ALBERT WATER MANAGEMENT ZONE

RESEARCH TITTLE

‘‘ASSESSMENT OF WATER RESOURCES AVAILABILITY, ALLOCATION AND MANAGEMENT ALONG RIVER MPANGA’’

SUPPORTED BY

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CHAPTER ONE: INTRODUCTION

1.1. Background

Water resources play a unique role in promoting socio-economic development and protecting the ecological system, which has become a major strategic natural resource of a country (Cosgrove, W.J. and Loucks, D.P., 2015). The Water Resources Assessment is a comprehensive study aimed at building understanding of the water resources in the catchment. The Assessment is a crucial source of the necessary information to make informed decisions about water resource allocation and management.

However, the uneven spatiotemporal distribution of water resources, the increasing water demand due to the rapid urban expansion and population growth have caused conflicts between social and environment for available water resources. The optimal allocation of water resources is one of the most efficient ways to mitigating conflicts, which can effectively allocate the limited available water resources among regions and departments through various engineering measures and non-engineering measures. Furthermore, the identification of the water availability and water demand is the prerequisite for optimal water resources allocation. However, due to the impacts of climate change and human activities, the heterogeneity in the spatial and temporal distribution of water availability and water demand has intensified, which suggests daunting and urgent challenges on water resources allocation. The Intergovernmental Panel on Climate Change (IPCC) report indicated a changing climate in the past that the global average temperature has increased by 1.5 °C. This research was set out to determine the spatial and temporal distribution of available water resources, current and planned water use, and project future demand, evaluation of water demand management options, and assessment of the influence of anthropogenic and land use activities on water quality and populace perception on controlled activities within the river buffer zone.

1.2. Objectives

1.2.1 General objective

The general objective of the study was to assess water resources availability, allocation and management along river Mpanga

1.2.2 Specific objectives

Specifically, the research was;

a) To determine the spatial and temporal distribution of available water resources, factoring the influence of climate change in the Mpanga Catchment
b) To determine the current and planned water use, and project future demand
c) To evaluate water demand management options and allocation under different scenarios, in a sustainable manner
d) To assess the influence of anthropogenic and land use activities on water quality
e) To assess populace perception on controlled activities within the river buffer zone, in accordance with the Environment act 2019

1.3. Significance of the study

Knowledge of the rainfall trend and its significance is vital for planning for water resources availability and strengthening community mechanism to water use management.

Important to policy makers and regulatory bodies in the water and meteorological sector, with an improved understanding of the dynamic of the changes in climatic dryness across river Mpanga catchment.

The research broadens academic understanding of the influence climatic indices to water availability and the essential information required in catchment management planning. The recommendation offers opportunity for further research areas, hence contributing to further academic fields

1.4. Study area

River Mpanga originates from the Rwenzori Mountain in western part of Uganda, East Africa. **Error! Reference source not found.**shows Mpanga catchment location with a total surface area covering 5204.37 km². Hydrologically, the catchment is delineated in to four sub-catchments, which includes upper, middle, and lower Mpanga and Rushango. The river flows through Kabarole, Kyenjo, Kamwenge and Kitagwenda, which constitute the upper, middle and lower Mpanga subcatchment. A section of the sub-catchment (Rushango) joins the main river in Kamwenge district. This part of the sub catchment includes Ibanda, Kazo, Kiruhura, Buweju and Mbarara districts. River Mpanga, eventually discharges in Lake George The present study is to determine the spatial and temporal distribution of available water resources factoring the influence of climate change in the Mpanga Catchment.

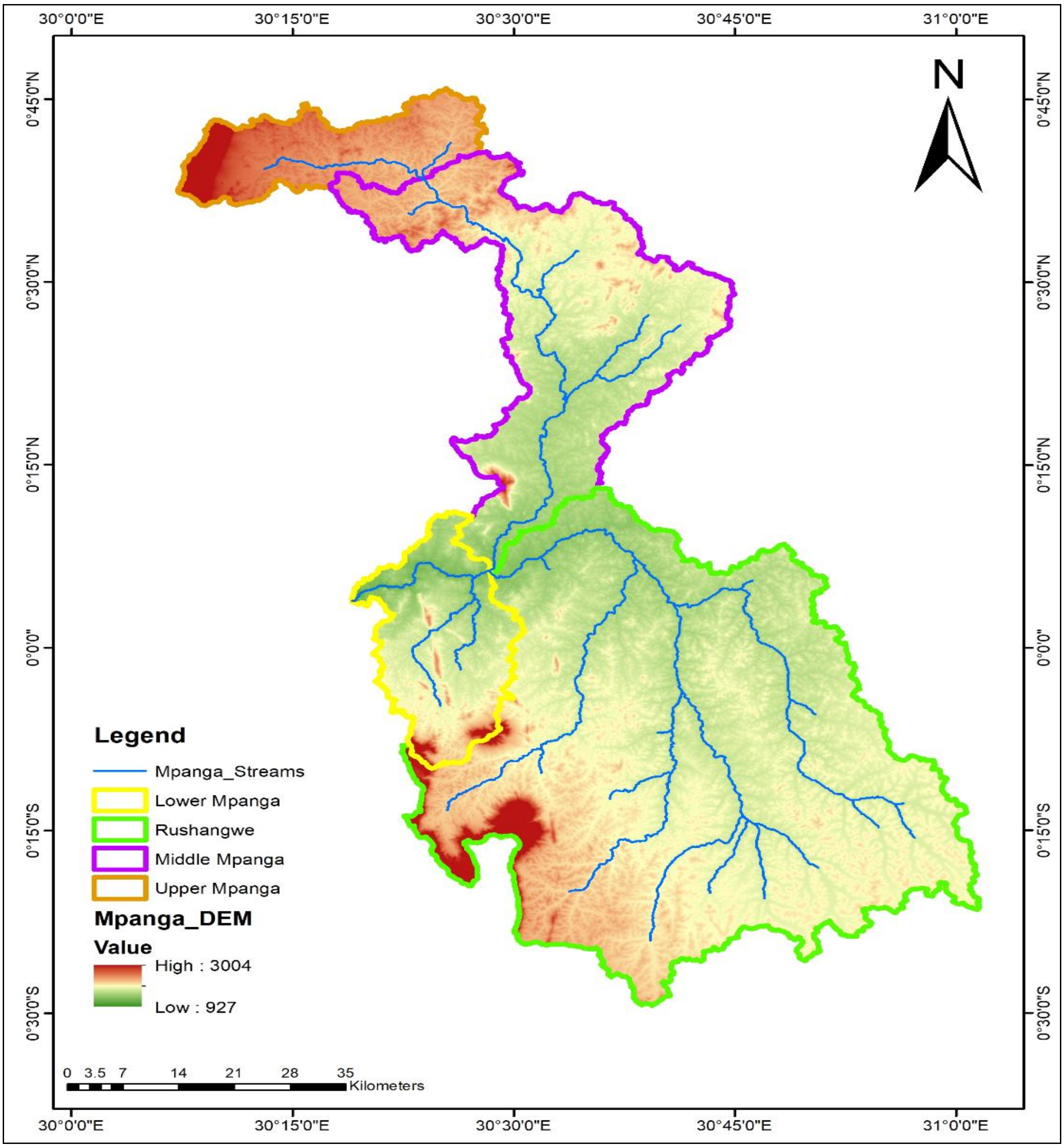


Fig 1. 1: Study area

GIS analysis established that the catchment covers a total of 5,202 square kilometers over 11 districts. These include Kabarole, Kyenjojo, Kamwengye, Kitagwenda, Ibanda, Buhweju, Bundibugyo, Mbarara, Kazo, Bunyangabu, and Kiruhura.

1.5. Chapter Summary

This chapter introduces the research area together with the justification for carrying out the study and the determination of spatial and temporal distribution of water resources availability looking at the influence of climate change in the Mpanga catchment in Uganda. The chapter also describes the purpose and specific objectives of the study. Further, linkages between rainfall and selected climatic indices trends and variability were presented. This understanding guided the literature search and limited data acquisition.

CHAPTER TWO: DETERMINATION OF THE SPATIAL AND TEMPORAL DISTRIBUTION OF AVAILABLE WATER RESOURCES, FACTORING THE INFLUENCE OF CLIMATE CHANGE IN THE MPANGA CATCHMENT

2.1 Introduction

The research study looked at the maximum annual daily and average annual daily rainfall, changes in number of days with very low extreme rainfall and potential evapotranspiration. Water resource availability is highly associated surplus and deficit in rainfall received over land surface. Globally, there is experience of surplus and period of scarcity to water availability and this varies disproportionately. The East Africa region and Uganda in particular experiences extremes in rainfall and temperature distribution and this varies both in time and in space. This study establishes the trend and variation in rainfall received across river Mpanga catchment in relation to influence by changes in climate. Observed daily rainfall and temperature datasets obtained from UNMA, covering 9 weather stations from 1991 - 2022, were used to statistically characterized the distribution of the water resources across the catchment

2.2 General objective

The present study is to determine the spatial and temporal distribution of available water resources factoring the influence of climate change in the Mpanga Catchment.

2.2.1 Specific objectives

- To analyse trend in rainfall and determine the significance of change
- To determine variability in average and maximum annual precipitation across the catchment
- To characterize spatial variation in the climatic condition in Mpanga catchment

2.3 Literature review one

2.3.1 Trend analyse trend in rainfall

Various studies have been conducted to analyse spatial-temporal trend in meteorological (rainfall, temperature, evapotranspiration, humidity, etc) time series using parametric (simple linear regression) and non-parametric (Mann-Kendall, Spearman's rho, Kendall rank correlation, modified Mann-Kendall and Thiel-Sen's) methods. Onyutha, C., Turyahabwe, C. and Kaweesa, P., (2021). Trend analysis helps understand the changing pattern of hydro-climatic variables in a river catchment (Adarsh and Reddy, 2015). It looks at both the slope and direction of the changes in variables over time. This is important because, the predictability of the likelihood of future occurrence in changes in climatic condition can be easily derived. Such certainty further guides planning process in management of catchment water resources (Onyutha, et al., 2021).

2.3.2 Determination of the significance of change

According to Onyutha (2018), trend magnitude indicates the amount variables changes linearly over a specific time of observed data. Trend magnitude is also known as trend slope. The linear trend magnitude (*m*) is computed using (Theil, 1950) and (Sen, 1968) methods, as shown in equation below.

$$m_i = \text{Median}\left(\frac{x_j - x_i}{j - i}\right), \text{for } i = 1,2, \dots \dots \dots, n$$

Where *n* is the number of data points in the time series, x_j and x_i are data values at time *j* and *i* $(j > i)$. From equation (1), the significance of m_i is tested, for a no trend, H_0, $m_i = 0$ and alternative, H_1, $m_i \neq 0$ at a selected α.

The need for significance assessment of trend is because the direction can be influenced, e.g, by noise, which subsequently influences the sample variation (Onyutha, 2017) in terms of CV. In order to check if a linear increase or decrease is significant, trend tests are carried out by both parametric and non-parametric methods.

2.3.3 Variability in average and maximum annual precipitation

According to the World Meteorological Organization (WMO) (2019), climate variability is defined as the variations in the mean state and other statistics of the climate on all temporal and spatial scales, beyond individual weather event. It is used to check alteration of climatic statistics over the time span (e.g. a month, season or year). Variability can be classified as a combination of preferred spatial patterns, for example as modes of climate variability (Wodaje et al., 2016).

Different methods are available and used in the analysis of variability. These include; Non-parametric Anomaly Indicator Method (NAIM), Quantile Perturbation Method (QPM), Empirical Orthogonal Function (EOF), Auto correlation Spectral Analyses (ASA), the use of Coefficient of Variation (CV), Standard deviation (SD).

2.3.4 Chapter summary

The discussion in this chapter draws on the findings of previous studies undertaken in the same field. Review of trends and variability in precipitation and evapotranspiration, as factors that influence change in climatic condition were all investigated under different studies.

2.4 Material and Methods one

2.4.1 Sources of data

2.4.1.1 Hydro-meteorological data

The hydro-meteorological data that was required for hydrological modelling using Arc GIS, HMSV, QDF and CSD-NAIM_v.1 in this study was obtained from Uganda National Meteorological Authority (UNMA). The observed data from selected stations across the catchment was considered for analysis and included precipitation, river discharge, temperature (minimum and maximum), solar radiation, wind and relative humidity. The data period considered covered a period of 30-years

2.4.1.2 Extreme climatic indices

The extreme climatic indices selected for determining the influence of climate change on the availability of water resources in Mpanga catchment included those of rainfall. The rainfall indices considered are NDD1, NDD5 and NDD10.

NDD per annum were extracted for rainfall less than 1mm (NDD1), 5mm (NDD5) and greater than 5mm (NDD5) and 10mm (NDD10). NDD1 and NDD5 less explain a characteristic condition of extreme dryness and NDD10 a characteristics condition for wet condition. A good index indicates a risk of inadequate water supply especially in an irrigation and urban water supply area. In this case, an annual time scope was considered for all the rainfall indices. The lower thresholds (1 and 5 mm/d)/ (10mm/d) was selected to characterize dryness/wetness over the catchment in a defined period. This is because dry condition reduces water availability for water demand in the catchment.

2.4.1.3 Topographical data

Spatial data required for use in the study such as Digital Elevation Model (DEM) was obtained online from the hole-filled DEM of 30 m × 30 m (Jarvis et al., 2008) via https://lta.cr.usgs.gov.

2.4.1.4 Hydrological flow data

River flow data was obtained from the database of the Ministry of Water and Environment's Directorate of Water Resources and Management (DWRM). This dataset was obtained in cumecs and converted in to daily discharge.

2.4.2 Research design

The study used quantitative method in determine the spatial and temporal distribution of available water resources factoring the influence of climate change in the Mpanga Catchment. Analysis adopted a descriptive approach to establish the relationship between average annual daily average and annual maximum daily rainfall across the catchment with changes in extreme climatic indices. In determining spatial and temporal distribution, change detection in water availability, the extreme climatic indices and characterization of climatic conditions, the study used both statistical and graphical techniques to analyse changes in trend and variability.

2.4.3 Research Approach

The study used quantitative research approach to analyse the changes in climatic indices and variability of hydro-meteorological time series in terms of variation statistics, trend direction and slope across the Mpanga catchment.

2.4.4 Methods

2.4.4.1 Trend analysis

The trend analysis was graphically analysed using linear least square method. The linear model polynomial function at 1degee represented by equation (1) below.

$$F(x) = P_1 x + P_2 \qquad (1)$$

The magnitude (x) of the linear trend computed in each hydro-meteorological parameter and extreme climatic index from the observed stations will be computed using Theil, (1950) and Sen, (1968) and significance of this magnitude interpreted.

2.4.4.2 Variability analysis

Variability of the spatial distribution will be analysed by testing the H_0 (natural randomness) in each hydro-meteorological parameter and extreme climatic index. Any deviation from central tendency of disproportionate magnitude was analysed.

Sum of Squares Due to Error

This statistic measures the total deviation of the response values from the fit to the response values. It is also called the summed square of residuals and is usually labelled as *SSE*.

$$SSE = \sum_{i=1}^{n} w_i (y_i - \hat{y}_i)^2 \qquad (2)$$

A value closer to 0 indicates that the model has a smaller random error component, and that the fit will be more useful for prediction.

R-Square

This statistic measures how successful the fit is in explaining the variation of the data. Put another way, R-square is the square of the correlation between the response values and the predicted response values. It is also called the square of the multiple correlation coefficient and the coefficient of multiple determination.

R-square is defined as the ratio of the sum of squares of the regression (*SSR*) and the total sum of squares (*SST*). *SSR* is defined as

$$SSR = \sum_{i=1}^{n} w_i (\hat{y}_i - \bar{y})^2 \qquad (3)$$

SST is also called the sum of squares about the mean, and is defined as

$$SST = \sum_{i=1}^{n} w_i (y_i - \bar{y})^2 \qquad (4)$$

Where,

$$SST = SSR + SSE \qquad (5)$$

Given this definition, R-square is expressed as

$$\mathrm{R-Square} = \frac{SSR}{SST} = 1 - \frac{SSE}{SST} \qquad (6)$$

R-square can take on any value between 0 and 1, with a value closer to 1 indicating that a greater proportion of variance is accounted for by the model. For example, an R-square value of 0.8234 means that the fit explains 82.34% of the total variation in the data about the average.

If you increase the number of fitted coefficients in your model, R-square will increase although the fit may not improve in a practical sense. To avoid this situation, you should use the degrees of freedom adjusted R-square statistic described below.

Note that it is possible to get a negative R-square for equations that do not contain a constant term. Because R-square is defined as the proportion of variance explained by the fit, if the fit is actually worse than just fitting a horizontal line then R-square is negative. In this case, R-square cannot be interpreted as the square of a correlation. Such situations indicate that a constant term should be added to the model.

2.4.4.3 Correlation analysis

The purpose of conducting correlation analysis was to establish linear relationship between the climate indices, number of dry days (NDD1, NDD5 and NDD10), as an indicator of climate change with different continuous variables (maximum annul daily temperature/rainfall, total annual rainfall and average annual daily rainfall).

