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Water Quality Mapping of Ruvu River in Tanzania

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Abstract: Increase in population and industrialization has strongly impacted the rivers and lakes all over the world. Meanwhile, Tanzania river's water quality faces the same challenges. The Government of Tanzania is trying to overcome the problems by analyzing water quality data from its rivers. However, a lot of data collected require to be converted into a single value "index" understandable by decision and policy-makers. Therefore, the assessment by using different water quality indices like the National Sanitation Foundation for Water Quality Index (NSFWQI), River Pollution Index (RPI) and Overall Index of Pollution (OIP) are very useful. The present paper used water quality indices and land use maps to assess and investigates the water quality of the Ruvu river in Tanzania. Water quality samples collected from 14 sampling locations for the year 2014-2017 were used. The three water quality indices used in evaluation categorized the water quality of the Ruvu river as a medium, polluted and moderately polluted as per NSFWQI, OIP and RPI respectively. The index values were; 53.2, 4.69 and 4.78 for NSFWQI, OIP and RPI respectively. The impact of land use on water quality was analyzed by using Geographic Information Systems (GIS) and Remote Sensing (RS) techniques and ERDAS imagine. These assessment tools revealed that urban land use and agricultural land uses were the major sources of water pollution in this river.

Keywords: Water Quality, NSFWQI, RPI, OIP, GIS and RS, Ruvu River

1. Introduction

Water pollution has become a major challenge to the water body's managers, government agencies and environmentalist in many countries. The prolonged exposure to contaminated water can put human health into a great risk as well as an increase of water scarcity. In the current situation, 2018, the United Nations World Water Development Report [1] shows that the global water demand is increasing at a rate of 1% per year. Industrial and domestic water demand are increasing faster compared to agricultural demand. At present, 3.6 billion people, near to 50% of the total population live in high water-scarce areas. It is expected that this population may increase to 4.8–5.7 billion people by 2050 [1]. Therefore, any issues contributing to the contamination of water need to be prevented from occurring in future. This is possible by using monitoring tools.

Tools like GIS and water quality indices can be useful for making a decision very quickly. A geographical representation of water quality (Mapping system) will facilitate the managers and policy makers by taking the right decision at a right time. The present paper gives the detailed concept of water quality mapping by using several indices and land use analysis for water quality monitoring. This study will be useful for better management of water resources in Tanzania.

Several researchers have approached water quality issues in different perspectives pertaining to land use and water quality indices for example, Kumar et al. 2014, Rickwood and Carr 2009 have shown the methodologies of converting a large number of water quality parameters into a single value i.e. "Index" that express the overall water quality [2-3]. Rai 2012 and Tyagi et al. 2013 reviewed the significance of index number from a practical point of view and identified that index number can accurately assess the pollution levels of water bodies [4-5]. Sharma et al. 2009 used one of the index "NSFWQI" to assess the water quality of the Yamuna river in India. The results have shown the river to be under a category, class E of pollution level [6]. Liou et al. 2003 used

'RPI' and 'RQI' to evaluate the trends in river quality and proved that these indices provide logical results [7]. Sharda and Sharma 2013 also assessed the quality of Swan River, India by using GIS and RS. The study categorized the river water quality as varying from 'Acceptable to slightly polluted' and 'Good to Medium' as per OIP and NSFWQI [8]. Bordalo et al. 2001 used Scottish WQI to assess Bangpakong river in Thailand and found that the river is very polluted [9]. Apart from water quality indices, GIS has been used similarly in the assessment of land use impacts on water quality. For instance, Sliva and Williams 2001 used GIS tool and multivariate analysis to assess the impact of land use on river water quality of Ontario river in Canada and identified that water quality was highly impacted [10]. Tong and Chen 2002 used watershed-based assessment tools to establish the relationship between land use and water quality in Ohio, America. The statistical analysis showed that stream water quality was significantly affected by phosphorus, nitrogen and fecal coliform [11]. Zhao et al. 2015 identified that water quality was affected by the land uses practices in Shanghai, China [12]. Guo et al. 2010 in Hanyang District, China used buffer analysis and regression models for studying the influence of land use type and water quality and identified that land use and the spatial pattern impacted the water quality [13]. Wang 2001 incorporated water quality management and land-use planning in Little Miami watershed in the USA. The results showed very poor water quality in the areas located downstream from human settlement areas [14]. Fiquepron et al. 2013 proved that land uses have a direct impact on water quality and can increase the water price [15]. Calijuri et al. 2015 studied the land use impact on water quality in the Alto Paraguaçu catchment in Brazil and revealed a significant change in hydrological behavior of the catchment [16]. Seeboonruang 2012 used contamination potential index (CPI) to assess the impact of land uses on water quality and revealed that water quality was altered by off-season rice farming, raising poultry, and residential activities [17]. Ding et al. 2015 reported that urban land uses affected the water quality of the Dongjiang river in China [18]. Kändler et al. 2017 showed that the water quality of the upper Nisa river in Germany is affected by settlement areas, whereas, forested areas showed the smallest levels of concentration [19].

