Assessment of water levels and the effects of climatic factors and catchment dynamics in a shallow subtropical reservoir, Manjirenji Dam, Zimbabwe

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ABSTRACT

Natural water level fluctuations have associated effects on water quality and resident aquatic communities, although their impacts are magnified if the dams have other non-seasonal designated multiple uses. Research demonstrates that excessive water level fluctuations impair ecosystem functioning, ultimately leading to shifts between clear-water and turbid states in shallow lakes. However, these data lack for Manjirenji Dam in Zimbabwe, thus hampering efforts towards effective freshwater resources management in the shallow reservoir. This study analyzed water levels and their fluctuations, and assessed the effects of climatic factors and catchment dynamics using a combination of historical and remote sensed data for the shallow Manjirenji Dam in Zimbabwe. Time series and multiple regression analysis were used to determine water level trends, and the influence of catchment and climatic components in Manjirenji Dam. Lake levels have increased since construction, though their non-significant seasonal variation in the Manjirenji Dam reflects the overlapping effects of catchment and climatic variables. Despite the inferred high stability and resilience, the high fluctuation widths expose the dam to hydrodynamic and climate shocks which have major ecological and conservation implications. A climate change based integrated water resources management approach is necessary for sustainable water resources utilisation in the Manjirenji Dam.

Key words | climate change, hydrodynamics, semi-arid region, shallow lakes, water abstraction

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INTRODUCTION

High evapotranspiration rates and fluctuations in intensity of precipitation can cause wide shifts in the water levels of shallow reservoirs with multiple designated purposes (Wantzen *et al.* 2008). Shallow tropical lakes located in arid areas have extensive periods of low water levels intertwined with increased levels in the rain season (Antenucci *et al.* 2003; Carvalho & Lyche-Solheim 2013). Natural water level fluctuations (WLF) have associated effects on the water quality and resident aquatic communities (Wantzen *et al.* 2008). The effects of natural water level fluctuations on water quality and aquatic organisms are magnified if the dams have non-seasonal water abstraction present (Abrahams 2008). Wide water volume fluctuations can affect physical–chemical and biological conditions in freshwater systems (Wang *et al.* 2011). Regardless, water level fluctuations promote high species diversity in littoral zones and increase productivity of the lakes (Antenucci *et al.* 2000; Kolding & van Zwieten 2006, 2012).

Water fluctuations have an impact of constantly moving the ecotone up and down the shoreline, a process which facilitates nutrient recycling (Kolding & van Zwieten 2006). This increases species diversity in response to high nutrients in shallow lakes (Abrahams 2008). In addition, water level fluctuations determine the dominant functional

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phytoplankton, macroinvertebrates and macrophytes in some subtropical reservoirs (Wang *et al.* 2011). Similarly, the interlinkage of the concept of aquatic resilience, defined as the homeostatic capability of an aquatic ecosystem, to withstand perturbation to the relative lake level fluctuation (RLLF) has acquired prominent application in both deep large and shallow small lakes (Reynolds 2002; Wang *et al.* 2011; Hipsey *et al.* 2015).

Lake productivity is also determined by abiotic factors such as lake depths, shoreline shapes, drawdown zone length and nutrient availability (Bond *et al.* 2008; Kolding & van Zwieten 2012). Thus, the categorization of lakes has been traditionally based on lake morphology and limnochemistry (Kolding & van Zwieten 2006). Lake parameters and physical–chemical factors are interlinked to primary productivity in most tropical lakes (Ives & Carpenter 2007; Abrahams 2008). However, the persistent sunlight and elevated temperatures induces higher evapotranspiration in the tropics, thus affecting lake levels and water volumes (Ouma & Tateishi 2006). The effect of climatic variables on lake level fluctuations has received scant attention, whilst the effect of lake level fluctuations on lake ecology has been largely neglected in most large and small African lakes (Kolding & van Zwieten 2012).

There is a dearth of research on the ecological and socio-economic consequences of water level fluctuations and the key drivers for shallow tropical lakes in Africa (Nhiwatiwa & Marshall 2007; Hofmann *et al.* 2008; Kolding & van Zwieten 2012). Reservoirs located in the semi-arid lowveld region of Zimbabwe, including the shallow Manjirenji Dam, were mainly constructed for agricultural and domestic water provision purposes, although other upstream and downstream abstractive uses of the water have developed (ZINWA 2014). Water level fluctuations are purported to be seasonal (intense during crop planting season and less intense during harvesting), compounded by erratic natural rainfall patterns and high evapotranspiration due to persistently high temperatures (ZINWA 2014). In order to assess the ecological and socio-economic implications of lake level fluctuations there is a need to first understand the historical trends in terms of water level fluctuation and integrate catchment and hydrological dynamics (Wang *et al.* 2011). Thus, in order to provide useful data integral for sustainable water resources utilisation for similar shallow reservoirs in tropical Africa, this study analysed the trends and assessed the effects of climatic factors and catchment dynamics on the water levels of the Manjirenji Dam in Zimbabwe.

