American Journal of
Environment Studies
(AJES)

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American Journal of Environment Studies
ISSN 4520-4738 (Online)
Vol.6, Issue 1, pp 59 - 73, 2023
www.ajpojournals.org

The Trends and Effects of Flood Occurrences in the Shire River Basin in Chikwawa District of Malawi: A Historical Perspective (1980 - 2019)

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Article history
Submitted 04.04.2023 Revised Version Received 20.04.2023 Accepted 26.04.2023

Abstract

Purpose: The purpose of this study was to examine historical trends in flooding in Malawi's Shire River Basin (SRB). The basin is prone to severe flooding and most affected in the country. For many years, flooding has posed a significant threat to communities in and around the basin. Therefore, the main objective of the study was to document the historical perspective of flood occurrences in terms of frequency and impact in the Shire River Basin of Chikwawa District, Malawi, from 1980 to 2019.

Methodology: A mixed survey design was used for the study. Both random and purposive sampling were used to identify participants. A total of 384 respondents took part in the study. The study collected both primary and secondary data. Primary sources of data were collected using household surveys, interviews with key informants, and focus group discussions, while secondary sources of data were collected using documents from both non-governmental and Malawian governmental departments and agencies (MDAs) as well as existing literature. Data from focus group discussions (FGDs), interviews with community elders (CEIs), and key informant interviews (KIIs) were recorded in Chichewa with a voice recorder, transcribed in Chichewa, and then translated into English. Household survey data were processed using Statistical Package for Social Scientists (SPSS) version 25 and secondary data were converted to time series data and then analysed using STATA software to produce charts and graphs.

Findings: The results showed that all three hydrometeorological extremes (mean annual temperature, average rainfall and baseflow index) increased, suggesting that both the intensity and frequency of flooding in the Shire River Basin of Chikwawa District were also increasing in absolute terms. People's perceptions of flooding showed that the Shire River Basin in Chikwawa District experienced excessive flooding every 5 years. This 5-year cycle was, among other factors the result of climate change and forest loss in the study area, leading to an increase in river sedimentation.

Recommendations: This article found that the local people in the Shire River Basin of Chikwawa District will always live with increasing levels of flooding. Therefore, they should be proactive in flood management and understand the process as an ongoing activity for future risk assessment. Analysing the history of river basin flooding is important as it helps the Malawi's Department of Disaster Management Affairs (DoDMA) officials to be alert and estimate the time frame for the next flood in the Shire River Basin of Chikwawa District to strengthen the flood forecasting accuracy.

Keywords: *Chikwawa District, Flood Occurrences, Hydrometeorological Extremes, Malawi, Shire River Basin*

1.0 INTRODUCTION

Floods, which occur due to a variety of natural and anthropogenic factors, are the most common environmental hazards affecting people worldwide (Bhat *et al.,* 2019). For more than half a century, a combination of factors such as land degradation, increased rainfall, and extreme weather events have increased in magnitude and frequency as a result of climate change, causing flooding that has threatened socioeconomic development in the Shire River Basin of Chikwawa District (Zuzani *et al.,* 2019). The presence of these factors has resulted in people being unable to predict when another flood will occur in the basin. As in most river basins, flood disasters pose serious challenges, causing loss of life and food security, as well as delaying economic development by affecting infrastructure and macroeconomic stability (Aziz *et al.,* 2016; Okyere, Yacouba, and Gilgenbach, 2012).

Flooding is a natural phenomenon that more or less regularly affects all river basins worldwide (Watson and Adams, 2011). Flood occurrences follow an established pattern with three duration classes categorized as follows: short (1-7 days); medium (8-20 days) and long (over 21 days) (Najibi and Devineni, 2018). Flood frequencies also range from annually or yearly occurring to multi-year or perennial occurring. Therefore, determining the pattern of flood occurrences helps local people to be proactive in flood management and develop emergency resilience systems to combat the disaster. In addition, knowledge of changes in flood occurrences is important for future risk assessments to mitigate damages (Albrecher, *et al.,* 2019). Effective analysis of flood occurrences also helps communities to understand that coping with flood disasters should be an ongoing process.

The hydrology and type of flooding differ around the world depending on the physiography and geography of an area. Historically, however, the total number of affected flood occurrences from 2000 to 2018 was 41% in Asia, followed by the Americas (23%), Africa (17%), Europe (14%) and Oceania (4%) (Perera *et al.,* 2019). In this context, various countries have experienced major flood events over the past half century. In the United States, the most commonly used records, called "the Annual Maximum Series (AMS)", were used to record the largest instantaneous discharge of the year at various gauging stations that would cause flooding (Collins *et al.,* 2022). Flooding is reported to occur annually in most of the states' river basins.