The literature review shows that water quality has been affected by the type of land uses within the watershed. This relationship can be proved by assessing and expressing pollution levels in terms of water quality indices and mapping. The present paper uses GIS and water quality indices to assess the water quality of the Ruvu river in Tanzania. The mapping system will be very useful to water managers and decision-makers in the proper management of rivers in Tanzania.

2. The Case Study Location

The present study works on the Ruvu river catchment area located in the eastern part of Tanzania between latitudes 6°05'S and 7°45'S and longitudes 37°15'E and 39°00'E as shown in Figure 1.

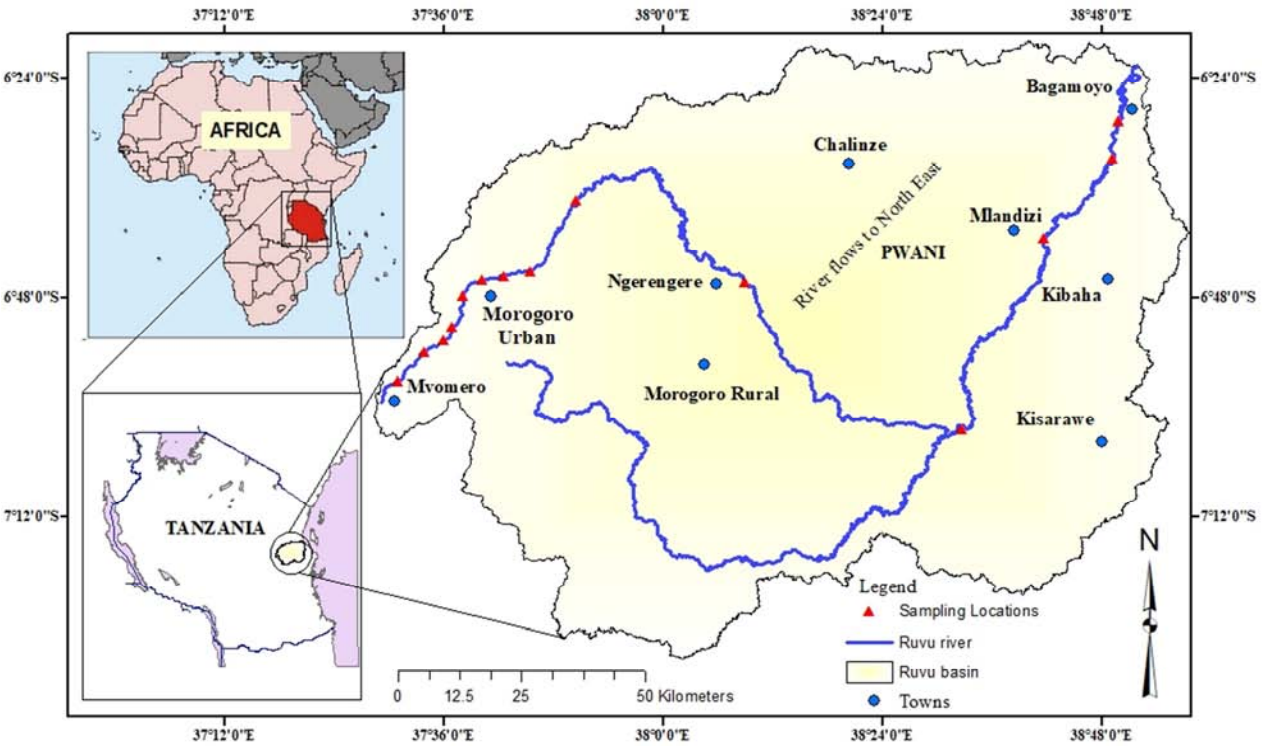

Figure 1. *Geographical location of Ruvu river in Tanzania [20-21].*

The catchment area of the Ruvu river basin is about 11,789 km^2 and the river is about 316 km long as per currently available data from the Ministry of water and irrigation of Tanzania [22]. The river starts from small tributaries emerging from the Uluguru Mountains in Morogoro Region and flows through Morogoro city, Coastal regions and Bagamoyo which finally drains into the Indian Ocean.

As the river starts passing through different towns like Mvomero, Morogoro urban, Ngerengere, Morogoro rural, Kisarawe, Kibaha, Mlandizi and Bagamoyo it receives pollutants from different points and non-point sources which are the result of anthropogenic activities. These pollutants contribute to pollution of the river which affects aquatic microorganisms and disturbs the ecosystem as well. Further water pollution may put a human into a great health risk, including water scarcity for domestic uses.

3. Methodology

3.1. Data Collection and Analysis

Water quality data were collected from the water quality officer in Wami/Ruvu basin in Morogoro Region. The agency is under the Ministry of Water and Irrigation of Tanzania working to protect and manage water quality of the basin. The agency collects and analyses water samples from 14 sampling locations of the river once each year from the month of July–October from 2014–2017. The water quality samples were analyzed by using standard methods recommended by Clesceri, APHA 1998 and APHA 2005 [23-24]. The water quality parameters analyzed were; Temperature (°C), pH, Turbidity (NTU), color (PT. Co. Unit), TSS (mg/L), TDS (mg/L), DO (mg/L), BOD_5 (mg/L), PO_4 (mg/L), NO_3 (mg/L), Hardness (mg/L), Cl_2 (mg/L), SO_4 (mg/L), fecal coliform (CFU/100mL) and Total coliform (CFU/100mL). The analysis of this study considered the average of water quality results obtained from the year 2014–2017. Higher concentrations of these parameters in water bodies are the initial indicators of poor water quality.