DATA AND METHODS

Study area

Manjirenji Dam, formerly known as Lake McDougal, was constructed in 1964–1967 and started infilling in 1971. It lies east of Masvingo in the south eastern lowveld region of Zimbabwe (Figure 1). It is a rock fill built dam with an inclined clay core, and it closes off a section of the Chiredzi River, a catchment area of 1,536 km^2, maximum depth of 47 m and mean depth of 1.35 m (ZINWA 2014). Its area at full saturation level (FSL) is 2020 ha and it has a maximum volume of 650,000 m^3. It was built to provide irrigation water to the Mkwasine sugar cane farming estates in the lowveld region. Due to the seasonality of rainfall, high surface evaporation and intermittent water withdrawal for the downstream Mkwasine sugarcane estates, there are wide lake level fluctuations in the dam. The lake and its surroundings are protected as Manjirenji Dam Recreational Park (ZINWA 2014).

Data collection

The mean depth and lake level data were obtained from historical lake records at Zimbabwe National Water Authority. Weekly water levels data for Manjirenji Dam for the period 1983–2011 were used. Water level and stream flow datasets for the tributary rivers, Chiredzi and Murerezi, were obtained from the Zimbabwe National Water Authority (ZINWA 2014). Using the data, mean monthly water levels and stream flows were calculated and later categorized into wet and dry seasons based on the months. The wet season water levels, stream flow and abstractions comprised of the months November, December, January, February, March, April, May and the dry season comprised of June, July, August, September and October.

Daily precipitation, mean temperature, wind speed and relative humidity for the Manjirenji catchment for the