A study in the transboundary Chenab River Basin in Pakistan showed that flooding followed a specific pattern. The majority of elders observed that floods occurred every four or five years (Turi, *et al.,* 2019). Turi, *et al.,* (2019) further observed that there was a natural cycle of flooding associated with incessant behaviours, such that people were almost certain that the floods would hit the area in the next year, when four consecutive years without flooding passed. This knowledge helped communities prepare for the disaster. In Greece, flooding occurs in small flash flood-prone watersheds that are drained annually by ephemeral watercourses (Diakakis, 2017). Flooding is also an annual event in India caused by rains that occur due to the movement of monsoon winds during the June/September summer period, destroying bridges, crops and human life (Singh & Kumar, 2017).

The African continent is also exposed to flood risks as it is affected by endemic poverty, poor technology and increased population growth in flood-prone areas (Ringo *et al.,* 2016). Therefore, flooding is common in both rural and urban areas. In Ghana, flooding has become an annual event with severe consequences, particularly affecting poorer populations in rural and urban areas (Okyere, Yacouba and Gilgenbach, 2012).

Malawi also experiences frequent and severe floods that have caused varying degrees of destruction. From 1942 to 2019, torrential rains caused by Cyclones Ellin, Japheth and Idai hit the country affecting hundreds of thousands of lives, homes, livestock and crops (Malawi Government, 2019; ICRC, 2004 as cited by Mijoni & Izadkhah, 2009). Projections indicate that Malawi will continue to experience increased flooding due to increased risk and exposure to El Nino and La Nina events (Malawi Government, 2018; Mijoni & Izadkhah, 2009).

After the Zambezi River, the Shire River in Malawi is one of the largest catchment areas in southern Africa and is often hit by violent flood disasters during the rainy season (January/March) due to temporally and spatially different rainfall and discharge conditions The Shire River Basin in Chikwawa District is an important hydrological system that represents Malawi's most important water resource and supports significant development activities in the country (Zuzani *et al.*, 2019). These activities include fishing, irrigation, transportation and tourism. About 90% of the total annual precipitation in the basin is concentrated during this period, resulting in high discharge from the River Shire and its tributaries.

The 2014 floods and 2019 Tropical Cyclone Idai flooding were so devastating that both local and international assistance were required (Malawi Government, 2019; Malawi Government, 2015). There is therefore a need for effective flood risk management strategies to mitigate the impact. However, little attention has been paid to understanding the historical perspective of flood disasters and their implications for risk management (Petrucci, 2021). Therefore, this paper examines the historical trends and impacts of flood events in the Shire River Basin of Chikwawa District to provide a benchmark for establishing a risk mitigation flood cycle. In order to fully understand flood frequency and its impact, the following questions were answered by participants in individual interviews, group discussions and household surveys:

1) How have the climatic characteristics been since 1980?
2) How have the hydrological characteristics evolved since 1980?
3) How do people perceive the frequency of flood occurrences?

2.0 METHODOLOGY

2.1 Location of the Study Area

The study was conducted in the Shire River Basin of Chikwawa District (Figure 1). Chikwawa District has a total area of 4,755 km^2 which is about 15% and 5.04% of the area of the southern region and the country, respectively (Government of Malawi, 2017). It is the second largest district in the southern region and the fifth largest in Malawi. It is bounded by the lines of longitudes, 34° 01' 3" E and 35° 05'3 E and the lines of latitudes, 15° 2' 0" S and 16° 3'0" S (Malawi Government, 2019). The area is underlain by a basement of Precambrian to Lower Palaeozoic Mozambique Belt with high grade charnockitic granulites and biotitehornblende gneisses (semi-pelitic), referred to as the Malawi Basement Complex (Monjerezi *et al.*, 2011). Chikwawa's climate is characterized by two well-defined seasons; the hot and dry season from May to October and the warm and wet season from November to April.

Vegetation includes tree species such as *Acacia hygrescens*, *Acacia ataxacantha*, *Albizia harveya*, *Dalbergia melanaxylonand pterocarpus lucens*, and open/closed mixed forests containing tree species such as *Brachystegia spp*, *Julbernadic spp*, *Diplorynchus spp*, *Combretum spp*, *terminalia*, *seicea and scelerocary caffra* (Government of Malawi, 2017). However, over the past three decades, the Shire River Basin in Chikwawa District has experienced significant changes in its forest structure, composition and land cover (Palamuleni *et al*., 2007). Most of the mountains like Mwangala and Thyolo are completely bare, caused by a number of factors such as land expansion mainly for subsistence farming, charcoal burning, house construction, uncontrolled fires, tobacco treatment, and rapid population growth (Mwale, 2014). Removal of vegetation cover poses a threat because it promotes runoff that causes flooding along rivers.

