Hindawi
International Journal of Ecology
Volume 2023, Article ID 7353898, 11 pages
https://doi.org/10.1155/2023/7353898

Research Article

Fish Productivity Response to Water Quality Variations: A Case Study of Nyumba ya Mungu Dam, in Pangani Water Basin, Tanzania

Halima O. Mangi[1], **Simon M. Onywere**[2], **and Esther C. Kitur**[3]

[1]*Department of Development Studies, College of Social Sciences and Humanities, Sokoine University of Agriculture, P.O. Box 3035 Chuo Kikuu, Morogoro, Tanzania*
[2]*Department of Environmental Planning and Management, School of Environmental Studies, Kenyatta University, P.O. Box 43844-00100, Nairobi, Kenya*
[3]*Department of Environmental Sciences, School of Environmental Studies, Kenyatta University, P.O. Box 43844, Nairobi 00100, Kenya*

Correspondence should be addressed to Halima O. Mangi; halima.mangi@sua.ac.tz

Received 12 December 2022; Revised 29 June 2023; Accepted 7 July 2023; Published 24 July 2023

Academic Editor: Agoes Soegianto

Fish habitat degradation, such as water pollution due to the rapid expansion of incompatible land uses, is one of the noteworthy challenges to freshwater ecosystems. Elevated contents of nutrients and contaminants in water are some of the imperative challenges. This research was conducted to investigate the link between water qualities and fish productivity in the Nyumba ya Mungu Dam, whose fishery potential had decreased by 95% between 1972 and 2018. Physicochemical characteristics, namely, temperature, pH, dissolved oxygen (DO), turbidity, total nitrogen, total phosphorus, chlorophyll a, and the water depth of fishing net location, were assessed following standard procedure. Fish catches per unit effort representing fish biomass/productivity were monitored for twelve months from January to December 2019. Pearson's correlation analysis indicated that fish catch per unit effort was positively and significantly correlated with turbidity ($r = 0.461$, $P < 0.01$) and TP ($r = 0.405$, $P < 0.01$). Stepwise multiple regression model results indicated that turbidity, dissolved oxygen, and the depth of the fishing net location are the statistically significant predictors of fish catch per unit effort which represented fish biomass. Findings further indicated that the model combining turbidity and dissolved oxygen predicted a 24% change in fish catch per unit effort, whereas turbidity, dissolved oxygen, and the depth of fishing net location contributed a 28.9% change in fish catch per unit effort. In conclusion, fish productivity in the NMD is limited by organic matter availability and nutrient levels that cause algae bloom occurrence. Turbidity is an indicator of organic matter availability and the effect of algae bloom on fish productivity. Inflow of nutrients to the dam nourishes the algae biomass, thus creating vicious cycles on fish productivity as fish species in the dam failed to take advantage of high primary production by algae.

1. Introduction

Safe, clean, and sufficient freshwater is essential for human life and the survival of other living organisms in the environment [1–3]. The deterioration of water quality has become a global problem due to its inherent ability to significantly adjust the hydrological cycle [1, 2]. Many fresh water bodies worldwide face dramatic environmental degradation with downward trends in water quality. According to Tsitsis et al. [3], among the fundamental problems that have widely affected the lakes and their ecological condition are the phenomenon of eutrophication due to an excessive input of nutrients and organic matter, insufficient watershed erosion control, and contamination by toxic substances.

Furthermore, intensive anthropogenic activities and rapid economic growth have added to the pressure on the environment and ecosystems, resulting in soil and water resource degradation, severely limiting sustainability [2, 3]. The presence of chemical compounds is the cause of pollution in both groundwater and surface water. These chemical substances significantly impact whether or not the water is suitable for human consumption and use in industry and agriculture. In recent decades, increased urbanization, wastewater disposal, wetland regulation, and more intensive agricultural practices have increased nutrient loading in many lakes [3, 4]. The inflow of suspended particulate matter from agricultural lands and the widespread presence of toxic substances from activities in freshwater bodies are also common practices [3].

Climate, the depletion of water resources from exploitation and use, summer drought, and climate change, on the other hand, have the potential to exert significant pressure on the hydrology of fresh waters, such as lake's ecosystem. At the same time, the spread of crops and urban areas has eliminated wetlands (e.g., wet meadows, hedgerows, and pastures), resulting in adverse effects on the entire ecosystem and especially on avifauna.

Fish habitat degradation, such as water pollution from agrochemicals such as phosphate and nitrate, due to the rapid expansion of incompatible land uses, is one of the significant challenges to freshwater ecosystems [5–8]. Elevated contents of nutrients and contaminants in water are some of those challenges [9, 10].

Eutrophication is freshwater ecosystems' first typical biological response at high nutrient levels. The phenomenon is characterized by a heavy growth of phytoplankton and aquatic plants or algae blooms (blooms of cyanobacteria) [11–17]. Often phytoplankton biomass increases while its diversity decreases [15]. The degree of its intensity has been categorized as oligotrophic, mesotrophic, or eutrophic [15, 18]. Eutrophication degrades water quality and may lead to killing of fish during summer due to anoxic conditions [15–17, 19–21]. However, before it kills the individual fish, it disrupts the dam's ecology and the food base for fish. Alteration of the food base decreases the reproduction success of fish. Asiyo et al. [22] reported a decrease in species richness and abundance in a wetland near a highly disturbed agricultural land in Uganda. As the degradation got worse over time, even highly tolerant species declined. The lowest number of species in that area was recorded during the dry season when water quality was relatively poorer [22].

Excessive phytoplankton growth depletes dissolved oxygen in the water column, changing water pH and nutrient cycles in the aquatic system [17, 23]. Since phytoplankton is a small photosynthetic organism, oxygen production is usually high during the day. During the night, there is increased oxygen consumption due to the respiration process. Both plants and other organisms use oxygen at night to respire and none produces it, resulting in anoxic conditions [24]. Very few aquatic organisms can tolerate anoxic conditions, with an oxygen saturation level below 30%. Most fish species cannot survive at this level of oxygen. For instance, most cichlid species prefer dissolved oxygen levels above $4\ mgL^{-1}$, and those below $0.3\ mgL^{-1}$ cause stress and death [25]. A study by Chapman et al. [26] revealed that various fish species subjected to dissolved oxygen below $0.2\ mgL^{-1}$ (in hypoxic condition) died within 25 minutes.

Most pesticides are lethal or sublethal to living organisms [14, 27–30]. They contain active ingredients, a chemical property influencing their ability to suppress growth or kill organisms. If not correctly handled, they find their way to the aquatic system and affect unintended organisms, including fish. High nitrogen loads in San Francisco Estuary, California, led to pelagic fish collapsing due to food web changes [27].

The current paper combines biological, chemical, and physical parameters to describe the state of water and the ecological condition of the water body. This research investigated the link between water quality and fish productivity in Nyumba ya Mungu Dam. The catch was used to represent the fish biomass which also represents fish production of the dam. The Nyumba ya Mungu Dam became a vital fishery development area after its closure in the late 60s, but the fishery decreased by 95% between 1972 and 2018. Therefore, the study aimed to investigate water quality's role in the dam's fish productivity. Due to the fact that plant, invertebrate, and fish species interact and affect water quality in ecosystems, bioindicators have been used in water quality evaluation and measurement techniques in the last 30 years. These organisms are also a tool for investigating an ecosystem's environmental quality changes. Collecting and identifying bioindicator species belonging to different biological groups, such as algae, macrophytes, inland water invertebrates, and fish, provides an opportunity to assess long-term water and ecosystem quality alteration [3].

