Huria Journal, Vol 28(1), March 2021: 75-104

Seasonal Variability of Water Quality in the Zigi River, Northern Tanzania

Ramadhan Nyambukah
nyambokah@gmail.com
Tanga Urban Water and Sanitation Authority, Tanga
Matobola Joel Mihale
joel.mihale@out.ac.tz
The Open University of Tanzania

ABSTRACT

Water quality parameters (colour, total suspended solids (TSS), turbidity, electrical conductivity (EC), pH, dissolved oxygen (DO), total dissolved solids (TDS), temperature, nitrate, phosphate and faecal coliforms) were evaluated during wet and dry seasons in relation to human activities in Zigi River and its tributaries. Samples were taken from nine strategic sampling points located in different areas of river. The samples were processed and analysed using established procedures. Results of temperature, EC, TDS, TSS, nitrate, colour, turbidity and E. coli were higher in wet season than in dry season. Significant variations ($p < 0.05$) of temperature, EC, TDS, nitrates, colour and turbidity with changing seasons were observed. Also, results on variations of other parameters were more or less the same in both seasons. Temperature, EC, TDS, nitrate and E. coli were increasing and DO decreasing downstream in both seasons probably due to increased anthropogenic activities along the river. High Pearson correlation coefficient ($r^2 > 0.53$) observed between these parameters indicated that these values are closely related. Results of assessment of water using water quality index have revealed that the river water in both seasons is unsuitable for use as drinking water and that the water is more unsuitable for use during the wet season than during the dry season. Implications of the findings on water treatment are vivid and immediate measures are recommended to minimise the further diminishing quality of the water in this river and thus reduce the costs of treating the water for domestic use.

Keywords: *Seasonal variation, Zigi river, water quality index, drinking water, human activities*

INTRODUCTION

Water is currently regarded as a fundamental human right due to its significance to human health. This is evidenced by the fact that about 8 million people die every year because of water-related problems such as water – borne diseases (Rahmanian et al., 2015). The quality of water deteriorates when it contains substances that contaminate it, making the water unfit for human consumption. Important physicochemical parameters during water quality analysis include, among others, colour, total suspended solids (TSS), turbidity, electrical conductivity (EC), pH, dissolved oxygen (DO), total dissolved solids (TDS), temperature, nitrate, phosphate and faecal coliform (FC).

The visible colour of the water is mainly due to particulate substances in it or the failure of some wavelength to be absorbed (Chapman, 1996), which gives water its apparent colour. Colour in water can be caused by weathered rocks /soil as well as dissolved organic acids from trees and plants. The colour of the water may provide evidence that there is some form of contamination that imparts adverse effects on human health and the aquatic environment. Colour is not considered a toxic characteristic but is listed as a secondary (aesthetic) parameter affecting the appearance and palatability of the water.

Turbidity is a useful indicator of the effects of runoff from various anthropogenic activities such as agricultural practices, logging activity and discharges (USEPA, 1991). Intensive agricultural activities and mining can aggravate the erosion process that occurs naturally (Chapman, 1996). The colour and turbidity are the main controllers of transmitted light that controls primary productivity (Chapman, 1996). Like turbidity, temperature and TSS variations also depend largely on the extent of human activities

Dissolved oxygen (DO) influences all biochemical processes in the water (Chapman, 1996). Measuring DO can be used to measure the extent of pollution, organic matter decomposition as well as the self-purification of the water. Dissolved oxygen is related to temperature as temperature affects the solubility of oxygen. The presence of coliform bacteria such as *Escherichia coli* in water is a good indicator that given water is polluted by faecal matter. *E. coli* has long been used as an indicator for faecal contamination of the water that originated from animals like humans (Odonkor and Ampofo, 2013). The presence of faecal contamination is an indication that there are potential health risks to individuals exposed to the water. The presence of human activities in such areas can further aggravate the problem.

Nitrate is commonly found in natural water, which originates from land drainage, plant and animal debris or igneous rocks. Phosphates occur mostly as dissolved orthophosphate polyphosphates or organically bound phosphates. It is rare to find elevated levels of phosphates. Together with nitrate, phosphates levels cause eutrophic conditions and may stimulate algal growth. The eutrophic condition can lead to deoxygenation of sediments that can cause nutrient remobilisation, particularly in slow-flowing rivers. Eutrophication can also cause changes in pH and DO because of the fluctuations between primary production and bacterial decomposition (Chapman, 1996). Eutrophication also can cause excessive phytoplankton growth that poses problems with the intake of drinking water as well as increased treatment costs. Phosphates and temperature are usually included in the monitoring because the temperature has a relationship with many other variables such as temperature, pH and DO.

Rivers are considered the major sources of water for domestic purposes. The Zigi River is the source of water for different purposes for the community living in the river catchment. The Mabayani dam, which is downstream of the Zigi River, is the sole source of water supply in Tanga City and its environs. There are a lot of agricultural activities along the Zigi river (Mwanyoka, 2005), some are seasonal (e.g. food crop growing) and some are all year round (e.g. livestock keeping and mining activities). The principal food crops grown include maize, paddy, sorghum, cassava, millet, bananas, beans, sweet potatoes and nuts, supplemented by fruits and vegetables such as tomatoes, Irish potatoes, peppers and pumpkins. The principal commercial cash crops include sugar cane, sisal and spices (cardamom, ginger, cinnamon and cloves). Livestock kept in the Zigi include goats, cattle sheep and poultry. Bee-keeping and fishing are done though to a lesser extent. These agro-pastoral activities are done on the river banks due to the presence of water, fertile soil and greener pasture throughout the year (Kapinga et al., 2019).

Studies have revealed that there are various socio-economic activities taking place around the Zigi River. Mixed agriculture is practised by more than 80% of the population, while small scale mining activities take place, employing less than 3% of the population (Mwanyoka, 2005). Both socio-economic activities are practised along the Zigi River and its environs. Mwanyoka (2005) observed small scale and illegal gold mining activities taking place at Sakale where gold processing was taking place in one of the streams forming the Zigi River. There are also timber activities, which are secretly practised in the forest reserves around the river. Such anthropogenic activities could be impacting the river and diminishing the quality of water.

The increased human activities cause serious land-use changes, which impact the quantity, flow and quality of the water resulting from increased deposition of large loads of sediments and organic matter into the river (Mwanyoka and Jambiya, 2009). Furthermore, there is accelerating growth of water hyacinths observed in the Mabayani dam, which results in to change of colour and turbidity. This could increase health risks and increase treatment costs. There is also a difference in the quality of water due to changes in the seasons as a result of changing patterns of human activities in the Zigi River and its environs (Kapinga et al., 2019). This study was intended to unveil the seasonal changes in the quality status of water in the Zigi River and its tributaries by assessing the levels of the selected water parameters and their contribution to water quality in relation to different anthropogenic activities along the river.

METHODOLOGY

The Study Area

The study was conducted in the Zigi river catchment, which lies between latitudes 4^{o} 48’S and 5^{o} 15’S and longitudes 38^{o} 34’E and 39^{o} 03’E. Whereas the upper reaches of the Zigi catchment is dominated by the Sambaa ethnic group, the lower reaches are dominated by the Bondei ethnic group. Both ethnic groups engage in mixed agriculture; subsistence cropping and livestock keeping as well as small scale mining activities.

The samples were collected from eight (8) established sampling locations within the Zigi River catchment (Figure 1). The selection of these points was based on the closeness to human activities. The catchment was divided into three sampling zones: upper, middle and lower Zigi. Five sampling points were selected in the Upper Zigi (Sakale, Kwamkoro bridge, Spice Garden, Timber bridge and Longuza), one in the middle Zigi (Lanzoni) and two in the lower Zigi (Mjesani and Mabayani dam).

Sakale was selected because of presumed little anthropogenic activities. As a result, the point was taken to offer baseline data for the study.

Kwamkoro Bridge, which is a junction of the Kihara and Kiganga rivers, was taken to establish the water quality pollution due to tea plantations and subsistence agricultural activities along the Kihara River. Spice garden was selected to assess the water quality pollution due to subsistence farming activities carried out at Mlesa, Shebomeza, Chemka and Mbomole along the Zigi River. The point was also intended to capture the water pollution from farming activities along the Nanguruwe and Dodwe streams. Timber Bridge is a confluence of the Zigi and Kihuhwi rivers. The point was taken to assess the quality of water from the Kihuhwi River, which flows from Potwe passing through various subsistence farms and a rubber plantation.

