



Spatio-Temporal Variations in Physico-Chemical Properties of Freshwater Bodies in Pangani Basin, Tanzania: Implications for Catchment Land Management

¹Halima Omari Mangi

¹ Department of Development Studies, College of Social Sciences and Humanities, Sokoine University of Agriculture, Tanzania. Email: halima.mangi@sua.ac.tz

Received: December 12, 2023; **Accepted:** September 28, 2024; **Published:** December 12, 2024

Abstract: The integrity of river basin ecosystems is closely intertwined with land development activities, which significantly influence water quality. Freshwater bodies in the Pangani Basin serve as receptors for both intentional and accidental material residues from land-based activities. Recent increases in agricultural and settlement activities have heightened nutrient loads in these aquatic systems, surpassing the natural capacity of ecosystems to assimilate and cycle these nutrients. This study investigated the spatio-temporal variations in the physicochemical properties of freshwater bodies within the upper Pangani River Basin. Water samples were systematically collected from Nyumba ya Mungu Dam, Kikuletwa River, Ruvu River, and Pangani River, utilizing a purposive sampling method to identify thirteen sampling points. Analysis of Variance (ANOVA) was employed to assess spatial and temporal variations in water quality parameters, including dissolved oxygen, turbidity, and chlorophyll-a, with a confidence level of 95% using SPSS software. Results revealed that dissolved oxygen concentrations were notably lower in the Pangani River (ranging from 0.2 mg/L in March to 2.8 mg/L in September) compared to the other sites. Turbidity peaked in the Kikuletwa River during May and June (354 FNU), while chlorophyll-a levels were highest in the Nyumba ya Mungu Dam (120 µg/L), with a mean value of 25 ± 24 µg/L, in contrast to the rivers ($P < 0.05$, $df = 155$). The findings suggest that seasonal variations, particularly run-offs from agricultural land during rainfall, are significant contributors to Total Nitrogen levels in these freshwater bodies. The study underscores the need for effective catchment land management strategies to mitigate nutrient pollution and safeguard water quality.

Keywords: Spatio-temporal variations, physicochemical properties, freshwater bodies, nutrient pollution, catchment land management

1. Background Information

Land use and management practices within river basins have long been recognized as critical factors influencing the ecological health of freshwater systems (Chiwa, 2012). Historically, the states of water bodies have been significantly shaped by terrestrial development, with freshwater systems serving as sinks for both intentional and unintentional material discharges (PBWB, 2009). The interaction between land use activities and water quality has increasingly come under scrutiny due to its profound effects on aquatic biological resources (Mao *et al.*, 2018; Selemani *et al.*, 2017; Kimenju, 2018). Notably, fish populations often exhibit fluctuations in response to alterations in their physical, chemical, and biological habitats, a phenomenon driven by changes in land use and cover (Piana *et al.*, 2017; Mangi *et al.*, 2023). Consequently, effective land management practices are essential to mitigate adverse impacts on water quality and to ensure the sustainability of both human and ecological water resources (PBWB, 2009; Mangi *et al.*, 2022).

Agriculture and urban expansion have emerged as notorious contributors to the degradation of freshwater ecosystems (Huang *et al.*, 2013). These activities have introduced significant nutrient loads into aquatic systems, surpassing the ecosystems' capacity to assimilate these inputs naturally (Loosmore *et al.*, 2006; Trautwein *et al.*, 2012; Huang *et al.*, 2013). The surplus of nutrients, particularly phosphorus (P) and nitrogen (N), from agricultural lands frequently ends up in aquatic systems, including dams and rivers, leading to deteriorating water quality (Mugwe, 2007; Loosmore *et al.*, 2006; Walker *et al.*, 2007; Kremser, 2016). Additionally, land clearing for agricultural and settlement purposes has further compromised the nutrient filtering capacity of catchments, resulting in increased nutrient-rich runoff into water bodies (Nonga *et al.*, 2011; Trautwein *et al.*, 2012; Mangi *et al.*, 2022).

The global increase in soil degradation has exacerbated the use of fertilizers and agrochemicals, driven by practices such as inadequate organic manure application, improper tillage, and continuous cropping (Mugwe, 2007; Ugboh & Ulebor, 2011; Mohan & Sajayan, 2015; Mangi *et al.*, 2022). This has resulted in soil fertility depletion and heightened reliance on synthetic fertilizers and pesticides to maintain agricultural productivity (Glibert, 2010; Lema, Machunda, & Njau, 2015; Mohan & Sajayan, 2015). Soil fertility challenges in African regions, including Sub-Saharan Africa, have led to a significant decline in per capita food availability, with production dropping from 150 kg to 130 kg per person over the past 35 years (Mugwe, 2007). In semi-arid regions, this issue is further complicated by nutrient deficiencies, low organic matter, moisture stress, and high soil erodibility (Ugboh & Ulebor, 2011).

In Tanzania, the National Agriculture Policy of 2013 has promoted high-value crops such as horticulture, recognizing their importance in enhancing household incomes and livelihoods (Misana, 2003; Wineman *et al.*, 2020). Regions like Kilimanjaro and Arusha, major horticultural hubs, have seen a surge in horticulture farming, driven by both local and tourism-related demands (Lema *et al.*, 2014; van den Berg & Lively, 2019). Many of these farms are irrigated and situated near water bodies, increasing the risk of agrochemical runoff (Makarius *et al.*, 2015; Lema *et al.*, 2014). Farmers in these regions often rely heavily on pesticides and inorganic fertilizers to manage pests and increase yields, with common inputs including nitrogen and phosphate compounds as well as various classes of pesticides (Mohan & Sajayan, 2015; Selemani *et al.*, 2017; Lema *et al.*, 2014). However, inadequate adherence to application protocols has exacerbated the risk of chemical contamination, with significant levels of pesticides, phosphates, and nitrates detected in local water sources (Selemani *et al.*, 2017; Lema *et al.*, 2014; Makarius *et al.*, 2015).

Despite the growing recognition of these issues, comprehensive studies examining the spatio-temporal variations in the physicochemical properties of water bodies in the Pangani Basin remain limited. Understanding how water quality fluctuates spatially and temporally is crucial for effective catchment land management and the preservation of aquatic ecosystems. This gap in knowledge underscores the need for detailed investigations into how land use and agricultural practices influence water quality over time and across different locations within the basin.

This study aimed to investigate the spatio-temporal variations in the physicochemical properties of freshwater bodies within the upper Pangani Basin. By systematically analyzing fluctuations in water quality across various spatial and temporal dimensions, the study sought to identify specific patterns of degradation and their correlates. The findings were intended to provide actionable insights for

developing targeted land management strategies and interventions to improve water quality and ensure sustainable management of water resources within the basin.

2.0 Methodology

2.1 Description and Location of the Study Area

Nyumba ya Mungu Dam (NMD) is a large artificial lake in East Africa, straddling Mwanga District in the Kilimanjaro Region and Simanjiro in the Manyara Region. Covering 15,000 hectares, the dam is an inclined rock fill structure linking the Kikuletwa and Ruvu rivers. Its downstream end is the outflow for the Pangani River. The NMD catchment is situated between latitudes 3°00'00" and 4°03'50" S and longitudes 36°20'00" and 38°00'00" E (Figure 1).