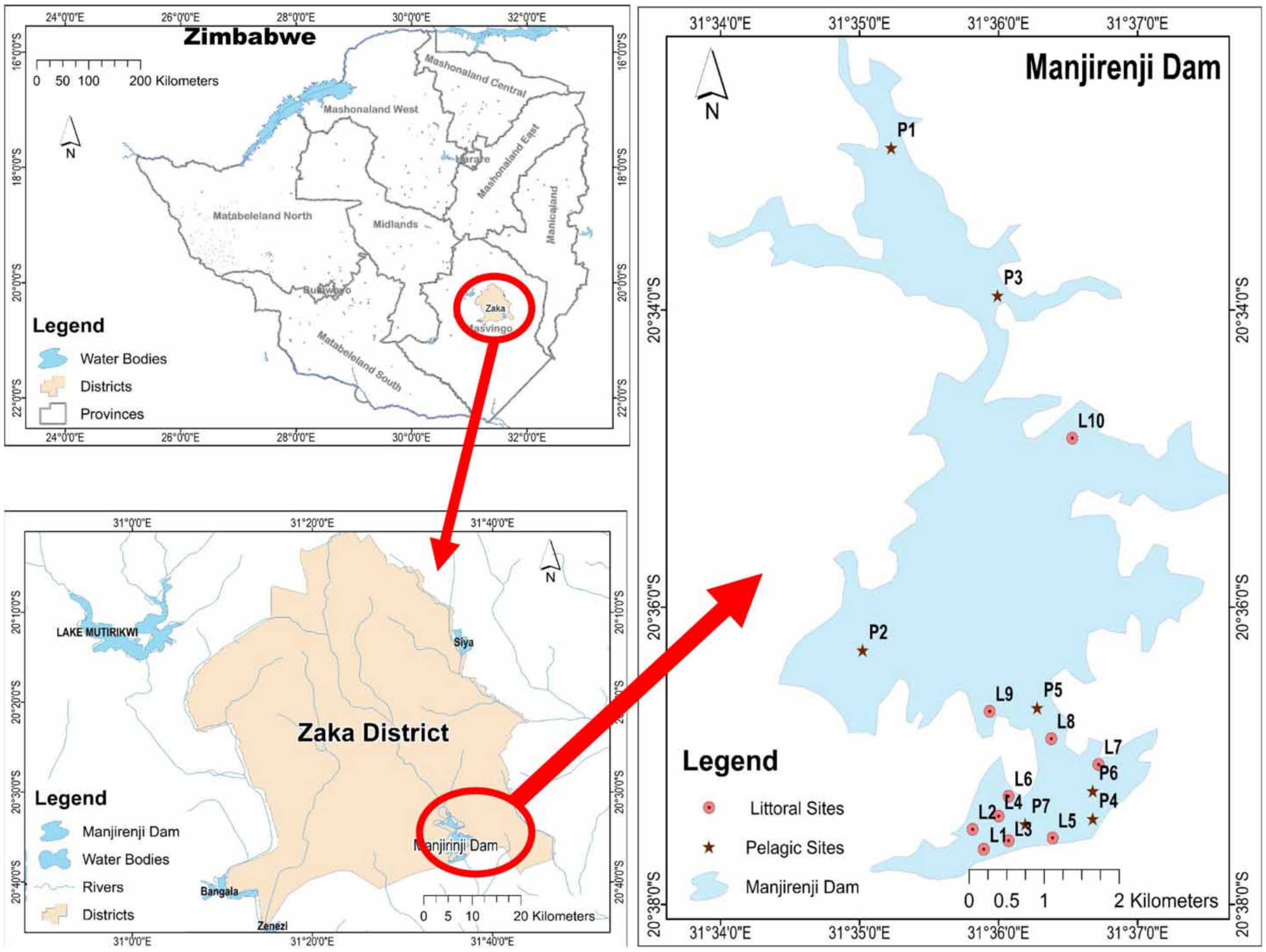

Figure 1 | Location of sites in the Manjirenji Dam, south eastern lowveld in the Zaka district of Zimbabwe.

period 1983–2011 were also analysed in order to explain the variations in water levels. Daily precipitation data were made available by the Meteorological Services of Zimbabwe. The data for mean temperature, daily wind speed and relative humidity were downloaded from the agro-climatic data website (www.larc.nasa.gov). 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. Monthly averages of each climatic variable were calculated and categorized into wet and dry seasons as for water level and stream flow datasets.

Landsat multispectral images for the years 1990, 1993, 1994, 1996, 1998, 1999, 2007, 2009, 2010 and 2011 were downloaded from the United States Geological Survey (USGS) (www.usgs.gov). All Landsat images were downloaded for the months of March and April so as to ensure time and space consistence in the pattern of Land Use Land Cover (LULC). Additionally, these months were selected because it was deemed that during these months satellites can capture distinct LULC types well as they are relatively cloud free periods in Zimbabwe (Mugandani *et al.* 2012). Landsat images were acquired in Digital Numbers (DN) format and radiometric calibration was performed to convert the DNs to spectral radiance units ($\mathrm{Wm^{-2}\,sr^{-1}\,\mu m^{-1}}$] in Envi 5.1, as outlined by Chander *et al.* (2009). The Fast Line-of-sight Atmospheric Analysis of Spectral Hypercube (FLAASH) model (Felde *et al.* 2003) was used for atmospheric correction of the images.

Thereafter, the pre-processed images were classified into different LULC types using the maximum likelihood classifier algorithm. A training sample set of six distinct landcover classes was generated for the following classes: builtup/bare, cultivated fields, water, shrubland, woodlands and grasslands. Areas covered by each landcover class were thereafter calculated for the respective catchment area in ArcMAP 9.3 using the geometry function as outlined by McCoy & Johnston (2001). The classification results were mapped in ArcGIS to indicate the changes in LULC across the catchment for the Manjirenji Dam.

Data analysis

Trends in water levels

Prior to all statistical analysis, the water levels data were tested for normality using the Shapiro–Wilk test. The data deviated from normality and consequently non-parametric tests were used. Trends of water levels of the dry and wet seasons were analysed for the Manjirenji Dam during the period 1983–2011 using the Mann–Kendall (MK) test. 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 1984a). The MK test is not affected by the actual distribution of the data and is less sensitive to outliers. It was first proposed by Mann in 1945 then enhanced by Kendall in 1975, with the current version improved by Hirsch & Slack (1984a). In statistical terms, this is a determination of whether the probability distribution from which the data arise has changed over time. The relative lake level fluctuation index (RLLFI) was calculated following the method by Kolding & van Zwieten (2012) using the formulae:

$$\text{RLLF Index} = \left[\frac{\text{Mean lake level amplitude (m)}}{\text{Mean depth (m)}}\right] \times 100.$$

Analysis of the influence of catchment dynamics on water levels

The Mann–Whitney *U*-test was used to assess statistical differences between wet and dry seasons water levels of the Manjirenji Dam. To determine the influence of catchment dynamics on water levels, the effect of catchment properties comprising mean monthly climatic variables (precipitation, mean temperature, relative humidity, wind speed and stream flows) were regressed on the wet and dry season water levels using multiple regression analysis. Catchment properties were used as independent variables, and monthly water levels for the wet and the dry season were separately used as dependent variables. Linear regression was also used to determine the effect of Land Use Land Cover Change on water levels. The LULC classes were used as independent variables and water level as the dependent variable. All tests were performed at the $p < 0.05$ significance level.

RESULTS

Water level fluctuations

Mean interannual lake level fluctuations show marked drops in lake level amplitude, particularly for the years comprising 1984, 1987, and the periods 1988–1991 and 1992–1995 during the wet seasons in the Manjirenji Dam. There were markedly sharp increases in water levels in 1985–1986 and 1991–1992, with a relatively high water level regime sustained from 1996–2011 in the Manjirenji Dam during the wet season (Figure 2). An overall increasing water level trend was noticed in the dam during the wet seasons for the period studied, 1983–2011, with a Sen Slope = 1.38, Z = 3.10 and $p = 0.025$.

