The Role of Anthropogenic Activities on Water Quality and River Restoration. *A case of Monik River, Arusha-Tanzania*

Abstract

Rapid urbanization, agricultural expansion, and industrial development have intensified pressure on the river's water resources, leading to elevated levels of pollutants. This study investigates the impacts of anthropogenic activities on the physicochemical water quality parameters in the Monik River in Arusha, Tanzania, and explores their implications for sustainable water management, peace, and cooperation. Using field sampling from a total of 9 sampling points, water samples were collectedat upstream, midpoint and downstream, 3 sampling sites from each point respectively. BOD, COD, phosphate, pH, EC, TDS, turbidity, DO and nitrate were analysed at each sampling point.Anthropogenic activities around Monik River were also documented.A multi parameter probe meter (HATCH HD401) was used to measure pH, EC, TDS, turbidity, temperature, and DO while Turbidity was measured by turbid meter (Wag-WT3020) in-situ. Nitrate and phosphate were determined from filtered water samples using photometric method (HACH DR/2700).BOD and COD analysed using bottle incubation method for five days (BOD incubator) and dichromate method (COD digester) respectively. DO, nitrate, phosphate, pH,and turbidity found to be beyond the permissible limit of international and National standards (WHO and TBS). EC, TDS, temperature, COD, and BOD were within permissible limit of WHO and TBS. Observation was used to analyze the anthropogenic activities which were presented descriptively.Livestock keeping and deforestation are the dominant anthropogenic activities at the upstream. The laboratory analysis, and spatial-temporal assessment, the research highlights significant deviations from established water quality standards, raising concerns about environmental health and resource conflicts. The findings underscore the critical need for collaborative governance and community engagement to mitigate pollution sources, promote sustainable use, and prevent potential conflicts over water resources. This study emphasizes that safeguarding water quality through cooperative efforts, watershed management using nature-based solutions that can serve as a catalyst for peace and regional stability in water-scarce environments.

Keywords:*Anthropogenic activities; physicochemical water quality; Monik River; Arusha; Tanzania*

Introduction

Anthropogenic activities driven by human needs and desires, can have significant impacts on ecosystems, biodiversity, and the planet's overall health. They are human actions that modify the natural environment, either directly or indirectly.When conductedalong water sources, anthropogenic activities are the major driver of environmental degradation (Glibert, 2020). Agriculture and deforestation among othershave put remarkable pressure on the ecological conditions and sustainability of aquatic ecosystems. These activities have not only increased the quantities of nutrients but also changed forms and percentage of nutrients to the environment which leads to adverse effects on water quality (Doggart et al., 2020). It is reported worldwide that there is proved correlation between increasing anthropogenic activities and decreasing qualityof receiving water sources(Akhtar et al., 2021; Sidabutar et al., 2017). For example, the study by Liu et al., (2014) has shown that industrial activities on urban stream water quality in China have tremendous changes of physico-chemical parameters while a study by Anh et al., (2023) demonstrates the key factors on river water quality in urban and rural areas accelerated by anthropogenic activities.In African context, things are not different. A review study conducted to trace the condition of physicochemical water quality parameters in Ethiopia showed that urban streams are highly impaired than agricultural streams while forested streams have better water quality (Bakure et al., 2020).The study by Chisanga et al., (2022)in Zambezi River in Zambia has shown that the livestockkeeping cause severe impacton riparian ecosystem and water chemistry. Therefore, the demand for river health assessment is becoming frequently.

Rivers are the most important freshwater resources for living organisms. However, the problem affecting river system due to unsustainable anthropogenic activities has shown to magnify over eastern Africa region. For example, in Kenya, increasing pressure for agricultural land and human settlement has resulted to encroachment into water catchment areas (Nyasulu et al., 2024).Several studies in Tanzania showedthat industrial activities, small-scale agriculture, and settlement near the river are the sources of heavy metals, chemicals, and organic wastes from pit latrines to Msimbazi River in Dar-es-Salaam, Ngerengere river in Morogoro, and Pangani River in Tanga City (Mbonaga et al., 2024). Regular monitoring of water resources and management and conservation of rivers are important for assessment of the impact of anthropogenic activities on water quality.