3.2. Water Quality Indices

Water quality data were converted into three water quality indices which are; National Sanitation Foundation for Water Quality Index (NSFWQI), River Pollution Index (RPI) and Overall Index of Pollution (OIP) these indices has been recommended by different researchers as best for river quality assessment [2, 6-7, 25-26].

3.3. Land Use Analysis

Land use was analyzed by using multi-spectral satellite images obtained from Landsat 8 in the month of July 2017. The satellite data are freely available from USGS website [27]. The Image processing, mosaicking, Geo-referencing and classification was done by using ERDAS IMAGINE 2015. The final maps were prepared by using ArcMap 10.4.1. Land uses were classified into five classes as settlement areas, agricultural areas, water bodies, forest and bare land. The percentage coverage of the five classes was calculated by using area variation. Bare land covered 26.45% of total area, the forest covered 37.23%, water bodies covered 0.14%, agricultural and settlement areas covered 32.8% and 3.38% respectively.

4. Water Quality Data

As stated earlier that, water quality data collected were converted into three indices (NSFWQI, RPI and OPI). These index results are recapitulated in Table 1. The characteristics of sampling locations basing on physical observations are as follows; Sampling location S_1 receives water from the Uluguru mountain in Morogoro Region. Areas around those mountainous lands are characterized by scattered settlement, less population and small-scale irrigation farms. Water coming from mountain areas drains towards the lowlands. The water passes through the small towns of medium population and few agricultural lands. Water from sampling location S_2-S_3 drains into the Mindu dam. The Dam is in an approximate area of 3.2 km^2 and a perimeter of 10.67 km located at sampling location S_4. The water from the dam outlet starts receiving wastewater from domestic areas, urban areas and industrial areas as it passes through sampling locations S_5-S_7. The agricultural impact was observed at sampling location S_8-S_{10} and S_{12}-S_{14}. The little improvement of water was observed in bare land and forested areas at sampling location S_{11}.

