Journal of Limnology and Freshwater Fisheries Research

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Spatial and Temporal Variations in Water Quality Along the Bua River, Malawi

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ABSTRACT

Water quality in freshwaters is declining worldwide due to increases in human populations, expansion of agricultural activities, and climate change. There are quite a number of regions of the world, Africa inclusive, that are understudied, and little to no baseline information exists related to water quality. This study was focused on the Bua River in Malawi, which supports sustenance fishing and basic needs for local communities. A portion of the river has elevated levels of protection because it is found within the Nkhotakota Wildlife Reserve. The focus of this study was to understand the spatial-temporal variations of water quality at five sites in the Bua River from May 2018 to June 2020 capturing the three main seasons (warm wet, cool dry, and hot dry). Although other water quality parameters did not vary spatially. Spatially, the Bua River mouth registered the highest values of Soluble reactive phosphorus and the Bua River upstream had the lowest. However, there were greater temporal differences across seasons for water temperature, water pH, and chlorophyll a. For instance, chlorophyll-a was higher during the hot dry season (3.28 µgL-1) compared to the cool dry season (2.10 µgL-1) and warm wet season (1.91 µgL-1). Water transparency, as measured by secchi depth was lowest during the warm wet season, which coincides with higher concentrations in SRP. All measurements of salt content, Electrical Conductivity (EC), Total Dissolved Solids (TDS), and salinity) were higher during the hot dry season and correlated negatively with SRP. Similarly, bicarbonate and alkalinity were also higher during the hot dry season. Principle Component Analysis indicated that the parameters responsible for variations of Bua River water quality are mainly related to soluble minerals, water temperature, and surface runoff associated with agricultural activities and domestic waste accounting for 78.49 % of the total variance in the data set.

Keywords: Water quality, freshwater habitats, principal-components analysis, seasonality, Southern Africa

ARTICLE INFO

REVIEW

Received : 11.02.2022
Revised : 22.08.2022
Accepted : 31.08.2022
Published : 30.12.2022

DOI:10.17216/LimnoFish.107220

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How to Cite
Balaka Y, Chagoma HJ. 2022. Spatial and Temporal Variations in Water Quality Along the Bua River, Malawi. LimnoFish. 8(3): 210-226 doi: 10.17216/LimnoFish.107220

Introduction

Rivers support various ecosystem services worldwide and provide important societal services, including food, water for domestic use (washing clothes, drinking water, cooking uses, and watering livestock), agriculture, hydroelectric power generation, navigation, and industrial production. These sustained pressures on rivers lead to fragmentation, habitat degradation, pollution, loss of connectivity, and a decline in water quality affecting many fundamental processes and functions. Sometimes, balancing these competing ecosystem services that rivers provide among the different resource users become a main concern worldwide (Islam et al. 2017).

Surface water quality of rivers is influenced by anthropogenic influences (urban, industrial, agricultural, exploitation of water resources) and natural processes (changes in precipitation, erosion, weathering) degrade surface water and impact their ecosystem services.

The aquatic ecosystems have been continuously modified by agriculture, disposals from urban, mining and industrial wastes, and engineering modifications to the environment and inappropriate resource management along the catchments globally (Allan 2004). More industries would mean increased discharge of effluent and other wastes into Rivers, whereas fertilizers from agricultural runoff are the main source of nutrients in aquatic ecosystems. The increased nutrients may lead to increased primary productivity, a phenomenon commonly called cultural eutrophication. The effects of eutrophication include oxygen depletion in the water column (Aure and Stigebrandt 1990), increased phytoplankton production and algal blooms (Dillion and Rigler 1974), presence of cyanobacteria associated with organic enriched nutrients (Laws 2000) and impacts on macro invertebrates and other benthic communities. Thus, addition of large amounts of exogenous nutrients, whether from agricultural runoffs or other point or non-point sources will not only increase phytoplankton biomass, but will also favour nitrogen fixing bacteria and the presence of potentially toxic phytoplankton species to fish and humans (Guildford et al. 1999). Overall, degradation of River water quality will have detrimental negative impact to fish and other aquatic organisms.

The pollution of rivers and aquifers is a growing threat to freshwaters in southern Africa (Dan-Hassan et al. 2012; Amadi 2010). River pollution results in changes in water quality and quantity, as well as in loading of silt and other materials, which directly affect a river's form (Limuwa et al. 2013). More generally, the majority of pollution into rivers originates from industrial and domestic wastewater as well as agricultural drainage (Carpenter et al. 1998; Jarvie et al. 1998). Seasonal variations in both anthropogenic activities and natural processes such as temperature and precipitations, affect the quality of river water and lead to different attributes between seasons (Vega et al. 1998).

Inappropriate use of the water resources has an immediate impact on the livelihoods of some of the world's most vulnerable human communities such as fishers, as they rely on the water resource for basic needs. Current data indicate that the Bua River fishery continues to dwindle due to overfishing, but little has been done to elucidate the effect of water quality and habitat alterations on *Opsaridium microlepis* and other Riverine fish species. As noted by Limuwa et al. 2013 that *O. microlepis* is facing serious problems not only as a result of fishing pressure, but also from environmental degradation, such observations call for measures to monitor the River ecosystem to come up with good management practices.

Our objective was to understand the temporal-spatial variations of water quality throughout the Bua River, Malawi in order to understand its ability to fully support competing ecosystem services that it currently provides. Large gaps remain in our understanding of water quality in many key rivers throughout the world, but particularly in understudied areas in Africa. Lake Malawi/Nyasa support a unique biodiversity of fishes and its rivers, such as the Bua River, provide an important connection between the Lake and its surrounding landscape. Therefore, it was evaluated on a monthly basis, the water quality at five sites in the Bua River from May 2018 through June 2020 capturing the three main seasons (warm wet, cool dry, and hot dry) to a provide baseline understanding of its water quality both longitudinally and over time and to identify possible pollution sources. Ultimately, our results aimed at informing the local communities about the water quality of the Bua River, and identifying some of the key factors that managers and policymakers can target for monitoring/research programs.

Materials and Methods

Study Area

The Bua River is one of the major rivers that drains into the western coast of Lake Malawi/Nyasa, Malawi flowing through the Nkhotakota Wildlife Reserve where it has elevated levels of protection. It has a catchment area of 10,658 km^2, it is 186 km long, and its width varies from 16 to 87 km (Kelly et al. 2019). The climate of the Bua River catchment is classified as sub-tropical (Government of Malawi 2017) with three seasons, including warm wet (1st November - 30th April); cool dry (1st May - 31st August); and hot dry (1st September - 31st October; Government of Malawi 2017). The average annual rainfall is estimated as 897 mm (range 800-1000 mm; Government of Malawi 2011). Our sampling sites are concentrated in the lower river from Tongole Pool in the upper extent of the Nkhotakota Wildlife Reserve, excluding administrative districts from Mchinji to Kasungu (Figure 1, Table 1). As the Bua River leaves the Nkhotakota Wildlife Reserve, it passes through agricultural lands dominated with rice fields and sugarcane plantations. Where the river meets the lakeshore floodplain, the catchment drops rapidly through a series of steep slopes leading to high levels of sedimentation across the lakeshore floodplain as the gradient flattens out (Kelly et al. 2019). This lower part of Bua River supports potamodromous fish species that migrate from the lake to spawning grounds in the mainstream and tributaries that have gravel and sandy-bottomed shallows, including Mpasa *O. microlepis*, which is an important fish for economic and cultural purposes (Tweddle 1983).