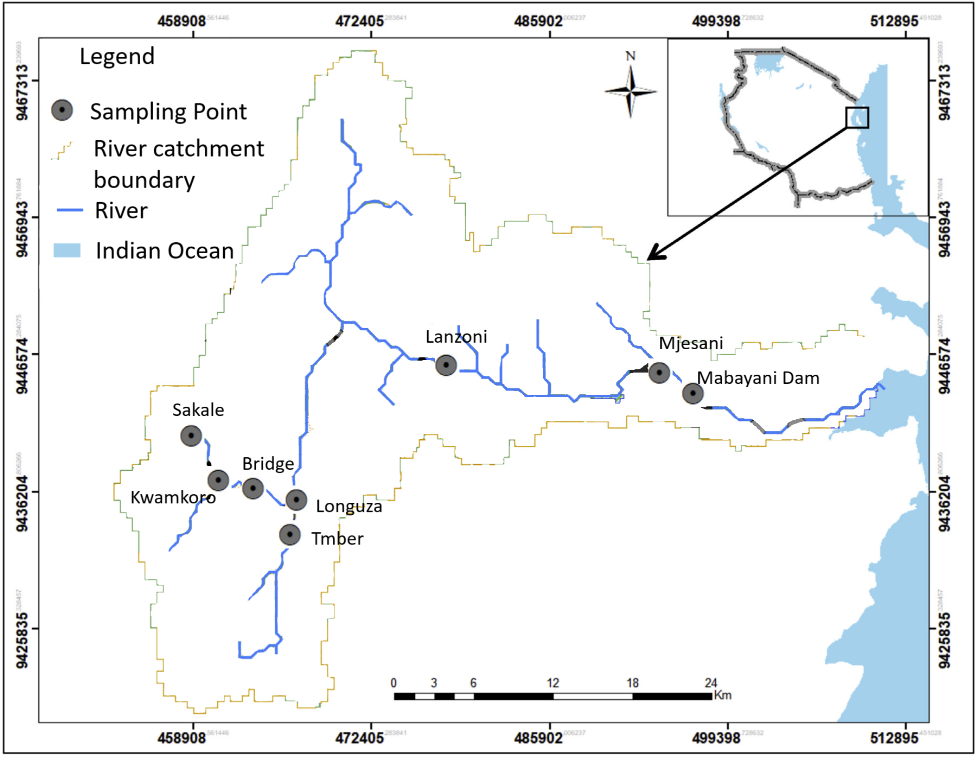

Figure 1 Map showing the location of sampling points. Adopted from Maskini et al., (2018)

Longuza was taken to assess the quality of water due to the presence of the Longuza teak plantation. Lanzoni, which is the confluence of Zigi and Muzi rivers, was taken to assess the quality of water in relation to sisal as well as subsistence farming activities as carried out along the Muzi River. The Mjesani Bridge was taken to assess the pollution of water due to the

Mjesani sisal plantation. This point is also the mouth of the Mabayani dam. Mabayani dam was taken to assess the quality of water in the dam (Figure 1), whose water is used for domestic purposes in Tanga city and its environs.

Sampling

Water sampling was conducted at the eight selected points in dry and wet seasons, where six sampling campaigns were conducted per season. During the dry season, the water samples were taken between 31st January 2015 and 7th March 2015 at one-week intervals when there was decreased water flow. Wet season water sampling was done between 20th April 2015 and 25th May 2015 during heavy rainfall and storm runoffs.

Sampling and preservation of the samples were carried out in triplicate in accordance with the Greenberg et al., (2005) methods and Tanzania Bureau of Standards (TBS) guidelines for water quality (TZS 789: 2016). Samples for analysis of physicochemical parameters were taken in pre-cleaned 1-litre polythene plastic bottles. Except for *in-situ* measurements, samples for analysis of nitrate and total phosphate were acidified with concentrated sulphuric acid (Analar grade) to pH 1.5. Samples for bacteriological tests were taken using sterilized glass sampling bottles (200 mL). The water samples for laboratory analysis of other physicochemical parameters were kept in ice chests at < 6 °C and transported to the Tanga Urban Water and Sewerage Authority (TANGA UWASA) laboratories where they were stored and analysed within two days.

Sample Analysis

Analysis of Physico-chemical Parameters

Analysis of the physicochemical parameters was done using the standard methods (Greenberg et al., 2005). Temperature, pH, dissolved oxygen and EC were measured *in-situ* immediately after sampling while other parameters were determined in the laboratory. The temperature was measured using a handheld thermometer. The pH and EC measurements were determined using a pH and EC meter (HANNA model HI 98130). Dissolved oxygen was measured using the DO meter. The apparent colour was determined within two hours after sample collection. Apparent colour (AC) and nitrate were determined by Spectrophotometric methods (Greenberg et al., 2005) while TP was determined using the ascorbic acid method (Greenberg et al., 2005). Turbidity was measured using a

Turbidimeter (TURB 550). TSS and TDS were determined in a well-mixed sample. The sample was filtered through a standard GF/F glass fibre filter and the residues on the filter were dried in an oven at 103 - 105 °C to constant weight. Later the residues were weighed using an analytical balance (Model HT244). The temperature was recorded in °C, TDS, nitrate and phosphate were recorded in ppm (mg/L), EC in µS/cm, turbidity in nephelometric turbidity units (NTU), apparent colour in platinum-cobalt units (Pt-Co) and DO in mg/L.

Analysis of Bacteriological Parameters

Bacteriological analysis was conducted using HACH (2011) Membrane Filtration Method. Collected samples for bacteriological tests were analysed using the Potable laboratory Kit, which provides a direct count of bacteria in water based on the development of colonies on the surface of the membrane filter. The water sample (100 mL) was filtered through a membrane filter (0.45 µm diameter). The filter membrane was then placed on an absorbent pad (in a Petri dish) saturated with a culture medium (M-endo agar), selective for coliform growth. The Petri dish containing the filter and pad were later incubated upside down for 24 hours at 44.5 °C. The *E. coli* colonies were identified and counted using a microscope and recorded in colony-forming units per 100 mL (CFU/ 100 mL).

Quality Assurance and Control

The quality assurance and quality control, QA/QC, procedures were followed throughout the analytical steps. Blanks and recovery tests were determined to check for the accuracy of the method and the reliability of the results obtained. Procedural blank samples were included in every batch and were subjected to similar treatments as normal samples. Blank correction of the samples was done as appropriate. In addition, calibration of all the instruments was done prior to any measurement.

Data Analysis

Data were analysed using IBM SPSS (v. 23). A two-tailed Student t-test was performed to determine the difference in the means between seasons at $p < 0.05$ and 95% confidence level. Where the t-test normality test failed for a given variable (e.g. TSS, nitrate, phosphate, colour, turbidity and *E. coli*), the Mann-Whitney Rank sum test was performed. Pearson correlation and Principal Component Analysis (PCA) were also performed to assess the correlation and associations between variables. Graphing was done using SigmaPlot (v. 11.0).

RESULTS AND DISCUSSION

Levels of water quality parameters

Temperature

The levels of water quality parameters in the Zigi river are given in Figures 1 and 2. The mean temperature values of water from the Zigi ranged from 28 ± 0.49°C to 32.2 ± 0.8 °C in the dry season and from 24.05 ± 0.15 °C to 26.5 ± 0.26 °C in the wet season. There were higher water temperatures during the dry season compared to the wet season in all sites (Figure 1a). The mean observed values of temperature were higher than those observed from a pristine Sakale point (25.0 ± 0.6°C) in the dry season but lower than the Sakale values in the wet season. The mean temperature of the water was relatively increasing downstream in both seasons (Figure 1a). The difference in the mean values between the wet and dry season water temperatures in the Zigi river is statistically significant ($p = 0.001$). The observed mean temperatures of water at all sites were lower than the maximum value of 35 °C set by TBS (TBS, 2016).

The variation of geochemical parameters in a river depends on, among others, (i) the presence of soluble or highly weathered minerals such as gypsum or calcite, (ii) precipitation (iii) the presence of hotspots that release an enormous amount of organic matter, (iv) temperature, (v) soil cover and (vi) thickness of the weathered mineral rock (Chapman, 1996). Anthropogenic activities have a tendency of enhancing natural processes like leaching and erosion. As a result, natural and artificial compounds are added, altering the physic-chemical parameters and increasing the burden in the water.