The theory of panarchy [11] guided the study. According to Holling [11], the structures and functions of complex adaptive systems are organized in a hierarchal order (multiscale) over time and space according to their characteristics and levels of resilience (Figure 1). They are also linked across scales between slow and broad structures and small and fast processes [31]. Panarchy is a super configuration in which social and natural systems are interlinked in progressive, adaptive cycles of growth, renewal, restructuring, and accumulation of resources and knowledge [11]. It illustrates the evolving hierarchical organization with various interconnected elements. Therefore, their interactions and structures are characterized by hierarchal orders and panarchal relations [31]. The hierarchal order demonstrates that slow and broad elements restrict and shape the small and fast ones in a top-down interaction style. However, the panarchal relation suggests top-down and bottom-up interactions whereby bottom, small, and fast components interact and affect the system's top, slow, and broader components and vice versa [32]. Therefore, the cross-scale interaction influences processes above and below.

Sediment, nutrients, and hydrology flow alterations are the lower hierarchy elements leading to water level fluctuations, water quality variation, and algae bloom occurrence. These elements and processes (adaptive cycles) create a different form of the system determined by the elements

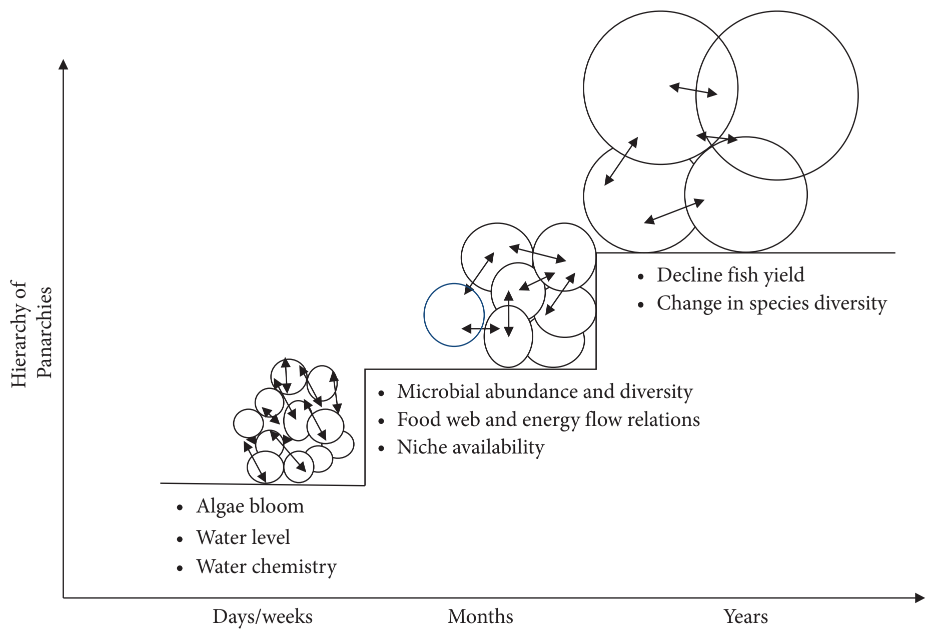

Figure 1: A model of panarchy conceptualized from Holling's view on adaptive systems (source: developed based on Holling [11, 33]).

below it [11, 33]. For instance, water chemistry and water level determine food web and energy flow relationships among benthic organisms. Benthic organisms are different levels of the adaptive cycle. They also influence the complex adaptive cycle above it, which in this case includes fish species diversity and abundance. In this study, the model was used to illustrate the organization of the adaptive cycle's components in the dam, including its riparian land, where most inputs come from over time (Figure 1).

2. Materials and Methods

2.1. Description and Location of the Study Area. Nyumba ya Mungu Dam (NMD) is a large artificial lake in East Africa, between Mwanga District in the Kilimanjaro Region and Simanjiro in the Manyara Region. The 15,000 ha dam is categorized as inclined rock fills joining Kikuletwa and Ruvu rivers. Its downstream end forms the outflow of the Pangani River. The NMD catchment is located between latitudes 3°00′00″ and 4°3′50″ South and longitudes 36°20′00″ and 38°00′00″ East (Figure 2). The dam catchment falls on the upper section of the Pangani River Basin (PRB) in the northeastern part of Tanzania. It covers 42,200 km^2, and approximately 5% of the area is in Kenya [34]. Furthermore, two rivers drain the catchment: Kikuletwa, which collects water from Mt. Kilimanjaro and Mt. Meru, and Ruvu, which originates from Lake Jipe [35]. Pangani River draws water from NMD to the rest of the dam downstream.

2.2. Sampling Procedures, Measurements, and Analysis

2.2.1. Sampling and Measurement of Physical-Chemical Parameters of Water. Dissolved oxygen and turbidity were measured on-site (in situ) using a calibrated Professional Multiparameter Meter (Hanna HI9829). Turbidity, dissolved oxygen, and temperature were measured in eight sites in the dam, two on the upper section of the dam, four points in the middle of the dam, and the other two sampling points at the lower section of the dam. Measurements were taken once per month for twelve months (January to December 2019). Measurements were done between 09:00 a.m and 11:00 a.m due to the spatial distribution of the sampling points and accessibility.

For the total nitrogen and total phosphorus parameter analysis, water was sampled from Nyumba ya Mungu Dam, Kikuletwa, and Ruvu River, using a water scooper and transferred to one-litre high density polyethylene plastic bottles. Before sampling, one-litre high density polyethylene bottles were cleaned with phosphorus-free detergents and rinsed with sample water three times before filling with the sample [36]. One millilitre of sulfuric acid was added in every sample. The samples were then labelled, kept in a cooler box, and transported to a laboratory in Mwanza City.

Water subsamples were collected and stored in a one-litre glass amber bottle for chlorophyll a analysis. The bottles were sealed with a piece of black polythene bag and covered by a black polythene bag to prevent light. Bottles were labelled and packed in a box for transportation. The samples were also transported to the accredited laboratory in Mwanza City for analysis.

2.3. Laboratory Analysis for Total Nitrogen, Phosphorus, and Chlorophyll a Parameters. Spectrophotometric methods were used as outlined in Wetzel and Likens [37], Baird [38], and Johan et al. [39]. In the laboratory, the samples were allowed to attain room temperature. The sample was then divided into suitable aliquots for examining the nutrients.

