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RESEARCH ARTICLE

Water Quality Evaluation in Costal Rivers of Tanzania Using Water Quality Index

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Abstract:

Water quality for drinking purposes is a global concern in both developed and developing countries. The quality of water in Zigi, Pangani, Ruvu, Wami, and Kizinga rivers used as drinking water sources in Tanzania was assessed using the water quality index (WQI). Most geochemical water parameters in rivers deviated negatively, indicative of meeting legal specifications. However, total dissolved solids (TDS) in Ruvu River, total suspended solids (TSS) in Wami and Zigi rivers, dissolved oxygen (DO) in Pangani, Zigi, and Kizinga rivers, ammonia in Wami River, and turbidity in Wami, Zigi, and Kizinga rivers deviated positively, indicating that they are responsible for water quality changes in rivers. Higher aquatic environment index values in Wami, Pangani, Zigi, and Kizinga rivers are indicative of a relatively good water environment, and vice versa in Ruvu River, indicative of anthropogenic activities. WQI indicated that the quality of water in these rivers ranged from good (Pangani River) to polluted (Zigi River), while other rivers were between this range. Frequent water quality monitoring campaigns are needed.

Keywords: Zigi River, Water quality index, Pangani River, Wami River, Ruvu River, Geochemical parameters

Introduction

Water is a fundamental human right due to its significant role in human welfare [1]. The chemistry of the water, and therefore the quality of water, is mainly governed by natural as well as human factors [2-3]. The natural factors affecting the water quality include the interaction of the water with the lithogenic structure during water flow, geochemistry as well as the chemical composition of the river.

The discharge of domestic wastewater, industrial sewage, and agricultural drainage water into the river are among the anthropogenic factors that can affect the quality of water [4]. The impacts are severe when human activities are more dominant than natural factors [5]. Land use activities such as industrialisation, agriculture, and urbanisation in the river catchments determine the amount as well as the quality of runoff from rainfall [6]. As a result, the quality of water in a river is related to the changes in land use activities as aggravated by population pressure.

The water quality of a river can be evaluated by analysing the physicochemical parameters [4], describing the reasons for the contamination [7], and then comparing with the international standards such as World Health Organization (WHO) as well as other regional or local set standards. The water quality criteria used usually specify the level of a given parameter, above or below which such water becomes not suitable for a certain purpose [5]. The most commonly used physicochemical parameters that describe water quality include temperature, dissolved oxygen (DO), pH, electrical conductivity (EC), turbidity, total dissolved solids (TDS), and total suspended solids (TSS). Of these, temperature, DO, pH, EC, and TDS play a significant role in the bioavailability and toxicity of contaminants as well as their dissolutions in the aqueous phase [5]. Further inclusion of bacteriological parameters (such as *Escherichia coli*, faecal coliforms, or total coliforms) provides a relatively comprehensive measure of water quality. Such assessment provides a measure that satisfies set standards for different uses of the water [7]. However, each parameter in such an assessment provides a criterion that might differ from the other and so there will be as many criteria as there are physicochemical and bacteriological parameters. As a result, getting a single measure of the water quality of a system becomes difficult. This can be achieved by using a water quality index [8], where a single qualitative and/ or quantitative value can be obtained.

Water quality index (WQI) is a single number obtained from a transformation of a large number of water quality data to represent the water quality of a water body [9]. WQI is a useful measure for characterising the potable water quality by using the composite influence of different water quality parameters on the overall quality of water [2,4,10]. Integrating a different and varying number of water quality parameters has resulted in the development of various water quality indices [4]. Examples of the developed national methods for determining water quality include the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI), United States National Sanitation Foundation Water Quality Index (NSF WQI), British Columbia Water Quality Index, and China Water Quality Identification Index (CWQII). Other regional and local WQI include Oregon WQI, and Florida Stream WQI [9]. The various developed WQIs are usually based on the comparison of water quality parameters to given standards to provide a single WQI value for a given source [2]. The major difference between these methods is the way statistics are integrated as well as the way the water parameters are interpreted [9].

Water quality assessment using the CCME WQI, for example, involves the assessment of the water quality of a water body relative to the available water quality guidelines, which can be site-specific or internationally accepted standards. The CCME WQI is determined by calculating the scope (F_1), frequency (F_2), and amplitude (F_3) [11] such that:

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

where F_1 = percentage of some parameters that did not meet the guideline (scope), F_2 = percentage of tests that did not meet the guideline (frequency), and F_3 = amount of the failed tests that did not meet the guidelines (amplitude).

The F_1, F_2, and F_3 have their respective calculation formula. This WQI method is useful when there is yearlong continuous monitoring (at least 10 samples per year) of the water body and the assessment is done using at least eight parameters (but < 20 parameters) of concern, sampled at least four times a year. WQI for a particular river can only be determined using CCME WQI when specific measured data for each parameter are available [11].

