FOOD SCIENCE & TECHNOLOGY | RESEARCH ARTICLE

Fish catches, and the influence of climatic and non-climatic factors in Lakes Chivero and Manyame, Zimbabwe

Beaven Utete1,2*, Crispen Phiri3, Sibonani S. Mlambo4, Never Muboko3 and Bernadette T. Fregene2

Abstract: Inland fisheries provide income, food security and nutrition and act as a labour buffer. Yet they scarcely receive consideration in water resource allocation and economic decisions. Inland peri-urban fisheries face many challenges to their sustainability such as urban encroachment, environmental degradation and climate change. This study aimed to assess the historical fish catches, species composition, and investigate the effects of climatic variability and catchment dynamics in peri-urban Lakes Chivero and Manyame in Zimbabwe. The Mann-Kendall test was used to analyse time series trends in fisheries and climatic data. Multiple regression analysis was used to assess relations between fish catches and climate data for Lakes Chivero and Manyame. Fish catches have significantly declined in Lakes Chivero and Manyame over the periods considered with a shift towards a monospecies dominance in the fish community. Peri-urban lakes are characterised by highly adapted, relatively large sized fish species which have an ability to utilise a directional environmental disturbance such as hypereutrophication. Climatic factors have significant effects in fish catches in Lake Chivero. Despite the potential negative socioeconomic consequences inferred from declining fish catches, water pollution, gross under-reporting, poor recording and preservation of fisheries statistics remains a massive threat to the survival of inland peri-urban fisheries in Lakes Chivero and Manyame.

ABOUT THE AUTHOR

Beaven Utete has just finished off his PhD in Fisheries Science and Aquatic Conservation at the Chinhoyi University of Technology in Zimbabwe. He had his post masters fellowship in the Department of Aquaculture and Fisheries Management at the University of Ibadan, Nigeria, under the Climate Impact Research Capacity and Leadership Enhancement (CIRCLE) programme funded by the Department for International Development (DFID). He is a senior lecturer and research fellow in the Department of Wildlife, Ecology and Conservation at the Chinhoyi University of Technology in Zimbabwe. The major interests of Beaven and his co-authors are fisheries, climate change, aquaculture, macroinvertebrates, terrestrial ecology, fishing communities, biotechnology sciences, aquatic ecology, water resources conservation and economics of small scale fisheries.

PUBLIC INTEREST STATEMENT

Culture capture fisheries are the mainstay of Zimbabwe's fishery sector as aquaculture has failed to take off in a positive trajectory. Sustainability of culture capture inland fisheries is under threat from an array of factors such as urban encroachment, environmental degradation and climate change. Moreso fisheries related statistics are not diligently maintained in developing countries, thus, they are excluded in national economic planning. This paper analysed historical trends in fisheries catches and changes in climatic factors over the period 1983–2016 and assessed their statistical relations in peri-urban Lakes Chivero and Manyame. Fish catches have sharply declined in the two lakes with changes in water quality, quantity, and some climatic variables like water abstraction, wind speed and evapotranspiration having a positive relation with fish catches. This study infers on the negative socioeconomic consequences of declining fish catches on the livelihoods of fish and fishing dependent communities in peri-urban lakes in Zimbabwe.
1. Introduction

Small scale inland fisheries (SSIFs) play a significant role as a source of livelihood, food security and nutrition, labour buffer and measurable income for millions of people in both developed and developing countries (Allison & Ellis, 2001). The SSIFs abound in developing and low income countries mostly located in the tropics because most fishes and invertebrates inhabit shallow waters accessible by low cost fishing gears (Berkes, Mahon, McConney, Pollnac, & Pomeroy, 2001). Exploitation of inland lakes resources through obsolete multigear equipment, small and poorly built vessels, poor regulation and management exposes the dependent fishing communities to climate vagaries and ecosystem uncertainty (Badjeck, Allison, Halls, & Dulvy, 2010). Such a scenario is compounded by inherent systematic failure to properly record and publish annually the fisheries statistics for most developing nations (Bartley, De Graaf, Valbo-Jørgensen, & Marmulla, 2015; FAO, 2013). Future planning and ecological predictions as well as attendant socio-economic inferences do not suffice for data deficient SSIFs (Béné, Hersoug, & Allison, 2010). Consequently, SSIFs are often underreported and often ignored in national economic planning programs and water allocation exercises at local and national levels (Béné et al., 2010; Cooke et al., 2013).

