 (3.24)[a]	62.29(1.29)[b]	−5.097	0.000
Total Hardness (mgL^{-1})	500	500	53.20 (2.12)	43.78 (2.71)[a]	62.62 (0.84)[b]	−6.637	0.000
TDS (mgL^{-1})	1500	1200	106.92 (5.24)	87.33 (8.14)[a]	126.51 (2.42)[b]	−4.612	0.000
Turb (NTU)	5	5	249.32 (31.82)	351.42 (52.92)[a]	147.21 (11.93)[b]	3.764	0.000
TP (μgL^{-1})	2000	2000	171.53 (8.33)	184.92 (7.37)[a]	158.15 (14.50)[b]	1.646	0.015
TN (μgL^{-1})	2000	2000	1104.58 (61.69)	1264.73 (55.88)[a]	944.42 (97.63)[b]	2.848	0.528
NO_3–N (μgL^{-1})	10000	10000	162.87 (16.17)	210.00 (27.82)[a]	115.75 (6.45)[b]	3.301	0.003
NO_2–N (μgL^{-1})	3000	1000	19.05 (0.75)	20.63 (1.22)[a]	17.48 (0.73)[b]	2.216	0.041
NH_3–N (μgL^{-1})	500	500	33.30 (3.30)	46.95 (4.76)[a]	19.65 (0.64)[b]	5.687	0.001
SRP(μgL^{-1})	NS	NS	40.20 (3.22)	52.10 (4.88)[a]	28.30 (1.52)[b]	4.659	0.000
SiO_2 (μgL^{-1})	NS	NS	32.37 (1.69)	29.32 (3.07)[a]	35.42 (1.12)[b]	−1.865	0.000
FC Counts (cfu/100 ml)	Nil (0)	Nil (0)	512.23 (35.90)	540.50 (43.94)[a]	483.96 (57.30)[a]	0.783	0.561

Note: Mean seasonal values in the same row that do not share a superscript letter are significantly different ($p < 0.05$).
Key: DO: dissolved oxygen; BOD: biological oxygen demand; EC: electrical conductivity; TDS: total dissolved solids: Turb: turbidity; TP: total phosphate; TN: total nitrogen; NO_3–N: nitrate-nitrogen, NO_2–N: nitrate-nitrogen; NH_3–N: ammonia-nitrogen; SRP: soluble reactive phosphorus; FC: fecal coliforms.

downstream with an overall mean of 52.59 mgL^{-1}. These results indicate that TA and TH levels are relatively uniform across the river length, implying that the erosion and weathering of limestone minerals from the catchment's geology to the river have been occurring at roughly uniform rates. However, the levels of TA and TH were higher in the dry season than in the wet season (Table 4) which could be attributed to the accumulation of large amounts of limestone minerals by high evaporation rates during the dry season and the effect of water dilution during the wet season by the large amounts of rainfall. The results of the study suggested that the observed TA and TH levels in the river were within the maximum permissible limits for drinking water set by NEMA (2017) and WHO (2017).

Turbidity measures the relative cloudiness or clarity of water caused by suspended particulates that are normally imperceptible to the human eye (USGS, 2018). Mean turbidity varied from 193.03 NTU recorded upstream to 316.45 NTU recorded downstream (overall mean of 249.32 NTU), and exhibited a general increasing trend from the upstream stations to the downstream stations indicating that high amounts of sediments eroded from the upper reaches of the catchment end up downstream through runoff. Seasonally, the mean turbidity was higher in the wet season (351.42 NTU) compared to the dry season (147.21 NTU) due to heavy sedimentation resulting from the deposition of high amounts of suspended solids by the surface runoff brought by the rains of the wet season. The results depicted that the level of turbidity in the river at any station or season exceeds the permissible limit of 5 NTU recommended by NEMA (2017) and WHO (2017) for drinking water.

Silicates (SiO_2) in river waters originate from the physical and chemical weathering of silicate minerals from the lithology of the catchment and can be beneficial to humans or cause water quality and treatment problems (EPA, 2019). In the present study, with very slight differences in the mean values, the SiO_2 concentrations in various sections were constantly oscillating around 30 μgL^{-1} across the river length during the entire sampling period. This trend implies that the rate of physical and chemical weathering of silicate minerals from the lithology of the river basin has been fairly uniform across the river length. Silicate levels during the dry season (35.42 μgL^{-1}) were significantly higher than in the wet season (29.32 μgL^{-1}) which is an unusual occurrence because silicates are normally higher in the wet season than in the dry season because the rainfall-runoff dissolves high amounts of silicate minerals from the entire watershed and deposits them in the rivers. Nonetheless, the low silicates observed during the wet season could be attributed to high silica utilization by planktonic organisms especially the diatoms (Bacillariophyceae family) which have been known to utilize silica for building their cell walls to be photosynthetic (Patil et al., 2013).