MonikRiver (MR),which is found in northern part ofTanzania, discharges its water in Lake Natron Ramsar Site (LNRS). MR is among the reported riversthat experience water pollution and interfere with the ecosystem services offered. Human activities taking place around LNRSincludeagricultural activities, deforestation, and overgrazing that resultin eutrophication, acidification and sediment inflow, which consists of organics and trace metals (Yona et al., 2023). As a result, MR shows ecosystem deterioration and a reduction of its services. Lake Natron Ramsar Site (LNRS), which is located in East Africa,with catchments including Monik, Pinyinyi, Ewaso Ngiro, and Ngare Sero (Rajabu et al., 2024). Activitiesalong the LNRS contribute to water pollution, reduce water quantity, oxygen for aquatic species and pH,increase soil erosion, which contributes to the watershed degradation and the breeding cycle of different animal species, including the common Flamingoes (Sadikiel E. Kaale et al., 2024). While previous scholars came up with scientific findings of significance to conservation and management of the site, there is still a knowledge gap on the impacts of these anthropogenic activities conducted around the catchments of LNRS and the MR water quality. Therefore, this study aimed to analyze the physicochemical water quality parameters of water under anthropogenic activities at LNRS.

Methodology

This study was cross-sectional in nature, using quantitative data collection and analysis method. The study was carried out at Monik River(MR) in Monik ward at Ngorongoro district, Arusha, Tanzania. The whole catchment of LNRS covers approximately 7600km^2 (Rajabu et al, 2024). This watershed is made up of four major rivers, namely the Ewaso Ngiro River, Pinyinyi River, Ngaresero River, and Monik River (Mgimwa et al., 2021)(Figure 1).

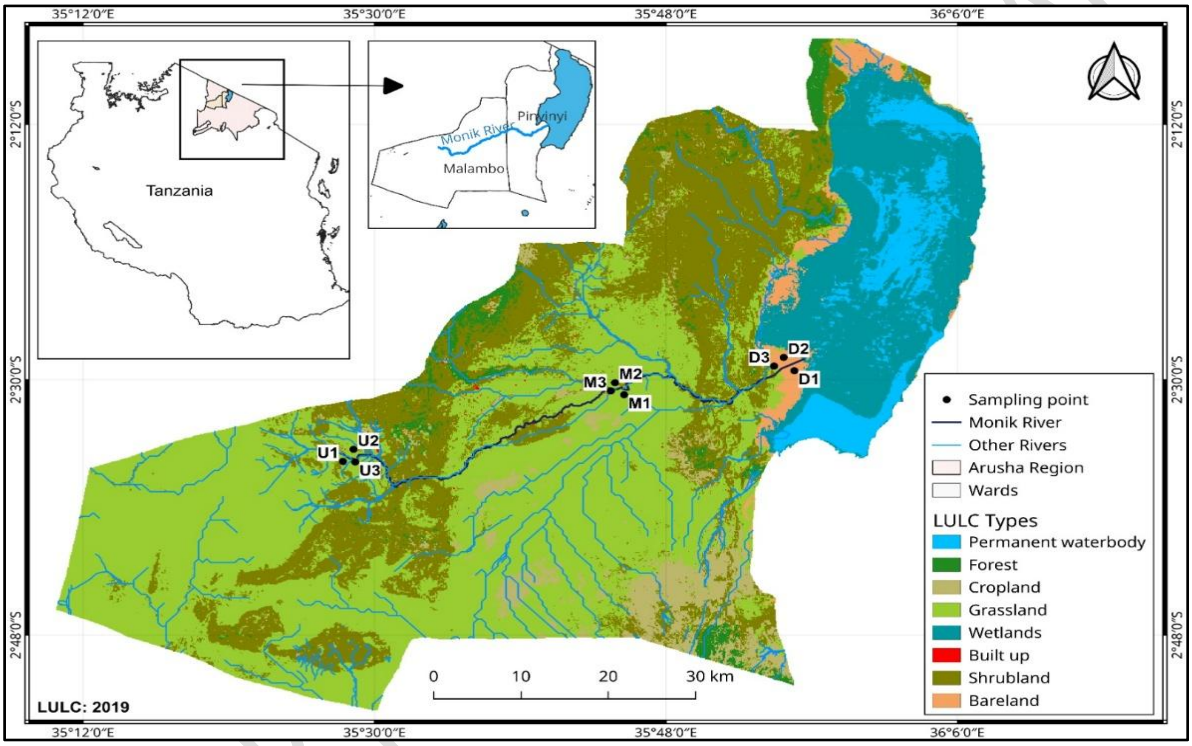

Figure 1.A map of study area showing sampling points along the Monik River

As shown in Figure 1, the upstream points (U1, U2 and U3) located furthest from the river mouth and defined as a point where there was very minimal level of disturbance to water quality and used as the reference points. At the mid-section points of the river; M1, M2 and M3 are defined as the points where intensively agricultural activities, livestock keeping, bathing, washing, sand mining and water diversion take place. It is defined as agricultural points and it defined as a point with maximum disturbance. At the river mouth or downstream points D1, D2 and D3 are characterized as points with minimum disturbance due to minimal agricultural activities taking place but the area is susceptible to organic pollutants which lowered the level of dissolved oxygen in the river caused by the animal faeces washed away to the river during irrigation and rainfall.