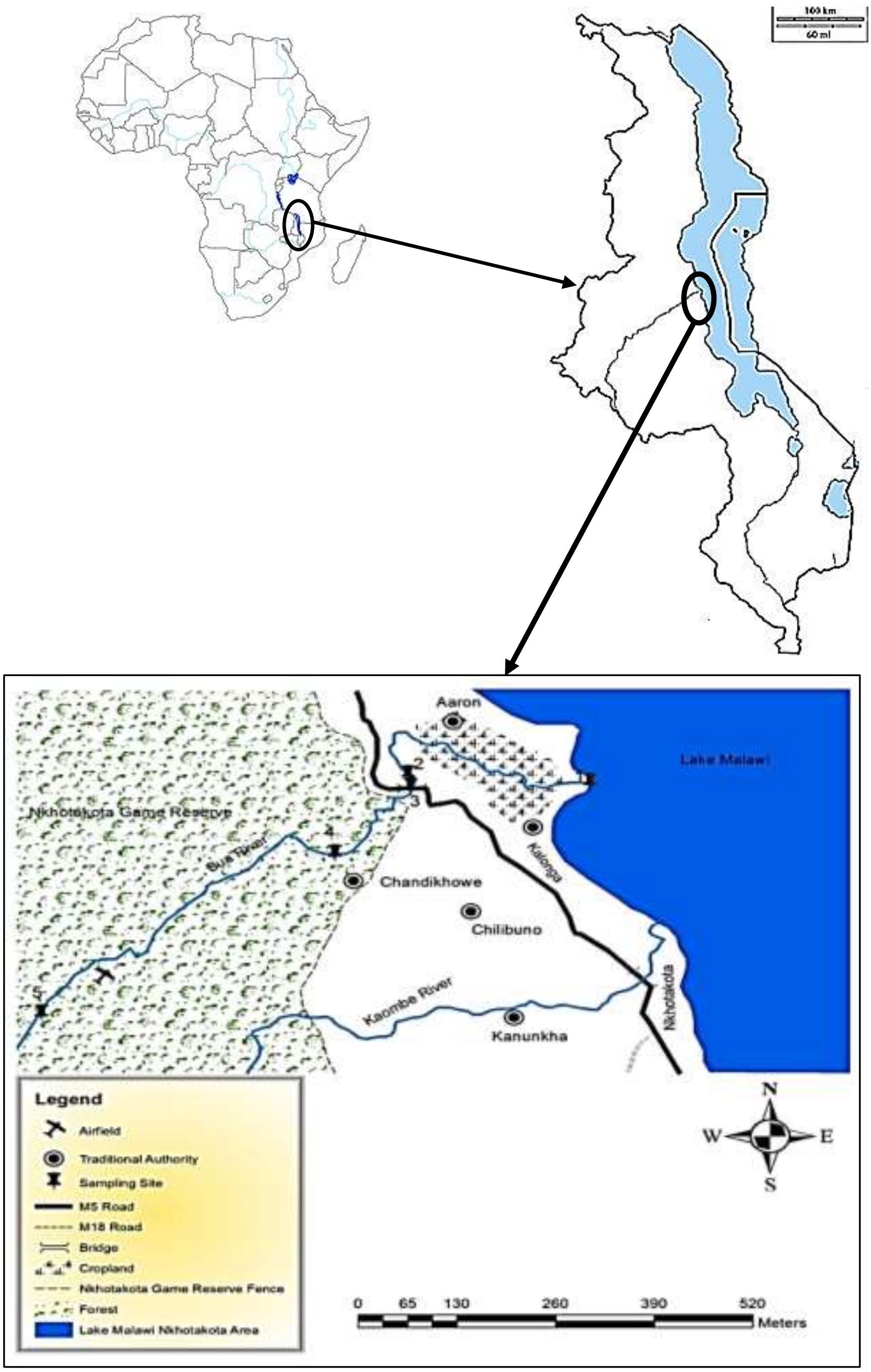

Figure 1. The Bua River, Malawi showing five sampling sites

Table 1. Description and coordinates of five sampling sites along the Bua River, Malawi from May 2018 to June 2020

ID	Site Name	Description	GPS Coordinates
1	Bua Mouth	10m upstream of confluence with Lake Malawi/Nyasa	-12°47`19.59``S 34°16`30.92``E
2	Bua Weir	Irrigation intake	-12°47`05.75``S 34°11`41.81``E
3	Bua Bridge	At road crossing (M5)	-12°47`15.86``S 34°11`46.72``E
4	Nandinga Pool	Inside the Nkhotakota Wildlife Reserve	-12°49`54.57``S 34°09`32.23``E
5	Tongole Pool	Upstream of Nandinga pool, but inside Nkhotakota Wildlife Reserve	-12°54`42.47``S 34°02`56.53``E

Water Sampling and Analysis

The water samples were collected from five sampling sites across three seasons (warm wet, cool dry and hot dry). The sample collection was done monthly and targeted the first week of each month between May 2018 to June 2020, except for July 2018 and May 2020. The sample sites start where the Bua River meets Lake Malawi/Nyasa and move upstream pass a diversion dam into the Nkhotakota Wildlife Reserve. The grab samples were taken from 20 cm below the surface with 1L polyethylene bottles. The samples were stored on wet ice in a cooler before analyses for chlorophyll-a and phosphorus within 24 hours.

Water temperature (oC), pH, electrical conductivity (µS/cm), total dissolved salts (mg/L), and salinity (psu) were measured by using a multiparameter water quality monitoring instrument *in situ* (Orion ThermoScientific, 8107UWMMD/013005MD). Calibration of sensors was performed before every survey. Water transparency was also determined *in situ* using a secchi disk that is 30 cm in diameter. It was measured alkalinity and bicarbonates with acidimetric titration using the Gran function plot method (Wetzel and Likens 2000).

The water samples were stored in a freezer before analysing for SRP. After thawing, 1 L water sample was filtered immediately through 47 mm diameter GF/F Whatman filter paper. Following the protocol from Stainton et al. (1977) and Wetzel and Likens (2000), the soluble reactive phosphorus was measured. Then, the filters were wrapped in aluminium foil and kept them frozen for subsequent chlorophyll analysis. Chlorophyll-a were extracted in 90 % acetone for 24 hours and fluorescence readings were made using a Turner 10-000 R fluorometer after the addition of 2 drops of 2 M HCl.

All water quality parameters were evaluated across seasons and sites using both Spearman's Rank Correlation and Kruskal-Wallis and Mann-Whitney's tests. Spearman's rank correlation coefficient allowed us to measure the correlation coefficient between all parameters because it is a non-parametric measure of association between the variables of non-normally distributed datasets. Kruskal-Wallis and Mann-Whitney non-parametric tests were performed to analyse the significant spatial and temporal differences for each parameter in this study ($\alpha = 0.05$). IBM SPSS Statistics 20.0 were used to analyse the data.

Results

Correlation of Water Quality Parameters

In the Bua River, Chlorophyll-a had strong positive significant correlation with EC ($r= 0.550$, $p= 0.000$), salinity ($r= 0.549$, $p= 0.000$) and TDS ($r= 0.564$, $p= 0.000$) suggesting that with increase or decrease in the concentration of Chlorophyll-a that electrical conductivity, salinity and total dissolved salts would also increase or decrease. Similarly, water clarity correlated positively with EC ($r= 0.573$, $p= 0.000$), salinity ($r= 0.569$, $p= 0.000$), TDS ($r= 0.560$, $p= 0.000$), bicarbonate ($r= 0.619$, $p= 0.000$), alkalinity ($r= 0.562$, $p= 0.000$) and showed a negative correlation with SRP ($r= -0.631$, $p= 0.000$; Table 2) suggesting that water clarity (secchi depth) increased with decreasing soluble reactive phosphorus concentration.

All measurements of salt content correlated positively with each other and negatively with SRP, EC, and salinity (Table 2; $r= 0.976$, $p= 0.000$), EC and TDS ($r= 0.958$, $p= 0.000$), EC and bicarbonate ($r= 0.691$, $p= 0.000$), EC and Alkalinity ($r= 0.678$, $p= 0.000$), salinity and TDS ($r= 0.952$, $p= 0.000$), salinity and bicarbonate ($r= 0.550$, $p= 0.000$), salinity and alkalinity ($r= 0.537$, $p= 0.000$), TDS and bicarbonate ($r= 0.525$, $p= 0.000$), TDS and alkalinity ($r= 0.516$, $p= 0.000$), bicarbonate and alkalinity ($r= 0.974$, $p= 0.000$; Table 2). SRP correlated negatively with EC ($r= -0.795$, $p= 0.000$), salinity ($r= -0.773$, $p= 0.000$), TDS ($r= -0.783$, $p= 0.000$), bicarbonate ($r= -0.626$, $p= 0.000$) and alkalinity ($r= -0.463$, $p= 0.010$).