Nutrients are vital parameters of water quality, which depict the status of pollution and anthropogenic load in river water (Suthar et al., 2010). The mean concentration of all the phosphoric nutrients (TP and SRP) and nitrogenous nutrients (NO_3-N, NO_2-N, NH_3-N, and TN) analyzed from the water samples of the Migori River were within their respective maximum permissible limits for drinking water (Table 3 or 4), which implies that the usage of phosphatic and nitrogen-based fertilizers in the farms of the watershed is low level, and therefore hasn't impacted the water quality. Although there were no significant spatial variations in the mean values of the nutrients analyzed (Table 3), the concentration of phosphatic nutrients, TP (with an overall mean of 171.53 μgL^{-1}), and SRP (with an overall mean of 40.20 μgL^{-1}), were highest in the downstream and gradually decreased toward the upstream stations (Table 3). This demonstrates that the downstream receive enormous phosphate nutrient loads eroded by runoff from various sources in the river basin, including fertilized agricultural lands, waste streams from residential settlements, mining activities, and inflowing tributaries. On the contrary, the concentrations of nitrogen-based nutrients (NO_3-N, NO_2-N, and NH_3, with exception of TN) were highest in the upstream and gradually decreased toward the downstream stations (Table 3). This shows the intensity of usage of nitrogen-based fertilizer in the upper reaches of the watershed. These spatial nutrients variations are related to the closeness of the sampling stations to the river banks, the intensity of agricultural practices nearby, and the density of the riparian vegetation cover. The concentrations of both phosphoric (with exception of TP) and nitrogenous nutrients analyzed for Migori River nutrients were significantly higher during the wet season than in the dry season (at $p < 0.05$) (Table 4), because in the wet season the surface runoff generated from the rains drains huge volumes of phosphatic and nitrogen-based pollutants from agricultural farms, industrial effluents, animal excreta, mining sites, and residential areas to the river.

A fecal coliform is a group of bacteria originating from fecal matter as they specifically reside in the intestines of warm-blooded animals, and although not normally pathogenic on their own, they can indicate the presence of other pathogens (disease-producing bacteria or viruses) in river water (Sanchez et al., 2020). The overall mean count of FC was 512.23 cfu/100 ml, which far exceeded the maximum permissible limit of zero/100 ml recommended by NEMA (2017) and WHO (2017); which indicates that the waters of Migori River are contaminated with fecal matter and thus may contain disease-causing pathogens. The high concentration of FC in the river is attributable to the presence of several households along the stretch of the river which dispose of animal and human feces, animal carcasses, and decomposing food wastes in the river. The mean FC in the downstream (632.55 cfu $100ml^{-1}$) was higher than that of the upstream (307.51 cfu $100ml^{-1}$), and the mean values exhibited a general increasing trend from the upstream stations to the downstream stations, an indication that population, housing, and livestock densities increase from the upstream section to the downstream section. Bensig et al. (2014) observe that FC counts are linked to the population density, housing density, livestock density, and imperviousness of the area. Seasonally, the mean FC observed during the sampling period ranged from 399.32-621.97 cfu $100ml^{-1}$ in the dry season and 471.64- 611.63 cfu $100ml^{-1}$ in the wet season; hence the FC count for the wet season was significantly higher due to the increased inflow of fecal materials by rainfall runoff from point and non-point sources in the watershed. This observation is similar to the findings of Seo et al. (2019) in the Nakdong River in South Korea.

3.2. Analysis of factors influencing spatio-seasonal variations in river water quality using multivariate statistical techniques

The ANOVA results presented in Table 3 showed no statistically significant ($p < 0.05$) spatial variations in the studied river water quality parameters, excluding DO (F (2, 33) 8.498, $p = 0.000$), BOD (F (2, 33) 15.009, $p = 0.000$), and FC (F (2, 33) 14.588, $p = 0.000$). On the other hand, the T-test results presented in Table 4 identified statistically significant interactions between seasons for the studied river water quality parameters, excluding DO (t (34) 2.347, $p = 0.191$), BOD (t (34) 4.727, $p = 0.195$), pH (t (34) 1.736, $p = 0.377$), and FC (t (34) 0.783, $p = 0.561$). Pearson correlation analysis was performed among the studied water quality variables in the Migori River water to assess possible similar sources, and hence indicate connections among variables; the results are shown in Table 5. A significantly strong correlation was observed between temp and conductivity, salinity, TA, TH, & TDS (r = 0.895-0.919), while a strong negative relationship was observed between temp and

Table 5. Pearson Correlation coefficient matrix of water quality variables of the Migori River ($p < 0.05$).