Agriculture is the main economic activity done by the majority of the residents but the sector depends on seasonal rainfall that is currently under threat from climatic extremes that either cause drought or floods (Government of Malawi, 2017). Because of their accessibility and vulnerability, people of the following Traditional Authorities (T/As) of Mlilima, Kasisi, Makhuwira, and Lundu participated in the study.

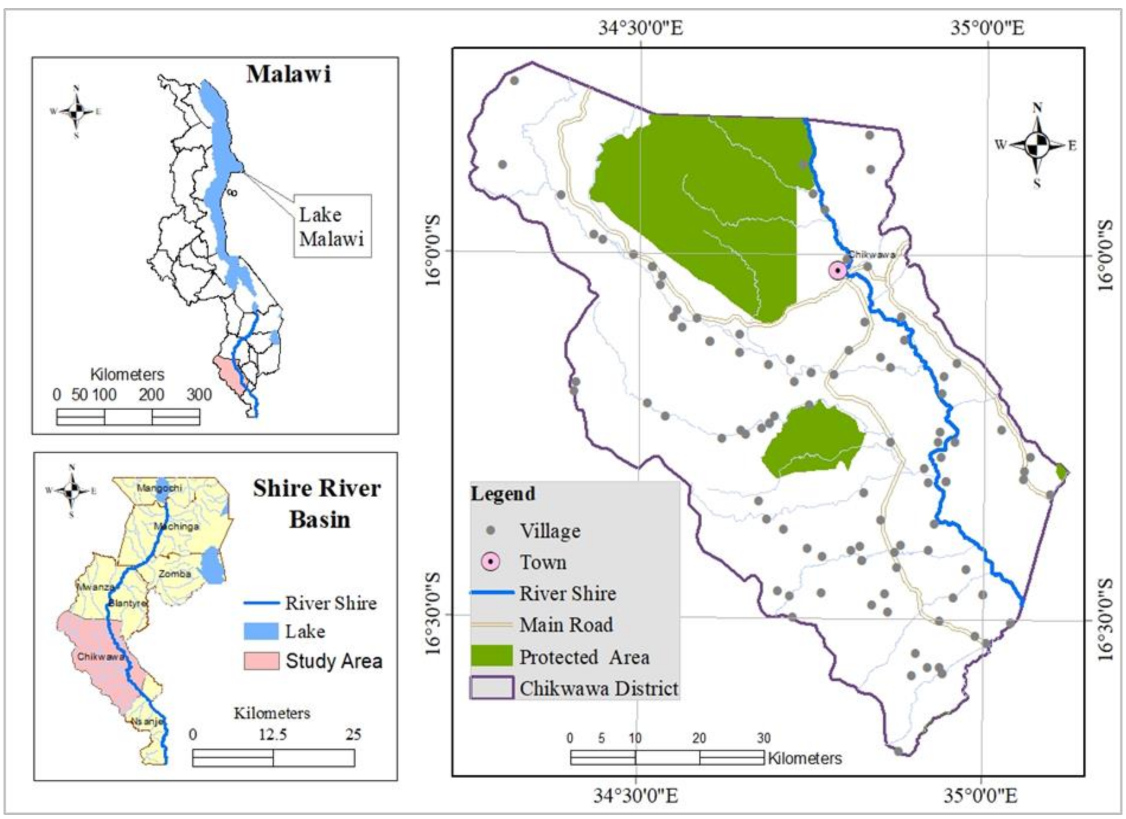

Figure 1: Shire River Basin in Chikwawa District (Hussein, 2022)

2.2 Sample Size

According to 2008 Population and Housing Census projections for 2017, Chikwawa has a population of 590,368 of which 301,289 are women and 289,079 are men (Malawi Government, 2019a). Sample size was determined using Fisher's formula as used by Ayaa & Kipterer (2018). The target sample size was calculated as follows;

To get the desired sample size, the formula was calculated as follows;

$$n = \frac{Z^2 pq}{d^2}$$

Where;

n = sample size

Z = 95% at standard value of 1.96

p = population proportion assumed to be at 50 % (0.5)

q = the desired level of precision 1 – 0.5 (0.5)

d = statistical significance set at 5% (0.05)

The number of people participating in the study was 384. The sample size was calculated by substituting the values as follows;

$$n = \frac{z^2 \times \hat{p}(1-\hat{p})}{\varepsilon^2}$$

$$n = \frac{1.96^2 \times 0.5(1-0.5)}{0.05^2} = 384.16$$

The formula was used in accordance with the suggestion by Ayaa (2013), who recommended it for a population greater than 10,000 inhabitants, as was the case in Chikwawa District. Of the calculated study population, 270 participated in the household survey, 96 formed gendered disaggregated focus group discussions, 8 were community elders, and 10 were key informants (6 government officials and 4 NGOs).

