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The interactive effects of rainfall, temperature and water level on fish yield in Lake Bangweulu fishery, Zambia

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ABSTRACT

Climate variability and climate change have negative impacts on fisheries ecosystems and people who derive livelihoods from them. Zambian climate is projected to increase 2 °C in mean temperature by 2070, and further reports suggest that rainfall will drop by 8–30% of the normal average. This study was undertaken to determine the effects of rainfall, temperature and water level on fish yield. The study used both primary and secondary data sources. The major statistical techniques employed in this research include estimation of mean frequencies and correlation coefficients, as well as multivariate regression analyses, to determine the relationships among climate (temperature, rainfall), water level, and fish yield, using the Statistical Package for Social Sciences. The results showed an increase in temperature of 0.3 °C, a decrease in rainfall of 3% and a water-level loss of 1.7 m since 1974. During the same period, fish yield increased by 53%, compared to increases in fishers and boats of 57% and 55%, respectively. The resultant Catch per Unit of Effort (CpUE) decreased from 12 kg/net/night to 1.5 kg/net/night. Findings indicate that there are significant correlations between temperature, rainfall (one-year lag), water level and fish yield. Based on the results, there is strong recommendation to incorporate climate variability and change in the modelling of fisheries management to reduce the impacts of climate variability and change on fisheries-based livelihoods.

1. Introduction

The onset of climate variability and change has negatively impacted the fisheries ecosystem of Lake Bangweulu (10^0 15′-$12^0$30′ S and $29^0$30’ − $30^0$30′ E) and derived livelihoods (Kolding and van Zwieten, 2012; IPCC, 2007; Pauly and Zeller, 2016). According to the Intergovernmental Panel on Climate Change (IPCC) and United Nations Framework Convention on Climate Change (UNFCCC), global concentrations of greenhouse gases (GHGs) in the atmosphere have been increasing since the industrial revolution as a result of human activities (Harris et al., 2017; Kahsay et al., 2016). Earth's global temperature rose by almost 0.74 °C during the last decade and is expected to rise between 1.1 °C and 1.6 °C by the end of 21st century (IPCC et al., 2014). The Zambian National Adaptation Programme of Action (NAPA) projected increasing mean temperatures for the period 2010–2070 averaging approximately 2 °C and further reports that rainfall will drop by 8–30% of the normal average (MTENR, 2007). Like any other aquatic system, the Lake Bangweulu fishery is a freshwater ecosystem susceptible to the dictates of climate variability and change (Patrick, 2016).

The Lake Bangweulu fishery contributes approximately 15,000 tons of fish annually and is the single most important industry among the local communities (Kolding and van Zwieten, 2012; Musonda and Ngosa, 2011). Lake Bangweulu is shallow and oligotrophic with a seasonally fluctuating fishery whose production is stimulated and enhanced by seasonal nutrient inputs from rivers and marginal flooded areas during the rainy season (Kolding and van Zwieten, 2012; Bos and Ticheler, 1996; Evans, 1978). Lake productivity is modified by the rainfall inflows from the rivers and evapotranspiration, which is being exacerbated by the climate-induced high temperature, but the degree of interaction with other physical variables is not known (Musonda and Ngosa, 2011). The tradeoff between rainfall inflow and water loss from outflows and evapotranspiration is critical for the aquatic ecosystem at different levels of biological organization (Ipinjolu et al., 2014).

The Bangweulu complex is situated in a high rainfall area with an annual precipitation of 1200 mm to 1400 mm per annum and collects water from the 109,469 km^2 catchment area (Thurlow et al., 2009). The highest water level is recorded in April shortly after the rainy season, and the lowest water level is recorded in November/December before

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the rainy season. The mean water level variation between the two peaks (highest and lowest) is 1.39 m (Evans, 1978; Kolding and van Zwieten, 2012). The swamps mitigate flooding by causing a lag in the mean deviation of water levels in the lakes. There is no permanent stratification in the water column, but there is diurnal stratification with a 2–3 °C difference in day water temperature which later breaks in the night. The diurnal stratification and turnover results in the daily mixing of the nutrients in the water column (Ticheler et al., 1998). The dissolved oxygen levels in the lakes have been found to be much lower than in the swamps. The pH of the lake ranges between 7.0 and 9.0, while in the swamps it oscillates around pH 6.4. The early rainfall dilutes moderate dissolved oxygen and acidity levels when stagnant water is flushed out in the open lakes. Despite the effects of early rainfall flushes, lake Bangweulu experiences continuous pH fluctuations due to the poor buffering ability of the lake (Bos and Ticheler, 1996).