WQI that incorporate multivariate methods such as principal component analysis (e.g., [12]) as well as various modified methods of the already-developed methods (e.g. [13] and [14]), are available. In the multivariate analysis method, Euclidean distance is used as a measure of similarity. Here, the similarity coefficients of all the water parameters calculated using Euclidean distance are used to classify water variables using Q-mode Principal Component Analysis (Q-PCA), which is used for grouping cases. The resulting factor loadings of each variable in the PCA are employed to cluster the water source into the established water quality assessment groups. The principal components are used to decide the number of clusters based on the percentage variation of the principal components.

Assessment of the water quality index may also involve the use of the weighted arithmetic method, which is a modified NSFWQI [13,15]. In this method, the assessment involves the determination of weight (wi), quality rating (qi), and sub-index (SI).

Generally, the WQI provides a summary of various water quality data into a single value that describes the water quality status of a system [10]. It is an effective tool for evaluating the quality of water in a system over a certain period to monitor water quality for humans as well as the ecosystem [16]. Besides, WQI can be used to communicate with policymakers, decision-makers as well as the general public regarding water quality issues, such as the vulnerability of pollution, extreme demand, and their diminishing concerns [4]. Whereas the assessment of water quality can be done by measuring the physical, chemical, and biological parameters and comparing with the global, regional, and national standards, water quality assessment using WQI can be determined to evaluate the quality of water for different purposes. For example, Al-Janabi [17] observed that the water from the Tigris River were unsafe for human consumption while Chabuk [7] later observed that the water quality from the same river was good. Tian et al. [18] observed that the quality of water from the Luanhe River, northern China ranged from bad to excellent. Similarly, Shil et al. [4] observed that the quality of water from the Mahananda River was bad for irrigation and industrial uses, while Wu et al. [19] observed that the water quality of the rivers in the Lake Chaohu basin (China) was moderate. WQI can be used for assessing the quality of water of individual river systems to facilitate the comparison of water quality from different rivers.

In Tanzania, assessment of water quality in rivers has been done by different researchers. For example, Selemani et al. [3] and Hellar-Kihampa [5] assessed the water quality in the Pangani River while Ngoye and Machiwa [6], Alphayo and Sharma [16], and Kashindye et al. [20] evaluated the quality of water in the Ruvu River. On the other hand, GLOW-FIU [21] and Mkude et al. [22] assessed the quality of water in the Wami River. The quality of water in the Zigi River was assessed by Kashindye et al. [20]. Most of these studies were done mainly by measuring and comparing the physicochemical parameters of a river. Besides, no study evaluated the water quality in the Kizinga River. On the other hand, Alphayo and Sharma [16] assessed the water quality in the Ruvu River using the NSFWQI and observed that the quality of water in this river was medium. Little knowledge is available on the use of WQI to assess the water quality in the Pangani, Wami, Zigi, and Kizinga rivers, which are used for drinking purposes. Similarly, the current WQI of the Ruvu River is not known. In addition, no study compared the water quality indices of these rivers in relation to their use as drinking water sources. This study, therefore, was intended to evaluate and compare the quality of water in the selected tropical coastal rivers of Tanzania used as drinking water sources using the parametric level analysis and water quality index.

Materials and methods

Study areas

The Pangani River, which is located in northern-eastern Tanzania (Fig 1), covers an area of about 43,700 km^2 and runs for about 500 km from the sides of Kilimanjaro and Meru mountains, and drains into the Indian Ocean. The Pangani River and its basin are managed by the Pangani Basin Water Office (PBWO) under the Ministry of Water. The Pangani River supplies water for various uses in the different urban and rural centres of the administrative regions of Manyara, Kilimanjaro, Arusha, and Tanga [23]. The main socio-economic activities in the Pangani basin include industrial, agricultural (fishing, crop farming, and livestock keeping), and mining activities. As a result of increased population and socio-economic activities in the river basin, the quality of water in the river has been threatened [5,24].

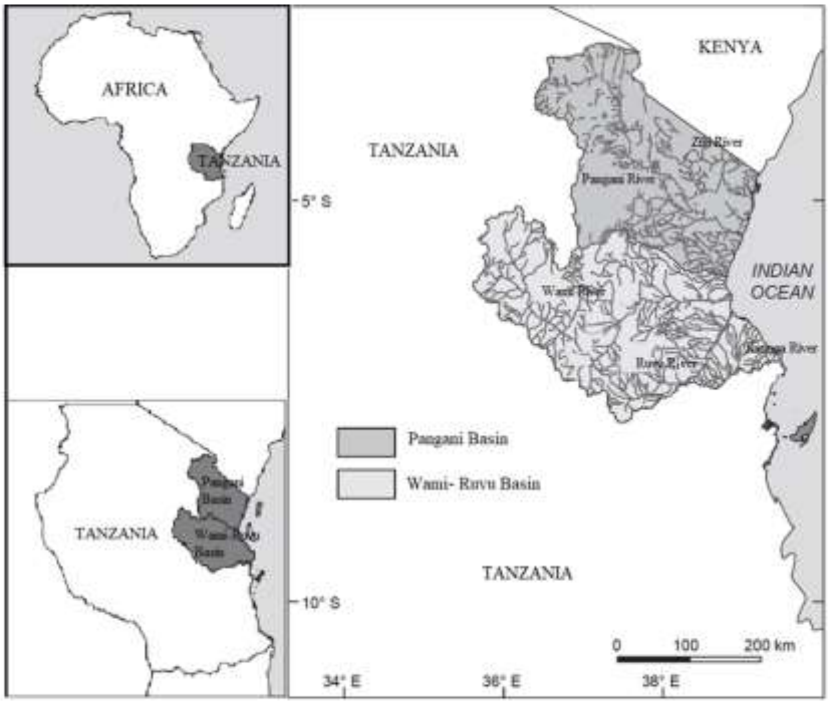

Figure 1. Map showing the selected coastal rivers in Tanzania. Modified from [26]