Most small scale fisheries have not been well managed with an open access system still practised in over the 10,000 small dams present in Zimbabwe (FAO, 2014). The existing approaches have failed to constrain fishing capacity, manage conflict, reduce fish poaching or minimise damage to the aquatic habitats (FAO, 2013, 2014; Mhlanga & Mhlanga, 2013). They have not kept pace with technology upgrades or with the driving forces of economics, population growth, increasing demand for food and proteins and poverty. It entails for urgent reform in the management and governance of small scale fisheries (Donda, 2006; FAO, 2014; Mhlanga & Mhlanga, 2013). A primary reason for the collapse of small scale fisheries has been the lack of a nationally coordinated consistent fish stock assessment program, with no reliable fisheries statistics to be used for planning towards the socio-economic needs of dependent fishing communities (Donda, 2006). Thus, most small scale fisheries have collapsed or greatly reduced their fishing activities (FAO, 2013; Muzvondiwa, Chiwara, & Ngwenya, 2013). Moreover, a lack of an appreciation of the integrated nature of the confounding effects of climatic and non-climatic factors on the productivity of inland urban and peri-urban fisheries in the drylands of Africa leads to collapse of otherwise resilient fisheries (Kolding, van Zwieten, Martin, & Poulaín, 2016).

The commercial fishery on two contiguous hypereutrophic peri-urban Lakes Chivero and Manyame in Zimbabwe utilises seine nets in the marginal shallow regions and gill nets in the shallow to relatively deeper waters (Marshall, 2011). The fishery sector for the two lakes comprises the commercial and culture capture and recreational fishery with no aquacultural activities existent (Mhlanga & Mhlanga, 2013). From the anecdotal records, fish production in Lake Chivero was estimated to have reached 250 kg h⁻¹ yr⁻¹ in 2000 with no proper records of fish production in Lake Manyame (Marshall, 2011). The main challenge lies in the failure to systematically record and annually publish catch/effort data for commercial fisheries in the two peri-urban lakes (FAO, 2013; Mhlanga & Mhlanga, 2013). Thus, there is a need for fisheries data reconstruction, estimation and its annual publication using the few available anecdotal in many cases underreported sources for such lakes (FAO, 2003).

1.1. Aims of the study

This study aimed to assess the historical fish catches, species composition, and investigate the effects of climatic variability and catchment dynamics in two contiguous hypereutrophic peri-urban Lakes Chivero and Manyame in Zimbabwe.
2. Study area

The present study was conducted in peri-urban Lakes Chivero and Manyame in the upper Manyame catchment, Zimbabwe (Figure 1). The two artificial lakes or dams are constructed on Manyame River which drains ultimately to the Zambezi River in north western Zimbabwe. The two lakes have locational coordinates of 17°.90′ 33″ S, 30°.79′ 82″ E for Lake Chivero, and 17°49′ 18.9″ S, 30°29′ 43.08″ E for Lake Manyame. Lake Chivero (formerly McIlwaine), was built in 1952 and lies 29 km southwest downstream of Harare, the capital city of Zimbabwe on the Manyame River (Zimbabwe National Water Authority, 2014). Lake Chivero has three main tributaries Marimba, Mukuvisi and Manyame, which discharge copious loads of pollutants (Magadza, 2003). It has a capacity of 247,181 × 10^6 m³, a mean depth of 9.4 m and a surface area of 2,630 ha and is Harare’s main water supply. Lake Manyame (formerly Darwendale Dam) was built in 1975 and lies downstream of Lake Chivero on the Manyame River to the western side of Norton Town in Mashonaland West Province (Zimbabwe National Water Authority, 2014). It is bordered by the Mazowe catchment with the Gwebi River a significant tributary (Thornton & Nduku, 1982; Zimbabwe National Water Authority, 2014). On the upstream end, two main tributaries, Muzururi and Manyame (Hunyani) upload large amounts of sewage effluent into Lake Manyame. The main concern with the two lakes derives from the shallow maximum depths which are 27 m for Lake Chivero, and 23 m for Lake Manyame, and thus, incessant pollution threatens the water quality and quantity (Marshall, 2011; Nhapi & Gijzen, 2004).