2.5 Results and discussion

2.5.1 Rainfall trend

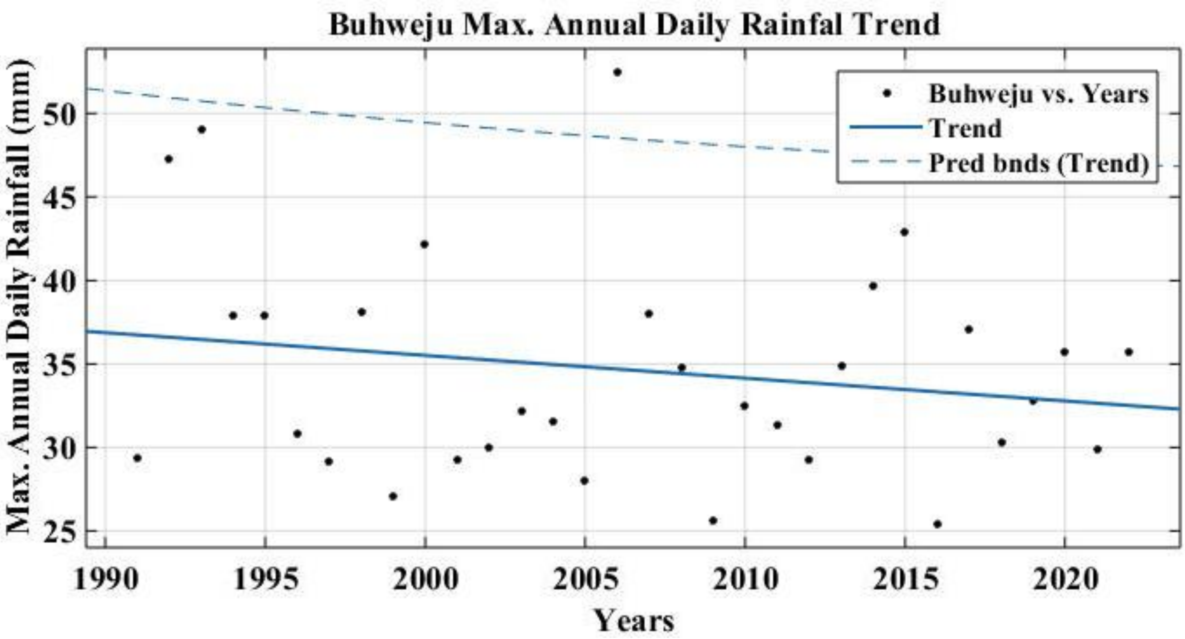


Fig 2. 1: Buhweju station maximum annual daily rainfall trend

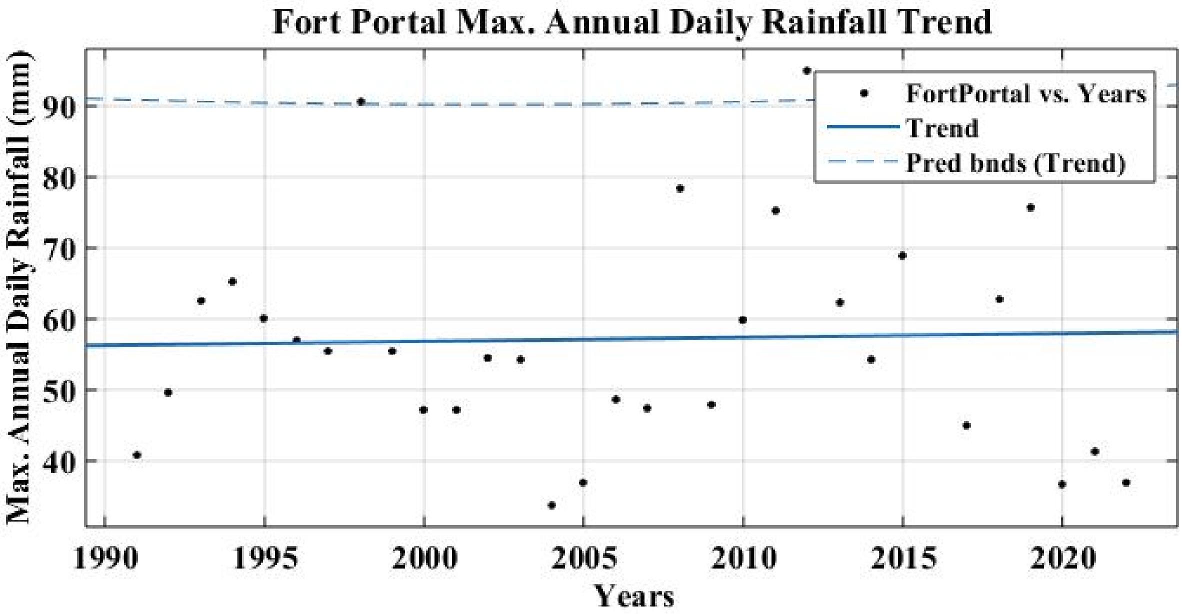


Fig 2. 2: Fort Portal station maximum annual daily rainfall trend

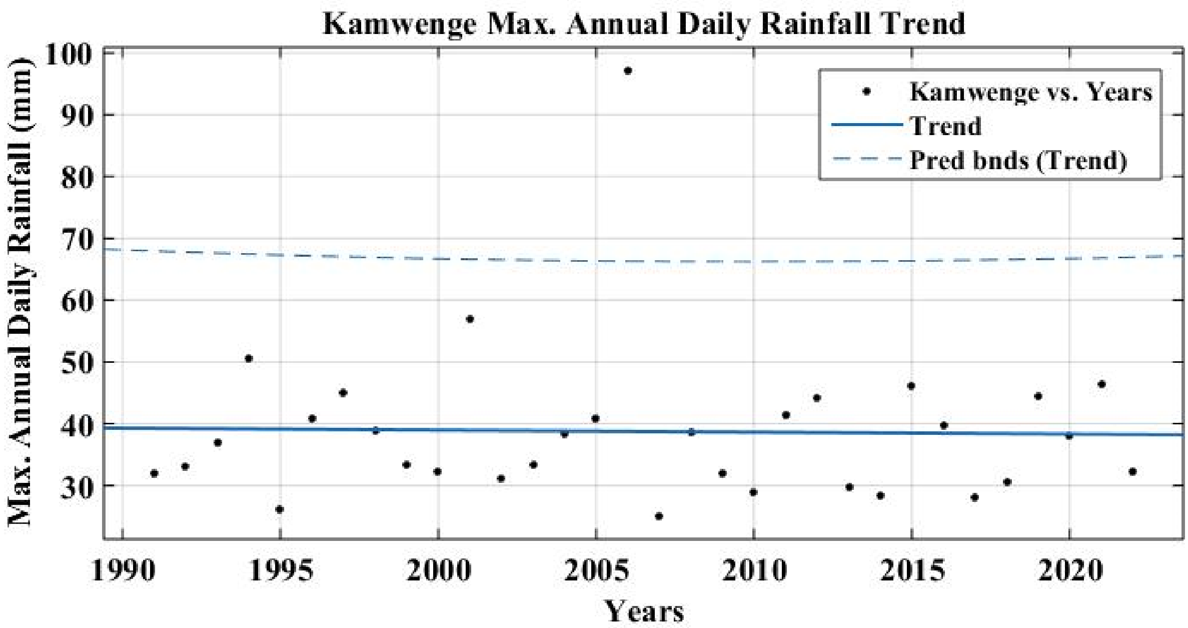


Fig 2. 3: Kamwege station maximum annual daily rainfall trend

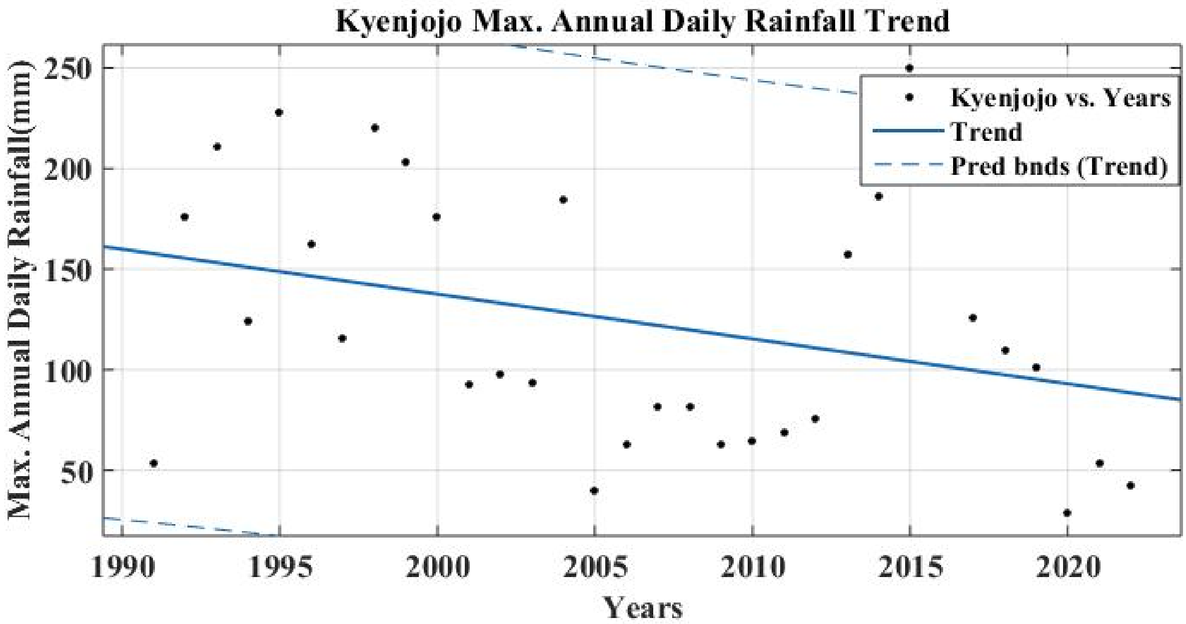


Fig 2. 4: Kyenjojo station maximum annual daily rainfall trend

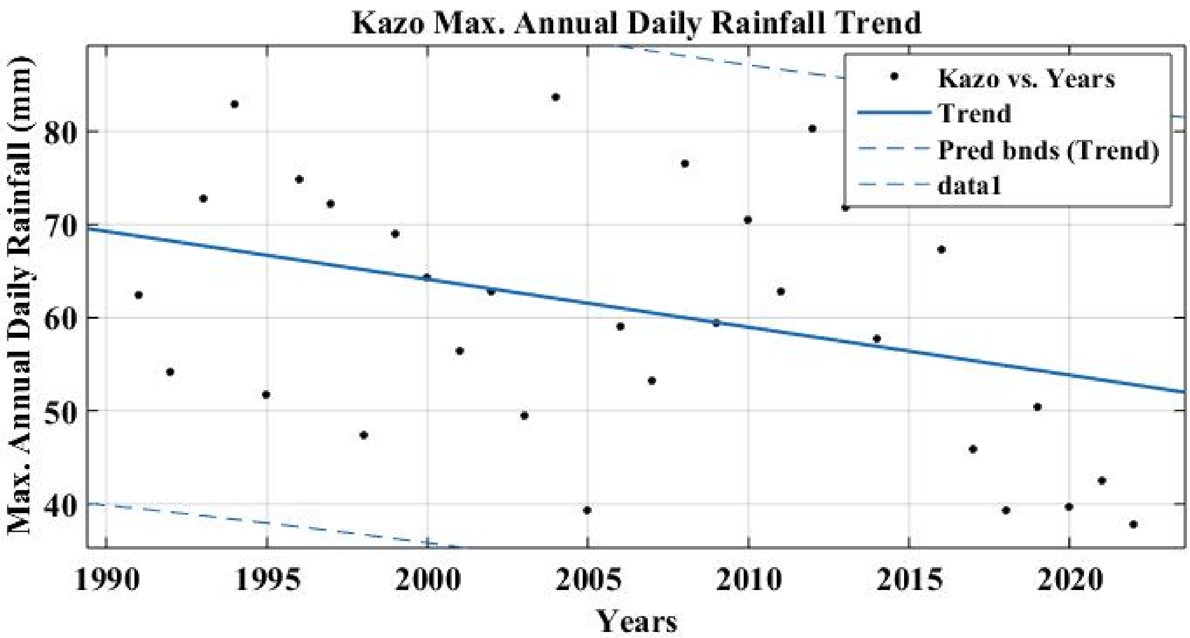


Fig 2. 5: Kazo station maximum annual daily rainfall trend

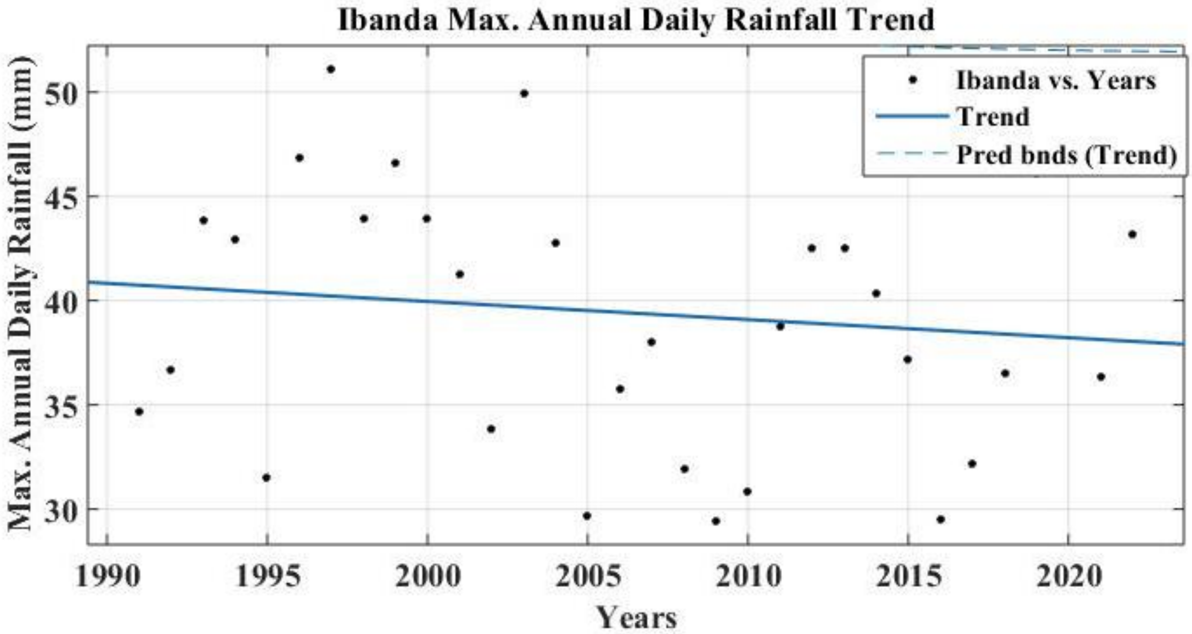


Fig 2. 6: Ibanda station maximum annual daily rainfall trend

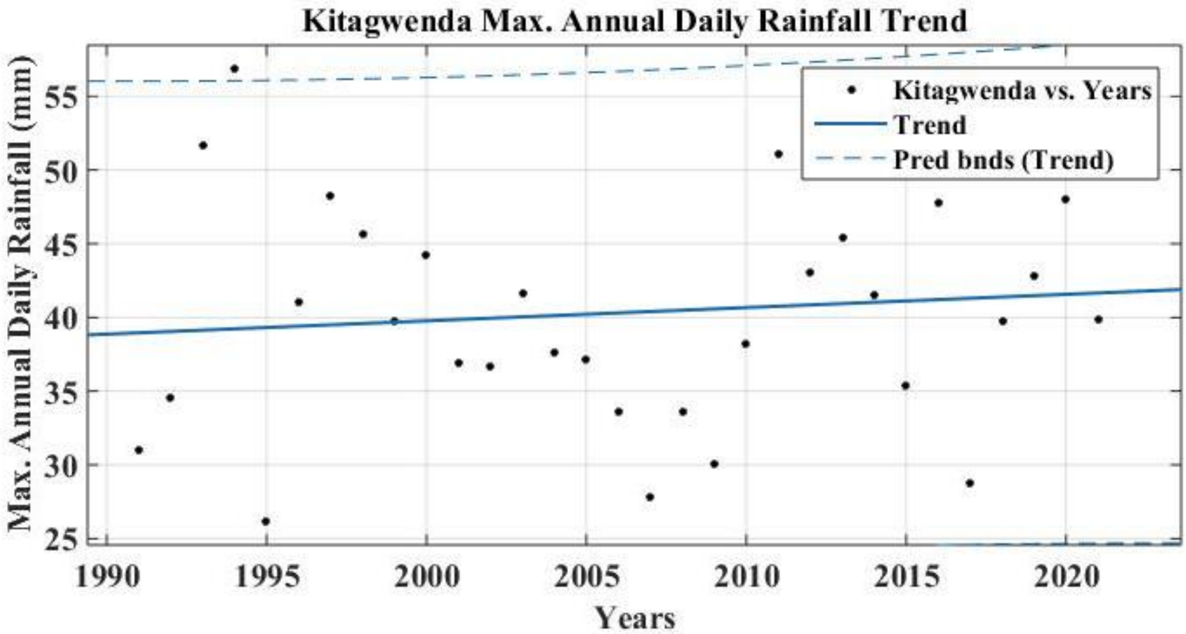


Fig 2. 7: Kitagwenda station maximum annual daily rainfall trend

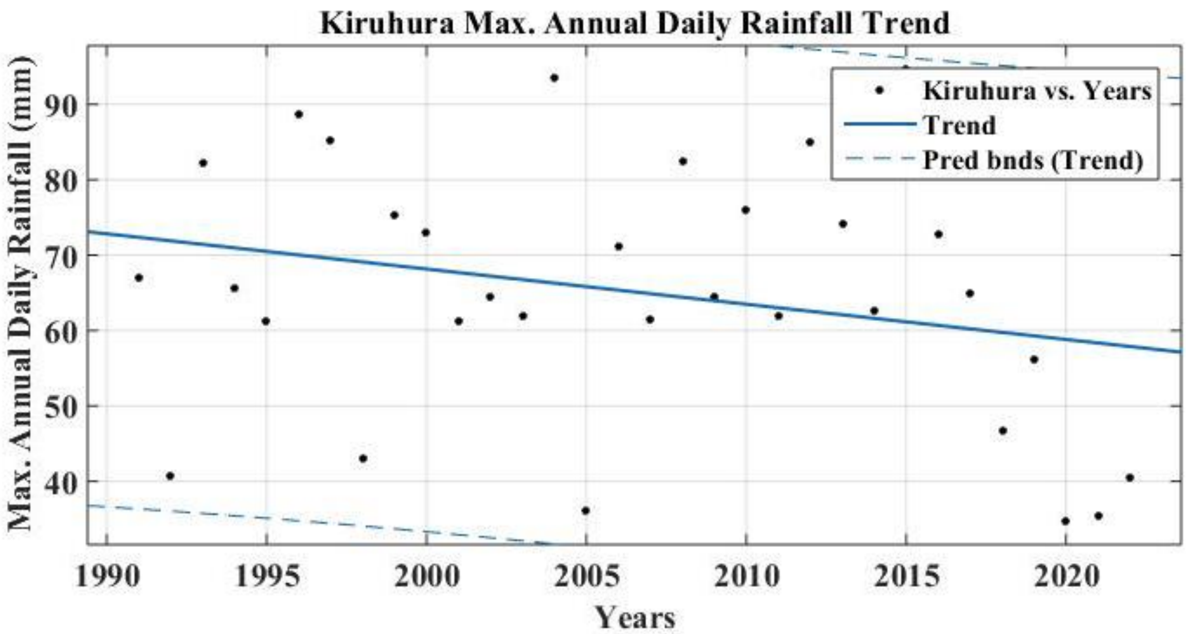


Fig 2. 8: Kiruhura station maximum annual daily rainfall trend

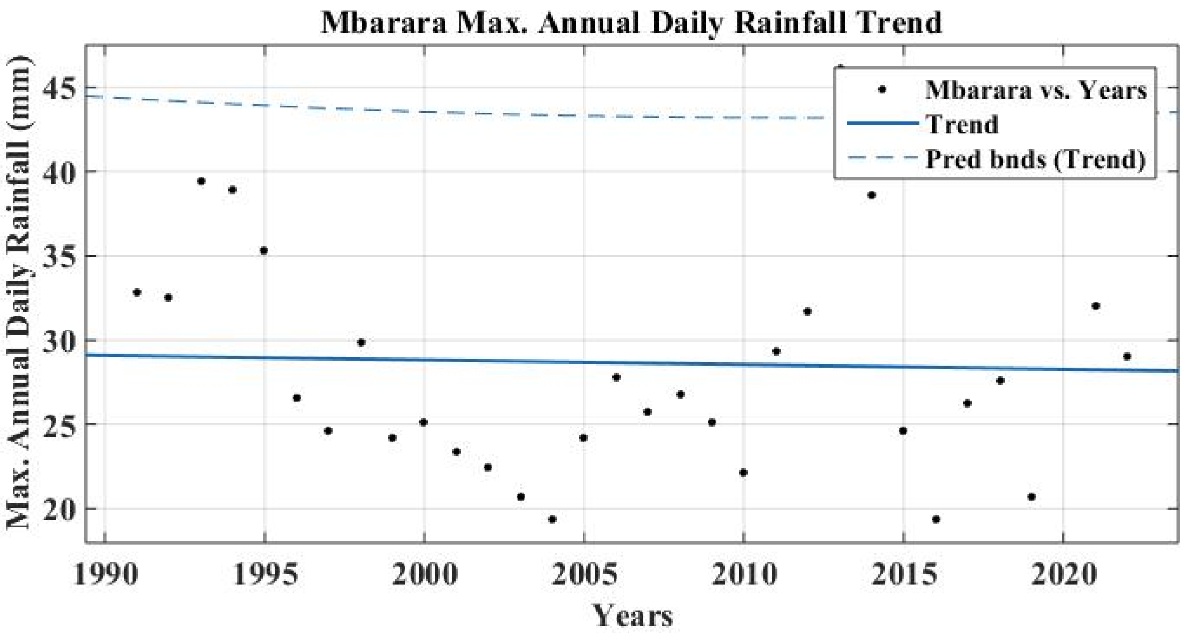


Fig 2. 9: Mbarara station maximum annual daily rainfall trend

Table 2. 1: Summary of Trend magnitude

S/N	Station name	Data record length		Slope value (Max. Annual Daily Rainfall)	Slope value (Total Annual Rainfall)	Slope value (Annual Daily Average Rainfall)
		From	To			
1	Fort Portal	1991	2022	-0.0769	5.1482	0.0140
2	Kyenjojo	1991	2022	-2.7500	-34.7095	-0.0953
3	Kamwenge	1991	2022	0.0069	4.1736	0.0116
4	Ibanda	1991	2022	-0.0990	0.0164	0.0004
5	Kitagwenda	1991	2022	0.1272	2.4246	0.0068
6	Kiruhura	1991	2022	-0.4324	-0.4405	-0.0015
7	Kazo	1991	2022	-0.5892	3.0855	0.0086
8	Buhweju	1991	2022	-0.0649	0.5449	0.0014
9	Mbarara	1991	2022	-0.0567	1.5506	0.0041