Water temperature in natural conditions fluctuates between 0 °C and 30 °C (Chapman, 1996). The temperature of the running water tends to gradually increase from the source downstream due to increased metabolic activities caused by wastewater discharges from different sources. Anhwange et al., (2012) observed that the temperature of any given water may determine the rate of metabolism in an aquatic ecosystem. As expected, the temperature of the Zigi water was increasing with increasing distance in both seasons. The high temperature of the water favours microbial growth, which may consequently deteriorate the colour, odour and taste of water (WHO, 2011). Microbial activities as well as wastewater discharges increase the water temperature to levels that pose problems to organisms due to increasing levels of toxic substances and increased oxygen demand, and hence low dissolved oxygen (Walczyńska and Sobczyk, 2017).

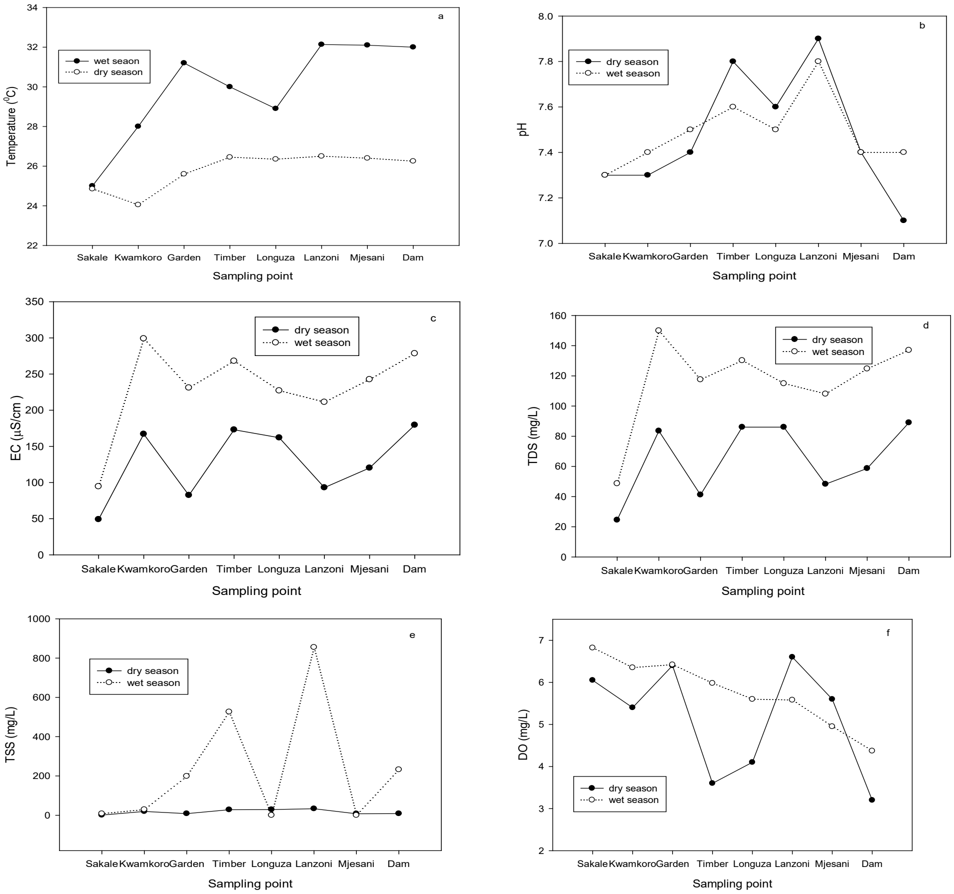

Figure 1: Seasonal variation of temperature (a), pH (b), EC (c), TDS (d), TSS (e) and DO (f) in the Study area

The mean pH values in the Zigi River varied from 7.1 ± 0.05 to 7.9 ± 0.2 in the dry season and 7.30 ± 0.04 to 7.8 ± 0.2 in the wet season. The pH levels were higher than the values observed in Sakale (7.3 ± 0.08) in both seasons. In fact, the levels were more or less similar to the lower boundaries of the observed pH values in both seasons. The mean pH values of the water were relatively increasing downstream in both seasons (Figure 1b). The difference in the mean values of pH between wet and dry seasons was not statistically significant ($p = 0.912$). The mean pH values were lower than the WHO and TBS set standards of 8.5 and 9.2, respectively.

The pH influences many biological and chemical processes (Chapman, 1996). A change in pH is a good indicator of the presence of effluents (pollutants), particularly when measured together with EC (Chapman, 1996). Most natural waters have a pH ranging from 6.0 to 8.5. The observed pH values in the Zigi river water were within the recommended optimal range in both seasons. A decrease or increase in pH has implications for the quality of water. For example, water pH below 4.5 favours solubility of some metals to levels that may be toxic (Gensemer and Playle, 1999). Lower pH makes water to be corrosive. Similarly, high pH values can alter the toxicity of other pollutants.

Electrical Conductivity

EC values varied from 82.3 ± 3.4 µS/cm L to 179.5 ± 5.7 µS/cm in dry season and from 7.4 ± 0.04 µS/cm to 299.0 ± 0.2 µS/cm in wet season. The mean EC values in other sites were higher than the values observed in a pristine Sakale site (49 ± 3.0 µS/cm to 94.5 ± 18.15 µS/cm) in both seasons. The mean values in the dry season were lower than the mean values in the wet season in all sites (Figure 1c). The mean EC values were relatively increasing downstream in both seasons. The difference in the mean values between the wet and dry season EC in the Zigi river is statistically significant ($p = 0.003$). Mean EC values observed were lower than the TBS and WHO standards of 1000 µS/cm except at Sakale and Garden sites in the dry season.

Conductivity is used as a substitute for salinity measurements (Dodds, 1998). Freshwater usually has EC between 0 and 1,500 µS/cm and higher conductivity values are expected for typical seawater (e.g. 50,000 µS/cm). High conductivity values in freshwater always indicate the extent of pollution (Raut et al., 2011). Conductivity values below 50 µS/cm are regarded as low, while those which are above 600 (µS/cm) are taken as high. Conductivity >1000 µS/cm is an indication of pollution or land runoff (Chapman, 1996). Low levels of salts found naturally in waterways are important for plants and animals to grow. High levels of salts in freshwater can cause problems to humans and aquatic organisms, thus becoming unfit for use. Observed conductivity values in the Zigi river is an indication that water has acceptable values for use. However, EC values were increasing downstream in both seasons probably due to increased salts from anthropogenic activities. Atekwana et al., (2004) observed that increase in the concentration of organic, inorganic and dissolved salts in water may increase the TDS in water.

TDS

TDS varied from 41.18 ± 2.49 mg/L to 89.0 ± 2.2 mg/L in dry season and from 108.0 ± 4.61 mg/L to 149.9 ± 5.80 mg/L in wet season. The mean values of TDS in other sites were higher than those from a pristine Sakale site (24.5 ± 1.2 mg/L to 48.6 ± 2.9 mg/L) in both seasons. The mean values were relatively the same in all sites in the dry season but had an irregular trend in the wet season (Figure 1d). The difference in the mean values of TDS between seasons was statistically significant ($p = 0.02$). The observed mean TDS values observed were lower than the TBS standard of 1000 mg/L but higher than the WHO standard of 50 mg/L except at Sakale, Garden, Lanzoni and Mjesani sites in the dry season.

TDS has an influence on water quality as water with extremely low concentrations of TDS may also be unacceptable because of its flat, dull taste. Similarly, extremely high TDS levels are unacceptable. TDS levels are categorized as excellent when the concentration is less than 300 mg/L, good when concentration is between 300 and 600 mg/L, fair when concentration is between 600 and 900 mg/L, poor when concentration is between 900 and 1200 mg/L and unacceptable when concentration is greater than 1200 mg/L (Bruvold and Ongerth, 1969). The observed TDS levels were in the range of 41.18 ± 2.49 mg/L to 89.0 ± 2.2 mg/L, which is acceptable (i.e. excellent condition). However, increased human activities may increase TDS in the water, making them unacceptable.

TSS

TSS mean values varied from 7.49 ± 1.50 mg/L to 33.35 ± 11.06 mg/L in dry season and from 29.03 ± 7.21 mg/L to 854.7 ± 110.6 mg/L in wet season. Dry season mean values of TSS were relatively similar in all sites but wet season mean values had an irregular trend (Figure 1e) that was generally increasing downstream. The mean TSS values in other sites were higher than those observed at a pristine Sakale site (0.93 ± 0.16 mg/L to 7.9 ± 3.32 mg/L) in both seasons. There was no statistically significant difference in the median values of TSS between the two seasons ($p = 0.382$). No WHO or TBS set standard was available for comparison.