Exploitation of lake Bangweulu fisheries resources through multi-gear fishing methods, small canoes, and poor regulation and management exposes the fisheries-based households to impacts of climate variability and change. Exploitation rates and factors leading to declines in fish yield have not been fully understood, due to inherent systematic failure to properly record fisheries statistics (FAO, 2013). As such, factors contributing to the decline in fish yield and consequent management programmes are affected. The existing management approaches have failed to constrain fishing capacity, manage conflict, or reduce fishing pressure and damage to aquatic habitats (FAO, 2013). Most fisheries management approaches and programmes have not kept pace with technology upgrades and driving forces in the fisheries industry. Although poor fisheries management approaches have been primarily attributed to lack of a nationally coordinated consistent fish stock assessment programme, with no reliable fisheries statistics to be used for planning, the lack of an appreciation of the integrated nature of the confounding effects of climate variability and change leads to collapse of multi-species and resilient fisheries (Kolding et al., 2016).

Fisheries ecosystems are heavily affected by unsustainable fishing methods and overfishing. Recently, climate variability and change have been affecting hydrological processes and fish stocks (Ana et al., 2018). Climate variability and change affect fish populations at different life cycles. Successive life history stages (eggs, larvae, juveniles, and adults) have been affected, since fish of various size classes have specific habitat requirements, live in separate habitats, and occupy different trophic levels (Heincke, 2013; Ye Le et al., 2011). Unless a better understanding of the influence of climate variability and change on fish yield is achieved, sustainable fisheries management models will not achieve their purpose. This study endeavoured to determine the interactive effects of rainfall, temperature and water level on fish yield.

2. Methodology

2.1. Study area

The study was conducted on the Lake Bangweulu fishery in south-eastern Luapula province, Zambia (Fig. 1). It is shared by the Luapula, Northern, Muchinga and Central provinces of Zambia. Bangweulu is a collective name for the five inter-connected lakes, which lies in a hollow depression in the centre of an ancient craton platform (Evans, 1978).

Lake Bangweulu proper is separated in the west from Lake Chifunabuli by the sandy Ifunge Peninsula and in the east from Lake Walilupe by the swampy Mbabala Island. In the south, Lakes Kampolombo and Kangwena are separated but interconnected by man-made channels and by rivers. The Chambeshi River enters the swamps through the Nsamba area from the north-eastern direction, while the Luapula River outflows from the southern direction. The permanent swamps form one of the largest swampy areas in Africa, covering over 5000 km^2 and comprising 16% of the complex, which reduces to 10% in the dry season (Mbewe, 2007).

2.2. Research design

The study used both primary and secondary data sources. Primary data collection included key informant interviews with long-standing members of the community who have stayed in the Bangweulu area for more than 35 years. The 35-year period was chosen due to the climatic period and availability of data. Secondary data was sourced from the Zambian Meteorological Department, Ministry of Agriculture, Ministry of Fisheries and Livestock, and Samfya District Council. The data collected included annual average rainfall, temperature, water level and fish yield in Lake Bangweulu for the period of 35 years (1974–2010).

2.3. Data analysis

The major statistical techniques employed in this research include mean and bivariate correlation analysis. The annual means were obtained by adding all monthly scores and dividing by the number of months, hence annual mean fish yield, temperature, water level and rainfall. Correlation and multivariate regression analyses were performed to determine the interrelationship among climate (temperature, rainfall), water level, and fish yield, using XLSTAT (Yue and Wang, 2004) and the Statistical Package for Social Sciences (Norušis, 2005). Pearson's correlation coefficient was used to measure the strength of associations between fish yield and climatic variables (temperature, rainfall), as well as the strength of association between fish yield and water level. Linearity, homogeneity, normality and non-multi-collinearity were tested for each data set before running regression. Trends in fish yield, temperature, rainfall and water level between 1974 and 2010 were also tested using the Mann-Kendall trend test, since it has been widely used to detect homogeneity and changes in climatic time series data (Setia, 2017; Yue and Wang, 2004).

Furthermore, multivariate correlation analysis was used to reflect the extent to which changes in determinant variables affected changes in the other independent variables. In this work, it was utilized to establish the interrelationships among temperature, rainfall, water level and fish yield. Through this statistical technique the magnitude and direction of the perceived association between temperature and fish yield were estimated.

The correlation method employed was the Pearson's Product Moment Correlation (PPMC), which is regarded as the most powerful correlation statistic. A linear regression model was developed with temperature, rainfall and water level as independent variables (x) and fish yield as the dependent variable (y).

The linear regression model;

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + e$$

$$\text{Fish Yield} = \beta_0 + \beta_1 \text{temperature} + \beta_2 \text{rainfall} + \beta_3 \text{water level} + \text{error}$$

$$y = \beta_o + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \varepsilon i$$

where

y_n = fish yield time at time n
β_o = intercept.
β_1 = measure of the rate of increase in mean annual temperature.
β_2 = measure of the rate of increase in mean annual rainfall.
β_3 = measure of the rate of increase in maximum water level in Lake Bangweulu.
x_1 = mean annual temperature for each year over the period of assessment (1974–2010).
x_2 = mean annual rainfall for each year over the period of assessment (1974–2010).
x_3 = maximum water level for each year over the period of assessment (1974–2010).
ε_i = error term representing the vertical deviation of the ith observed value from the fitted line.