Parameter	Temp	DO	BOD	pH	EC	Salinity	TA	TH	TDS	Turb	TP	TN	NO_3-N	NO_2-N	NH_3-N	SRP	SiO_2	FC
Temp	1																	
DO	−0.275	1																
BOD	−0.370*	.619**	1															
pH	−0.028	0.257	.449**	1														
EC	.911**	−0.201	-.426**	−0.097	1													
Salinity	.919**	−0.309	-.506**	−0.098	.949**	1												
TA	.909**	−0.288	-.457**	−0.076	.979**	.952**	1											
TH	.901**	−0.212	-.421*	−0.147	.950**	.932**	.942**	1										
TDS	.895**	−0.229	-.418*	−0.096	.975**	.943**	.960**	.940**	1									
Turb	-.705**	.403*	.598**	0.212	-.745**	-.737**	-.777**	-.661**	-.724**	1								
TP	−0.195	.336*	0.265	0.240	−0.170	−0.164	−0.177	−0.196	−0.227	.416*	1							
TN	-.386*	0.320	.372*	0.072	-.432**	-.542**	-.456**	-.470**	-.441**	.360*	0.117	1						
NO_3-N	-.491**	0.189	−0.041	0.073	-.446**	-.426**	-.477**	-.541**	-.480**	0.212	0.245	0.314	1					
NO_2-N	-.588**	−0.034	0.094	0.077	-.671**	-.608**	-.620**	-.674**	-.684**	.370*	0.296	0.283	.482**	1				
NH_3-N	-.514**	0.110	0.229	0.211	-.533**	-.539**	-.537**	-.698**	-.573**	0.210	0.216	.347*	.698**	.538**	1			
SRP	-.807**	0.217	.354*	0.240	-.858**	-.842**	-.843**	-.885**	-.874**	.689**	0.242	.492**	.621**	.698**	.585**	1		
SiO_2	.712**	−0.182	−0.153	−0.217	.764**	.681**	.726**	.668**	.782**	-.710**	-.366*	-.342*	-.491**	-.487**	−0.323	-.760**	1	
FC	0.001	.460**	.643**	0.198	−0.050	−0.118	−0.088	−0.003	−0.043	0.195	−0.037	0.152	−0.324	−0.180	−0.133	−0.110	0.128	1

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

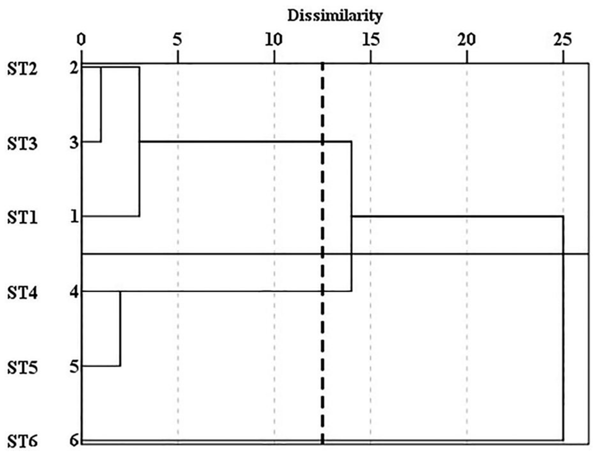

Figure 2. Dendrogram showing grouping of the sampling stations using hierarchical cluster analysis (CA) based on the water quality of Migori River.

turbidity (r = −0.705) & SRP (r = −0.807). These correlations may indicate the influence of temperature on the dissolution of mineral salts in river water. A strong positive relationship was also found between EC and salinity, TA, TH, & TDS (r = 0.949-0.979); while a strong negative correlation was observed between EC and turbidity (r = −0.745) and SRP (r = −0.858). This demonstrates that these variables originate from similar sources, the weathering of minerals and salts from the geology of the watershed. A strong negative correlation between TDS and turbidity & SRP, and between TH and SRP depict the inorganic nature of the pollutants entering the river. The weak positive or negative correlations observed among certain water quality variables could be attributed to variations between pollution sources and catchment geochemical properties.