2.1. Methods

Historical and current fisheries catches and species composition for Lakes Chivero and Manyame were obtained from Lake Chivero Station in Zimbabwe for the available periods. Stream flows data were obtained from the Zimbabwe National Water Authority (ZINWA). Daily precipitation, mean temperature, wind speed, relative humidity and extra-terrestrial radiation data which was downloaded from the agro-climatic data website (www.larc.nasa.gov) for upper Manyame catchment area for the period 1983–2015 was used in this study. The website integrates data collected from various weather stations around the world into a comprehensive database and the datasets are later interpolated to create a continuous distribution surface of climatic variables. The calculated monthly averages of each climatic factors were categorised into wet and dry season climatic variables. Using the downloaded mean temperature and extra-terrestrial radiation data, the potential evapotranspiration (Eto) of upper Manyame catchment area was estimated following the Hargreaves evapotranspiration method (Hargreaves & Samani, 1985).
2.2. Data analysis
To test for trends in fisheries catches, temperature, humidity, evapotranspiration, rainfall, water level/volume, stream flow and water abstraction rates for Lakes Chivero and Manyame for the period 1983–2016 the Mann-Kendall (MK) test was used. The MK test is non-parametric and has been extensively applied to detect trends in hydrological data because of its robustness against departures from normality (Hirsch & Slack, 1984). The relationship between climatic variables (annual average precipitation, annual average temperature), water levels/volume, and stream flow and water abstraction rates and fisheries catches for the period 1983–2016 was tested using multiple regression analysis. Climatic variables were used as independent variables and the dependent variable was annual average water levels/volume data for the same period in SPSS 21.

3. Results

3.1. Fish catches in Lakes Chivero and Manyame in Zimbabwe
Available fisheries returns data indicate that there was an initial increase in fish catches from the late 1970’s in Lake Chivero up to 2000, with peak catches of more than 1,000 tonnes recorded in the 2000–2002 period (Figure 2). However, fish catches began to gradually decline from 2006, with sharp decreases in catches recorded from 2008 up to 2016 (Figure 2). The anecdotal fisheries statistics available for Lake Manyame indicate that fish catches peaked at 6,000 tonnes in 2003 (Figure 3). From 2005 onwards the fish catches have been declining with current catches hovering around 1,000 tonnes for the active fishing companies in Lake Manyame (Figure 3). The Mann Kendall trend analysis indicate that fish catches have significantly changed ($\tau = -0.358$, 2-sided $p$-value = 0.0012412) over the time period considered for this research 1977–2016 in Lake Chivero. Though the available fish statistics for Lake Manyame were anecdotal and rather few, the Mann Kendall analysis indicate that fish catches have also significantly changed ($\tau = -0.538$, 2-sided $p$-value = 0.012372) over the time period analysed 2002–2016.

Although species composition records indicate that there were at least 27–33 species in the immediate post filling period in Lake Chivero (Marshall, 2011), records used for this study indicate at least 14 prominent fish species including: *Hydrocynus darlingi*, *H. vittatus*, *Serranochromis robustus*, *Oreochromis mossambicus*, *Marcusenius macrolepidotus*, *Micropterus salmoides*, *Cyprinus carpio*, *Brycinus imberi*, *Tilapia rendalli*, *Clarias gariepinus*, *O. niloticus*, *Labeo altivelis*, *Labeo cylindricus* and *O. macrochir*. Other records indicate the occasional presence of species such as *Tilapia sparmanii*, *Mormyrus longirostris* and *O. andersonii* after the initial filling period (Marshall, 2011), however, these were not quantified. Species composition for readily available data indicate initial domination of Lake Chivero by *L. altivelis*, *T. rendalli*, *H. vittatus* in the 1975–1985 period as indicated in Figure 4. There were sizeable portions of the grass carp, *C. carpio*, largemouth bass, *M. salmoides*, the African...
carp, *L. cylindricus*, and the Yellow belly bream, *S. robustus* from 1975 to 1991, which however, sharply declined from 1992 onwards.