Table 1. *Water quality status of the Ruvu river by indices.*

Sampling Locations	NSFWQI		RPI		OPI	
	Average Score	Water quality status	Average Score	Water quality status	Average Score	Water quality status
S_1	52.8	Medium	4.17	Moderately Polluted	4.43	Polluted
S_2	61.2	Medium	2.75	Slightly Polluted	3.31	Slightly Polluted
S_3	64.0	Medium	3.17	Moderately Polluted	3.15	Slightly Polluted
S_4	61.7	Medium	3.50	Moderately Polluted	3.84	Slightly Polluted
S_5	49.4	Bad	7.50	Gross Polluted	4.77	Polluted
S_6	44.0	Bad	8.17	Gross Polluted	8.37	Heavily Polluted
S_7	41.1	Bad	7.83	Gross Polluted	5.67	Polluted
S_8	50.8	Bad	5.50	Moderately Polluted	5.02	Polluted
S_9	53.8	Medium	4.83	Moderately Polluted	4.65	Polluted
S_{10}	53.1	Medium	4.33	Moderately Polluted	4.67	Polluted
S_{11}	57.0	Medium	2.67	Slightly Polluted	3.59	Slightly Polluted
S_{12}	50.3	Bad	3.50	Moderately Polluted	4.89	Polluted
S_{13}	54.4	Medium	4.50	Moderately Polluted	4.13	Polluted
S_{14}	51.8	Medium	4.50	Moderately Polluted	5.21	Polluted
Average	53.2	Medium	4.78	Moderately Polluted	4.69	Polluted

Table 1 shows the characteristics of water quality status of 14 sampling locations (S_1-S_{14}) and the relationship between the three indices (NSFWQI, RPI and OPI). The results presented in table 1 are the average of water quality results obtained from the year 2014–2017. The overall results of indices categorized the river as a Medium, Moderately Polluted and Polluted level of pollution as per NSFWQI, RPI and OPI respectively.

5. Water Quality Mapping

Water quality mapping has been prepared by using GIS and Remote Sensing (RS) while the sampling location characteristics were interpolated using the Inverse Distance Weighted (IDW) method. This method forecast a value for any unmeasured location. The measured values of locations closer to the predicted location will have more impact on the predicted value than those located further away. In this way, IDW assumes that each measured point has an influence that decreases with distance. Therefore, the locations having similar characteristics were assigned the same color.

5.1. Water Quality Mapping by NSFWQI

NSFWQI classify water quality of a river in five grades, each grade having its unique color as blue, green, yellow, orange and red for grade A (91-100), B (71-90), C (51-70), D (26-50) and E (0-25) respectively as discussed by Thomas 1975 [28]. These colors show the quality of water as excellent, good, medium, bad and very bad respectively as presented in Figure 2. Since the overall grade as per NSFWQI is 53.2 as shown in table 1 and ranging from (51-70) in classification, then the water quality of the river is in the medium category of pollution level [29].