Data collection methods

Anthropogenic Activities performed along Lake Natron Ramsar Site

Secondary data obtained from the government documents anda parallel similar study previously conducted in the Lake Natron Ramsar site catchment area and reported byRajabu et al., (2024). In this study, observation was used to analyze the anthropogenic activities which were descriptively presented.

Water sampling

Water sampling was carried out at the selected sampling locations categorized as upstream (U), midstream (M) and downstream (D) of the river and recorded using the global positioning system (GPS). Water samples were taken from 9 sampling sites, three from each location during dry season (Sept-October, 2024) and during wet seasons (March-April, 2024). Sampling was doneweekly for three weeks in dry season and similarly repeated during the rainy season, making the total of 54 samples.

Composite sampling technique was used to take water samples following the recommendation by Golnick *et al*. (2016), collected in the labeled 1-litre plastic bottles which were prior rinsed with distilled water, stored in a cool box at 4^oC and transported immediately to the laboratory of Arusha Technical College (ATC) for nitrate, COD, BOD and phosphate analysis.

Analysis of Physicochemical Parameters

On-site measurement was suggested for parameters that usually changeover time due to chemical reactions or biological changes (APHA 2022). Thus,water pH, EC, TDS, turbidity, temperature and DO weremeasured in situ usingmultiparameter probe meter (HATCH HD401) and Turbidity by using a turbid meter (Wag-WT3020).

In the ATC laboratory, the samples were filtered using a 0.45µm size filter membrane. After filtration, water samples were stored at 4 °C before analysis. Unfiltered water samples were tested for alkalinity using the titrimetric method with 0.1NHCl and the resultswere expressed as HCO_3^- (mg/l) as explained by APHA *et al*. (2022). NO_3^- and PO_4^{-3}were determined from filtered water samples using the photometric method (HACH DR/2700).

StatisticalAnalysis

The datasets were tested for normality using the Shapiro-Wilk test, in which a null hypothesis that a variable is normally distributed was rejected if $p < 0.05$.Descriptive statisticswere used to refer to the basic features of the data andsummarise variation in physicochemical water parameters among sampling sites. A one-way t-test was used for seasonal variation of water quality to determine whether the means of samples from two seasonsare significantly different at 95% confidence level. Hierarchical Cluster Analysis (HCA) was used in characterizing the different sampling locations to assess the similarities and differences among them and identify possible patterns and most polluted part of the river based on the measured parameters.All analyseswere performed byusing PAST statistical software (version 4.03) unless otherwise indicated.

The analyzed water quality parameter values were compared with the Tanzania drinking water quality standard (2018) and the World Health Organization guideline (2018) for drinking water for the compliance check with both national and international standards. Furthermore, the standards were used to categorize the status of the river as to guide the allowable required standard limits of each selected water parameter in Monik River.

Results and discussion

Activities performed along the Monik River

Livestock keeping and deforestation are the dominant activities at the upstream points.Herbicides, pesticides, industrial fertilizers, and animal wastes washed away to the river which also contributes to changes in water quality (Figure 2).

Figure 2: Anthropogenic activities along Monic River

Seasonal Variation of Physicochemical Water Parameters

The concentrations of physicochemical parameters were generally in the pattern of increasing to the midstream and decreasing to the downstream for both seasons as summarized in Table 1.

Table 1. Concentration Mean and Standard Deviation values for measured physicochemical characteristics fromthree sampling points along Monik River during the dry and rainy seasons

	Dry season (n=27)			**Rainy season (n=27)**			**WHO**	**TBS**
	Upstream (Means±SD)	*Midstream (Means±SD)*	*Downstream (Means±SD)*	*Upstream (Means±SD)*	*Midstream (Means±SD)*	*Downstream(Means±SD)*		
Temp (°C)	20.24±0.22	20.36±0.26	20.29±0.24	18.91±0.26	19.04±0.26	18.93±0.30	20-25	20-25
DO (mg/L)	6.93±0.23	7.04±0.24	6.96±0.26	6.32±0.20	6.21±0.15	6.23±0.14	8-10	5-7
EC (μS/cm)	328.89±9.60	335.33±10.58	329.89±11.74	293.89±6.21	297.33±8.40	295.11±7.85	2500	2500
NO_3^- (mg/L)	1.46±0.31	1.63±0.29	1.48±0.37	2.67±0.20	2.78±0.26	2.66±0.34	50	30
PO_4^{3-} (mg/L)	0.12±0.02	0.14±0.02	0.12±0.03	0.26±0.02	0.27±0.03	0.26±0.03	6	6
pH	7.14±0.11	7.20±0.11	7.16±0.13	6.66±0.11	6.63±0.16	6.62±0.14	6.5-8.5	6.5-8.5
TDS (mg/L)	209.22±9.77	215.44±11.20	210.00±13.25	188.56±6.00	191.56±8.59	190.44±7.67	500	1000
Turbidity (NTU)	17.11±2.42	18.89±2.37	18.11±3.06	50.11±4.01	51.89±5.30	51.56±4.39	5	<25
BOD (mg/L)	2.67±0.21	2.81±0.24	2.71±0.29	4.39±0.28	4.56±0.38	4.53±0.33	10	2-6
COD (mg/L)	13.67±1.41	14.67±1.41	13.78±1.92	25.67±.00	26.44±2.88	26.11±2.37	60	60