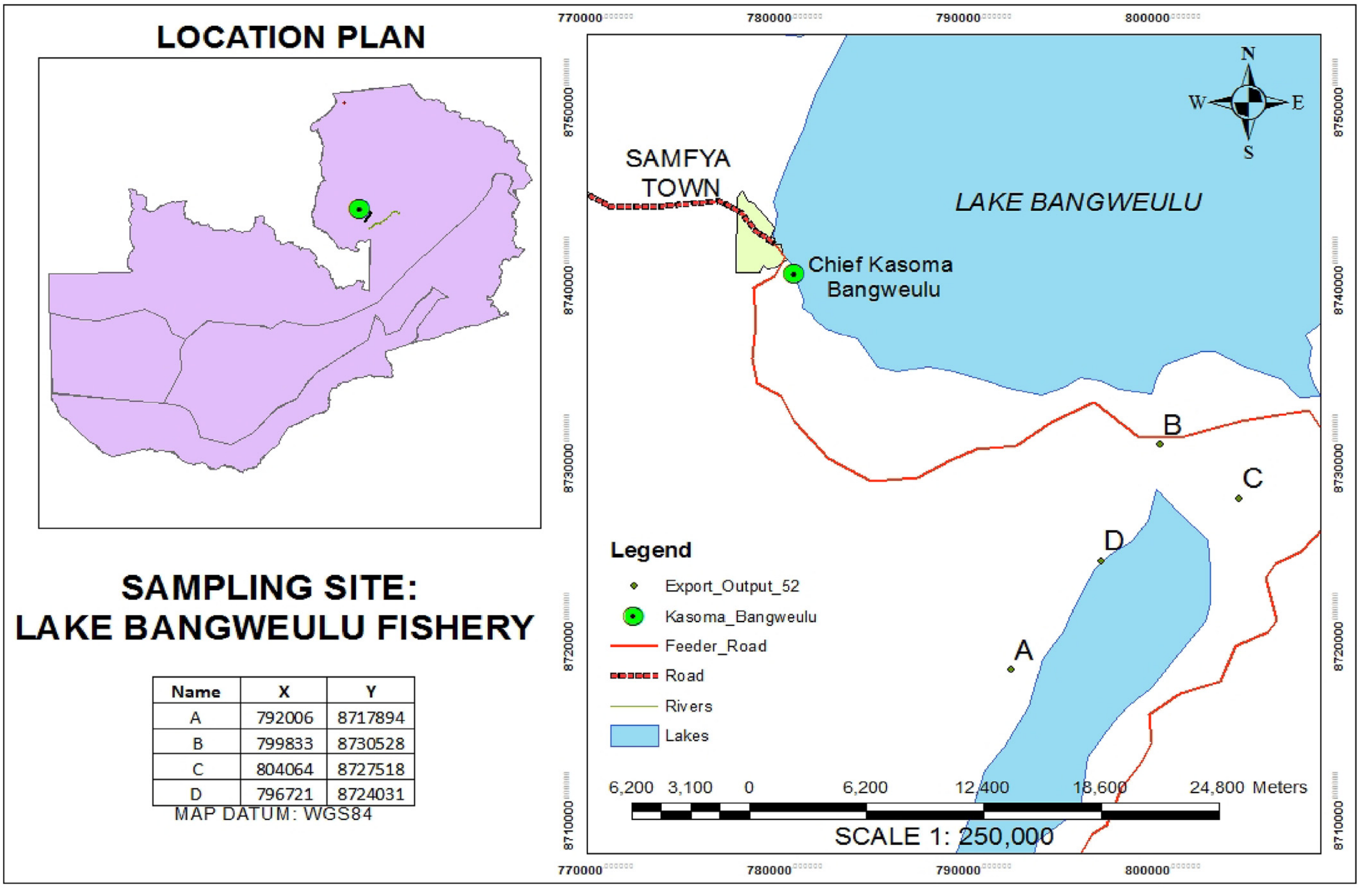

Fig. 1. Lake Bangweulu fishery. Source: Adapted from Kolding et al., (2003).

3. Results

3.1. Normality test

The test for normal distribution of the data set indicated that all the samples followed a normal distribution using the Shapiro-Wilk Normality Test. The Shapiro-Wilk Normality Test works on the assumption that data are normally distributed when the p-value is larger ($p > 0.05$), and data are not normally distributed when the p-value is small ($p < 0.05$). In this study, all the data sets had Shapiro-Wilk normality values greater than $p < 0.05$, implying that they were normal and satisfied assumptions for linear regression.