Higher TSS values observed in both seasons indicate that there are continuous anthropogenic activities taking place in the study area regardless of the season. In the study area, there are a lot of subsistence farming activities during the wet season and local scale mining activities during the dry season. These activities could result in higher TSS in the river water. Also, there could be increased river flow at some sites which increases the turbulence and thus more suspended solids are observed.

DO

Dissolved oxygen (DO) varied from 3.2 ± 0.5 mg/L to 6.6 ±0.3 mg/L in dry season and from 4.4 ± 0.1 mg/L to 6.4 ± 0.2 mg/L in wet season. The mean values of DO in other sites were relatively lower than those from a pristine Sakale site (6.1 ± 0.29 mg/L to 6.82 ± 0.08 mg/L). There was no regular trend in both seasons, but there was a decreasing trend downstream in both seasons (Figure 1f). The difference in the mean values of DO between wet and dry seasons in the Zigi river was not statistically significant ($p = 0.260$). DO standards set by WHO and TBS were not available.

DO in rivers may vary between seasons. The decrease in DO of water is due to its poor ability to hold oxygen at high temperatures as a result of the higher rate of microbial metabolism. According to Gupta and Gupta, (2006), the atmosphere and photosynthesis are sources of dissolved oxygen in the aquatic environment and depends on its solubility. DO values close to 10 mg/L, indicates unpolluted water and below 2 mg/L, indicates polluted water or low dissolved oxygen that may lead to the death of aquatic organisms (Chapman, 1996). DO levels in the Zigi river were higher than 2 mg/L, but less than 10 mg/L. The Do levels were, however, decreasing downstream in both seasons. This clearly indicates that the extent of pollution was increasing downstream. Reduced DO levels are associated with high metabolic activities of aerobic bacteria during the decomposition of dead decaying matter. The observed low level of DO in the study area could be associated with the anthropogenic activities that produce a lot of organic matter into the river. The decreased DO is also associated with the increased temperature that favoured increased microbial activities.

Nitrate

The mean nitrate values varied from 2.2 ± 0.96 mg/L to 15.87 ± 4.0 mg/L in dry season and from 8.69 ± 0.69 mg/L to 39.4 ± 3.20 mg/L in wet season. The mean nitrate values observed in other sites were higher than those from a pristine Sakale site (0.05 ± 0.05 mg/L to 0.08 ± 0.07 mg/L) in both seasons. Mean nitrate values in the dry season were lower than those in the wet season. The values were increasing downstream in both seasons (Figure 2a). The difference in the median values of nitrate between wet and dry seasons was statistically significant ($p = 0.05$). The determined nitrate values in all sites were lower than WHO and TBS standards of 50 mg/L and 75 mg/L, respectively.

Natural water usually has nitrate levels less than 0.1 mg/L nitrate-N and concentrations greater than 0.1mg/L indicates pollution. Nitrate levels less than 5 mg/L are indicative of pollution by wastes (human or animal) or fertilisers from water runoff. In rural areas where subsistence agriculture is a key economic activity, the use of nitrogenous fertilisers can be a major source. For example, Fried (1991) indicated that significant nitrate contamination was associated with agricultural development. Nitrate levels in the Zigi were generally increasing downstream in both seasons. But, the levels in both seasons were below the WHO recommended value is 50 mg/L or 113 mg/L nitrate-N (WHO, 2011) and TBS set standard. Exceptionally higher values were observed at the Kwamkoro site in both seasons. This could be due to poor farming practices. This is evidenced by the extensive tea plantation and subsistence farming along the Kihara River. It has been observed that poor farming practices can be a source of pollution in a river (Jambiya et al., 2011).

Phosphate

The mean phosphate values varied from 0.0 ± 0.0 mg/L to 0.17 ± 0.06 mg/L in dry season and from 0.0 ± 0.0 mg/L to 0.23 ± 0.06 mg/L in wet season. The mean phosphate values observed in other sites were relatively higher than those from a pristine Sakale site (0.0 ± 0.0 mg/L) in both seasons. Like nitrate values, the phosphate values in the dry season were lower than wet season values and the values were generally increasing downstream in both seasons (Figure 2b). The difference in the median values of phosphate between the wet and dry season values was not statistically significant ($p = 0.721$). The observed mean phosphate levels were lower than the WHO standard of 10 mg/L. No TBS value was available.

Phosphate levels in most natural waters have values in the range of 0.005 to 0.02 mg/L PO_4-P, while pristine areas can have as low as 0.001 mg/ PO_4^{3-}-P (WHO, 2011). High levels of phosphate are indicative of pollution and are responsible for eutrophic conditions. The phosphate values were generally low and were generally increasing downstream in both seasons. However, the levels were higher than the pristine areas. Exceptionally higher phosphate values were observed at Spice Garden in both seasons could be due to phosphate fertilizer applications during extensive subsistence farming at Chemka, Shebomeza, Mbomole and Mlesa along the Zigi River.

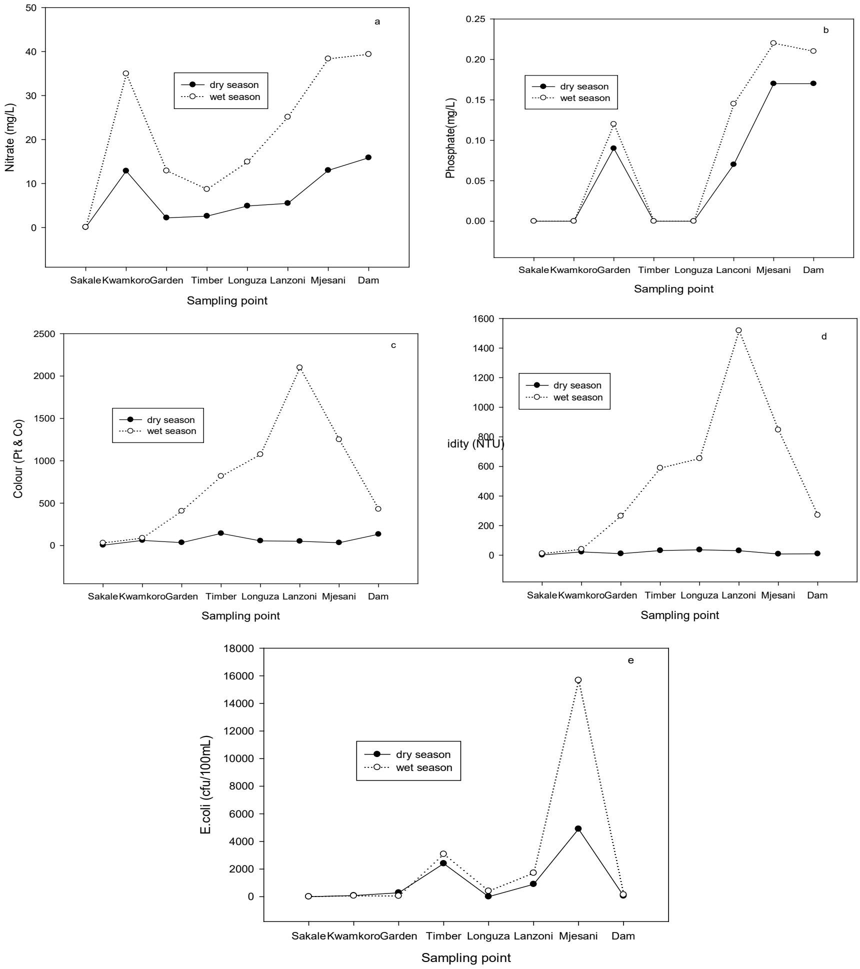

Figure 2: Seasonal variation of nitrate (a), phosphate (b), colour (c), turbidity (d) and *E. coli* (e) in the Zigi River

Apparent Colour

The apparent colour of water in the Zigi River varied from 33.0 ± 5.2 Pt-Co to 143.0 ± 13.6 Pt-Co in the dry season and from 40.0 ± 11.0 Pt-Co to 2099 ± 1013.2 Pt-Co in the wet season. The mean values of colour in the dry season were lower than wet season values. Whereas dry season values were similar in all sites, wet season values were generally increasing downstream (Figure 2c). The mean values of colour were higher than those from the pristine Sakale site (4.0 ± 1.67 Pt-Co to 31.0 ± 9.0 Pt-Co in both seasons. There is a statistically significant difference in the median values of colour between wet and dry seasons ($p = 0.015$). The mean apparent colour was higher than the TBS standard of 50 Pt-Co at all sites in the dry season and Sakale and Kwamkoro in both seasons.