For the dry season, the mean lake levels decreased sharply in 1984, 1987, 1988–1991, 1992–1995, and 1998 in the Manjirenji Dam (Figure 3). Sharp increases in water levels were noted in 1985–1986, 1988, 1995–1997, and 1999, with a relatively stable high water level regime from 2000–2010 observed during the dry seasons in the Manjirenji Dam (Figure 3). There was an overall increase in water levels in the Manjirenji Dam during the dry season for the period studied (1983–2011) with a Sen Slope = 1.81, Z score = 3.15 and $p = 0.034$.

The Mann–Whitney test indicated no significant seasonal differences (U = 13494.50; $p = 0.186$) in the water level fluctuations in the Manjirenji Dam, with a calculated mean RLLFI for the dam being 4.53 ± 1.75.

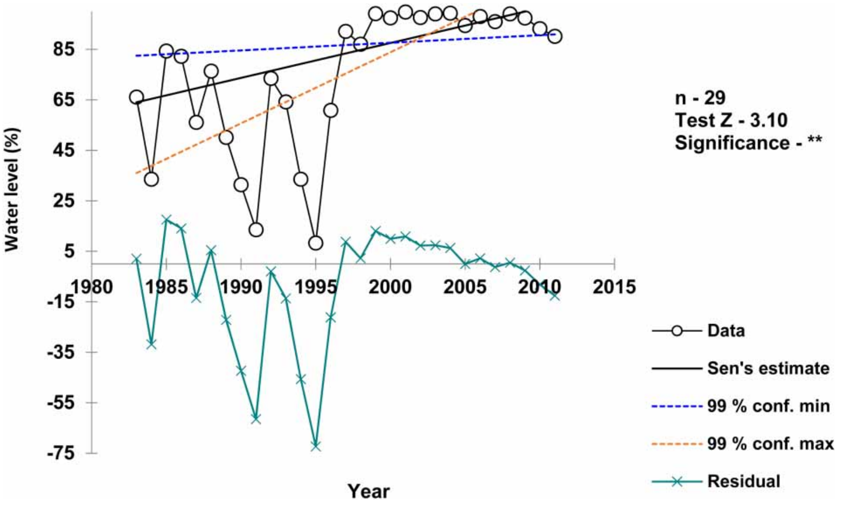

Figure 2 | A plot of the mean interannual lake levels of Manjirenji Dam in the wet season from 1983–2011.

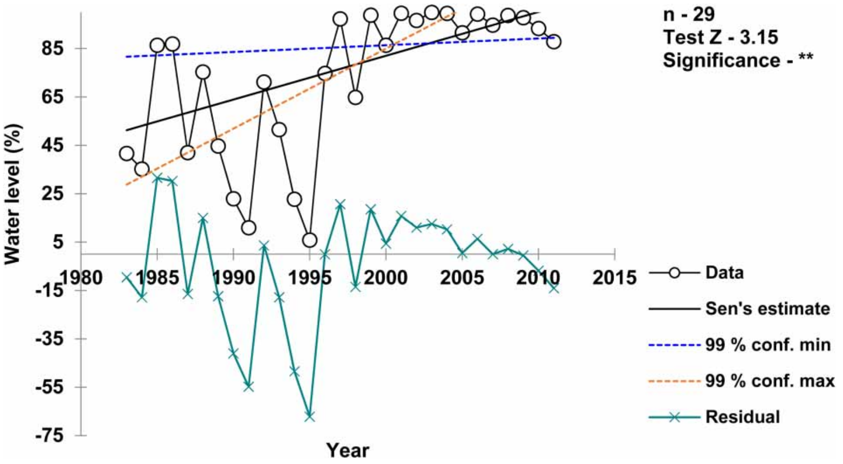

Figure 3 | A plot of the mean interannual lake levels of Manjirenji Dam in the dry season from 1983–2011.

Relative comparisons of the RLLFI for the Manjirenji Dam and extrapolation to resilience and stability criteria in Table 1, used on several African lakes by Kolding & van Zwieten (2012), reflect that the dam has moderate-wide fluctuation widths, moderate-high resilience and high stability. Table 2 indicates the RLLFI of the Manjirenji Dam relative to the RLLFI of selected and documented tropical reservoirs in Africa for inference purposes on lake level classifications and their implications on the ecology. From previous studies by Utete & Tsamba (2017), the dam is mesotrophic and relatively shallower than prominent lakes in Africa (Table 2).

Table 1 | Kolding & van Zwieten's (2012) classification of lakes and reservoirs based on the RLLFI, resilience and stability with the calculated example of classification for the Manjirenji Dam marked*

Relative lake level fluctuation index (RLLFI)	Fluctuation width	Resilience	Stability
0.01–4.00	Low	Low	Extremely high
4.10–8.00	Moderate-wide	Moderate-high	High
8.10–15.00	High-wide	High-	Moderate-high
15.10 and above	Extreme wide	Extremely high	Low
*Manjirenji Dam – 4.53	Moderate-wide	Moderate-high	High

*Indicates an example of the classification of the Manjirenji Dam.

