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# Water policy and resilience of potable water infrastructure to climate risks in rural Malawi

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ABSTRACT

Adverse effects of climate risks on access to potable water are increasingly being acknowledged in sub Saharan Africa. Resilient infrastructure supported by appropriate governance arrangements, is therefore central to water security under these extreme weather events. For several decades, governments in sub Saharan Africa have developed governance arrangements including infrastructure and legislation to ensure water security. However, the effectiveness of policy consideration in resilience of potable water infrastructure to climate risks/extreme weather events as well as their seasonality has been a neglected area. Using Zomba rural in Southern Malawi as a case study, this study was therefore aimed at addressing this gap by assessing the effectiveness of local water policy responses to extreme weather events using the 2015 flooding effects on potable water in Zomba rural in Southern Malawi as a case study. The study firstly analysed rainfall and extremes indices for evidence of trends of climate risks in Zomba during the period from 1982 to 2015. To understand the effects of the 2015 flooding on water infrastructure and access to potable water as well as evaluate policy provisions for responses to climate risks, the study further applied a qualitative approach through policy document review, key informant interviews, focus group discussions. The results suggest a generally decreasing annual rainfall pattern with high variability by seasons and frequent occurrences of droughts and flooding. The annual rainfall decrease was not statistically significant at $\alpha = 0.05$ level, whereas the extremes indices were statistically significant. However, the study found that current policy frameworks are more biased towards drought preparedness as compared to flooding preparedness. For instance, the 2015 floods destroyed vital water supply infrastructure and the responsible institutions could not rehabilitate the damaged infrastructure, leaving communities with intermittent and no supply of potable water for over six months. On the other hand, during dry seasons and drought conditions, the intakes are above the water level. These results show that the present rural water infrastructure is vulnerable and not resilient enough to extreme weather events. In addition, the water institutions are especially not prepared to handle flooding events and their impacts. In this regard, water legislation and infrastructure designs do not adequately take into consideration the effects of extreme events on access to potable water, making water security a challenge in rural Malawi.

## 1. Introduction

Adverse effects of climate risks on access to potable water are increasingly being acknowledged in the sub Saharan Africa. Climate risks affect both quality and quantity of groundwater and river/stream flows (Al Adif, 1999; Bates et al., 2008; Savenije and Van Der Zaag, 2008; Government of Malawi, 2010), consequently human right to water[1] (de Albuquerque, 2009). Resilient infrastructure, supported by appropriate governance arrangements, is therefore central to water security under these extreme weather events. Resilience is the ability of a system and its counterparts to anticipate, absorb, accommodate or recover from the effects of a hazardous event in a timely and efficient

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[1] Defined as the right of everyone to sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic uses".

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manner (IPCC, 2012). Reducing infrastructure vulnerability to climate impacts means increasing resilience. Vulnerability of infrastructure systems to climate events is the susceptibility of those infrastructures to harm from climate hazards (Boyle et al., 2013). The vulnerability of particular infrastructure depends on its sensitivity to climate risk – that is, the tendency of infrastructure to be affected due to at least three factors: the age, the composition and the design of infrastructure – and the adaptive capacity of the sector by minimizing negative impacts and/or maximizing positive ones (ibid). Garnaut (2011) estimates that about 40% of global economic climate impacts are related to infrastructure hence "it is important to have a more climate resilient and robust infrastructure network that is able to cope with projected climate impacts e.g. increased flexibility to cope with uncertainty without excessive failure and economic cost" (HM Government, 2011). This is the main focus of Sustainable Development Goal 9 - building resilient infrastructure. In the context of water resources management, resilience of new water infrastructure can be achieved by ensuring that it is located, designed, built and operated with the current and future climate in mind (ibid). Recent extreme events have revealed that water suppliers in a catchment need to rethink and review their vulnerability assessments, not to only rely on historical forecasts but to plan for more extreme circumstances outside previous assumptions (WHO, 2011). For existing infrastructure, ensure that maintenance regimes should incorporate resilience to the impacts of climate change over an asset's lifetime (HM Government, 2011). In this regard, water utilities adaptation measures should (HM Government, 2011; The US EPA, 2014; Sayers et al., 2015):

- Ensure that infrastructure is resilient to potential increases in extreme weather events such as floods and droughts.
- Ensure that investment decisions take account of changing patterns of consumer demand as a result of climate change.
- Build in flexibility so that modification to existing infrastructure (in the long term), recovery or replacement costs after occurrence of e.g. a flood should not involve excessive, or unnecessary, cost.

Ensure that infrastructure organisations and professionals have the right skills and capacity to implement adaptation measures.

In the context of flooding, a resilient water utility is able to "withstand a flooding event, minimize damage and rapidly recover from disruptions to service" (The US EPA, 2014). Against this background, ensuring the resilience of water infrastructure is essential for sustained access to potable water. Additionally, adequate capacity of water institutions to manage/adapt to floods and droughts is also important. Water security is in part attained when all people have access to "enough safe, affordable water to lead a clean, healthy and productive life" (Global Water Partnership (GWP), 2000). This definition primarily emphasizes universal "access to potable water for basic human needs or domestic use" (Lautze and Manthrithilake, 2012), addressing unequal distribution of potable water (Savenije and Van Der Zaag, 2008; Bogardi et al., 2012; Loftus, 2014). Water security focuses on improving quality of life for all, specifically disadvantaged groups including the vulnerable and poorest (Bogardi et al., 2012; Lautze and Manthrithilake, 2012; Loftus, 2015).