Water temperature is one of the concern in the surface water because it influences physicochemical, biological processes and ecosystem balances in water bodies (Wilson et al., 2019). High temperature influences the rise of biological oxygen demand which indicates the poor water quality and attributed to loss of riparian vegetation in the catchment (Johnson et al., 2024).The water temperature recorded from Monik River was in the range of18.5-20.7 °C with the maximum during the dry season and the minimum during the rainy season. Results from t-test analysis show that there is statistical significant difference between temperature values recorded during the rainy season and dry season (t=19.47, p=1.54×10^{-25}). Temperature increases the density of water that cause the increase in metabolic rates and decrease the solubility of oxygen which threats the aquatic organisms. Water temperature is a crucial factor in river health and water quality, as it influences dissolved oxygen levels, the types of aquatic life that can survive, and the rate of chemical and biological reactions. The permissible range of water temperature for healthier water sources is 20-25°C (WHO, 2018 and TBS, 2018), whereby all the recoded conformwith the recommended level.

DO is the quantity of gaseous oxygen dissolved in an aqueous solution. Suitable dissolved oxygen is necessary to withstand aquatic biota. The range of 6.6–7.4 mg/L, with the maximum DO recorded at the upstream sampling point during wet season. This range of DO values showsgood dissolved oxygen levels, indicating healthy aerobic conditions.Oxygen content is important for the direct need of many organisms and affects the solubility of many nutrients and periodicity of aquatic ecosystem (Katonge & Gayo, 2025). In the summer time dissolved oxygen decreases due to upturn in temperature and increased microbial activities (Yona *et al.*, 2022). Results from t-test analysis show that there is statistical significant different between DO recorded during the rainy season and dry season (t=12.92, p=7.33×10^{-18}). However, results from this study are within the recommended range of DO in surface water for healthier environment. The lowest acceptable dissolved oxygen concentration for aquatic life, range from 6 mg/L in warm water to 9.5 mg/L in cold water (WHO, 2018). The permissible limit of DO is 5 – 7 mg/L (TBS, 2018) and 8-10 mg/L (WHO, 2008). Previous studies from the tropical conditions similar to this study also conform with the standards. Rajesh and Rehana, (2022) further elaborated thatDO plays a role of regulator of metabolic activities of organisms and thus manages metabolism of the biological community as a whole and used as an indicator of tropical status of the water. Low DO is an indication that, the aquatic ecosystem is degraded and some organisms that use aerobic conditions will not be able to survive due to lack of oxygen (Mbaruku, 2016).

EC is another parameter analysed which is a measure of water capacity to convey electric current. It signifies the amount of total dissolved salts (Mezgebe*et al.*, 2015). The range of EC from 285–352 μS/cm was recorded with minimum during rainy season and maximum during dry season. A statistical t-test analysis at 95% confidence level showed that, there was a significant difference of EC recorded in rainy season and dry season (t=14.39, p=8.9×10^{-20}). The range of values recorded implies the moderately fresh water with some mineral content. The permissible limit of EC is < 1500 μS/cm (WHO, 2008) and 1000 μS/cm (TBS, 2018). In all sampling sites, values of EC during dry and rainy seasons were within the permissible limit. The higher EC in water is an indication of salts in water that are not acceptable to macroinvertebrates, because some cannot tolerate salinity conditions (Mbaruku, 2016).