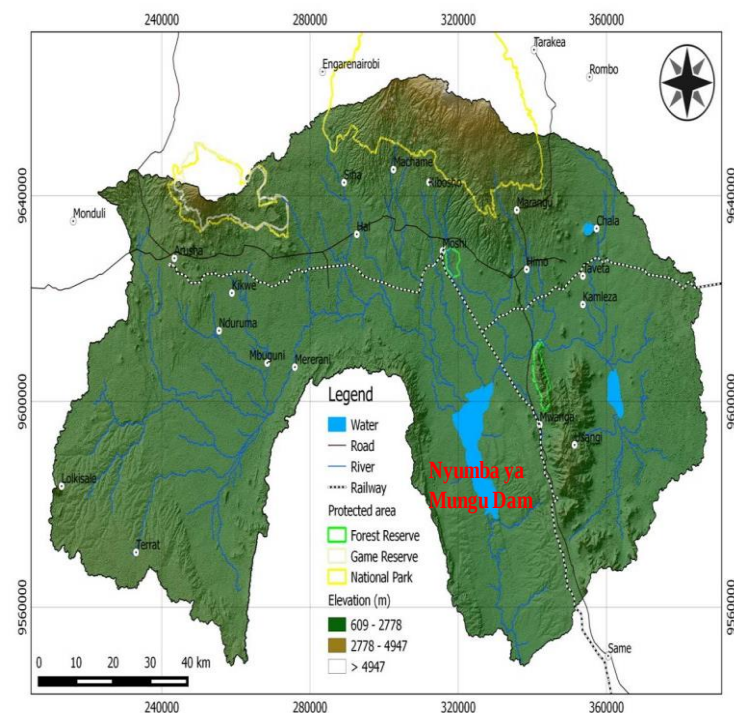


Figure 1: Map of northern Tanzania showing the location of NMD and its catchment area.

The dam catchment is located in the upper section of the Pangani River Basin (PRB) in northeastern Tanzania, covering 42,200 km², with about 5% in Kenya (Ndomba, 2010). It is drained by two rivers: Kikuletwa, fed by Mt. Kilimanjaro and Mt. Meru, and Ruvu, which originates from Lake Jipe (Ndomba *et al.*, 2008). The Pangani River carries water from the dam downstream.

2.2 Water Sampling Procedures and Data Collection

Water samples were collected from NMD, Kikuletwa River, Ruvu River, and Pangani River (Figure 2 and Table 1). Sampling points were selected purposively: in Kikuletwa and Ruvu rivers, two sites each were chosen, with one upstream and one downstream (Figure 2 and Table 1). For the Pangani River, a single site was selected 10 kilometers from the dam. In NMD, eight sites were identified: two in the upper section, four in the middle, and two in the lower section of the dam (Figure 2 and Table 1).

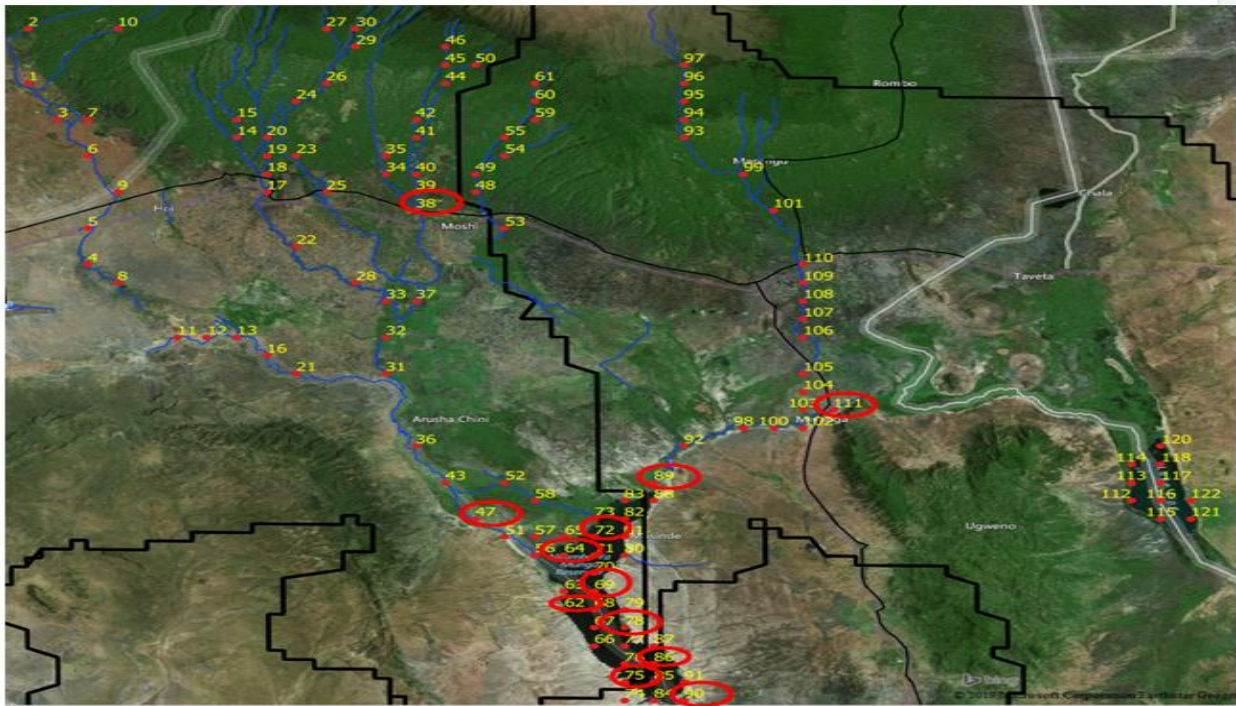


Figure 2: Sampling Points in the Nyumba ya Mungu Catchment (Kikuletwa River, Ruvu River, Pangani River, and Nyumba ya Mungu Dam)

Table 1: GPS Coordinates for Sampling Sites at Nyumba ya Mungu Dam, Kikuletwa River, Ruvu River, and Pangani River

Sampling sites	Latitudes	Longitudes	Altitudes (Metres)	Descriptions
38	3°22'33.0" S	37°19'16.2" E	1369	Kikuletwa river_upstream
47	3°33'08.9" S	37°18'25.6" E	982	Kikuletwa river_downstream
111	3°31'44.1" S	37°33'44.6" E	947	Ruvu river_upstream
89	3°34'51.4" S	37°27'52.1" E	944	Ruvu river_downstream
90	3°49'56.3" S	37°27'58.4" E	745	Pangani river_spill way
64	3°39'24.5" S	37°26'14" E	830	NMD_upper section
72	3°39'08" S	37°26'16" E	831	NMD_upper section
78	3°46'18.9" S	37°27'39.7" E	779	NMD_middle section
69	3°41'45.9" S	37°25'27.5" E	829	NMD_middle section
62	3°48'51" S	37°27'09.9" E	765	NMD_middle section
67	3°41'55" S	37°25'27.2" E	828	NMD_middle section
75	3°48'59.4" S	37°27'45.2" E	770	NMD_lower section
86	3°48'16.4" S	37°28'24.6" E	766	NMD_lower section

Data were collected monthly from January to December 2019, between 08:00 and 11:00, to accommodate the distribution and accessibility of sampling points. On-site measurements for temperature, pH, dissolved oxygen, oxygen saturation, turbidity, total dissolved solids, electrical conductivity, and salinity were performed using HANNA HI 9829 instruments.