For several decades, governments in sub Saharan Africa have developed governance arrangements including infrastructure and legislation to ensure water security. However, the effectiveness of policy consideration in resilience of potable water infrastructure to climate risks/extreme weather events as well as effect of seasonality of natural disasters (specifically shocks) on access to potable water have been the neglected areas (Chambers, 2009). From Chambers (2009) perspective:

> "The seasonality of disasters is so evident and obvious that it can pass unrecognised. When seeing how seasonal dimensions interlock as cyclical screws, it is easy to miss shocks which may not come every season, but to which people and communities are vulnerable at certain times of the year. In rural communities most of these are during the rains: floods, landslides, riverbank erosion, storm surges and high waves.

This study is premised on the notion that understanding appropriateness of national water policy and legislation to ensure resilient infrastructure is central to improved access to potable water because these provide legal basis for holding actors accountable. This study was therefore conducted to address this gap in Malawi owing to its vulnerability to increased trends of extreme weather events and related impacts on water resources management (Government of Malawi, 2011). Table 1 shows the top 10 natural disasters in Malawi from 1900 to 2015 in terms of populations affected. It is worth noting that 9 of the 10 disasters occurred over the past two decades. From December 2014, Malawi was affected by heavy rainfall that caused rivers to overflow and disastrous flooding especially in the southern part of the country. By 5 January 2015, over 600,000 people were affected by flooding (Table 1). Based on the number of people affected, this is considered among the worst flooding events on record since 1900 (Table 1). Zomba which is located in Southern Malawi was one of the affected districts.

Therefore, this study was aimed at assessing the effectiveness of local water policy responses to extreme weather events, using the 2015 flooding effects on potable water in Zomba rural in Southern Malawi as a case study.

## 2. Study area, data and methods

The study focused on four villages namely Kasonga, Mtuluma, Makombe and Mpheta (Fig. 1) in Zomba District in southern Malawi. The villages are located in small river sub—basins that are tributaries to the Shire River in the upper section. Mtuluma and Kasonga Villages are upper catchment communities while Makombe and Mpheta Villages are downstream communities along the Shire River tributaries.

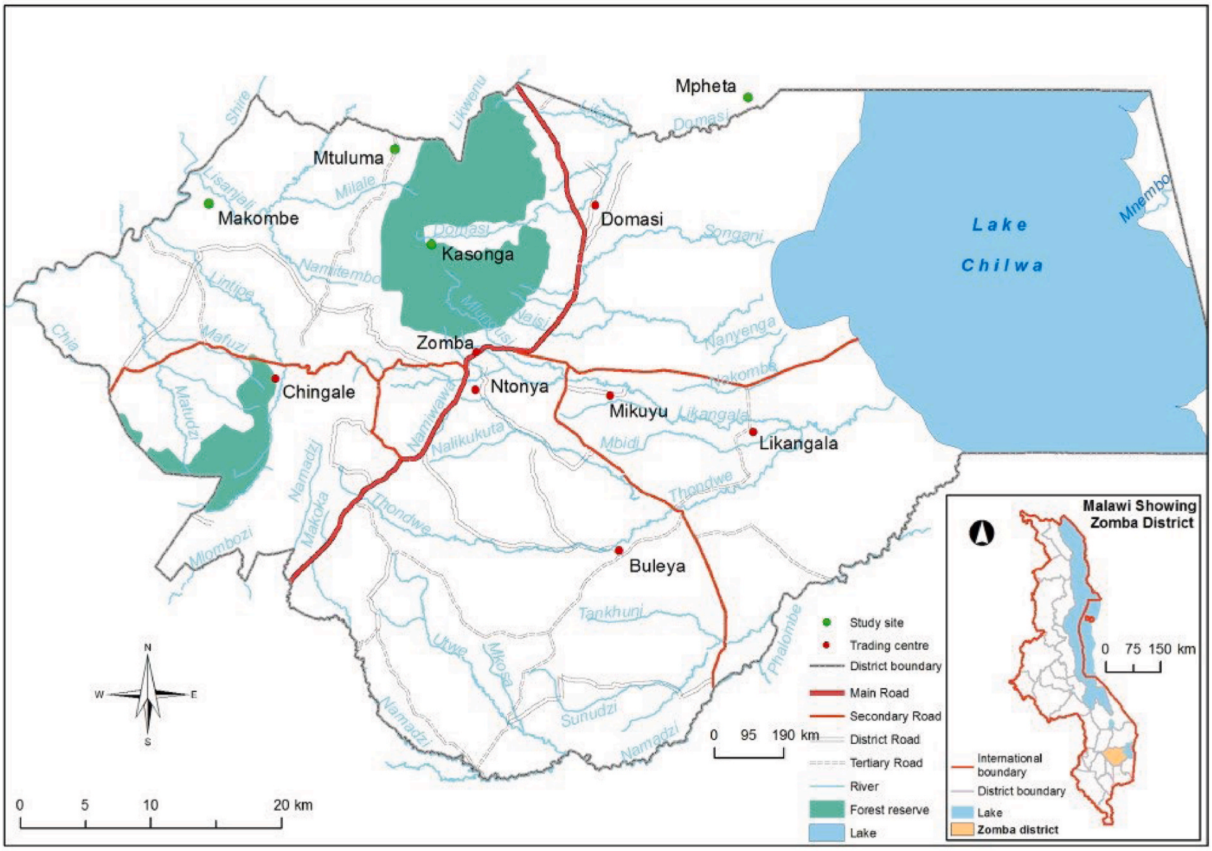
The study firstly analysed rainfall data for evidence of trends of climate risks in Zomba District during the period from 1982 to 2015. From the climate data, the following indices of climatic extremes were extracted using Rclimdex Package of R software (Zhang and Yang, 2004): Annual Precipitation(PRECPTOT: Total wet day annual precipitation when PRCP$>$1 mm); Consecutive number of Dry Days (CDD: Maximum number of consecutive days with RR $<$ 1 mm); Consecutrive number of wet days (CWD: Annual maximum number of consecutive days with RR $\geq$ 1 mm); Simple Daily Intensity Index(SDII: Annual total precipitation divided by the number of wet days when PRCP$\geq$1.0 mm), R25mm (Annual count of days when PRCP$>$25 mm); Rx1day (Annual Maximum 1-day Precipitation). These indices are recommended by the recommended by the World Meteorological Organization– Commission for Climatology (WMO–CCL) and the Research Programme on Climate Variability and Predictability (CLIVAR). The significance of trends in the extremes were analysed using the Mann-Kendall statistic (Mann, 1945; Kendal, 1975).