The Zigi (or Sigi) River basin with an estimated area of 1,100 km^2 originates from the Eastern Usambara Mountains. The river flows eastwards and enters the Indian Ocean north of the Tanga region. The Zigi River is subjected to various socio-economic activities, which include tea, sisal, and cattle farming [25], subsistence agriculture, and small-scale mining. These anthropogenic activities could jeopardise the quality of water in the basin. The Pangani and Zigi rivers are within the Pangani basin (Fig 1).

The Wami River, which occupies an estimated area of 40,000 km^2, originates from the Kaguru Mountains in the Morogoro region and passes into the Wami Delta before flowing into the Indian Ocean. The river, being in the Wami – Ruvu river basin, is managed by the Wami – Ruvu Basin Water Office (WRBWO) under the Ministry of Water. The river is subjected to various domestic, agro-pastoral, industrial as well as agricultural activities [21] that could have an impact on the quality of water.

River Ruvu, which is located in Eastern Tanzania, originates from the southern Uluguru Mountains and flows north-eastwards into the Indian Ocean through Morogoro and Coast regions [16,27]. The Ruvu river basin, which is part of the Wami-Ruvu basin under WRBWO, has an estimated area of about 17,900 km^2 [28]. Socio-economic activities in the Ruvu River include livestock keeping, agriculture (both rain-fed and irrigation), and industrial (beverage, soap, pharmaceutical, textile, brewery, garage, butchery) activities [27,28]. The quality of water in this river could be threatened by these activities.

The Kizinga River, together with the Mzinga River, flows into the Mtoni estuary, through the Dar es Salaam Harbour into the Indian Ocean. The river is a source of drinking water to some of the Dar es Salaam residents where water is pumped from the Mtoni water station. The river drains the urbanised areas of the city that has a lot of socio-economic activities. As a result, the quality of water quality from this river could be threatened due to suspicion of carrying a variety of wastes from residential, industrial as well as agricultural sources. The Wami, Ruvu and Kizinga rivers, together with other rivers, constitute the Wami-Ruvu basin (Fig 1).

Water quality data

The water quality assessment described here is based on part of the data presented in several studies [3,5,6,20,21,22]. Studies by Selemani et al. [3] and Hellar-Kihampa et al. [5] provided temperature, pH, EC, TDS, DO, nitrate, nitrite, ammonia, and phosphate data for the Pangani River. Similarly, studies of Ngoye and Machiwa [6] and Kashindye et al. [20] provided temperature, pH, EC, TDS, DO, and turbidity data for the Ruvu River. Furthermore, GLOW-FIU [21] and Mkude et al. [22] studies provided temperature, pH, EC, TDS, TSS, DO, nitrate, ammonia, phosphate, and turbidity data for the Wami River. The study conducted by [20] provided temperature, pH, EC, TDS, TSS, DO, nitrate, phosphate, and turbidity data for the Zigi River while the study done on the Kizinga River provided pH, EC, TDS, TSS, DO, ammonia, phosphate, and turbidity data.

Evaluation of the river water for drinking purposes

Assessment of water using parametric level analysis

Parametric level analysis was used to evaluate the geochemical water parameters. The deviation values of all the eleven geochemical water parameters in the selected rivers were determined using the equation proposed by [29] such that:

$$QDI = \frac{(C_{Mi} - C_{LVi})}{C_{LVi}} \times 100 \qquad 2$$

where QDI = deviation of the measured water parameter from the legal limit, C_{Mi} = measured value of the geochemical water parameter, and C_{LVi} = limit value of the geochemical water parameter.

The aquatic environment was assessed by using the aquatic environment assessment (AEA). The AEA was based on the aquatic assessment algorithm developed earlier [29] to which the water chemistry parameters only were taken into account. The first step in AEA is the categorization of the water bodies; all were categorized as rivers [30]. Then, the quality assessment of geochemical water parameters was carried out using the measured values of the geochemical water parameters and the limit values defined by the global (i.e. WHO) as well as the national (i.e. TBS) standards. These criteria were used to determine the water quality classes for a given water parameter. A total of five water quality classes were developed. Later, the weight index determination was done by paired comparison and normalization for all the geochemical water parameters [29].