The maximum annual daily rainfall trend (fig 2.1–2.9) exhibited negative magnitude across the catchment from 1991 to 2022 and summarized in table 2.1. Similarly, the annual daily average rainfall showed insignificant negative trend (table 2.1) across the catchment. However, a positive trend in the total annual rainfall was observed in seven out of the nine hydro meteorological stations across the catchment. Rainfall is an essential climatic variable in understanding water availability and very critical in carrying out water balance of a catchment. As a result, establishing trend of the average, maximum and total annual daily rainfall was necessary in determining temporal water availability in the catchment. Onyutha C., et al., (2022) established a steady total rainfall increase over Mpanga catchment, based on long-term trend from 2000 to 2019, which agrees with the current study finding.

Table 2. 2: Goodness of fit statistics

Station	Sum of Squares due to Error (SSE)	R-Square	DFE	Adjusted R-Square	Root Mean Squared Error (RMSE)
Buhweju	1334.9	0.0366	30	0.0044	6.6707
Fort Portal	7649.5	0.0011	30	-0.0322	15.9682
Kamwenge	5278.1	0.00053	30	-0.0328	13.2642

Kyenjojo	115020.0	0.1055	30	0.0757	61.9202
Kazo	5507.1	0.1161	30	0.0867	13.5488
Ibanda	1244.2	0.0163	30	-0.0165	6.4399
Kitagwenda	1871.8	0.0117	30	-0.0213	7.8988
Kiruhura	8341.5	0.0666	30	0.0355	16.6749
Mbarara	1491.7	0.0014	30	-0.0319	7.0515

2.5.2 Rainfall variability

According to World Meteorological Organization (WMO), climate variability is defined as the variations in the mean state and other statistics of the climate on all temporal and spatial scales, beyond individual weather event (WMO, 2019). It is used to check alteration of climatic statistics over time span (e.g. a month, season or year). Variability can be classified as a combination of preferred spatial pattern, for example as modes of climate variability. Knowledge of historical records and their variations helps in understanding variability and trends. In this particular case, we considered wet condition analysis based on hydrological variable that defined the average and maximum daily rainfall. These variables were used to understand the predictive nature of water availability in the catchment in terms of trend and variability. Figure 2.10-2.45 below indicate the maximum daily, average, and maximum residual annual rainfall variability in spatial temporal terms across the catchment.

The annual maximum and average daily rainfall variability was graphically analysed using MATLAB. The maximum annual daily rainfall showed both negative and positive trend across the catchment over the period 1991-2022. Spatially, in all the nine meteorological stations, Buhweju (Figure 2.11-2.12) exhibited negative (positive) trend (1992-2004) (1991-2005) respectively. Fort Portal (Figure 2.15-2.16) exhibited negative (positive) trend (1994-2003) (1991-2000) respectively. Nevertheless, there was a negative trend with magnitude of trend slope across the catchment (Table 2.3). This downward trend in the maximum and average annual daily rainfall can be explained by the negative trend in the maximum annual daily rainfall anomaly shown in Figure 2.47.

