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Water Quality Assessment of Ruvu River in Tanzania Using NSFWQI

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

The assessment of rivers by using different water quality indices like NSFWQI is very useful. However, Tanzania has not yet utilised these tools to assess the quality of its rivers. This paper attempts to assess the water quality of the Ruvu River by using NSFWQI. Physical, chemical and biological parameters like Temperature, pH, Turbidity, Total Solids (TS), Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Total Phosphates (PO_4^{3-}), Nitrates (NO_3^-) and Faecal Coliforms (FC) collected from 14 sampling points in three years were used to assess NSFWQI. The results showed that overall NSFWQI score was 49.9, 52.0 and 57.8 for the year 2014, 2016 and 2017 respectively. The overall NSFWQI (51-70) is found as 53.2 indicating that water quality of river in study stretch is in the medium range. BOD, DO and FC was found to be most stressing parameters overall sampling locations due to improper sanitation systems, discharge of untreated and partially treated wastewaters from industries and domestic into the river. Watershed management and pre-treatment of wastewaters from Industries and domestic were recommended to improve the water quality of the river.

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1. INTRODUCTION

Water quality is the physical, chemical and biological characteristic of water for a particular user while the water quality profile indicates the pollution level of a stream/river from upstream to downstream [1–3]. The river water quality assessments are useful for water managers/municipalities and policymakers as well as the public at large. The importance of assessing the water quality of the river is to maintain the water quality for human population and ecosystems [4,5,3,6]. However, anthropogenic activities in the river catchment provide a fair idea about the quality of freshwater bodies [7,8].

The application of quality indices is a tendency in studies of environmental monitoring, used in a quite wide way, allowing the comparison of results of different areas. A study on water quality assessment of Bangpakong River in Easter part of Thailand using the Scottish Water Quality Index (WQI) revealed that the averaged WQI was low showing its very poor environmental quality [9]. The Water Quality Profile of Yamuna River in India based on NSFWQI showed that the river stretch at Delhi is highly polluted [1] and is found in water quality E. Further, the assessment of surface water quality in the Ebro River (Spain) showed that spatial and seasonal variations in pollutant discharges affected the quality and hydrochemistry of river water [5]. Water quality assessment of Swan River in Himachal Pradesh, India evaluated using NSFWQI and an overall index of pollution (OIP) indicated that water quality of Swan River varied from 'Good to Medium' and is 'Acceptable to slightly polluted' by OIP method [6]. A study on the ecological health of Chambal River using multiple indices like NSFWQI, CTSI and SDI showed that the overall ecological health is in a good range and indicated that the sanctuary area is pollution free [8,10]. Similar situations were observed in Africa where the physical and chemical parameters, nutrients and heavy metal ions of Huluka and Alaltu Rivers of Ambo, Ethiopia were studied. The results showed that the pollution level is increasing from upstream to downstream of the river [11]. The study conducted to assess the water pollution along Modjo River in Ethiopia using the National Environmental Quality Standard (NEQS) showed different water quality from upstream to downstream [12]. Water quality assessment of streams/rivers using benthic macroinvertebrate (North Carolina USA) emphasises the importance of multihabitat assessment and the use of both coarse and fine mesh samplers. The results were found to be related to more conventional physical/chemical measurements. This method has potential as a rapid and economical method of monitoring streams [13]. Assessment of surface water quality using multivariate statistical techniques (Fuji River Basin, Japan) showed that the parameters responsible for water quality variations are mainly related to wastewater discharge, temperature and organic pollution and nutrients in highly polluted areas in the basin [14].

The above literature survey shows what has been done in various rivers. There is no evidence whether there has been any study carried out to assess the quality of the Ruvu River in Tanzania. Accordingly, the Ruvu River in Tanzania is selected for the assessment of water quality and its profile along the stretch. The results obtained may be useful to managers/policy makers to tackle the water quality issues of the said river.

2. THE STUDY AREA

Ruvu River Basin is located in the eastern part of Tanzania lying between latitudes 6° 05' and 7° 45' south and longitudes 37° 15' and 39° 00' east with a catchment area of 11,789 km^2 and 316 km long [15]. Ruvu River originates from the southern part of the Uluguru Mountains in Morogoro Region, flows through Morogoro, Kibaha, Mlandizi and Bagamoyo and finally drains into the Indian Ocean [15]. Fig. 1 shows the location of the Ruvu River in Tanzania.