2.3 Data Collection

The study collected both primary and secondary data. Primary sources of data were collected using a household survey, interviews with key informants and focus group discussions. The questionnaire contained closed and open questions. All of the participants' responses were recorded in the spaces provided in the questionnaire. Additional responses from participants deemed important for the research were written in a notebook and also analysed. Household surveys were conducted in the local Chichewa language, and the results translated into English. The key informant category with the Malawian government and NGO officials used interview guides prepared to collect information from them. The interviews were conducted in English. Responses were recorded using a Sonny voice recorder and also written in a notebook. Interviews with the community elders were conducted in the local Chichewa language. Responses were recorded using a Sonny recorder and also written in a notebook and later translated into English for clarity of information.

On the other hand, secondary data sources included hydrometeorological data such as Shire River discharge obtained from the Department of Surface Water in Lilongwe and meteorological data (rainfall and temperatures) obtained from the Department of Climate Change & Meteorological Services in Blantyre. All data from the different Malawian government departments were kept in softcopies and stored in hard disc for analysis.

2.4 Data Analysis

After data collection, all qualitative data were organized into different thematic areas. Content analysis and triangulation approaches were applied to improve the reliability of the study. The emic approach was applied to analyse the data to reflect the respondents' actual responses. Quantitative data from household surveys were analysed using a Statistical Package for Social Scientists (SPSS) version 25.1. The hydrometeorological data (discharge, precipitation, temperature) were converted into different values. Rainfall data were converted to annual mean rainfall, maximum and minimum temperatures were converted to annual mean temperature whereas discharge was converted to baseflow index (BFI). The data were saved in Micro Soft Excel version 13 and then imported into STATA software for time series analysis, from which graphs were generated.

3.0 FINDINGS

3.1 Temperature Trends

Figure 2 shows the yearly temperature for Chikwawa District from 1980 to 2019. The maximum annual temperature was 31.2 ^{0}C in 2010, followed by 30.3 ^{0}C in 1983, and 30.2 ^{0}C in 2004. The lowest temperature recorded during the period was 26.1 ^{0}C in 1999. The average annual temperature for this period was 28.4 ^{0}C. The year 2019 when flooding triggered by Tropical Cyclone Idai occurred, also recorded a slightly above mean temperature reading of 29.8 ^{0}C. The slope trend showed that the temperature fluctuated significantly from 1980 to 1990, with a sharp increase being recorded from 2010 onwards. In general, the results indicated that the temperature had been high for most of the 39 years studied. This agrees with the study by Zuzani *et al.*, (2019) that extreme minimum and maximum temperatures in the Shire River Basin showed increasing trends at the 5% level of significance. Jury (2014) also observed a temperature increase in temperature in the Shire River Basin from 3 mm day $^{-1}$ between January and July to 5 mm day $^{-1}$ between September and November. Such an increase also led to an increase in potential evaporation that would eventually lead to rainfall. Whitfield (2012) added credence by saying that an increase in temperature increased the risk of flooding through the processes of evapotranspiration.

At both global and local levels, warming increases the atmosphere's capacity to hold water and accelerates its distribution leading to formation of rainfall. Therefore, the rise in temperature in the Shire River Basin suggests that atmospheric flood-generating activities are likely to increase in the near future. According to Tabari (2020), a warmer atmosphere contains about 7% more moisture, so an increase in extreme precipitation was to be expected, as recent studies show that global warming would likely increase by 6-7% in the near future. This would also increase global temperature.

In addition, evaporation increases humidity, which means that more precipitation that was short and intense would occur, increasing the risk of flooding. As observed by Wasko (2021), as the temperature increases, the water vapour saturation of the atmosphere also increases, resulting in larger precipitation extremes that lead to flooding. In the Shire River Basin of Chikwawa District, the temperature is lowest in winter (May, June and July) and rises as summer progresses due to increased solar radiation as the sun is over the Southern Hemisphere at this time.