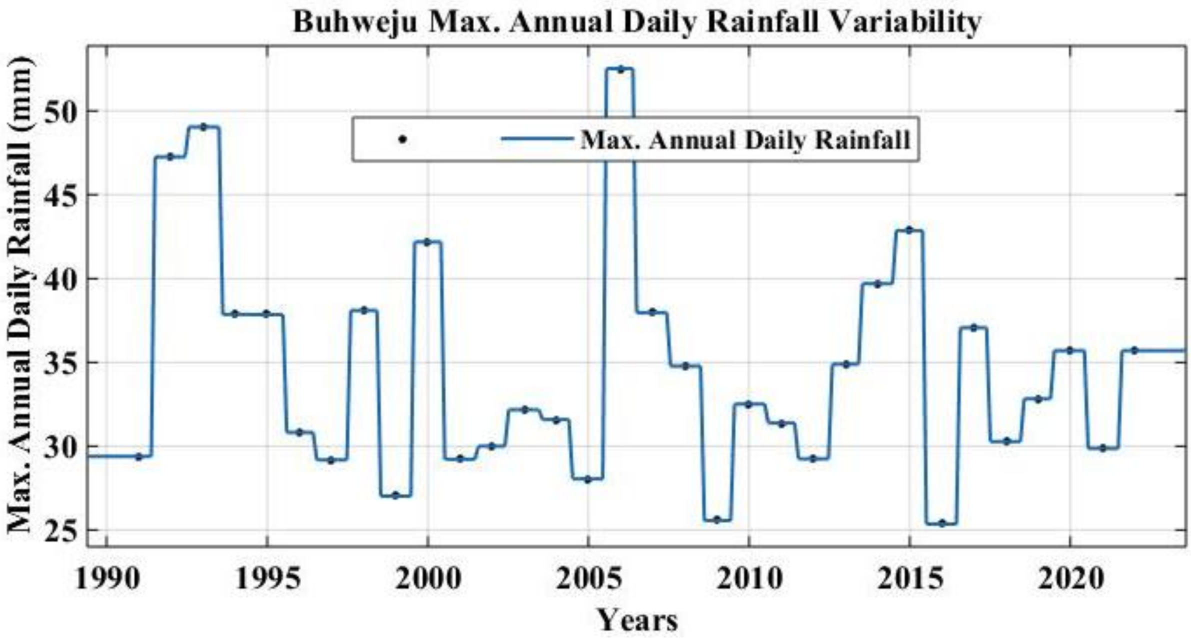


Fig 2. 10: Buhweju maximum annual daily rainfall hydrograph

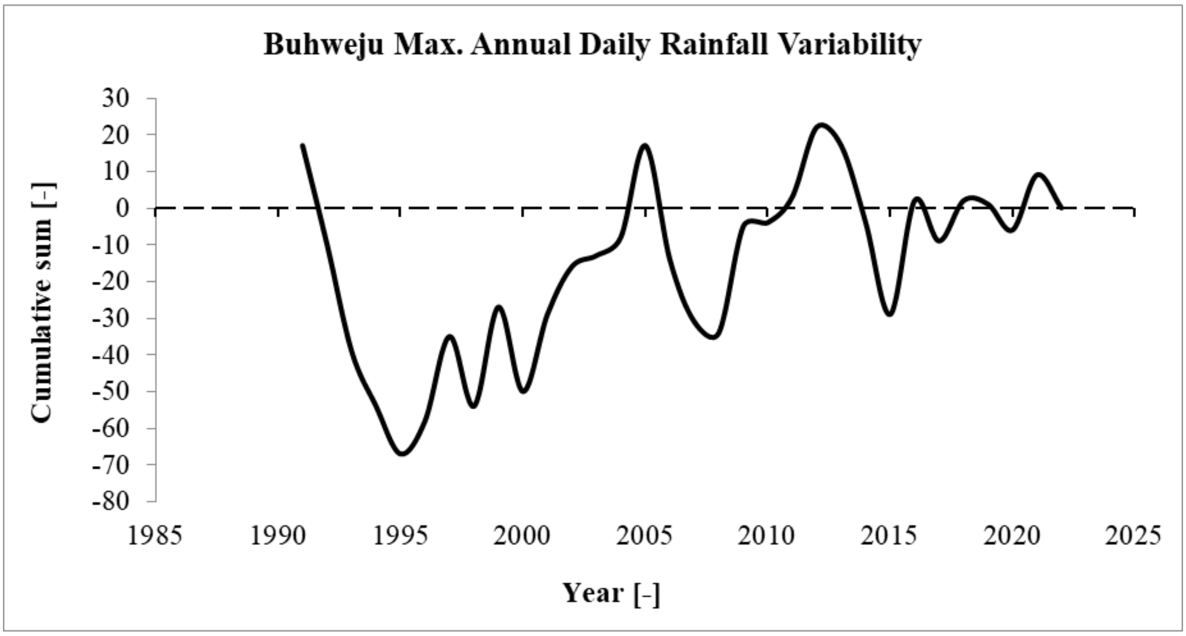


Fig 2. 11: Buhweju maximum annual daily rainfall variability

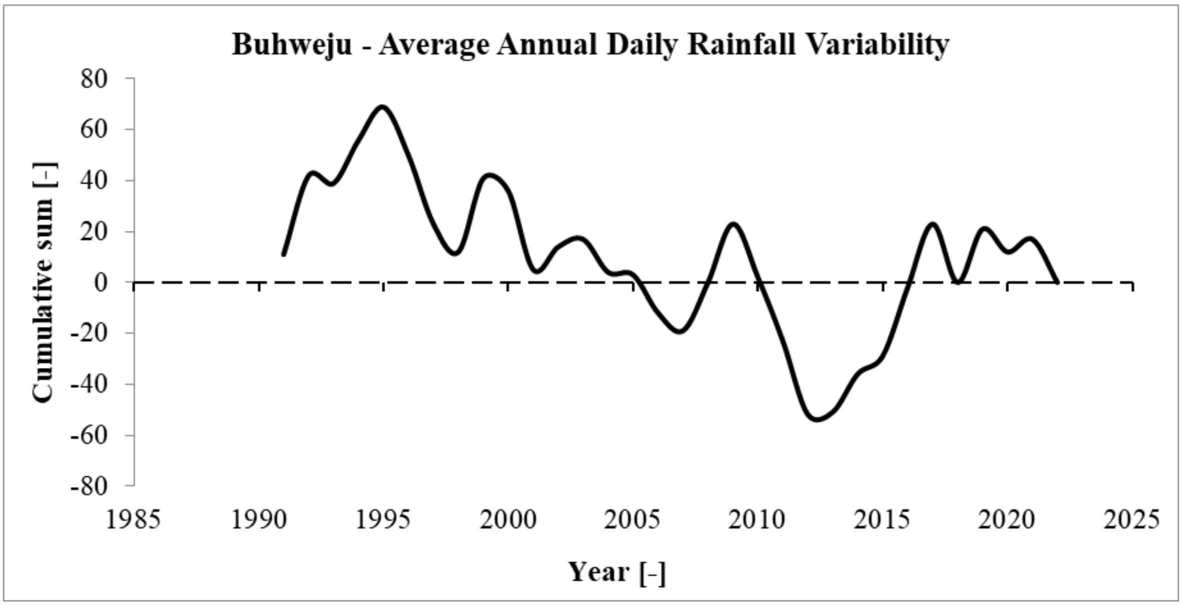


Fig 2. 12: Buhweju average annual daily rainfall variability

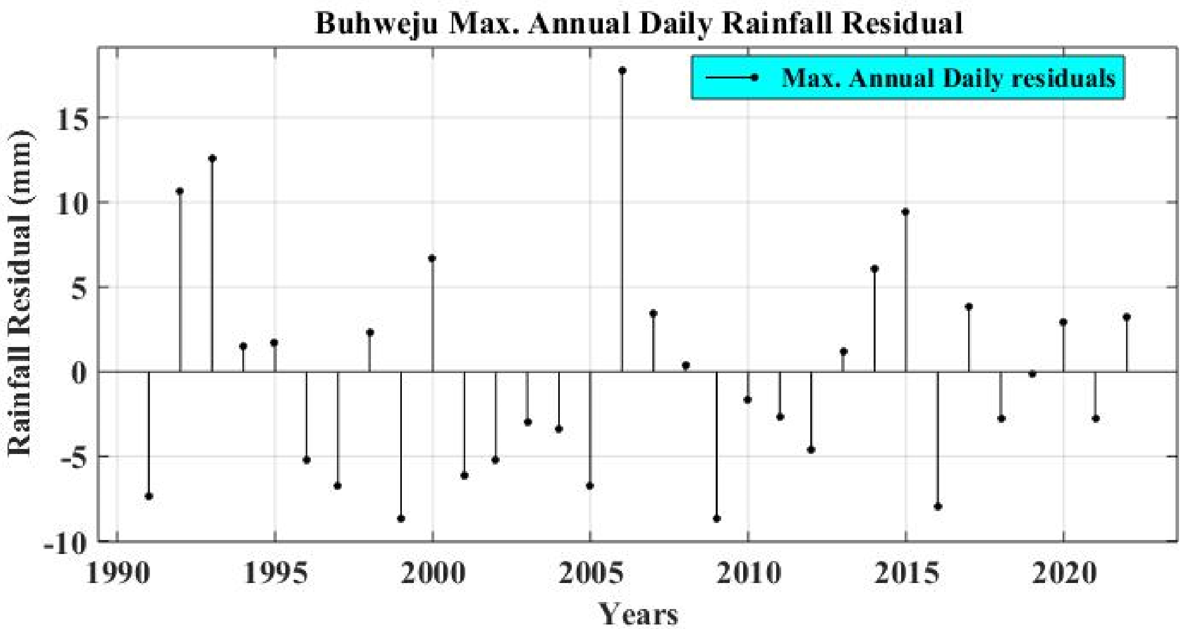


Fig 2. 13: Buhweju maximum annual daily rainfall residual

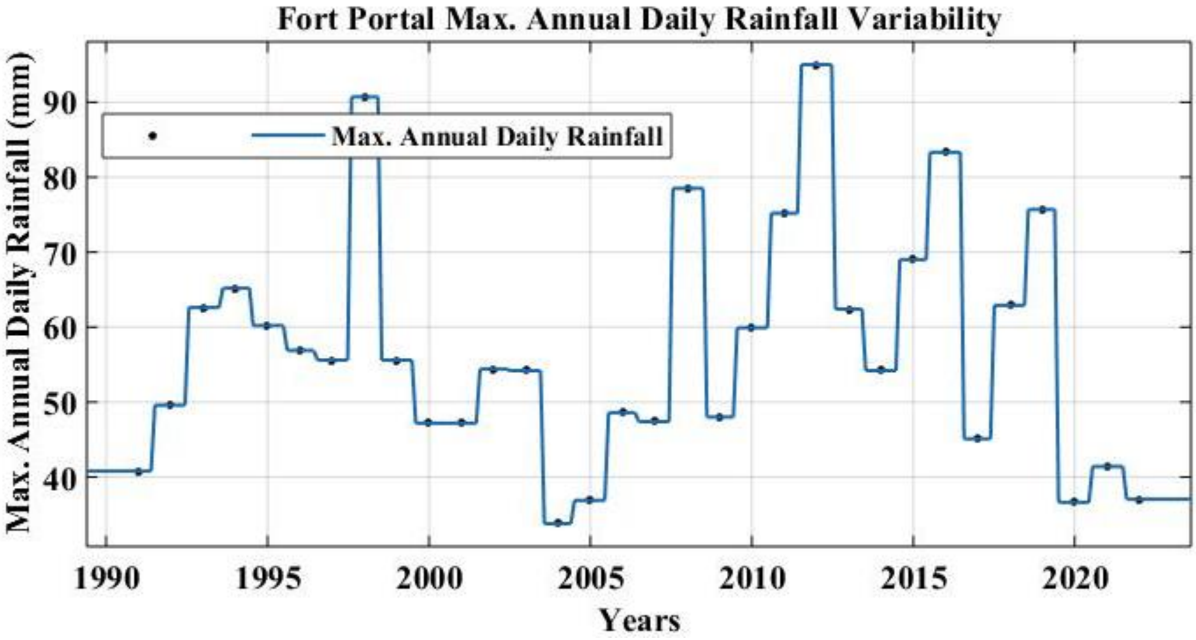


Fig 2. 14: Fort Portal maximum annual daily rainfall hydrograph

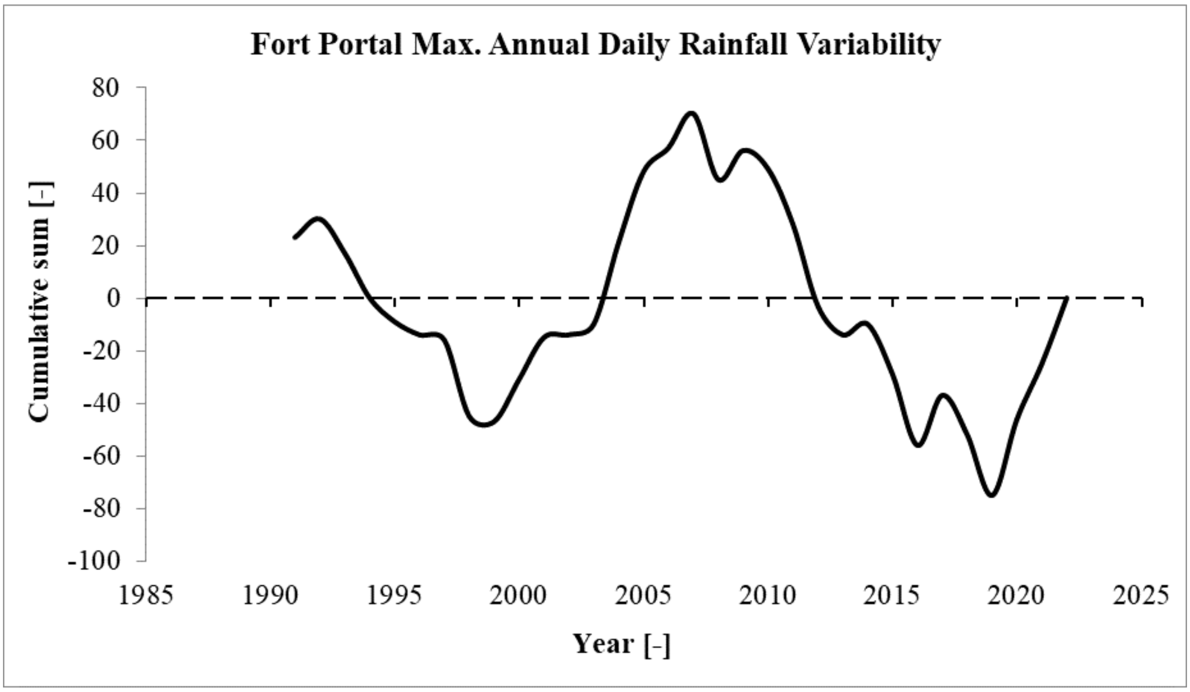


Fig 2. 15: Fort Portal maximum annual daily rainfall variability

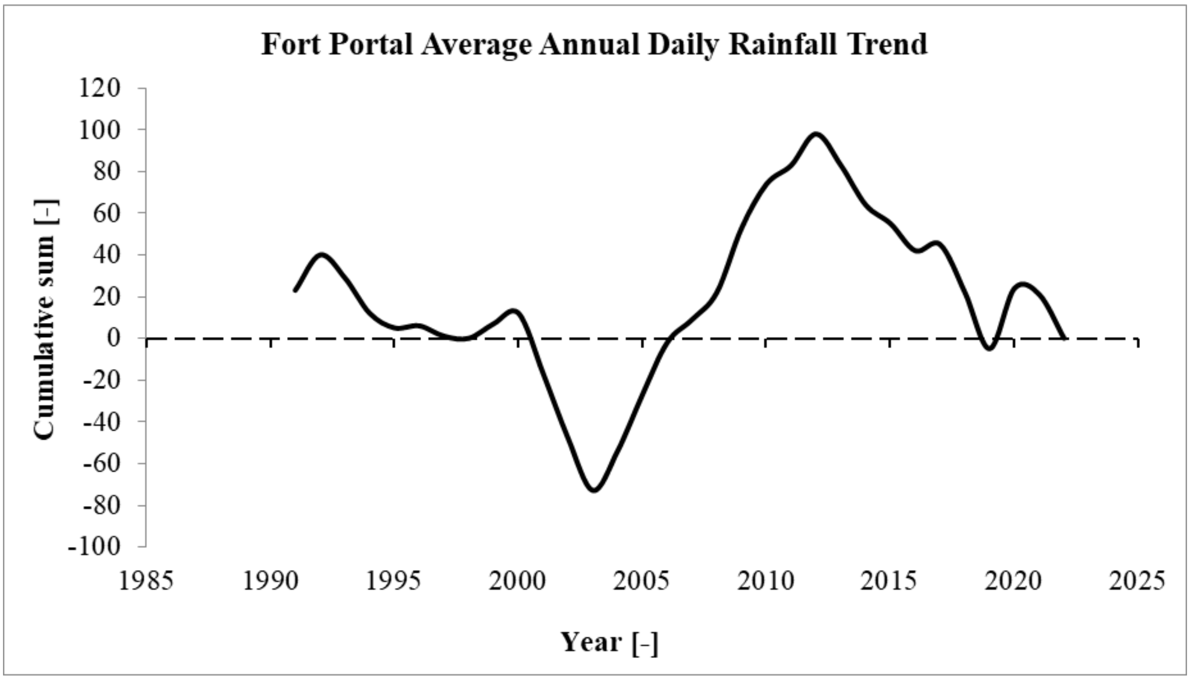


Fig 2. 16: Fort Portal average annual daily rainfall variability

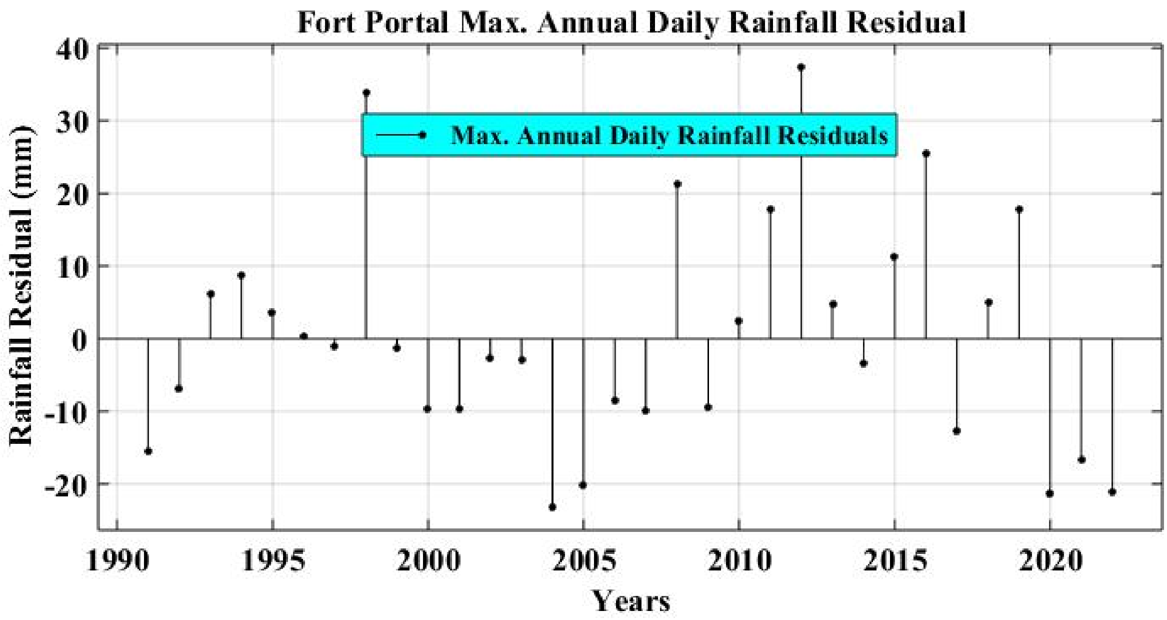


Fig 2. 17: Fort Portal maximum annual daily rainfall residual

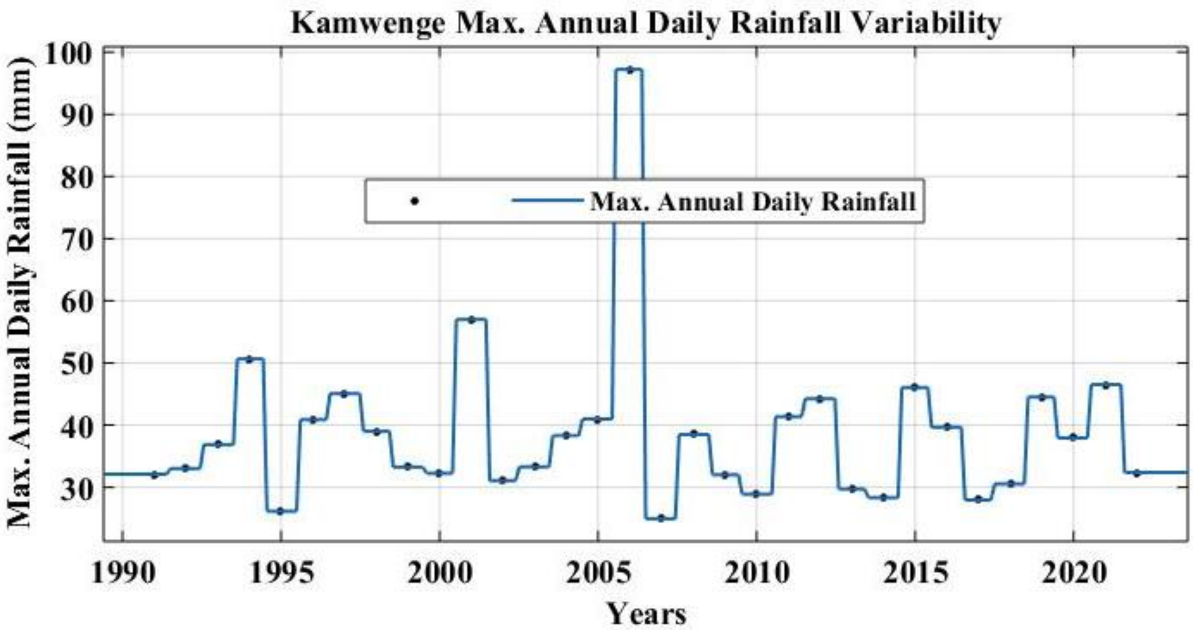


Fig 2. 18: Kamwenge maximum annual daily rainfall hydrograph

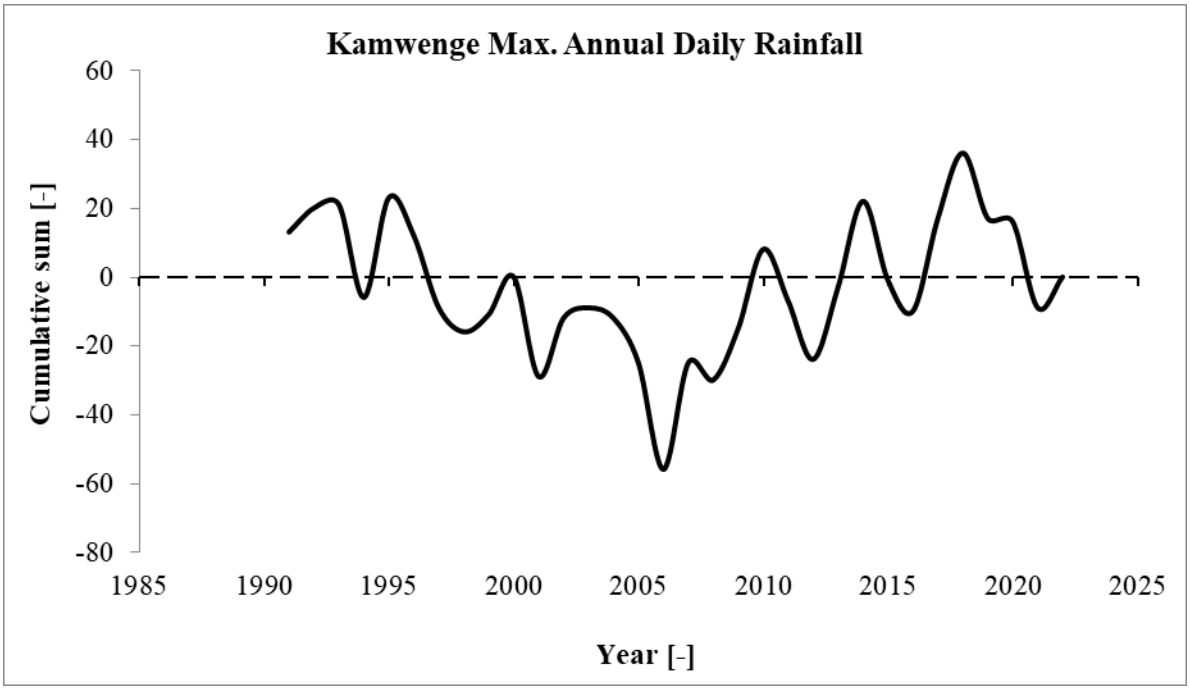


Fig 2. 19: Kamwenge maximum annual daily rainfall variability

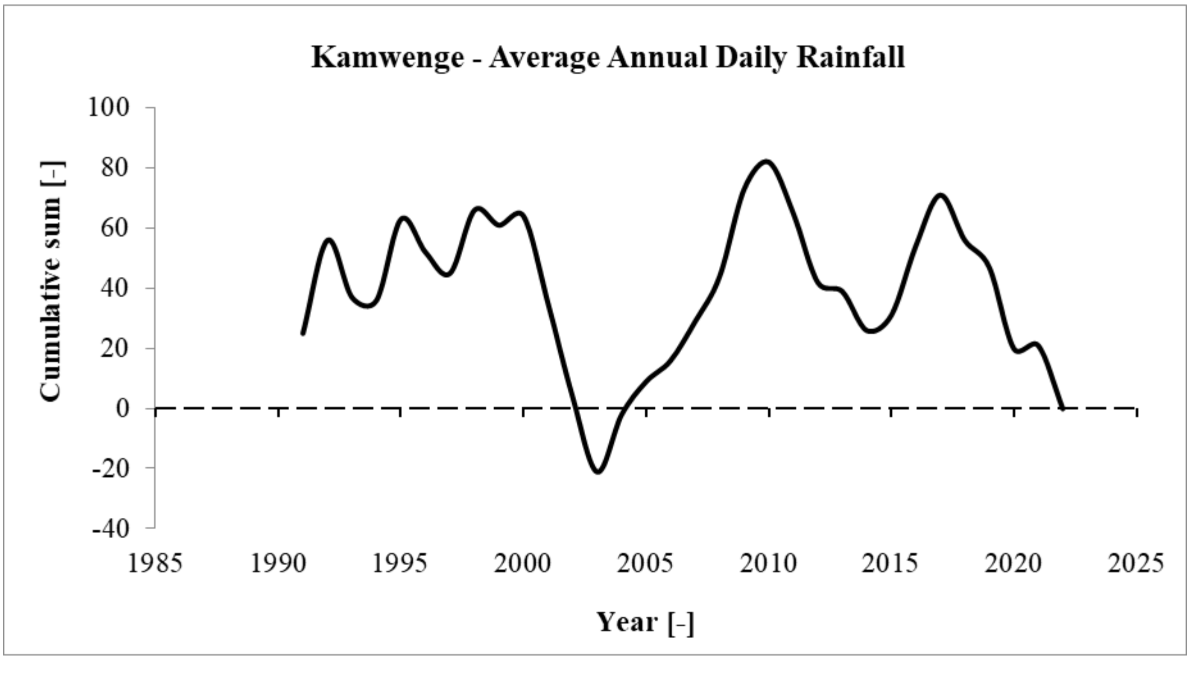


Fig 2. 20: Kamwenge average annual daily rainfall variability

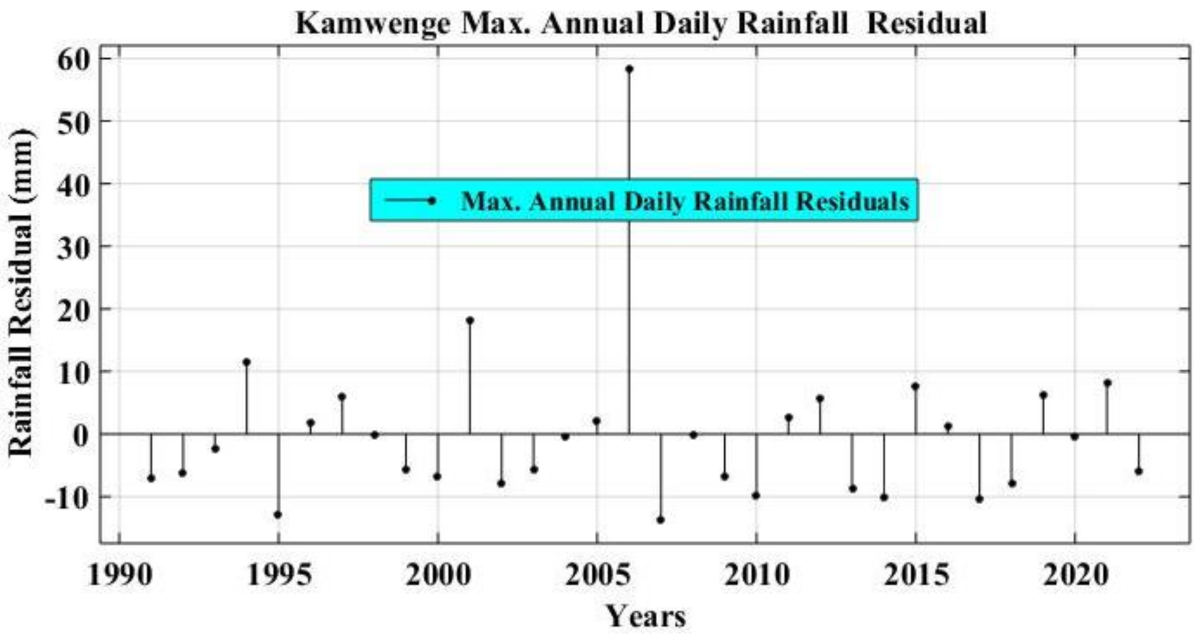


Fig 2. 21: Kamwenge station maximum annual daily rainfall residual

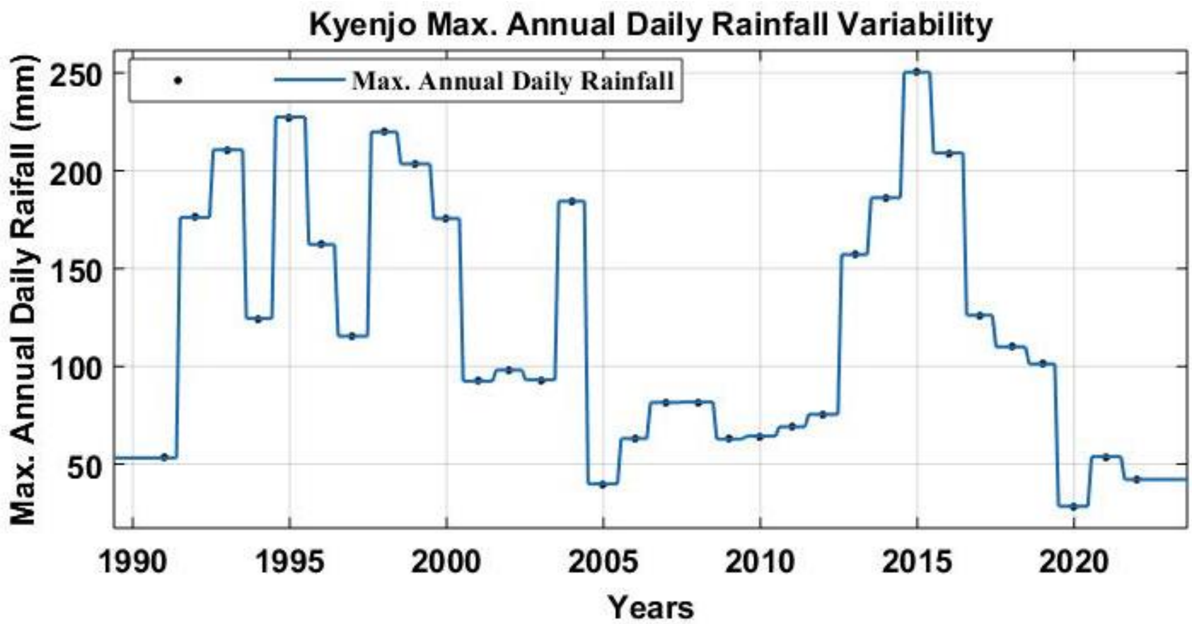


Fig 2. 22: Kyenjojo maximum annual daily rainfall hydrograph

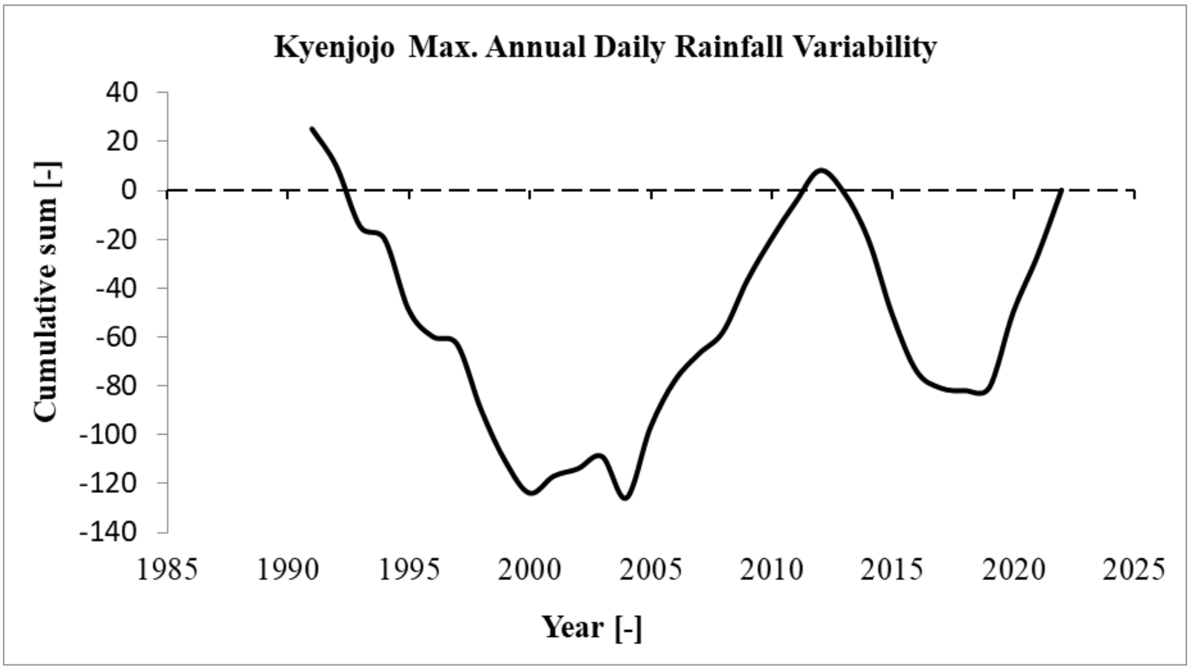


Fig 2. 23: Kyenjojo maximum annual daily rainfall variability

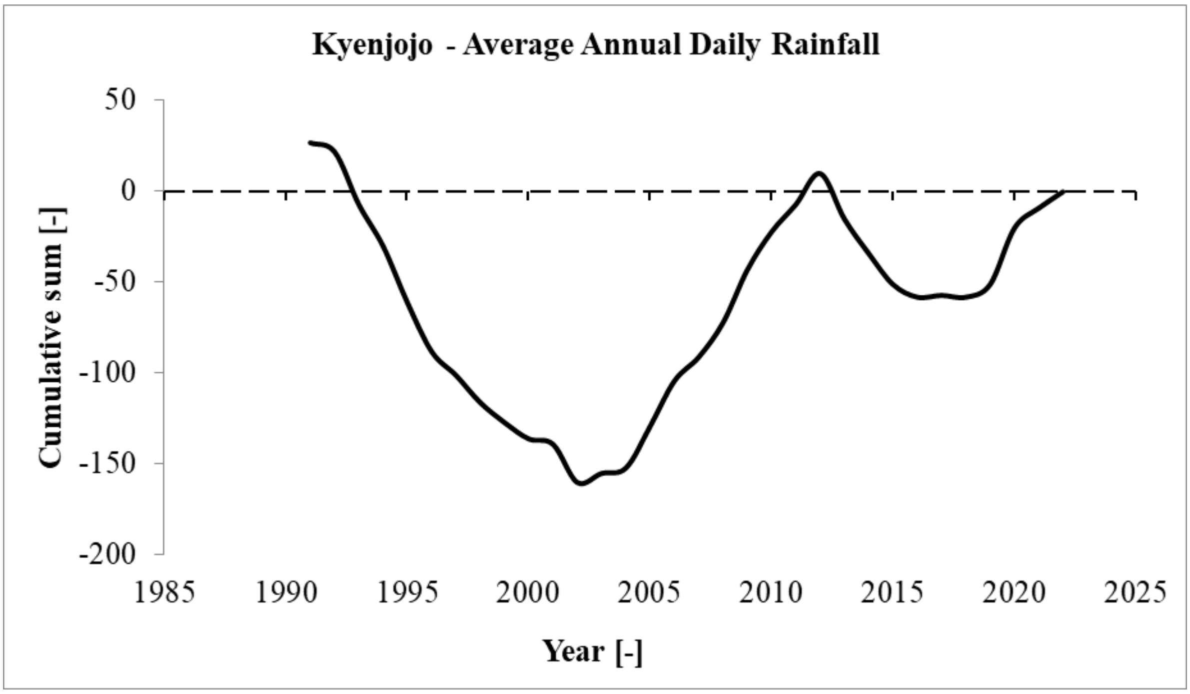


Fig 2. 24: Kyenjojo average annual daily rainfall variability

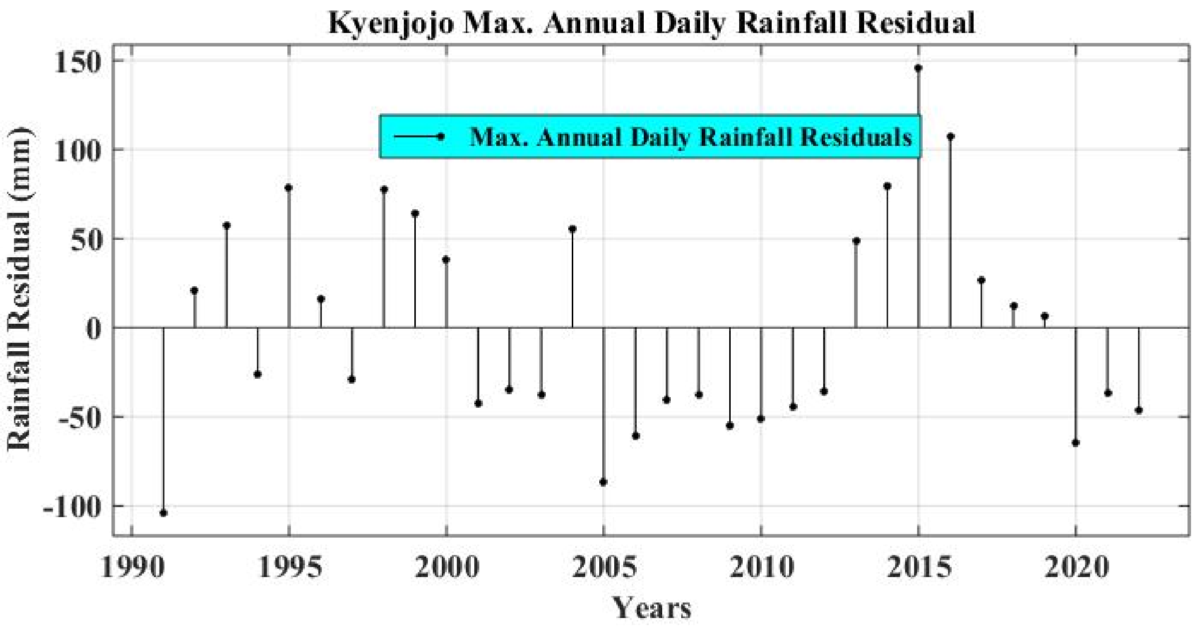


Fig 2. 25: Kyenjojo station maximum annual daily rainfall residual

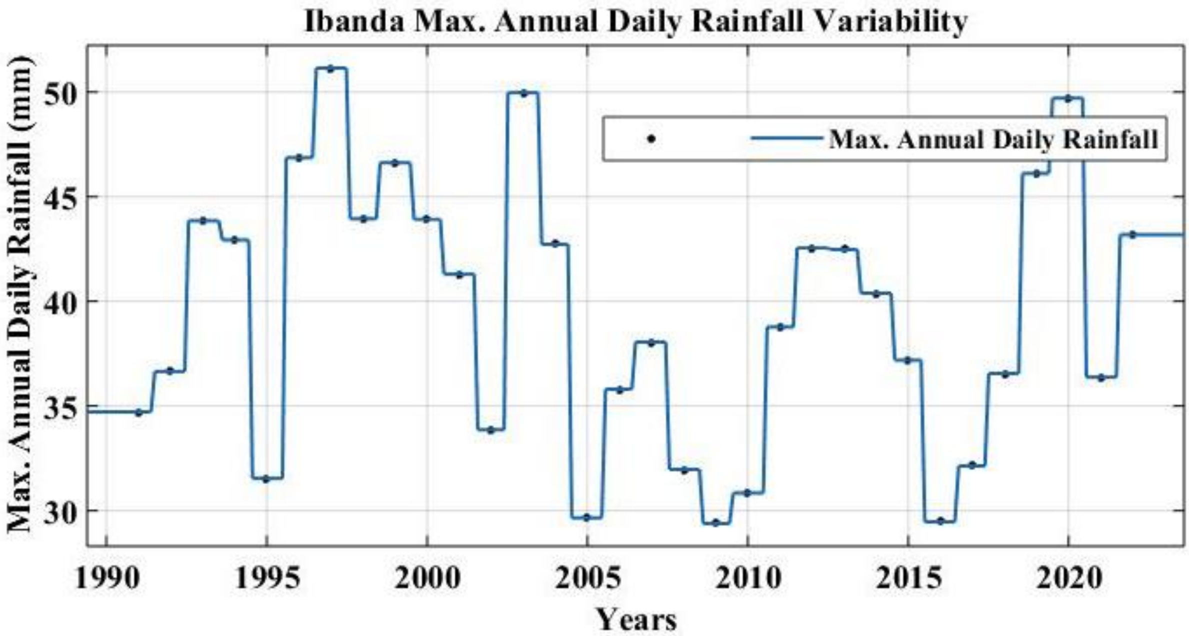


Fig 2. 26: Ibanda maximum annual daily rainfall hydrograph

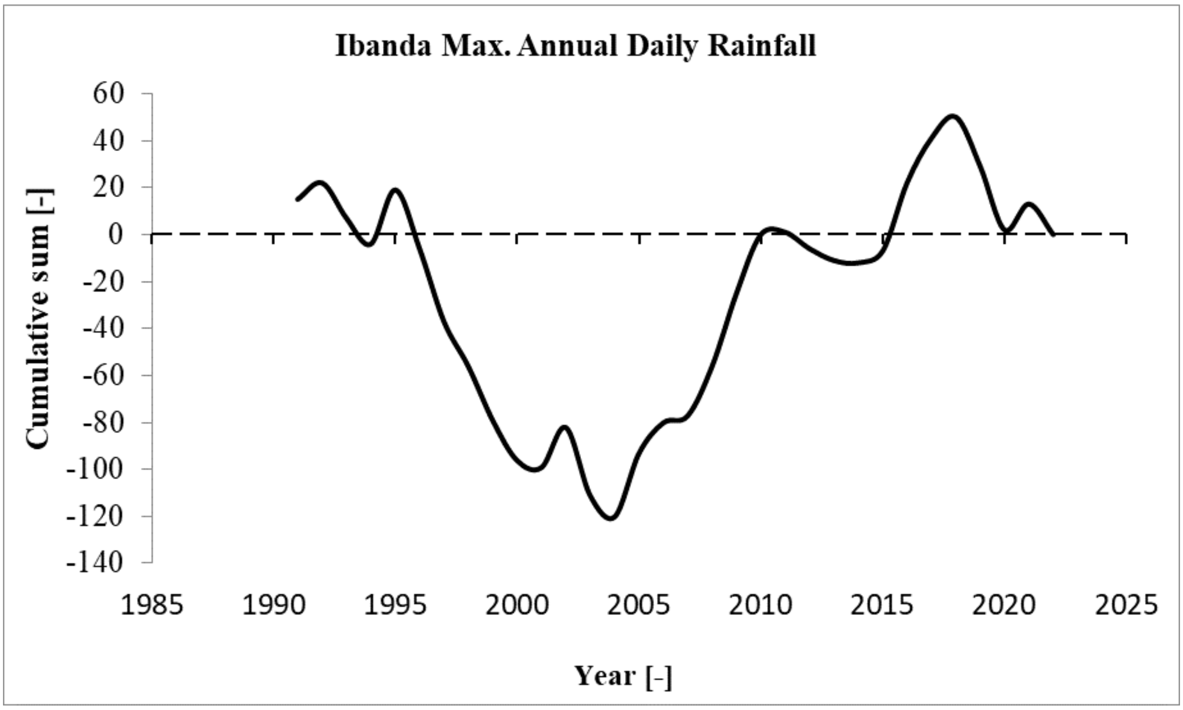


Fig 2. 27: Ibanda maximum annual daily rainfall variability

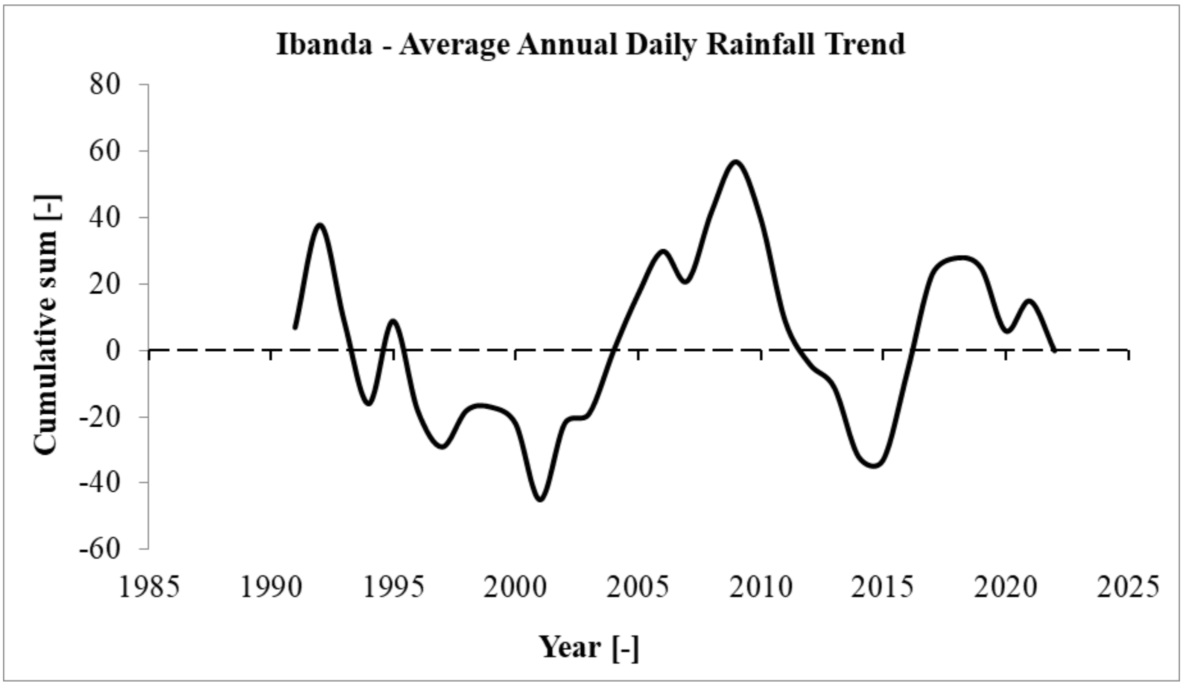


Fig 2. 28: Ibanda average annual daily rainfall variability

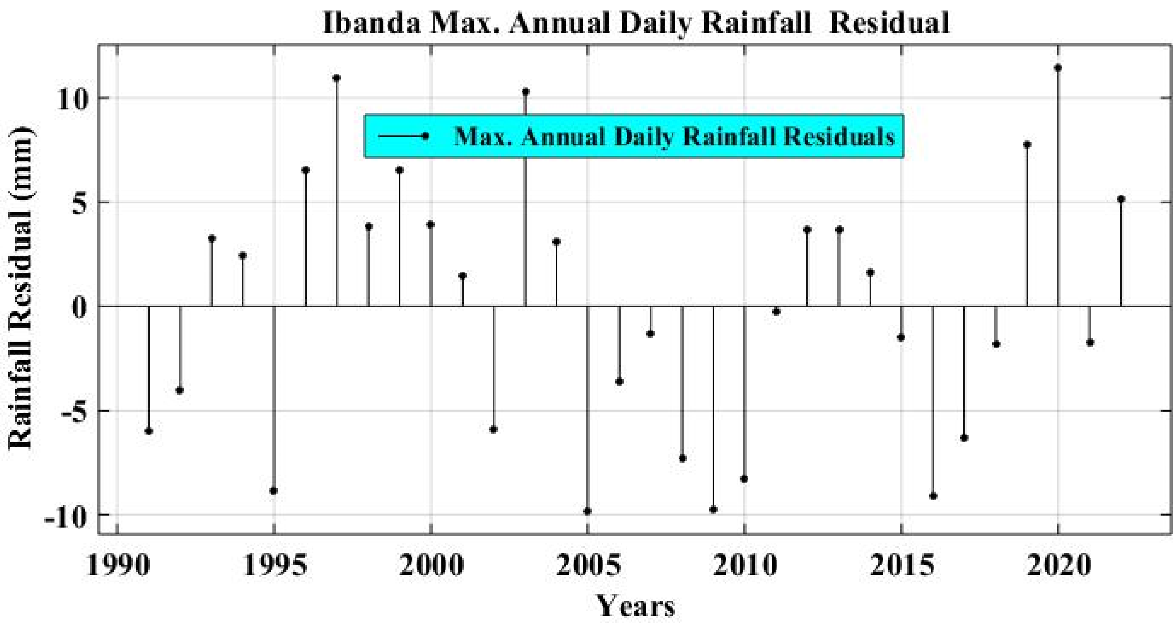