Secondly, the study evaluated the integration of extreme weather events in the design and rehabilitation of selected drinking water

**Table 1**
Top 10 natural disasters in Malawi sorted by number of people affected 1900–2015.

| Type of extreme event | Date | Total number of people affected |
|---|---|---|
| Drought | Apr-1992 | 7000000 |
| Drought | Oct-2005 | 5100000 |
| Drought | Feb-20002 | 2829435 |
| Drought | Feb-1990 | 2800000 |
| Drought | Aug-2012 | 1900000 |
| Drought | 1987 | 1429267 |
| Flood | Jan-2015 | 638645 |
| Drought | Nov-2007 | 520000 |
| Flood | Jan-2001 | 500000 |

Source: Guha-Sapir et al., 2015



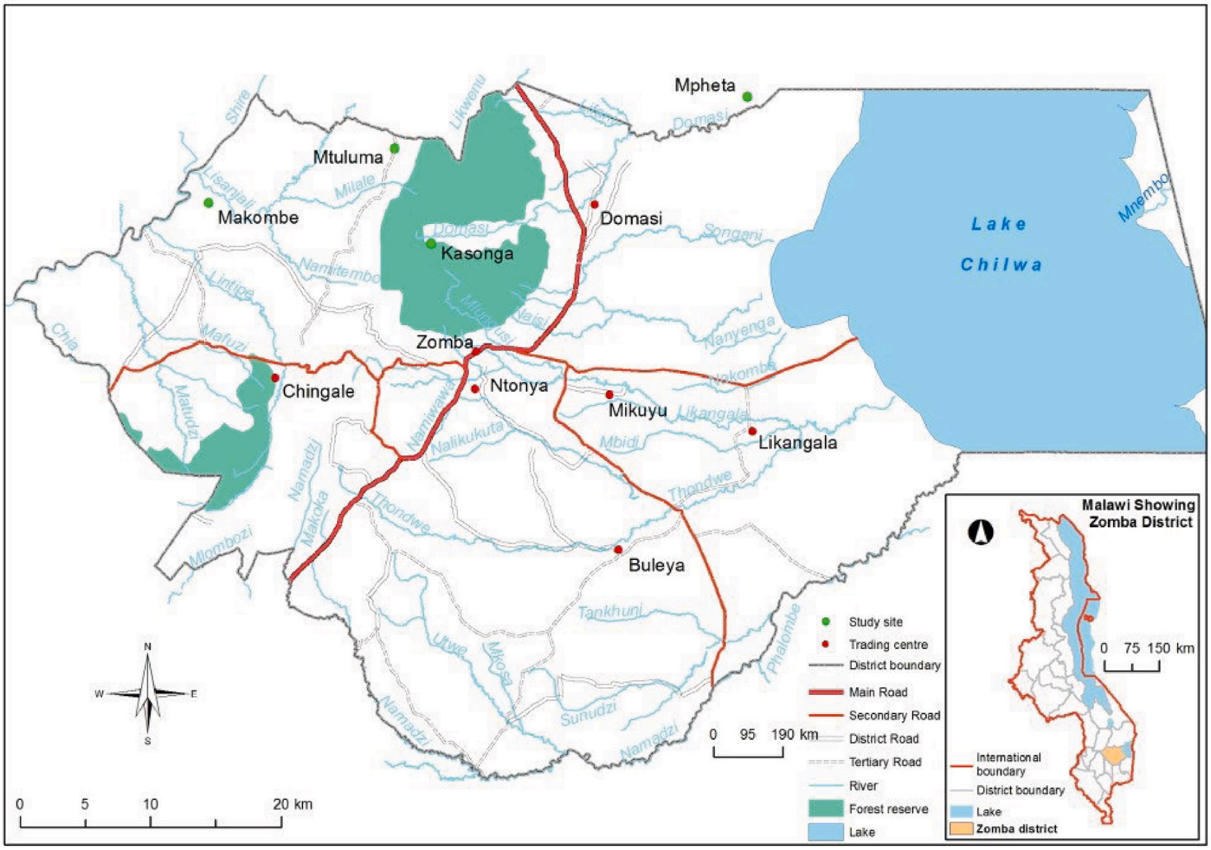


**Fig. 1.** Map of Zomba showing the study area.

infrastructure. The study further applied a qualitative approach through thematic review of water policy and legislation, key informant interviews and focus group discussions to evaluate policy provisions for responses to climate risks and their delivery in response to the effects of the 2015 flooding on water infrastructure and access to potable water.