For the period 1983 onwards there was interchangeable domination by cichlids such as *O. mossambicus*, *O. macrochir*, whilst the predators, *H. vittatus* and *H. darlingi* presence gradually declined from 1985 to 2003. From 2001 the exotic cichlids; *O. niloticus* and *O. macrochir* gradually increased their abundance. Oral evidence from the Parks officials (N. Songore, 2017 pers. comm) indicate that *O. niloticus* has virtually taken over the lake, and is now the dominant species in seine, gill and angling catches. Due to the unavailability of long term data, the accurate species composition for Lake Manyame was anecdotal. However, current fisheries data available for Lake Manyame at functional fishing companies/cooperatives indicate that *O. niloticus*, *C. gariepinus* dominate catches punctuated with seasonal catches of grass carp, *C. carpio* and odd angling catches of the yellow belly bream, *S. robustus*, largemouth bass, *M. salmoides* in the upstream parts where Gwebi River enters the lakes (N. Songore. pers. comm, 2017).

### 3.2. Trends in climate parameters in the catchment of Lakes Chivero and Manyame

Average annual wind speeds have gradually increased in the catchment of Lakes Chivero and Manyame from the relatively lower values of 2.12 km/hr recorded in 1983 to 3.98 km/hr noted in 2003 (Figure 5). The lowest value of 2.02 km/hr wind speed was recorded in 2007, though there has been a gradual increase in windspeed hitherto (Figure 5). Overall, there is a significant change ($r = 0.545$, 2-sided $p$-value = 8.7023e-06) in windspeed in the catchment of Lakes Chivero and Manyame.
The average annual temperatures in the catchment of Lakes Chivero and Manyame indicate constrained fluctuations within a 0.2°C range (Figure 6). On average, the surface temperatures were at 22.2°C in the catchment of Lakes Chivero and Manyame, however, the overall trend indicate slight or marginal increases in surface temperatures. Overall, the Mann Kendall statistics indicate no significant differences ($τ = −0.0341$, 2-sided $p$-value = 0.79224) in surface temperatures in the catchment of the two lakes.

The annual average humidity for the catchment of Lakes Chivero and Manyame indicate an inconsistent fluctuation pattern hovering around 45 g of vapour per m³ volume of air (Figure 7). High humidity values of 53 g of vapour per m³ volume of air were recorded in 1985, 1997, 1999, 2006 and 2015. Whilst the lowest annual average humidity values of 42 g of vapour per m³ volume of air were recorded in 1986, 1990, 1992, 2005, 2012–2013 (Figure 8). Overall, there has been a slight increase in the annual average humidity in the catchment of Lakes Chivero and Manyame, though there is no statistically significant change ($τ = −0.072$, 2-sided $p$-value = 0.56645).
The annual average evapotranspiration reflects an upward trajectory for the period considered 1983–2015 punctuated by higher evapotranspiration values of 11–13 ETO from 2010 onwards (Figure 8). Overall, there was a significant difference ($\tau = 0.36$, 2-sided $p$-value = 0.0034066) in evapotranspiration for the catchment of Lakes Chivero and Manyame.

The average annual rainfall indicate a variable inconsistent pattern with high or peak values of 266 mm recorded in 2005, whilst the lowest (dip) values of 32 and 42 mm were noted in the years 1992 and 2005 for the catchment of Lakes Chivero and Manyame (Figure 9). Despite the wide fluctuations shown in Figure 9, overall there was a decline in average annual rainfall amounts of the catchment of Lakes Chivero and Manyame. However, there were no statistical significant differences ($r = 0.36$, 2-sided $p$-value = 0.76856) in average annual rainfall amounts for the period considered 1983–2015.