Table 2. Correlation of water quality parameters for all the five sites in the Bua River, Malawi from May 2018 to June 2020

	SD(m)	Chl-a	WT	pH	EC	Salinity	TDS	SRP	Bicarb	Alka
Secchi Depth(m)	1									
Chlorophyll 'a'	0.237*	1								
Water Temp	-0.243**	0.276**	1							
Water pH	0.242**	-0.075	-0.336**	1						
EC	0.573**	0.550**	0.234*	-0.061	1					
Salinity (psu)	0.569**	0.549**	0.267**	-0.074	0.976**	1				
TDS(mg/L)	0.560**	0.564**	0.203*	-0.017	0.958**	0.952**	1			
SRP	-0.631**	-0.355	0.205	0.094	-0.795**	-0.773**	-0.783**	1		
Bicarbonate	0.619**	0.341*	-0.094	0.130	0.691**	0.550**	0.525**	-0.626**	1	
Alkalinity(mg/L)	0.562**	0.355*	0.027	0.172	0.678**	0.537**	0.516**	-0.463*	0.974**	1

**. Correlation is significant at the 0.05 level (2-tailed).*

***. Correlation is significant at the 0.01 level (2-tailed).*

Chlorophyll-a varied temporally in the Bua River with the highest mean monthly concentration recorded in December followed by November and the lowest mean monthly concentration was recorded in March. The long-term variation of chlorophyll-a varies throughout the year with the warm wet season registering both the highest and lowest values (Figure 2). The highest phytoplankton biomass of 14.32 µgL-1 was recorded at Bua mouth in November of 2018 and the lowest phytoplankton biomass was recorded at Bua mouth in January of 2020. Kruskal Wallis test revealed significant differences ($p<0.01$) across the categories of sampling months with an overall mean chlorophyll-a concentration of 2.45 µgL-1.

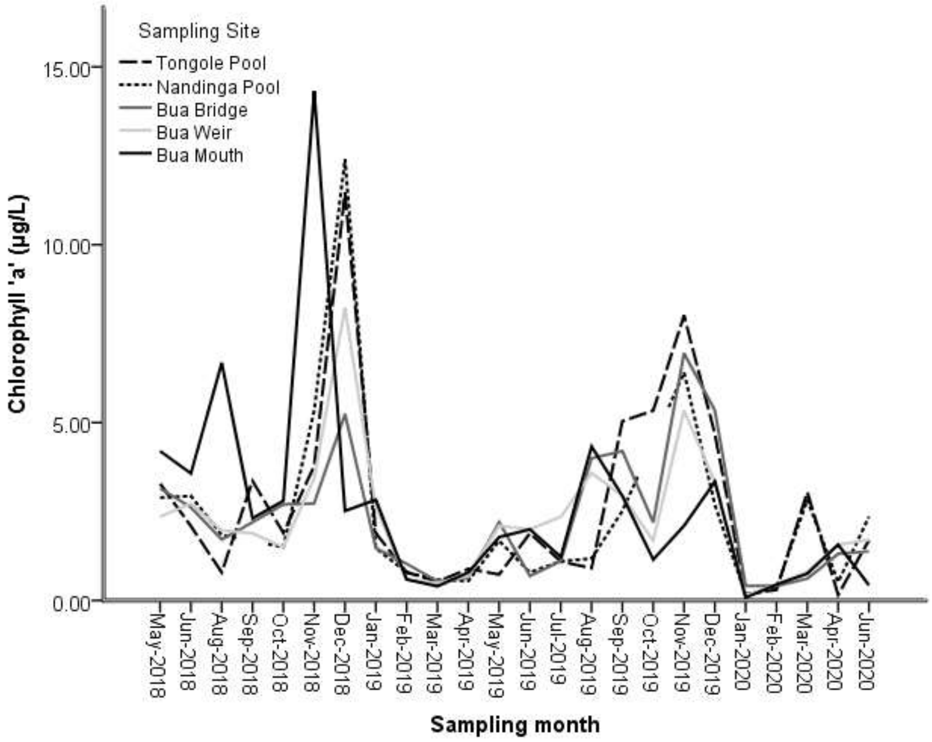

Figure 2. Monthly Chlorophyll-a (µg/L) variations by station, (May, 2018 to June, 2020)

Phytoplankton biomass estimated as Chlorophyll-a ranged from 0.08 µgL-1 to 14.32 µgL-1, with higher mean values ($p<0.05$) during the hot dry season (3.28 µgL-1) as compared with cool dry season (2.10 µgL-1) and wet season (1.91 µgL-1). The Mann-Whitney post hoc test revealed significant differences ($p<0.05$) between cool dry season and hot dry season and also between hot dry season and warm wet season (Figure 3).

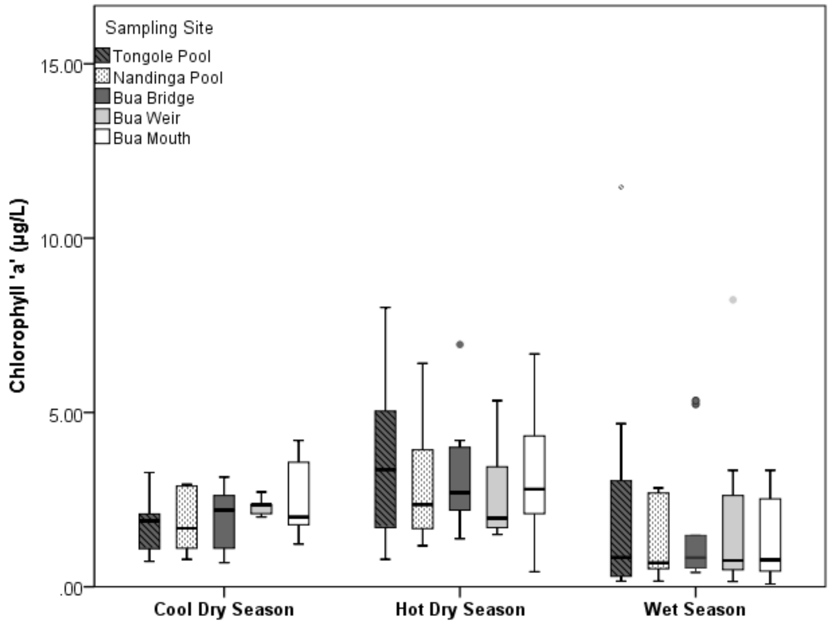

Figure 3. Seasonal Chlorophyll a variation in Bua River, Malawi by site

Mean monthly secchi depth measurements varied monthly ($p=0.000<0.05$). It decreased appreciably from September to March, and the followed an increasing trend from April to August revealing the significant aspect of seasonality (Figure 4, Figure 5).

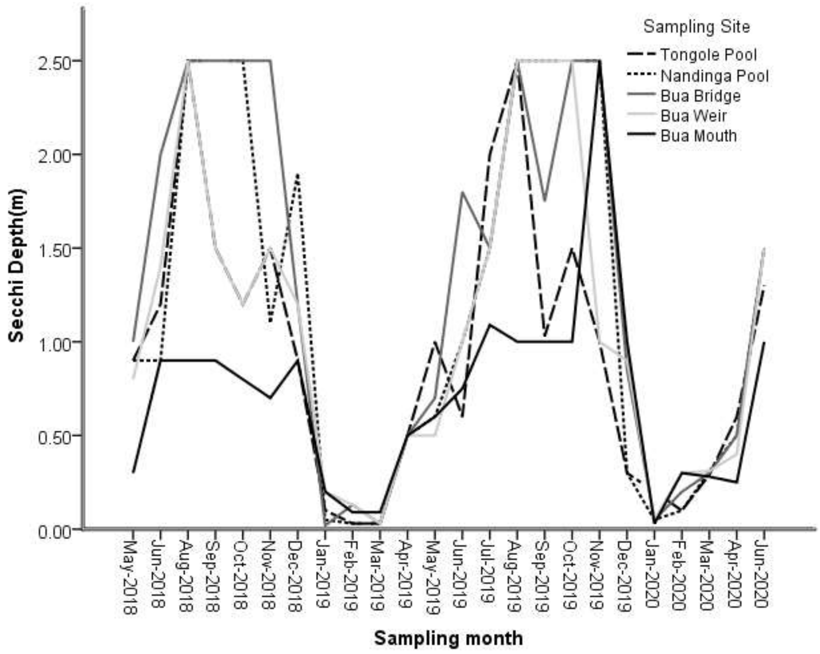

Figure 4. Monthly Secchi depth variations by site in the Bua River, Malawi from May, 2018 to June, 2020