The colour of water is an important physicochemical parameter, especially for drinking water. Colourless water is considered pure but it may be unsafe for human health. The colour of water during the wet season was generally increasing downstream, with values up to 2100 Pt-Co at some sites. The water colour in the dry season was more or less similar in all sites, but higher than the European Union (EU) standard of 20Pt-Co. This is an indication that the water contains other pollutants (e.g., organic matter) that changed the colour of the Zigi water. Water containing dissolved organic matter may form trihalomethane when in contact with chlorine during water treatment. For example, chloroform, which is a common trihalomethane, is considered to be a potential carcinogen. As a result, World Health Organisation (WHO) has set a limit for total trihalomethanes (TTHMs) in public water supplies at 0.1 ppm (100 ppb).

Turbidity

Turbidity values varied from 8.3 ± 4.1 NTU to 36.5 ± 10.6 NTUL in the dry season and from 40.00 ± 11.06 NTU to 1518 ± 718 NTU in the wet season. Similar to colour, mean values of turbidity were lower in the dry season than in the wet season. Furthermore, dry season values were similar in all sites, while wet season values were generally increasing downstream (Figure 2d). Turbidity values in the Zigi water were higher than the values from a pristine Sakale site (1.8 ± 0.4 NTU to 10.83 ± 4.26 NTU) in both seasons. The difference in the median values of turbidity between wet and dry seasons was statistically significant ($p = 0.002$). The observed turbidity values in the dry season and at Sakale and Kwamkoro in both seasons were lower than the WHO standard of 5.0 NTU, while in the wet season were higher than the WHO standard.

Natural processes, as well as human activities, have a tendency of increasing turbidity. Turbidity was more pronounced during the wet season probably due to increased subsistence farming during the season. In addition, anthropogenic activities such as cultivation and settlement can increase the sediment load in the river. Larsen et al., (2011) observed that land-use practices such as ploughing near the stream bank, on the steep slopes and clearance of riparian vegetation are likely to increase sediment load (Pettigrove and Hoffmann 2003; Carew et al. 2007). Turbidity was increasing downstream and the high turbidity values at Lanzoni in both seasons are linked to the sisal plantation as well as subsistence farming along the Muzi river.

E.coli

The mean number of *E.coli* varied from 58 ± 24 CFU/ 100 mL to 4900 ± 3387 CFU/ 100 mL in dry season and from 46 ± 44 CFU/ 100 mL to 15675 ± 4603 CFU/ 100 mL in wet season. The dry season numbers were relatively lower than those in the wet season and they were increasing downstream in both seasons (Figure 2e). The mean numbers of *E.coli* in the Zigi were higher than those detected in the pristine Sakale site (1-2 CFU/ 100 mL) in both seasons. The difference in the median values of *E.coli* between seasons was not statistically significant ($p = 0.721$). The values of *E.coli* observed were higher than the WHO and TBS standard values of 0 CFU/ 100 mL in both seasons.

The presence of coliform bacteria in a drinking water source in both seasons is evidence of contamination by faecal material. In areas where animal and human wastes are inappropriately collected and treated like the developing countries, faecal contamination is the predominant water quality problem in rivers (Chapman, 1996). High amounts of *E.coli* bacteria in the water are detrimental as may cause urinary tract infections (Gannon and Busse, 1989, Edberg et al., 2000). Faecal coliforms were generally increasing downstream in both seasons to around 4000 CFU/100 mL during the dry season and around 16,000 CFU/100 mL during the wet season. High levels were restricted at Mjesani, which could be linked to the settlement expansion and agro-pastoral activities in the area. Their presence in drinking water is a very serious concern due to its detrimental health effects on humans.

Relationships between Water Quality Variables

Correlation between Water Variables

Pearson correlation coefficients were determined using the mean values of the selected geochemical parameters in both seasons. Table 1 has indicated that pH in both seasons was positively correlated with TSS ($r^2 > 0.81$) and turbidity ($r^2 > 0.69$) in both seasons. Similarly, while TDS in both seasons was correlated to EC in both seasons ($r^2 > 0.80$), phosphate was positively correlated with nitrate in both seasons ($r^2 > 0.61$). Temperature in both seasons correlated positively with TSS ($r^2 > 0.65$) and turbidity ($r^2 > 0.61$) in wet season. The pH in both seasons positively correlated with colour in the wet season ($r^2 > 0.75$). Phosphate in both seasons correlated positively with temperature in the dry season ($r^2 > 0.75$) and negatively correlated with DO in the wet season ($r^2 > -0.76$) and positively correlated with *E. coli* in both seasons ($r^2 > 0.53$).

In the wet season, pH was positively correlated with temperature ($r^2 = 0.542$) and colour ($r^2 > 0.75$), colour was positively correlated with TSS ($r^2 = 0.972$) and DO was negatively correlated with both EC ($r^2 > -0.838$) and TDS ($r^2 > -0.833$). Moreover, while nitrate was negatively correlated to EC ($r^2 = 0.672$), turbidity was positively correlated to temperature ($r^2 = 0.717$) and TSS ($r^2 = 0.973$). In addition, TSS was positively correlated with *E. coli* ($r^2 = 0.754$) and temperature positively correlated with TSS ($r^2 = 0.795$).

In the dry season, DO was negatively correlated with EC ($r^2 = -0.838$) and TDS ($r^2 = -0.833$). Colour was positively correlated with EC ($r^2 = 0.80$) and TDS ($r^2 =0.779$) but negatively correlated with DO ($r^2 = -0.831$). Similarly, TDS was positively correlated with turbidity ($r^2 = 0.548$). Furthermore, temperature in the dry season was positively correlated with EC ($r^2 = 0.568$), TDS ($r^2 = 0.588$), TSS ($r^2 = 0.649$), turbidity ($r^2 = 0.61$) and nitrate ($r^2 = 0.597$) in wet season and negatively correlated with DO ($r^2 = -0.725$) in wet season. Further positive correlations were observed between TSS in dry season and colour in wet season ($r^2 = 0.638$) as well as between turbidity in dry season and TSS in wet season ($r^2 = 0.747$). Scatter plots showing the relationships between some of the analysed variables are given Figure 3.

Table 1 Pearson Correlation Coefficients of the Analysed Parameters in Wet and Dry Seasons

	T^d	T^w	pH^d	pH^w	EC^d	EC^w	TDS^d	TDS^w	TSS^d	TSS^w	DO^d	DO^w	NO_3^d	NO_3^w	Colour d	Colour w	TU^d	TU^w	*E.Coli* d	*E.coli* w	PO_4^d	PO_4 w
T^d	1																					
T^w	**0.689**	1																				
pH^d	0.208	0.493	1																			
pH^w	0.518	0.542	**0.873**	1																		
EC^d	0.273	0.185	-0.046	0.029	1																	
EC^w	0.568	0.118	-0.030	0.183	**0.835**	1																
TDS^d	0.256	0.198	-0.012	0.056	**0.997**	**0.815**	1															
TDS^w	0.588	0.114	-0.030	0.187	**0.808**	**0.997**	**0.790**	1														
TSS^d	0.229	0.363	**0.825**	**0.816**	0.407	0.352	0.452	0.347	1													
TSS^w	**0.649**	**0.795**	**0.861**	**0.964**	0.051	0.130	0.071	0.132	**0.826**	1												
DO^d	-0.096	-0.326	0.154	0.156	**-0.838**	-0.478	**-0.833**	-0.429	-0.157	0.053	1											
DO^w	**-0.725**	**-0.650**	0.142	-0.094	-0.520	-0.471	-0.508	-0.475	-0.053	-0.353	0.516	1										
NO_3^{-1d}	0.447	-0.005	-0.493	-0.242	**0.582**	**0.659**	**0.550**	**0.673**	-0.129	-0.142	-0.340	**-0.731**	1									
NO_3^{-1w}	**0.597**	0.077	-0.333	-0.044	0.484	**0.672**	0.456	**0.699**	-0.020	0.057	-0.161	**-0.729**	**0.964**	1								
Colour d	0.378	0.381	0.093	0.235	**0.800**	**0.659**	**0.779**	**0.606**	0.347	0.297	**-0.831**	-0.486	0.324	0.238	1							
Colour w	**0.610**	**0.734**	**0.751**	**0.806**	-0.029	0.060	-0.001	0.087	**0.638**	**0.972**	0.177	-0.412	-0.004	0.194	0.010	1						
TRB^d	0.143	0.328	**0.754**	**0.698**	0.497	0.382	**0.547**	0.375	**0.975**	**0.747**	-0.271	-0.028	-0.142	-0.070	0.365	0.524	1					
TRB^w	**0.610**	**0.717**	**0.765**	**0.828**	-0.055	0.050	-0.031	0.076	**0.634**	**0.973**	0.204	-0.387	-0.019	0.184	0.019	**0.997**	0.506	1				

