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Social Vulnerabilities and Adaptation Options to Climatic Hazards Affecting Rural Water Supply in Barotse Floodplain Catchment Zambia

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Abstract: *This study sought to investigate the susceptibility of rural communities in the Barotse Floodplains Catchment to climate change impacts on rural water supply and identify adaptation options to ensure sustainable rural water supply in a changing climate. The data was collected from three villages namely Nakanya, Lealui and Malengwa villages in Mongu District. The study adopted the Social Vulnerability Index (SVI) to assess the susceptibility of rural communities to climate change impacts. The findings of the study show that Nakanya Village is the most vulnerable, having recorded an SVI score of 0.52 followed by Lealui village with an SVI score of 0.45 and finally Malengwa village with an SVI score of 0.39. The study highlights risks associated with climatic hazards affecting rural water supply and the various adaptation strategies being implemented by various stakeholders to minimise the adverse effects of climate change impacts on water supply. The adaptation strategies include digging and deepening wells, traveling longer distances to fetch water, limiting water usage, borehole drilling and construction of water supply mini schemes. The study identified adaptation options that can enhance the local communities' resilience against climate change impacts on water supply. These include household clustering, recharge mapping and riverbank infiltration. From the findings of the study, it can be concluded that development of climate change resilient water infrastructure is critical in enhancing the rural communities' resilience against the impacts of climate change on water supply systems.*

Keywords: *Climate change, social vulnerability, adaptation, rural water supply, Barotse floodplains.*

1. Introduction

Climate change a key component of the triple planetary crisis has been widely recognised as a major global challenge with far-reaching implications for ecosystems and human societies (Milupi *et al*., 2019; Sahoo and Sridevi, 2021). One significant impact of climate change is its negative effect on water supply systems. Climate change is affecting the world's water in various ways, and extreme weather events like intense rainfall, high temperatures, increase in frequency and severity of dry spells, drought and floods are making water more scarce, unpredictable, or polluted (Nkhonjera and Dinka, 2017). In Zambia, climate change is already exerting negative effects such as dry spells, high temperatures, off-season rains, drought and floods (Mubanga *et al*., 2022). These effects threaten water availability as well as distribution around the country leading to water insecurity. A study by Hamududu and Ngoma, (2020) found that rainfall which is the major source of water resources in Zambia has been experiencing variability with droughts and floods becoming more frequent and more severe as a result of climate change. This has negatively affected the nation's water supply systems with rural communities being more vulnerable to these impacts. Rural communities are particularly vulnerable to the impacts of climate change on water resources because of their high dependence on natural water sources and low adaptive capacity which is characterized by lack of resources and inadequate infrastructure (Hamududu and Ngoma, 2020). Rural communities highly depend on natural water sources like shallow wells and streams as they do not have access to piped water. In Zambia only about 1.6% of the rural population have piped water with the rest of the rural residents obtaining water from sources such as hand pumps, streams, dams, and rainwater (Hamududu and Ngoma, 2020). As a result, they are highly susceptible to water scarcity and depletion, because of the impacts of climate change. Climate change poses significant threats regarding the future sustainability of rural water supply systems (Nhemachena *et al.*, 2020) hence there is need to identify adaptation options that can enhance the communities' resilience to climate change impacts on rural water supplies and ensure the safety and reliability of the rural water supplies in the face of climate change. According to Dinka, (2018) a water supply system is considered to be safe and reliable if it meets all basic needs such as drinking, cleaning, hygiene and sanitation, and food preparation, is easily accessible to all community members, reliable across seasons and between years, and its consumption does not pose a health risk.

Therefore, this study aimed to investigate the susceptibility of rural communities in the Barotse Floodplains to climate change hazards affecting rural water supply and identify adaptation options for ensuring sustainable rural water supply in the face of climate change.

2. Conceptual Perspectives: Climate Change Adaptation And Social Vulnerability

Climate change adaptation refers to the implementation of actions or strategies to moderate the negative and/or enhance the positive impacts of climate change (Fankhauser, 2017; Teshome, 2018). Adaptation aims to reduce the vulnerability and enhance the resilience of vulnerable systems to current or anticipated climate change impacts (Teshome, 2018). The adaptation theory therefore provides a systematic approach to analyse and address climate change challenges hence enhancing adaptation efforts and resilience against climate change impacts (Berrang-Ford *et al.*, 2015). As the impacts of climate change become increasingly evident, it is crucial to develop effective adaptation strategies that minimizes negative impacts and maximizes the potential benefits of climate change (Rawlins and Kalaba, 2021). In order to address climate change impacts it is important to assess the climatic conditions, the risks and vulnerabilities, the interconnectedness of social-ecological systems and adaptation mechanisms (Teshome, 2018).

Social vulnerability refers to the susceptibility of social groups to the effects of hazards like climate change due to the interaction of socio-economic and demographic factors like gender, income, employment type, education, and age amongst others (Dumenu and Tiamgne, 2020; Singh *et al.*, 2014). As a theory, social vulnerability explains how various factors, such as social structures, cultural norms, economic conditions, political systems, and institutional practices, interact to influence unequal distribution of risks and impacts amongst different populations (Spielman *et al.*, 2020).