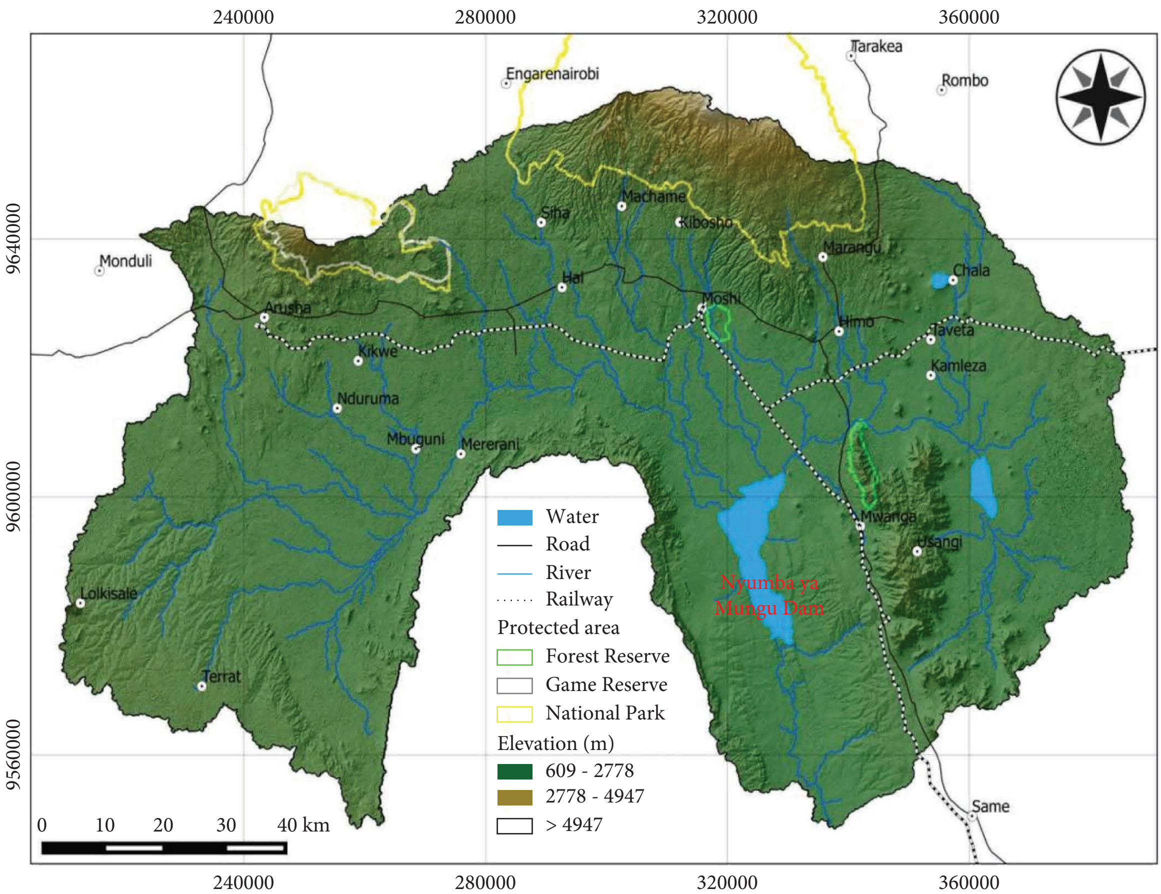

Figure 2: Map of the northern part of Tanzania presenting the location of NMD and its catchment area (source: fieldwork (2020)).

2.3.1. Total Nitrogen (TN) Determination. Oxidative digestion of all nitrogen elements to nitrate was used to determine the amount of total nitrogen in the water sample, preceded by estimating the nitrate concentration. Under heated alkaline persulfate environment and ultraviolet radiation, nitrogen compounds were digested and oxidized to nitrate as described by Wetzel and Likens [37] and Baird (2017). Alkaline oxidation occurred at 100 to 110°C to convert both inorganic and organic nitrogen compounds to nitrate. Total nitrogen concentration was revealed by evaluating the nitrate in the digestate. Automated cadmium reduction was used to determine total nitrogen levels. Total nitrogen is proportional to the pink dye absorbed at 540 nm. A standard curve was processed by plotting the absorbance of the standards created through the manifold versus nitrogen concentration.

2.3.2. Total Phosphorus (TP) Determination. Total phosphorus analysis involved two significant procedures. The first procedure was transforming phosphorus species into a dissolved form, orthophosphate. Total phosphorus includes various phosphorus species mixtures with organic matter. To effectively release phosphorus as orthophosphate, organic matter is oxidized through a digestion method. Since phosphorus digestion occurs under an acidic environment, nitric acid, and sulfuric acid were used with lower pH to attain a value <2. Dissolved orthophosphate was determined in a colourimetric step. The resulting digested solution was injected into a manifold to allow the orthophosphate ion (PO_4^{3-}) to react with ammonium molybdate and antimony potassium tartrate under an acidic setting to create a composite. The formed composite compound was reduced by ascorbic acid to generate a blue compound that absorbs light at 880 nm. The amount of total phosphorus in the sample is proportional to the absorbance level of the composite compound. A standard curve with absorbance plots was used to calculate the total phosphorus concentration on a linear graph.

2.3.3. Chlorophyll a Extraction. Chlorophyll a pigment was extracted in the laboratory using 90% ethanol and analyzed using spectrophotometric methods [37, 39]. Microalgae were extracted through centrifugation for 10 min at 4000 rpm in a centrifuge machine before spectrophotometric analysis was performed [39]. The UV-Visible spectrophotometer with wavelengths of 750 nm, 664 nm, 647 nm, and 630 nm was used to measure the absorbance levels of microalgae [39] (Hitachi U-1900). 90% acetone was used as a blank solution in the spectrophotometer. Then, the absorbance at 750 nm was subtracted from the three wavelengths to give the turbidity-corrected value [39].

To compute the amount of chlorophyll a in the sample, the following equation was used:

$$\mathrm{Chl}-a\left(\frac{\mu g}{L}\right) = (11.85\mathrm{xE}664) - (1.54\mathrm{xE}647) - (0.08\mathrm{xE}630),$$
$$\text{Concentration of Chl}-a\left(\mathrm{mgL}^{-1}\right) = \frac{[\mathrm{Chl}-a\,x\,v]}{V\mathrm{x}L}, \tag{1}$$

in which v = volume of 90% acetone, V = volume of the water sample, L = light path of cuvette, cm, E664 = value of absorbance at a wavelength of 664 nm, E647 = value of absorbance at a wavelength of 647 nm, and E630 = value of absorbance at a wavelength of 630 nm.

2.4. Fish Yield Data Collection. Each month, 24 fishermen were assessed on their monthly fish yield. The monthly fish yields were estimated from fishermen from January to December 2019. Three landing sites, one at the dam's upper, middle, and lower sections, corresponding to water quality and sampling sites, were purposively selected. At each landing site, eight fishermen were randomly chosen each month. Their fishing nets were measured for length and width. The net mesh size was also recorded.

Fishermen were allowed to fish on their own time and effort and record the average fish catch, fish sizes, and fish species caught. At the end of the month, they reported on their fishing activities, estimates of fish caught, and related information such as fishing depth. The weights of fish were weighed using a spring balance, whereas the size of fish corresponding to the net fishing mesh used by fishermen was measured using a ruler.

The location of their fishing nets during that month was marked as high or shallow water. Locations with 1 to 5 meters depths were categorized as shallow water, while locations above 5 meters were classified as high water.

2.5. Statistical Analysis. Analysis of the link between fish catch per unit effort (in kg) and water quality parameters and the depth of fishing area was carried out in SPSS. Variables with substantial contributions to the model's ability to predict the outcome were selected through correlation analysis. Multiple linear regressions were run to establish the functional relationship between fish catch (dependent variable (Y)) and independent variables (X). In this case, water quality parameters and the depth of the fishing area were analyzed.