3.2. Trend analysis

Temperature and water level exhibited significant changes at $p < 0.05$. Rainfall declined, although not significantly, as shown by the value of Sen's slope estimator (Table 1). Temperature and fish yield showed positive trends, while rainfall and water level exhibited negative trends during the period under review. The hydrological factor (rainfall) that increases water level in the lake had decreased, while temperature (a factor influencing evapotranspiration) increased, with a resulting reduction in the water level as shown by the value of Sen's slope (−0.016).

Table 1
Trend in Rainfall, Temperature, Water level and Fish yield.

Mann-Kendall trend tests	p-value	Sen's slope
Rainfall	0.430	−2.35
Temperature	< 0.0001	0.036
Water level	0.005	−0.016
Fish Yield	0.008	147.5

3.2.1. Trend in temperature

Temperature (Fig. 2) exhibited an increasing trend. Temperature has increased by 0.3 °C since 1974. Comparing the periods before introduction of co-management (1974–1992) and after introduction of co-management (1992–2010), it was discovered that the latter period was hotter by 0.3 °C. The lowest peak in temperature was 26 °C in the years 1999 and 2003, while the highest peak was 29.2 °C in the years 2007 and 2009.

3.2.2. Trend in rainfall

The results indicated 3% reduction in rainfall since 1974 (Fig. 3). However, this reduction was not significant at $p < 0.05$. The highest rainfall (1657 mm) was recorded in 1978/79, while the lowest rainfall (636 mm) was recorded in 2004/5.

3.2.3. Trend in water level

The results indicated a decline in water level since 1974 (Fig. 4). Water level decreased by 1.7 m between 1974 and 2010 ($p < 0.05$). The lowest water level was in the year 2000 at 0.74 m, while the highest water level was at 2.48 m in the year 1979, coinciding the respective minimum and maximum rainfall.

3.2.4. Trend in fish yield

The results indicate a steady increase in the annual fish yield since 1974 ($p < 0.05$). However, the yield oscillated between 7598 tons in 1977 and 16,383 tons in 1994 (Fig. 5). According to the results from key informants, there are higher rates of increase in the numbers of fishers and boats. The annual fish yield, number of fishers and boats

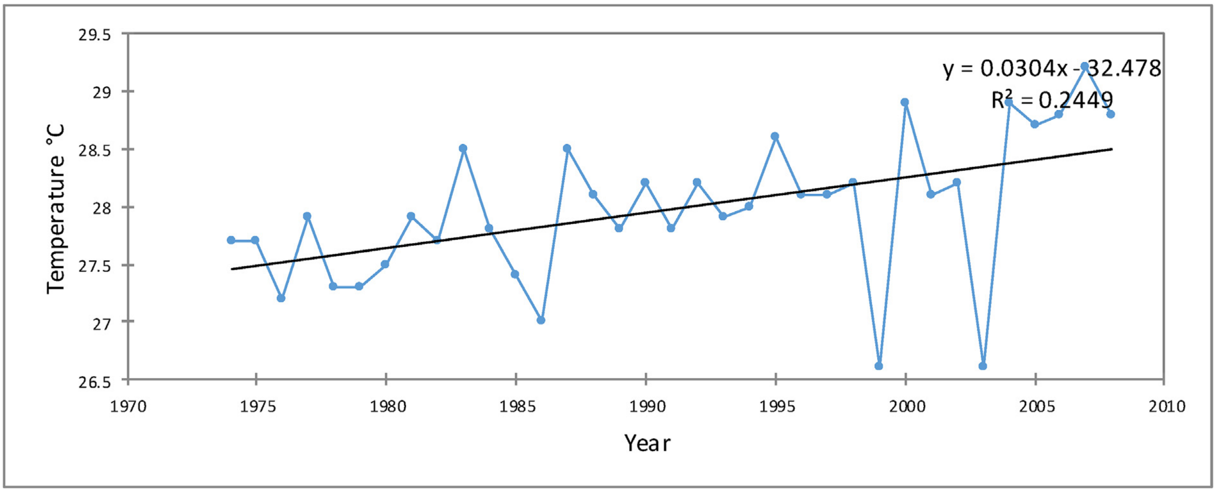

Fig. 2. Temperature trend between 1974 and 2010.

increased by 53%, 57% and 55%, respectively. Furthermore, the results indicated a reduced rate of Catch per Unit of Effort (CpUE) from 12 kg/net/day in 1974 to 1.5 kg/net/day in 2010.

3.3. Interactions among rainfall, temperature, water level, and fish yield

Results indicate that temperature and water level affect fish yield in the Lake Bangweulu fishery (Table 2). The overall linear regression model in the equation was not significant at $p < 0.05$. However, the overall linear regression model was significant without rainfall at $p < 0.05$. When rainfall was subjected to a one-year lag, all three (3) variables were significant at $p < 0.05$. Temperature affected water level more than rainfall, although the latter had an effect on temperature. The linear equation indicated that water level affected fish yield ($p < 0.05$). Based on these results, rainfall had no effect on the water level, while water level and temperature interacted significantly ($p < 0.05$).