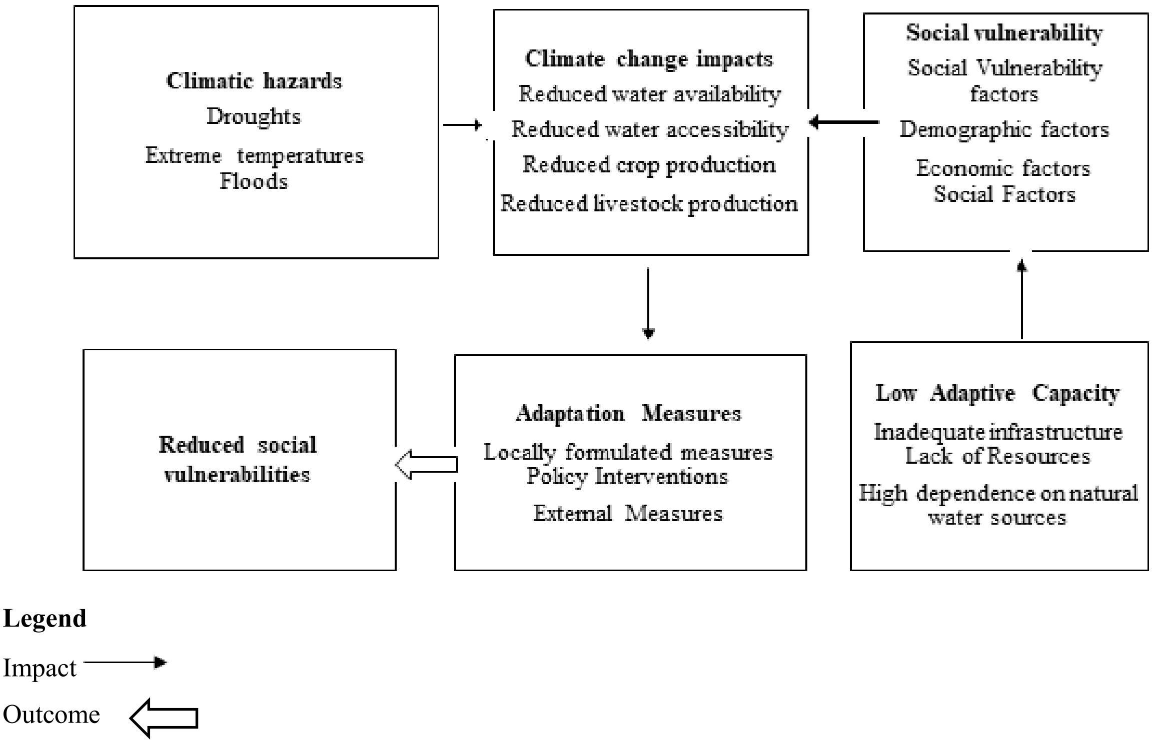

Figure1. *Climate change adaptation and social vulnerability linkage*

3. Study Area

The study was carried out in the rural communities of Mongu District in Barotse Floodplain a designated Wetland of International Importance under the Ramsar Convention. Mongu District is the provincial capital for Zambia's Western Province (Figure 2) and is located approximately 600 Km west of Lusaka, capital of Zambia. It covers an area of 5959.8km^2 and has 27 wards that are split into 2 constituencies namely Mongu Central and Nalikwanda. The district has dual governance systems comprising traditional authority and Central government. Traditionally the District is governed by The Baroste Royal Establishment headed by the Litunga, who is assisted by senior chiefs and headmen. Under Central Government, the District is governed by both Local Government headed by a Mayor and Central Governance headed by a District Commissioner.

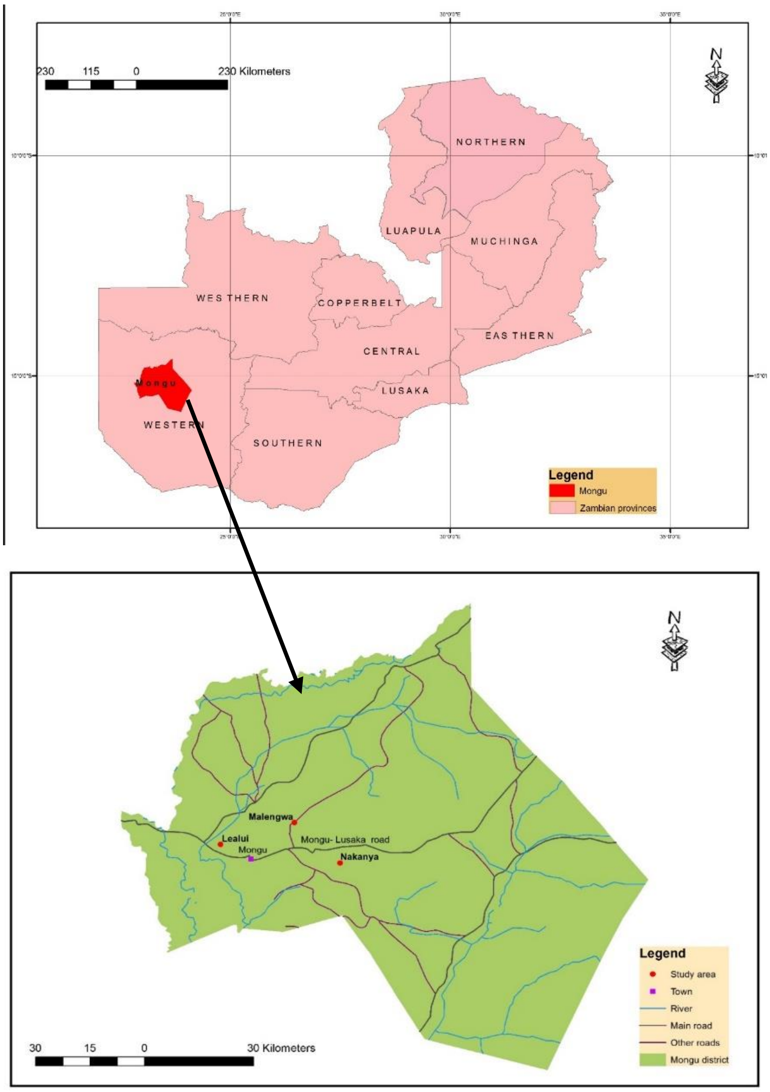

Figure 1. *Map of Mongu District showing the study sites*

Source: *Cartography Unit, Department of Geography and Environmental Studies, University of Zambia, 2025*

Mongu District lies between longitudes 22º 49' and 24º 00' east and Latitudes 14º 37' and 15º 49' south at 1080m above sea level (Mongu Municipal Council.). It receives mean annual rainfall of between 800mm and 1000mm with average temperature in varying between 10 degrees Celsius in July which is the coldest month to 38 degrees Celsius in October which is the hottest month. The district is predominantly covered by Kalahari sands and poorly drained clay soils in valley dambos and hydromorphic plains. The dominant landcover types are woodland dominated by *Brachystegia spiciformis*, dambo grassland, agriculture and floodplain.