In addition, a review of 38 water policy and related documents (national legislation) was employed to understand formal water governance in relation to climate risks. Four focus group discussions (FGDs) were held with poor women. Poor women were in this study defined as single mothers who are household heads and mostly depend on agriculture production for their livelihoods. The study focused on such women because: 1) they play a central role in water provisioning in their households (Benería, 1995; Makoni et al., 2004; Singh et al., 2005; Geere et al., 2010; Boone et al., 2011; Sorenson et al., 2011; Earle and Bazilli, 2013); 2) are vulnerable to climate risks because of their low adaptive capacity; 3) and are mostly voiceless (de Albuquerque, 2012). Furthermore, a total of 14 key informant interviews with water officials and community water executive committee members were used to explore contradictions raised by the FGDs. Key informant interviews fell into three groups: village leaders (chiefs (VL1) and executive committee members (VL2)), NGO staff (working in village in water related interventions)) (NGO1) and government staff (community (G1) and district water officers (G2)) selected in their official capacity. The key informant interviews were also used to complement documentary analysis on policy adaptation to climate risks. All interviews were recorded, translated into English (if conducted in local language) and the relevant contents were carefully transcribed verbatim (Bryman, 2004). Qualitative content analysis was applied to the transcripts using the computer assisted qualitative data analysis software (CAQDAS) Nvivo. Deductive codes derived from socio ecological systems (SES) theoretical framework were applied to units of each transcript. The unit of data include a line of transcript or sentence(s) or complete paragraph (Saunders et al., 2012). The coded texts for each code (or combination of codes) (Bryman, 2012) were retrieved and critically analysed for emerging patterns in issues raised.

## 3. Results and discussions

### 3.1. *Empirical evidence of trends of climate risks in Zomba from 1982 to 2016*

The results suggest a generally decreasing annual rainfall pattern (Fig. 2) with high variability by seasons and frequent occurrences of droughts and flooding. Annual mean rainfall during the period was 1220 mm, with a coefficient of inter-annual variability of 31%. The lowest annual rainfall during the period, totaling 455 mm, was recorded in 1994/95 season at the end of the four-year major drought that hit the entire southern African region. On the other hand, monthly mean rainfall was 102 mm, although most of this can be accounted for during the main rain season months between November and April. The highest monthly rainfall of 701 mm was observed in March 1985 whereas the second highest amounting to 630 mm was observed in January 2015. The later event resulted in significant flooding and infrastructural damage in many parts of Zomba as most of it (over 300 mm) was distributed over a three-day period between 12 and 15 January 2015. Unlike the annual rainfall temporal pattern, the monthly regime (Fig. 3) exhibits a generally more stable pattern.

Both the annual and monthly rainfall did not have statistically significant trends at $\alpha = 0.05$ level, according to the Mann-Kendal test statistics. The rainfall trend results confirm study findings by previous studies such as McSweeney (2008, 2010) and Ngongondo (2011, 2015). Similar results on annual and monthly rainfall trends were found in four other weather stations surrounding the study sites namely Liwonde, Chingale, Ntaja and Namwela.

Analysis of the rainfall extreme indices (i.e. SDII, CWD-, CDD, Rx1day and R25mm) suggests that they have in recent years been more intense, meaning that most of rainfall can be accounted for by a small number of rainy periods (shown by increasing CWD) and followed by periods of more consecutive dry days (CDD). In addition, the Simple Daily Intensity Indices (SDII) suggest more intense rainfall events (increasing SDII) whenever it rains. This may result in total annual rainfall being the same but with uneven seasonal distribution.

Chingale weather station, which is located closest to the study villages and has record length similar to that of Zomba, depicts negative trends in total annual rainfall and maximum one day precipitation but these are not statistically significant at $\alpha = 0.05$ level (Figs. 4 and 5 respectively). The linear regression trend test shows negative slope of 1.2 mm per year. The area also features an increasing trend of consecutive dry days statistically significant at $\alpha = 0.05$ level and consecutive wet days (Figs. 6 and 7 respectively). This further suggests concentration of heavy rains within a few days and lengthy dry spells or early cessation of rains. Such trends have the potential for flooding during days of heavy rains followed by dry spells within the same season. This pattern is crucial for both surface and underground water availability especially during the dry season, as flooding may result in reduced seepage due to increased overland flow. Reduced seepage means low water tables which can result into low water yield for boreholes and springs as well as low stream flow for tap water during dry season and consequently pose challenges for villagers.

### 3.2. *Policy consideration of climate risks and resilience of water infrastructure*

The National Water Policy (Government of Malawi, 2007) and legislation (Government of Malawi, 2013) acknowledge increasing frequency of extreme weather events, specifically floods and droughts as well as associated water access challenges. The policy documents also recognize temporal variations of potable water access. In response, the policy documents include provisions aimed to address these challenges including associated water access challenges. Key strategies include: catchment management, infrastructure water development e.g. community and multipurpose dams to regulate variable water flows and flood control and capacity building in the water sector. There are also other provisions specific for managing drought conditions (Table 2). These strategies have potential to make service provision resilient to