4. Discussion

Global climate variability and change due to anthropogenic greenhouse gases have also affected the Lake Bangweulu fishery. The primary effect of climate variability and change on Lake Bangweulu is the reduction in rainfall and water level and the increase in temperature. This study confirms the findings of other studies indicating that in the last century, temperature has increased while rainfall has decreased (Antwi-Agyei et al., 2012; Ayub, 2010; Farnsworth et al., 2011; Patrick, 2016).

4.1. Trend in temperature

The increase in temperature observed in this study resonates with ocean-atmosphere phenomena, such as El Niño Southern Oscillation (ENSO) and the Indian Ocean Dipole Zonal Mode (IOD). ENSO is highly responsible for climate variability and change at interannual timescales and is characterized by Sea Surface Temperature (SST) (Farnsworth et al., 2011). The positive "El Niño" phase occurs when SSTs are warm in the eastern tropical Pacific Ocean, contrasting with the negative "La Niña" phase when they are cool. ENSO effects on African climate occur in part via tropical Atlantic and Indian Ocean teleconnections (Williams and Hanan, 2011). Globally, observed and remote sensing temperature recordings have indicated an increasing trend (Collins, 2011; Hulme et al., 2001). Collins (2011) concluded that significant increasing temperature trends were found in the Southern Hemisphere in Africa. New et al. (2006) analysed daily (maximum and minimum) temperature between 1961 and 2000 for the Southern Africa Development Community (SADC) region and concluded that temperature extremes show patterns consistent with warming over most of the region, with diurnal temperature range showing consistent increases in a zone across Namibia, Botswana, Zambia, and Mozambique, coinciding with more rapid increases in maximum temperature than minimum temperature

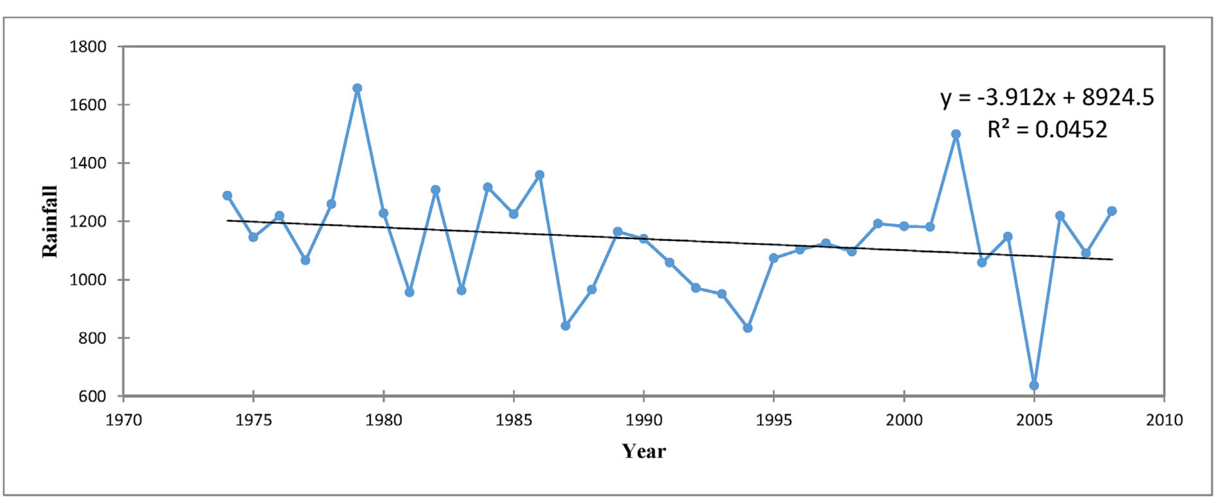

Fig. 3. Trend in rainfall between 1974 and 2010.