The residents of Mongu District engage in various economic activities which include agriculture (livestock rearing and food crop production), horticultural production, fishing, beer brewing, charcoal burning, crafts, and trading in agricultural products. Crops grown in Mongu district are maize, cassava, rice, legumes, millet, sorghum groundnuts and sweet potatoes. Horticultural production involves vegetables like tomatoes, rape, cabbage and tree crops like cashew, avocado, citrus fruits.

4. Methodology

4.1 Data collection and Analysis.

Data for the assessment of social vulnerability and adaptation strategies to climate change impacts on rural water supplies were collected from a total of 205 respondents. The sample size was determined using equation1.

$$n = \frac{N}{1+N(e)^2} \text{.............. Equation 1}$$

n is the sample size, N is the population size (total number of rural households), and e is the level of precision. The researcher used 7% level of precision and total number for the rural households of 26140.

A two-stage sampling method was used whereby the villages from which the data was collected were purposively sampled and the households randomly sampled. The sampled villages were Malengwa, Lealui and Nakanya villages. The purposive sampling was to ensure that the data was collected from villages with different geographical characteristics. Data for adaptation options that will increase the resilience of rural water supplies to climate change and its impacts were collected from key informants from the Department of Water Resources Development, Department of Water Supply and Sanitation and Western Water and Sewerage Company.

To collect the data a household survey was conducted and a semi-structured interview administered. The interview questions were translated from English to *Silozi* which is the native language of the respondents.

4.2. Social Vulnerability Factors and Indicators

This study integrates demographic, economic and social factors to assess the social vulnerability to climate change impacts on water supplies. The factors and their corresponding indicators are described and explained in Table 1.

Table 1. *Social vulnerability factors, Indicators and indicator-vulnerability functional relationship*

Vulnerability Factors (Major Components)	Indicators (Sub-components	Description of Sub-components	Impact on vulnerability	Source
Demographic	Household size	The average number of household members in each ward	The higher the household size the greater the level of vulnerability	(Dumenu and Obeng, 2016; Dumenu and Tiamgne, 2020; Sahoo and Sridevi, 2021)
	Household head gender	Percentage of households that are headed by females	Female headed households are more vulnerable than male headed households	(Sam *et al.*, 2017; Tasnuva *et al.*, 2021)
	Literacy level	Percentage of households where the head has attained at least primary school	Households with a household head having education below the primary level are more vulnerable	(Dumenu and Obeng, 2016; Dumenu and Tiamgne, 2020; Sahoo and Sridevi, 2021)
Economic	Household Income level	The average income of households in each ward	The lower the level of income the higher the vulnerability	(Dumenu and Tiamgne, 2020)
	Climate sensitive occupation	Percentage of households reporting agriculture or fishing as the only source of income	Households dependent on agriculture or fishing are more likely to be vulnerable to the	(Dumenu and Obeng, 2016; Sahoo and Sridevi, 2021)

			reduction of crop and fish production	
Social	Access to climate change information	Percentage of households with access to climate change information	Households with access to climate change information are less vulnerable to climate change	(Dumenu and Obeng, 2016; Dumenu and Tiamgne, 2020; Sahoo and Sridevi, 2021)
	Social Networks	Percentage of households that can seek help or obtain help from social networks	Households that can obtain help from others in times of need (social networks) are less vulnerable	(Pandey *et al*., 2015)
	Access to community benefits	Percentage of households with access to community projects or benefits	Households with access to community projects and benefits are less vulnerable	(Sahoo and Sridevi, 2021)
	Dependence on natural water sources	Percentage of households using natural water source	Natural water sources are sensitive to climate change and its impacts. Households relying on natural sources are more vulnerable	(Pandey *et al*., 2015; Sam *et al*., 2017)
	Reliable source of water	Percentage of households with a reliable source of water	Households that have a reliable source of water are less vulnerable	(Sam *et al*., 2017)
	TV or radio ownership	Percentage of households that own a TV or a radio	Households that own these assets are more likely to be less vulnerable as have access to climate change information	(Dumenu and Tiamgne, 2020; Tasnuva *et al*., 2021)

Demographic factors: Demographic structure and composition influences vulnerability of households to climate change and its impacts. This study uses household size, literacy and household head gender. Household size plays a critical role in influencing the overall vulnerability of a household as larger households tend to be more vulnerable to climate change impacts (Mba *et al*., 2021). This is because larger households tend to channel most of their resources towards the welfare of household members leaving them with little to no resources to cope with climate change impacts (Dumenu and Tiamgne, 2020). High literacy level reduces vulnerability with households having education below the primary level being more vulnerable to climate change than households with above primary education (Sahoo and Sridevi, 2021). Higher literacy allows access to better paid jobs and thus to the generation of higher salaries. Female headed households are often more vulnerable to impacts of natural hazards because of poor overall literacy rates, limited access to resources and lack of networking ability (Sam *et al*., 2017; Singh *et al*., 2014). These factors limit their capacity to adapt to climate change and its impacts.