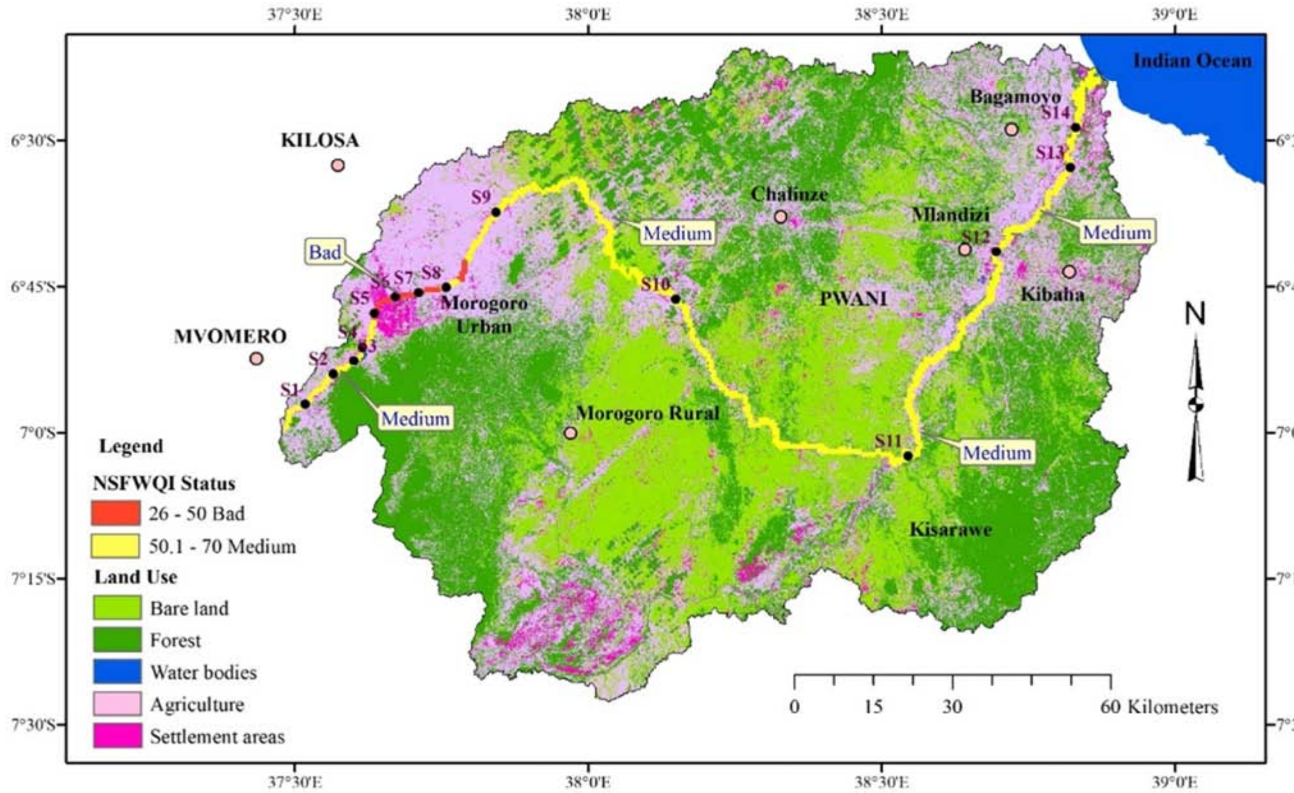

Figure 2. *Water quality profile by NSFWQI.*

Figure 2 shows that the overall water quality of the Ruvu river is categorized in a medium class of water quality status. The yellow color shows the average class of water quality. Morogoro urban (S_5-S_8) having a red color is in the bad range due to industrial wastewater discharges and urban runoffs from residential areas, specifically, domestic wastewater [29].

5.2. Water Quality Mapping by RPI

RPI categorizes water quality of a river in four fits of rage as (0-2), (2-3), (3-6) and (>6). Each range has its grades as good, slightly polluted, moderately polluted and grossly polluted respectively. More details on RPI was discussed by Liou et al. 2003 and Kumar et al. 2014 [2, 7]. Table 1 shows that the mean RPI of the river was 4.78 which indicate that the river status was moderately polluted. The highest value of RPI of 8.17 was recorded at Sampling location S_6 while the lowest value of 2.67 was recorded at Sampling location S_{11}. Anthropogenic activities were linked to causing deterioration of the water quality of the river. The overall status of the water quality is moderately polluted.