The aquatic environment index (AEI) was assessed using five water quality classes and categories according to the Egyptian Governmental Decree No. 92/2013 [31,32] to which the legal values for the different geochemical water parameters were obtained. The AEI was calculated using equation 3 according to [29].

$$AEI = \frac{\sum_i^n (QC \times W)}{n} \qquad 3$$

where QC = quality class of the geochemical water parameter, W = relative weight of the water parameter, and n = number of the analysed water parameters.

The interpretation of the AEI values was based on the different water quality categories (QCs) developed elsewhere [29] as excellent, good, proper, weak, and bad. The relative weights (Wi) of each parameter used in this study are the same relative weights used in the determination of WQI, except that they are presented in percentages.

Assessment of water quality

The quality, as well as the suitability of water in the selected rivers for drinking purposes, were assessed by determining the water quality index. Water quality indices of the selected rivers were assessed using the method described by [13]. In this method, WQI was determined by assigning a weight (wi) for each geochemical parameter based on the relative significance in determining the overall quality of the drinking water. The standard limits from the World Health Organisation, [33,34] and the Tanzania Bureau of Standards [35,36] were employed as the benchmarks. A weighted value (wi) of 5 and 1 were assigned to geochemical parameters that have a significant and insignificant effect on water quality, respectively. Thus, TDS, ammonia, nitrate, nitrite, and phosphate were assigned wi of 5 due to their significance in the assessment of water quality. Turbidity and TSS were assigned the weight of 2 due to a relatively insignificant role in the water quality assessment. Other geochemical parameters were assigned weights between 2 and 5 depending on their relative significance in the assessment of water quality. The *wi* was then used in computing the relative weight (*Wi*) according to equation 4.

$$Wi = \frac{wi}{\sum_i^n wi} \quad (4)$$

The quality rating (qi) was computed using the observed values of the geochemical parameters as well as the available guideline values such as the WHO, national or regional standards. Thus:

$$qi = \frac{Ci}{Si} \times 100 \quad (5)$$

where, qi = quality rating, Ci = observed value of the geochemical parameter, i, in the water, and Si = Standard guideline value or acceptable limit of water parameter in the drinking water.

Multiplying the qi and Wi for a given parameter gives the SI. The WQI for a given river, then, can be determined from the summation of the sub-indices obtained such that:

$$SI = W_i q_i \quad (6)$$

and

$$WQI = \sum_i^n SI = \sum_i^n (Wi \times qi) \quad (7)$$

The computed WQI was then compared with the established ranges of WQI used to classify water for drinking water as per Table 1.

Table 1: Drinking Water Classification criteria [37]

Level	Classification	WQI
1	Excellent	<50
2	Good	50 – 100
3	Poor	100 - 200
4	Very poor	200 - 300
5	Polluted	300 - 400
6	Very polluted	> 400

Results and discussion

Variation of geochemical water parameters in the rivers

The extracted geochemical water data used for the study are presented in Table 2. The mean water temperatures were more or less similar in all the selected rivers and fluctuated between 18.0 °C and 32.1 °C. The water temperatures in these rivers were within the TBS set standard of $<$ 35°C, indicating the absence of thermal pollution. Changes in water temperature could control the biotic and abiotic processes in a water body and may influence, among others, the level of nutrients, pollutants, as well as dissolved matter in water [38].

The pH values in all rivers were moderate alkaline (6.4 to 8.9). The pH of the water was more or less the same in all rivers and within the WHO and TBS set standards of < 8.5 and < 9.2, respectively. The pH of water in the Wami River was slightly lower than those of other rivers. Water with pH > 9.2 tastes bitter while that with pH < 5.3 reduces the assimilation of minerals and vitamins [39]. The pH of drinking water greatly affects the water temperature, amount of organic compounds as well as solubility of toxic metals and therefore influences the health and body chemistry [38].

Higher mean EC, TDS, and phosphate values were observed in the Kizinga River compared to other rivers. The observed EC, TDS, and phosphate were lower than the WHO and TBS limits (Table 2). The increase in EC has long been known to increase the TDS [40]. Higher TSS values were observed in the Wami River. The mean TSS in the Kizinga River was lower than WHO and TBS standards. However, TSS values in other rivers were higher than WHO and TBS standard values. High TSS could be due to increased disease-causing agents, oxygen-demanding wastes as well as salts whose presence in drinking water may cause an unpleasant taste [39]. Higher TSS affects the chemical quality, turbidity as well as colour of the water [38].

The levels of DO in Wami and Zigi rivers were higher than the WHO and TBS set standards while DO values in the Kizinga River were lower than the WHO and TBS standards. DO values of up to 14.5 mg/L are expected in natural waters, but lower DO in the water below the optimum range of 4 – 6 mg/L is an indication of organic pollution caused by atmospheric dissolution, oxygen-consuming autotrophic processes, and heterotrophic activities that consume the oxygen in water [39]. The levels of dissolved salts, the temperature of the water, and biological processes taking place may dictate the level of oxygen detected in a river [38].

The relatively lower DO values observed in the Kizinga River compared to other coastal rivers clearly indicate that there could be some discharge of industrial and domestic wastes that increased the organic matter load. The presence of organic matter tends to increase the oxygen-consuming processes in the river. Mihale et al. [41] have observed that sewage organic matter is one of the major contributors to the organic matter in the area.