Ruvu River is an important source of water for the surrounding communities, who drive their livelihood through fishing, domestic uses and several other activities [18]. However, the river is threatened by anthropogenic pollution. The human activities are negatively impacting the water quality of the river stretches resulting in the cost escalation of water supply and increasing the scarcity of water resource, especially, for domestic uses.

A number of irrigation projects are also located in the catchment of the river. The Lower Ruvu Basin has several industries like textiles,

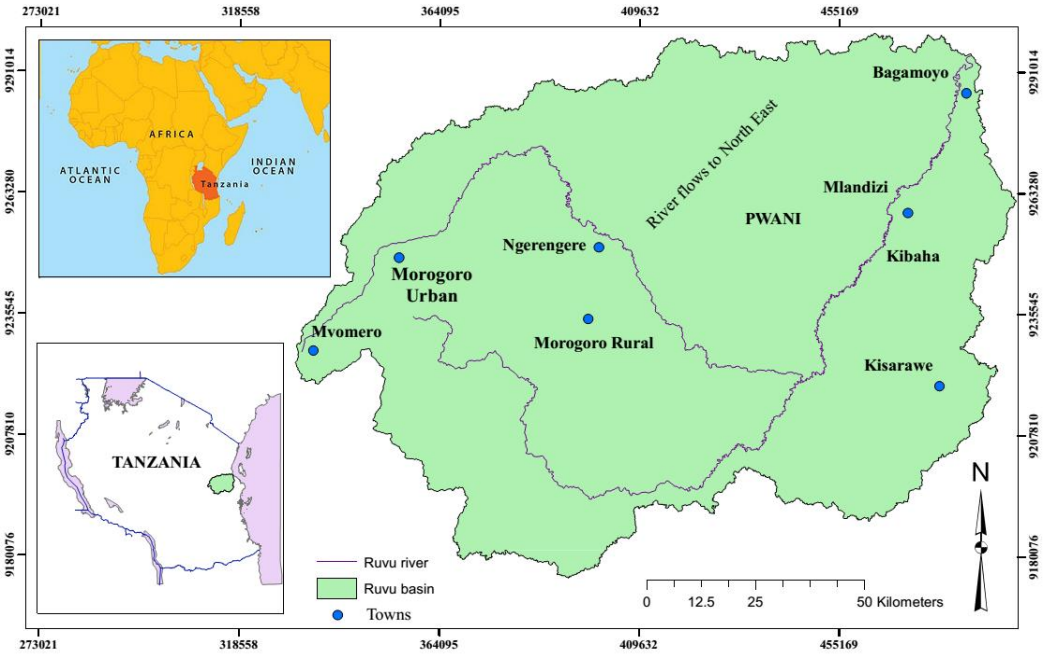

Fig. 1. Ruvu River Basin in Tanzania [16,17]

beverage, brewery, tobacco processing, pharmaceutical, soaps and service industries e.g. slaughterhouses and garages, which all end into the discharge of effluents into this river. The growth of irrigated agriculture and industrialisation along the Ruvu River does not only increase the potential for pollution but also putting more and more demands of water for various uses [19].

3. SELECTION OF STUDY SITES

A total of 14 sampling locations were selected in river stretches designated from S_1-S_{14}, and the samples were collected from 2014 to 2017 with specific geographic locations of the sites. Table 1 details the latitude, longitude and the main feature of each location, which are also shown in Fig. 2.

Table 1. Sampling points, locations and its characteristics

Sampling location ID	Sampling location name	Latitude (degree)	Longitude (degree)	Main features/use and occupation of the sampling locations
S_1	Mlali	-6.95223	37.51737	U/s of S_1 has scattered settlement and small-scale irrigation schemes.
S_2	Mzinga at the Bridge	-6.89998	37.56547	Water passes through a small-town of the medium population and has few agricultural fields.
S_3	Ngerengere at Konga	-6.87774	37.60013	The river receives water from residential houses as well as agricultural runoffs.
S_4	Mindu Dam	-6.85429	37.61491	D/s of Mindu dam (approx..3.2km^2 with the perimeter of 10.67km).
S_5	Ngerengere Mahita at Bridge	-6.79583	37.6354	D/s of a bridge just at the start of a mega city Morogoro. The river receives water from residential, universities and irrigation schemes.
S_6	Industrial area (Effluents)	-6.76792	37.67097	500m d/s of the industrial area. The location is capturing effluent from TLAI (Tanzania leather Associate Industry) treatment plant.