Nitrate is one of the essential nutrients in aquatic ecosystem for plants growth and limits algal growth (Bwalya, 2015). Nitrogen contains elements which are crucial for all biotic processes in the aquatic environment. Nitrate level of1.0–3.1 mg/L was obtained with minimum from dry season at downstream point and maximum during rainy season at midstream. A statistical analysis showed that, there was significant different between seasons (t=14.57, p=5.35×10^{-20}). The permissible limit of nitrate is 50 mg/L for WHO, (2018) and30 mg/L for TBS, (2018).The recorded amount from this study might be due to natural background range and shows some mild nutrient input even though it iswithin the recommended threshold of both standards. The increase of nitrate concentration in rivers is due to anthropogenic activities and during floods, the run off from agricultural activities conveys fertilizers to the rivers. The concern of nitrate is due to its pollution of water bodies. The upturn of nitrate causes excessive algal growth, up on decomposition too much algal growth lowers oxygen levels and thus some aquatic organisms cannot stand anaerobic condition (Mbaruku, 2016). High nitrate levels noted in surface water in most cases originate from human activities such as agricultural activities and livestock keeping (Lalika *et al*., 2015). High nitrate concentration observed in many river systems may be due to drawn-out sources from urban and agricultural runoff and to point discharge from sewage treatment plants (Mbaruku, 2016).

Phosphate is the most important nutrient for plants growth, phosphorus can occur in a variety form in aquatic ecosystem namely: as mineral phosphorus, inorganic phosphorus and organic phosphorus (Phosphorus bound up with carbon and oxygen in plant matter) and as dissolved soluble reactive orthophosphate (PO_4^{-3}) (Mbaruku, 2016). The range of 0.1–0.3 mg/L of Phosphate was detected, with the highest being during rainy season. The statistical tests showed a significant different of mean phosphate values recorded during dry season and dry season. The permissible limit of phosphate is 6 mg/L for both WHO, (2018) and TBS, (2018). The values obtained are low detectable and are within the permissible range but might reflect minor agricultural runoff.In aquatic ecosystems if phosphorus outstrips the acceptable limit, affects aquatic ecosystem by dwindling the oxygen after excess algal growth (Bwalya, 2015). The use of soaps, shampoos, and other personal care products can introduce chemicals such as phosphates, surfactants and fragrances into the water (Mgimwa*et al*., 2021). Fertilizers, after being used for agricultural activities are splashed down to the water bodies bringing in great loads of phosphorus (Bwalya, 2015).
The minimum values of inorganic phosphate recorded during dry season could be due to adsorption to particulate matter and subsequent sedimentation (Melaku *et al*., 2007). The maximum values of inorganic phosphate recorded from upstream to downstream during wet season are due to agricultural activities, bathing, washing and livestock keeping (Bwalya, 2015; Melaku *et al*., 2007).

pH indicates the strength of the acidic or alkalinity character of a solution and is controlled by the dissolved chemical compounds and biochemical progressions in the solution (Mezgebe*et al*., 2015). This study recorded a pH range of 6.4–7.4 which is neutral to slightly alkaline. A t-test analysis shows that there is statistically different between pH values during rainy season and dry season at t=15.47 and p=4.23×10^{-21}. The highest pH value was recorded during the dry season and the lowest during the rainy season. This observation was due to the fact that during the rain, rivers receive runoff that may increase water dilution and hence increase the concentrations of hydrogen ions that consequently reduce the pH. This has also been found by other researchers like Mhande et al., (2022) who studied waterquality changes in rivers during rain events and found that pH showed some decreasing trends during rainfall.Since the pH is most essential in determining the corrosive nature of water, its frequent monitoring is essential for assessment of water ecosystem health, irrigation and drinking water, industrial discharge and surface water run-off. The findings are within the recommended pH values of 6.5 to 8.5 (WHO, 2018; TBS, 2018). Water which has pH value of more than 9 or less than 4.5 becomes unfitting for domestic use like drinking. Low pH increases the solubility of metals and nutrients such as nitrates and phosphates making them available for uptake by plants and animals (Mbaruku, 2016). It is usually monitored (Mezgebe*et al*., 2015). The higher pH at upstream sampling site could be due to bicarbonate and carbonate of calcium and magnesium in water and the main sources of such chemicals could be due livestock keeping, bathing and washing in river water course (Suthar *et al.*, 2010).

TDS indicates the ability of water to dissolve various inorganic and some organic minerals or salts like sulphates, magnesium, chlorides, bicarbonate, sodium, calcium and potassium (Mbaruku, 2016). TDS values in this study were in the range of 180–235 mg/L, minimum value was obtained during rainy season while maximum during the dry season at the midstream of the river which might be due to due to high rate of evaporation, water diversion, deforestation, dissolution of rocks and pesticides from agricultural activities. According to Lalika *et al*. (2015) the maximum value of TDS during dry season are attributed to high rate of evaporation, dissolution of rocks, pesticides, herbicides and insecticides from agricultural activities. This further proved by the t-test results that show a statistical significance difference of TDS values recorded on dry season and that from rainy season (t=8.19, p=6.17×10^{-11}).