Table 2: Geochemical Water Parameters (mean ± SD and range) in the Selected Rivers

Geochemical Parameter	Wami River[a]	PanganiRiver[b]	RuvuRiver[c]	ZigiRiver[d]	KizingaRiver[e]
Temperature (°C)	28.1 ± 2.1			27.8 ± 2.9	NA
	(24.5 - 32.0)	(21.0 - 30.5)	(18.0 - 32.0)	(24.1 - 32.1)	
pH	7.1 ± 0.3			7.5 ± 0.3	7.9 ± 0.1
	(6.4 - 7.6)	(6.8 - 8.9)	(7.0 - 8.1)	(7.1 - 7.9)	(7.8 - 8.0)
EC (µS/cm)	320.4 ± 82.3			141.7 ± 57.2	1814.4 ± 251.3
	(208.0 - 518.0)	(97.0 - 1350.0)	(39.8 - 48734.0)	(49.0 - 299.0)	(1666.0 - 2104.5)
TDS (mg/L)	748.1 ± 1225.3	276.7 ± 236.0		69.7 ± 27.9	915.9 ± 126.8
	(128.9 - 2930.0)	(270.1 - 283.3)	(19.9 - 24367.0)	(24.5 - 149.9)	(841.0 - 34333.3)
TSS (mg/L)	261.7 ± 279.1	NA	NA	141.7 ± 251.8	24.1 ± 9.2
	(45.0 - 730.0)			(0.9 - 854.7)	(15.1 - 39.3)
DO (mg/L)	5.6 ± 2.7			5.4 ± 1.1	4.4 ± 0.8
	(0.0 -9.8)	(2.0 - 8.3)	(6.0 - 16.8)	(3.2 - 6.8)	(3.1 - 5.2)
Nitrate (mg/L)	0.1 ± 0.2	21.7 ± 21.6	NA	3.0 ± 3.0	NA
	(0.0 - 0.3)	(2.5 - 84.0)		(0.1 - 3.9)	
Nitrite (mg/L)	NA	0.7 ± 1.3	NA	NA	NA
		(0.1 - 4.7)			
Ammonia (mg/L)	1.0 ± 0.6	0.0 ± 0.1	NA	NA	0.4 ± 0.3
	(0.2 - 1.6)	(ND - 0.1)			(0.3 - 0.8)
Phosphate (mg/L)	0.6 ± 0.3	0.1 ± 0.1	NA	0.1 ± 0.08	1.3 ± 1.1
	(0.3 - 1.2)	(0.0 - 0.2)		(0.0 - 0.3)	(0.0 - 2.1)
Turbidity (NTU)	39.6 ± 46.8	NA		241.7 ± 412.4	19.9 ± 7.6
	(3.6 - 182.0)		(3.0 - 840.0)	(1.8 - 1518.0)	(12.5 - 32.5)

[a][21,22]; [b](3,5]; [c][6,20]; [d]Nyambukah and Mihale, (Unpublished results); [e]Mhande, (Unpublished results); NA = Not analysed; ND = not detected

On the other hand, DO is affected by, among others, temperature such that higher DO values are expected at lower temperatures and vice versa.

Relatively high mean nitrate values were observed in the Pangani River while lower nitrate values were observed in the other rivers. The observed nitrate values were lower than the WHO and TBS standards. The high levels of nitrate in drinking water could cause a serious health hazard. Bacteria in the digestive system can reduce nitrate to nitrite, which when reacts with the haemoglobin in the red blood cells methemoglobin is formed, which lacks the oxygen-carrying ability [39]. The person consuming water containing the nitrate will lack sufficient oxygen for various metabolic activities, and consequently may die if nitrite levels are higher. Fortunately, the observed nitrate and nitrite values in the rivers were lower than the WHO and TBS, indicating that the nitrate-nitrite conversion was relatively low.

Higher ammonia values were observed in the Wami River compared to Pangani possibly due to chemical fertilizers used in agricultural activities in the catchment. Similarly, higher phosphate values were observed in the Kizinga River probably due to increased use of phosphate-containing synthetic detergents in the households. Relatively higher turbidity values were detected in the Zigi River followed by the Wami River. From Table 2 it can be observed that ammonia values in the Wami River were higher than the WHO limit, but were lower in other rivers. The observed phosphate levels were lower than the WHO set limit while turbidity levels were higher than the WHO limit. TBS set limits for nitrite, ammonia, phosphate, and turbidity could not be established.

Evaluation of geochemical water parameters using parametric level analysis

The parametric level analysis gave a plot of the QDI as a function of the relative weight of the water parameters in the selected coastal rivers (Fig 2). From the figure, it can be seen that the majority of the geochemical water parameters in all rivers deviated negatively, indicative of meeting the legal specifications. However, TDS in the Ruvu River, TSS in the Wami and Zigi rivers, DO in the Pangani, Zigi, and Kizinga rivers, ammonia in the Wami River, and turbidity in the Wami, Zigi, and Kizinga rivers deviated positively. This is an indication that these geochemical water parameters do not meet the legal specifications in these rivers.