Water samples for total nitrogen and total phosphorus analysis were collected from Nyumba ya Mungu Dam, Kikuletwa River, and Ruvu River using a water scooper and transferred to cleaned, one-liter polyethylene bottles. Each bottle was pre-rinsed with sample water and treated with 1 milliliter of sulfuric acid (18.80 M, 98% concentration) before filling. Samples were labeled, stored in a cooler, and transported to a laboratory in Mwanza City.

For chlorophyll-a analysis, samples were collected in one-liter glass amber bottles, sealed, wrapped in black polythene to block light, labeled, and transported in a box to an accredited laboratory in Mwanza City.

2.3 Measurement of Turbidity, Dissolved Oxygen, and Electrical Conductivity

Turbidity and electrical conductivity (EC) were measured using a calibrated HANNA HI 9829 multiparameter meter. Turbidity was assessed with a HI-7609829-4 sensor by immersing it 30 cm into the water and allowing it to stabilize before recording the readings. Electrical conductivity was measured using the HI-7609829-3, a 4-ring electrode sensor, also immersed 30 cm into the water.

2.4 Laboratory Analysis for Total Nitrogen, Phosphorus, and Chlorophyll-a

In the laboratory, samples were brought to room temperature and then aliquoted for nutrient analysis. Spectrophotometric methods, following Wetzel and Likens (1991), Baird (2017), and Johan *et al.* (2014), were employed for analyzing total nitrogen, phosphorus, and chlorophyll-a.

2.4.1 Total Nitrogen (TN) Determination

Total nitrogen was measured by oxidizing nitrogen compounds to nitrate through oxidative digestion under heated alkaline persulfate and ultraviolet radiation, as described by Wetzel and Likens (1991) and Baird (2017). This process, conducted at 100 to 110°C, converts both inorganic and organic nitrogen to nitrate. Nitrate concentration, indicative of total nitrogen, was measured using automated cadmium reduction. The nitrogen level was determined by the absorbance of pink dye at 540 nm, with a standard curve plotted against nitrogen concentrations.

2.4.2 Total Phosphorus (TP) Determination

Total phosphorus was analyzed by first converting phosphorus species to dissolved orthophosphate through acidic digestion using nitric and sulfuric acids. The digested sample was then mixed with ammonium molybdate and antimony potassium tartrate, producing a blue complex reduced by ascorbic acid. The intensity of the blue color, measured at 880 nm, was proportional to the total phosphorus concentration, calculated using a standard curve.

2.3.3 Chlorophyll-a Extraction

Chlorophyll-a was extracted using 90% ethanol and analyzed spectrophotometrically (Wetzel and Likens, 1991; Johan et al., 2014). Microalgae were first centrifuged at 4000 rpm for 10 minutes. Absorbance was measured with a UV-Visible spectrophotometer (Model HITACHI U-1900) at 750 nm, 664 nm, 647 nm, and 630 nm. Absorbance at 750 nm was subtracted to correct for turbidity. Chlorophyll-a concentration was computed using the following equations:

$$Chl - a \left(\mu \frac{g}{L} \right) = (11.85 \times E_{664}) - (1.54 \times E_{647}) - 0.08 \times E_{630} \dots \dots \dots (1)$$

$$Concentration \ of \ Chl - a \left(\mu \frac{g}{L} \right) = \frac{[Chl - a \times v]}{V \times L} \dots \dots \dots (2)$$

In which:

v = Volume of acetone 90%,

V = Volume of the water sample,

L = Light path of cuvette, cm,

E₆₆₄ = Value of absorbance at wavelength 664 nm,

E₆₄₇ = Value of absorbance at wavelength 647 nm, and

E₆₃₀ = Value of absorbance at wavelength 630 nm.

2.5 Statistical Analysis

Analysis of Variance (ANOVA) was used to assess spatial and temporal differences in water physicochemical and biological parameters at a 95% confidence level using SPSS. ANOVA, known for its robustness, compares data groups to determine if differences are statistically significant, testing the null hypothesis of no difference and the alternative hypothesis of significant variation (Field, 2009).

Additionally, correlation analysis was conducted to explore relationships between physicochemical and biological

parameters across rivers and the dam. This analysis identified significant connections between water quality variables.

3.0 Results and Discussion

3.1 Dissolved Oxygen

Dissolved oxygen levels varied significantly throughout the study. In Kikuletwa River, levels ranged from 1 mg/L in July to 7.5 mg/L in April and November, with a mean of 5.4±1.9 mg/L. Ruvu River showed a range from 0.6 mg/L in May to 5.6 mg/L in November, with a mean of 2.6±1.4 mg/L. Pangani River had values from 0.2 mg/L in March to 2.8 mg/L in September, averaging 1.7±0.1 mg/L, which were generally lower than Kikuletwa and Ruvu. In the dam, dissolved oxygen ranged from 1.4 to 7.8 mg/L, with a mean of 5.1±1.6 mg/L.

One-way ANOVA revealed significant differences in mean dissolved oxygen across rivers ($P < 0.05$, $df = 59$) and when including the dam data ($P < 0.05$, $df = 155$). The Hochberg test showed that dissolved oxygen in Ruvu and Pangani Rivers was significantly lower than in Kikuletwa (Hochberg, $P < 0.05$), but Ruvu and Pangani did not differ significantly from each other (Hochberg, $P > 0.05$) (Figure 3).

When the dam was included in the analysis using the Hochberg test, the mean dissolved oxygen of the dam was statistically the same as that of the Kikuletwa River (Tukey, $P = 0.86$). Conversely, the mean dissolved oxygen of the NMD was significantly different from that of Ruvu and Pangani River ($P < 0.05$) (Figure 3).

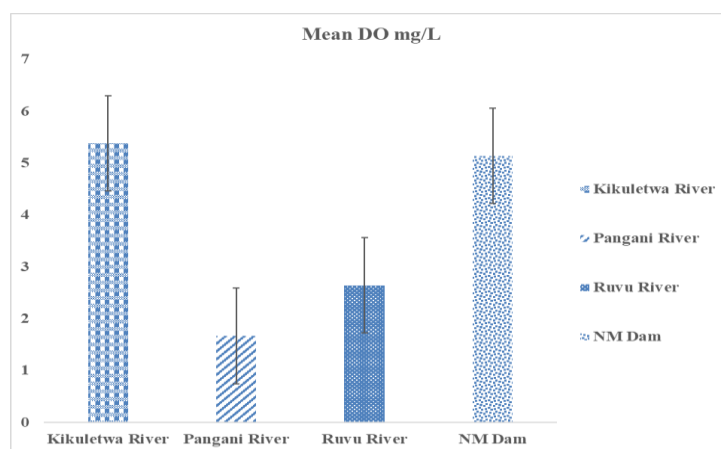


Figure 3: Mean dissolved oxygen (DO) levels (mg/L) for Kikuletwa River, Ruvu River, Pangani River, and Nyumba ya Mungu Dam, based on monthly data from January to December 2019

Comparing mean dissolved oxygen concentrations by month revealed significant differences ($P < 0.05$, $df = 155$, One-way

ANOVA). June differed significantly from most months, including March, November, and December (Hochberg, $P < 0.05$) (Figure 4).