Economic Factors: It has been noted that income levels greatly influence vulnerability of individuals, households or communities as low-income levels result in economic insecurity and instability whilst a thriving economy serve as an effective safety net against environmental hazards (Dumenu and Tiamgne, 2020; Sahoo and Sridevi, 2021). Low-income level households usually struggle to access basic needs like healthcare, education and clean water and are more vulnerable to shocks as they have limited capacity to cope with negative impacts. In terms of vulnerability to climate change impacts on water supplies low-income communities often lack adequate infrastructure and have low access to clean, safe and reliable water exacerbating the impacts of climate change on water supply. High dependence on climate sensitive occupation like crop production and fishing increases household's vulnerability as any unfavourable change in environmental conditions caused by climate change negatively impacts production (Sahoo and Sridevi, 2021). Diversified sources of income help improve household's adaptive capacity in the time of crisis as it provides insurance against shocks minimising exposure to the negative impacts of climate change because livelihood is derived from different income sources (Dumenu and Tiamgne, 2020).

Social Factors: These factors significantly impact households' or communities' ability to withstand the adverse effects of climate change. Social factors determine the extent to which individuals and communities are aware of climate change and can access resources, support networks, and social services that enable them to adapt to climate change impacts. This study uses access to climate change information, social networks, access to community benefits, dependence on natural water sources, reliability of the source of water and TV or radio ownership. Social networks are considered as mechanisms of information delivery and a pathway for economic and social support (Dumenu and Obeng, 2016). TVs and radios are important means of disseminating information on climate change, early warning and adaptation strategies (Dumenu and Tiamgne, 2020). Early warning system is considered as a technological measure that improves rural households' adaptive capacity to climate change and its impacts. Dependence on natural water sources increase communities' vulnerability to the impacts of climate change on water supply as these water sources are highly sensitive to climate change and increases the communities' exposure to climate change (Pandey *et al*., 2015; Sam *et al.*, 2017).

4.3. Calculating social vulnerability index

The study adopted the Social Vulnerability Index (SVI) which is a quantitative indicator with values ranging between 0 and 1. 0 is the lowest value and represents the lowest vulnerability level in a study area whilst 1 is the highest value and represents the highest vulnerability levels in a study area. Hence, the lower the SVI value the lower the vulnerability and the higher the SVI value the higher the vulnerability (Dumenu and Tiamgne, 2020). The data on the social, economic and demographic factors of the rural households was collected in their respective units and standardized or normalized using the following equations:

$$IndexKf = \frac{Kmax - Kf}{Kmax - Kmin} \text{..........................Equation 1}$$

If the overall vulnerability was decreasing with the increase in value of indicators. Or

$$IndexKf = \frac{Kf - Kmin}{Kmax - Kmin} \text{ ....Equation 2}$$

If the overall vulnerability was increasing with the increase in value of indicators.

Kf is the original value of sub-component for each village and Kmax and Kmin are the maximum and minimum values of each subcomponent determined using data from all households and the sampled villages. For variables that show frequencies, for example, the percentage of households with access reliable water, the minimum value was set at 0 and the maximum value at 100. The researcher assumed equal weightings for the indicators.

After normalization the indicators were averaged to determine the value of each major component using equation 4:

$$Kv = \frac{\sum_{i=1}^{n} Index\ kf^{i}}{n} \text{.................................... Equation 4}$$

where Kv is the averaged index value of one of the major components of social vulnerability, Index kf^i is the actual value of the indicator for each of the villages indexed by i and n is the number of indicators for each social vulnerability major component.

Finally, for the overall social vulnerability of the households in the villages, the various indices were substituted into equation 5:

$$SVI = \frac{1}{N}(DF + EF + SF) \text{ .... Equation 5}$$

N is the number of indicators, DF are the demographic factors, EF economic factors and SF social factors.

5. Results And Discussion

5.1. Social Vulnerability to climate change impacts on rural water supplies.

The results of the study revealed that there are disparities in the social vulnerability of rural households to climate change across the three sampled villages (Table 2). Nakanya village exhibited the highest social vulnerability, with a social vulnerability index (SVI) value of 0.52, indicating a greater susceptibility to the adverse effects of climate change on water resources. In comparison, Lealui village recorded an SVI value of 0.45, while Malengwa village showed the lowest vulnerability, with an SVI value of 0.39. Table 2 presents the social vulnerability factors (major components) and their respective indicators (sub-components) that influenced the vulnerability of the households in the villages.

Table 2. *Indexed sub-components, major components and overall social vulnerability index of smallholder farmers in the three villages*

Social vulnerability factors (major components)	Indicators (subcomponents)	Sub-components indices			Major components index		
		Malengwa	Lealui	Nakanya	Malengwa	Lealui	Nakanya
Demographic	Household size	0.22	0.34	0.45	0.26	0.23	0.25
	Household head gender	0.47	0.33	0.23			
	Literacy	0.08	0.03	0.06			
Economic	Income level	0.88	0.91	0.97	0.47	0.66	0.69
	Climate sensitive occupation	0.06	0.41	0.40			
Social	Access to climate change information	0.14	0.09	0.11	0.44	0.45	0.64
	Social networks	0.53	0.63	0.77			
	Access to community benefits	0.80	0.80	0.72			
	Dependence on natural water sources	0	0.36	0.68			
	Reliable Source of Water	0.65	0.32	0.78			
	Ownership of a TV or a radio	0.49	0.49	0.77			
	Overall social vulnerability index				0.39	0.45	0.52

The variation in vulnerability among the sampled villages can be attributed to their geographic location, with Nakanya village being the most marginalized and least developed, thereby exacerbating its vulnerability. This is in line with the findings of Sahoo and Sridevi, (2021) who found that the overall social vulnerability to climate change of the less developed village was higher than the developed village. Another study by Pandey *et al*., (2015) to assess the climate related water vulnerability of households in mountainous region found that the rural communities (less developed) were more vulnerable to climate change impacts on water resources than the urban areas (more developed). Marginalised communities are often characterized by limited access to resources, less economic opportunities and insufficient or poorly maintained infrastructure. These factors increase their exposure and sensitivity to the impacts of climate change whilst limiting their capacity to adapt. The results of the study show highest dependence on natural water sources that are sensitive to climate change and its impacts in Nakanya village because of insufficient infrastructure.