Whereas water quality in the Ruvu River is controlled mainly by TDS, the quality of water in the Zigi River is controlled by turbidity, DO, and TSS. Similarly, the quality of water in the Kizinga River is mainly influenced by DO and turbidity. Figure 1 has indicated that the quality of water in these rivers is controlled by various geochemical parameters. It has indicated that TDS, TSS, DO, ammonia, and turbidity are the geochemical water parameters that influence the water quality in these rivers, but each river is controlled by different geochemical water parameters. For example, the quality of water in the Wami River is mainly influenced by turbidity, DO, ammonia, and TSS, while the water quality in the Pangani River is controlled mainly by DO.

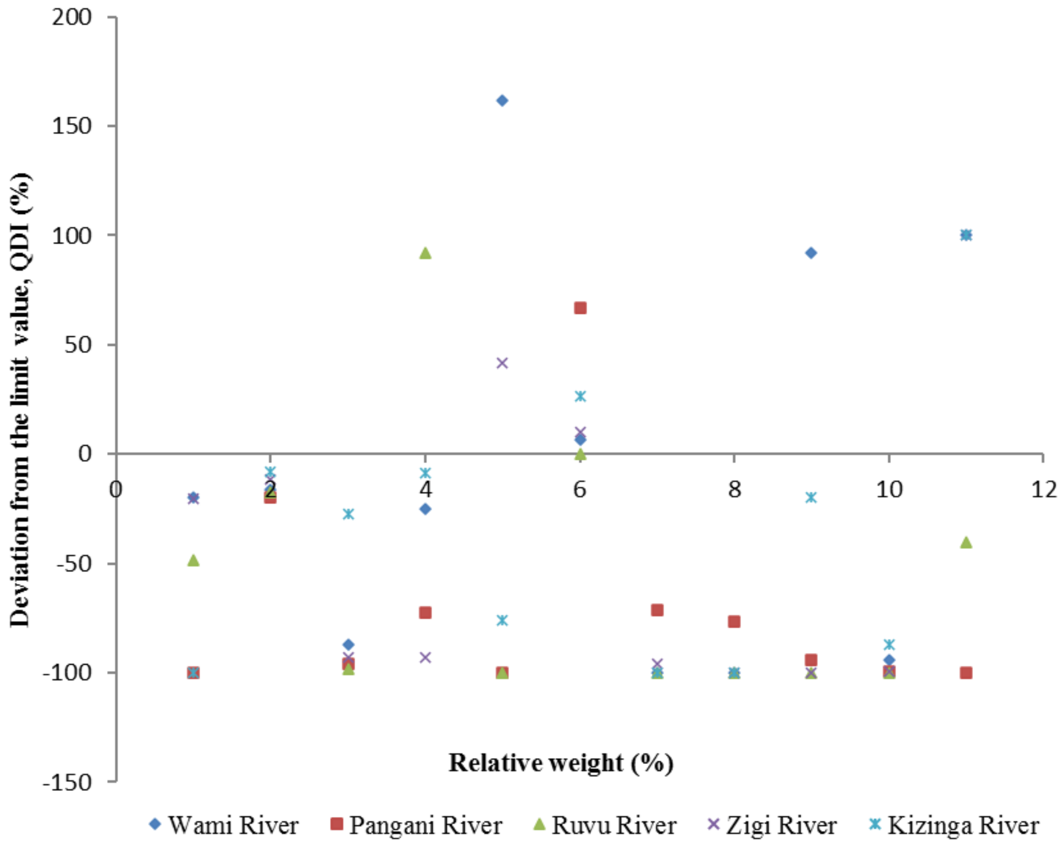

Figure 2: Deviation of Geochemical Water Parameters as a function of their relative weights

The determination of the mean AEI values and the AEI intervals was done by the substitution method [29]. When river water is of excellent quality for all the geochemical parameters (quality class 5), the calculated mean AEI using equation 3 is 44.0. Similarly, ranking all the geochemical water parameters in quality class 1 (bad quality) will give a mean AEI of 8.8. Using a similar method, the mean AEI values for weak, proper, and good quality classes were obtained. The lower and upper limit values of an interval for a given quality class were determined by averaging the neighbouring mean AEI values. The mean AEI and AEI intervals are given in Table 3.

Table 3: Evaluation categories for the quality classes of the coastal rivers

Category Descriptions	Category Class	Mean AEI value	AEI interval
Bad	1	8.8	$13.2 < AEI$
Weak	2	17.6	$13.2 < AEI < 22.0$
Proper	3	26.4	$22.0 < AEI < 30.8$
Good	4	35.2	$30.8 < AEI < 39.6$
Excellent	5	44.0	$39.6 < AEI$

The water quality classes of the different rivers were assessed based on the minimum values of the individual geochemical water parameter. The qualitative assessment of the geochemical water parameters in the selected rivers is presented in Table 4. It can be seen from Table 1 that the qualitative classification of geochemical water parameters in the selected rivers displayed similar findings to those observed in Fig 2. For example, the quality of water in the Wami River is influenced by variable levels of TSS, DO, and turbidity. Furthermore, water quality in the Pangani River is mainly affected by variations of DO and EC to some extent. Moreover, the quality of water in the Ruvu River is influenced by TDS and EC, the closely related geochemical parameters. Whereas water quality in the Zigi River is affected by TDS, TSS, and DO, water quality in the Kizinga River is influenced by TSS and DO.