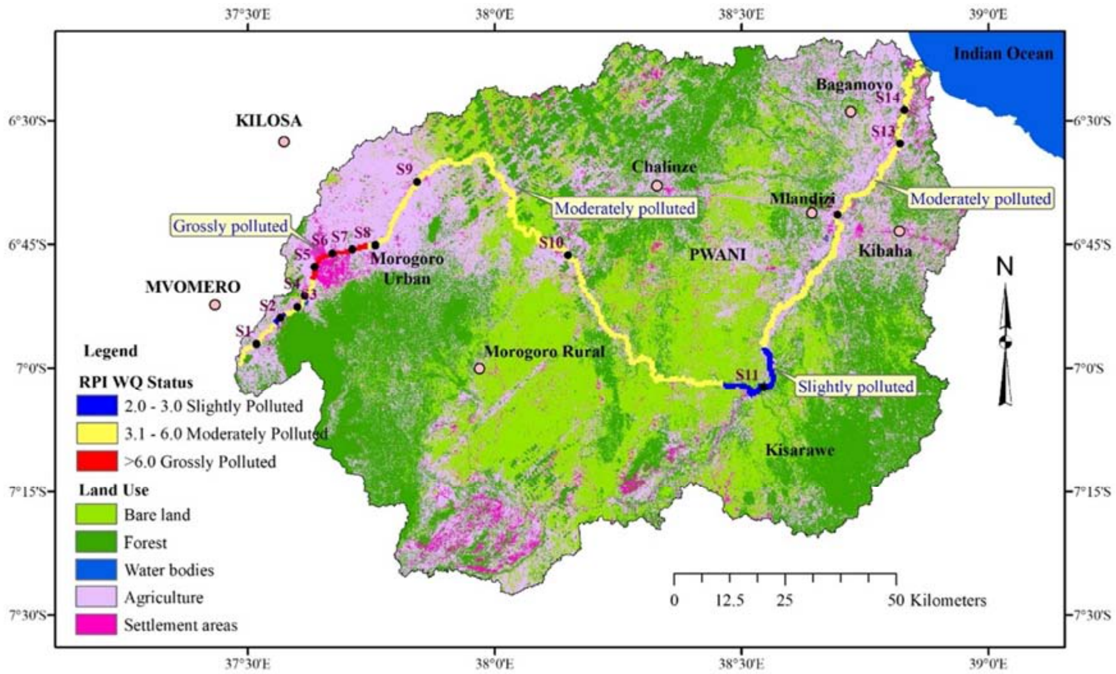

Figure 3. Water quality profile by RPI.

The water profile in Figure 3 shows that yellow color dominated the profile showing that the river is categorized in moderate pollution level. On the other hand, Morogoro urban at sampling location S_5-S_6 has a gross pollution level due to urban wastes and industrial wastewater whereas water quality improved at sampling location S_{11}.

5.3 Water Quality Mapping by OIP

OIP categorizes water quality of a river in five classes of pollutants as C1 (0-1), C2 (1-2), C3 (2-4), C4 (4-8) and C5 (8-16). Each range has its grades as excellent, acceptable, slightly polluted, polluted and heavily polluted respectively as discussed by Sargaonkar and Deshpande 2003 [26]. The OIP was 4.69 (Table 1) which indicates that the river water quality status was polluted. The highest value of OIP of 8.37 was recorded at Sampling Location S6 while the lowest value of 3.15 was recorded at Sampling Location S_3. The overall OIP of the river was at category C_4 (4-8). This indicated that the river was within the polluted water quality status. Anthropogenic activities along the river can be the reason for the poor water quality of the river. Consider Figure 4.