Sampling location ID	Sampling location name	Latitude (degree)	Longitude (degree)	Main features/use and occupation of the sampling locations
S_7	Tungi Bridge	-6.76075	37.71088	D/s of Morogoro city it receives residential wastes and any kind of wastes from the city.
S_8	Ngerengere/ Kingolwira	-6.75208	37.75792	This point there a lot of agricultural field with large-scale and small-scale plantations.
S_9	Sangasanga	-6.62326	37.8427	Agriculture practices with low settlement along the river
S_{10}	Ngerengere at Mgude	-6.77197	38.14852	A small town which practises pastoralism and irrigated agriculture
S_{11}	Ruvu at Gwata	-7.04016	38.54484	Characterised by forest and bare land, scattered settlement and fewer agriculture practices.
S_{12}	Ruvu at Morogoro Road	-6.69088	38.69481	Characterised by high plantation scheme and towns.
S_{13}	Ruvu at Kongo	-6.5468	38.82129	The agriculture practices are high with the high discharge of wastewater to the river.
S_{14}	Bagamoyo – Msata Road	-6.47841	38.8304	The location where the river discharges into the Indian Ocean. There are towns along the river to u/s as well as agriculture fields.

Note: (-ve) Latitude means below the Equator

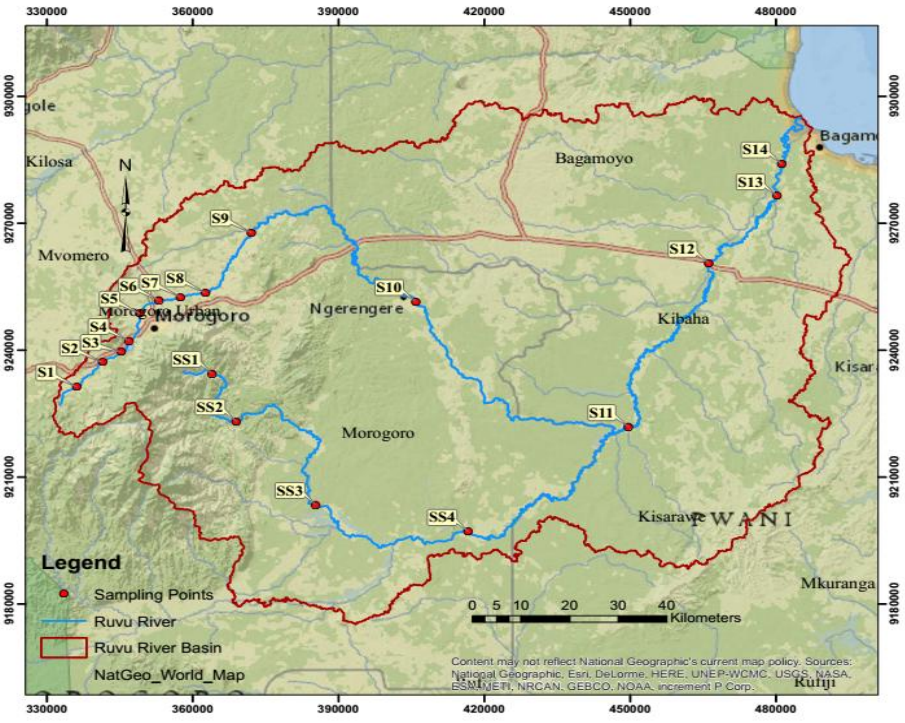

Fig. 2. Sampling points

Sampling points of two branches of the Ruvu River, i.e., One branch starts from S_1-S_{14} and second branch starts from SS_1-S_{14} are shown in Fig. 2.

4. METHODOLOGY

4.1 Sample Collection and Data Analysis

Water quality data for the river was collected from Water Quality Officer, Wami/ Ruvu Basin Water Office, Morogoro Region, Tanzania from 2014-2017. The agency collects and analyses water quality samples for 21 parameters once per year in the months of July-October for the purpose of managing the trends of water quality in the basin [20].