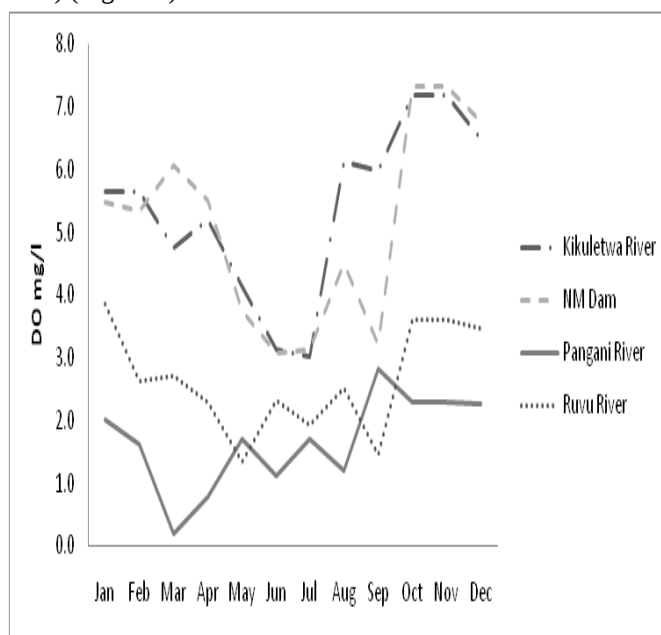


Figure 4: Temporal variation in mean dissolved oxygen (mg/L) in Kikuletwa River, Ruvu River, Pangani River, and Nyumba ya Mungu Dam.

Dissolved oxygen (DO) levels varied significantly during the study. In Kikuletwa River, DO ranged from 1 mg/L in July to 7.5 mg/L in April and November, with a mean of 5.4 ± 1.9 mg/L. Ruvu River showed a range from 0.6 mg/L in May to 5.6 mg/L in November, with a mean of 2.6 ± 1.4 mg/L. Pangani River's DO ranged from 0.2 mg/L in March to 2.8 mg/L in September, averaging 1.7 ± 0.1 mg/L, which was lower than Kikuletwa and Ruvu. At the dam, DO ranged from 1.4 to 7.8 mg/L, with a mean of 5.1 ± 1.6 mg/L.

One-way ANOVA revealed significant differences in mean DO between the rivers ($P < 0.05$, $df = 59$) and between the dam and the rivers ($P < 0.05$; $df = 155$). The Hochberg test showed that DO levels in Ruvu and Pangani Rivers were significantly lower than in Kikuletwa ($P < 0.05$), but not significantly different from each other ($P > 0.05$) (Figure 3).

Comparing mean DO across months, significant differences were observed ($P < 0.05$, $df = 155$). June had significantly different DO levels compared to several months, including the wet season months of March, November, and December (Hochberg, $P < 0.05$) (Figure 4).

The difference in mean DO between NMD and Pangani River is notable since other parameters were similar, despite Pangani River originating from NMD. The difference might be due to the mixing effect of turbines at Nyumba ya Mungu Dam before water flows downstream. The similar DO levels in NMD and Kikuletwa suggest that nutrient levels from Kikuletwa River influence microbial activity in the dam.

High DO levels were recorded during the wet season (March, April, and November) in both rivers and the dam, whereas low levels were observed during the dry season (July, August, and September) (Figure 4). Pangani River's DO appeared influenced by dam water levels and discharge rates, with lower DO at low dam levels (March) and higher levels with increased flow (Figure 4).

According to Hellar-Kihampa *et al.* (2013), typical DO concentrations in uncontaminated water range from 8 to 10 mg/L. Values below this range indicate nutrient enrichment and pollution (Lema *et al.*, 2015; Guo *et al.*, 2018). DO levels in this study were below 8 mg/L, suggesting high oxygen demands and potential challenges for aquatic organisms. Seasonal variations in temperature and nutrient inputs contribute to DO fluctuations.

Low DO (0.6 mg/L) in Ruvu River is linked to Lake Jipe, which has low oxygen levels due to pollution and organic matter decay (Selemani *et al.*, 2017; Hellar-Kihampa *et al.*, 2013). Since Ruvu River recharges from Lake Jipe, its DO is similarly low. Intensive farming in riparian areas, including the use of excess fertilizers and pesticides, may also impact DO levels.

Comparing this study with others, Hellar-Kihampa *et al.* (2013) reported DO levels from 2.0 mg/L in Ruvu River to 8.3 mg/L in Kikuletwa River, slightly higher than in this study. Lema *et al.* (2015) found DO levels ranging from 1.56 to 6.05 mg/L in Usa and Nduruma Rivers, with a lower range than in this study but a similar upper range. PBWO/IUCN (2007) reported a DO level of 0.6 mg/L in Ruvu River, consistent with this study.

Guo *et al.* (2018) reported DO levels from 5.77 to 12.06 mg/L in Xinlicheng Reservoir, significantly higher than this study's findings. They noted higher DO in spring and autumn, similar to this study's pattern of lower DO in summer. Kitur (2009) reported mean DO levels from 6.2 to 9.0 mg/L in five Kenyan reservoirs, all higher than the mean DO in NMD during this study.

3.2 Turbidity

Turbidity varied widely during the study period (Figure 5). In Kikuletwa River, turbidity ranged from 8.8 FNU in August to 354 FNU in May and June, with a mean of 83 ± 112 FNU. Ruvu River's turbidity ranged from 5.9 FNU in June and August to 114 FNU in November, averaging 38.6 ± 34.2 FNU. Pangani River had turbidity between 7.1 FNU in October and 52.8 FNU in August, with a mean of 21.9 ± 15.2 FNU. In NMD, turbidity ranged from 7.2 FNU in January to 266 FNU in May, with a mean of 36.3 ± 38 FNU (Figure 5).

One-way ANOVA revealed significant differences in turbidity among Kikuletwa, Ruvu, and Pangani Rivers ($P = 0.04$, $df = 59$). However, Hochberg's post hoc test showed no significant differences in mean turbidity values among these rivers ($P > 0.05$). Including NMD in the analysis showed

significant differences in turbidity ($P < 0.05$, $df = 59$), with Kikuletwa River having significantly higher turbidity than Ruvu, Pangani, and NMD. The turbidity values for Ruvu, Pangani, and NMD were not significantly different.

Monthly variations in turbidity also showed significant differences (One-Way ANOVA, $P < 0.05$, $df = 155$). May's mean turbidity was significantly different from January and February (Hochberg's test, $P < 0.05$), but other months did not show significant differences (Hochberg's test, $P > 0.05$, $df = 155$).

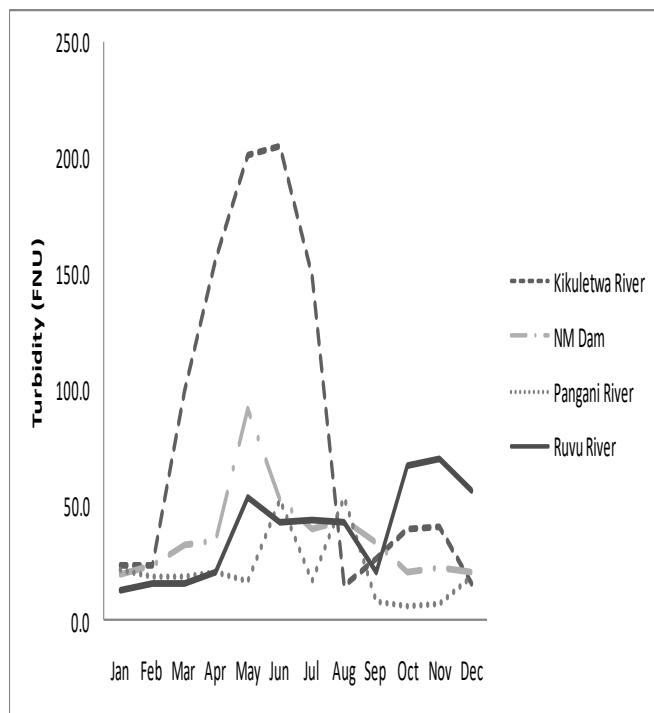


Figure 5: Monthly turbidity variations for Kikuletwa River, Ruvu River, Pangani River, and Nyumba ya Mungu Dam from January to December 2019

Turbidity measures the amount of suspended particles in water, affecting its clarity. High turbidity, often caused by clay, silt, and algae, was observed during the rainy season in the study area, indicating high sedimentation from eroded soil due to cultivation and deforestation. This finding aligns with Miheso (2008) in Kenya's Motoine River dams. The peak turbidity in Kikuletwa River is linked to agricultural runoff from Mount Kilimanjaro and Meru. Turbidity decreases in the dry season due to reduced storms and lower river flow, which limits sediment transfer.