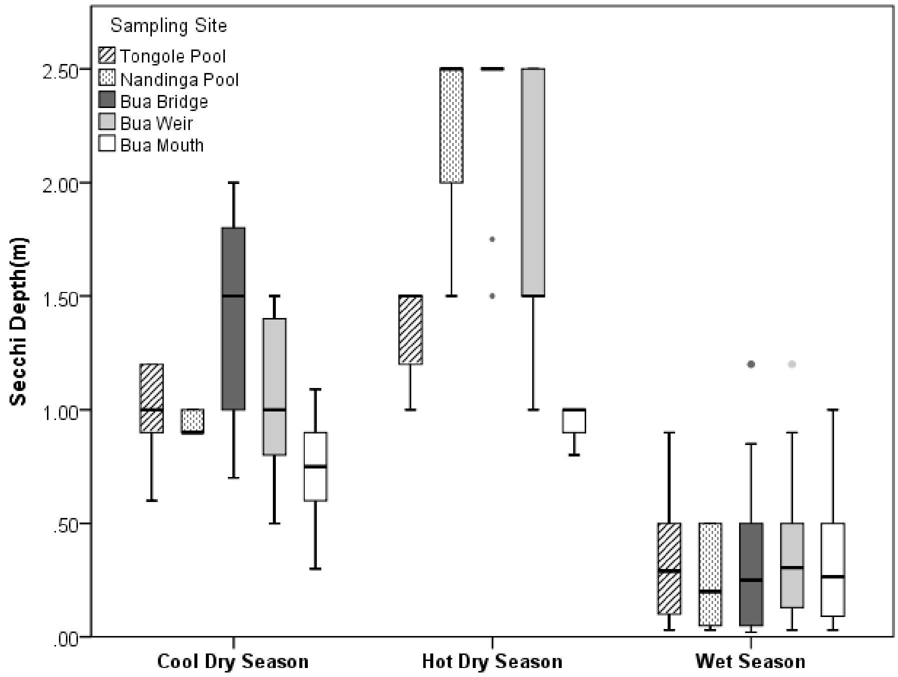

Figure 5. Seasonal Secchi depth (m) variations in the Bua River, Malawi from May, 2018 to June, 2020 by site

Water temperature varied monthly and responded to seasonal changes as expected. The highest monthly water temperature of 34ºC was recorded at Bua Weir and Bua Bridge in December 2018 and also at Bua Nandinga pool in March 2019. In contrast, the lowest monthly water temperature of 19.70ºC was recorded at Nandinga pool in June 2020. Generally, the long-term variation of temperature varied consistently with regards to seasonal changes, with the lower values being recorded in the cooler months and vice versa (Figure 6). Kruskal Wallis test revealed significant differences ($p<0.01$) across the categories of sampling months with an overall mean water temperature of 26.35ºC.

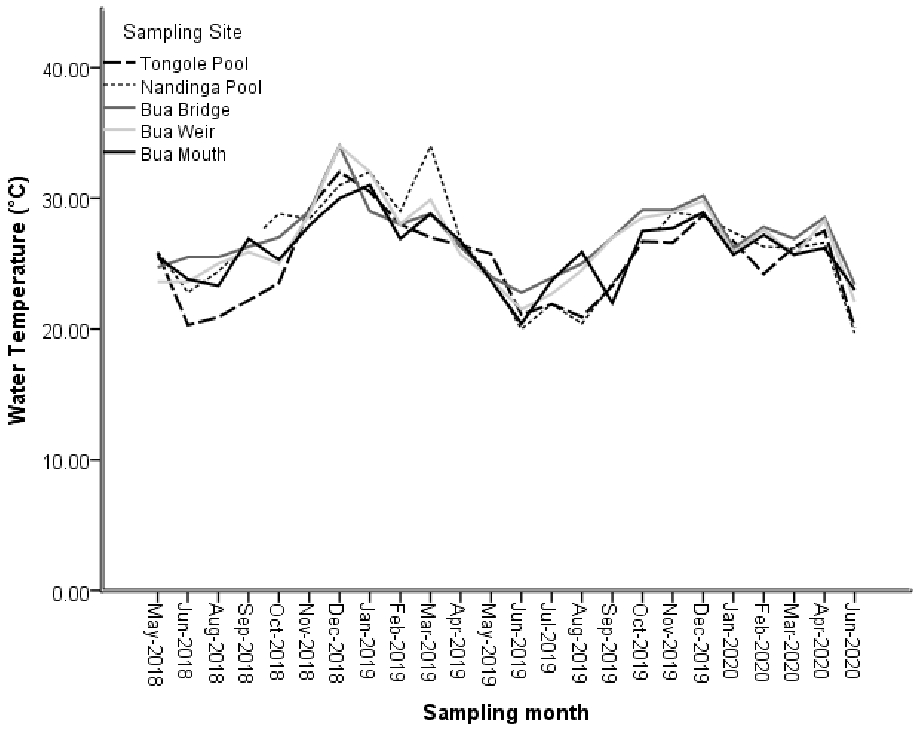

Figure 6. Monthly Temperature (ºC) variations by site in the Bua River, Malawi from May, 2018 to June, 2020

Water temperature varied significantly across the seasons ($p<0.05$) with higher mean temperature observed during the wet season (28.30ºC) followed by hot dry season (25.44ºC) and lastly cool dry season (23.31ºC). Spatially, during the cool dry season Bua Bridge registered the highest mean water temperature of 24.18ºC and Nandinga pool registered the lowest mean water temperature of 22.92ºC while during the hot dry season, Bua Bridge registered the highest mean water temperature of 26.82ºC and Tongole pool registered the lowest mean water temperature of 23.71ºC. On the other hand, during the wet season Nandinga pool registered the highest mean water temperature of 28.79ºC and Bua mouth registered the lowest mean water temperature of 27.71ºC (Figure 7). Overall, a well-defined spatial variation was observed with Bua Bridge registering the highest mean water temperature of 27ºC and Tongole pool registering the lowest mean water temperature of 25.25ºC.

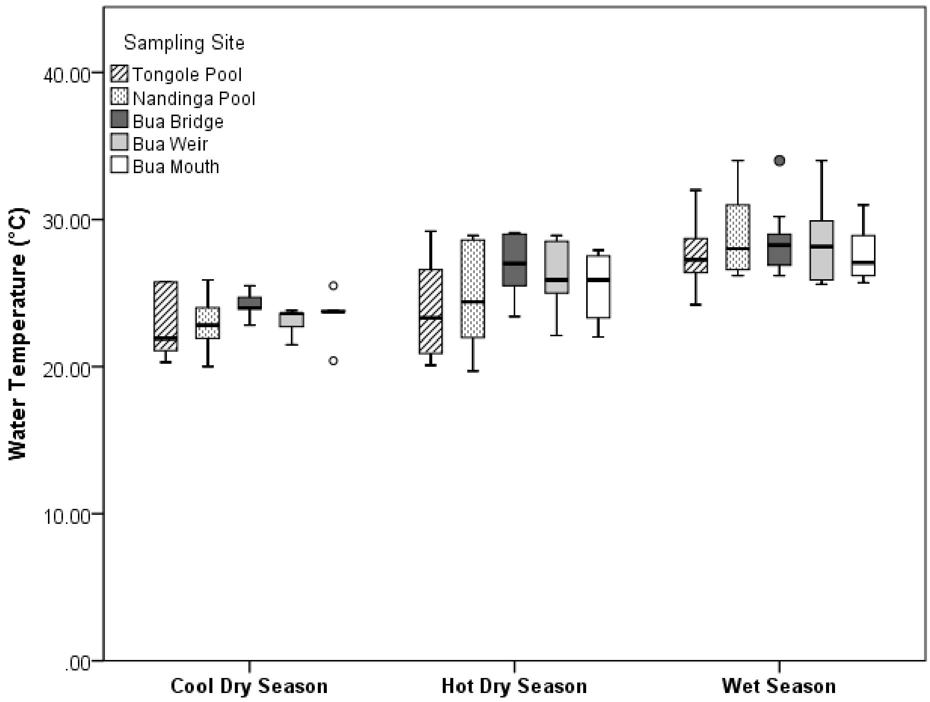

Figure 7. Seasonal water temperature variations in Bua River, Malawi from May, 2018 to June, 2020

Soluble reactive phosphorus (SRP) greatly varied throughout the study period with a minimum concentration of 0.98 µg/L (Bua weir, December 2018) and a maximum concentration of 30.2 µg/L, (Nandinga pool, January 2019; Table 3; Figure 8). The highest mean monthly phosphorus concentration of 22.49µg/L was recorded in the month of January whereas the lowest mean monthly phosphorus concentration of 2.25 µg/L was recorded in the month of October (Figure 8). Kruska-Wallis test revealed significant differences ($p<0.05$) across the categories of sampling months with an overall mean phosphorus concentration of 9.37 µg/L (Table 3).