Table 2 | Morphometric, hydrological, trophic status and the mean RLLF indices of selected African lakes (*Source:* Kolding & van Zwieten 2012) compared to the Manjirenji Dam*

Country	Reservoir/lake	Area (km^2)	Average depth (m)	Mean RLLF index	Current-trophic status
Zambia-Zimbabwe	Kariba	5,364	30.00	4.32	Mesotrophic
Malawi-Tanzania-Mozambique	Malawi	29,600	290.00	0.10	Mesotrophic
Zambia-Tanzania, Burundi-DR Congo	Tanganyika	32,900	580.0	0.04	Oligotrophic
Kenya-Uganda-Tanzania	Victoria	69,485	40.00	0.60	Meso-eutrophic
Ghana	Volta	8,500	18.80	7.02	Mesotrophic
Kenya	Naivasha	125	3.35	15.45	Mesotrophic
Malawi	Chiuta	113	2.50	19.53	Mesotrophic
Zambia, DR Congo	Mweru	2,700	8.00	7.20	Meso-eutrophic
Zambia	Bangweulu	2,735	3.50	7.39	Oligotrophic
*Zimbabwe	Manjirenji	20.2	1.35	4.53	Mesotrophic

*Indicates the morphometric, hydrological, trophic status and the RLFFI of the Manjirenji Dam relative to selected African reservoirs.

Catchment dynamics and their effects on water levels

Landuse landcover changes for the Manjirenji catchment for the period 1990–2011 are shown in Figure 4, with the trend patterns indicated in Figure 5. Built-up/bare areas have increased in size from 1990–2011, whilst cultivated fields initially decreased from 1990–1999, but are steadily increasing, grasslands have decreased in size for the period considered, 1990–2011 (Figures 4 and 5). Woodlands have decreased from 1994–2007, but increased gradually from 2007 onwards in the Manjirenji catchment, with water covered areas decreasing slightly in the period assessed, 1990–2011 (Figures 4 and 5). Interspersed decreases were observed in grassland, woodland, whilst shrubland increased near built-up areas within the Manjirenji catchment (Figures 4 and 5). Multiple regression analysis of land use and land cover patterns indicate that all the land use patterns considered, comprising built-up/bare area, cultivated fields, grasslands, woodlands, shrubland and water covered areas, have a significant effect ($p = 0.002$) on water levels in the Manjirenji Dam. Furthermore, all land use cover patterns have an overall significant effect of the streamflows of the Murerezi ($p = 0.006$) and Chiredzi ($p = 0.004$) rivers.

For the climatic factors considered important to water levels in Manjirenji Dam, consisting of rainfall, temperature, humidity, wind speed and a non-climatic factor; stream flows, the multiple linear regression analysis was separated into wet and dry seasons. Results indicate that, in the wet season, temperature ($p = 0.007$), humidity ($p = 0.000$), wind speed ($p = 0.000$) and stream flows at the Murerezi River mouth ($p = 0.000$) had significant effects ($p < 0.05$) on the water levels of the Manjirenji Dam. However, rainfall ($p = 0.394$) and stream flows of the main tributary ($p = 0.092$), the Chiredzi River, did not have a significant influence on the water levels of the Manjirenji Dam in the wet season. In the dry season, temperature ($p = 0.005$), wind speed ($p = 0.000$), and stream flows of the Chiredzi River ($p = 0.003$) had a significant effect on the water levels of Manjirenji Dam. Rainfall ($p = 0.274$), humidity ($p = 0.974$) and stream flows ($p = 0.153$) of the smaller tributary, the Murerezi River, had no significant effects on water levels of the shallow Manjirenji Dam in the dry season. The rest of the results are summarised in Table 3.

DISCUSSION

The main objective of this baseline study was to analyse the trends and assess the effects of climatic factors and catchment dynamics on the water levels of the shallow Manjirenji Dam, located in an arid lowveld region in Zimbabwe. There was a positive uptrend in the water levels of the Manjirenji Dam in both the wet and dry seasons. Regardless, there were sharp and marked drops in the interannual lake level variations for both seasons in the dam. The sharp drops in water levels were prominent in either drought stricken years or post-drought recovery periods, such as