Despite its significance, turbidity is often overlooked in water quality assessments. Marmontel *et al.* (2018) found that streams with agricultural activities had higher turbidity and poorer water conditions compared to those with natural riparian vegetation. Irenosen *et al.* (2012) reported lower turbidity (5.6 to 8.8 FNU) in Thomas Dam, indicating minimal sediment and particulate organic matter.

3.3 Electro-Conductivity (EC)

Electro-conductivity (EC) in the study area varied widely. For Kikuletwa River, EC ranged from 48 $\mu\text{S/cm}$ in July to 1282 $\mu\text{S/cm}$ in August, with a mean of 412 ± 437 $\mu\text{S/cm}$. In Ruvu River, EC varied between 612 $\mu\text{S/cm}$ in April and 1030 $\mu\text{S/cm}$ in January, averaging 831 ± 437 $\mu\text{S/cm}$. Pangani

River showed a narrower range, from 828 $\mu\text{S/cm}$ in June to 1025 $\mu\text{S/cm}$ in May, with a mean of 926 ± 79 $\mu\text{S/cm}$. The stable EC in Pangani River suggests mixing of upstream waters from Kikuletwa and Ruvu in the NMD before flowing downstream.

ANOVA revealed significant differences in mean EC values among the rivers ($P < 0.05$, $df = 59$), with Kikuletwa showing higher values than Ruvu and Pangani (Hochberg's test, $P < 0.05$, $df = 59$). Including NMD in the analysis showed significant differences compared to Kikuletwa (Hochberg's test, $P < 0.05$, $df = 59$), but no significant differences among Ruvu, Pangani, and NMD. Seasonal variations in EC values were not significant (Hochberg's test, $P = 0.95$, $df = 59$).

EC is a key indicator of dissolved solids in water. High EC levels, indicating high dissolved solids, can affect water quality. Hellar-Kihampa *et al.* (2013) reported a natural EC range of 10 to 1000 $\mu\text{S/cm}$ for unpolluted water; values above this suggest pollution. The study area's EC levels were within permissible limits for potable water (2500 $\mu\text{S/cm}$, WHO 2004). The highest EC was recorded downstream in Kikuletwa River, and the lowest at its upstream.

These findings align with previous studies. Hellar-Kihampa *et al.* (2013) found similar EC ranges in the Pangani basin, while Lema *et al.* (2015) reported higher EC values in Nduruma and Usa Rivers compared to this study. Namadi (2017) noted higher EC during dry months due to evaporation and lower values during wet months due to dilution. Pacheco *et al.* (2015) reported lower EC in São Paulo streams compared to this study. For dams, Kitur (2009) reported lower mean EC values than those for NMD, while Siriwardana *et al.* (2019) found comparable surface EC but lower bottom EC. León *et al.* (2016) reported EC values in Argentina within the range of this study, suggesting similar pollution levels.

3.4 Total Nitrogen (TN)

Total Nitrogen (TN) concentrations varied significantly across the study area (Figure 6). In Kikuletwa River, TN ranged from 230 $\mu\text{g/L}$ in March to 15,797 $\mu\text{g/L}$, with a mean of $10,912 \pm 3,896$ $\mu\text{g/L}$. Ruvu River had TN values between 206 $\mu\text{g/L}$ in March and 23,110 $\mu\text{g/L}$ in January, averaging $11,093 \pm 4,430$ $\mu\text{g/L}$. Pangani River's TN ranged from 237 $\mu\text{g/L}$ in March to 14,345 $\mu\text{g/L}$ in November, with a mean of $10,781 \pm 4,323$ $\mu\text{g/L}$. For NMD, TN ranged from 89 $\mu\text{g/L}$ in March to 26,428 $\mu\text{g/L}$ in June, with a mean of $10,781 \pm 5,568$ $\mu\text{g/L}$ (Figure 6).



Figure 6: Monthly variations in mean TN values (µg/L) for Kikuletwa River, Ruvu River, Pangani River, and NMD from January to December 2019

Total Nitrogen (TN) concentrations varied notably across the study area (Figure 6). In Kikuletwa River, TN ranged from 230 µg/L in March to 15,797 µg/L in August, with a mean of $10,912 \pm 3,896$ µg/L. Ruvu River had TN concentrations from 206 µg/L in March to 23,110 µg/L in January, with a mean of $11,093 \pm 4,430$ µg/L. Pangani River's TN ranged from 237 µg/L in March to 14,345 µg/L in November, averaging $10,781 \pm 4,323$ µg/L. NMD had TN values between 89 µg/L in March and 26,428 µg/L in June, with a mean of $10,781 \pm 5,568$ µg/L.

One-way ANOVA showed no significant difference in mean TN values among Kikuletwa, Ruvu, and Pangani Rivers ($p = 0.9$, $df = 59$), nor when NMD was included ($p = 0.9$, $df = 155$). However, month-to-month variations in TN were significant ($p < 0.05$, $df = 155$), with March values differing significantly from other months (Hochberg's test, $p < 0.05$, $df = 155$).

These results suggest that TN concentration in the Upper Pangani River basin is relatively uniform but influenced by seasonality, with higher levels during the rainy season due to nutrient runoff from agriculture. This is evident from higher TN values observed in wet months (May and June) compared to lower values at the start of the rainy season (March). The lack of a specific nutrient source in the catchment indicates that nutrient loading is broadly distributed.

The findings align with previous studies. For example, Pacheco *et al.* (2015) reported TN concentrations between 1,524,200 µg/L and 2,072,500 µg/L in Brazil, and 1,143.2 to 1,505.6 µg/L in the Funil Reservoir, which are lower than

those in this study. Both studies attribute high TN levels to nutrient inflow from agricultural lands.

3.5 Total Phosphorus (TP)

In Kikuletwa River, TP ranged from 68 µg/L in February to 1,239 µg/L in May, with a mean of 263 ± 333 µg/L. Ruvu River had TP values from 76 µg/L in September to 668 µg/L in November, averaging 323 ± 175 µg/L. Pangani River's TP varied from 63 µg/L in February to 396 µg/L in June, with a mean of 168 ± 104 µg/L. NMD had TP concentrations from 47 µg/L in November to 791 µg/L in May, averaging 172 ± 142 µg/L. Kikuletwa exhibited the widest range of TP values.

One-way ANOVA indicated no significant difference in mean TP values among Kikuletwa, Ruvu, and Pangani Rivers ($p = 0.2$, $df = 59$). However, when NMD was included, mean TP values differed significantly ($p < 0.05$, $df = 155$), with Ruvu River showing higher TP compared to NMD. TP values did not vary significantly by month during the study period.