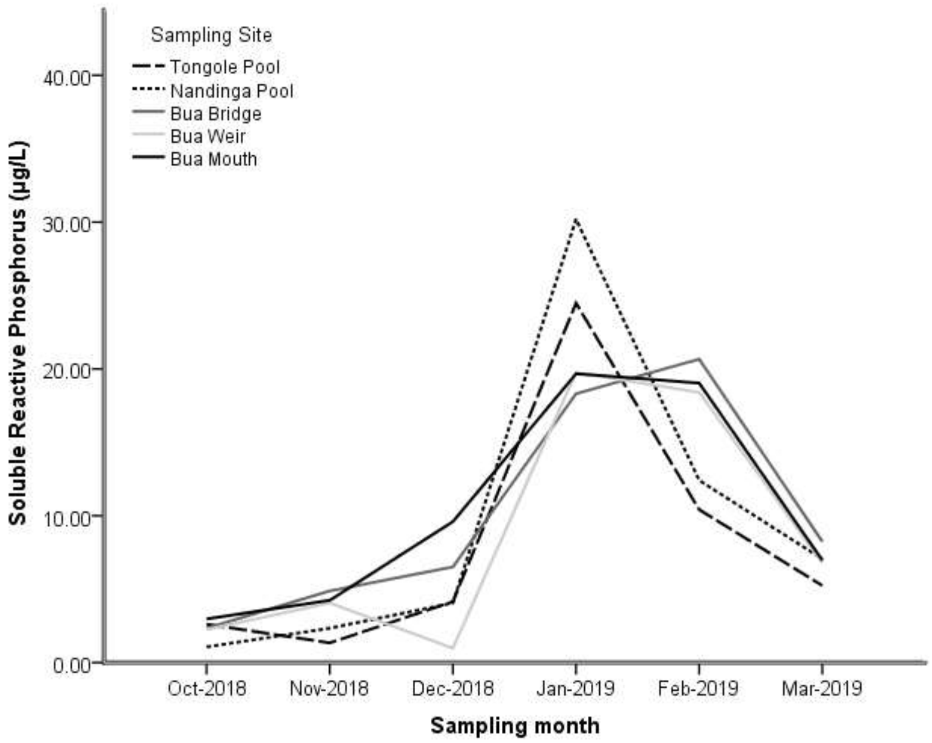

Figure 8. Monthly Soluble Reactive phosphorus (μgL^{-1}) measurements in across sites in the Bua River, Malawi

Table 3. Descriptive statistics for various water quality parameters across five sites in the Bua River, Malawi from May 2018 to June 2020

Parameter	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
Secchi Depth (m)	2.48	0.02	2.50	1.03	0.82	0.67
Chlorophyll a (µg/L)	14.24	0.08	14.32	2.45	2.39	5.73
Temperature (°C)	14.30	19.70	34.00	26.20	3.12	9.71
Water pH	3.76	6.22	9.30	7.95	0.67	0.45
EC (µScm^{-1})	304.78	78.82	383.60	242.19	73.27	5369.21
Salinity (psu)	0.18	0.06	0.24	0.17	0.04	0.00
TDS (mg/L)	126.00	51.90	177.90	118.64	31.74	1007.21
Alkalinity (mg/L)	144.60	56.70	201.30	129.44	44.21	1954.56
SRP (µg/L)	29.22	0.98	30.20	9.37	8.06	64.96
Bicarbonate (mg/L)	184.10	58.50	242.60	151.14	53.95	2910.43

The distribution of soluble reactive phosphorus was not uniform across temporal categories with a significant difference ($p < 0.01$) between the wet season and hot dry season. The wet season had recorded higher SRP mean values (12.65 µg/L) compared with the hot dry season which had the lowest (2.81 µg/L). Spatially, Bua Bridge and Bua mouth registered and recorded the highest mean soluble reactive phosphorus concentration of 3.61 µg/L and Nandinga pool registered the lowest mean soluble reactive phosphorus concentration of 1.70 µg/L during the hot dry season, while, Bua mouth registered the highest mean soluble reactive phosphorus concentration of 13.82 µg/L and Tongole pool registered the lowest mean soluble reactive phosphorus concentration of 11.07 µg/L during the wet season (Figure 9).

Spatially, the overall distribution of soluble reactive phosphorus was not uniform across the sampling stations. Bua mouth recorded the highest mean soluble reactive phosphorus of 10.41 µg/L and Tongole pool recorded the lowest mean soluble reactive phosphorus concentration of 8.04 µg/L

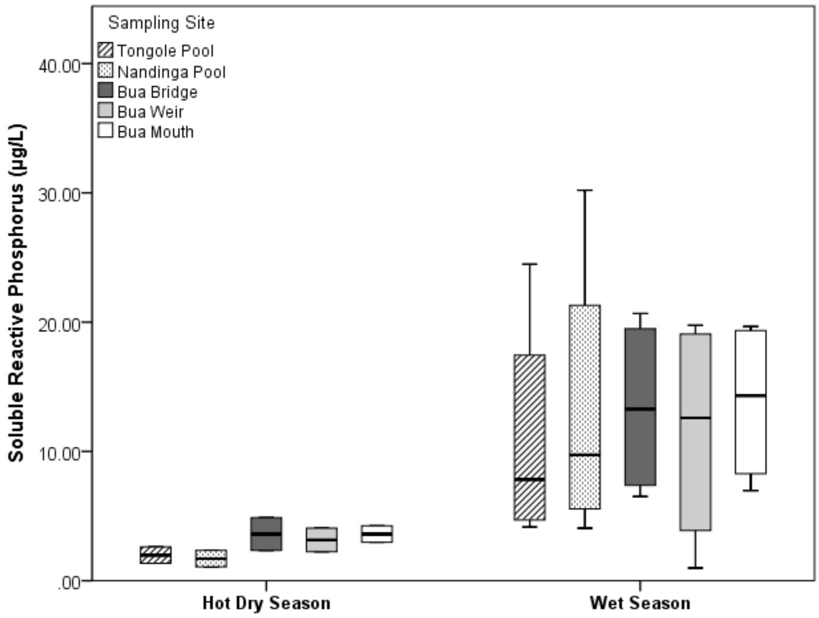

Figure 9. Seasonal Soluble Reactive Phosphorus variations (µgL^{-1}) in Bua River, Malawi across sites from May, 2018 to June, 2020

The highest monthly surface water pH value of 9.3 was recorded at Bua Bridge in July 2019 whereas the lowest monthly pH value of 6.22 was recorded at Tongole pool in March 2019 (Figure 10). The months of January, February and March of 2019 were associated with low mean water pH values of 7.29, 7.22 and 6.83 respectively. The highest mean monthly water pH value of 8.55 was recorded in July and the lowest mean monthly pH value of 7.46 was recorded in March. Kruskal-Wallis test revealed significant differences ($p< 0.05$) across months with an overall mean water pH value of 7.95 (Table 3). The cool dry season (mean pH= 8.32) was associated with consistently higher mean values above 8.00 than the other seasons (Figure 11). Significant differences in mean values were found across the seasons ($p < 0.05$) with higher mean value recorded during the cool dry season (8.32), followed by the hot dry season (7.92) and lower mean value recorded during the wet season (7.78). Mann-Whitney test showed that no significant differences ($p = 0.06>0.05$) existed between hot dry season and warm wet season.