Multiple regression models assumed the following equation:

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_6X_6, \ldots, \tag{2}$$

where Y is the dependent variable (monthly total fish yield (kg)); X represents the independent variables (temperature, dissolved oxygen, turbidity, chlorophyll a, total nitrogen, total phosphorus, and depth of fishing area); a is the intercept (a) that minimizes the squared deviations between the expected and observed values of Y; $b1$ is the estimated slope of a regression of Y on X_1 if all other X variables could be kept constant, and so on for $b2$, $b3$, etc.

Regression analysis was also used to predict the average fish catch per unit effort (kg) from dissolved oxygen, total phosphorus, total nitrogen, chlorophyll a, water temperature, turbidity, and depth of fish area.

$\hat{Y}$ is the expected value of Y for a given set of X values.

$b1$ is the estimated slope of a regression of Y on $X1$ if all other X variables could be kept constant, and so on for $b2$, $b3$, etc; a is the intercept. We are not going to attempt to explain the math involved. However, multiple regression finds values of $b1$, etc. ("partial regression coefficients") and the intercept (a) that minimizes the squared deviations between the expected and observed values of Y. Besides, a correlation test was also used to test the relationship between annual water levels and fish yield.

3. Results and Discussion

3.1. The Link between the Water Quality of the Dam and Fish Productivity. The results in Table 1 indicate that fish catch per unit effort significantly correlated with turbidity, total phosphorus, depth of fishing area, dissolved oxygen, and temperature. Fish catch per unit effort positively correlated to turbidity ($r = 0.461$, $p < 0.01$) and total phosphorus ($r = 0.405$, $p < 0.01$). Nevertheless, dissolved oxygen ($r = -0.287$, $p < 0.05$), temperature ($r = -0.239$, $p < 0.05$), and depth of fishing area ($r = -0.253$, $p < 0.05$) were negatively correlated to fish catch per unit effort (Table 1).

Positive correlations indicate a linear relationship in which monthly fish catch per unit effort increases with an increase in turbidity and total phosphorus. These variables, therefore, may have a positive influence on fish production. On the contrary, a negative correlation indicates that the dissolved oxygen, oxygen saturation, temperature, and fishing depth negatively influenced the fish catch per unit effort.

Stepwise multiple regression analysis, in which variables that showed a strong correlation with fish catch per unit effort, namely, turbidity, total phosphorus, depth of fishing area, dissolved oxygen, and temperature, were included in the model hierarchically, was performed; it indicated that turbidity, dissolved oxygen, and depth of the fishing area are statistically significant predictors of monthly fish catch per unit effort (Table 2). The overall model, including the three variables, presents F (3, 92) = 12.4 and $p < 0.01$, with $R^2 = 0.289$ and adjusted $R^2 = 0.265$.

The results indicate that turbidity has the most substantial effect on the monthly fish catch per unit effort compared to dissolved oxygen and the depth of the fishing area (Table 2). Turbidity alone predicts a 20.4% change in fish catch per unit effort (Table 2). The model combining turbidity and dissolved oxygen was able to predict a 24% change in fish catch per unit effort, whereas turbidity, dissolved oxygen, and depth of fishing area together contributed a 28.9% change in fish catch per unit effort. The model including turbidity as a predictor of fish catch per unit

Table 1: Pearson correlations between fish catch per unit effort and water quality parameters.

	CPUE	Turbid	TP	TN	Chl-a	Depth	Temp	DO
CPUE								
Turbid	0.461**							
TP	0.405**	0.680**						
TN	0.123	0.190*	0.340**					
Chl-a	−0.167	−0.256**	−0.294**	−0.079				
Depth	−0.253**	−0.336**	−0.307**	0.029	−0.055			
Temp	−0.239*	−0.202*	−0.054	−0.186*	−0.093	0.144		
DO	−0.287**	−0.174*	−0.057	−0.051	−0.123	0.182*	0.110	

CPUE = catch per unit effort (kg), turbid = turbidity, depth = depth of the fishing area (m), temp = temperature (°C), DO = dissolved oxygen (mgL^{-1}), TN = total nitrogen (μgL^{-1}), TP = total phosphorus (μgL^{-1}), and Chl-a = chlorophyll a (μgL^{-1}). *Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed).

Table 2: Multiple linear regression coefficients, prediction of monthly fish catch per unit effort relation to turbidity level, dissolved oxygen (DO) concentrations, and depth of the fishing net location.

Model		Unstandardized coefficients		Standardized coefficients	t	Sig.	Collinearity statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	5234.877	441.594		11.855	0.000		
	Turbid	40.448	8.033	0.461	5.036	0.000	1.000	1.000
2	(Constant)	7412.254	1,024.013		7.238	0.000		
	Turbid	37.201	7.968	0.424	4.669	0.000	0.970	1.031
	DO	−400.022	170.620	−0.213	−2.345	0.021	0.970	1.031
3	(Constant)	9729.800	1,516.765		6.415	0.000		
	Turbid	31.935	8.249	0.364	3.872	0.000	0.875	1.143
	DO	−363.290	168.740	−0.193	−2.153	0.034	0.959	1.043
	Depth	−355.298	173.894	−0.191	−2.043	0.044	0.880	1.136
	R	R^2	R^2 residual	F	P value		Durbin–Watson	
1	0.461[a]	0.212	0.204	25.357	0.000[b]			
2	0.506[b]	0.256	0.240	16.033	0.000[c]			
3	0.537[c]	0.289	0.265	12.445	0.000[d]		1.257	

a, significant at 0.05; b, significant at 0.05; c, significant at 0.05; d, significant at 0.05.

effort also indicated high prediction power of changes in fish catch (F (1, 94) = 25.4, $p < 0.01$) compared to models including dissolved oxygen (F (2, 93) = 16, $p < 0.01$) and model with both dissolved oxygen and depth of the fishing area (F (3, 92) = 12.4, $p < 0.01$).

According to the multiple regression models, an increase in 1 FNU of turbidity increases fish catch per unit effort by 31.9 kg (Table 2 and Figure 3). An increase in 1 mgL^{-1} of dissolved oxygen reduces 363.3 kg of fish (Table 2 and Figure 4), and rise in 1 m depth of the fishing area leads to a decrease in 355.3 kg of fish (Table 2 and Figure 5). These variables' contribution to the fish catch per unit effort was statistically significant. Turbidity had a more outstanding contribution to the variation in fish catch per unit effort (t (92) = 3.9, $p < 0.01$), compared to dissolved oxygen (t (92) = −2.2, $p < 0.05$) and depth of fishing area (t (92) = 2.0, $p < 0.05$).

Results indicate that fish catch per unit effort increases as turbidity increases; this could be because, in the study area, turbidity seems to be composed of sediments full of nutrients and organic matter. At the onset of rainfall, two phenomena happen; the first, the velocity of inflow water increases, thus destroying algae filaments and hence, moderating their production. Second, runoff, as a result of rainfall during February to June (long rains) and November to December (short rains), collects plant remains and sediments from farmland to the rivers and the dam. Although they increase turbidity in the dam, nutrients, sediments, and organic matter contents become primary food sources and energy sources in the dam's food pyramid. Since the dam is so rich in nutrients, its influence on primary production (excessive growth of micro-algae) no longer benefits the fish. The destruction of algae and moderation of their products seem to create conditions favorable to the microorganisms in the food chain and the fish; hence, their growth and reproduction increase [40, 41].