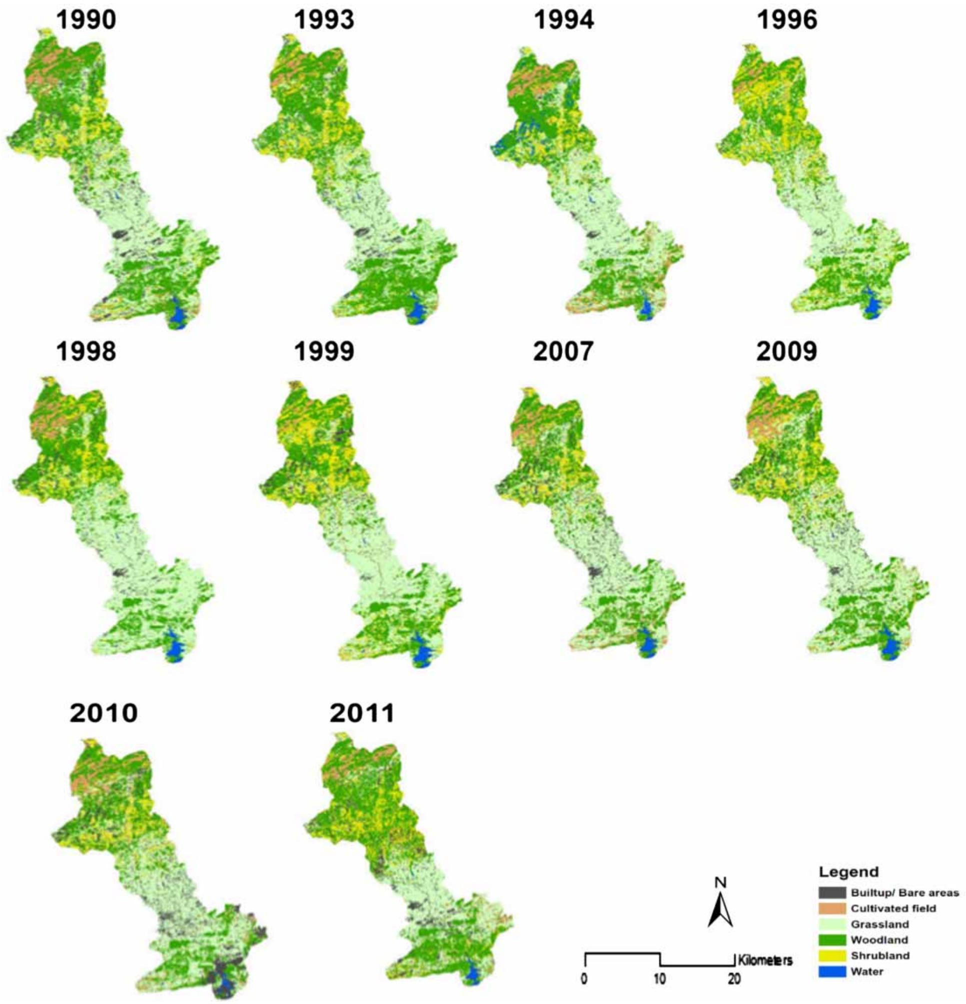

Figure 4 | Landcover land use changes for the Manjirenji catchment for the period 1990–2011.

1984, 1987, 1988–1991, and 1992–1995 (Mugandani *et al.* 2012). Significant increases in lake levels were observed during periods of sustained abundant rainfalls, such as 1996–2011, or the immediate post-drought recovery periods (1985–1986, 1991–1992), especially in the wet season. In the wet season temperature, humidity, wind speed and stream flows in the second largest tributary, the Murerezi River, had a significant impact on the water levels of the Manjirenji Dam. Wetzel (2001) indicates that natural precipitation and related aspects of the water budget, such as evapotranspiration and runoff, significantly impacts water levels in shallow lakes in the wet seasons.

Rainfall and streamflows from the main tributary, the Chiredzi River, were not significantly related to water levels in Manjirenji Dam in the wet season. This finding indicates a need to further investigate the influence of other climate and catchment factors affecting the water balance in the wet season. Factors such as evaporation or catchment dynamics, including water abstraction or underground leakages, which were not explored in this study due to lack of reliable and consistent data, need to be explored for future studies. Even for the wet seasons a combination of hydrological factors and catchment dynamics tend to exert extra pressure on the water balance of shallow reservoirs like the Manjirenji Dam, which has multiple designated purposes in the drought or post-drought years (Hollis & Stevenson 1997). In tropical arid regions such as the lowveld area in Zimbabwe, with abundant sunshine and high