On the other hand, Malengwa village is located approximately 10km North of Mongu's central business district and is characterized by better access to resources and economic opportunities, and low dependence on natural water sources. This reduces their exposure and sensitivity to the impacts of climate whilst increasing their adaptive capacity. Finally, Lealui village exhibits a moderate level of marginalization, which is relatively lower compared to Nakanya village. This lower marginalization, coupled with better access to resources, infrastructure, and economic opportunities, contributes to Lealui village's reduced vulnerability to climate change impacts on water resources.

In terms of the social vulnerability, economic factors largely influenced high vulnerability in the three sampled villages as it had the highest values, followed by social factors with demographic factors being the least. The economic factors had indices of 0.69 for Nakanya village, 0.66 for Lealui village, and 0.47 for Malengwa village. The high indices for economic factors are mainly because rural households in Mongu district are characterised by low levels of income. According to Dumenu and Tiamgne, (2020) income levels influence vulnerability because high-income level gives economic security and stability, as a result, households can leverage alternative entitlements and access resources to better withstand shocks, strengthening their resilience.

Low-income communities often lack adequate infrastructure and have low access to clean, safe and reliable water exacerbating the impacts of climate change on water supply. Also contributing to the high economic indices is the dependence on climate sensitive occupation. Solely depending on climate sensitive occupation like crop production and fishing increases household's vulnerability to the impacts of climate change as it reduces their resilience and adaptive capacity especially in times of low crop or fish production (Dumenu and Obeng, 2016). This is because any unfavourable change in environmental conditions caused by climate change negatively impacts production, thereby affecting their livelihoods and disposable household income (Sahoo and Sridevi, 2021).

The study also revealed significant differences in social factors contributing to vulnerability among the three villages with Nakanya village recording the highest index value of 0.64. The critical indicators that contributed to the highest index score for social factors in Nakanya village were lack of a reliable source of water (0.78), low ownership of radio or television (0.77), very weak social networks (0.77) and high dependence on natural water sources (0.68). The highest index value for reliable source of water in Nakanya village shows that Nakanya village has the highest percentage of the residents that face significant challenges in accessing water for domestic use or to support their livelihoods. In addition, low ownership of radios or televisions in Nakanya village indicates limited access to climate change information, which further exacerbate their vulnerability. TVs and radios are important means of accessing climate related information for enhancing adaptive capacities among rural communities (Kapinga *et al*., 2020).

Dependence on natural water sources like streams and shallow wells increase communities' vulnerability to the impacts of climate change on water supply. This is because these water sources are highly sensitive to climate change and increases the communities' exposure to climate change. In addition, depending on natural water sources means that communities' have limited control over the water supply increasing their vulnerability to the impacts of climate change.

Demographic factors had the least influence on social vulnerability having recorded the lowest index value among the three social vulnerability factors across the three villages. Malengwa village recorded a demographic factor index of 0.26, with Nakanya village recording 0.25 and Lealui village 0.23. All the three districts showed high literacy levels as 92% household heads in Malengwa village, 94 % in Nakanya village and 97% in Lealui village reported to have obtained at least primary level education. Households having education below the primary level are more vulnerable to climate change than households with above primary education (Sahoo and Sridevi, 2021) as literate people tend to better understand information and acknowledge risk (Dumenu and Tiamgne, 2020).

5.2. Risks associated with climate change impacts on water resources

The study found that the risks being experienced because of climate change impacts on water resources are loss of crops, loss of livestock, drinking contaminated water, water shortages, hunger and starvation, diseases, reduced fishing activities and human wildlife conflict. The researcher also tried to assess the severity of the risks being faced because of climate change impacts on water resources by asking them to state the risk that has been the most severe. The results are presented in figure 3.

Based on the responses that were recorded the effects of climate change being experienced in the Barotse floodplains are an increase in the frequency of drought, increase in temperatures, changes in rainfall patterns, lack of rainfall, floods, and heavy winds. A study by Nyamwanza, (2018) found that climate change is being manifested through increasing intra-seasonal dry spells, increasing drought cycles and floods. The findings of this study are also in line with Banda *et al*., (2015) who found that communities around the Barotse Floodplains have started experiencing the negative impacts of climate change which include increase in atmospheric temperature and excessive heat in the plains, floods, prolonged dry spells, reduction in precipitation, unexpected changes in seasons and their durations and reduction in water supply. Other studies conducted in the Zambezi River Basin in which the Barotse floodplains lies have predicted rising temperatures, decreasing precipitation, extended drought periods and severe floods (Hamududu and Ngoma, 2020; Ndhlovu and Woyessa, 2021). These effects are already being experienced in the communities around the Barotse floodplains.