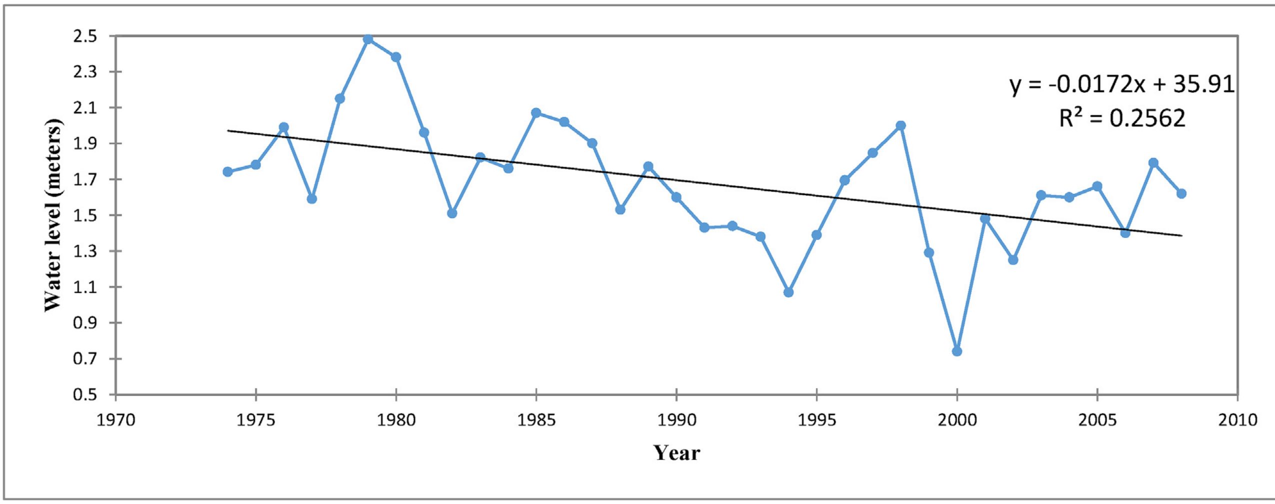

Fig. 4. Trend in water level.

extremes. Hulme et al. (2001) concluded that temperatures in southern Africa during the 1990s were higher than they were earlier in the century and are currently between 0.2 and 0.3 °C warmer than the 1961–1990 average. This study observed changes in temperature between same time periods to be 0.3 °C. The interaction of reduced rainfall and high evapotranspiration (from increased temperature) has a net effect of reducing water level and the lake's total water volume. The reduction in the water level is likely to have negative effects on fish composition, distribution and yield (Rijnsdorp et al., 2009). Enhanced temperature has limited and temporally positive effects on growth rate in terms of breath rates, feed consumption, enzyme activity, oxygen consumption and food metabolism (Ipinjolu et al., 2014). Growth rate determines the size at maturity, fecundity and recruitment in the exploitable phase, as well as population size (FAO, 2009). However, temperature is the most limiting factor in the aquatic ecosystem. Temperature affects dissolved oxygen (DO) through an inverse relationship; increase in temperature (reduced DO) increases survival of bacteria but reduces fish survival, natural food availability and reproductive capacity (Hall, 2009). The Lake Bangweulu fishery is a relatively shallow areas area of open water and swamps with average 1- to 10-m depth (Kolding et al., 2003). Wetlands and shallow water bodies are more susceptible to changes in temperature and rainfall inflows. Increased temperature coupled with reduced water levels may result in stronger, earlier and longer stratification leading to limited or no seasonal turnover. Limited seasonal turnover causes deoxygenation of the bottom layers, lowering primary productivity, fish distribution ranges and yield (Ye Le et al., 2011; Freitas et al., 2007). Freshwater species such as those of the Lake Bangweulu fishery can only tolerate a specific range of environmental conditions that, among other factors, places constraints upon their ranges of distribution. Studies have shown that temperatures beyond tolerant levels reflect reduction in aerobic scope, limiting the energy available for activity, growth, reproduction, and other vital functions (Pörtner and Knust, 2007). It is the reduction in fish composition, species ranges and yield that will regulate the level of vulnerability of fish-based livelihoods to impacts of climate variability and change (Kolding and van Zwieten, 2012; IPCC, 2007).

Table 2
Correlation matrix for rainfall, temperature, water level, and fish yield.

Variables	Fish yield	Water level	Temperature	Rainfall
Fish Yield	**0**	**0.046***	**0.024***	0.791**
Water level	**0.046***	**0**	**0.047***	0.117
Temperature	**0.024***	**0.047***	**0**	**0.049***
Rainfall	0.791**	0.117	**0.049***	**0**

*Significance $p < 0.05$.
** Significant at one-year lag.