E. coli^d	0.428	0.442	0.223	0.060	0.048	0.172	0.012	0.189	-0.046	**0.630**	0.020	-0.347	0.221	0.287	0.031	0.407	-0.087	0.410	1			
E. coli^w	0.401	0.370	0.053	-0.086	-0.015	0.110	-0.047	0.142	-0.176	**0.754**	0.097	-0.409	0.339	0.403	-0.146	0.379	-0.208	0.369	**0.957**	1		
PO_4^{-3d}	**0.750**	0.432	-0.374	-0.084	0.028	0.254	-0.011	0.278	-0.417	0.138	-0.035	**-0.765**	**0.618**	**0.672**	0.105	0.226	-0.488	0.222	0.432	**0.533**	1	
PO_4^{-3w}	**0.776**	0.495	-0.225	0.075	0.014	0.219	-0.018	0.244	-0.264	0.363	0.008	**-0.808**	**0.625**	**0.705**	0.109	0.404	-0.372	0.406	0.440	**0.535**	**0.967**	1

Bold values are significant at the level of 0.05 (2-tailed). T = temperature; TRB = turbidity; Superscripts *d* and *w* indicate dry and wet seasons, respectively

Figure 3 has indicated that DO was decreasing with increasing temperature (Figure 3a). This implies that increasing temperature decreased the DO due to decreasing solubility of oxygen. On the other hand, the temperature has been shown to have no direct relationship with pH (Figure 3b) and turbidity (Figure 3f).

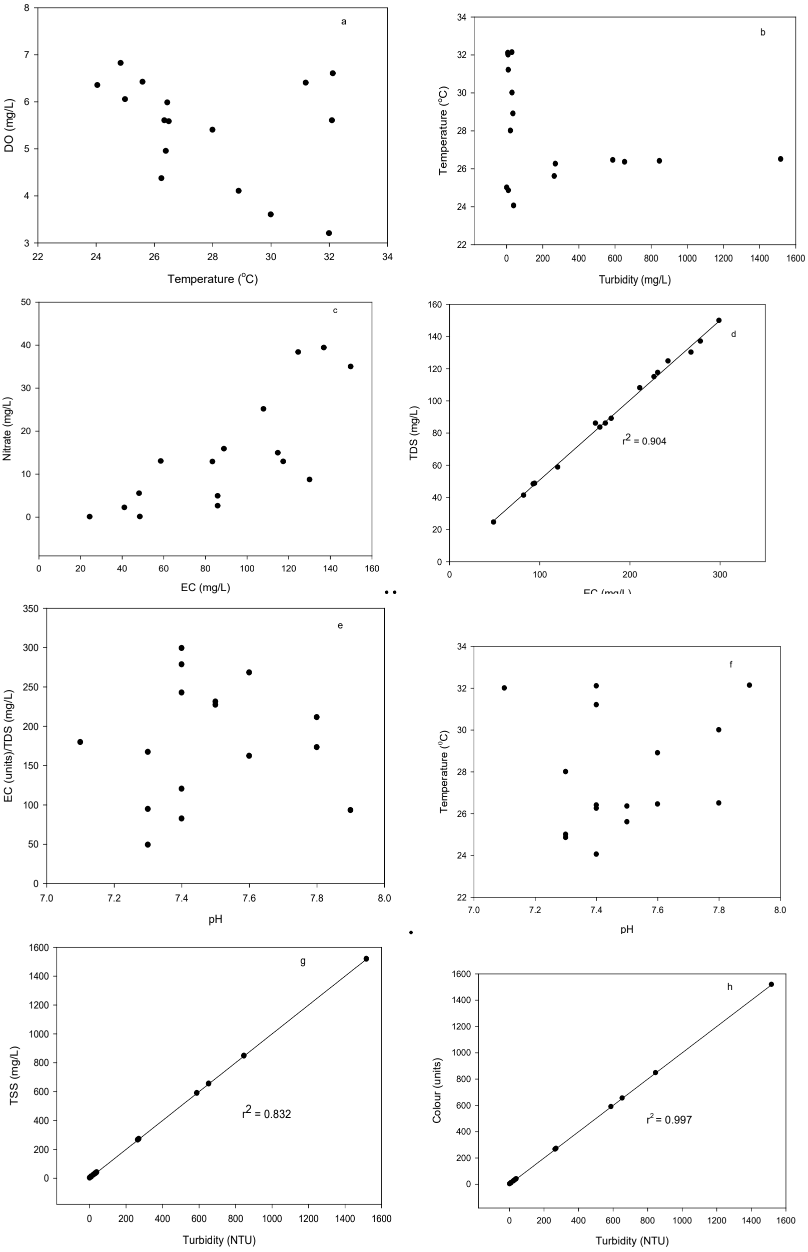

Figure 3: Scatter plots showing relationships between analysed parameters

EC in this river was increasing with increasing nitrate (Figure 3c) and TDS (Figure 3d), indicating that increasing nitrate levels such as by applying nitrogenous fertilisers in agricultural fields as well as TDS will increase EC in the river water. The EC, however, has no direct relationship with pH (Figure 3e). Turbidity was increasing with increasing TSS (Figure 3g) and colour (Figure 3h), which implies that any activity that increases TSS and water colour will increase turbidity. Most activities that can increase TSS, water colour, TDS as well as nitrates are usually anthropogenic, increasing one or more of these parameters will not only increase the parameters but also may affect the temperature and pH as well.

Principal Component Analysis

In order to determine the relationship between variables, multivariate analysis such as Principal component analysis (PCA) after varimax rotation with Kaiser normalisation can be used to compare and contrast the variables, aiming at detecting relationships and possible common source. In this study, a principal component (PC) or varifactor was considered significant when its eigenvalue was greater than 2 (Singh et al., 2004, Shrestha and Kazama, 2007). The measured physicochemical parameters were used as variables (total 11), with the concentrations of the physicochemical parameters obtained during wet and dry seasons in the different sampling stations as objects (total 176). Prior to analysis, the suitability of these data for PCA analysis was checked by performing Kaiser–Meyer–Olkin (KMO) and Bartlett’s sphericity tests. The determined KMO was 0.74 and the value for Bartlett’s test of sphericity was 216.78 ($p = 0.000$), indicating that this is a useful statistic in this study (Varol, 2011; Li et al., 2013).

The application of PCA indicated that the 11 variables from each season can be represented by 3 new varifactors that accounted for 88.92% of the total variance in the original data sets (Table 2). Based on the loading distribution of the variables, TSS, pH, turbidity, *E. coli* as well as wet season colour and temperature had strong loadings in the PC1, explaining 37.62% of the variance. Similarly, TDS, EC, nitrate as well as dry season colour and DO have strong loadings in the PC2, which explained 30.4% of the variance (Table 2). Phosphate as well as dry season temperature and wet season DO have strong loadings in the PC3, which explained 20.89% of the variance. Wet season nitrate had strong positive loading in both the second and third varifactors.