The grab samples collected in 27 locations within the basin (small streams/rivers) were analyzed and the results presented to the Ministry of Water and Irrigation for follow-up. This study selected sampling locations that fall within a mentioned river stretch making a total of 14 out of 27 sampling locations. This study is confined only to the first branch from S_1-S_{14} as shown in Fig. 2. The geographical position information of sampling locations was all converted to decimal degrees as shown in Table 1.

The data on Temperature, pH, Turbidity, Color, Suspended Solids (SS), TDS, DO, BOD_5, Phosphates, Nitrate, Hardness, Chloride, Sulphate, Faecal coliforms, Total Coliforms etc. were analysed at the water quality office in Morogoro using standard methods of analysis. The following parameters and methods were used as shown in Table 2.

4.2 Methodology for Evaluation of NSFWQI

In this study, NSFWQI has been used to evaluate water quality. NSFWQI classifies water quality into 5 categories starting from 0 to 100 score (Table 3). The classification of river water quality status based on NSFWQI including its colour codes was recommended by several studies as the best option for river classification [1,3,6]. The NSFWQI is expressed mathematically as

$$WQI = \sum_{i=1}^{n} WiIi$$

Where

Wi: Weights are given for nine parameters.
Ii: Sub index value of the i^{th} parameter determined graphically.
n: is the number of water quality parameters available.

4.3 Water Quality Data

Table 4 represents the results of the analysis of water samples for selected parameters at different locations of the Ruvu River in Tanzania in the year 2014-2017. The water quality parameters were converted into a single value NSFWQI.

Table 4 shows that the overall NSFWQI is found as 53.2 (51-70) indicating that water quality of the river in study stretch is in the medium range [8,24,25].

Table 2. Methods used for analysis [21,22]

SN	Parameter name	Unit	Method used
1	Temperature	(°C)	Conductivity-Temperature Meter
2	pH		pH Meter (Electrometric) at 25°C
3	Turbidity	(NTU)	Nephelometric Hatch
4	Colour	(Pt.Co.Unit)	Photometric - Platinum-Cobalt (Hazen)
5	Suspended Solids	(mg/l)	Gravimetric Method
6	TDS	(mg/l)	TDS-Salinity-Conductivity Meter - 25°C
7	DO	(mg/l)	Oxygen Meter
8	BOD_5	(mg/l)	5-Day Dilution, Winkler Method
9	Phosphate	(mg/l)	Acid Persulphate Digestion
10	Nitrate	(mg/l)	Cadmium Reduction
11	Hardness	(mg/l)	EDTA Titration
12	Chloride	(mg/l)	Silver Nitrate Titration
13	Sulphate	(mg/l)	Turbidimetric Method
14	Faecal Coliforms	CFU/100mL	Membrane Filtration
15	Total Coliform	CFU/100mL	Membrane Filtration

Table 3. NSFWQI Classification [23]

Numerical range	Category	Descriptor word	Colour code
91-100	A	Excellent Water Quality	Blue
71-90	B	Good Water Quality	Green
51-70	C	Medium/Average Water Quality	Yellow
26-50	D	Bad/Fair Water Quality	Orange
0-25	E	Very Bad/Poor Water Quality	Red

Table 4. Average water quality of Ruvu River for the year 2014-2017.

Sampling locations	NSFWQI Score (2014)	NSFWQI Score (2016)	NSFWQI Score (2017)	Average NSFWQI Score	Category	Status of pollution	Colour code
S_1	47.2	54.2	57.2	52.8	C	Medium	Yellow
S_2	63.0	60.4	60.3	61.2	C	Medium	Yellow
S_3	64.8	62.1	65.1	64.0	C	Medium	Yellow
S_4	54.1	67.3	63.8	61.7	C	Medium	Yellow
S_5	47.5	46.4	54.4	49.4	D	Bad	Orange
S_6	35.3	39.8	57.0	44.0	D	Bad	Orange
S_7	38.4	32.4	52.5	41.1	D	Bad	Orange
S_8	50.2	44.3	57.8	50.8	D	Bad	Orange
S_9	51.4	53.4	56.6	53.8	C	Medium	Yellow
S_{10}	51.0	51.3	57.0	53.1	C	Medium	Yellow
S_{11}	53.5	58.9	58.6	57.0	C	Medium	Yellow
S_{12}	49.1	48.5	53.3	50.3	D	Bad	Orange
S_{13}	49.8	55.4	57.9	54.4	C	Medium	Yellow
S_{14}	43.6	53.4	58.3	51.8	C	Medium	Yellow
Average	49.9	52.0	57.8	53.2	C	Medium	Yellow