High levels of TDS reduce algal productivity and growth and give a picture of the poor water quality (Mezgebe*et al.*, 2015). Irrigation with high TDS water result in soil salinization and a drop in macro-porosity but do not decrease farm yield (Rajabu et al., 2024). The permissible limit of TDS is 500 mg/L (WHO, 2018) and 1000 mg/L (TBS, 2018). The TDS level recorded in this study are within the permissible limit (WHO, 2018; TBS, 2018).

Turbidity is a measure of how clear the water is (Mezgebe*et al.*, 2015). Turbidity in most water is due to colloidal and extremely fine dispersion. Turbidity of 14–59 NTU was recorded, at MR with minimum during dry season and maximum on the rainy season. This may be attributed to increased rainfall runoff from the land that carries different sorts of materials into the rivers. The minimum level of turbidity might be due to local sediment or erosion as the water during that time is still and undisturbed.During the rainy season, turbidity is influenced either naturally by rainfall run off or anthropogenic activities such as industrial activities. The statistical t-test results proved that there is statistically significant different of turbidity levels seasonally (t=33.07, p=1.34×10^{-36}). While the permissible limit of turbidity of WHO, (2018) is 5, the limit by TBS, (2018) is set to <25 NTU. Hence, the recorded turbidity levels of Monik River are partially complying with local standards during dry season and don’t comply with international standards. Turbidity water affects photosynthesis because it limits permeation of light (Mbaruku, 2016). In extreme cases, turbid water can harm animals and deposit heavy sediment on leaves reducing photosynthesis. Turbid water also affects how well disinfection techniques including ultraviolet light and chlorination work and slows the establishment of vegetables (Mezgebe*et al*., 2015). According to Mezgebe*et al.* (2015), Khatri and Tyagi (2014), the maximum value of turbidity attributed to sand mining, making bricks and deforestation. In this study the maximum value of turbidity recorded from dry season could be due to sand mining, livestock keeping, fishing, bathing, agriculture, water diversion, washing and deforestation.

Chemical Oxygen Demand (COD) is an indication of the amount of Oxygen required to oxidize organic materials in the water Oxygen demand as a measure of pollution indicators was determined by COD and BOD_5. Correspondingly, the value of COD was detected from 11-31mg/L in while BOD_5 was in the range of 2.3-5.1mg/L. All the minimum values were from dry season and maximum from the rainy season. It was further proved by statistical analysis results that showed there is a statistical significant difference between COD and BOD_5 values determined between dry season and dry season at t=33.0721.86, $p=7.07\times10^{-28}$ and t=22.4, $p=2.08\times10^{-28}$ respectively. Other research findings such as by Muniz *et al*. (2011) and Mustapha *et al*. (2013) have reported that organic pollutants discharged specifically from households and agricultural activities are the main causes of organic waste leading to COD and BOD_5 loads. The recorded COD values from this study are within the permissible range of 60mg/L for both WHO, (2018) and TBS, (2018). The permissible range of BOD_5 is 2 – 6 mg/L for TBS, (2018) and 10mg/L for WHO, (2018) and all determined values are within the recommended range.

Clustering of river's sampling points

A two-way hierarchical clustering results ofwater quality parameters was used to present the similarities in some sampling points along the river from both rainy season and dry seasons. presented in Figures 3 and Figure 4.