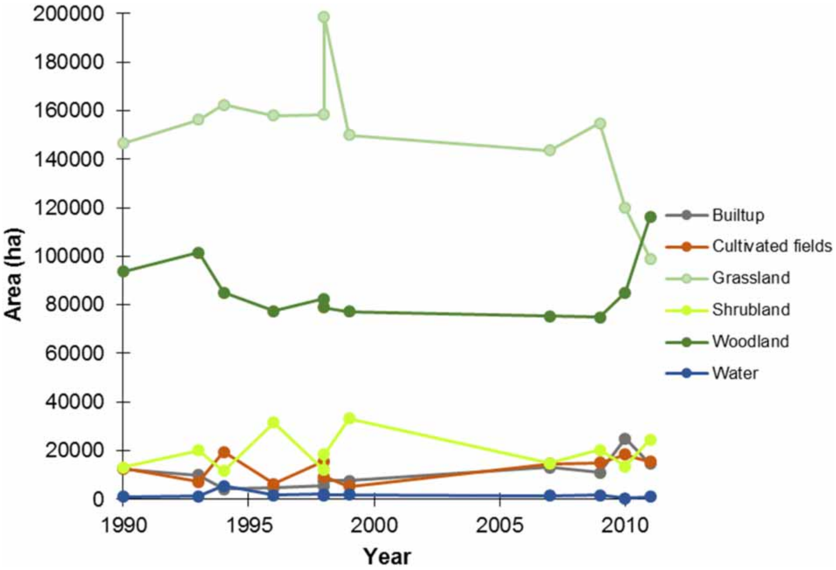

Figure 5 | Trends in landcover land use changes for the Manjirenji catchment for the period 1990–2011.

Table 3 | Regression output for the relations between water levels and catchment factors in the Manjirenji Dam in the wet and dry season (1983–2011)

	B	Significant error	B	t	p
Wet season					
Constant	0.426	0.296		1.437	0.152
Rainfall	0.000	0.000	0.067	0.854	0.394
Temperature	−0.034	0.012	−0.263	−2.748	0.007*
Humidity	0.01	0.002	0.341	4.346	0.000*
Wind	0.198	0.052	0.321	3.822	0.000*
E108M	0.000	0.000	0.118	1.694	0.092
E159M	0.000	0.000	−0.268	−3.913	0.000*
Dry season					
Constant	0.740	0.368		2.010	0.046
Rainfall	−0.001	0.001	−0.101	−1.097	0.274
Temperature	−0.039	0.013	−0.433	−2.867	0.005*
Humidity	0.000	0.005	0.003	0.032	0.974
Wind	0.270	0.056	0.617	4.839	0.000*
E108M	0.000	0.000	0.240	3.004	0.003*
E159M	0.000	0.000	−0.112	−1.438	0.153

Note: Stream flows recorded at a gauging station at the Chiredzi river mouth (E108M) and the Murerezi river mouth (E159M). Dependent variable is water level.
*Significant *p* values.

atmospheric temperatures, the wet seasons have low humidity, and high surface temperatures and variable wind speeds (Chipindu 2008; Mugandani *et al.* 2012). A combination of low inflows from the main tributary, the Chiredzi River, and fluctuations in the hydrologic factors of the water budget significantly decrease water levels in shallow wetlands such as the Manjirenji Dam (Coops *et al.* 2003).

Similar to the wet season patterns, the dry season water levels in the Manjirenji Dam dropped sharply during the drought or post-drought years. Increases in the water levels in the dry season coincided with periods of high precipitation amounts (Chipindu 2008; Mugandani *et al.* 2012). Rainfall, humidity and stream inflows of the smaller tributary, the Murerezi River, did not have a significant influence on water levels of the Manjirenji Dam in the dry season. This is largely expected as low precipitation, humidity and runoff in the dry season do not have a significant impact on the levels of shallow lakes (Loaiciga *et al.* 1996; Mazvimavi 2010). Fluctuations in wind speed, surface temperatures and low stream flows in the main tributary, the Chiredzi River, affects water levels in the Manjirenji Dam during the dry season. Wetzel (2001) and Kolding & van Zwieten (2012) indicate that evapotranspiration (which conjoins surface temperature and wind speed), as a component of the water budget, largely influences water levels in shallow wetlands. Due to a lack of consistent, reliable long term outflow data in the Manjirenji Dam, the long term and seasonal effects of water withdrawing activities were not estimated. Although controlled water abstractions were not explored, logical deductions tends towards further lowering of shallow lake levels by lake outflows in the dry season (Mazvimavi & Vandewiele 1987; Mazvimavi 2010).

Among the most frequently mentioned non-climatic pressures in relation to fluctuations in water levels and quality of inland lakes such as Manjirenji is variation in LULC patterns within the catchment (Kibena et al. 2014; Tendaupenyu et al. 2016). Analysis of LULC detected changes in the spatiotemporal dynamics of six prominent land classes (built-up/bare area, cultivated fields, grasslands, woodlands, shrubland and water covered areas) in the Manjirenji catchment for the period 1990–2005. Intermittent changes in all LULC classes have a significant effect on water levels in the Manjirenji Dam. Apart from natural hydrologic patterns and dynamics of water budget components, anthropogenic and climate change driven shifts in LULC tend to impact the water levels of immediately surrounding tropical lakes (Tendaupenyu et al. 2016). Further regression analysis indicated a significant relation among LULC in the Manjirenji Dam and the stream flows of the Murerezi and Chiredzi rivers. Changes in LULC in the watershed impacts the hydrological cycle and processes, thus influencing stream flow variations and in turn affecting lake levels.