Multiple regression indicate that surface temperature ($p = 0.000188$), evapotranspiration ($p = 0.0001$) and surface inflows at Mukuvisi River-entrance ($p = 0.028958$) strongly influenced fish
catches in Lake Chivero. The rest of the factors considered comprising of rainfall, water abstractions, surface inflows at Marimba River entrance, Manyame-Nyatsime River entrance did not significantly influence fish catches in Lake Chivero. For Lake Manyame no climatic parameters and catchment factors strongly influenced ($p > 0.05$) the fish catches for the short duration data available.

4. Discussion
Fish catches have significantly declined in the two hypereutrophic peri-urban Lakes Chivero and Manyame. Numerous hypotheses ranging from eutrophication, inadequate control of the exotic water hyacinth, fish poaching, inaccurate data entry, underreporting and overfishing were advanced to explain this decline (Donda, 2006; FAO, 2013; Magadza, 2003; Marshall, 2011). As well there has been a sharp decline in terms of fish species composition for the two lakes. From an estimated number between 27 and 33 fish species depending on the source, commercial fishermen, and the anecdotal fisheries returns indicate dominance by the exotic Nile tilapia and the hardy Sharptooth catfish in Lakes Chivero and Manyame. Marshall (2011) indicated that changes in water quality altered the dominant phytoplankton species and altered the fish assemblages in Lake Chivero. Zengeya and Marshall (2007) reflect that Oreochromis niloticus has been implicated in reducing the abundance of indigenous species and even some exotic cichlid species through competitive exclusion and hybridisation in trophic interlinkages in Lake Chivero. The ever present Sharptooth catfish is a hardy species which proliferate even under the hypereutrophic conditions in Lakes Chivero and Manyame (Marshall, 2011). The underlying observation was that there were statistically significant changes punctuated by a decline in fish catches for Lakes Chivero and Manyame. Such a finding has potential ramifications and negative consequences on food security and the well-being of fishing and fish dependent peri-urban communities (Béné et al., 2010).

Lack of long term consistent historical fisheries data on Lake Manyame exposes an inherent data deficient scenario prevalent for most small scale inland fisheries in developing countries (Berkes et al., 2001; FAO, 2013). This hampers research and integration of economically important inland fisheries into national economic planning programs (Cooke et al., 2013). For instance various sources of information in this study avail different net yardage used by fishing cooperatives operating in the same lakes which complicates calculations of catch per unit efforts (CPUE). Such a data deficient scenario hampers investigations on the effort exerted to catch the fish which enables calculation and indirect estimation/measure of the abundance of a target species. Further economic inferences which could be made from the CPUE of the fisheries in Lakes Chivero and Manyame are impossible. This scenario complicates the integration of fisheries economics into local and national economic
planning programs hence their underrepresentation (FAO, 2013). Ultimately, the significance of fish and in particular the smaller sized fish for sustainable and healthy livelihoods is undervalued primarily because of a paucity of updated fisheries statistics (Kolding, Jacobsen, Andersen, & van Zwieten, 2015).

The advent of confounding effects of catchment dynamics and climate change have not been considered in previous studies for the two lakes save for studies by Magadza (2003) whose research was still biased towards water quality deterioration. The significant relations between stream flows at the Mukuvisi River entrance and fish catches in Lake Chivero indicate either the influence of fluctuations in water levels of the river on fish ecology and biology or it invariably suggest that changes in water quality in the Mukuvisi River influence fish catches in Lake Chivero. Changes in water quantity and quality of inflowing rivers impact the lake ecosystem and inhabitant hydrobionts (Hohensinner, Habersack, Jungwirth, & Zauner, 2004). The present study reflect that climatic factors do not do show a concatenated pattern, although they have a significant confounding effect on fish catches in Lake Chivero. For Lake Manyame, there were no significant confounding climatic effects on fish catches, probably due to the paucity and short duration of the available fisheries statistics. Predictive climate change studies by Masimba (2016) indicate that surface temperature will increase by close to 0.18°C in the catchment of Lakes Chivero and Manyame. Masimba (2016) predicts significant decreases by almost 20% in precipitation amounts for the catchment of Lakes Chivero and Manyame. Studies by Chikodzi, Murwendo, and Simba (2013) show that rainfall amounts for the rest of Zimbabwe will decline by 18–22%. Mugandani, Wuta, Makarau, and Chipindu (2012) indicate that there will be significant declines in relative humidity and average rainfall for most agro-ecological regions in Zimbabwe in the near future.