Another explanation about the positive relationship between turbidity and fish is based on the ability of turbidity to block light penetration in the water column [42]. Turbidity limits light penetration for photosynthesis and the chemical process through which algae process food and excess biomass stored as algae filaments [43]. This optimizes algae levels, allowing optimal biological processes for the organisms in the dam including fish.

Turbidity is related to rainfall, and its influence on fisheries is based on how rain affects the flow velocity and organic matter particulates in the dam. Turbidity increases at the beginning of the rainfall, during which sediments and

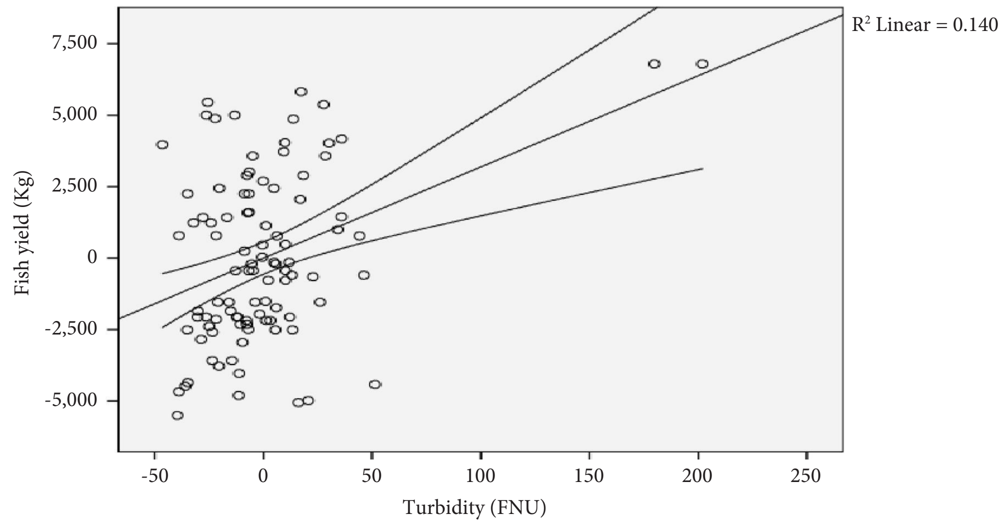

Figure 3: The relationship between fish catch per unit effort (kg) and turbidity (FNU).

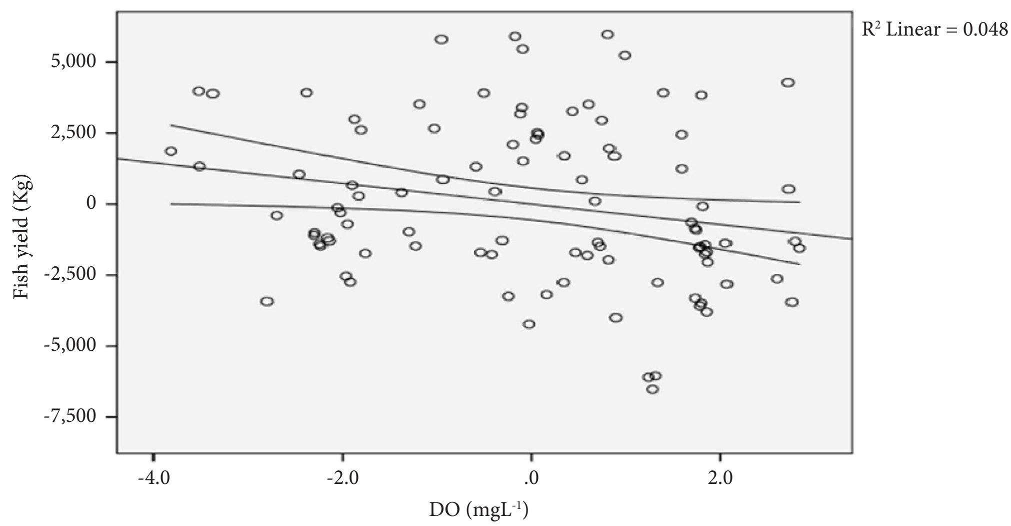

Figure 4: The relationship between fish catch per unit effort (kg) and dissolved oxygen (mgL^{-1}).

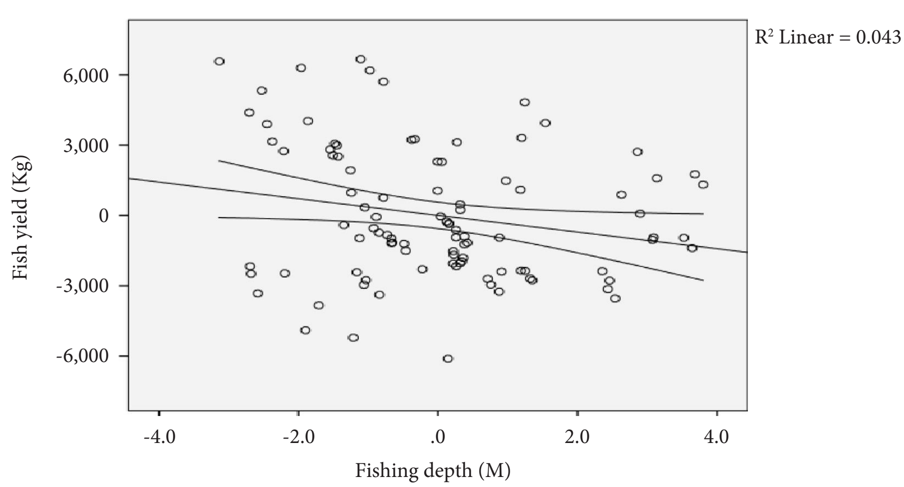

Figure 5: The relationship between fish catch per unit effort (kg) and depth of fishing area (m).

organic matter are brought to the dam, thus providing food to decomposers, shredders, and filter feeders. Turbidity sharply decreases soon as rainfall stops; in this case, fish catch takes a similar trend (Figure 6). This indicates that the energy supply at the base of the food pyramid of the dam is affected by rainfall, which is represented by turbidity [17]. As turbidity declines, chlorophyll a increases because the cloudy and suspended particles that prevent light penetration are reduced [44]. Since the rain has also stopped, the mechanical effect of water flow velocity, which destroys the algae filaments, also stops allowing algae filaments to grow.

The negative effect of dissolved oxygen on fish catch per unit effort is linked to chlorophyll a concentration trend and organic matter availability in the dam. During the rainfall season, March to June, although organic matter concentration is high, the growth of algae biomass is moderate (Figure 6). Hence, levels of oxygen are optimally sufficient for most organisms and various fish species. Therefore, fish growth and their general physiological activities increase.

As indicated in Figure 6, chlorophyll a concentration is higher during the dry season, both the short dry season between January and February and the long dry season between July and October, meaning that algae biomass is high. During these periods, the competition for oxygen is high since algae, microorganisms, and fish consume oxygen. Although photosynthetic algae produce oxygen during the daytime, they consume oxygen at night without light [45]. On the other hand, the high biomass of algae increases the demand for dissolved oxygen for microorganisms to decompose them [46, 47]. Since algae biomass is too high during the dry season, that situation creates oxygen-deficient conditions (anoxic conditions).