5. RESULTS AND DISCUSSION

The results of NSFWQI, as obtained in Table 4, are shown in Fig. 3 which shows that the water quality from S_5 to S_7 is in bad range due to industrial wastewater discharges and urban runoffs from residential areas, specifically, domestic wastewater. For other locations, like S_8 onward, water improved into medium range due to self-purification ability of the river.

5.1 Water Quality for Sampling Location S_1-S_4

This location was generally of medium water quality. According to NSFWQI, it had an average index value of 59.9 indicating the water in the medium range. The status of the water of this site is influenced by upstream scattered settlements with some portions of agricultural lands. There are no land uses, which could highly impact the quality of the water, compared to the rest locations.

5.2 Water Quality for Sampling Location S_5-S_8

The decline in water quality from 59.9 to 49.3 NSFWQI score for location S_5-S_7 has been contributed by the increase in land use intensity. This includes discharges from Morogoro Town, locations S_6 and S_7 was mainly capturing water from the industrial area and therefore it had the lowest index scores of 44.0 and 41.1 respectively. This indicates that water at this point is not suitable for beneficial use like drinking and recreation [20]. However, the water quality started to improve at sampling location S_8 due to self-purification of the river and no further intense pollution.

5.3 Water Quality for Sampling Location S_9-S_{14}

This location is located further downstream of Morogoro city. At this site, it was expected that the quality of the water will improve from the pollutants from the Municipal wastes and industrial wastewater. NSFWQI showed improvements in water quality from 49.3 to 53.4. With respect to the quality upstream score of 59.9 (S_1-S_4), still, the average index seems to be dropped. This is because of continuous agricultural fields, settlements, small industries and some populations besides the river.