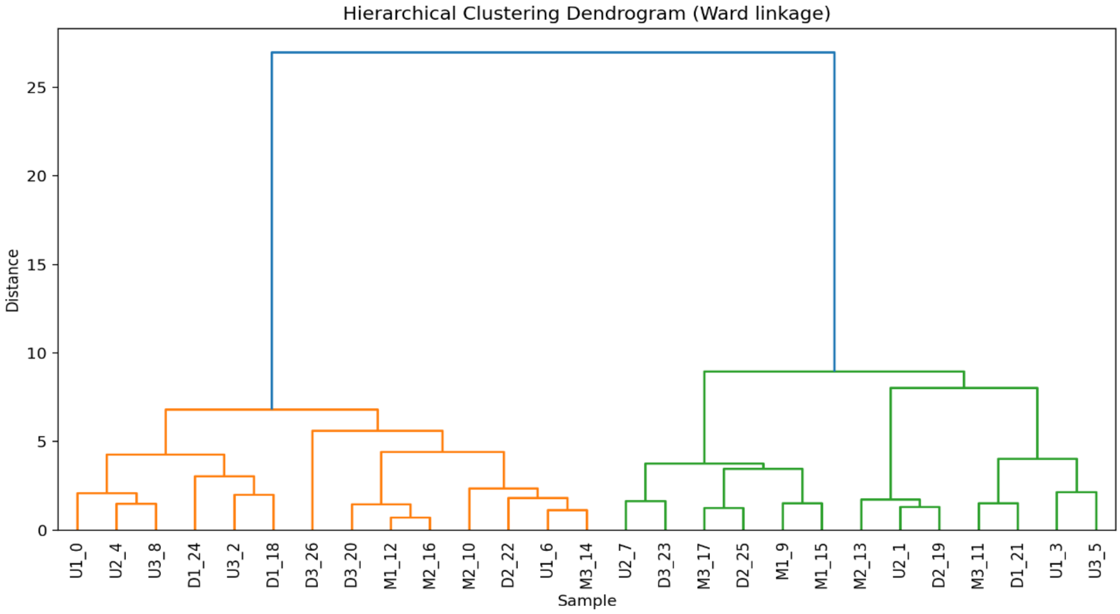

Figure 3: The dendrogram showing overall similarities (*Ward linkage, Euclidean distance on z-scored variables*)

Figure 3 presents the dendrogram from hierarchical analysis (Ward linkage, Euclidean distance on z-scored variables) that groups the 27 water-quality observations by overall similarity. The shorter the horizontal linkage line, the more alike the samples are and the long jumps indicate distinct clusters.

The dendrogram confirms that season (dry and rainy) and site type (U, M, D) both influence the water chemistry, however, there are some data from U-site in dry season resemble D-site in rainy samples, indicating mixing. Cluster one which is the largest contains most “baseline” measurements that share moderate temperature, conductivity and nutrient levels. These are sites in the low-concentration cluster fall comfortably within typical agricultural-irrigation guidelines and pose minimal salinity or nutrient hazard. Moreover, cluster two groups’ samples with slightly higher turbidity/TDS and lower dissolved-oxygen values, while Cluster three is driven by noticeably higher rainy-season turbidity/BOD/COD peaks, separating those storm-influenced readings. the highest nitrate/phosphate and EC, pointing to stronger nutrient loading and ionic strength possibly near a pollution source recorded in Cluster four which suspected to be more agricultural land. Finally, cluster five links the warmest/most-oxygenated dry-season readings with elevated organic demand, suggesting a different hydro-chemical regime (For example, upstream/unmixed zone). Results suggest that, the focus should be on Clusters four and fiveso that to isolate specific pollution events or hotspots for targeted management.

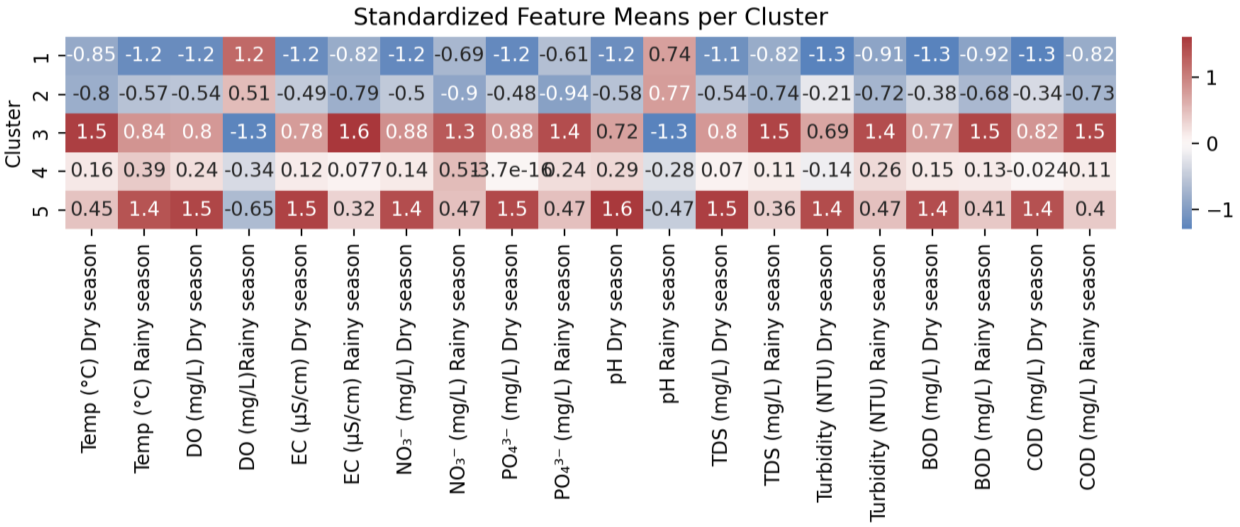

Figure 4. Heatmap shows, how far each cluster’s mean (z-score) for every variable, sits above (red) or below (blue) the grand average.