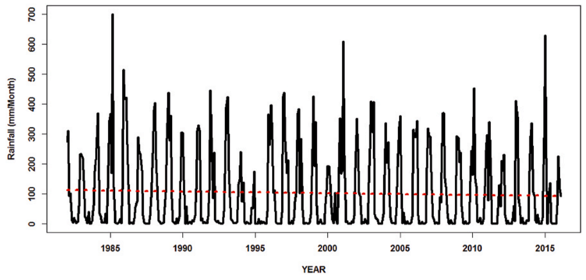


**Fig. 2.** Monthly rainfalls for Zomba during 1982–2016.

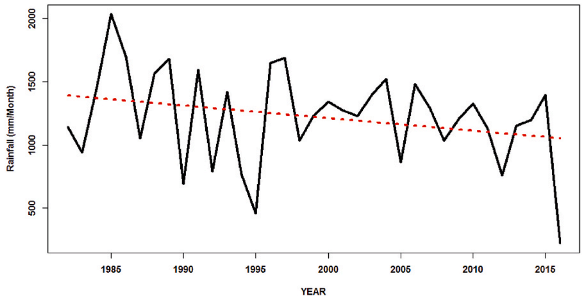


**Fig. 3.** Annual rainfall for Zomba during 1982–2016.

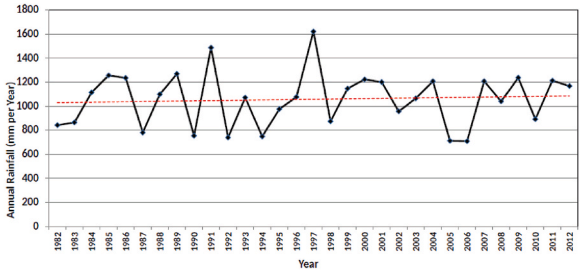


**Fig. 4.** Annual total wet-day precipitation for Zomba during 1982–2016.

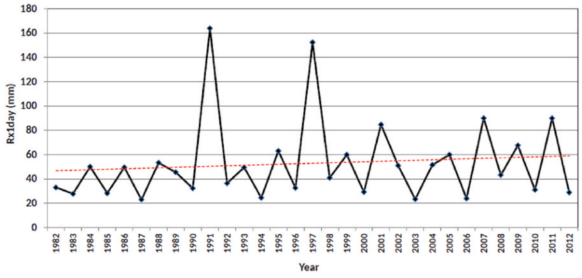


**Fig. 5.** RX1day maximum at Chingale during 1960–2012.

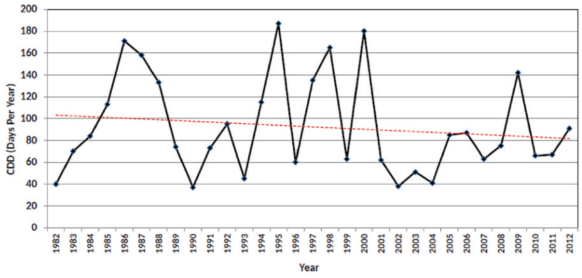


**Fig. 6.** Consecutive number of dry days (CDD) at Chingale during 1982–2012.

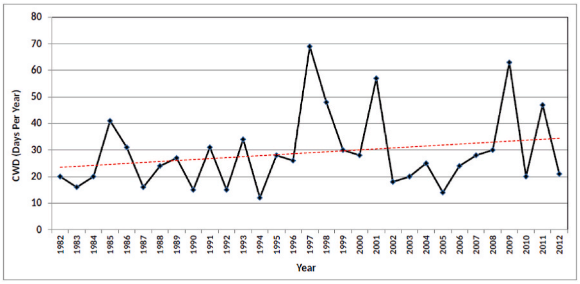


**Fig. 7.** Consecutive number of wet days at Chingale during 1982–2012.

extreme weather events. However, resilience does not feature in the National Water Policy hence there is no guarantee that implementation of the strategies is likely to conform to current and projected trends in extreme weather events specifically floods and droughts. Additionally, the National Water Policy acknowledges inadequacies of local governments' "*contingency plans or capacity to mitigate the impact of water related disasters*" (NATW3 -National Water Policy). Hence the suggested strategies aim to address this challenge and ensure "*timely provision of potable water … for vulnerable communities especially children, women … during water-related disasters;*" and provision of "*basic requirements of potable water supply to all affected areas*" through provision of "*emergency water supply systems including boreholes, hand-dug wells and portable treatment units*" (NATW3).

**Table 2**
Drought and flood management strategies in water policy and legislation.

| Strategy | Aim | Details in policy and legislation |
|---|---|---|
| Catchment protection and rehabilitation | Conserve water, reduce physical scarcity & pollution | The Act makes provision of establishment, composition and purpose of a catchment area, catchment management committee and incentives (funding). |
| Rehabilitation of water infrastructure | Loss minimisation; reduce impact of shocks | Rehabilitation of catchment areas, boreholes and gravity-fed water supplies as a safeguard to reduce the impact of supply shocks from droughts (NEP, 2004; NSSD, 2004)<br>Water Policy (2005) promotes undertaking rehabilitation and reduction of unaccounted-for-water of existing community water supply schemes (gravity-fed water supply schemes and boreholes) as a priority.<br>Water Users Association (WUA) is expected to "*construct, rehabilitate, operate and maintain any works for the purposes of management of the water resource in its area of operation* (WRA, 2013) |
| Controlling certain activities | | The Minister may declare any part a controlled area and control certain activities in relation to drought or shortage/anticipated shortage of water e.g. irrigation (WRA, 2013 sections 86 & 87) |
| Suspend water rights & regulate abstraction/rationing | Ensure equitable consumption | The WRAs (1969 & 2013) mandate the Minister responsible for Water resources to suspend water rights and regulate its abstractions when the resource is insufficient or expected to be insufficient.<br>WUAs are also expected to *agree by consensus of its members equitable reductions in the quantities of water abstracted from the source under its responsibility in times of drought or other restrictions on resource availability*" (WRA, 2013 p81). |
| Water infrastructure development and extension e.g community and multipurpose dams | To regulate variable water flows and flood control | Borehole drilling, construction of small community dams, expansion of gravity-fed water supply systems (NSSD, 2004).<br>Ensure the existence of strategic and contingency water resources development and management plans that guarantee availability of water in cases of droughts, floods and population pressures (NWP, 2005) |
| Rainwater harvesting | | promotion of affordable and user friendly rain water |

Key: DEMG = Decentralized Environmental Management Guidelines; NSSD=National strategy for sustainable development; NWP=National Water Policy; NEP=National Environmental Policy; WRAs = Water resources Acts (1969&2013).