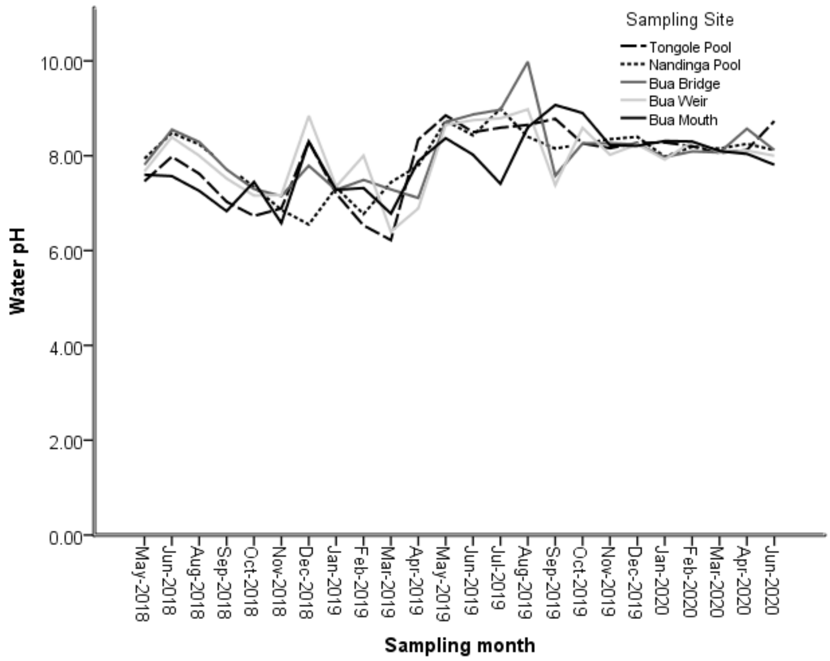

Figure 10. Monthly pH variations in the Bua River, Malawi from May, 2018 to June, 2020

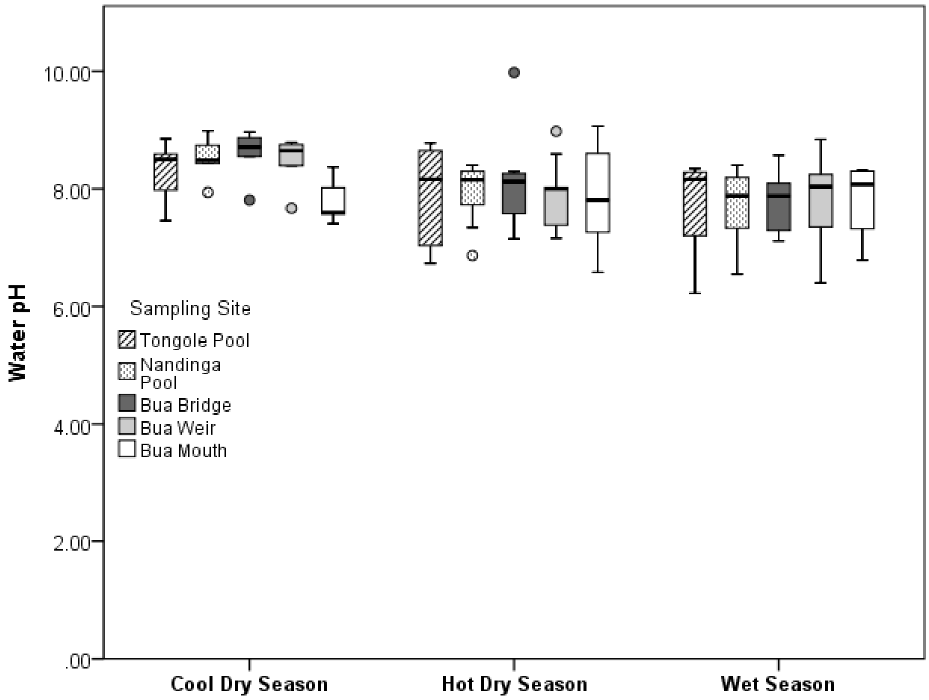

Figure 11. Seasonal pH variations in the Bua River, Malawi across sites from May, 2018 to June, 2020

Most pH values were well above 7.00, indicating that the River is relatively alkaline in nature. Throughout the study period, it was noted that acid buffering capacity for Bua River alternated between 56.70 mg/L and 201.30 mg/L, with the highest mean monthly alkalinity (192.96 mg/L) recorded in November 2018 and lowest mean monthly alkalinity (86.74 mg/L) recorded in March 2019. Significant differences ($p<0.05$), were found between seasons with higher mean values during the hot dry season (161.32 mg/L) and cool dry season (130.96 mg/L) with the lowest mean value of 115.99 mg/L observed during the warm wet season. Spatially, acid buffering capacity alternated between 124.30 mg/L and 135.14 mg/L across the sampling stations, with the highest mean alkalinity recorded at Bua Mouth and lowest mean alkalinity at Nandinga Pool.

Bicarbonate measurements ranged from a minimum of 58.50 mg/L to a maximum of 242.60 mg/L with an overall mean of 151.14 mg/L (Table 3). Bicarbonate had the highest mean values during the hot dry season (195.63 mg/L) followed by cool dry season (155.95 mg/L) and then the warm wet season (127.18 mg/L). The distribution of Bicarbonate was not uniform across sampling stations, with the highest mean value (157.40 mg/L) recorded at Bua Mouth and lowest mean Salinity measurements ranged from a minimum of 0.06 psu to a maximum of 0.24psu with an overall mean value of 0.17 psu (Table 3). The maximum salinity measurement was recorded at Bua Bridge in the month of October 2019 and the minimum salinity measurement was recorded at Bua mouth in the month of February 2019 (Figure 12). The highest mean monthly salinity measurement of 0.23 psu was registered in November whereas the lowest mean monthly salinity measurement of 0.13 psu was registered in April (Figure 12). Kruska-Wallis test revealed significant differences ($p<0.05$) across the categories of sampling months with an overall mean salinity measurement of 0.17 psu (Table 3). value (145.49 mg/L).

Salinity measurements were consistently higher during the hot dry season (median=0.1940 psu) than the other seasons. Both Levene's test for equality of variance and Kruskal-Wallis non-parametric test indicated significant differences ($p<0.05$) among seasons with higher mean value during the hot dry season (0.2 psu) followed by the cool dry season (0.16) and the warm wet season (0.15 psu). On spatial scale, all stations recorded an average salinity value of 0.17 psu and no significant differences were found across the sampled stations. (Figure 13).

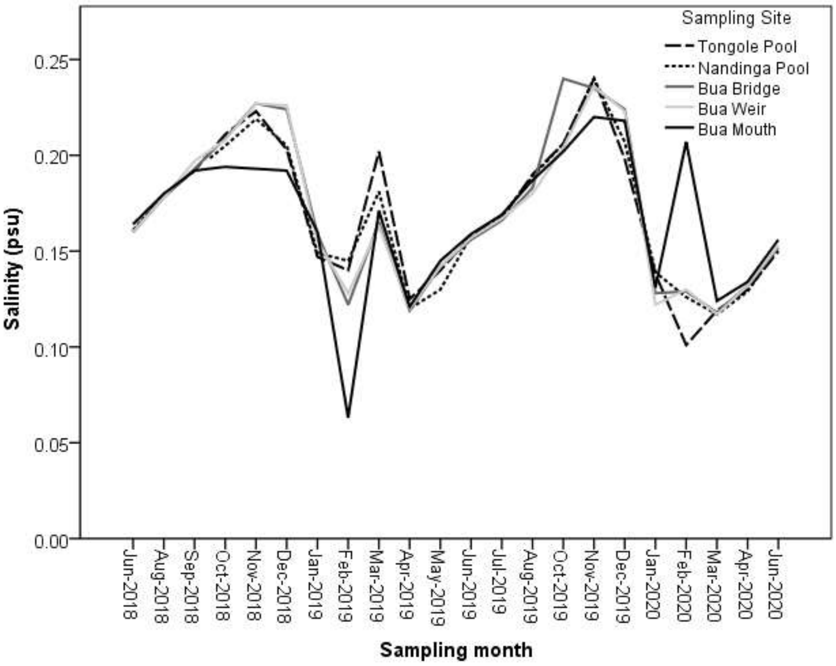

Figure 12. Monthly salinity (psu) variations in the Bua River, Malawi across sites from May, 2018 to June, 2020