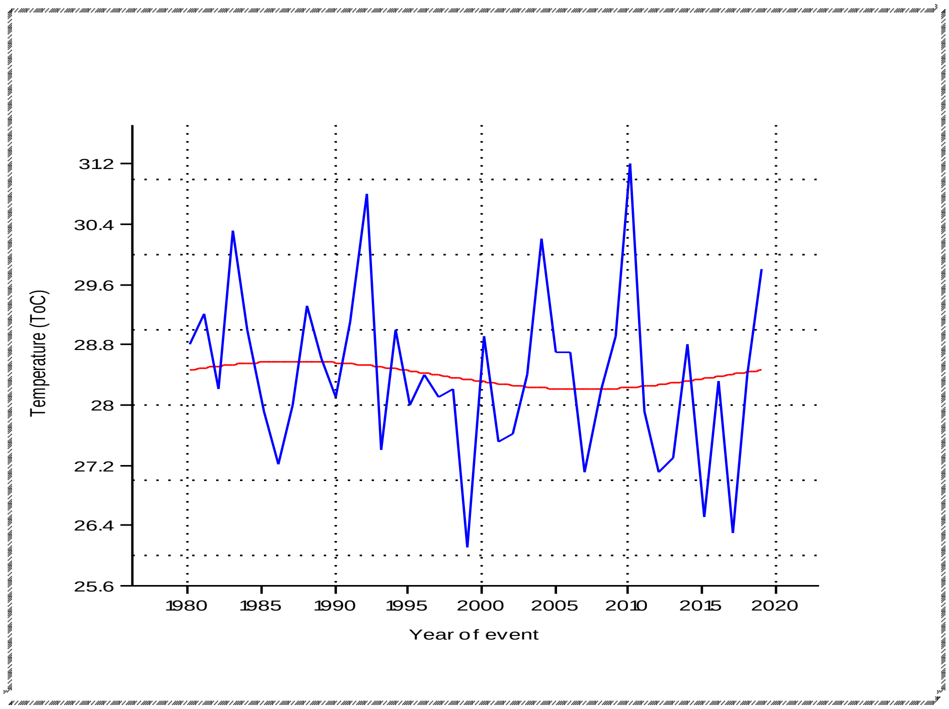

Figure 2: Annual Mean Temperature of Chikwawa District (Hussein, 2022)

3.2 Rainfall Trends

Figure 3 shows annual average rainfall for Chikwawa District. Recorded data shows that the highest precipitation fell in 2007 at 1390.3 mm, followed by 1148.6 mm in 1997 and 1068.9 mm in 1989. The average annual precipitation over the 39-year period was 756.2 mm. The rainfall that triggered 2019 Tropical Cyclone Idai was 887.6 mm. The trend line indicates a strong negative correlation of rainfall (y = -0.5098x). The offset was (+76.66 mm) and statistically significant. The slope (r^2 = 0.0008) was far from 1. The five-year moving average trend showed that rainfall in Chikwawa District was below average for 23 years and above average for 16 years, although rainfall increased to about equal or above average from 2015 to 2019. As reported by Zuzani et al., (2019), rainfall trend in the Shire River Basin was erratic and showed no clear pattern, therefore sub-periods showed both increasing and decreasing changes.

In this context, the mean annual rainfall in 2019 coincided with one of the worst Tropical Cyclones, Idai that formed in the Mozambique Channel, bringing heavy rains and strong winds (Malawi Government, 2019). Therefore, rainfall trend analysis is one of the most important factors that directly affect the flood generation mechanism in the Shire River Basin of Chikwawa District. Several factors are identified that cause frequent flooding in the basin. As suggested by (Mijoni & Izadkhah, 2009), previous flooding in the Shire River Basin was caused by the banks of the Shire and Ruo Rivers breaking after heavy rains, affecting families, homes and several hectares of farmland destroyed.

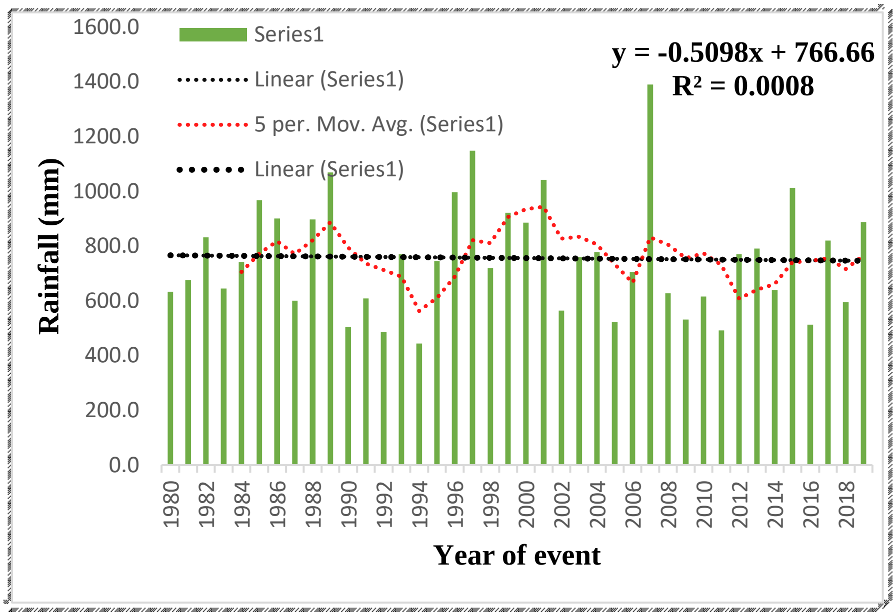

Figure 3: Average Annual Rainfall Trends of Chikwawa District (Hussein, 2022)

3.3 Base Flow Index Analysis

Figure 4 shows the Shire River annual base flow index. Results showed that the maximum annual baseflow index was 0.9968 in 2017, with a minimum of 0.7891 in 1997. The average annual base flow index was 0.9451. From 1980 to 1997, the Shire River's baseflow index steadily declined and thereafter rose significantly until 2010. From 2010 to 2019, the Chikwawa District's base flow index was above the annual average, an indication that water flow in the Shire River had also been increasing. Base flow is the groundwater flow that keeps water flowing in streams and rivers even during extended periods of drought (Liu *et al.*, 2015). A base flow index is the main source of streamflow during the dry season to meet ecological water needs and irrigation.