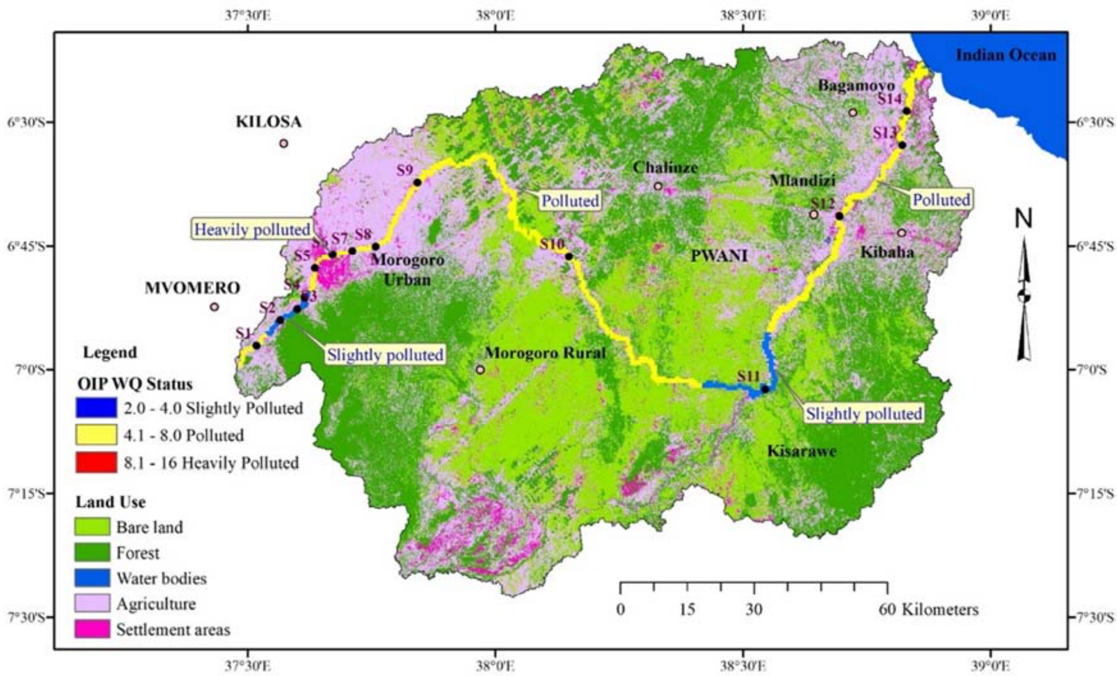

Figure 4. Water quality profile by OIP.

The water profile in Figure 4 shows that yellow color was too long in the profile showing that the river is categorized in "polluted" level of pollution. On the other hand, Morogoro urban at sampling location S_6 has a heavy pollution level. At this location, it seems that the pollution levels were contributed by industrial discharges. The rest of the sampling locations show the improved water quality.

6. Results and Discussions

Figure 5 shows the water quality profile plotted to show the water quality of the river water stretch basing on NSFWQI, RPI and OIP simultaneously. The upper and lower river line in Figure 5 represent river water quality as per OIP and NSFWQI as discussed in Figure 4 and 2, therefore, are not in a correct position. The middle line represents RPI. This Figure aims to show the comparison of the three water quality indices in assessing the water quality of the Ruvu river.

By considering Figure 5, the entire map shows that the yellow color covered a major part of the river. This means the overall river pollution level is Polluted, Medium and Moderate as per OIP, NSFWQI and RIP. The red color shows the high pollution levels, which were linked to an increase in human activities in urban areas, especially in Morogoro urban. The blue color showed the Improved of water quality because of the self-purification of water as it passes through the forested areas.