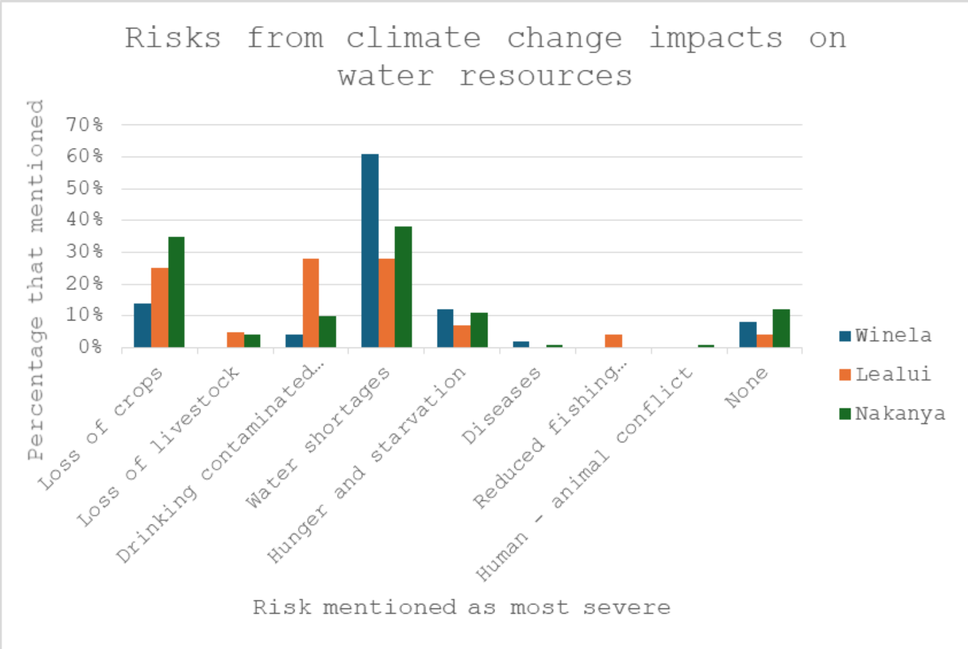

Figure 2. *A summary of the risks considered as most severe by the respondents*

Source: Field Data, 2024

Despite the many climatic hazards being experienced in the Barotse floodplains, drought and excessively high temperatures are considered the most severe by a larger percentage of the population. This is because of the drastic effects drought and excessively high temperatures have had on the rural water supply, agricultural production, livestock production, fish production and the overall well-being of the communities. The climate change induced drought and extreme temperatures have reduced water availability and water accessibility as some of the of the streams, wells, and boreholes where communities used to get water from had dried up. One responded stated that "*The lack of rainfall has severely impacted our maize crops, causing them to dry up, which has led to starvation*". Another one added "the *stream which we depend on is drying up due to excessive heat*". Another one shared "*Currently the hand pump isn't working, we alternatively fetch from wells which are also drying up due to drought*". Another one remarked "*because of the drought I have seen long queues for mealie meal that I had never seen before*"

A study by Abedin *et al*., (2014) in Khulna and Sutkhira districts of Bangladesh found that drought was one of the major causes of water scarcity. As a result, women walked for long distances from one village to the other to meet the household's daily water needs. Another study by Rankoana, (2020) also found that drought, increased temperatures and low rainfall led to an inconsistent water supply for household consumption because of excessive water evaporation from the river. Consequentially the residents of the rural communities in Limpopo province travel a distance to fetch water from public sources. According to Kumar, (2016) climate change and water supply system are closely connected as it affects the hydrologic cycle by influencing precipitation, evapotranspiration, and soil moisture. Niang *et al*., (2014) also state that many studies in Africa point to a future decrease in water abundance due to a range of drivers and stresses that include climate change, a phenomenon already being experienced in the Barotse floodplains.

In addition, climate change has had drastic effects on agricultural production which is the main source of livelihood for the rural households. Loss of crops and livestock have been recorded as some of the risks being faced as result of climate change impacts on water resources. Rural communities in the

Barotse depend on rainfed agriculture which is highly sensitive to climate change and variability. The climate change induced drought has severely impacted crop yields, causing crops like maize, rice, and cassava to dry out in the fields and resulting in little to no harvest. This has led to high food insecurity as majority of households are struggling to access adequate food resulting in hunger and starvation. A study by Nyamwanza, (2018) found that water for agricultural and domestic purposes was becoming scarcer. In addition, the study also noted there has been an increase in drought frequency over the years and these droughts have led to total crop failure, drying up of rivers and boreholes and livestock deaths (Nyamwanza, 2018). However, the drying of cassava which was reported by some of the respondents is different from the findings of Mupakati and Tanyanyiwa, (2017) where cassava was actually introduced in Chilonga ward in Chiredzi Zimbabwe as an adaptation option to cope with drought and climate change as it is considered a drought resistant crop.

Unavailability of water and grazing land has reduced livestock production as households can no longer keep livestock for food or for sale. There has also been an increase in cattle deaths and diseases because of climate change. These findings are in line with some of the findings by Rankoana, (2020) who reported that some of the participants mentioned that raising of livestock is curtailed due to a drop in the river water level because of drought.

Drying of water bodies and lowering of water levels have also led to fish resources depletion resulting in reduced fishing activities which is a major source of livelihood for some of the households. One respondent said, "*streams are drying up and fish cannot breed making it difficult for us to make money*". These findings are in line with Milupi *et al*., (2019) who found that the major impacts of climate change being experienced in the Barotse floodplains were; low food production due to drought, reduction in cattle population due to excessive heat, lack of animal pastures due to drought, depletion of some fish species and reduction or low yields in crop harvest like maize and rice amongst others. This is supported by Abedin *et al*., (2014) who state that in the rural communities fisheries and livestock-based livelihoods are curtailed due to lack of safe water.

The impacts of climate change induced drought on water resources have had a negative effect on the people's health in the rural communities of the Barotse floodplains. Because of water scarcity people end up fetching water from unsafe sources like contaminated wells and there have been cases of diarrhoea and other related illnesses in the district. This is supported by Huang *et al*., (2021) who states that in times of reduced water quantity and quality people living in rural communities may have to use alternate sources with poor quality due to unavailability of safe water resources and high cost of water purification techniques. One respondent stated that "*Water levels have gone down leaving us with no choice but to drink dirty water*". Impacts of climate change on water resources have also led to poor hygiene being practiced by the local communities as they are struggling to access water for hygiene practices like handwashing. Some residents said that they can go for a week without taking a bath. A study by Buriro *et al*., (2024) found that rising temperatures are contributing to an increase in heat-related illnesses, such as heatstroke, while erratic rainfall patterns and droughts are exacerbating water shortages, leading to poor sanitation and the spread of waterborne diseases like cholera and diarrhoea in Sindh Pakistan.