Hierarchical cluster analysis (CA) generated 3 clusters at $(D_{link}/D_{max})\times100 < 50$ (Figure 2). The first cluster contained just one sampling station (ST6), the second cluster comprised two sampling stations (ST4 and ST5) and the third cluster was made of three sampling stations (ST1, ST2, and ST3). The three clusters are found in the downstream, midstream, and upstream of the watershed, respectively. This clustering is consistent with the land use practices, especially in the downstream section of the watershed where human activities like agricultural production, mining, and urbanization have intensified, and can be related to increased pollution levels in the Migori River. Clusters 2 and 3 can be regarded as less polluted when compared to cluster 1. Cluster 3 is situated in a low-population region, even though farming and livestock keeping activities are practiced. In particular, ST6 (cluster 1) is located in the lower section of the river length and recorded the highest levels of pollutants of all six sampling stations. Water quality deteriorated downstream of the watershed, as increased runoff from the upper reaches of the catchment increased the loading of organic and inorganic contaminants, and increased the level of pollution in the river. The CA results illustrate similarities between sampling stations, offering a methodological approach for categorizing a watershed, decreasing the number of sampling stations, and enhancing the efficiency and cost-effectiveness of long-term water quality assessment programmes (Wang et al., 2014).

The PCA was used to pinpoint the major variables that spatially influence the water quality of the Migori River. The datasets suitability tests performed before PCA using

Table 6. Principal component analysis (PCA) results in the Migori River.

Parameter	PC1	PC2	PC3	PC4
TDS	0.962	0.068	0.156	0.049
TA	0.958	0.006	0.212	0.021
EC	0.957	0.060	0.22	0.057
TH	0.956	0.102	0.089	−0.113
Salinity	0.950	−0.043	0.222	−0.052
SRP	−0.922	−0.142	0.067	−0.001
Temp	0.913	0.078	0.186	0.058
SiO_2	0.785	0.130	−0.082	0.397
Turb	−0.782	0.314	−0.075	−0.403
NO_2-N	−0.692	−0.353	0.111	−0.002
NH_3-N	−0.635	−0.251	0.353	0.493
NO_3-N	−0.577	−0.414	0.446	0.281
TN	−0.535	0.167	−0.002	0.396
FC Counts	−0.050	0.827	−0.238	0.193
BOD	−0.493	0.786	0.019	0.123
DO	−0.343	0.670	0.247	0.098
TP	−0.323	0.170	0.649	−0.448
pH	−0.205	0.408	0.549	0.001
Eigen value	9.500	2.495	1.403	1.087
% Total variance	52.778	13.860	7.794	6.037
% Cumulate	52.778	66.638	74.432	80.469

the Kaiser-Meyer-Olkin (>0.5) and Bartlett's sphericity tests ($p < 0.05$) showed that the dataset is satisfactory for PCA. The PCA performed on the correlation matrix of means of the studied water quality variables by site indicated that 4 principal components (those with Eigen values greater than 1) represented approximately 80.5% of the total variation in the entire dataset (Table 6). PC1 accounted for 52.8% of the total variations between stations, with positive loadings on TDS, alkalinity, conductivity, hardness, and salinity, which would correspond to variations in the natural weathering of salts of the catchment. In PC2, 13.9% of the total variance is explained by positive loadings on fecal coliforms, BOD, temperature, DO, and pH, which generally represent the influence of runoffs with high loads of organic matter from domestic wastes and industrial effluents and its degradation processes through the catchment. Further, 7.8% of the total variance is explained by the PC3 whilst 6.0% of the site variations are explained by the PC4.

3.3. Evaluation of water quality status using CCME-WQI

The CCME-WQI was used to assess the spatio-seasonal variations in the suitability of the Migori river water for domestic purposes. The CCME-WQI scores for drinking water suitability were calculated using the NEMA (2017) and WHO (2017) standards. The CCME-WQI provides valuable non-technical water quality information for communicating outcomes with professionals, decision-makers, and the general public alike. The overall spatial analysis of the CCME-WQI ranked the river's condition 'poor' to 'marginal' (Table 7), meaning that its water quality variables usually deviate from recommended water quality standards and the water is polluted and unfit for human consumption (drinking purposes) due to physical impurities and bacterial contaminants. The upstream waters presented the best condition 'marginal' with a value of 46.9, whilst the midstream and downstream waters were classified as 'poor'; this indicates that as the river flows downstream the quality of the water deteriorates due to the influence of human activities, domestic and industrial wastewater pollution, mining activities of gold and copper, and agricultural runoff from the landscape along the stretch of the river.