While this is commendable, trends in droughts and floods suggest that adaptation is also essential - but it is yet to be included in the National Water Policy. Thus, there is no reference to adaptation and resilience to climate risks in the policy and legislation. Considering the current and projected trends of climate risks specifically floods and droughts, explicit mention and special attention to adaptation and resilience in water resources development and management are central to ensure mainstreaming and consequently resilient infrastructure and sustainable service provision. These gaps have potential effects on poorly informed interventions on the ground consequently intensifying marginalisation of the rural poor in drinking water service provision.

### 3.3. *Integration of flooding effects in the design of drinking water infrastructure*

From key informant interviews, it was learnt that designs of formal water infrastructure consider climate risks in location of utility systems including intakes, distribution and storage for piped water systems. This includes ground water sources and more specifically boreholes. Service providers use historical hydrological trends and return periods – 50–100 years meaning that the designs ensure that the infrastructure is well protected from a 50-100-year flood as emphasized by one key informant:

> Factors considered when constructing or rehabilitating, first intakes: the hydrological data of the river or stream for the last 50–100 years if available or verbal history of the river from the communities around hence the designs are considered on the worst years of drought and floods. The drought year helps to locate the intake pipe where some flows will be able to go through the pipe and the floods; the strength of the structure. As for the distribution pipes, types of pipes which will withstand the pressures mainly from the rocks during floods at the intake and thus running along the river or across the river as these mostly are above ground. Thus, pipes away from the river and underground are installed at average depth of 1 m" (KI, GOV)

It was apparent from the interviews that the designs only consider extremes under stationary climatic conditions, which is not the case under varying and changing climate as demonstrated by the extremes. Thus, future projections are not factored into the design standards. This is in contrast to resilient thinking that emphasizes that a resilient system is 'an infrastructure network that is resilient to today's natural hazards and prepared for the future changing climate … by ensuring that an asset is located, designed, built and operated with the current and future climate in mind' (HM Government, 2011). The pattern of the rainfall extremes suggest that a better approach would be to design infrastructure that can withstand changes and variations in climate. This justifies why the following section analyses the delivery of policy provisions on the ground and resilience of water infrastructure to floods in the study sites. It focuses on flooding effects on water systems.

### 3.4. *Flooding effects on water infrastructure and access to water*

Although there were a few contradictions in responses between key informants and focus group participants, all the study sites in general experienced flooding in January 2015, which caused significant damage to water infrastructure and disruption to service. Community members noted differences between the 2015 and recent rainfall seasons as reported by key informants from Mtuluma and Makombe: "*Last season rain was heavy because it was damaging. The way it was falling, nothing of this nature had happened before*" (VL2 – Mtuluma); "*Flooding damaged a lot and it has never happened before*" (VL1 – Makombe).

However, the effects on water sources and access were varied (Tables 3 and 4). Table 3 shows that flooding water affected the water sources especially the rivers and wells in three villages and taps in one village. For the taps, the entire system from intake to distribution was actually impacted by the high flow velocities and discharges. The water intake structures were clogged with excess silt and in many cases washed away. The distribution system piping and appurtenances that were laid underground along curvets and under bridges were all washed away. However, boreholes were least affected. FGD participants in Kasonga further added that, during the rains it becomes hard for women to draw water from the drinking water sources because the paths become impassable: the routes are "*slippery and steep* (crosstalk*)* … *Sometimes we fall down and break the pot and go back home empty handed*" (FGD2 – Kasonga). During the flooding period, this problem was coupled with long hours of waiting for water to subside to have access to water sites: "*we were waiting for the flooding water to go* … *Five hours of waiting for the flooding water to go*" (FGD2 – Kasonga).

The study also established that the effect of flooding on water sources such as intakes was exacerbated by deforestation–catchment degradation. There was no mention of design standards linked to climate resilience. The following quote is an illustrative example from key informants' perspective: "*The forest was protecting the intake but now it has been destroyed* … *If there were trees we know that yes rains came but there could be less destruction than it happened*" (VL2 – Mtuluma). This suggest catchment management problems as a result of failure to implement policy e.g. catchment protection.

Additionally, the study established that most water infrastructure was vulnerable to floods because they were mostly below design standards. A survey of selected infrastructure specifically intakes and distribution pipes showed limited application of design standards (Figs. 8 and 9). This was echoed in one key informant report that "*most structures are constructed or rehabilitated by local artisan supervised by untrained people who do not know the implications of under designed structures*" (KI -GOV). In some locations, the intakes are above water level during dry seasons and drought conditions (Figs. 8 and 9).

Table 4 shows effects of flooding on household access to water used for food consumption. These included intermittent to no supply in taps as the most severe effect, followed by congestion at the least affected sources (boreholes and springs), increased distance to available water sources, limited access and (unacceptable) dirty water.

The effects were much felt in two villages Mtuluma and Makombe and one section of Mpheta village (located in the Lake Chilwa wetland). These areas had experienced real challenges with their respective water sources as reported by one key informant in Makombe: "*we were very affected such that we were scrambling for water*" because water sources were "*flooded* … *rain fell all day and night hence going to the river to access water was impossible.*" Similarly, a key informant in Mtuluma highlighted that "*flooding waters have damaged a lot* … *to ensure that there is water supply [in taps], we had to work day and night. It was found that all the intakes were washed away by flooding* (VL2). Results from key informants agree with findings from focus groups in particular the challenges experienced during the flooding and post flooding period. Focus group participants in Mtuluma reported that the water problem was very intense because sources including "*wells [had] dried up so quickly because of the sand which came from the mountain to fill the wells*" relative to same period during the previous year. "Six months after the flooding, Mtuluma and Makombe villages still experienced access problems relative to the other villages which experienced access challenges during the flooding period only. In Mtuluma, access challenges persisted for over six months after floods for both tap water system and wells as reported in the group discussion: "*The problem was there and still existing till now. it was repaired but there is difference as compared to the previous time that the well was constructed properly. It was just that we should drink not that it was repaired permanently*" (FGD2 – Mtuluma). The key informants shared the same view that wells were affected by flooding "*very much and the problems are still prevalent, they have not yet ended. The river where people*