For both seasons, land use changes within the Manjirenji catchment significantly affect the stream flows of the main tributaries, the Chiredzi and Murerezi rivers. The classes of land uses within the catchment are mainly dominated by built-up areas, shrublands, woodland and cultivated fields. The main seasonal activities, such as cultivation and tree felling for firewood, in the Manjirenji catchment result in soil erosion whose effects are noticeable in the reduced stream flows of the main tributary, the Chiredzi River, in the dry season (Mazvimavi & Vandewiele 1987). Agricultural intensification and population increases in the Runde catchment, where the Manjirenji subcatchment is located, leads to decreased run off (Lørup et al. 1998). Reduced runoffs in the two main tributaries leads to lowered water levels in the Manjirenji Dam, particularly in the dry season when precipitation is low (Mazvimavi 2010). Moreover, there are non-seasonal water abstraction activities from the Chiredzi River as well as the Manjirenji Dam for irrigating the vast Mkwasine sugarcane estates. These non-seasonal activities further reduce stream flows in the two rivers and leads to lowered water levels in Manjirenji Dam.

The RLLFI for Manjirenji Dam was 4.53, a figure significantly high relative to larger and deeper African tropical lakes (Table 2). Adoption of the lake classification criteria by Kolding & van Zwieten (2012) leads to categorization of the Manjirenji Dam as an aquatic system with moderate-wide lake level fluctuations, a moderate–high resilience, and high stability. Significance of the relative lake level fluctuation derives mainly from the imbrication of control processes that maintain ecosystem resilience (Allison 2004; Carpenter & Brock 2004). Although the RLFF concept has gained prominence in estimating lake productivity as morphological parameters are conceptually static and therefore difficult to define in fluctuating aquatic environments, its correlation to lake resilience and stability and trophic status is still tangential (Kolding & van Zwieten 2012).

The RLLF indices, subject to availability of historical lake level data, can be used as comparable proxies for lake productivity, resilience, stability and integrity restoration capacity (Carpenter & Brock 2004; Wang et al. 2011). Non-convergence (and their cost related aspects) of comprehensive methods of measuring lake productivity and assessment of resilience necessitates simple indicator indices that can aid management and conservation of lake ecosystems, especially in poor, developing countries (Kolding & van Zwieten 2012). Reliance of the RLLFI on the mean depth further strengthens its utility as the mean depth parameter encapsulates several other lake morphometric attributes (Wetzel 2001; Kolding & van Zwieten 2012). By no means does the RLLF substitute for more rigorous episodic limnochemical and biomonitoring methods (Wang et al. 2011; Kolding & van Zwieten 2012). It merely acts as a pointer to lake stability, resilience and productivity. Historical, contemporary and predicted future lake level data can also be applied together with forecasted climatic and catchment data to estimate lake productivity, resilience and stability (Kolding & van Zwieten 2012). This is advantageous for aquatic systems facing threats due to climate change, such as the Manjirenji Dam which is located in a drought ravaged and arid region in Zimbabwe (Mazvimavi 2010).

Fluctuating water levels are necessary to maintain dynamic, diverse and healthy wetlands (Antenucci *et al.* 2003). Non-directional cycles of high and low water levels create diverse wetland vegetation that is more resilient to other stresses impacting the system (Abrahams 2008). Thus, determination of lake level fluctuations and drawdown zone extensions can therefore be a proxy for bottom-up driven processes (Abrahams 2008). For shallow lakes such as the Manjirenji, non-seasonal differences in lake level fluctuations over decades imply elevated stability and this translates to a highly resilient system punctuated by an ecotone zone with high nutrient exchange between the terrestrial and aquatic habitat (Carpenter & Brock 2004; Anderies *et al.* 2006; Kolding & van Zwieten 2012). Hence, a permanent succession of highly adapted hydrobionts community assemblages are expected (Carpenter & Brock 2004; Anderies *et al.* 2006; Mayo & Jackson 2006). Shallow tropical lakes with multiple designated uses like the Manjirenji Dam are prone to extreme shocks such as wide WLF in drought ravaged and post-drought years, despite the inferred high stability and resilience contrary to widely held assertions (Abrahams 2008; Wantzen *et al.* 2008).

CONCLUSIONS

There was an uptrend in the water levels of the Manjirenji Dam over the study period although we detected no significant seasonal heterogeneity in water level fluctuations. This suggests overlapping non-seasonal effects of catchment and climatic variables on lake levels of the shallow tropical reservoir. Regardless of the inferred high resilience and stability indicated by the calculated RLLFI of 4.53, there is a need for strict regulation and astute management of anthropogenic activities such as water abstraction, unregulated outflows and even upstream processes. A combination of catchment dynamics such as land use patterns and some climatic factors have significant effects on the water levels of the dam. Thus, for shallow tropical lakes located in arid regions, such as the Manjirenji Dam, which have multiple designated purposes, we recommend long term continuous monitoring of water level fluctuations in light of their exposure to extreme climate variability and climate change.

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