During summer, chlorophyll a levels are very high, indicating a high algae growth rate. As shown in Figure 6, chlorophyll a peaks to the maximum point and oxygen decreases to its minimum point, followed by a decrease in fish catch per unit effort. The sharp decline in chlorophyll a that follows the highest peak indicates the occurrence of the algae blooms. In this case, algae bloom seems to occur during January and September. Oxygen levels tend to increase following the algae bloom [48]. This indicates that the algae have decomposed and were consumed by low-oxygen-tolerant organisms. After the algae bloom biomass clears, the water oxygen level raises rapidly, a tendency that indicates the role of chlorophyll a on oxygen consumption [49]. Nevertheless, fish production decreases because there is not enough organic matter in the dam during summer.

Fishing depth is the depth from the water surface where fishermen place their nets during fishing. It is determined by the fishermen, guided by their experiences and their knowledge of the conditions of the dam. According to the results, monthly fish catch decreases as the fishing depth increases, and vice versa. This means that fish species mainly endemic tilapia such as, *Sarotherodon jipe*, *S. pangani*, *S. esculentus*, and *Tilapia rendalli* concentrate more in the shallow water area, the littoral zone, as compared to the deep water area.

Fishing depth is negatively correlated with turbidity ($r = -0.336$, $p < 0.01$), meaning that as turbidity increases, the fishing depth decreases, and it mainly happens during rainfall season, when the water level of the dam is also

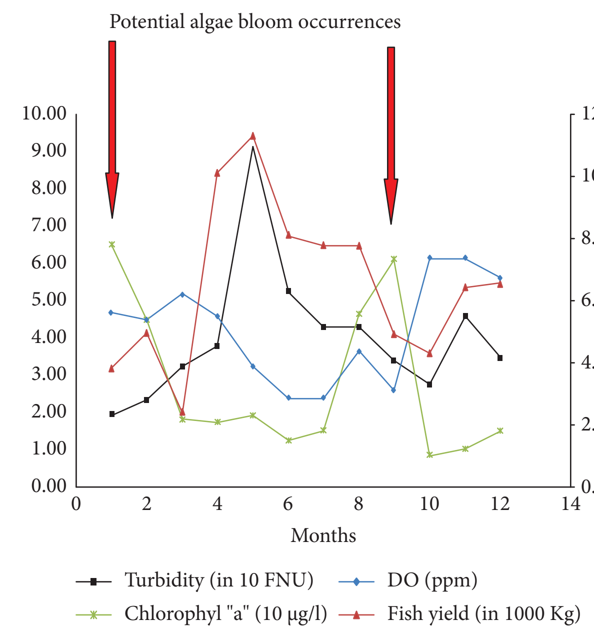

Figure 6: Monthly trends of fish catch per unit effort, turbidity, chlorophyll a, and dissolved oxygen.

increasing. It might be due to high turbidity that fish tend to avoid high water and move to shallow water, or the water level is a biological trigger for fish to start spawning [50]. Fishermen change the location of their nets to maximize their catch at the coastal area where fish are spawning. For instance, the average fishing depth in May is around 5.6 m. In other words, fishing activities are taking place at the littoral zone during this period. Since this is a rainy season accompanied by high turbidity levels, due to sediments, organic matters, and nutrients brought from farmlands, which provide food to fish, there is a high probability that this is also a breeding season. Thus, breeding fish spend most of their timein the littoral zone for spawning [50, 51]. The fishermen, therefore, learned from their experience, moving to the littoral zone, coinciding with the fish breeding period. In addition, fish productivity might be high due to food availability during the rainy season, increasing fish catch.

Phosphorus was excluded from the regression model despite its strong positive and negative correlation with fish catch per unit effort. This may be because of the multicollinearity effect; they also had a high correlation with other predictor variables. Phosphorus significantly correlated with turbidity ($r = 0.680$, $p < 0.01$). The high correlations have masked the effect of phosphorus in predicting change in fish catch per unit effort.

According to Miranda et al. [52], further reductions in dissolved oxygen are likely to be caused by nutrient increases and associated algal blooms that tend to increase dissolved oxygen highs, and, when they collapse, increase the lows.

Egertson and Downing [53] reported a weak positive correlation between fish catch per unit effort and trophic variables such as chlorophyll a, total nitrogen, and total phosphorus (Figure 7). However, the current study has indicated no significant correlation with chlorophyll a concentrations. This means that fish species in the dam

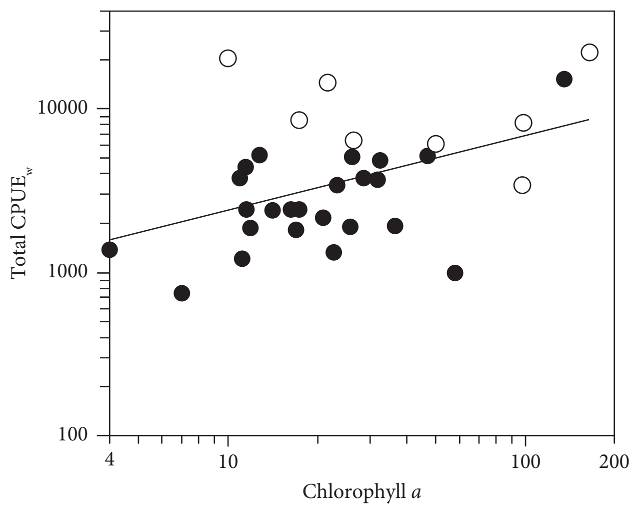

Figure 7: Correlation between total fish catches per effort and chlorophyll a concentration (source: Egertson and Downing [53]).

Table 3: Significant correlation coefficient (r) between independent variables and catch per unit effort by weight (CPUE) of individual and grouped species.

	BLG	BLC	WHC	CARP	BBHD	CCF	SPORT	BENTH
LType	−0.44			+0.51	+0.68		−0.42	+0.61
$\overline{Z}$				−0.46	−0.40			−0.58
SA	−0.39			+0.53				+0.47
Cond		+0.40		+0.48	+0.37	−0.39		+0.37
DO							−0.37	
Chl-a				+0.39				+0.57
TN				+0.35				
TP								+0.40
TSS			+0.37					

Source: Egertson and Downing [53].

have failed to take advantage of the high primary production energy generated by algae at a higher trophic state (eutrophic and hypereutrophic) and could have been completely excluded in the energy flow chain [53]. Simply, the high biomass of algae/phytoplankton is not benefiting the fish [53].

Fish species respond differently to trophic states; the most tolerant to nutrient-rich waters will increase production at eutrophic and hypereutrophic states. Egertson and Downing [53] reported that carp, white crappie, and benthivores were the only fish groups that responded positively to indices of lake trophic status. Chlorophyll a and total nitrogen were positively correlated with carp CPUE, while total suspended solids correlated positively with the CPUE of white crappie (Table 3).

Chapman et al. [53] found total fish catch to increase systematically with chlorophyll a. Their reservoir had a lower range of chlorophyll a concentrations (1–12 μg/l) compared to that of the present study (0–120 μg/l). In a dam with fewer microphytes such as NMD, algae fuel the base of the food pyramid.