**Table 3**
Effects on water sources.

| Village | Source | Source of water | | | | |
|---|---|---|---|---|---|---|
| | | Tap | Borehole | Spring | Well | River |
| Makombe | VL1 | – | No effect | – | Flooded and filled with mud<br>Dried up quickly due to mud | Flooded and filled with mud |
| | FGD | – | No effect | – | Flooded, filled with mud and collapsed<br>Dried up quickly due to mud | Flooded and filled with mud |
| Mtuluma | VL1 | Intake washed away | No effect | – | Flooded and filled with mud | Flooded, washed away and filled with mud |
| | VL2 | Intake washed away | – | – | – | – |
| | FGD | Intake filled with sand | No effect | – | Flooded and filled with sand<br>Dried up quickly due to muddy sand | Flooded, eroded and filled with mud |
| Kasonga | G1 | – | – | Those very close to rivers were completely damaged – filled with silt | – | – |
| | FGD | – | – | No effect on source but route very slippery | – | – |
| Mpheta | VL2 | – | No effect (upper part of the village)<br>Pumps collapsed on lower part of the village | – | Flooded and filled with silt (lower section of the village) | – |
| | FGD | – | Minimal | – | Flooded | – |

Note: Dashes represent not applicable.

**Table 4**
Effects of floods on access to water from FGD and key informants perspective.

| Drinking water source | Effect on access to water | Village mentioned | | | |
|---|---|---|---|---|---|
| | | Makombe | Mtuluma | Kasonga | Mpheta |
| Tap | Intermittent to no supply | – | ✓ | – | – |
| Borehole | Congestion - long waiting time | ✓ | – | – | – |
| | No effect | ✓ | ✓ | – | – |
| | Milky water on upper section of the village | – | – | – | ✓ |
| | Dirty water | – | – | – | ✓ |
| Spring | Increased distance to source | – | – | ✓ | – |
| | contamination | – | – | ✓ | – |
| | Wait for 5 h to access water | | | | |
| Well | Limited access & dirty water | – | ✓ | | |
| | Dirty water and some collapsed | – | ✓ | – | ✓ |
| | | ✓ | – | – | – |
| River | Limited access and dirty water – muddy sand | ✓ | ✓ | – | – |

Note: Dashes represent not applicable.

*were accessing water was flooded a lot so right now water access is difficult*" (VL1 – Mtuluma). Similarly, were taps as reported by WUA board member: "*Water is coming here though irregular. It can last one week without water and sometimes three days while some are maintaining the damaged site temporarily*" (VL2 - Mtuluma). Similar results were captured in Makombe and Mpheta. For example, one key informant in Mpheta highlighted the challenge faced by Bango area, one section of the village that was affected by the floods: "*The individual wells collapsed …. When they collapsed and people failed to access water, they turned to fetch water from rivers and irrigation channels*" (VL2).

Similar findings are reported by Chambers (2009) about the 1988 flooding effects in Bangladesh. "In 1988 two thirds of Bangladesh's sixty-four districts experienced extensive flood damage in the wake of unusually heavy rains that flooded the river systems, leaving millions homeless and without potable water" (Chambers, 2009). In 2007,

**Fig. 8.** Damaged pipe in Mtuluma (Source: Matthews Tsirizeni, LEAD).

**Fig. 9.** One of the intake structures in Mtuluma (Source: Matthews Tsirizeni, LEAD).

another flooding event in Bangladesh left many tube wells contaminated. Similarly, in 2000, flooding of 3000 septic tanks contributed to widespread contamination of potable water in Chokwi and Xia- Xia areas of Mozambique (WHO, 2009). In this regard, adaptation is essential. However, the study established that the affected communities are yet to adapt to floods. What was captured were coping strategies that were mostly weak to make communities resilient.

### 3.5. Coping strategies

The study established that there is a disjunct between what is provided in policy and in reality. To cope with limited access to water sources following flooding, many households relied on rainwater harvesting using various techniques as illustrated in the following quotes: "*People struggled a lot to have access to water. For example, some people used water from iron sheets for those whose houses have iron sheets. Some drunk from bad wells, it wasn't fine*" (VL2, Mtuluma) and:

> When it was flooding, there was so much rain that we could not go out to fetch water. This took about four days of rains, nonstop. Instead, those who had an umbrella used to put it on top of a bucket to direct water from the rains and use it for domestic use. For those who have houses with iron sheets, they could use the water from the iron sheets for domestic use. Some used plastic paper to trap water. And those without
>
> umbrellas also used water from grass thatched houses for use (FGD, Mtuluma).

Although rainwater harvesting is seen to supplement water supply during water shortages, appropriate measures need to be followed to ensure households fetch less contaminated water. Results show this was individually done without appropriate collection infrastructure and guidance. The technologies used in many households were likely to be prone to contamination e.g. water harvesting from trees, umbrellas and thatched roofs. In Makombe, Mtuluma and Mpheta, many (in particular those in proximity to boreholes) relied on boreholes because they were least affected by flooding. For example, in Makombe, FGDs emphasized this contribution: "*If we did not have the borehole, we could face a lot of problems for us to access water for drinking and cooking food*" (FGD2-Makombe). However, this applied to those who managed to pay for the user fees. Those who failed to pay turned to unsafe sources of water (Table 5). The most popular among the alternatives was the nearest borehole, complemented by rainwater harvesting in sround the homestead.