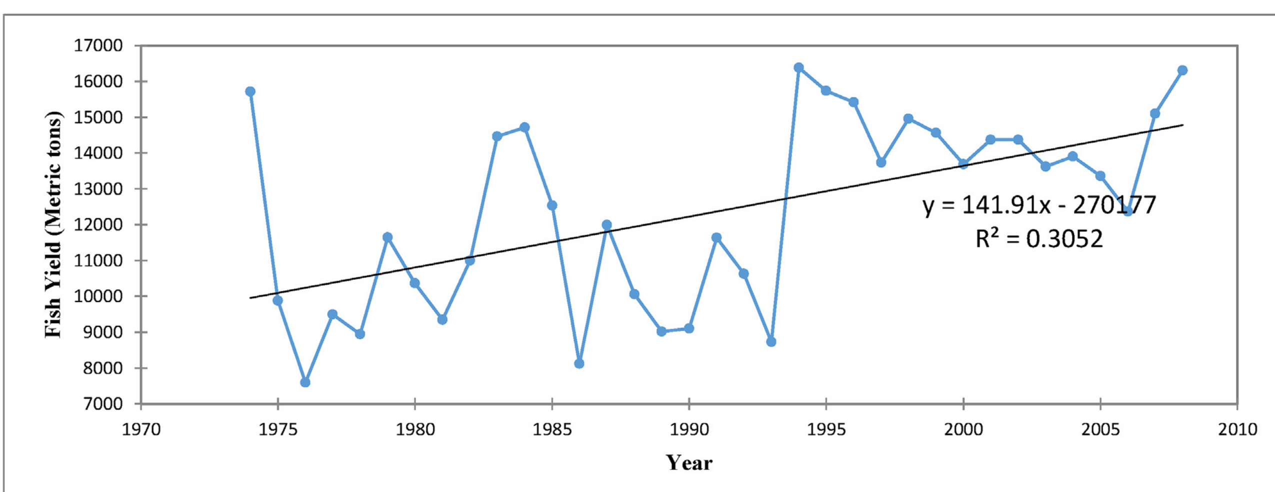

Fig. 5. Trend in fish yield.

4.2. Trend in rainfall

The study indicated decline in the rainfall distribution over time. These results are consistent with the local, national and regional (Southern Africa) assertions that rainfall has declined while there is increased frequency of dry spells and droughts (Farnsworth et al., 2011; Libanda and Ngonga, 2018; Makondo et al., 2014). Locally, the Lake Bangweulu fishery climate (agro-ecological zone III) is influenced by the oscillation of the Inter Tropical Convergence Zone (ITCZ) across the region (Chishakwe, 2010). The ITCZ is in turn influenced by three (3) circulation systems: the north-easterly monsoon which brings in warm and moist air from the tropical western Indian Ocean, the south Indian Ocean anticyclone which creates a flux of cooler and less saturated air from the mid-latitude Indian Ocean, and the inflow of cooler and less moist air from the south Atlantic redirected within the equatorial westerlies (Farnsworth et al., 2011; Williams and Hanan, 2011). Therefore, climate variability and change at Lake Bangweulu is not isolated to the effects of the ocean-atmosphere phenomena of El Niño Southern Oscillation (ENSO) and the Indian Ocean Dipole Zonal Mode (IOD). Rainfall and fish yield showed correlation at the one-year lag. The significant correlation at the one-year time lag may be explained by the spongy nature of the Lake Bangweulu swamps, which regulates the buffering system of the river-swamp-lake complex of the fishery. The positive correlation between rainfall and fish yield may be explained by the fact that rainfall stimulates nutrient input into the lake waters through inflow rivers, providing food for fish (Ayub, 2010). Additionally, the rainfall input is associated with sediment load and relatively high turbidity, providing suitable shelter from predators for fish larvae and juveniles. The effect of rainfall on fish yield would be felt a few years later after recruitment, agreeing with results of Meynecke et al. (2006), who found correlation between total catch of fish with one to two years lagged response to rainfall events in Queensland. Thus, the annual fish yield in the Lake Bangweulu fishery may be predicted one or two years ahead based on the rainfall in the area. The study provides the basis upon which the relationship between rainfall and fish yield can be predicted and considered in fisheries management programmes.

4.3. Trend in water level

The relatively reduced rainfall and high temperature observed results in reduced water inflow and evapotranspiration, respectively. The net result is reduced water level in the Lake Bangweulu fishery, which negatively affects nutrient concentration and primary productivity. The reduction in primary production, consequently, has adverse, cascading impacts on productivity of higher trophic levels, such as fish. Evidence of the impacts of climate changes expected in freshwater ecosystems, particularly those in the tropics, include changes in species composition, organism abundance, productivity and phenological shifts, including earlier fish migration as a consequence of warming and subsequent high evaporation rates and reduced rainfall and water levels (IPCC, 2007). The reduction in water level has affected the Lake Bangweulu ecosystem through several pathways: a physiological (size) response to changes in reduced water volumes and increased temperature, a behavioural (distribution) response due to limited breeding and feeding places, and population dynamics (growth, mortality and reproduction) resulting in reduced recruitment capabilities (Rijnsdorp et al., 2009). Changes in temperature and rainfall regimes have the potential to affect productivity and trophic levels. Isolated fishponds resulting from reduced water level, combined with fishers' experience, increases chances of over-exploitation of the fish resources, which further influences abundance and distribution (Brander, 2007).