The implications of changes in climatic factors will have a further negative impact on an already decreasing fisheries catches (Brander, 2010). The biology, ecology and geographical extent of fish species is related to the water quality and quantity, and climatic factors such as temperature, wind speed which affects spawning, timing of breeding and survival of juveniles (Bertolo & Magnan, 2006; Søndergaard & Jeppesen, 2007; Wetzel, 2001). Declines in fisheries catches accelerated by climatic factors will have a negative socioeconomic effect on the fishing and fish dependent communities in Lakes Chivero and Manyame. This is due to reduced direct measurable incomes, collapsed food security and nutrition, labour related stresses compounded by the current economic hardships prevailing in Zimbabwe. Deleterious activities such as fish poaching, deadly conflicts over fishing grounds, net stealing, and fishing in highly restricted zones with wrong gear which threatens fish abundance have been reported among highly stressed inland freshwater fisheries (Allison, 2002; Cohen, Kaufman, & Ogutu-Ohwayo, 1996).

The inland peri-urban lakes serve multiple purposes such as water abstraction for domestic, industrial, mining and agricultural and recreation for water sport enthusiasts (Magadza, 2003). However, due to the leeward locations within their catchment, recycled, reused water and polluted water is discharged into the lakes. Thus, the peri-urban lake systems are relatively stable and are only strongly pulsed ecosystems in periods of intermittent and unpredictable precipitation. Hence they do not conform strictly to the hydrological cycles of predominantly dryland freshwater systems prescribed by Kolding et al. (2016). Peri-urban freshwater systems are characterised by very productive, highly adapted, relatively large sized fish species which have an ability to utilise a directional environmental disturbance such as hypereutrophication in this case. Though alternative periods of low productivity are inevitable in response to an intensification of the environmental disturbance or overfishing and overexploitation of the water resources through excessive water abstraction and extreme variations in the natural hydrological regimes (Kolding et al., 2015).

5. Conclusion and recommendations
Our study showed that fish catches in the two inland peri-urban Lakes Chivero and Manyame have gradually declined for the study period with a shift from multispecies towards a bi or monospecies fish community. Climatic and non-climatic factors have a significant relation to fish catches in inland
peri-urban lakes. Though there are potential severe socioeconomic consequences inferred from declining fish catches, water pollution, gross underreporting and in some cases poor recording and preservation of fisheries statistics remains a massive threat to the survival of small scale inland peri-urban fisheries in Lakes Chivero and Manyame.

For future studies, it is imperative to undertake long term research on the limnology of both lakes and relate it to the changes in climatic factors over the catchment and other dynamics before concrete conclusions can be made on their implications to fish production, and the relative consequences to the fish and fishing dependent peri-urban communities.

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Competing interests
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Author details
Beaven Utete1,2 E-mail: mkiayo@gmail.com Crispen Phiri3 E-mail: crispenphiri@gmail.com Sibonani S. Mlambo4 E-mail: sibonanisi@gmail.com Never Muboko5 E-mail: mmbok@yahoo.co.uk Bernadette T. Fregene6 E-mail: tosanfregene@yahoo.co.uk
1 Department of Wildlife Ecology and Conservation, Chinhoyi University of Technology, P Bag 7724, Chinhoyi, Zimbabwe.
2 Department of Aquaculture and Fisheries Management, University of Ibadan, Ibadan, Oyo State, Nigeria.
3 Department of Freshwater and Fishery Science, Chinhoyi University of Technology, P Bag 7724, Chinhoyi, Zimbabwe.
4 Department of Biotechnology Science, Chinhoyi University of Technology, P. Bag 7724, Chinhoyi, Zimbabwe.

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