The calculated AEI for each selected river is given in Table 5. Higher AEI values were observed in waters of the Wami, Pangani, Zigi, and Kizinga rivers, and lower values were observed in the waters of the Ruvu River. Higher values are indicative of a relatively good water environment, and vice versa. Lower AEI value in Ruvu River could be explained by the influence of anthropogenic activities such as agriculture in the area. For example, fertilizers and pesticides used in agriculture contribute to the deterioration of water quality. El-Otify and Iskaros [42] observed that the use of fertilizers and pesticides in agricultural areas may result in an intermittent supply of contaminants into the water body such as rivers [42].

Assessment of water quality using water quality index

A total of 11 geochemical water parameters were used in the computation of the water quality indices. Table 6 has indicated that based on the WQI classification (Table 1), water from Pangani and Ruvu rivers have excellent quality for use as drinking water. The water from these rivers can be used for drinking with little or no cost of treatment. Similarly, the quality of water from the Kizinga River is good, implying that a relatively high cost can be incurred to treat the water from this river source compared to those from Pangani and Ruvu rivers. The quality of water from the Wami river is poor whereas that of the Zigi River is unsuitable based on the selected water criteria used in this study.

This has implications on the cost of treatment as a relatively high cost of treatment will be incurred to continue using the water from the Wami and Zigi rivers as drinking water. It should be noted that these values may change if other factors such as chemical (metals, pesticides, etc) and biological (*E. coli*, total and faecal coliforms) parameters are considered. Olasoji et al. [43] have indicated that WQI may display different indices and classifications once bacteriological parameters such as *E. coli*, faecal as well as total coliforms are involved. Nevertheless, this information is valuable in that it gives us the current status of the quality of the water in the selected rivers, though not to the highest precision.

By using information obtained from Tables 5 and 6, it is evident that there are minimal environmental threats to the quality of water in the Pangani River. However, the quality of water in the remaining rivers is threatened by various environmental and human factors that tend to put pressure on the water bodies. This calls for urgent and frequent water quality monitoring campaigns in all the rivers to ensure that the threats are minimised.

Table 4: Ranges of Measured values and their classification [29]

Parameter	Ranges of Measured values in Rivers					Ranges of Quality classes*				
	Wami River	Pangani River	Ruvu River	Zigi River	Kizinga River	Wami River	Pangani River	Ruvu River	Zigi River	Kizinga River
Temperature (°C)	24.5 – 32.0	21.0 – 30.5	18.0 – 32.0	24.1 – 32.1	NA	E	E	E	E	NA
pH	6.4 – 7.6	6.8 – 8.9	7.0 – 7.1	7.1 – 7.9	7.8 – 8.0	E	G to E	E	E	E
EC (µS/cm)	208.0 – 518.0	97.0 – 1350.0	39.8 – 48734.0	49.0 – 299.0	1666.0 – 2104.5	E	B to G	B to E	E	B
TDS (mg/L)	748.1 – 1225.3	270.1 – 283.3	19.9 – 24367.0	24.5 – 149.9	841.0 – 34333.3	E	E	B to E	B to E	E
TSS (mg/L)	45.0 – 730.0	NA	NA	0.9 -854.7	15.1 – 39.3	B to P	NA	NA	B to E	P to G
DO (mg/L)	0.0 – 5.6	2.0 – 8.3	6.0 – 16.8	3.2 – 6.8	3.1 – 5.2	B to W	B to P	P to E	B to P	B to W
Nitrate (mg/L)	0.0 – 0.3	2.5 – 84.0	NA	0.1 – 3.9	NA	E	E	E	E	NA
Nitrite (mg/L)	NA	0.1 – 4.7	NA	NA	NA	NA	E	NA	NA	NA
Ammonia (mg/L)	0.2 – 0.6	ND – 0.1	NA	NA	0.3 – 0.8	E	E	E	E	E
Phosphate (mg/L)	0.3 – 1.2	0.0 – 0.2	NA	0.0 – 0.3	0.0 – 2.1	E	E	E	E	E
Turbidity (NTU)	3.6 – 182.0	NA	3.0 – 840.0	1.8 – 1518.0	12.5 – 32.5	B to E	NA	B to E	P to E	P to G

*Based on the minimum and maximum detected concentrations; Legend: E = Excellent; G = Good; P = Proper; W = Weak; and B = Bad; NA = not analysed