4.4. Trend in fish yield

Fish yield increased at a lower rate than increases in fishing effort (fishers and boats). Therefore, the Catch per Unit of Effort (CpUE) has decreased during the same period. Despite the limited historical information on fishing effort over time, reduction in the fish yield has been attributed to over-fishing and destructive fishing gear and methods (Kolding and van Zwieten, 2012; Kolding et al., 2016; IAPRI, 2017). The confounding effects of climate variability and change have not been considered in previous studies, whose research was still biased towards stock assessment. The significant relationships among rainfall, temperature and fish yield indicate the influence of fluctuations in water levels on fish ecology and biology (Ayub, 2010; Pauly and Zeller, 2016). The effects of climate variability and change will have further negative impacts on an already declining fish catch (Mbewe, 2007). The effects of climate variability and change impact the biology, ecology and geographical extent of fish species, altering water quality and quantity, as well as climatic factors such as temperature and rainfall which affect spawning, timing of breeding and survival of juveniles (Ipinjolu et al., 2014; FAO, 2016). Declines in fish yield accelerated by impacts of climate variability and change will have a negative socio-economic effect on the fisheries livelihood (Lutz and Striessnig, 2015; Moore, 2016; Ndhlovu et al., 2017). This is due to reduced direct measurable incomes, collapsed food security and nutrition, and labour-related stresses compounded by the current economic hardships prevailing in rural communities (Brendan et al., 2017).

4.5. Interrelations of rainfall, temperature, water level, and fish yield

An attempt was made to understand the correlations among rainfall pattern, temperature, water level and fish yield in the Lake Bangweulu fishery. There were significant correlations between temperature, water level and fish yield. In this study, one-year lag correlation ($p < 0.5$) was observed between rainfall and fish yield. Other studies have indicated an increase in the fish yield after a wet year (Ayub, 2010). The major hydro-climatic factors of the Lake Bangweulu fishery include rainfall, runoff and river inflow (Bos and Ticheler, 1996; Evans, 1978). Rainfall is fundamentally the hydrological factor triggering the whole process of filling the lakes and swamps. The spongy nature of the swamps provides a time lag before significant refilling and its effect on the open lake is observed (Evans, 1978; Kolding and van Zwieten, 2012; Mbewe, 2007). The vegetation and "spongy" nature of the swamps have greater regulatory effects on the water volume in the open lake during wet and dry periods. On the other hand, increased temperature coupled with evapotranspiration accounts for hydrological deficiency in the swampy areas of the fishery. Rainfall has a complex effect on fish yield; increased rainfall increases nutrients, dissolved oxygen, turbidity and productivity in the water column while reducing yield, as catchability is negatively affected by expanded water volume in the peripherals (Orr et al., 2015).

The observed significant interaction effect of temperature and water level on yield confirms earlier assertions that temperature and water level could have greater effects on the fish yield in the Lake Bangweulu fishery (Law et al., 2013). Generally, years of high-water levels are always associated with subsequent high production years in terms of egg production, as well as larval survival and growth (Kolding and van Zwieten, 2012). Based on population dynamic considerations, change in temperature and water level regimes is expected to have the greatest impact on the size and location of suitable habitat, retention of eggs and larvae, match in timing of the fish larvae and their food, connectivity between habitats of successive life stages, growth, and fish populations (Ye Le et al., 2011). On the other hand, retreating waters during the dry season and deficit years normally expose the fish to fishing activities. The reduction in the water level may expose fish from protected boundaries, and they may become more susceptible to extensive fishing activities. Various sophisticated illegal fishing gears and methods are currently used at Lake Bangweulu (Mbewe, 2007). Intensive fishing due to low water levels may cause fish population to fail to recover from effects of poor year classes. The overall implication is the presentation of fishery impoverishment inducing stock structures that are not robust to excessive fishing pressure (Ottersen et al., 2006). Furthermore, reduction in water level affects the carrying capacity of the stock to sustain the ever-increasing demand for protein, income and employment among the local fishing community (Barange et al., 2014). Climate change induced impacts on water level and temperature affect the ecosystem to influence the bottom-up and top-down controlled system (Heath, 2007). The interaction of fishing with climate variability and change, in this case, will have the greater influence on species size structure and composition of fish populations (Daan et al., 2005; Anderson et al., 2008). Generally, fisheries management of the Lake Bangweulu fishery is limited to fishing effort related regulations, and climate variability and change are not parts of the management model. Notwithstanding the contribution of fishing type and method being practised, temperature and water level have significant contributions to the fisheries management model (Patrick, 2016; Daan, 2006).

5. Conclusion

Temperature, rainfall and water level have affected the Lake Bangweulu fishery during the last 36 years. The increase in temperature coupled with reduction in rainfall and water level have effects on fish yield. Temperature interacts with water level to play an important role in determining the fish yield. Temperature and water level variations may have greater effects on the management of the fisheries resources in the Lake Bangweulu fishery in the short term. Unsustainable fish yield results from lower water level, probably due to the increased exposure of fish from hiding boundaries. Increase in temperature may trigger evapotranspiration that may reduce the water level in the lake. Therefore, climate variability and change have great influence on the yield of fish in the lake. The study concludes that there are significant correlations between temperature, rainfall (one-year lag) water level and fish yield. Based on the results, there is strong recommendation to incorporate climate variability and change in the modelling of fisheries management approaches to reduce the impacts of climate variability and change on fisheries-based livelihoods.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jtherbio.2019.06.001.

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