The base flow index of the Shire River Basin in Chikwawa District has fluctuated from 1980 to 2019, indicating differential climate changes. In this context, the base flow is sensitive to climate change, making evaporative losses widespread and high from September to November (Jury, 2014). This is consistent with the findings of Miller et al., (2021), that the Lower Colorado River Basin in the United States of America experienced the largest decline in base flow index up to 33%, due to a larger increase in evapotranspiration and then a rapid increase by 35% as a result of climate change. In the Shire River Basin of Chikwawa District, the increase in the base flow index is attributed to a network of rivers such as the Mwanza and the Ruo. When it rains, the river channel quickly fills with water and causes flooding. The presence of water flows in the Shire River throughout the year was significant in that it often resulted in unprecedent flooding in the basin, as was the case with Tropical Cyclone Idai that caused flooding in 2019.

Anecdotal statements from one respondent alluded that:

"The Shire River Basin in Chikwawa District is a low-lying area, lower than the rest of the country at 50 metres above sea level. Not much rain does occur in Chikwawa. Key to flooding in the Lower Shire was the Shire River and its tributaries, most of which originate from high rainfall areas and drain their waters into the Shire River which eventually drains its waters into the Zambezi River.

The notable and notorious tributaries are the Mwanza and Ruo Rivers, both of which originate in the high-rainfall mountainous areas of Mwanza and Mulanje respectively," **[Director, Department of Climate Change and Meteorological Services]. 20th, January, 2022.**

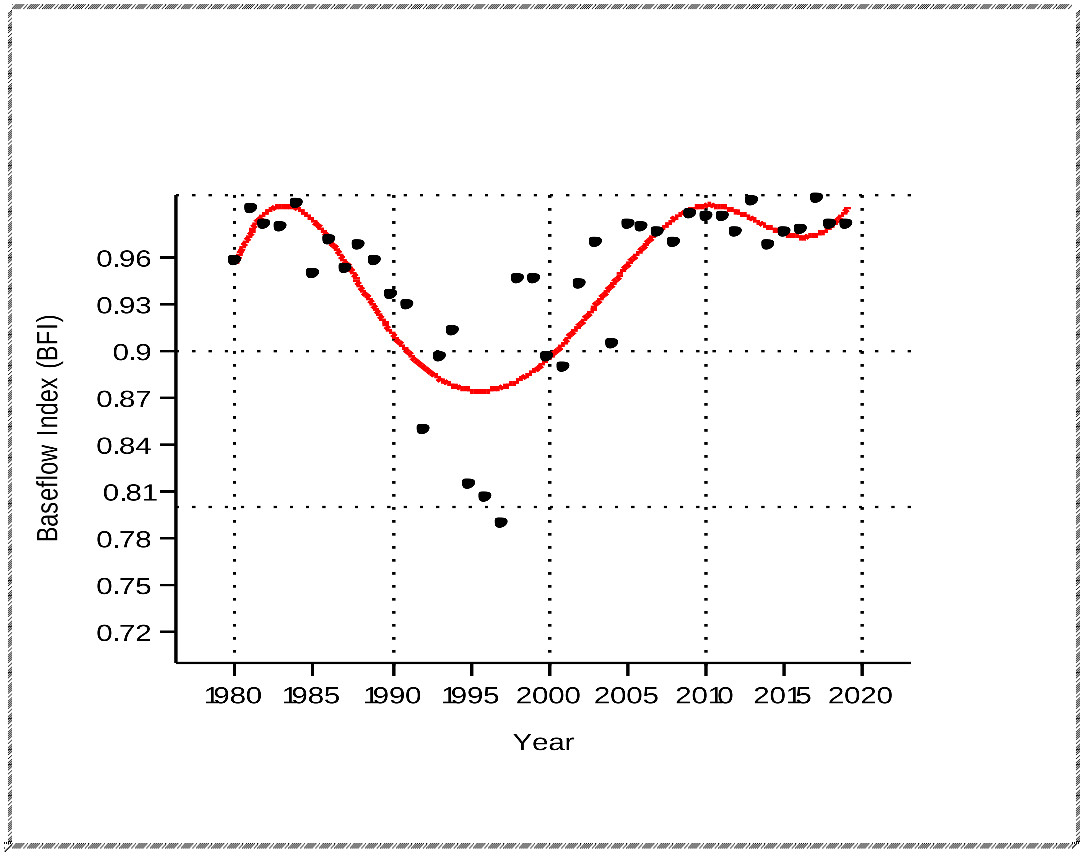

Figure 4: Trend Plot of Annual Base Flow of the Shire River (Hussein, 2022)