4. Conclusions and Recommendations

Fish production in the Nyumba ya Mungu Dam (NMD) is limited by organic matter availability and nutrient levels (bottom, small, and fast components of dam panarchal relations) that cause algae to bloom. Turbidity is an indicator of organic matter availability and the effect of algae bloom on fish production. Organic matter is brought to the dam through rivers that collect runoff from riparian land during rainy seasons (March to July). On the other hand, runoff contains nutrients (total phosphorus and total nitrogen) that nourish the algae biomass (represented by chlorophyll a concentration), thus viciously impacting fish production (top, broad, and slow component of dam panarchal relations). Fish species in NMD have failed to take advantage of high primary production by algae. They could have been wholly excluded from the energy flow chain; thus, they highly depend on the organic matter availability.

It is recommended that measures to increase organic matter input in the dam such as tree planting on the farm and protection of the land adjacent to the dam should be implemented. To reduce the amount of nutrient leaching down the river, some simple and affordable agro-ecology approaches to contain nutrients within farmlands may be used. These approaches should go together with soil fertility testing and advising farmers on the proper use of nutrients. In addition, wetlands at the river mouth, which are now degraded through sand mining, should be protected since they are potential nutrient filters.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

We acknowledge the financial support from DAAD for research which has resulted in this article.

References

[1] D. E. Gamvroula and D. E. Alexakis, "Evaluating the performance of water quality indices: application in surface water of lake union, Washington state-USA," *Hydrology*, vol. 9, no. 7, p. 116, 2022.

[2] H. O. Mangi, "Estimation of monetary values of the ecosystem services flow at the tidal Elbe River," *Advances in Ecology*, vol. 2016, Article ID 6742786, 8 pages, 2016.

[3] C. Tsitsis, D. E. Alexakis, K. Moustris, and D. E. Gamvroula, "Combining artificial neural network and driver–pressure–state–impact–response approach for evaluating a mediterranean lake," *Water*, vol. 15, no. 2, p. 266, 2023.

[4] H. O. Mangi, "Tide management in the elbe river and changes in ecosystem services," *Advances in Ecology*, vol. 2016, Article ID 9519637, 13 pages, 2016.

[5] G. Marmulla, *Dams, Fish and Fisheries Opportunities, Challenges and Conflict Resolution*, Vol. 419, FAO Fisheries Technical Paper, Rome, Italy, 2001.

[6] J. Geist, "Integrative freshwater ecology and biodiversity conservation," *Ecological Indicators*, vol. 11, no. 6, pp. 1507–1516, 2016.

[7] W. F. Henley, M. A. Patterson, R. J. Neves, and A. D. Lemly, "Effects of sedimentation and turbidity on lotic food webs: a concise review for natural resource managers," *Reviews in Fisheries Science*, vol. 8, no. 2, pp. 125–139, 2000.

[8] M. J. V. Zanden and Y. Vadeboncoeur, "Fishes as integrators of benthic and pelagic food webs in lakes," *Ecology*, vol. 83, no. 8, pp. 2152–2161, 2002.

[9] B. B. Jana, S. Lahiri, D. Ghosh, J. N. Bhakta, S. Mandal, and S. K. Bag, "Understanding the soil-water interactions for sustainable ecosystem services in aquatic environments," in *Wastewater Management through Aquaculture*, pp. 3–28, Springer Singapore, 2018.

[10] S. Levy, "Paleoecology—looking to the past to inform the future," *BioScience*, vol. 67, no. 9, pp. 791–798, 2017.

[11] C. S. Holling, "Resilience and stability of ecological systems," *Annual Review of Ecology and Systematics*, vol. 4, no. 1, pp. 1–23, 1973.

[12] U. Kremser and E. Schnug, "Impact of fertilizers on aquatic ecosystems and protection of water bodies from mineral nutrients," *Landbauforschung Volkenrode*, vol. 52, no. 2, pp. 81–90, 2002.

[13] P. S. Lake, M. A. Palmer, P. Biro et al., "Global change and the biodiversity of freshwater ecosystems: impacts on linkages between above-sediment and sediment biota," *BioScience*, vol. 50, no. 12, pp. 1099–1107, 2000.

[14] E. Lema, R. Machunda, and K. N. Njau, "Assessment of agrochemical residues in wastewater from selected horticultural farms in Arusha," *Tanzania*, vol. 6, no. 2, pp. 240–251, 2015.

[15] J. J. Ney, C. M. Moore, M. S. Tisa, J. J. Yurk, and R. J. Neves, "Factors affecting the sport fishery in a multiple-use Virginia reservoir," *Lake and Reservoir Management*, vol. 6, no. 1, pp. 21–32, 1990.

[16] V. H. Smith, G. D. Tilman, and J. C. Nekola, "Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems," *Environmental Pollution*, vol. 100, no. 1–3, pp. 179–196, 1999.

[17] J. L. Walker, T. M. Younos, and C. E. Zipper, "Nutrients in lakes and reservoirs: a literature review for use in nutrient criteria development," VWRRC Special Report, Virginia Water Resources Research Center, Blacksburg, Virginia, 2007.

[18] J. Wanzenböck, H. Gassner, B. Lahnsteiner et al., "Ecological integrity assessment of lakes using fish communities: an example from Traunsee exposed to intensive fishing and to effluents from the soda industry," *Water, Air, and Soil Pollution: Focus*, vol. 2, no. 4, pp. 227–248, 2002.

[19] K. K. Arend and M. B. Bain, "Fish communities in coastal freshwater ecosystems: the role of the physical and chemical setting," *BMC Ecology*, vol. 8, no. 1, p. 23, 2008.

[20] M. Rask, M. Olin, J. Horppila et al., "Lacustrine fishes and the trophic efficiency of lakes: prelude to the problem," *Fisheries Management and Ecology*, vol. 68, no. 2, p. 49, 1998.

[21] M. Zhang, Y. Yu, Z. Yang, X. Shi, F. Kong, and G. Weyhenmeyer, "The distribution of phytoplankton along trophic gradients and its mediation by available light in the pelagic zone of large eutrophic lakes," *Canadian Journal of Fisheries and Aquatic Sciences*, vol. 69, no. 12, pp. 1935–1946, 2012.

[22] S. G. Asiyo, J. Kipkemboi, J. M. Mathooko, J. Balirwa, and P. O. B. Kyambogo, "Variation of small-scale wetland fishery in relation to land use along Mpologoma riverine marsh in Eastern Uganda," *African Journal of Environmental Science and Technology*, vol. 8, no. 12, pp. 716–729, 2014.

[23] D. A. Jackson, P. R. Peres-Neto, and J. D. Olden, "What controls who is where in freshwater fish communities–the roles of biotic, abiotic, and spatial factors," *Canadian Journal of Fisheries and Aquatic Sciences*, vol. 58, no. 1, pp. 157–170, 2001.

[24] S. Joyce, "The dead zones: oxygen-starved coastal waters," *Environmental Health Perspectives*, vol. 108, no. 3, pp. A120–A125, 2000.

[25] J. S. Likongwe, T. D. Stecko, J. R. Stauffer, and R. F. Carline, "Combined effects of water temperature and salinity on growth and feed utilization of juvenile Nile tilapia *Oreochromis niloticus* (Linneaus)," *The Journal of Aquaculture*, vol. 146, no. 1-2, pp. 37–46, 1996.