Additionally to sampling site similarities, the heatmap (Figure 4) shows five generated clusters of water quality parameters based on seasonality. Cluster one shows a baseline organic signal on dry season dominated by high turbidity, BOD, and COD in the dry season suggests particulate/organic loading while other parameters stay near average. Cluster two indicates the points when rain results into nutrient spike with high amount of PO$_4^{3-}$, NO$_3^-$ plus slightly warmer dry-season temperature.Furthermore, clusterthree gives biggest positive shifts in conductivity and TDS, coupled with warmer temperature in dry season. This leads into high-ionic strength and solids loads and an influx of dissolved salts/solids during rain events. In Cluster four, cooler temperature, highest nitrate, and lowest dissolved-oxygen appeared on a contrary, entailing consistent cool inflow rich in oxidised nitrogen that depresses DO like groundwater seep or fertiliser runoff.The fifth cluster stands out by elevated dry-season pH, TDS and conductivity. It is more likely to reflect a mineral-rich, less-disturbed upstream source.Using the Heatmap, the key observed variables help in targeted monitoring plans. This can be done by focusing on the Cluster two sites during the rainy seasons for nutrient abatement, and Cluster four for low-oxygen episode.

River Restoration plans

Monik River offered ecosystem services such as habitat, sediment and nutrient absorption, provide water for domestic and wild animals and water for agriculture. Mgimwa*et al*. (2021) documented that, unsustainable agriculture and livestock keeping degraded many rivers in Tanzania. In this study Monik River degraded due to, deforestation, water diversion, agriculture activities, livestock keeping, sand harvesting and making of burnt blocks along the river. In-spite that there is possibility of River self-restoration (Yahaya et al., 2024), this process may take long compared to the rate of pollution. Based on the developed clusters of the river, it is therefore important thatMonik River restoration is taking place for the lost ecosystem services to get back.

Bell et al., (2025) suggested number of land management actions that can restore polluted river part which may include re-vegetation, riparian buffer creation, livestock exclusion, fencing, eradication of weeds, grading banks and agricultural best management practices. Others are addition of large woody debris and adding of boulders were the best ways of river restoration. In this study, several ways of restoring the lost ecosystem services in Monik River are possible to be considered.One strategy could be the riparian buffer creation or fencing of the water sources, which may include a provisioning of a streamside forest is one of the most effective ways to filter pollutants (Collins et al., 2013; Yahaya et al., 2024).

Another practice is the exclusion of livestock along the riverbank. This action has been reported to be beneficial by reduction in sediment and faecal discharge to the water (Kilgarriff et al., 2020).It is well advisable that if this action is chosen, prior education provision to the local community is needed to avoid conflicts with livestock keepers. Additionally, construction of alternative water sources such as wells could restrict community to use water directly from the river. In parallel to the adoption of agricultural best management practices which could include the allocation of irrigation water.

Conclusion and Recommendation

Conclusion

The study revealed thatEC, TDS, temperature, COD, and BOD were within the permissible limit of TBS and WHO in all sampling sites. DO during dry and rainy seasons, in all sampling sites were below the permissible limit of TBS and WHO. High pH was recorded at upstream during dry and rainy season are not with the permissible limit. High nitrate and phosphate from upstream to downstream recorded during wet season were not within the permissible limit of WHO and TBS.Turbidity at the downstream during dry season was above the permissible limit of TBS and WHO. The study revealed that Monik River was highly polluted during wet season compared to dry season. Furthermore, bathing, washing, agricultural activities, sand mining, livestock keeping and deforestation significantly affect the water quality of Monik River. The study has provided insights into the water quality of the Monik Riveras an impact of anthropogenic activities. The study also revealed that riparian buffer creation, strict laws, best management of agriculture practices, and education provision, livestock exclusion, and well construction are the best ways of Monik River restoration.

Recommendation

The study recommends collaborative governance and community engagement. The Ministry of Water and Irrigation through the office of Water resource basin should arrange for frequent workshops and training with community to plan for mitigation of pollution sources, promote sustainable use, and prevent potential conflicts over water resources. Moreover, the Urban and Sanitation Authority in the regional level should do monitoring to safeguard water quality through cooperative efforts, watershed management using nature-based solutions that can serve as a catalyst for peace and regional stability in water-scarce environments.

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Data availability

Data can be made available from the corresponding author upon request and if there is substantial motivation.

Conflict of Interest

No conflict of interest

Authors’ Contributions

M.P. contributed to conceptualization, data collection, formal analysis, investigation, methodology, resources, software, validation, visualization, and the writing of the original draft, as well as review and editing.T.A.M. provided supervision and contributed to methodology, software, validation, visualization, and review and editing of the original draft.

I.T.M. contributed to the review and editing of the original draft.H.M. contributed to the review and editing of the original draft

Declarations

We have no competing interests to declare. The AI tool (*Quillbot*) was used in grammar check only in this study. Ethical clearance was obtained from the Open University of Tanzania and approval to conduct research in the study area was granted by the Ngorongoro district, Arusha Tanzania.

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