Table 7. Spatial variation of water quality index in Migori River.

Section	F1 (Scope)	F2 (Frequency)	F3 (Amplitude)	CCME WQI	WQI Category
Upstream	40	27.8	85.8	46.9	Marginal
Midstream	40	32.8	97.7	36.2	Poor
Downstream	46.7	35	97.9	34.2	Poor

The overall seasonal analysis of the CCME-WQI indicated that the wet season had the better water condition with a value of 36.6, which is slightly higher than the 34.9 value recorded by the dry season (Table 8). However, the water quality of the river during both seasons was classified as 'poor'. The low CCME-WQI values, representing poor water quality, observed across the stretch of the river in both seasons were found to be mainly emanating from consistently higher values of temperature, DO, BOD, pH, turbidity, and FC in the river water which depicts the intensity of waste pollution from anthropogenic activities and inflowing tributaries.

3.4. Assessment of community utilization of river water and household health risk

Summary of survey responses to questions concerning perceived water pollution status, indicators, and causes, as well as health implications are presented in Table 9. Participants in this survey were exclusively women as households in Kenya culturally rely on children or women of child-bearing age (or both) for water collection. The survey revealed that 77.40% (n = 90) of the participants solely utilize water from the Migori River while the rest (13.09%) used other water sources like boreholes. This indicates that most households are at risk of exposure to polluted waters of the river. The majority of participants utilizing the river water felt that the water was most suitable for washing (76.2%) and cooking (55.6%), while 69.8% perceived the water as unsafe for drinking purposes. Regarding the status and severity of pollution of the Migori River, the majority (84.9%) of the survey participants acknowledged the polluted nature of river water which was ranked as moderate by 49.3% of the participants (Table 9). This claim seems to be supportive of the WQI findings which categorized the water quality between 'poor' to 'marginal'. Approximately 81% acknowledged the need for treatment of water for household usage; and by far the most forms of household treatment are cloth filtration (reported by 86.5% of households), boiling (reported by 63.4% of households), and chlorination (reported by 34.1% households) using Water Guard (small bottles of chlorine solution). These results suggested that the household water treatment forms used by the watershed communities are insufficient to remove pathogens in river water which may expose them to health vulnerabilities.

Concerning pollution indicators, the participants perceived that turbidity (colour of dirty water), increased debris suspension on the river, unusual taste, and unusual smell are the major indicators (Table 9). The main causes of river pollution reported by most of the participants included inflowing tributaries (90.8%), direct washing and bathing in the river (71.6%), discharge of mining wastes (62.5%), municipal/industrial wastewater (58.4%), and farm-eroded wastes (45.3%). The survey established that the pollution of the river has negatively impacted some socio-economic or health aspects of about 68% of the participating households (Table 9). Socio-economically, it has increased expenditure on household water treatment (as reported by 25% of participants), whereas health wise it has increased expenditure on treatment of water-borne illnesses (59.2%). About 37% of participants claimed to have experienced illnesses they attributed to the usage of the polluted river water, with typhoid (43.9%) and amoebiasis (38.6%) being the most commonly reported diseases. This raises serious concerns about the health impacts of river water usage among the communities nearby.

Table 8. Seasonal variation of water quality index in the Migori River.

Section	F1 (Scope)	F2 (Frequency)	F3 (Amplitude)	CCME-WQI	WQI Category
Dry Season	46.7	33.3	97.2	34.9	Poor
Wet Season	40	30.4	97.6	36.6	Poor

Table 9. Survey respondents' perceptions of river pollution condition, indicators, causes, and health implications.

Responses on river pollution and impacts		Freq. (N = 90)	Percent (%)
Level of river pollution	High	15	16.2
	Moderate	44	49.3
	Low	23	25.7
	No response	8	8.8
River pollution indicators*	Turbidity (dirty water colour)	58	64.5
	Increased debris suspension on the river	33	36.9
	Biochemical contamination	4	4.4
	Unusual taste	36	40
	Unusual odor/smell	11	11.7
	Others	1	0.9
Perceived causes of river pollution*	Direct disposal of household waste	18	19.9
	Direct disposal of farm-eroded waste	41	45.3
	Direct discharge of municipal/industrial wastewater	53	58.4
	Pollution from inflowing streams/runoff	82	90.8
	Direct bathing and washing in the river	64	71.6
	Discharge of mining waste	56	62.5
Impacts of river pollution*	Increased expenditure on livestock health	6	6.6
	Increased expenditure on treatment of water borne illnesses	53	59.2
	Increased expenditure on water treatment before household usage	23	25.0
	Increased river infestation of water hyacinth and other weeds	4	3.9
	Reduction in overall fish catch in the Migori river	5	5.3
Prevalent water-borne diseases caused by polluted river water	Cholera	20	22.1
	Typhoid	40	43.9
	Diarrhea	26	28.8
	Amoebiasis	34	38.6
	Skin infections	8	9.4