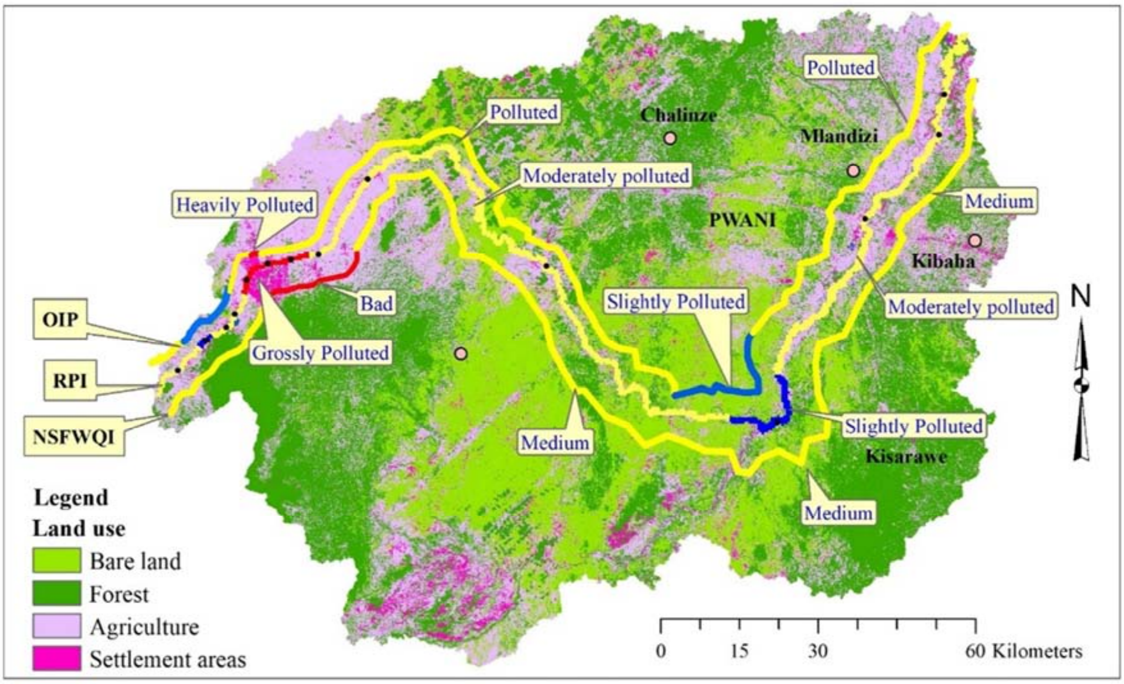

Figure 5. *Overall water quality profile.*

By comparison, OIP had a very small red color in the urban area showing that pollution was contributed by one-point source. NSFWQI extended the impact of an urban area by giving longer red color than other indices. RPI showed to compromise the result of other two indices in evaluating the impact of urban pollution on water quality. Furthermore, the indices behaved the same on blue color showing improvement of water quality. The mid-distance of the river shows slightly polluted level extended as per OIP, nothing in NSFWQI and compromised in RPI. Finally, by observing the above reasons, it is proved that RPI was the best index among the other three indices discussed in this study. Similar results were obtained by Kumar et al. 2014 who recommended that RPI is more effective and less time consuming compared to other indices [2].

This study identified that Agricultural activities and urban land use such as city sewage and industrial wastewater discharged into the river contributed to high pollution. Facilities to treat wastewater seems to be inadequate in the Morogoro urban area. At present, only a very small amount of wastewater is treated. The rest is discharged into the Ruvu river.

7. Mitigation Measures

This pollution can be reduced by identifying industries that are the biggest polluters of Ruvu river water. The industries should be strictly enforced to treat wastewater before disposal. Ruvu river basin management agency should have a regular qualitative and quantitative monitoring of water at a defined interval of time. The Morogoro Municipal Council is advised to construct a proper landfill site that will be monitored and treated. The government should revise Morogoro Masterplan maps to define an appropriate land use and provide enough area for waste treatment units. Agricultural areas require reconstruction and slope stabilization through vegetative planting and use of rocks and rip-rap methods to prevent soil erosion.

8. Conclusions

Ruvu river is among the important river in Tanzania used as the source of water for domestic uses, industrial uses, agricultural uses e.t.c. As the river passes through towns and cities it starts receiving pollutions from the point and non-point sources of pollution caused by anthropogenic activities. This study identified the most polluted locations of the river by using water quality data collected from 14 sampling locations of the river from the year 2014-2017. All the water quality data were converted and evaluated by using three water quality indices like NSFWQI, OIP and RPI. These indices categorized the water quality of the river as a medium, polluted and moderate polluted water quality status respectively. The index values were 53.2 for NSFWQI, 4.69 for OIP and 4.78 for RPI. The relationship of these three-water quality indices indicates that RPI was the best to assess the water quality of this river. Also, land use analysis showed that urban and agricultural land uses have negatively changed the water quality of the river. A very little improvement of water quality observed in some locations was due to the self-purification of water as it passes through the forested areas. This study recommended that municipalities and industries should be strictly enforced to treat wastewater before discharging into the river.

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