3.4 Flood Frequency

Figure 5 shows household perceptions of flooding in the Shire River Basin of Chikwawa District. The results of the study showed that more than half of the respondents (56.3%) reported that flooding occurred every five years, 28.1% reported that it occurred every two years, and 14.8% reported that it is an annual phenomenon. At 0.8%, very few respondents indicated that flooding occurs every 10 years.

Comments from participants regarding the flooding pattern in the Shire River Basin of Chikwawa District included the following:

1) A Malawian government representative stated that flooding occurs almost annually, but with varying degrees.
2) A representative of an NGO reported that floods occurred at least four years apart.
3) Community elder participants reported that severe flooding occurred every five years.
4) FGD participants reported that they suffer from flooding every year, but most of the times they could not cause much damage.

The responses above indicate that communities in the study area have experienced flooding of varying magnitude and severity, ranging from seasonal to once per decade over the past 39 years. In most cases, these floods were more active in the December to March rainy season. However, participants recalled past extreme floods by recounting an anecdote of events such as 1979, 1980, 1986, 1990, 1997, 2002, 2004, 2015, and 2019. A study by Mijoni & Izadkhah (2009) reported that recent flood disasters occurred in the Shire River Basin in 1997, 2001, 2003, 2006, and 2007.

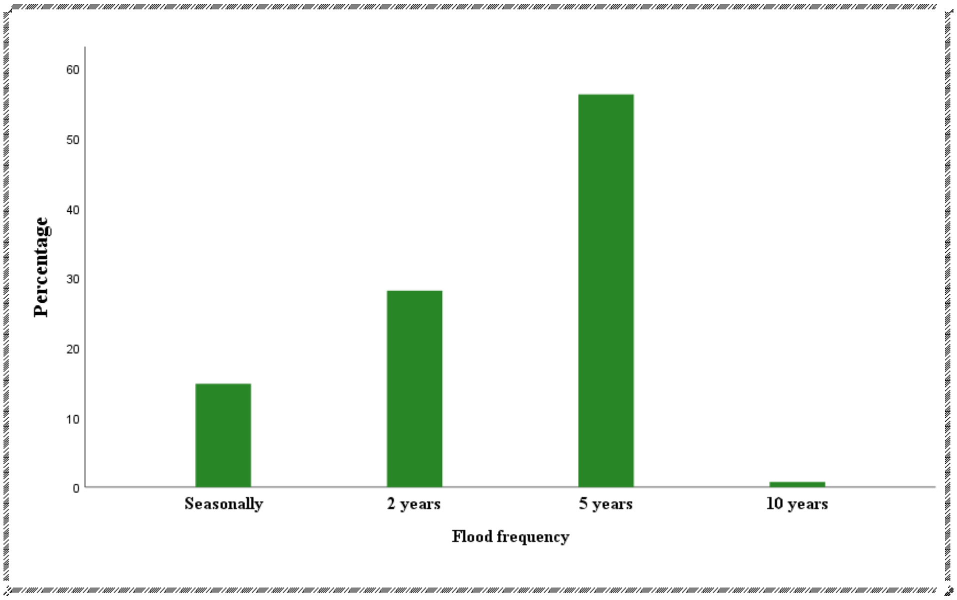

Figure 5: Participants' Perception of Flood Frequencies (Hussein, 2022)

3.5 Trends of Affected Households

Figure 6 shows the number of households affected by floods from 1980 to 2019. The results show that many people (34.34%: n=53,350) were affected by floods in 2015, followed by 30.03 % (n=46,391) in 2019 and 19.22 % (n=30,000) in 1997. The results of the findings show that the Shire River Basin in Chikwawa District has experienced severe flooding within a short period of time. Unlike other flood events, the 2015 floods affected more people because they covered a larger area and took several weeks to subside. The study results are in consistent with the Malawi Government (2015) report that found that the 2015 floods were the most devastating in terms of geographic coverage, severity of damage and extent of casualties. As observed by Trogrlić., (2018), the 2015 floods brought Malawi to the international news headlines and had a devastating impact on the Shire River Basin.