### 3.6. Maintenance of damaged sources

Following flooding, the traditional chiefs initiated the maintenance of damaged sources specifically, traditional sources such as unprotected wells and rivers, to improve access to water used for food consumption. The chiefs called for village meetings and organized community level workforce to maintain water sources. For example, in Mtuluma, this was emphasized by both the key informants and focus group participants. The chief emphasized that the work was initiated by her as quoted: "*Me the owner because the people are mine*" (VL1 – Mtuluma). This was supported by FGD2 participants who repeatedly reported that:

> *It took the chief's initiative to mobilize us after seeing that her people have a water problem. It was the chief who said here there should not be a problem; let us all jointly do the development work. Let's repair our place we should drink water so that when we are drawing the water should not be muddy and unclean or full of filthy so we all went there to do the task* (FGD2 – Mtuluma).

WUA board initiated the maintenance of tap water system as reported by Board chairperson when asked to describe who initiated the maintenance work: "*We the board members and people we work with and the government helped us with small assistance. The World Vision also helped us with pipes. When we informed the government [office] they assured us to wait for the* support *from Lilongwe because the damage is very huge. We are still waiting for the* support" (VL2 - Mtuluma). However, some sources especially damaged springs and wells were abandoned either because they were heavily eroded, completely filled with silt or seem irreparable (Table 6).

In Mtuluma, some water intakes were temporarily maintained due to lack of resources. The key informants reported that these might therefore be washed away if work was not completed before the onset of the next rainy season:

I should say the way we have repaired is temporary. That means this time the dry season will work but when we reach November, December when rainy season comes, these places will be washed away again even though water can be a little. As of now there is no protection. If the support can come very quickly and maintain all the places they can be strong and places like river crossing putting the GI there can still remain intact even when there can be heavy rainfall as we normally have all times" (VL2, Mtuluma).

For one intake, maintenance work was yet to be done at the time of data collection as reported by the WUA Board Chairperson:

> All pipes which were installed there are gone. Now we are planning that the government should come and see it such that it should be moved away to upper site. Where there was an intake it has been dug or eroded like a tree [heavily eroded] … But moving the pipes there e.g. the GI of steel kind and plastic pipes which are installed deep down requires a lot of money. The contractor we engaged estimated that we need to get almost K35 million to rectify the problem and have intake intact. That money is required to rebuild the Chigumula intake. All the intakes mostly in river crossing areas all pipes were washed away and we have just done temporary work. All these need to be worked on (VL2 – Mtuluma).

This was because the rehabilitation costs were too excessive (US $63,636.36) for local capacity. These results suggest limited capacity of formal structures to manage effects of floods on water infrastructure.

## 4. Conclusion

Climatic extremes specifically, flooding and drought continue to affect water supply systems among vulnerable communities in many countries through the destruction of infrastructure thereby limiting access to service facilities and water pollution (contamination). This vulnerability is exacerbated by limited technical capacity and inadequate design and implementation of water policy and legislation in particular with regards to management of flooding effects on potable water service provision. Addressing these challenges in the context of climate change adaptation can ensure resilience of freshwater management systems and consequently water security and attainment of

**Table 5**
Coping strategies following flooding.

| Village | Source | Coping strategy |
|---|---|---|
| Makombe | VL1 | Sourced from borehole – (congestion) and rainwater harvesting |
| | FGD2 | Sourced from borehole and rainwater harvesting (rooftop and plastics) |
| Mtuluma | VL1 | Sourced from borehole and rainwater harvesting |
| | VL2 | Sourced from well, rivers and rainwater harvesting (rooftop) |
| | FGD2 | Sourced from borehole (for households at lower side of the village); streams; rainwater harvesting ((rooftop, umbrellas and plastics) |
| Kasonga | G1 | Shift to other springs |
| | FGD2 | Boiled water from same source – normal practice in all rainfall seasons |
| Mpheta | VL2 | Sourced from earth irrigation channels |
| | FGD2 | Sourced from earth irrigation channels and river |

**Table 6**
Maintenance of damaged water sources following flooding from focus groups and key informants perspective.

| Village | Source | Water Source | | | | |
|---|---|---|---|---|---|---|
| | | Tap | Borehole | Spring | Well | River |
| Makombe | VL1 | – | – | – | Few maintained | Maintained |
| | FGD2 | – | – | – | Mostly abandoned | Maintained but water still dirty |
| Mtuluma | VL1 | Maintained by HEMA [WUA] | – | – | Maintained | Abandoned, established another source |
| | VL2 | Temporary maintenance on some intakes, one is yet to be maintained<br>-requires heavy input of funds | – | – | – | – |
| | FGD2 | Maintained by WUA | – | – | Partially maintained – still contains mud and continues to collapse | Abandoned, established another source |
| Kasonga | G1 | – | – | Abandoned | – | – |
| Mpheta | VL2 | – | – | – | Maintained by individual households | – |
| | FGD2 | – | Damaged yet to be maintained | – | Maintained by individual households/ sharing the source | – |

Note: Dashes represent not applicable.

human right to water in marginalized households. The results from this study suggest a generally decreasing annual rainfall pattern with high variability by seasons and frequent occurrences of droughts and flooding in Zomba District in Malawi. However, the study found that current policy frameworks are more biased towards drought preparedness as compared to flooding preparedness. For instance, the 2015 floods destroyed vital water supply infrastructure and the responsible institutions could not rehabilitate the damaged infrastructure, leaving communities with intermittent and no supply of potable water for over six months. On the other hand, during the dry seasons and drought conditions, the intakes are above the water level. These results show that the present rural water infrastructure is vulnerable and not resilient enough to extreme weather events. In addition, the water institutions are especially not prepared to handle flooding events and their impacts. In this regard, water legislation and infrastructure design do not adequately take into consideration the effects of extreme events on access to potable water in rural Malawi. Water security therefore remains a challenge in Malawi.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

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