Total Phosphorus (TP) reflects all forms of phosphorus in water and is crucial for assessing water quality. The TP concentrations in this study exceeded the recommended values of 1 µg/L to 300 µg/L, indicating a high nutrient load. Agricultural runoff is a likely source of elevated TP levels, especially in Kikuletwa and Ruvu Rivers. Kikuletwa contributes significantly to phosphorus during wet seasons, while Ruvu maintains stable phosphorus levels due to wetland runoff.

Previous studies show higher TP levels during wet seasons, though not as high as in this study. For instance, Pacheco *et al.* (2015) reported TP values of 42,400 µg/L to 88,300 µg/L in Brazil, higher than those in the current study. Similarly, Gao *et al.* (2016) reported TP values up to 400 µg/L in East China's Three Gorges Reservoir, which is higher than in NMD. These differences highlight that TP sources and concentrations vary by region and are influenced by local agricultural practices and land use.

3.6 Chlorophyll-a (Chl-a)

Chlorophyll-a (Chl-a) concentrations varied significantly between sampling stations and periods. In Kikuletwa River, Chl-a ranged from 0 µg/L in January to 34 µg/L in September, with a mean of 13 ± 9 µg/L. Ruvu River's Chl-a ranged from 0 µg/L in January to 30 µg/L in February, with a mean of 6 ± 6 µg/L. In Pangani River, Chl-a varied from 1 µg/L in May to 40 µg/L in January, with a mean of 9 ± 11 µg/L. NMD had Chl-a concentrations from 0 µg/L in February to 120 µg/L in January, with a mean of 25 ± 24 µg/L (Figure 7).

One-way ANOVA showed significant differences in mean Chl-a concentrations among Kikuletwa, Ruvu, and Pangani Rivers. Post hoc analysis using Hochberg's test revealed a significant difference between Kikuletwa and Ruvu Rivers ($p < 0.05$, $df = 59$). This difference may be due to Kikuletwa receiving more sediments and nutrients from intensively cultivated lands compared to Ruvu, which is fed by Lake Jipe, a source that retains water from upland areas.

Including NMD in the analysis showed its mean Chl-a concentration was significantly higher than that of the rivers ($p < 0.05$, $df = 155$). Monthly comparisons revealed that January Chl-a levels differed from other months, except February, August, and September ($p < 0.05$, $df = 155$, Hochberg's test). NMD's higher Chl-a concentration is likely due to its water retention characteristics, which promote algae growth.

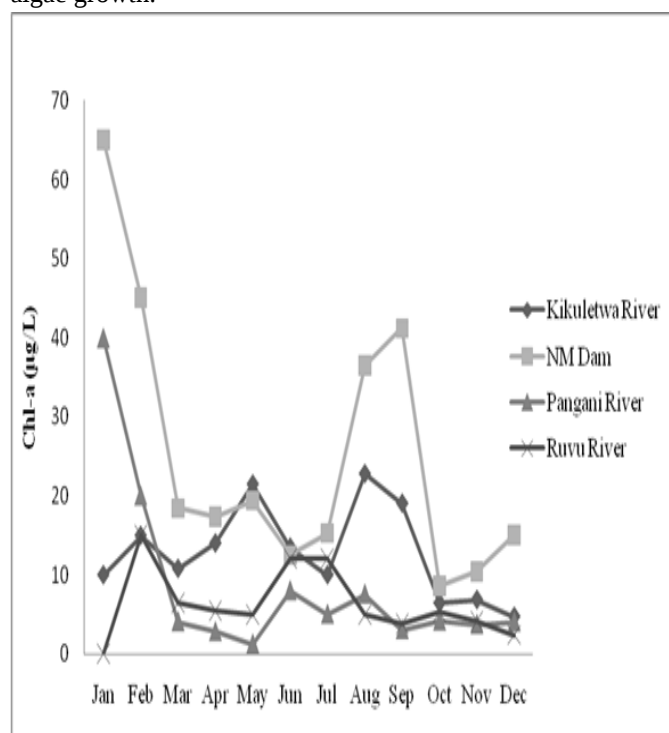


Figure 7: Monthly variations in mean Chlorophyll-a concentrations (µg/L) for Kikuletwa River, Ruvu River, Pangani River, and NMD from January to December 2019

Chlorophyll-a concentrations varied significantly between sampling stations and periods. In Kikuletwa River, Chl-a ranged from 0 µg/L in January to 34 µg/L in September, with a mean of 13 ± 9 µg/L. In Ruvu River, it ranged from 0 µg/L in January to 30 µg/L in February, with a mean of 6 ± 6 µg/L. Pangani River had Chl-a values from 1 µg/L in May to 40 µg/L in January, averaging 9 ± 11 µg/L. In NMD, Chl-a ranged from 0 µg/L in February to 120 µg/L in January, with a mean of 25 ± 24 µg/L.

The low Chl-a concentrations in the rivers, observed in January and February, are due to reduced nutrient inputs, primarily nitrogen and phosphorus, which are essential for

phytoplankton growth. The absence of Chl-a at sampling site 69 in the dam's middle section may be attributed to disturbances from human activities prior to measurements (Figure 7).

NMD had a higher mean Chl-a concentration compared to the rivers, likely due to the extended water retention period, allowing for nutrient accumulation and phytoplankton growth. Higher Chl-a concentrations were noted during dry periods, including January-February and June-October. This suggests that phytoplankton growth accelerates after the cessation of seasonal nutrient flushing (Mangi *et al.*, 2023).

Chlorophyll-a serves as a key indicator of algal biomass and water quality, reflecting responses to nutrient loading and potential eutrophication. Elevated Chl-a levels often lead to increased phytoplankton biomass and reduced oxygen levels, which can cause hypoxia.

Comparative studies reveal that the Chl-a concentrations in NMD are higher than those reported elsewhere. Egertson and Downing (2004) found concentrations between 1 and 130 µg/L in Iowa, USA. Utete & Tsamba (2017) reported a lower range of 3.57 µg/L in Manjirenji Dam, Zimbabwe. Janjua *et al.* (2009) noted values from 9.70 µg/L to 31.30 µg/L in Shahpur Dam, Pakistan. Li *et al.* (2018) observed ranges of 10 µg/L to 20 µg/L in Xin'anjiang Reservoir, China, and León *et al.* (2016) reported 4.6 µg/L to 10.8 µg/L in El-Carrizal Reservoir, Argentina. These comparisons underscore that NMD experiences higher Chl-a concentrations, indicating significant phytoplankton activity and nutrient enrichment.

3.7 Classification of the Dam Based on Trophic States

Using the trophic indices by Carlson and Simpson (1996) and Janjua, Ahmad, & Akhtar (2009), the dam fluctuates between eutrophic and hypereutrophic states throughout the study period (Table 2). Most of the time, the dam is classified as eutrophic based on the trophic state index (TSI) for chlorophyll-a concentration (TSI (Chl-a)). This index is favoured for its effectiveness in predicting algal biomass compared to indices based on total phosphorus, total nitrogen, or Secchi disc measurements. The TSI (Chl-a) ranged from 51 to 71 (Table 9). For about eight months, the dam remains eutrophic, transitioning to hypereutrophic for the remaining four months, typically during the dry season (Carlson and Simpson, 1996).