Fig 2. 29: Ibanda station maximum annual daily rainfall residual

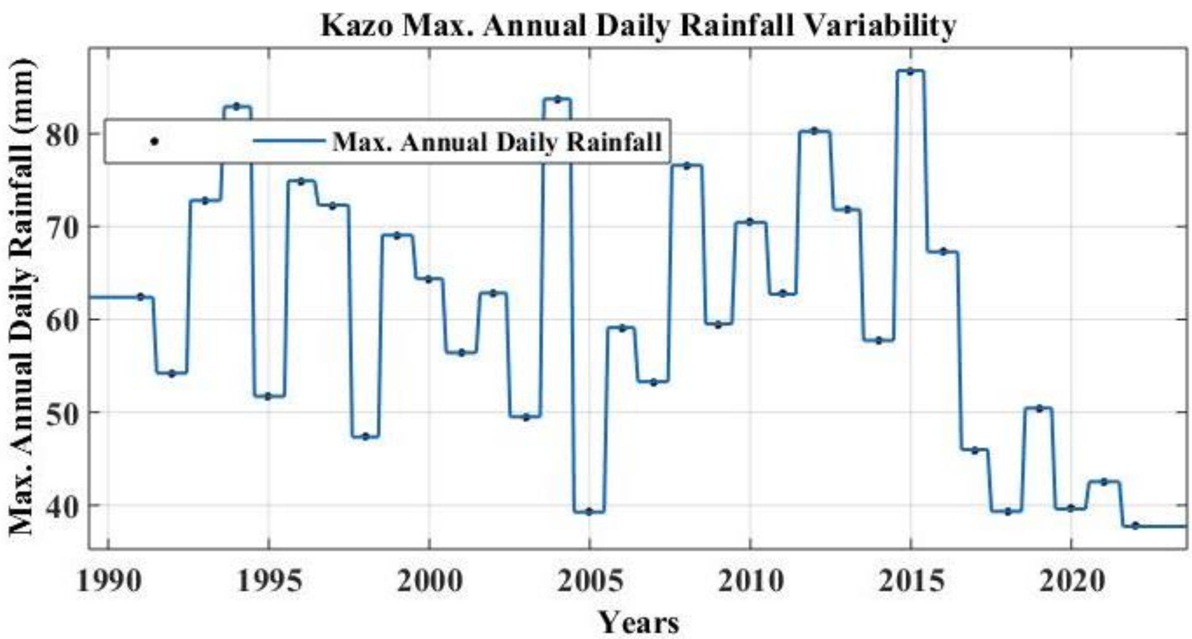


Fig 2. 30: Kazo maximum annual daily rainfall hydrograph

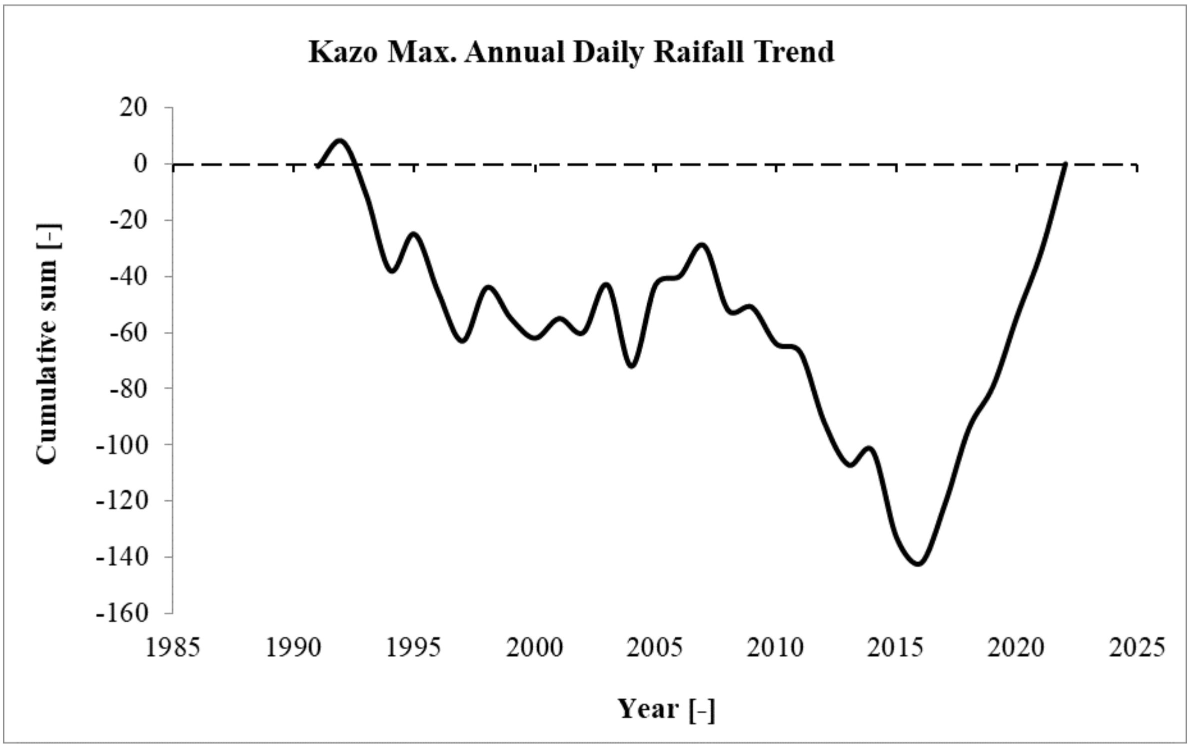


Fig 2. 31: Kazo maximum annual daily rainfall variability

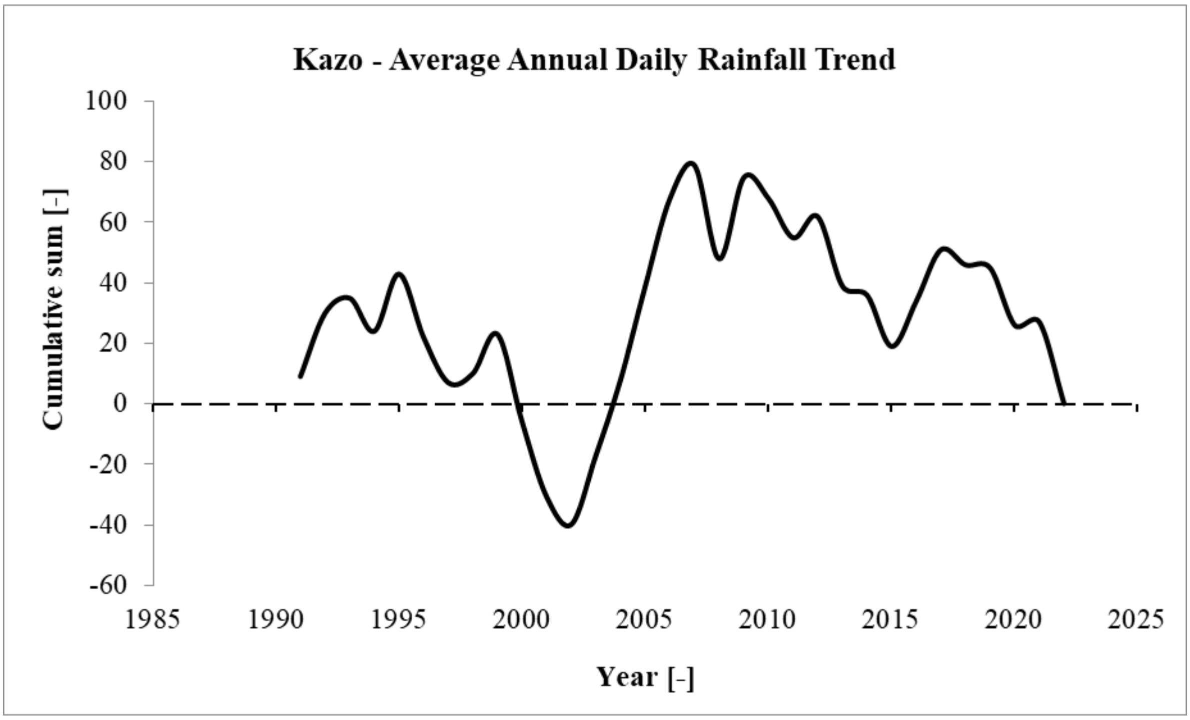


Fig 2. 32: Kazo average annual daily rainfall variability

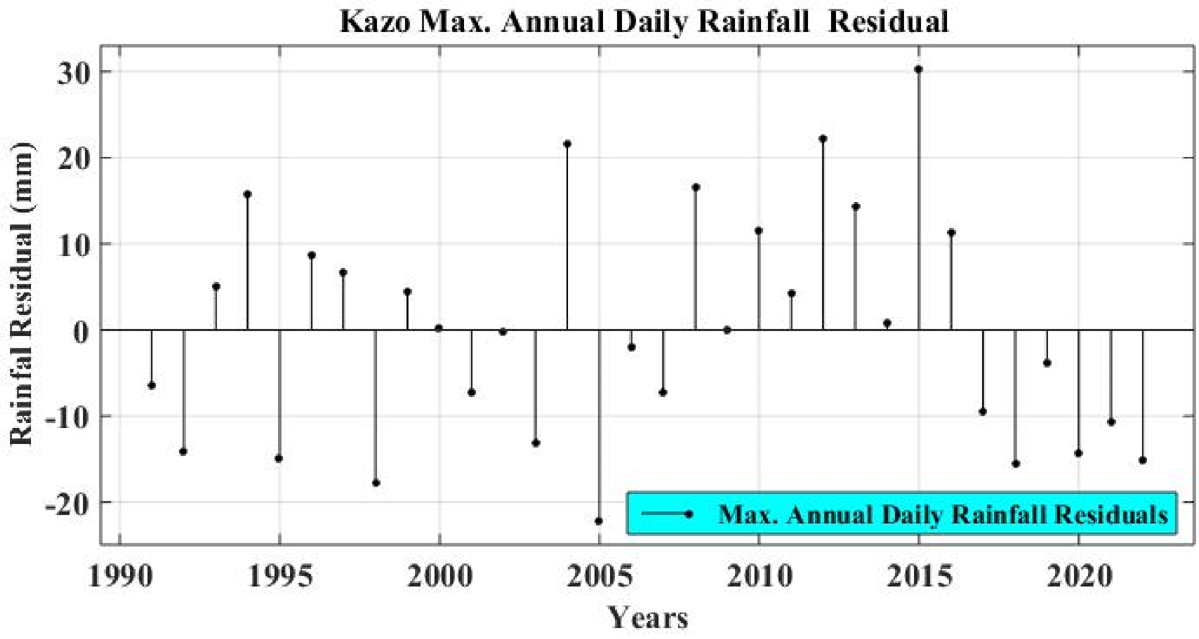


Fig 2. 33: Kazo station maximum annual daily rainfall residual

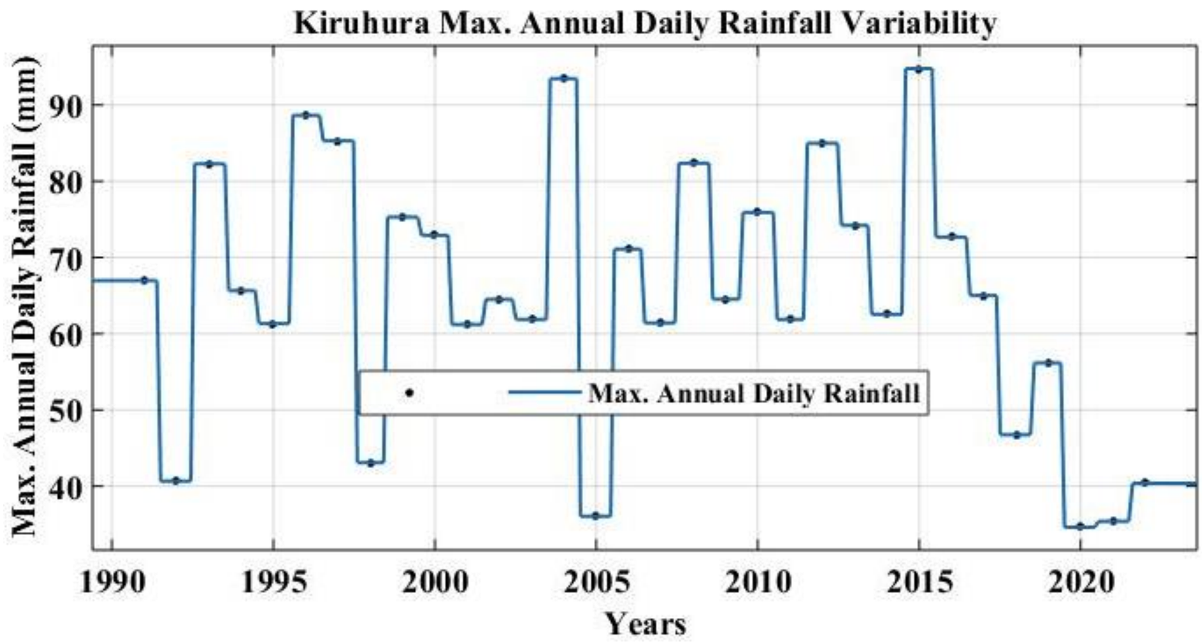


Fig 2. 34: Kiruhura maximum annual daily rainfall hydrograph

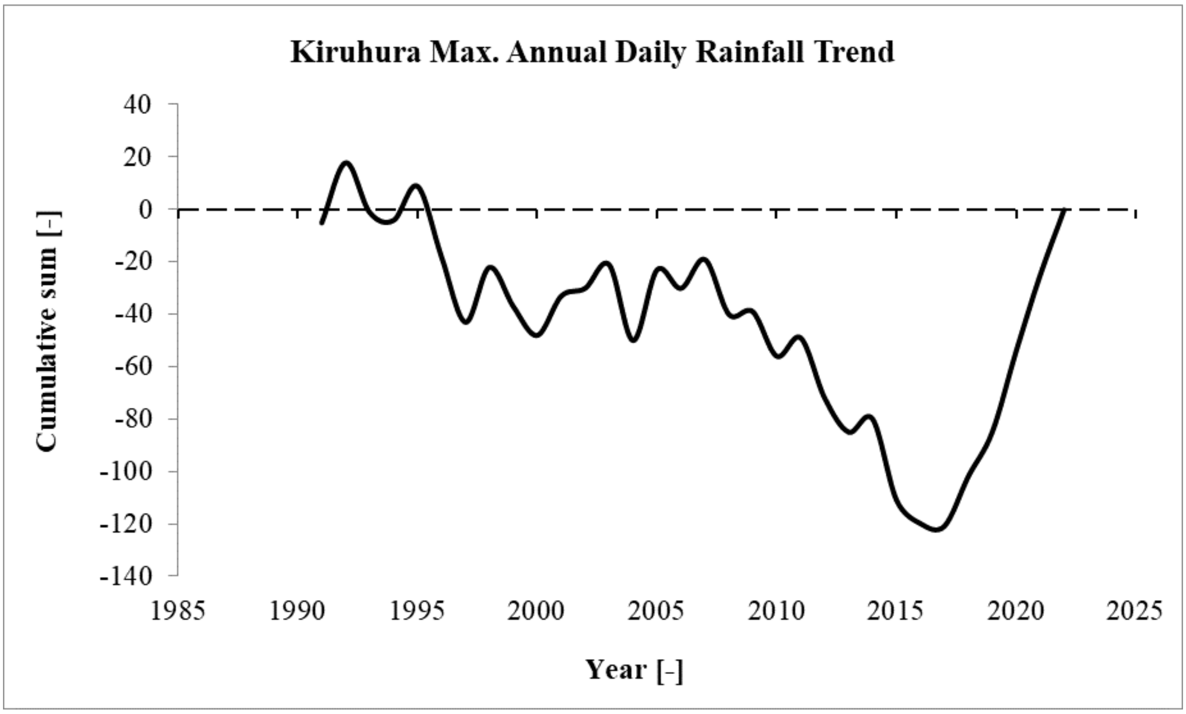


Fig 2. 35: Kiruhura maximum annual daily rainfall variability

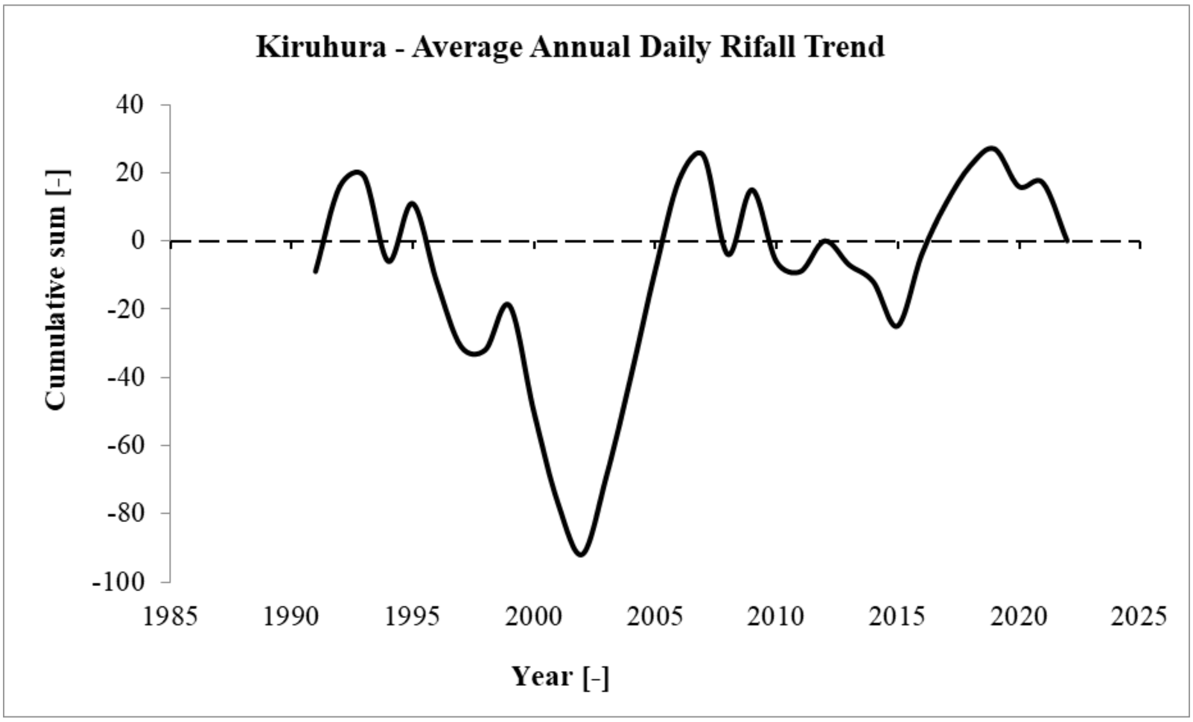


Fig 2. 36: Kiruhura average annual daily rainfall variability

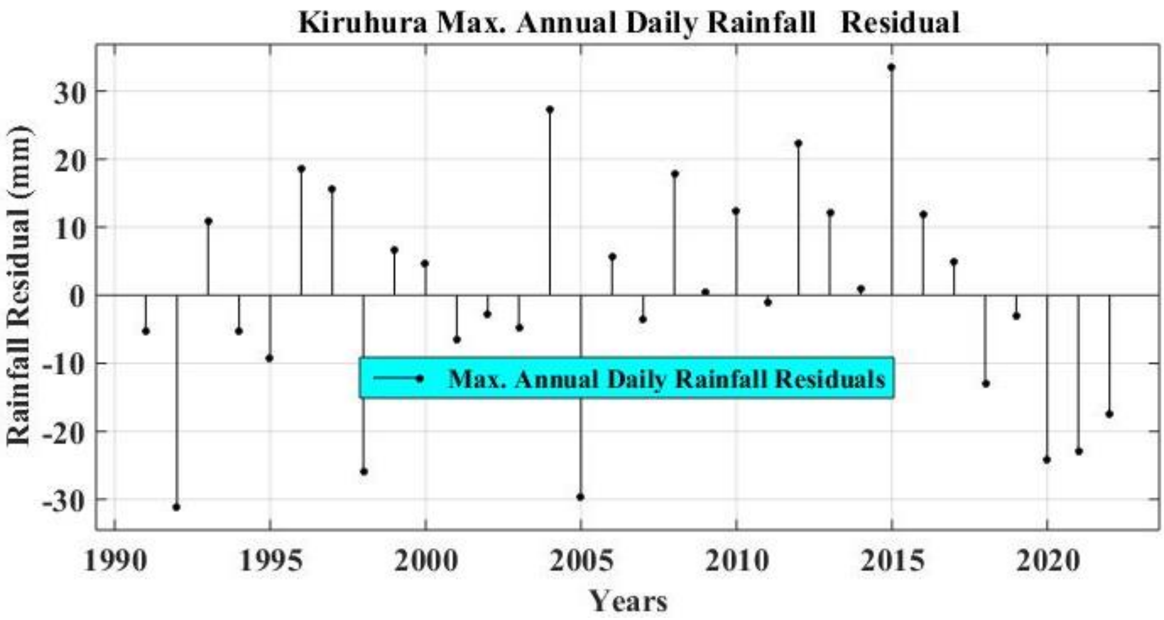


Fig 2. 37: Kiruhura station maximum annual daily rainfall residual

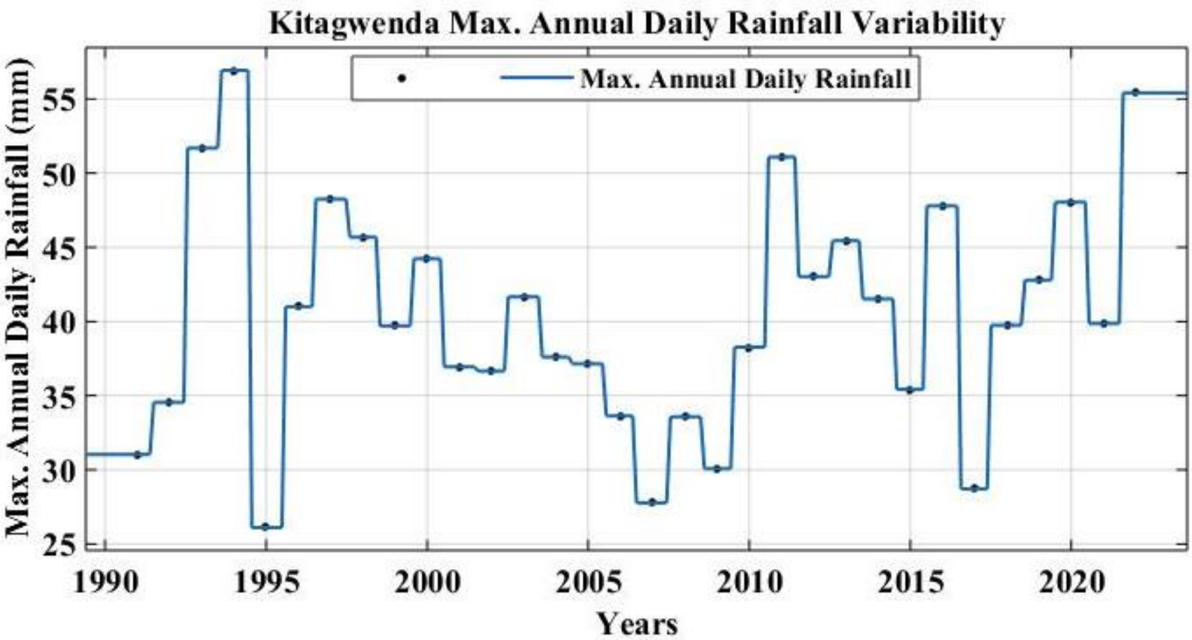


Fig 2. 38: Kitagwenda maximum annual daily rainfall hydrograph

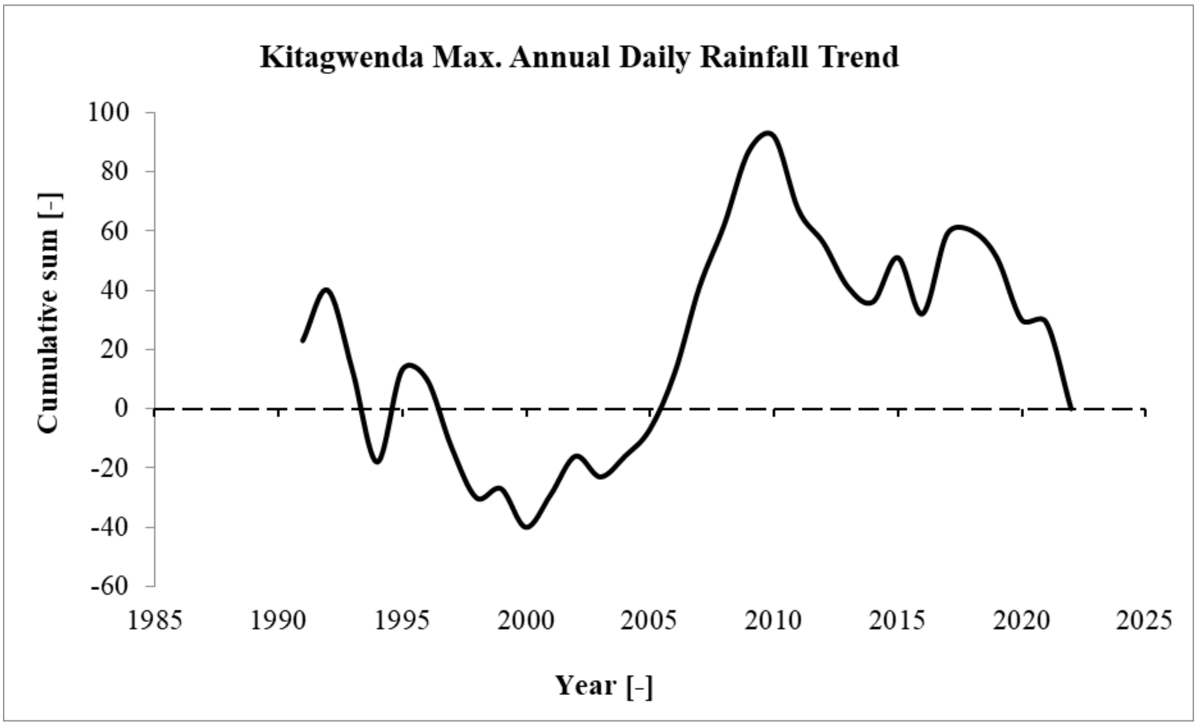


Fig 2. 39: Kitagwenda maximum annual daily rainfall variability

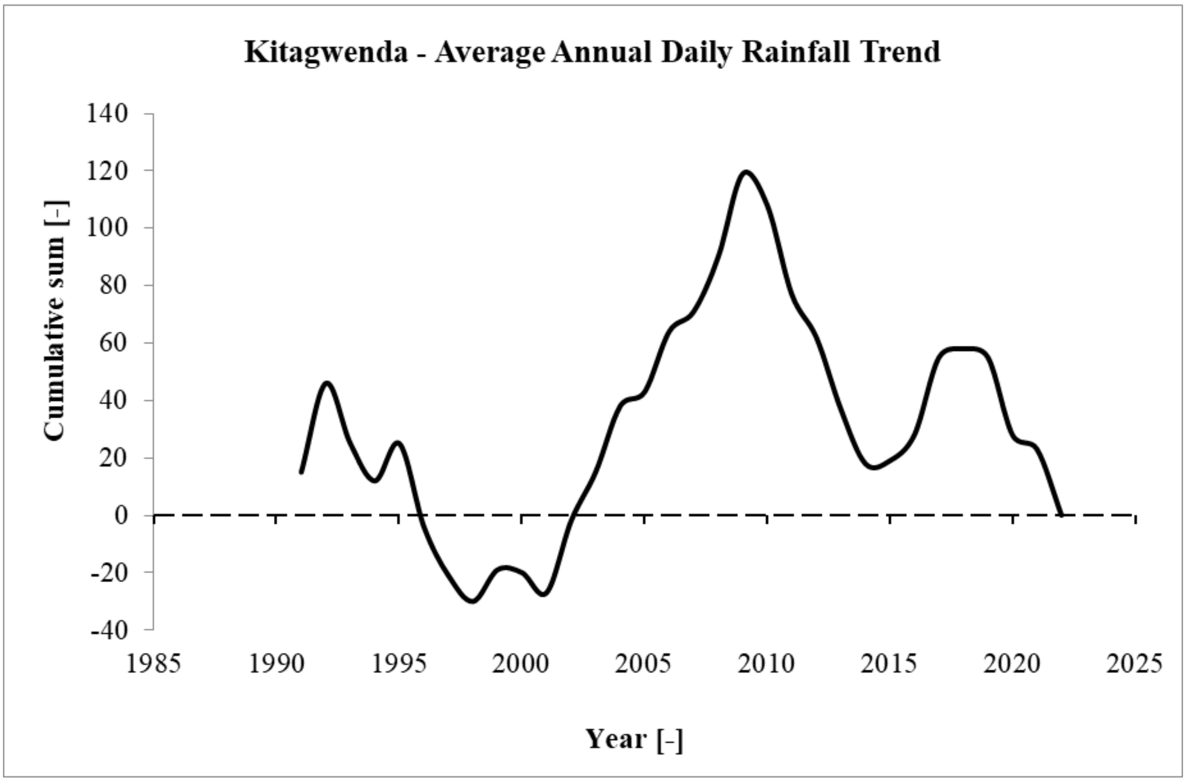


Fig 2. 40: Kitagwenda average annual daily rainfall variability

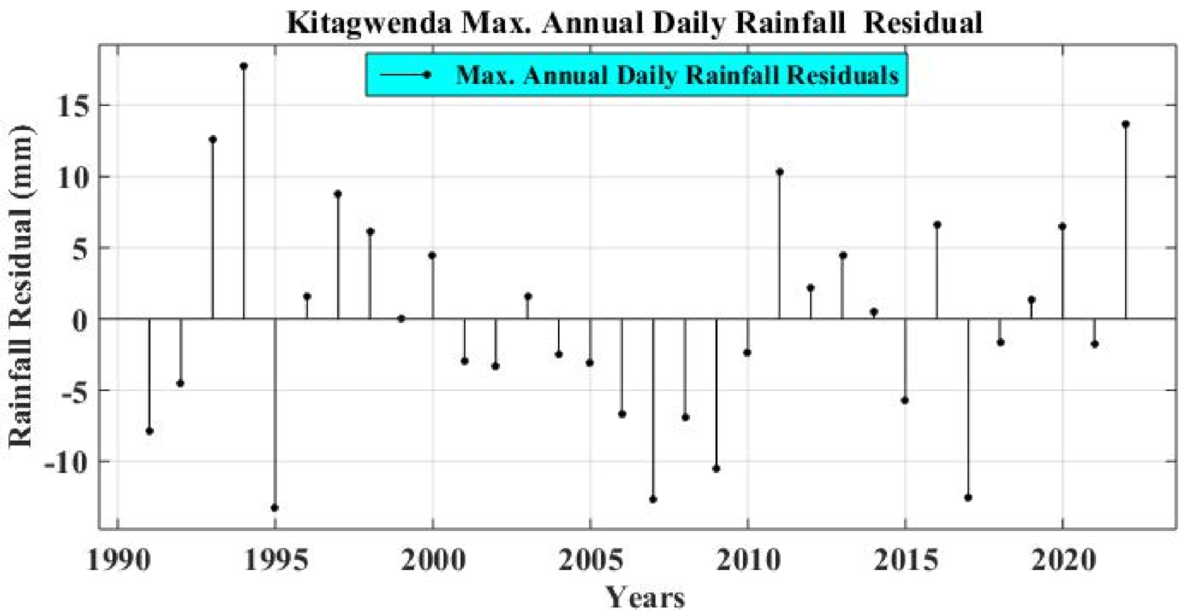


Fig 2. 41: Kitagwenda station maximum annual daily rainfall residual

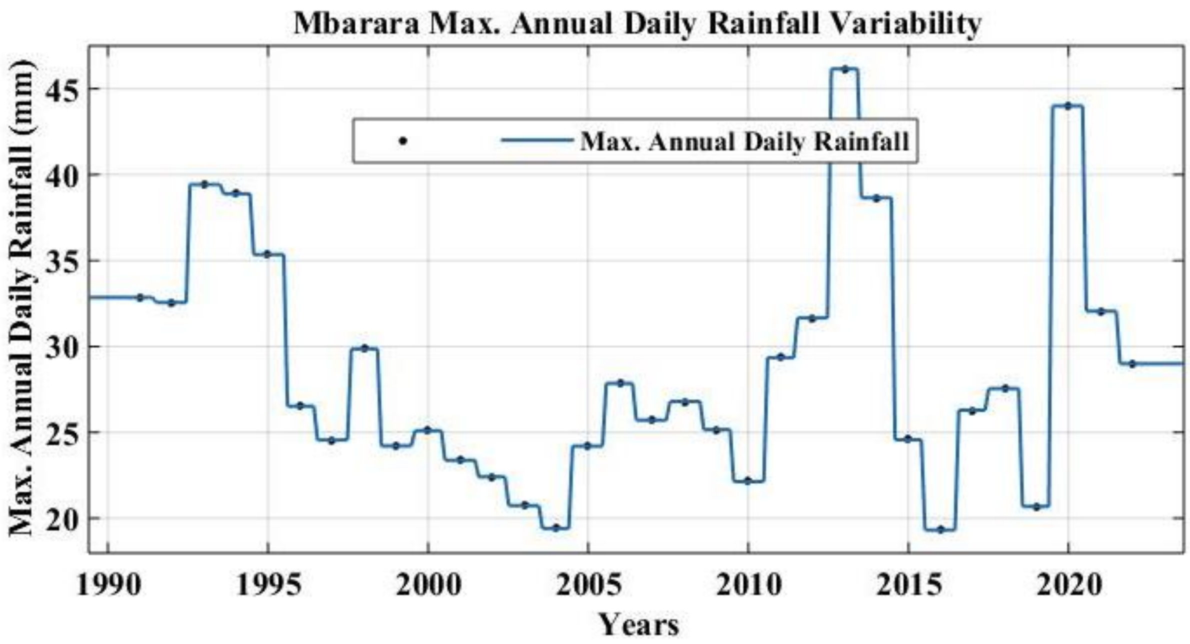


Fig 2. 42: Mbarara maximum annual daily rainfall hydrograph

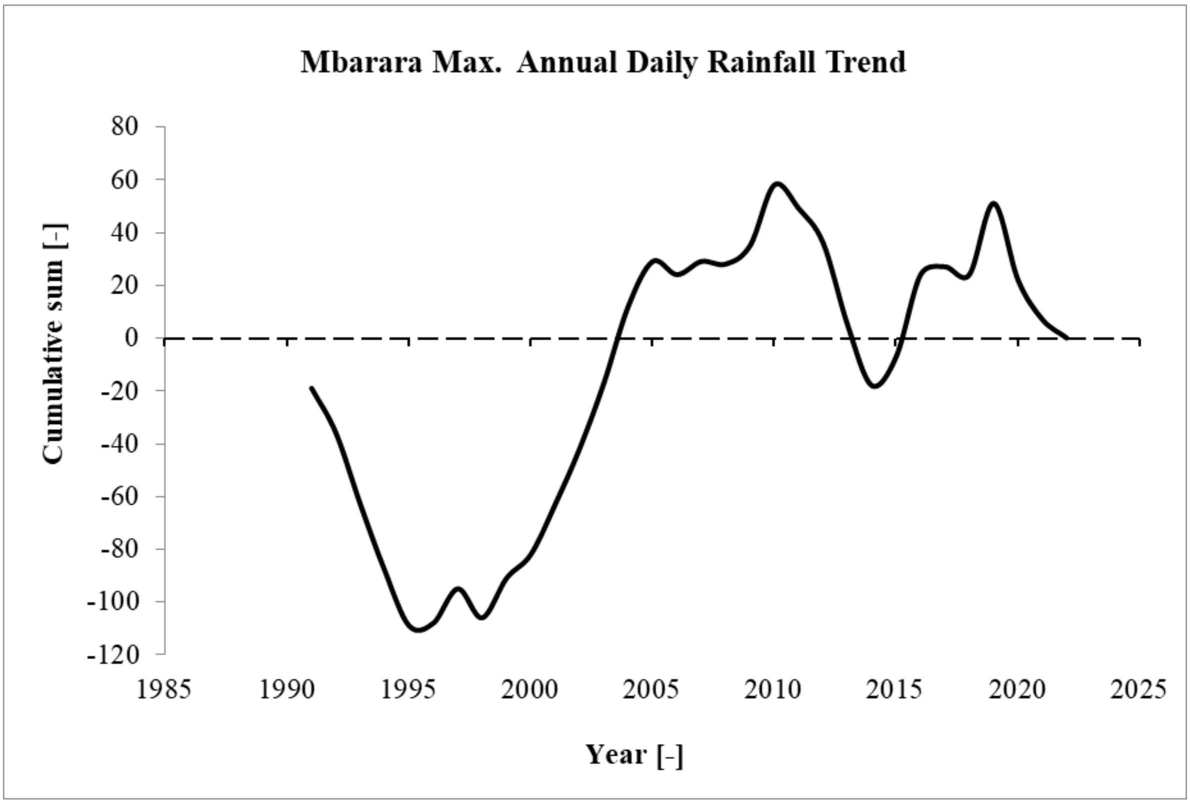


Fig 2. 43: Mbarara maximum annual daily rainfall variability

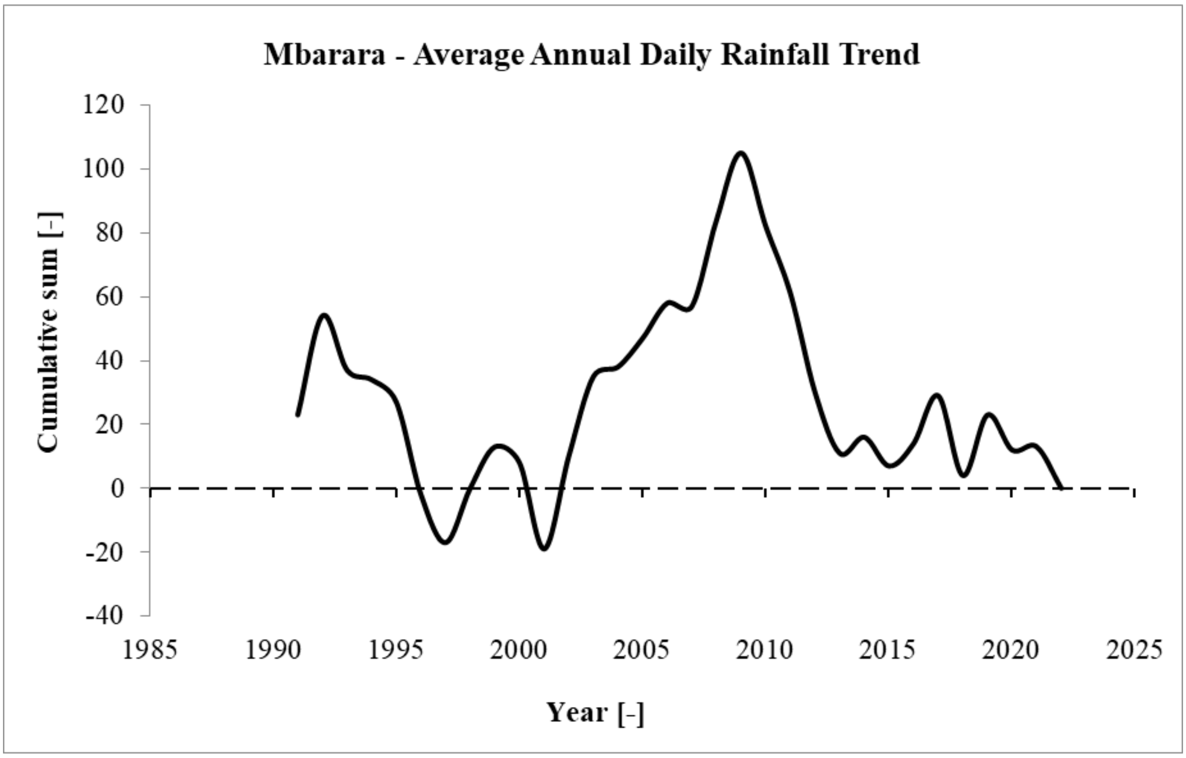


Fig 2. 44: Mbarara average annual daily rainfall variability

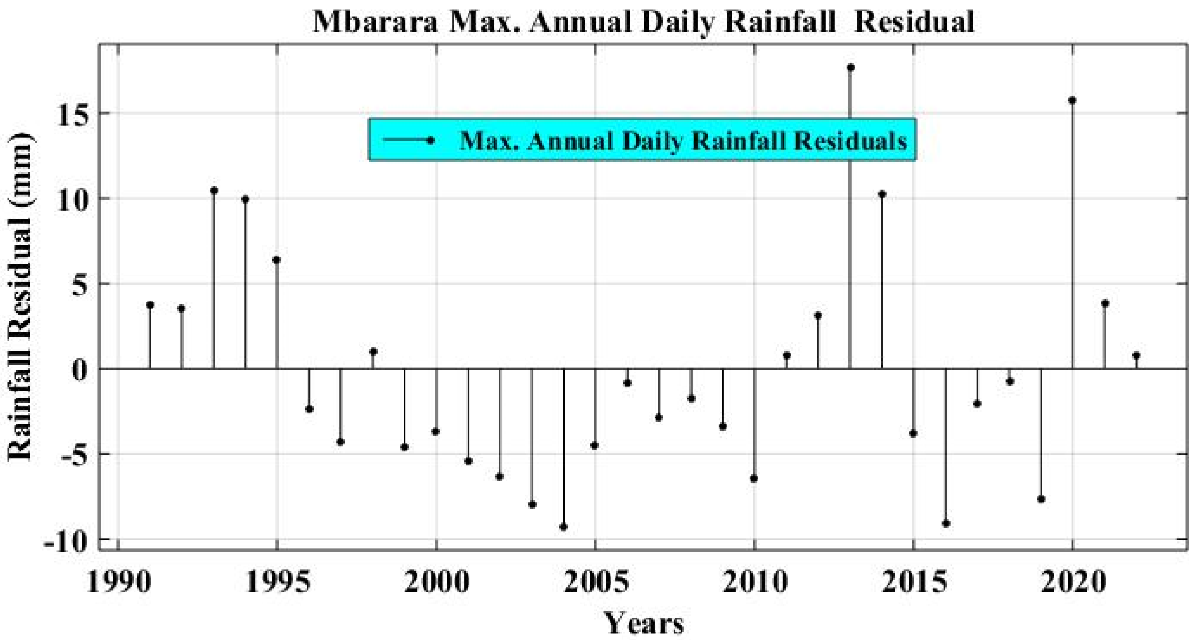


Fig 2. 45: Mbarara station maximum annual daily rainfall residual

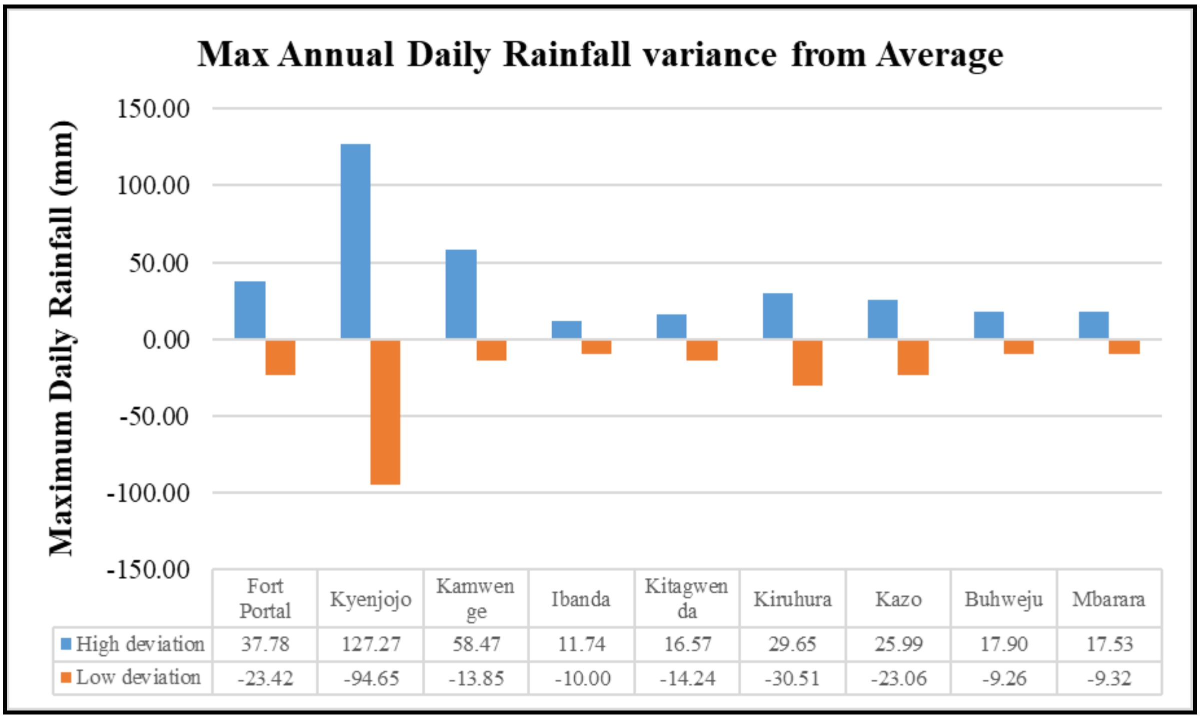


Fig 2. 46: Deviation of maximum annual daily rainfall from long term mean across the catchment

Table 2. 3: CRD test, Ho: 'There is no trend' at 5% level of significance

	Series	**Data record length**		**Statistic**			**Correction factor**	**Uncorrected Z_{crd}**