Equally devastating was Tropical Cyclone Idai in 2019 that also required local and international assistance. The flooding was caused by strong winds that brought a cyclone from the Indian Ocean in Mozambique. Tropical Cyclone Idai affected an estimated 975,000 people, displaced 86,976, killed 60, and injured 672 and caused economic damage of US $ 370.5 (Zuzani et al., 2019; Malawi Government, 2019b). On the other hand, the 1997 floods damaged the Bangula-Chilomo railway line in the Lower Shire Valley, apart from damage to crops and homes (Mijoni, & Izadkhah, 2009). The number of flood victims in the Shire River Basin of Chikwawa District will continue to increase due to the current annual population growth rate of 2.5% (Government of Malawi, 2017).

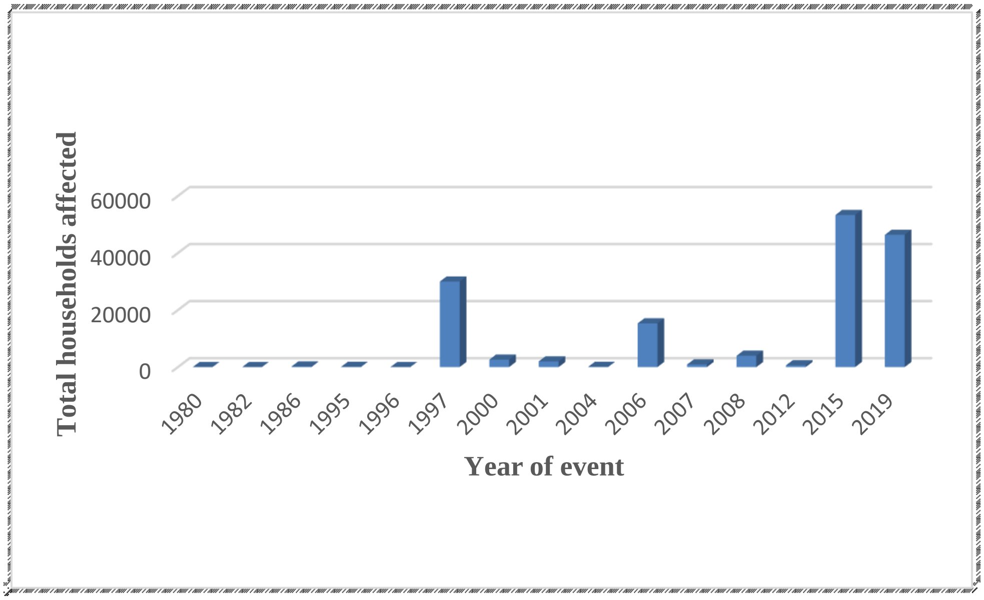

Figure 6: Households Affected By Floods (1980 – 2019)

Source: (Malawi Government, 2020)

4.0 CONCLUSION

This study documented the characteristics of flooding in the Shire River Basin, with an emphasis on the pattern of occurrence and impact. The results show that all three hydrometeorological extremes are increasing, suggesting that both the intensity and frequency of flooding in Chikwawa District's Shire River Basin are increasing. This is evidenced by the increase in temperature, rainfall and discharge in the basin. As precipitation trends are reflected in river discharge rates, both extremes are likely to increase due to declines in vegetation cover from charcoal burning and poor agricultural activity. These human activities are likely to increase runoff, that will consequently lead to sedimentation of the River Shire.

Again, the increase in the climatic extremes suggests that people in the Shire River Basin will continue to live with flooding. The results of the study indicate that people's perceptions of the history of flooding in the Shire River Basin of Chikwawa District indicated that major flooding occurs every 5 years. Several reasons have been suggested to cause this flood cycle. While the young and educated respondents attributed the 5-year flood cycle to climate change and climate variability, the majority of older respondents attributed the pattern to forest destruction. This has led to the disappearance of important plants and animals that they used to predict floods in the past. Some elders also mentioned sins such as increased homicides and family conflicts as other causes of the flood pattern. However, this study failed to model the three hydrometeorological extremes using the Peak-Over-Thresholds (POT), where parameters are estimated to fit a probability distribution for the selected extremes.

5.0 RECOMMENDATIONS

This study makes the following recommendations;

a) The Department of Disaster Management Affairs (DoDMA) officials are required to create flood vulnerability maps to delineate flood prone areas.

b) Communities in the Shire River Basin of Chikwawa District should intensify tree planting program to reduce runoff.

c) There is a need by local people to control population growth and reduce forest loss.

d) The flood forecasting system needs to be strengthened by officials from the Malawian Department of Climate Change and Weather Services to help the village committee members responsible for flood management to predict any flood event before it occurs.

6. 0 ACKNOWLEDGEMENTS

The authors thank the members of the community in Chikwawa District for their participation and collaboration in this study. Without their contribution, the study would not have been possible. Support for this research was made possible by a competitive capacity-building grant "*Training the next generation of scientists for Africa"* provided by the Carnegie Cooperation of New York through the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM).

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