Table 2 Rotated Principal Component Matrix

Parameter	**1st PC**	**2^{nd} PC**	**3^{rd} PC**
TSS^w	**0.961**	-0.021	0.262
pH^d	**0.958**	-0.144	-0.237
pH^w	**0.958**	-0.039	0.196
$Turbidity^w$	**0.908**	-0.159	0.329
$Colour^w$	**0.902**	-0.153	0.348
TSS^d	**0.883**	0.300	-0.088
$E.coli^w$	**0.867**	0.259	-0.308
$Turbidity^d$	**0.836**	0.411	-0.189
$E.coli^d$	**0.778**	0.307	-0.408
$Temperature^w$	**0.708**	0.075	0.452
EC^d	0.054	**0.995**	0.057
TDS^d	0.073	**0.993**	0.063
EC^w	0.135	**0.892**	0.171
TDS^w	0.133	**0.866**	0.189
$Colour^d$	0.284	**0.856**	0.142
DO^d	0.072	**-0.811**	-0.067
$NO_3^{-1\ d}$	-0.291	**0.704**	0.517
NO_3^{-1w}	-0.103	**0.616**	**0.609**
PO_4^{-3w}	0.107	0.097	**0.982**
PO_4^{-3d}	-0.098	0.143	**0.947**
DO^w	-0.147	-0.520	**-0.781**
$Temperature^d$	0.523	0.322	**0.699**
Eigen value	8.28	6.69	4.60
Contribution Rate (%)	37.62	30.40	20.89
Accumulated contribution rate (%)	37.62	68.02	88.92

Superscripts *d* and *w* indicate dry and wet seasons, respectively

Combining the results of the Pearson correlation and the PCA (Tables 1 and 2), it is clearly indicated that water colour in the dry season is more related to EC and TDS compared to water colour in wet season, which is more related to pH and wet season turbidity and TSS (Figure 4). This is an indication that colour is affected by EC and TDS in the dry season while in the wet season colour is affected by turbidity, TSS and pH. *E. coli* is more related to turbidity and TSS in the dry season whereas pH is more related to turbidity and TSS in the dry season (Figure 4). This could mean that change of seasons could change the effect of turbidity and TSS on other variables. Figure 4 has also shown that wet season temperature is more closely related to pH and wet season TSS, turbidity and DO, indicative of the fact that temperature during the wet season is more influenced by TSS, turbidity and DO than dry season temperature. On the other hand, phosphate, nitrate and dry season DO were not related to each other as well as not to other variables. This could indicate that these variables are not related to each other and other variables and that there could other factors that control their levels.

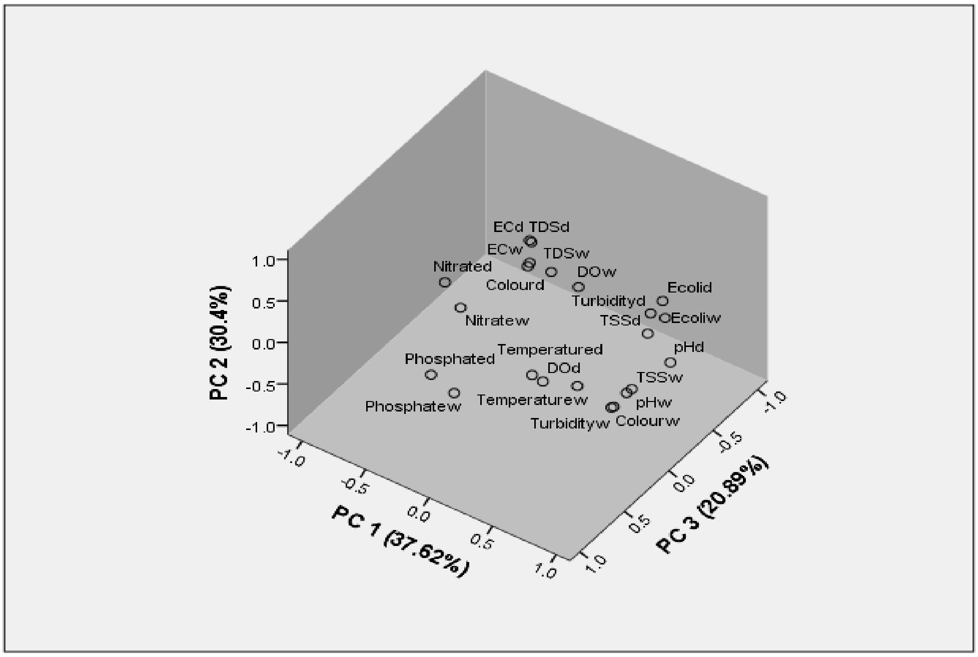

Figure 4: Three-dimensional score plot of geochemical parameters in Zigi River

Assessment of Water quality using the Water Quality Index

The quality of the drinking water can be evaluated using the water quality index (WQI). In order to compute the WQI, each geochemical parameter was assigned a weight (w_i) based on the relative significance in determining the overall quality of the drinking water (Vasanthavigar et al., 2010) as shown in Table 1. A weighted value of 5 was assigned to geochemical parameters that have a significant effect on water quality. Thus, TDS, nitrate, nitrite and phosphate were assigned wi of 5 due to their significance in the assessment of water quality (Ramakrishnalah et al., 2009). Temperature and TSS were the minimum weight of 1 due to an insignificant role in the water quality assessment. Other geochemical parameters were assigned weights between 1 and 5 depending on their relative significance in the assessment of water quality. A total of 11 geochemical parameters were used in the computation.

The wi was then used in computing the relative weight (Wi) according to equation 1:

$$Wi = \frac{wi}{\sum_i^n wi} \qquad 1$$

where, *Wi* = relative weight, *wi* = weight of geochemical parameter *i* and *n* = total number of geochemical parameters.

The quality rating scale (qi) was computed using the observed values of the geochemical parameters and the available guideline value (e.g., WHO or TBS) according to equation 2:

$$qi = \frac{Ci}{Si} \times 100 \qquad 2$$

where, *qi* = quality rating, *Ci* = observed value of geochemical parameter *I* in the water, and Si = WHO or Tanzania Bureau of Standards (TBS) guideline value/ acceptable limit of water standard. All calculations used WHO set standards except where there is no such standard.

The WQI of each river system was finally computed using the *Wi* and *qi* using equation 3;

$$WQI = \sum_i^n si = \sum_i^n (Wi \times qi) \qquad 3$$

The summary of the computed WQI results is presented in Table 3.

Table 3: Calculated water quality indexes by season

Geochemical Parameter	Mean levels		WHO[a]	TBS[b],	Weight (*wi*)	Relative weight (*Wi*)	*Qi*		*Si*	
	Wet season	Dry season					Wet season	Dry season	Wet season	Dry season
pH	7.5 + 0.2	7.5 + 0.3	<8.5	<9.2	4	0.105	88.24	88.24	9.29	9.29
Temperature (°C)	25.9 + 0.9	29.7 + 2.9		<35	2	0.053	74	84.86	3.89	4.47
TDS (mg/L)	84.9 + 24.6	54.4 + 23.0	50	1000	5	0.132	169.8	108.8	22.34	14.32
EC (µS/cm)	172.8 + 51.0	110.6 + 46.7	100	1000	5	0.132	172.8	110.6	22.74	14.55
TSS (mg/L)	308.1+ 326.2	16.8 + 4.2	30	100	1	0.026	1026.67	56	27.02	1.47
DO (mg/L)	5.8 + 0.8	5.0 + 1.3	5	6	3	0.079	116	100	9.16	7.89
Nitrate (mg/L)	3.8 + 3.5	2.2 + 2.4	50	75	5	0.132	7.6	4.4	1	0.58
Phosphate (mg/L)	0.1 + 0.1	0.08 + 0.08	10		5	0.132	1	0.8	0.13	0.11
FC (cfu/100 mL)	2347 + 5107.7	1230 + 1828.6	0	0	5	0.132	234700	123000	30881.6	16184
Colour (mg-Pt/L)	689.8 + 695.1	57.5 + 50.1		50	2	0.053	1379.6	115	72.61	6.05
Turbidity (NTU)	466.5 + 497.6	17.0 + 13.4	5		1	0.026	9330	340	245.53	8.95
Σ					38	1.000	**WQI**		**31295.3**	**16252**

[a]WHO, (1996, 2004, 2011); [b]TBS, (2016)

The computed WQI values were then compared with the range of WQI used to classify water for drinking water using the established criteria (Table 43).

Table 4: Drinking Water Classification based on WQI (Sahu and Sikdar 2008)

Level	Range	Classification
1	<50	Excellent
2	50 - 100	Good
3	100 - 200	Poor
4	200 - 300	Very poor
5	>300	Unsuitable

The findings have indicated that the general water quality in the Zigi River is at level five in both seasons. In addition, the water quality index during the wet season was worse than during the dry season. This implies that water quality in both seasons is unsuitable for use as drinking water and that during the wet season the water is more unsuitable for use than during the dry season. The unsuitability of the water from this river in both seasons imply that much more treatment costs in terms of chemicals and time will be needed to make this water suitable for drinking.