SNo.	**name**	**From**	**To**	**corrected**	**Threshold**	**p-value**		
1	Fort Portal	1991	2022	#	1.95996	0.96937	7.54495	-0.1055
2	Kyenjojo	1991	2022	-1.463	1.95996	0.14348	1.52922	-1.8091
3	Kamwenge	1991	2022	-0.1055	1.95996	0.91601	1	-0.1055
4	Ibanda	1991	2022	-0.6618	1.95996	0.50811	1.64108	-0.8478
5	Kitagwenda	1991	2022	0.68077	1.95996	0.49602	1.04423	0.69566
6	Kiruhura	1991	2022	-1.4153	1.95996	0.15698	1.00048	-1.4157
7	Kazo	1991	2022	-1.8344	1.95996	0.06659	1.06634	-1.8943
8	Buhweju	1991	2022	-0.4703	1.95996	0.63817	1.19061	-0.5131
9	Mbarara	1991	2022	-0.3881	1.95996	0.69798	1.59974	-0.4908

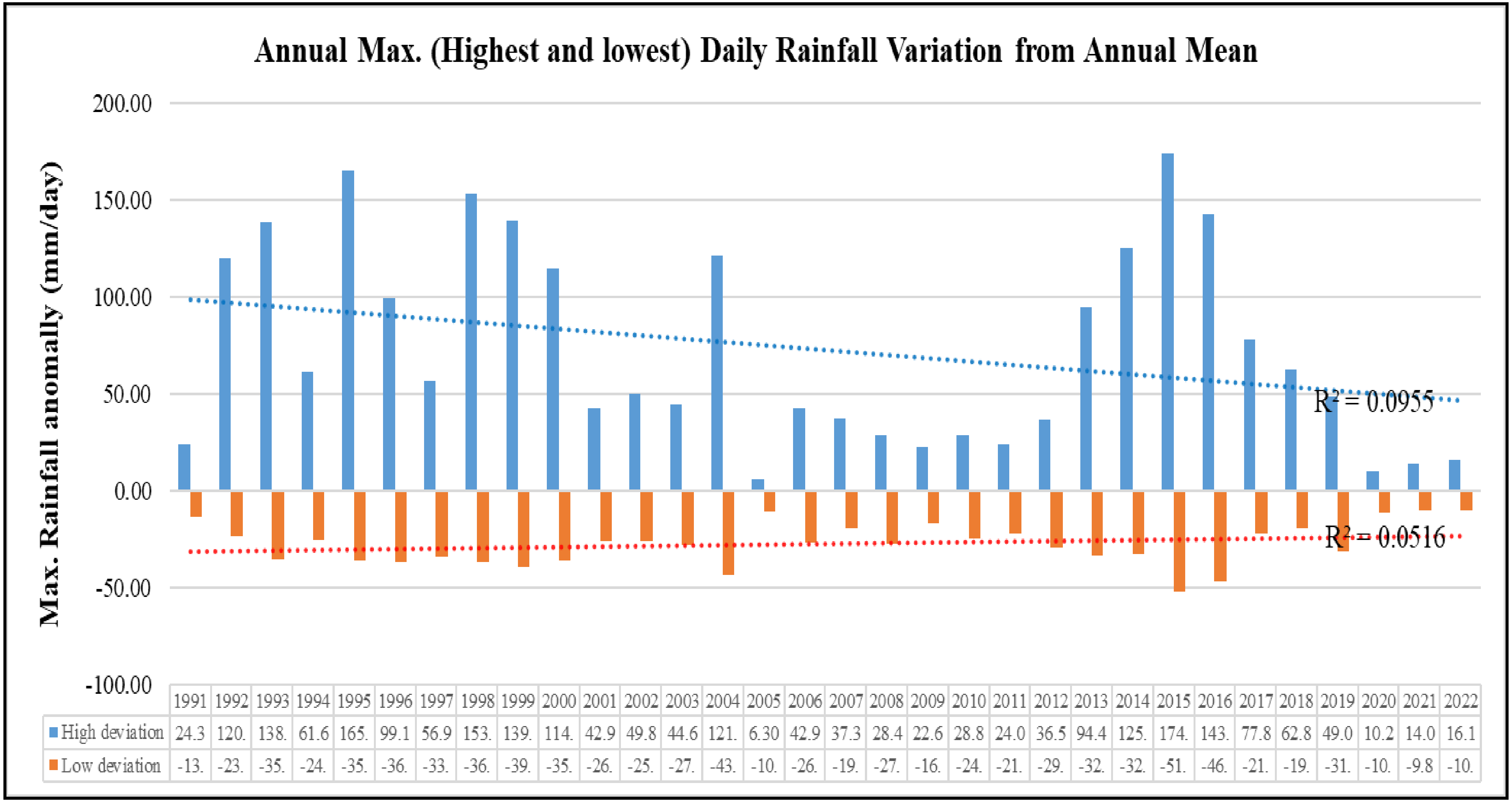


Fig 2. 47: Maximum annual daily anomaly trend (1991-2022) across the catchment

2.5.3 Correlation analysis

The purpose of conducting correlation analysis was to establish linear relationship between the climate indices, number of dry days (NDD1, NDD5 and NDD10), as an indicator of climate change with different continuous variables (maximum annul daily temperature/rainfall, total annual rainfall and average annual daily rainfall). Table 2. 4, shows correlation between maximum daily temperatures based on 30-year period and the selected climate indices. While the result was to determine how climate change influences water availability in this catchment.

Table 2. 4: Correlation between maximum daily temperatures with selected climate indices

S/N	Station	Correlation between maximum daily temperature and days with rainfall <1mm	Correlation between maximum daily temperature and days with rainfall <5mm	Correlation between maximum daily temperature and days with rainfall >5mm	Correlation between maximum daily temperature and days with rainfall >10mm
1	Fort Portal	-0.0289	-0.1874	0.1812	0.2210
2	Kyenjojo	0.0265	0.2477	-0.2407	-0.3024
3	Kamwenge	0.0959	-0.0020	0.0090	0.2813
4	Ibanda	0.1903	0.2841	-0.2571	-0.1598
5	Kitagwenda	0.1812	-0.0176	0.0343	0.3759
6	Kiruhura	-0.0218	0.1012	-0.0875	-0.2067
7	Kazo	-0.1511	-0.0910	0.1068	-0.0652
8	Buhweju	-0.1215	0.0410	-0.0358	-0.0767
9	Mbarara	-0.0400	-0.0086	0.0009	-0.1026