Key: * means the question allowed choosing more than one response, and the percentage for each response item is indicative of the number of responses out of the total sample population.

4. Conclusions and recommendations

The studied variables showed significant seasonal variability but no significant spatial differences throughout the sampling period, an indication of the influence of weather changes and pollution sources. While most of the physico-chemical variables of the water were within the maximum permissible limits, the level of the bacteriological parameter of fecal coliforms counts exceeded the prescribed standards and thus the CCME-WQI ranked the river's water condition between 'poor' to 'marginal'. The results show that the water of the Migori River is contaminated and potentially hazardous to over three-quarters of watershed households that solely utilize it for their household needs. Moreover, the household water treatment forms used by the watershed communities are insufficient to remove pathogens in river water which may expose them to health vulnerabilities. The CCME-WQI results indicated that the upstream section has better water condition that gradually decreases toward the downstream, which indicates that as the river flows downstream the quality of the water deteriorates. Further, the CCME-WQI showed that the water quality of the wet season is better than that of the dry season despite being in the same 'poor' water quality category. With these results, the CCME-WQI was able to identify the specific river section, season, or parameters upon which pollution management interventions can be directed. Therefore, spatio-seasonal variations in water quality variables and the results of the CCME-WQI show the vulnerability of the Migori River to pollution from anthropogenic activities in the watershed. This reveals therefore that a combined application of the CCME-WQI with multivariate statistical techniques is valuable in examining the river water quality status and helps to understand the sources of variations which may be helpful for proper water quality management.

The poor water quality of the Migori River is not only a potential public health risk to the millions that utilize it as a primary water source; it also shows the lack of inadequate environmental protection approaches. The paper thus recommends that appropriate management measures need to be taken by relevant government agencies, which may include regular water quality monitoring especially in the mid-to-downstream sections of the river and during the dry season, enforcement of the existing river basin protection laws and policies, development of water treatment infrastructure that can help local communities treat water before use to prevent water-borne diseases, and improved catchment protection measures. Further, the study recommends the nationwide application of the CCME-WQI in assessing the status of drinking water quality of freshwater resources in Kenya. Further studies are required on the connection of land use land cover change to the water quality status of the river.

Overall, the study identifies water quality hotspots in Migori River and some of the key drivers and hence it can substantially contribute to the achievement of SDGs 6 (on clean water and sanitation) and 3 (on good health and well-being of communities). By showing where water quality is good and where it is not, and how this quality is changing over time in Migori River, the study can guide relevant decision-makers in prioritizing better-targeted pollution management interventions needed to achieve target 6.3 (of SDG 6) on improving water quality by 2030. The study outcomes showing that high contamination of the river by pathogenic fecal coliforms might be causing waterborne illnesses among river water users in the surrounding communities may inform stakeholders to focus on reduction of exposure by reducing contamination sources and treating or avoiding the water source, thereby promoting access to safe drinking water which therefore contributes to the aspirations of SDG 3. Lastly, the study can raise awareness among local populations against household usage of raw water collected downstream or during the dry season, and on the need to protect the river from non-point source pollution in order to safeguard community health and riverine ecosystem.

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Author contributions

All authors contributed to the study's conception and design. Material preparation, data collection, and analysis were performed by Mr. Stephen Balaka Opiyo under the close supervision of Prof. Sammy Letema and Dr. Godwin Opinde. The first draft of the manuscript was written by Mr. Stephen Balaka Opiyo. Prof. Sammy Letema and Dr. Godwin Opinde critically reviewed the manuscript and contributed intellectual content. All authors read and approved the final manuscript.

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Stephen Balaka Opiyo http://orcid.org/0000-0003-3157-5192
Godwin Opinde http://orcid.org/0000-0002-7442-4100
Sammy Letema http://orcid.org/0000-0002-8766-0022

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