CONCLUSION

The levels of selected geochemical parameters in the Zigi River have been determined. Temperature, EC, TDS, TSS, nitrate, colour, turbidity and *E. coli* were higher in wet season probably due to increased river flow during wet season. Wet season levels of TSS, colour and turbidity also increased due to increased river runoff. Temperature, EC, TDS, nitrate and *E. coli* were increasing and DO decreasing downstream in both seasons probably due to increased anthropogenic activities along the river. This implies that water quality was decreasing downstream due to increased anthropogenic activities that cause pollution of the river. Seasonal water quality indicia have indicated that the water in the Zigi River is not suitable for drinking purposes in its current state. This has a great implication for the treatment costs of the water. Immediate measures are recommended to minimise further diminishing quality of the water in this river and thus minimise the costs of treating the water for domestic use.

REFERENCES

Anhwange, B. A., Agbaji, E. B., and Gimba, E. C. (2012). Impact assessment of human activities and seasonal variation on River Benue, within Makurdi Metropolis. *Int. J. Sci. Technol*, 2(5): 245-253.

Atekwana, E. A., Atekwana, E. A., Rowe, R. S., Werkema, D. D., and Legall, F. D. (2004). The relationship of total dissolved solids measurements to bulk electrical conductivity in an aquifer contaminated with hydrocarbon. *Journal of Applied Geophysics,* 56(4): 281-294.

Bruvold, W.H., and Ongerth, H. J., (1969). Taste quality of mineralized water. *Journal of the American Water Works Association* 61: 170-174.

Odonkor, S. T., and Ampofo, J. K. (2013). *Escherichia coli* as an indicator of bacteriological quality of water: an overview. *Microbiology Research*, *4*(1), e2. https://doi.org/10.4081/mr.2013.e2.

Carew, M. E., Pettigrove, V., Cox, R. L., andHoffmann, A. A. (2007). The response of Chironomidae to sediment pollution and other environmental characteristics in urban wetlands. *Freshwater Biology*, 52(12), 2444-2462.

Chapman, D., (Ed), (1996). Water Quality Assessments: A Guide to the Use of Biota, Sediments and Water in Environmental Monitoring, 2nd Edition. E&FN Spon, an imprint of Chapman & Hall.

Dodds, W. K., Jones, J. R., and Welch, E. B. (1998). Suggested classification of stream trophic state: distributions of temperate stream types by chlorophyll, total nitrogen, and phosphorus. *Water Research,* 32(5), 1455-1462.

Edberg, S. C. L., Rice, E. W., Karlin, R. J., and Allen, M. J. (2000). Escherichia coli: the best biological drinking water indicator for public health protection. *Journal of Applied Microbiology,* 88(S1).

Fried, J. J., (1991). Nitrates and their control in the EEC aquatic environment. In Nitrate Contamination (pp. 3-11). Springer Berlin Heidelberg.

Gannon, J. J., and Busse, M. K. (1989). E. coli and enterococci levels in urban stormwater, river water and chlorinated treatment plant effluent. *Water Research*, 23(9), 1167-1176.

Greenberg, A.E., Connors, J.J. and Jenkins, D., Eds (2005). Standard methods for the examination of water and wastewaters, 20th Edition, American Public Health Association (APHA), American

Water Works Association (AWWA) and Water Pollution Control Federation (APCF).

Gupta S.K, Gupta R.C., (2006). General and applied ichthyology (fish and fisheries). New Delhi: S. Chand and Company Ltd. Ram Nagar.

Hamilton, A. C., and Bensted-Smith, R., (Eds.) (1989). Forest conservation in the East Usambara Mountains, Tanzania (Vol. 15). IUCN.

Jambiya, G., Liwenga, E., and Shemdoe R., (2011). Livelihoods and Land Tenure Assessment Study for Equitable Payments for Watershed Services (EPWS) Programme in the East Usambara Mountains, Zigi River Basin WWF Tanzania Country Office. Unpublished consultancy report.

Larsen, S., Pace, G., and Ormerod, S. J. (2011). Experimental effects of sediment deposition on the structure and function of macroinvertebrate assemblages in temperate streams. *River Research and Applications*, 27(2), 257-267.

Li, F., Huang, J., Zeng, G., Yuan, X., Li, X., Liang, J., Wang, X., Tang, X., Bai, B., (2013). Spatial risk assessment and sources identification of heavy metals in surface sediments from Dongting Lake, Middle China. *J. Geochem. Explor.* 132, 75–83.

Gensemer R. W., and Playle R.C., (1999). The Bioavailability and Toxicity of Aluminum in Aquatic Environments, Critical *Reviews in Environmental Science and Technology*, 29(4): 315-450, DOI: 10.1080/10643389991259245.

Kapinga, A., Sangodoyin, A., and Ogunkoya, O. (2019). Traditional Utilization of Aquatic Resources in Eastern Arc Catchments of Tanzania. *Natural Resources*, 10: 153-178. doi: 10.4236/nr.2019.105011.

Masikini R., Kaaya L. T., and Chicharo L., (2018). Evaluation of ecohydrological variables in relation to spatial and temporal variability of macroinvertebrate assemblages along the Zigi River – Tanzania, *Ecohydrology & Hydrobiology,* 18(2): 130-141. https://doi.org/10.1016/j.ecohyd.2018.03.004.

Mwanyoka I. R., (2005). Payment for Water Services as a Mechanism for Watershed Management: The Case of the Sigi River Catchment, Tanga, Tanzania. A Research Report Submitted To WWF-Tanzania Programme Office. Accessed on 25th February 2022 at https://www.cepf.net/sites/default/files/wwf.pse_.report.pdf

Pettigrove, V., andHoffmann, A. (2003). Impact of urbanisation on heavy metal contamination in urban stream sediments: influence of catchment geology. *Australasian Journal of Ecotoxicology*, 9(2), 119-128.

Rahmanian, N., Ali, S. H. B., Homayoonfard, M., Ali, N. J., Rehan, M., Sadef, Y.and Nizami, A. S., (2015). Analysis of Physiochemical Parameters to evaluate Water Quality in the State of Perak, Malaysia. *Journal of Chemistry, Vol. 2015, 1-10.* http://dx.doi.org/10.1155/2015/716125.

Sahu, P., Sikdar P.K., (2008) Hydrochemical framework of the aquifer in and around East Kolkata Wetlands, West Bengal, India. *Environ Geol* 55(4):823–835.

Shrestha, S., and Kazama, F., (2007). Assessment of surface water quality using multivariate statistical techniques, a case study of the Fuji River basin, Japan. *Environ. Modell. Softw*. 22, 464–475.

Singh, K.P., Malik, A., Mohan, D., Sinha, S., (2004). Multivariate statistical techniques for the evaluation of spatial and temporal variations in water quality of Gomti River (India), a case study. *Water Res.* 38, 3980–3992.

Vasanthavigar, M., Srinivasamoorthy, K., Vijayaragavan, K., Rajiv Ganthi, R., Chidambaram, S., Anandhan, P., Manivannan, R., Vasudevan, S. (2010). Application of water quality index for groundwater quality assessment: Thirumanimuttar sub-basin, Tamilnadu, India. *Environ Monit Assess* (2010) 171:595–609 DOI 10.1007/s10661-009-1302-1.

TBS, (2016): Tanzania Potable Water Specifications- TZS 789:2016 – EAS 12:2014. ICS: 67.060.20, Third Edition, Dar es Salaam.

HACH (2011). USEPA Membrane Filtration Method (No 8074) for Coliforms –Total, Fecal and *E. coli*. DOC316.53.001224. HACH.

USEPA. (1991). Volunteer lake monitoring: *A methods manual.* EPA 440/4-91-002. Office of Water, U. S. Environmental Protection Agency, Washington, DC.

Varol, M., (2011). Assessment of heavy metal contamination in sediments of the Tigris River (Turkey) using pollution indices and multivariate statistical techniques. *J. Hazard. Mater*. 195, 355–364.

Walczyńska A., Sobczyk Ł., (2017). The underestimated role of temperature–oxygen relationship in large-scale studies on size- to-temperature response. *Ecology and Evolution*, 7:7434–744 DOI: 10.1002/ece3.3263.

WHO (2011). Guidelines for Drinking-water Quality, Fourth Edition, Geneva.

WHO, (1996)? Water Quality Assessments -A Guide to Use of Biota, Sediments and Water in Environmental Monitoring - Second Edition.

WHO, 2004. Guidelines for Drinking-water Quality. 3rd edition Vol. 1: Recommendations. WHO, Geneva.