Table 2. 5: Correlation between annual maximum, total and average daily rainfall, and number of days with rainfall less than 1mm

S/N	Station	Correlation between maximum annual daily rainfall and days with rainfall <1mm	Correlation between total annual rainfall and days with rainfall <1mm	Correlation between annual average daily rainfall and days with rainfall <1mm
1	Fort Portal	**0.2725**	-0.7321	-0.7323
2	Kyenjojo	**0.0478**	-0.2924	-0.2927
3	Kamwenge	-0.0321	-0.7685	-0.7689
4	Ibanda	-0.2032	-0.7062	-0.7053
5	Kitagwenda	-0.1400	-0.4940	-0.4958

6	Kiruhura	**0.5951**	-0.2929	-0.2927
7	Kazo	**0.5007**	-0.4699	-0.4704
8	Buhweju	**0.2949**	-0.7820	-0.7825
9	Mbarara	**0.2340**	-0.4983	-0.5003

Table 2. 6: Correlation between annual maximum, total and average daily rainfall, and number of days with rainfall less than 5mm

S/N	Station	Correlation between maximum annual daily rainfall and days with rainfall <5mm	Correlation between total annual rainfall and days with rainfall <5mm	Correlation between annual average daily rainfall and days with rainfall <5mm
1	Fort Portal	-0.0048	-0.9529	-0.9529
2	Kyenjojo	-0.3635	-0.7089	-0.7092
3	Kamwenge	**0.0971**	-0.8932	-0.8943
4	Ibanda	-0.2915	-0.8522	-0.8516
5	Kitagwenda	-0.3857	-0.7706	-0.7722
6	Kiruhura	**0.3590**	-0.6152	-0.6155
7	Kazo	**0.2419**	-0.7741	-0.7747
8	Buhweju	**0.1926**	-0.8248	-0.8253
9	Mbarara	-0.1171	-0.9114	-0.9126

Table 2. 7: Correlation between annual maximum, total and average daily rainfall, and number of days with rainfall greater than 5mm

S/N	Station	Correlation between maximum annual daily rainfall and days with rainfall >5mm	Correlation between total annual rainfall and days with rainfall >5mm	Correlation between annual average daily rainfall and days with rainfall >5mm
1	Fort Portal	**0.0031**	0.9482	0.9483
2	Kyenjojo	**0.3689**	0.7105	0.7108
3	Kamwenge	-0.0985	0.8952	0.8961
4	Ibanda	**0.2979**	0.8470	0.8458
5	Kitagwenda	**0.3957**	0.7778	0.7789
6	Kiruhura	-0.3504	0.6161	0.6161
7	Kazo	-0.2303	0.7781	0.7784
8	Buhweju	-0.1883	0.8261	0.8261
9	Mbarara	**0.1157**	0.9150	0.9157