5.3. Adaptation strategies to the impacts of climate change on rural water supply

To reduce the negative impacts of climate change on water resources, different stakeholders have adopted various approaches. The specific adaptation strategies of individuals, communities, and institutions such as local authorities, NGOs, and private sector all play a critical role because together they can potentially reduce adverse effects of climate change on rural water supply in an area (Abedin *et al*., 2014). The adaptation strategies being implemented by the sampled households are primarily focused on securing alternative sources of water, reducing water consumption, and improving water storage. On the other hand, strategies being implemented by institutions such as the Department of Water and the Western Water and Sewerage Company aim at increasing water availability and accessibility in the face of climate change. As shown in table 3, the most dominant adaptation strategies by the communities are digging and deepening of wells (30%), looking for alternative water sources (25 %), and limiting water usage (20%). The other strategies being employed by the rural communities include buying water, planting trees, storage of water in drums, shifting from upper land, and sinking personal boreholes.

Table 3. *Adaptation strategies against climate change impacts on water supply in the study sites*

Adaptation Strategies	Effectiveness of the adaptation strategies	Malengwa	Lealui	Nakanya	Total	Reason for Rating
		n=49	**n=75**	**n=81**	**n=205**	
Digging more wells and deepening the existing wells	Minimally effective		43% (32)	36% (29)	30% (61)	They don't have resources to very deep wells. Water levels have reduced hence it is difficult to access the water. The wells end up collapsing because of the sandy nature of the area
Moving long distances to look for alternative water sources	Minimally effective	14% (7)	43% (32)	15% (12)	25% (49)	The strategy is time-consuming and physically demanding. Hence, it is difficult to find water that can meet their needs.
Limiting water usage	Not effective	31% (15)	5% (4)	27% (22)	20% (41)	The available water is insufficient to meet their demands
Buying water from neighbours with boreholes	Very effective but not sustainable because of the low-income levels of the rural communities.	31% (15)			7% (15)	Boreholes are a reliable source of water and since they are privately owned, access is limited, thereby reducing demand on the water supply.
Planting of trees	Not effective		5% (4)	12% (10)	7% (14)	Low survival rate of the planted trees.
Storage of water in drums and containers	Moderately effective	18% (9)			4% (9)	This strategy depends on the availability and accessibility of the water resources.
Shifting from upper land to lower land	Not effective			10% (8)	4% (8)	It is not possible for every household along with all its members to shift.
Sinking personal boreholes	Very effective, however only a few can afford.	6% (3)			1% (5)	Boreholes are a reliable source of water and since they are privately owned, access is limited, thereby reducing demand on the water supply.
Boiling water before drinking	Effective in minimising diarrhea and other related illnesses.		4% (3)		1% (3)	Effective in mitigating diarrhea and associated illnesses, however accessing firewood for boiling the water is becoming increasingly difficult.

Rankoana, (2020) also reported looking for alternative sources of water as one of the primary strategies being employed by rural communities to adapt to climate change induced water scarcity. However, this strategy is time-consuming and physically demanding, particularly for women and children who are bearing the responsibility of fetching water. One responded stated "*we walk for hours just to get a 20liter bucket of water and we wake up as early as 4am to look for water*". Buying of water was also reported by Patrick, (2021)who found that respondents in Mkhanyakude District in South Africa were making personal arrangements such as buying water from water vendors to ensure water security within their households when faced with diminishing water resources. Limiting water usage and storage of water as adaptation measures were also reported by Rankoana, (2020) who found out that the residents of Maheni community stated that they collect and store water as it becomes available from the borehole and they have laid down restrictions as well on water uses during increasing water stress periods to ensure a sustainable water supply.

In addition to these household-level adaptation measures, institutions such as the Department of Water and the Western Water and Sewerage Company are also playing a critical role in supporting climate change adaptation efforts in the study area. They are also coming up with strategies to help communities cope with the adverse effects of climate change on water supply. The adaptation measures being implemented by the institutions are borehole drilling, construction of water supply mini schemes, identification of dam sites and lowering of borehole pumps. Lowering of borehole pumps is in line with findings from Kulkarni *et al*., (2021) whose study revealed that drilling deeper wells helps to sustain water yields as it increases borehole volume because the well's storage ability for percolating water is improved in deeper wells. Furthermore, food relief programs are also being implemented by the government to help abate the hunger and starvation that resulted from the climate change induced drought. However, government assistance in the form of food relief programs is considered unsustainable as it only offer short-term solutions instead of long-term benefits (Dumenu and Tiamgne, 2020).

5.4. Adaptation options to enhance the rural communities' resilience to climate change impacts on rural water supply.

From the research it was noted that there is need to help rural communities in the Barotse Floodplain build resilience against climate change impacts on water resources and ensure water security in the face of climate change and its impacts. This is because the current coping strategies being implemented are insufficient given the magnitude of the changes currently taking place. Therefore, through the key informant interviews the researchers explored adaptation options that can enhance the rural communities' resilience against climate change impacts on water supply systems. These adaptation strategies can be used to empower communities to integrate their indigenous knowledge and scientific knowledge to plan for and cope with climate change impacts on water resources increasing their resilience to the impacts. The identified adaptation options are household clustering, recharge mapping, riverbank filtration, rainwater harvesting, reforestation and revegetation, and deep drilling.