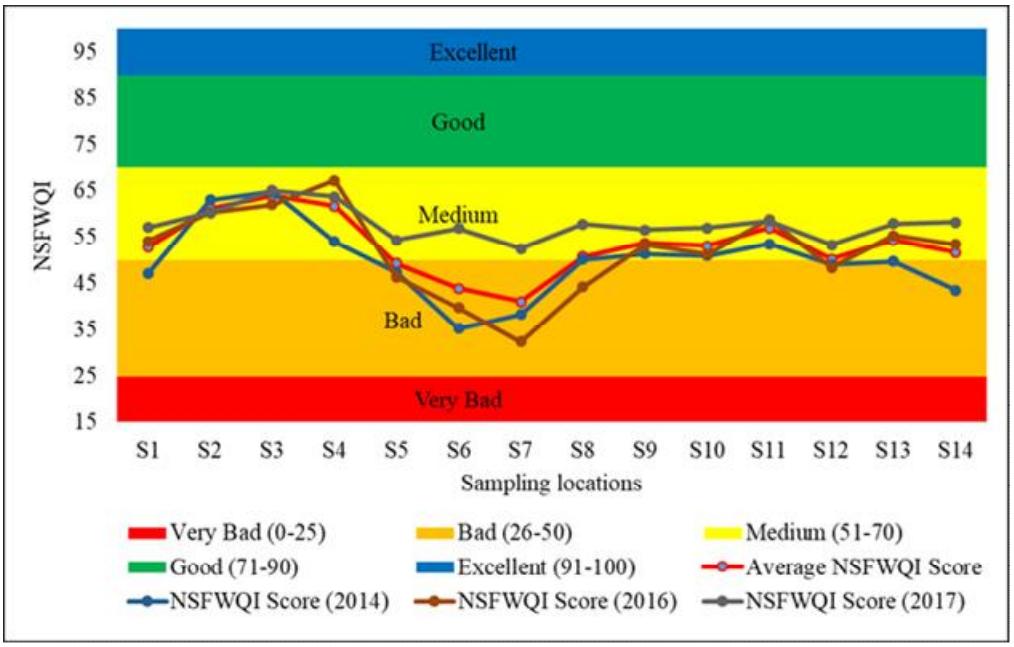

Fig. 3. Variation of water quality of the Ruvu river based on NSFWQI

6. STRESSING PARAMETERS

It was found that BOD_5, DO and Faecal Coliforms (FC) are the strongest stressors in this area as indicated by higher averages values for all 14 sampling points, which are 31.37 mg/l for BOD_5, 5.26 mg/l for DO and 493.24 CFU/100 mL for FC, against surface water quality of 30 mg/l, 6 mg/l and 0 respectively [26]. Table 4 shows the variation of BOD_5 and DO at sampling locations.

6.1 Biochemical Oxygen Demand (BOD)

The maximum average results for BOD_5 was 129.73mg/l at sampling location S_6 and the minimum was 1.86 mg/l at S_3. The high value is due to wastewater discharges from Industries and untreated domestic wastewater.

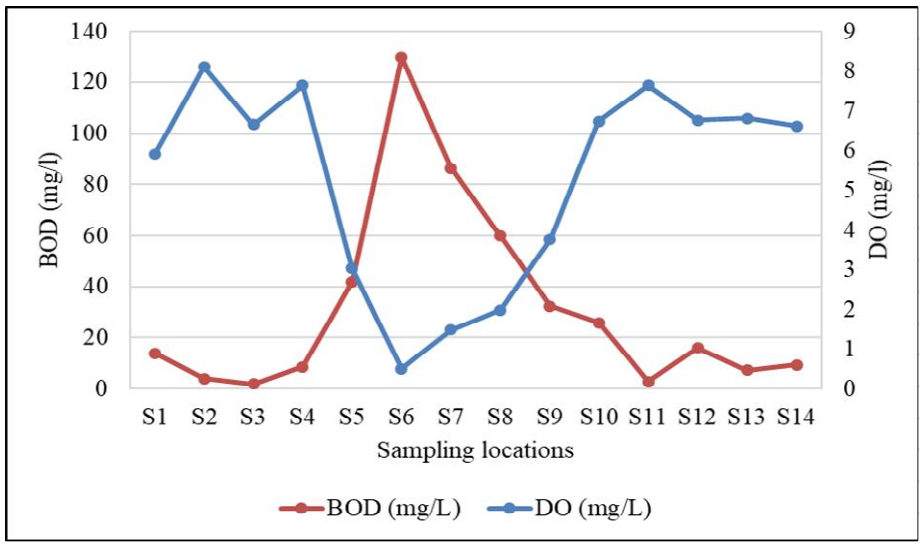

Fig. 4. BOD and DO variation at sampling locations

6.2 Dissolved Oxygen (DO)

Average Dissolved Oxygen (DO) levels assessed were between 1.49 mg/l to 8.1 mg/l at sampling locations S_7 and S_2 respectively. The DO drop shows the impacts of urbanisation and industrialisation. DO is vital to aquatic organisms, as it is useful for survival. Under low DO the aquatic ecosystem is degraded and some organisms may start dying due to lack of oxygen [27].

6.3 Faecal Coliforms (FC)

The acceptable value for Faecal Coliforms (FC) in surface water in Tanzania is 0 (CFU/100mL) [26]. The Faecal Coliforms (FC) for the 14 sampling locations along the river varied from one location to another. All the locations except S_6 were above the required value with the maximum value of 1143 CFU/100 mL at sampling point S_{12}. This is due to inadequate treatment of domestic waste from densely populated areas, grazing domestic animals and people bathing in the river.

7. CONCLUSIONS

The study has provided insights into the application of the NSFWQI for water quality assessment of the Ruvu River due to continuous urbanisation and industrialisation. Various parameters like Temperature, pH, Turbidity, Total solids, Dissolved Oxygen, Biochemical Oxygen Demand, Total Phosphates, Nitrates and Faecal Coliforms (FC) were considered. The overall NSFWQI (51-70) is found as 53.2 indicating that the river quality belongs to the medium range. This result shows the deterioration of water quality of the Ruvu River and therefore, it is important to treat domestic wastewater and effluents from Industries before discharging into the river. Municipal solid waste management is highly recommended for improvement of water quality in the study stretch of Ruvu River.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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