Table 5: Average AEI values for the Selected Rivers

Parameter	Minimum quality class*					Relative Weight (%)	QC × Wi				
	Wami River	Pangani River	Ruvu River	Zigi River	Kizinga River		Wami River	Pangani River	Ruvu River	Zigi River	Kizinga River
Temperature (°C)	5	5	5	5	NA	7.1	35.7	35.7	35.7	35.7	NA
pH	5	4	5	5	5	7.1	35.7	28.6	35.7	35.7	35.7
EC (µS/cm)	5	1	1	5	1	9.5	47.6	9.5	9.5	47.6	9.5
TDS (mg/L)	5	5	1	5	5	11.9	59.5	59.5	11.9	59.5	59.5
TSS (mg/L)	1	NA	NA	1	3	4.8	4.8	NA	NA	4.8	14.3
DO (mg/L)	1	1	3	1	1	7.1	7.1	7.1	21.4	7.1	7.1
Nitrate (mg/L)	5	5	NA	5	NA	11.9	59.5	59.5	NA	59.5	NA
Nitrite (mg/L)	NA	5	NA	NA	NA	11.9	NA	59.5	NA	NA	NA
Ammonia (mg/L)	5	5	NA	NA	5	11.9	59.5	59.5	NA	NA	59.5
Phosphate (mg/L)	5	5	NA	5	5	11.9	59.5	59.5	NA	59.5	59.5
Turbidity (NTU)	1	NA	1	3	3	4.8	4.8	NA	4.8	14.3	14.3
Average AEI value							37.4	42.1	19.8	36.0	32.4
Quality description							Good	Excellent	Weak	Good	Good

*Based on the minimum detected concentrations; NA = not analysed;

Table 6: Water Quality Indices of Selected Coastal Rivers

Parameter	Standards		Weight (wi)	Relative weight (Wi)	Qi					Si				
	WHO[a]	TBS[b]			Wami River	Pangani River	Ruvu River	Zigi River	Kizinga River	Wami River	Pangani River	Ruvu River	Zigi River	Kizinga River
Temperature (°C)		35	3	0.07	80.3	0.0	51.4	79.7	0.0	5.7	0.0	3.7	5.7	0.0
pH	< 8.5	< 9.2	3	0.07	83.5	80.0	82.4	88.2	91.8	6.0	5.7	5.9	6.3	6.6
EC (µS/cm)	2500	1000	4	0.10	32.0	3.9	1.6	7.2	72.6	3.1	0.4	0.2	0.7	6.9
TDS (mg/L)	1000	1000	5	0.12	74.8	27.7	191.9	7.0	91.6	8.9	3.3	22.8	0.8	10.9
TSS (mg/L)	30	100	2	0.05	872.3	0.0	0.0	472.3	80.3	41.5	0.0	0.0	22.5	3.8
DO (mg/L)	5	6	3	0.07	112.0	40.0	120.0	108.0	88.0	8.0	2.9	8.6	7.7	6.3
Nitrate (mg/L)	50	75	5	0.12	0.2	43.4	0.0	6.0	0.0	0.0	5.2	0.0	0.7	0.0
Nitrite (mg/L)	3		5	0.12	0.0	23.3	0.0	0.0	0.0	0.0	2.8	0.0	0.0	0.0
Ammonia (mg/L)	0.5		5	0.12	192.0	6.0	0.0	0.0	80.0	22.9	0.7	0.0	0.0	9.5
Phosphate (mg/L)	10		5	0.12	6.0	0.7	0.0	0.9	13.0	0.7	0.1	0.0	0.1	1.5
Turbidity (NTU)	<5		2	0.05	792.0	0.0	60.0	5432.0	398.0	37.7	0.0	2.9	258.7	19.0
Σ			42	1.00			WQI			134.5	21.0	44.0	303.2	64.5

[a][33,34]; [b][35,36]

Conclusions

The water quality of the selected coastal rivers used as drinking water sources has been assessed using the WQI. The water quality index of the water in the rivers was 134.5 for Wami River, 21.0 for Pangani River, 44.0 for Wami River, 303.2 for Zigi River and 64.5 for Kizinga River. The parametric level analysis and aquatic environmental index have revealed that water quality in the selected rivers is mainly influenced by TDS, TSS, DO, ammonia, and turbidity levels. Any factor that could cause a change in these geochemical parameters could influence the quality of the water in the rivers. However, the magnitude of the effect of these geochemical parameters on the water quality is different between rivers. A relatively good water environment of the Wami, Pangani, Zigi, and Kizinga rivers could be explained by the relatively low influence of anthropogenic activities that impact minimal environmental threats and vice versa. The water quality of the rivers based on the water quality index ranged from excellent to unsuitable, implying that the costs for treating the water in the rivers are indirectly related to the water quality. The presence of anthropogenic factors putting pressure on the water quality calls for urgent and frequent water quality monitoring campaigns in all the rivers to ensure that the threats are kept to non-threshold levels. A more comprehensive water quality index can be determined when physicochemical, biological, and chemical parameters are included in the calculation. There is a need for regular and detailed water quality monitoring campaigns to identify the trends in water quality over time and space. This will help to design specific pollution prevention programs to ensure that water from these rivers is safe for drinking.

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