Household clustering: Rural communities are often characterized by isolated homes that are scattered across the landscape with significant distance between them, and high dependence on natural water supplies that are vulnerable to climate change. Hence the efforts by the local authorities to drill boreholes which are resilient to the impacts of climate change in response to the prevailing climatic conditions. However, the key informant from Western Water and Sewerage Company emphasized that it is not possible to drill boreholes anywhere people settle as some of the places are not suitable for borehole drilling. Therefore, clustering households and drilling boreholes at designated points will help improve access to water resources in the face of climate change. The key informant from the Department of water supply and sanitation stated that "*clustering households makes it possible to implement the piped water supply system instead of the point water supply currently being implemented in rural communities thereby improving water accessibility in the face of climate change"*.

Recharge mapping: The key informants mentioned that there is need to identify and map areas where groundwater recharge can be enhanced or restored. The key informant from the Western Water and Sewerage Company particularly stated that "*when conducting feasibility studies for borehole drilling it is not enough to just identify the site for borehole drilling but there is need to identify the recharge point for the aquifer from which the borehole will be tapping water from*". He went on to say, "*identifying the recharge zones ensures that they are well maintained*". There has been an increase in the frequency and intensity of drought in the region which has led to a decrease in groundwater levels. Therefore, recharge mapping will help maximize groundwater recharge and ensure sustainable groundwater management.

Riverbank filtration: The key informant from Western Water and Sewerage Company strongly recommended riverbank filtration as one of the adaptation measures that will ensure communities' resilience against the impacts of climate change on water resources. He stated that "*Boreholes can be drilled at strategic positions along the Zambezi River and its tributaries where they will be intercepting the aquifer that is recharged by the river water.* He went on to say *"As the Western Water and Sewerage Company we have drilled a number of boreholes along Kambule stream, and these boreholes have not been affected by the prevailing drought conditions whilst some of the boreholes we drilled elsewhere away from the stream have dried. This shows the potential of riverbank filtration in increasing resilience of water supply systems to climate change"*. The key informant also added *"the water from riverbank filtration is free from iron and sediments as the riverbank filtration is a natural water treatment process that filters and purifies water using soil and sediments along the riverbank*". According to Umar *et al*., (2017) integrating riverbank filtration and aquifer recharge and recovery system can provide a lasting solution to water scarcity especially in arid and semi-arid climates. According to Osman *et al*., (2022) riverbank filtration can be used in drought-prone regions as a means of increasing water-storage capacity and it has been used for over 150 years in Europe to produce large quantities of drinking and industrial water at low cost and high quality, even during floods and droughts.

Reforestation and Revegetation: Incorporating reforestation and revegetation into adaptation strategies can also enhance the resilience of water resources to climate change and its impacts. The key informants stated that there is need to discourage the cutting down of trees in certain areas especially for charcoal production as this has a negative impact on water resources. This is because vegetation promotes water infiltration and retention, and reduction of moisture-stress during low rainfall by increasing soil porosity and soil cover reducing surface runoff. By increasing water filtration, vegetation also plays a critical role in promoting groundwater recharge. In Brazil, recovery of riparian forest areas around water bodies is one of the main strategies being used for water conservation as increasing forest areas, helps to improve hydrological conditions in hydrographic basins (Freitas *et al*., 2022).

Rainwater harvesting: The key informant from the Department of Water Resources Development stated that "*there is need to implement effective water harvesting systems, especially during floods whereby the excess water will be collected and stored for future use. This can enhance water security and reduce climate change induced water scarcity*". According to Huang *et al*., (2021) rainwater harvesting is listed among the specific adaptation measures which can be employed to cope with future climate change and its impacts on rural communities, particularly in regions of Africa. A study in Central Northern Namibia to investigate the application of rainwater harvesting found that rainwater harvesting in terms of the roof catchment systems was economically feasible and could provide comparable benefits to public water supply (Huang *et al*., 2021).

Deep drilling: The key informants stated that to enhance water accessibility in the face of decreased water levels from the climate change induced drought deep drilling can also be implemented. This will involve drilling boreholes to depth of about 200m or more. A study by Kulkarni *et al*., (2021) revealed that drilling deeper wells helps to sustain water yields as it increases borehole volume because the well's storage ability for percolating water is improved in deeper wells.

6. CONCLUSION AND POLICY IMPLICATIONS

This study demonstrates the use of the Social Vulnerability Index (SVI) to assess the susceptibility of rural communities to climate change impacts. Policymakers can use similar approaches to identify vulnerable communities and allocate resources accordingly. The findings of the study reveal that development of climate change resilient infrastructure is critical in enhancing the rural communities' resilience against the impacts of climate change on water supply systems. Therefore, the government should prioritize and allocate more funds for the development of climate-resilient water infrastructure such as rainwater harvesting systems, solar powered boreholes, dams and reservoirs, and protected wells. This study identifies adaptation options that can enhance local communities' resilience, such as household clustering, recharge mapping, and riverbank infiltration. Policymakers can incorporate these adaptation options into climate change adaptation plans and policies. This study highlights the importance of community-based adaptation strategies. Policymakers should support community-based initiatives and involve local communities in adaptation planning to ensure that adaptation strategies are context-specific and effective. Policymakers should also integrate climate change adaptation into water policy and planning to ensure sustainable rural water supply.

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DATA AVAILABILITY

The data collected during this research can be accessed through the following link https://docs.google.com/spreadsheets/d/17JdLd9q4ewvd2QaXYMaCk_w3-koc1a4i/edit?usp=drive_link&ouid= 105477594606935738332&rtpof=true&sd=true

HUMAN ETHICS AND CONSENT

Ethical clearance was obtained from the Natural and Applied Sciences Research Ethics Committee at the Directorate of Research and Graduate Studies Committee University of Zambia before proceeding with the data collection. Consent was sought from all participants who were to take part in this study, and every participant was assured anonymity, and only willing respondents participated in the study.

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