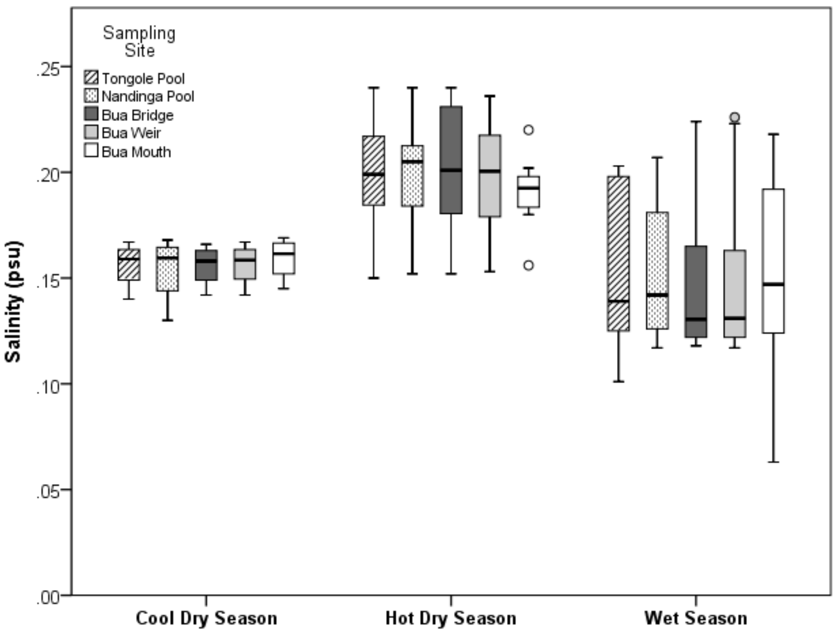

Figure 13. Seasonal salinity variations in Bua River, Malawi from May, 2018 to June, 2020

Electrical conductivity ranged from a minimum value of 78.82 μScm^{-}1 to a maximum value of 383.6 μScm^{-}1 with an overall mean of 242.19 μScm-1 (Table 3). Spatially, electrical conductivity did not differ between sampling stations (p>0.05) with average range between 232.96 μScm^{-}1 recorded at Nandinga pool and 247.20 μScm-1 recorded at Bua mouth. Significant differences (p<0.05) were found between cool and hot seasons, wet and hot season and no significant differences (p>0.05) were observed between cool dry season and wet season, with higher mean values in hot dry season (300.23 μScm^{-}1) and cool dry season (212.92 μScm^{-}1) and lower mean value in wet season (206.90 μScm^{-}1). The highest mean monthly conductivity of 364.44 μScm^{-}1 was recorded in November and the lowest mean monthly conductivity of 153.25 μScm^{-}1 was recorded in April.

Mean Total dissolved salts were higher during the hot dry season (140.58 mg/L) followed by the cool dry season (110.63 mg/L) and the warm wet season registered 102.53 mg/L. Significant differences ($p<0.05$) were observed between cool dry season and hot dry season, warm wet season and hot dry season and no significant difference ($p>0.05$) between cool dry season and warm wet season. The highest mean monthly TDS of 160.51 mg/L was recorded in December and the lowest mean monthly TDS of 74.66 mg/L was recorded in April.

Principle Component Analysis

Based on Principal Component Analysis (PCA), 78.49 % of the total variance in the data set could be explained from two main components. Component 1 explains 63.38 % and is attributed to EC, Temperature, Secchi depth, Chlorophyll a, Salinity, TDS, Alkalinity and Bicarbonate. Component 2 explains 15.11 % and is attributed to pH and SRP (Table 4). Factors in component 1 are associated with high eigenvalue (6.34) and loading values as compared to factors in component 2 which has eigenvalue of 1.51 and lower loading values. SRP had a negative loading factor with factor 1 and its negative relationship with salinity, electrical conductivity, TDS, alkalinity, and transparency (Figure 14, Figure 15).

Table 4. Factor loading matrix and variance explained

Variable	Component/Factor	
	1	2
Secchi Depth	**0.861**	0.097
Chlorophyll 'a'	**0.794**	0.094
Water Temperature	**0.681**	0.154
Water pH	0.495	**0.697**
Electrical Conductivity	**0.926**	-0.318
Salinity	**0.871**	-0.354
TDS	**0.933**	-0.301
Alkalinity	**0.809**	0.474
SRP	**-0.648**	**0.582**
Bicarbonate	**0.835**	0.322
Eigenvalue	*6.340*	*1.580*
% Total variance	*63.380*	*15.100*
Cumulative %	*63.380*	*78.490*

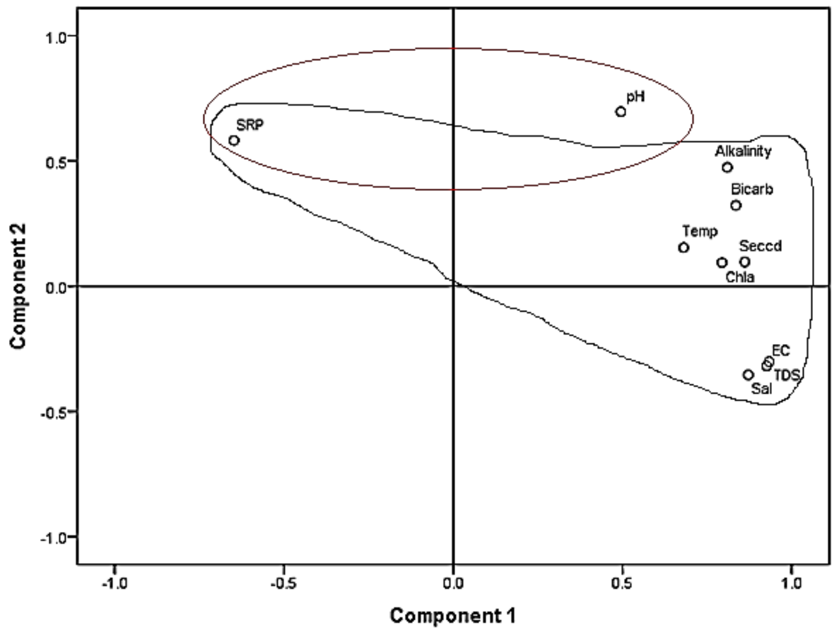

Figure 14. The loading plot of factors for component 1 and component 2

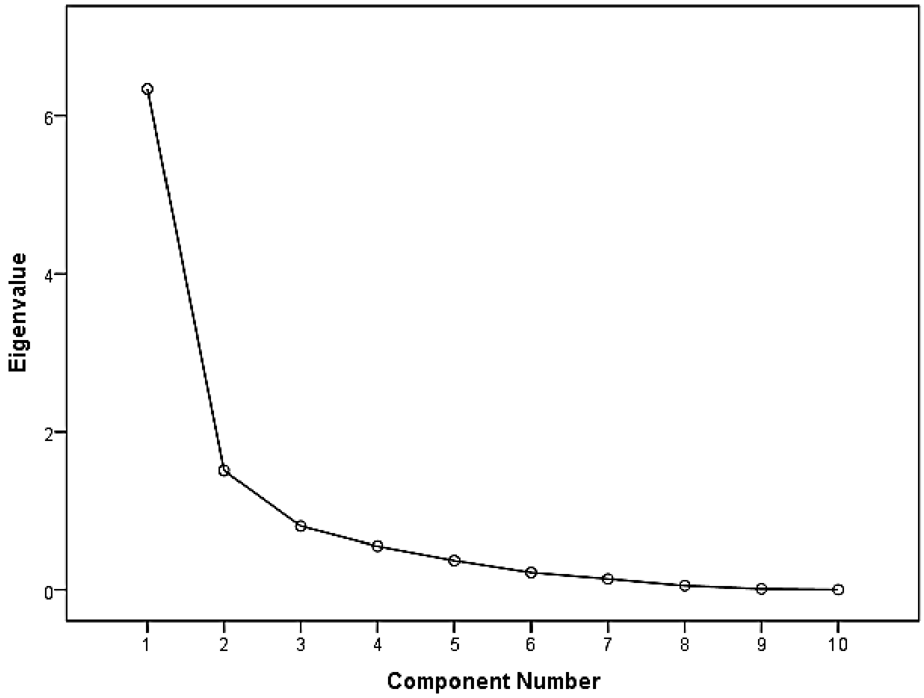

Figure 15. Scree plot of Eigenvalue against components

Discussion

The absence of significant spatial variation in all the parameters assessed, except SRP, is an indication that the water quality conditions are somehow similar along the different sections of the Bua River. However, most of the water quality parameters varied temporally.