Table 2: Monthly Trophic Status of Nyumba ya Mungu Dam, Classified According to Carlson's Trophic State Index (Carlson, 1996; Utete & Tsamba, 2017)

Months	TSI (CHL)	Chl- <i>a</i> (µg/L)	TP (µg/L)	State	Conditions
Sep	51	8.6	89.3	Eutrophic	Anoxic hypolimnia, and macrophyte problems are possible
Feb	53	10.4	78.5		
Apr	55	12.5	241.0		
Mar	57	15.3	225.3		
Jan	57	15.1	103.4		
Jul	58	17.4	253.1		
Jun	59	18.4	146.6		
Dec	59	19.4	304.3		
May	66	36.5	180.1	Eutrophic-Hypereutrophic	Blue-green algae dominate, algal scums and macrophyte problems
Aug	67	41.2	119.9		
Nov	68	45.0	167.0		
Oct	71	65.0	158.4		

Other studies using similar methods to classify dam trophic levels produce comparable results to this study. Utete & Tsamba (2017) classified Manjirenji Dam as Oligotrophic using both the Carlson Trophic State Index (Carlson, 1977) and the CCME Water Quality Index (CCME, 2001). This contrasts with the current study's findings, likely due to differing environmental contexts. Nyumba ya Mungu Dam, situated in a highly agricultural area with intensive irrigation, contrasts with Manjirenji Dam, which is part of a protected zone managed by the Zimbabwe National Parks and Wildlife Authority. While both dams face siltation, Manjirenji is less exposed to nutrient loading.

Janjua et al. (2009) used the Carlson Trophic State Index to classify Shahpur Dam, yielding a TSI (Chl-*a*) of 59 and a TSI (SD) of 74, categorizing it as eutrophic. Similarly, Jayasinghe *et al.* (2005) studied 45 non-perennial reservoirs in Sri Lanka, finding most with TSI values between 50 and 60, thus classifying them as eutrophic. These ranges align with the findings of the present study.

4.0 Conclusions and Recommendations

The water quality in Nyumba ya Mungu Dam and the lower sections of the rivers is significantly lower than in upstream areas, primarily due to high retention rates in the dam and nutrient loading from riparian lands. Water quality deteriorates further during the rainy season compared to the dry season. Key indicators such as dissolved oxygen (DO), turbidity, chlorophyll-*a* (Chl-*a*), total nitrogen (TN), and total phosphorus (TP) frequently fall below or exceed biologically tolerable levels. The elevated Chl-*a* levels in Nyumba ya Mungu Dam suggest a potential for algal blooms and anoxic conditions.

Increased turbidity during the rainy season is linked to soil erosion from agricultural activities and storm runoff in the catchment area. Nutrient loading is fairly uniform across the catchment, with runoff from agricultural land contributing significantly to TN in the rivers and dam. The Kikuletwa River, receiving runoff from intensive agriculture in lower Moshi, and the Ruvu River, collecting runoff from West Kilimanjaro and Lake Jipe, are major sources of phosphorus. Although the Kikuletwa River contributes substantial phosphorus during wet seasons, the Ruvu River consistently supplies phosphorus to the dam, likely due to the decomposition of wetland vegetation around Lake Jipe.

To mitigate nutrient loading and improve water quality, this study recommends the implementation of affordable nutrient filtering mechanisms. Vegetative buffer zones around and within farms can reduce nutrient leaching into rivers by promoting nutrient uptake, denitrification, and soil surface assimilation. These buffers also slow water flow, reducing erosion. Agroforestry practices should be adopted to further minimize soil erosion and enhance soil fertility. Additionally, the conservation of riparian vegetation, riverbanks, and sand beaches, which are currently degraded by sand mining and cultivation, should be prioritized to preserve their nutrient-filtering functions. These measures will help retain nutrients on farmland, enhance productivity, reduce agrochemical costs, and protect aquatic ecosystems.

Declaration of Conflict of Interest

I declare that there are no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

References

- Chiwa, R. (2012). Effects of land use and land cover changes on the hydrology of Weruweru-Kiladeda sub-catchment in Pangani river basin. Tanzania MSc thesis Kenyatta University, Nairobi.
- Egertson, C.J. and Downing, J.A., 2004. Relationship of fish catch and composition to water quality in a suite of agriculturally eutrophic lakes. *Canadian Journal of Fisheries and Aquatic Sciences*, 61(9), pp.1784-1796. <https://doi.org/10.1139/F04-109>
- Gao, Q., Li, Y., Cheng, Q., Yu, M., Hu, B., Wang, Z. and Yu, Z., 2016. Analysis and assessment of the nutrients, biochemical indexes, and heavy metals in the Three Gorges Reservoir, China, from 2008 to 2013. *Water Research*, 92, pp.262-274. <https://doi.org/10.1016/j.watres.2015.12.055>
- Glibert, P.M., 2010. Long-term changes in nutrient loading and stoichiometry and their relationships with changes in the food web and dominant pelagic



- fish species in the San Francisco Estuary, California. *Reviews in Fisheries Science*, 18(2), pp.211-232. <https://doi.org/10.1080/10641262.2010.492059>
- Guo, J., Zhang, C., Zheng, G., Xue, J., and Zhang, L., 2018. The establishment of season-specific eutrophication assessment standards for a water-supply reservoir located in Northeast China based on chlorophyll-a levels. *Ecological Indicators*, 85, pp.11-20. <https://doi.org/10.1016/j.ecolind.2017.09.056>
- Hellar-Kihampa, H., 2011. Pesticide residues in four rivers running through an intensive agricultural area, Kilimanjaro, Tanzania. *Journal of applied sciences and environmental management*, 15(2). www.bioline.org.br/ja
- Hellar-Kihampa, H., De Wael, K., Lugwisha, E. and Van Grieken, R., 2013. Water quality assessment in the Pangani River basin, Tanzania: natural and anthropogenic influences on the concentrations of nutrients and inorganic ions. *International journal of river basin management*, 11(1), pp.55-75. <https://doi.org/10.1080/15715124.2012.759119>
- Huang, J., Zhan, J., Yan, H., Wu, F. and Deng, X., 2013. Evaluation of the impacts of land use on water quality: a case study in the Chaohu Lake Basin. *The Scientific World Journal*, 2013. <https://doi.org/10.1155/2013/329187>
- Irenosen, O.G., Festus, A.A. and Coolborn, A.F., 2012. Water quality assessment of the Owena multi-purpose dam, Ondo State, Southwestern Nigeria. *Journal of Environmental Protection*, 3(01), pp.14-25. <http://dx.doi.org/10.4236/jep.2012.31003>
- Janjua, M.Y., Ahmad, T. and Akhtar, N., 2009. Limnology and trophic status of Shahpur dam reservoir, Pakistan. *The Journal of Animal & Plant Sciences*, 19(4), pp.224-273. <http://www.thejaps.org.pk/docs>
- Jayasinghe, U.A.D., Amarasinghe, U.S. and De Silva, S.S., 2005. Trophic classification of non-perennial reservoirs utilized for the development of culture-based fisheries, Sri Lanka. *International Review of Hydrobiology: A Journal Covering all Aspects of Limnology and Marine Biology*, 90(2), pp.209-222. <https://doi.org/10.1002/iroh.200410753>
- Johan, F., Jafri, M.Z., Lim, H.S. and Maznah, W.W., 2014, December. Laboratory measurement: Chlorophyll-a concentration measurement with acetone method using a spectrophotometer. In *2014 IEEE International Conference on Industrial Engineering and Engineering Management* (pp. 744-748). IEEE. <https://doi.org/10.1109/ieem.2014.7058737>
- Lema, E., Machunda, R. and Njau, K.N., 2014. Agrochemicals use in the horticulture industry in Tanzania and their potential impact to water resources. *International Journal of Biological and Chemical Sciences*, 8(2), pp.831-842. <https://doi.org/10.4314/ijbcs.v8i2.38>
- Lema, E., Machunda, R. and Njau, K.N., 2015. Assessment of agrochemical residues in wastewater from selected horticultural farms in Arusha, Tanzania. <https://doi.org/10.6088/ijes.6028>
- León, J.G., Beamud, S.G., Temporetti, P.F., Atencio, A.G., Diaz, M.M. and Pedrozo, F.L., 2016. Stratification and residence time as factors controlling the seasonal variation and the vertical distribution of chlorophyll-a in a subtropical irrigation reservoir. *International Review of Hydrobiology*, 101(1-2), pp.36-47. <https://doi.org/10.1002/iroh.201501811>
- Li, Y., Zhang, Y., Shi, K. et al. Spatiotemporal dynamics of chlorophyll-a in a large reservoir as derived from Landsat 8 OLI data: understanding its driving and restrictive factors. *Environ Sci Pollut Res* 25, 1359–1374 (2018). <https://doi.org/10.1007/s11356-017-0536-7>
- Lalika, M.C., Meire, P., Ngaga, Y.M. and Chang'a, L., 2015. Understanding watershed dynamics and impacts of climate change and variability in the Pangani River Basin, Tanzania. *Ecohydrology & Hydrobiology*, 15(1), pp.26-38. <https://doi.org/10.1016/j.ecohyd.2014.11.002>
- Mangi, H. O., Onywere, S. M., Kitur, E. C., Lalika, M. C., & Chilagane, N. A. (2022). Hydrological response to land use and land cover change on the slopes of Kilimanjaro and Meru Mountains. *Ecohydrology & Hydrobiology*, 22(4), 609-626. <https://doi.org/10.1016/j.ecohyd.2022.08.002>
- Mangi, H. O., Onywere, S. M., & Kitur, E. C. (2023). Fish productivity response to water quality variations: A case study of nyumba ya mungu dam, in pangani water basin, Tanzania. *International Journal of Ecology*, 2023. <https://doi.org/10.1155/2023/7353898>
- Misana, S.B., Majule, A.E. and Lyaruu, H.V., 2003. Linkages between changes in land use, biodiversity and land degradation on the slopes of Mount Kilimanjaro, Tanzania. *LUCID Working Paper*. https://cgsp.ace.cgiar.org/bitstream/handle/10568/1868/Lucid_wp38.pdf