[26] L. J. Chapman, L. S. Kaufman, C. A. Chapman, and F. E. McKenzie, "Hypoxia tolerance in twelve species of East African cichlids: potential for low oxygen refugia in Lake Victoria," *Conservation Biology*, vol. 9, no. 5, pp. 1274–1288, 1995.

[27] P. M. Glibert, "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*, vol. 18, no. 2, pp. 211–232, 2010.

[28] H. Hellar-kihampa, "Pesticide residues in four rivers running through an intensive agricultural area," *Kilimanjaro, Tanzania*, vol. 15, no. 2, 2011.

[29] H. E. Nonga, R. H. Mdegela, E. Lie, M. Sandvik, and J. U. Skaare, "Assessment of farming practices and uses of

agrochemicals in Lake Manyara basin, Tanzania," *African Journal of Agricultural Research*, vol. 6, no. 10, pp. 2216–2230, 2011.

[30] J. R. Selemani, J. Zhang, A. N. N. Muzuka et al., "Nutrients' distribution and their impact on Pangani River Basin' s ecosystem – Tanzania," *Environmental Technology*, vol. 39, no. 6, pp. 702–716, 2017.

[31] B. Walker, L. H. Gunderson, A. Kinzig, C. Folke, S. Carpenter, and L. Schultz, "A handful of heuristics and some propositions for understanding resilience in social-ecological systems," *Ecology and Society*, vol. 11, no. 1, p. 13, 2006.

[32] M. Schoon and S. Van Der Leeuw, "The shift toward social-ecological systems perspectives: Insights into the human-nature relationship," *Natures Sciences Societes*, vol. 23, no. 2, pp. 166–174, 2015.

[33] L. Gunderson, B. A. Cosens, B. C. Chaffin et al., "Regime shifts and panarchies in regional scale social-ecological water systems," *Ecology and Society*, vol. 22, no. 1, 2017.

[34] P. M. Ndomba, "Modelling of sedimentation upstream of Nyumba ya Mungu reservoir in Pangani River Basin," *Nile Basin Water Science and Engineering*, vol. 3, no. 2, 2010.

[35] P. M. Ndomba, F. W. Mtalo, and A. Killingtveit, *Estimating Long-Term Sediment Rate Yield Using One Hydrological Year Sampling Programme Data and Corrected Rating Curve*, University of Dar es Salaam, Tanzania and University of Science and Technology, Norway, 2008.

[36] A. Bahobail, S. M. F. Gad El-Rab, and G. A. Amin, *Standard Methods for the Examination of Water and Wastewater*, American Public Health Association/American Water Works Association/Water Environment Federation, Washington, DC, USA, 21st edition, 2005.

[37] R. G. Wetzel and G. E. Likens, *Limnological Analyses*, Springer, New York, NY, USA, 2nd edition, 1991.

[38] R. B. Baird, *Standard Methods for the Examination of Water and Wastewater*, American Public Health Association, Washington, D.C., USA, 2017.

[39] F. Johan, M. Z. Jafri, H. S. Lim, and W. O. Wan Maznah, "Laboratory measurement: chlorophyll a concentration measurement with acetone method using spectrophotometer," in *Proceedings of the 2014 IEEE International Conference on Industrial Engineering and Engineering Management*, pp. 744–748, Selangor, Malaysia, December 2014.

[40] F. Kaczala, P. S. Salomon, M. Marques, E. Granéli, and W. Hogland, "Effects from log-yard stormwater runoff on the microalgae Scenedesmus subspicatus: intra-storm magnitude and variability," *Journal of Hazardous Materials*, vol. 185, no. 2-3, pp. 732–739, 2011.

[41] W. Wang, *Effect of Turbidity on Algal Growth*, Illinois State Water Survey, Illinois, IL, USA, 1974.

[42] R. Fichez, T. D. Jickells, and H. M. Edmunds, "Algal blooms in high turbidity, a result of the conflicting consequences of turbulence on nutrient cycling in a shallow water estuary," *Estuarine, Coastal and Shelf Science*, vol. 35, no. 6, pp. 577–592, 1992.

[43] J. F. Talling, R. B. Wood, M. V. Prosser, and R. M. Baxter, "The upper limit of photosynthetic productivity by phytoplankton: evidence from Ethiopian soda lakes," *Freshwater Biology*, vol. 3, no. 1, pp. 53–76, 1973.

[44] S. Bee, "Seasonal and annual changes in water quality in the ohio river using landsatbased measures of turbidity and chlorophyll a," Doctoral dissertation, University of Cincinnati, Cincinnati, OH, USA, 2009.

[45] H. R. Nelson and A. H. Altieri, "Oxygen: the universal currency on coral reefs," *Coral Reefs*, vol. 38, no. 2, pp. 177–198, 2019.

[46] M. W. Brunson, C. G. Lutz, and R. M. Durborow, *Algae Blooms in Commercial Fish Production Ponds*, Southern Regional Aquaculture Center, Stoneville, MS, USA, 1994.

[47] D. J. Moriarty, "The role of microorganisms in aquaculture ponds," *Aquaculture*, vol. 151, no. 1-4, pp. 333–349, 1997.

[48] T. Sidabutar, E. S. Srimariana, and S. Wouthuyzen, "The potential role of eutrophication, tidal and climatic on the rise of algal bloom phenomenon in Jakarta Bay," in *Proceedings of the IOP Conference Series: Earth and Environmental Science*, vol. 429, no. 1, Bogor City, Indonesia, September 2020.

[49] M. Baxa, M. Musil, M. Kummel, P. Hanzlík, B. Tesařová, and L. Pechar, "Dissolved oxygen deficits in a shallow eutrophic aquatic ecosystem (fishpond)–Sediment oxygen demand and water column respiration alternately drive the oxygen regime," *The Science of the Total Environment*, vol. 766, Article ID 142647, 2021.

[50] L. Yu, J. Lin, D. Chen, X. Duan, Q. Peng, and S. Liu, "Ecological flow assessment to improve the spawning habitat for the four major species of carp of the Yangtze River: a study on habitat suitability based on ultrasonic telemetry," *Water*, vol. 10, no. 5, p. 600, 2018.

[51] I. J. Winfield, "Fish in the littoral zone: ecology, threats and management," *Limnologica*, vol. 34, no. 1-2, pp. 124–131, 2004.

[52] L. E. Miranda, G. Coppola, and J. Boxrucker, "Reservoir fish habitats: a toolkit for coping with climate change," 2019, https://www.friendsofreservoirs.com/wp-content/uploads/2020/01/Climate-change-toolkit.pdf.

[53] C. J. Egertson and J. A. Downing, "Relationship of fish catch and composition to water quality in a suite of agriculturally eutrophic lakes," *Canadian Journal of Fisheries and Aquatic Sciences*, vol. 61, no. 9, pp. 1784–1796, 2004.

[54] L. J. Chapman, L. S. Kaufman, C. A. Chapman, and F. E. Mckenzie, "Hypoxia tolerance in twelve species of east African cichlids: potential for low oxygen hypoxia tolerance in twelve species of east African cichlids: Potential for Low Oxygen Refugia in Lake Victoria," *Society for Conservation Biology*, vol. 9, no. 5, pp. 1274–1287, 2018.