The recorded low mean secchi depth value indicated that the mainstream Bua River is associated with high turbidity especially during the warm wet season probably due to high silt loading during rain events and to a lesser extent from the phytoplankton biomass, indicating that the suspended particulate matter contributed more to decreasing water transparency (Figure 5; Panigrahi et al. 2007). Rainfall increased flow and water turbidity due to silt and suspended particulate matter. High turbidity in water prevents light from reaching phytoplankton thereby reducing their capacity for photosynthesis resulting in reduced growth and also increased flow reducing the residence time of phytoplankton in the water column, as such less time is available for nutrient uptake. The limited phytoplankton growth observed in the wet season (Figures 2 and Figure 3) is more likely to have occurred in the Bua River because of lack of light from low water transparency or short residence times that do not allow phytoplankton to reach the maximum concentration permitted by the available nutrients (Araújo et al. 2011). Since the primary producers form the base of the food chain, any deleterious impacts will probably also be manifested in the invertebrate and fish communities (Wood and Armitage 1997).

On the other hand, the hot dry season was associated with high mean secchi depth and high mean phytoplankton biomass. This was mainly attributed to decreased water level and settling of suspended particulate matter which allowed maximum light penetration for photosynthesis and also decreased water flow allowing more nutrient uptake for phytoplankton growth. As an important index representing the phytoplankton biomass, chlorophyll-a did not exhibit a significant correlation with soluble reactive phosphorous indicating that phytoplankton were generally affected by other limiting environmental factors rather than soluble reactive phosphorus, which calls for further study.

Variations in the concentration of soluble reactive phosphorus were highly tied to seasonal changes with higher mean concentration in the wet season than the hot dry season, with Nandinga pool reaching as high as 30 μgL^{-1}. The high recorded level of soluble reactive phosphorus suggests being from fertilizer inputs from agricultural fields as runoff along the Bua River during periods of high rainfall. Ravindra and Kaushik (2003), indicated that the increased concentrations of phosphorus in the River water might be due to agricultural runoff containing phosphate fertilizers and detergents, which has the potential for pollution of the surface water and cause eutrophication. As noted during field observation visits, Bua River is associated with periods of low flow during the hot dry season where the velocity decreases creating conditions for sedimentation. Thus under oxic conditions, orthophosphate may combine with particles such as iron, aluminium and calcium forming stable products that can accumulate in the bed sediments (Addiscott et al. 2000) and be released into the River system when the sediment gets disturbed by factors such as rainfall (Webster et al. 2001). Phosphorus is essential for primary production i.e the growth of algae and other aquatic plants, but excess phosphorus may lead to eutrophication. In the present study soluble reactive phosphorus concentration changed by over 70 % from that of the oligotrophic nature observed in hot dry season, and since this change is much greater than 15 % prescribed by South African Water Quality Guidelines (DWAF 1996) it shows that the River is greatly impacted by phosphorus. The presence of relatively high amounts of soluble reactive phosphorus pollution indicates the impact of agricultural diffuse water and domestic discharges (Wu 2005).

Bua River ecosystem, as a running water system exhibit daily and seasonal temperature patterns which might expose aquatic organisms to potentially lethal or sub-lethal conditions. Anthropogenic causes of temperature changes in River systems include those resulting from stream regulation and changes in riparian vegetation (Wellborn and Robinson 1996; Ward and Stanford 1982; Quinn et al. 1997). Duffus (1980) postulate that an increase in water temperature decreases oxygen solubility and might also increase the toxicity of certain chemicals, both which result in increased stress in the associated organisms. It must be pointed out here that many life cycles of aquatic organisms such as migration, breeding and emergence are cued into temperature. As such, false temperature cues caused by modified temperature regimes may affect the timing of life history and thus interfering with normal development (Dallas and Day 2004). Fish, insects, phytoplankton, zooplankton and other aquatic species all have chosen temperature ranges such that deviations from the optimum range affect aquatic life as it determines which organisms will thrive and which will diminish in numbers and size. As observed by Jain et al. (2013), sudden changes in water temperature are believed to be deleterious to fish with abrupt changes of ±5ºC or greater likely to be harmful. Nevertheless, the observed temperature in Bua River still falls within the optimum range (18ºC to 33ºC) for the survival of tropical fish (Bone and Moore 2008) and the mean monthly temperature change of 1.74ºC is less than 5ºC.

It must be emphasized here that during the entire period of study water pH values were well within the optimum range for the survival of aquatic life (WHO 2006; UNECE-ECS 1992; DWAF 1996). The observed fluctuations in River pH can be caused by external factors such as agricultural runoff, acidic mine drainage (AWD), and fossil fuel emissions such as carbon dioxide, which creates a weak acid when dissolved in River water. Internally, the water pH is influenced by the metabolism of aquatic organisms and may oscillate due to metabolic processes associated with photosynthetic activity that capture CO_2 from the water (Araújo et al. 2011). The substantial low mean alkalinity and Bicarbonate observed during the wet season in the River system was mainly attributed to the influx of acid-forming sulphates from fertilizers. But the fact that seasonal variation was less than 1pH unit value and the minimum alkalinity ranged from 56.70 mg/L to 201.30 mg/L suggests that the River has relatively strong buffering capacity. In poorly buffered waters, pH can change rapidly, which in turn may have severe effects on the aquatic biota (DWAF 1996) thereby predisposing fish and other organisms to opportunistic infections such as Epizootic ulcerative syndrome (EUS). According to Wood and Rogano (1986), the direct effect of a change in pH is an alteration in the water, ionic and osmotic balance of individual whole organisms. This can, in turn, have sub-lethal effects such as slow growth and reduced fecundity (Berrill et al. 1991).

The correlation matrices showed that EC had strong positive significant correlations ($p<0.01$) with salinity ($r = 0.976$), TDS ($r = 0.879$), Bicarbonate ($r = 0.691$) and Alkalinity ($r = 0.678$). And on the other hand all the measurements of dissolved salt content had strong negative significant relationship ($p<0.01$) with SRP. These associations indicate that the parameters are affected by same factors such as low water levels in hot dry season and the dilution/ amplification of the water by rainfall in wet season. Similar observations were made by Marthe et al. (2015) who noted that nutrients have strong negative correlations with measured physicochemical parameters which indicate that these nutrients are usually brought to the water during rain events.

Factor analysis of the data sets outputs two factors with a total variance of 78.49 %. Factor one is the most important with strong significant loading of alkalinity, electrical conductivity, bicarbonate, total dissolved salts, secchi depth, temperature and salinity. Within the first factor, observed demarcations are that alkalinity, EC and bicarbonates indicate dissolution from natural formations, soluble reactive phosphorus indicates inputs from agricultural runoff whereas TDS, transparency and salinity explains pollution through runoff from catchment area. And lastly in the same category, temperature indicates seasonal influence in water quality. On the other hand, factor two which comprises of pH and soluble reactive phosphorus are attributed to anthropogenic activities and domestic wastes. Moreover, as Al-Badaii et al. (2013) observes, pollution can be accompanied with cultivation of the surrounding regions where phosphate, nitrogen and sulphate fertilizers are utilized. This was highly anticipated because the catchment is associated with maize farming, rice farming and extensive sugarcane plantations. To sum up, factors from principle component analysis indicated that the parameters responsible for variations of Bua River water quality are mainly associated with soluble minerals and temperature as natural sources as well as agricultural activities, surface runoff and domestic waste as anthropogenic activities.

Generally, it can be concluded from the study that the Bua River water resource at a large scale is moderately polluted. There are some smaller scale environmental incidents observed along the different sections of the river that have resulted in the deterioration in the physicochemical quality and a general rise in the nutrient level. This is mainly due to anthropogenic activities. The general public, therefore, has to be civic educated and be made aware of the consequences of the pollution. Periodic monitoring and preventative measures need to be emphasised to save the aquatic system from eutrophication. Additional work is also needed to determine the dynamics of the watershed's response to runoffs and land management practices under varying climatic conditions to better understand the complex physical and chemical processes causing the degradation observed in the present study, and also to ascertain the role of River discharge in nutrient dynamics within the River. Furthermore, absence of significant spatial variation in most of the parameters assessed is an indication that the water quality conditions are equally impacted along the different sections of the River. As such management measures must consider the whole stretch of the River from upper (i.e Mchinji area) to lower sections (Bua mouth).

Acknowledgements

Thanks to the Management of African Parks and USDA Forest Service for providing financial support. We are also indebted to the technical team at Senga Bay Fisheries Research Centre for their invaluable service in water sample analysis, especially Joseph Chombo and Victor Nantunga.

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