- Mohan, A. and Sajayan, J., 2015. Soil pollution-a momentous crisis. *International Journal of Herbal Medicine*, 3(1 Part A), pp. 45-47. <https://www.florajournal.com/vol3issue1/may2015/2-6-6.1.pdf>
- Morales-Marín, L.A., Wheater, H.S. and Lindenschmidt, K.E., 2017. Assessment of nutrient loadings of a large multipurpose prairie reservoir. *Journal of hydrology*, 550, pp.166-185. <http://www.elsevier.com/open-access/userlicense/1.0/>
- Mugwe, J.N., 2007. An evaluation of integrated soil fertility management practices in Meru South District, Kenya. *A PhD thesis submitted to Kenyatta University*.
- Nafi'u, S.A. and Ibrahim, S., 2017. Seasonal dynamics of zooplankton composition and abundance in Thomas Dam Dambatta, Kano, Nigeria. *Bayero Journal of Pure and Applied Sciences*, 10(1), pp.268-276. <http://dx.doi.org/10.4314/bajopas.v10i1.40>
- Nonga, H.E., Mdegela, R.H., Lie, E., Sandvik, M. and Skaare, J.J., 2011. Assessment of farming practices and uses of agrochemicals in Lake Manyara basin, Tanzania. [http:// doi: 10.5897/ajar11.271](http://doi:10.5897/ajar11.271)
- Pacheco, F.S., Soares, M.C.S., Assireu, A.T., Curtarelli, M.P., Roland, F., Abril, G., Stech, J.L., Alvalá, P.C. and Ometto, J.P., 2015. The effects of river inflow and retention time on the spatial heterogeneity of chlorophyll and water-air CO₂ fluxes in a tropical hydropower reservoir. *Biogeosciences*, 12(1), pp.147-162. <http://doi:10.5194/bg-12-147-2015>
- Piana, P.A., Cardoso, B.F., Dias, J., Gomes, L.C., Agostinho, A.A. and Miranda, L.E., 2017. Using long-term data to predict fish abundance: the case of *Prochilodus lineatus* (Characiformes, Prochilodontidae) in the intensely regulated upper Paraná River. *Neotropical Ichthyology*, 15. <https://doi.org/10.1590/1982-0224-20160029>
- PWBO/IUCN. 2010. Climate change modelling for the Pangani Basin to support the IWRM planning process. Pangani River Basin Flow Assessment. Pangani Basin Water Board, Moshi and IUCN Eastern and Southern Africa Regional Programme. V+36 pp. <https://policycommons.net/artifacts>
- Kimenju, J., 2018. *Evaluating payment potential for environmental services and watershed conservation of Thika Dam, Murang'a County, Kenya* (Doctoral dissertation, Kenyatta University).
- Roshinebegam, K. and Selvakumar, S., 2014. Seasonal changes in physico-chemical parameters of Mullai periyar river, Tamil Nadu, India. *Chem Sci Rev Lett*, 3(9), pp.66-73.
- Selemani, J.R., Zhang, J., Muzuka, A.N.N., Njau, K.N., Zhang, G., Mzuza, M.K. and Maggid, A., 2018. Nutrients' distribution and their impact on Pangani River Basin's ecosystem-Tanzania. *Environmental technology*, 39(6), pp.702-716. <http://dx.doi.org/10.1080/09593330.2017.1310305>
- Siriwardana, C., Cooray, A.T., Liyanage, S.S. and Koliyabandara, S.M.P.A., 2019. Seasonal and spatial variation of dissolved oxygen and nutrients in Padaviya reservoir, Sri Lanka. *Journal of Chemistry*, 2019. <https://doi.org/10.1155/2019/5405016>
- Utete, B. and Tsamba, J., 2017. Trophic state categorization and assessment of water quality in Manjirenji Dam, Zimbabwe, a shallow reservoir with designated multi-purpose water uses. *Water Sa*, 43(2), pp.192-199. <http://dx.doi.org/10.4314/wsa.v43i2.03>
- Usman L. U., Namadi, S., & Nafiu, S. A. (2017). Effects of physico-chemical parameters on the composition and abundance of phytoplankton in Ajiwa reservoir Katsina State, North Western Nigeria. *Bayero Journal of Pure and Applied Sciences*, 10(2), 16-24. <http://doi:10.4314/bajopas.v10i2.3>
- URT, 2013. *The United Republic of Tanzania National Agriculture Policy*. 4, 1-42.
- van den Berg, M., & Levely, I. (2019). Does a multi-faceted market-based approach to food crops stimulate food security and agricultural development in Tanzania?. International Initiative for Impact Evaluation.
- Wineman, A., Jayne, T. S., Isinika Modamba, E., & Kray, H. (2020). The changing face of agriculture in Tanzania: Indicators of transformation. *Development Policy Review*, 38(6), 685-709. DOI: 10.1111/dpr.12491