Table 2. 8: Correlation between annual maximum, total and average daily rainfall, and number of days with rainfall greater than 10mm

S/N	Station	Correlation between maximum annual daily rainfall and days with rainfall >10mm	Correlation between total annual rainfall and days with rainfall >10mm	Correlation between annual average daily rainfall and days with rainfall >10mm
1	Fort Portal	0.1159	0.9674	0.9673
2	Kyenjojo	0.6744	0.9240	0.9241
3	Kamwenge	-0.0160	0.7884	0.7876
4	Ibanda	0.4192	0.8692	0.8704
5	Kitagwenda	0.6192	0.8436	0.8431
6	Kiruhura	-0.0088	0.8139	0.8144
7	Kazo	0.0426	0.7993	0.7999
8	Buhweju	-0.0829	0.7984	0.7956
9	Mbarara	0.1572	0.8067	0.8054

2.5.4 Characterization of climate indices

The annual mean of the number of days with rainfall less than 1mm, 5mm and greater than 5mm and 10mm averaged over the entire catchment was analysed. The selected climate indices was to characterize variability of the climatic dry and wet condition across the catchment. Fig 2. 48 to Fig 2. 51, showed this averages and for rainfall less than 1mm and 5mm, number of days that received this rainfall was found to have varied negatively as compared to number of days that received rainfall above 5 and 10mm (varied positively) respectively. This trend indicate that the catchment was climatically wetter in the last decade.

Climate indices (NDD<1 & NDD<5) showed both negative and positive trend across the catchment over the period 1991-2022. NDD<1 (Fig 2.48) exhibited positive trend from around 2001 to 2008 and a negative trend for the rest of the period. NDD<5 (Fig 2.49) showed positive trend from 2000 to 2001 followed by negative trend for the rest of the period. NDD>5 and NDD>10 (Fig 2.50-2.51) showed positively declining trend from 2006 to 2022. While NDD>5 and NDD>10 indicated positive trend, this was observed to be oscillating downward since 2006 and can be explained by both the negative trend in the annual average and maximum daily rainfall observed over the catchment. However, this still explains that the catchment has been climatically wetter in the recent decades.

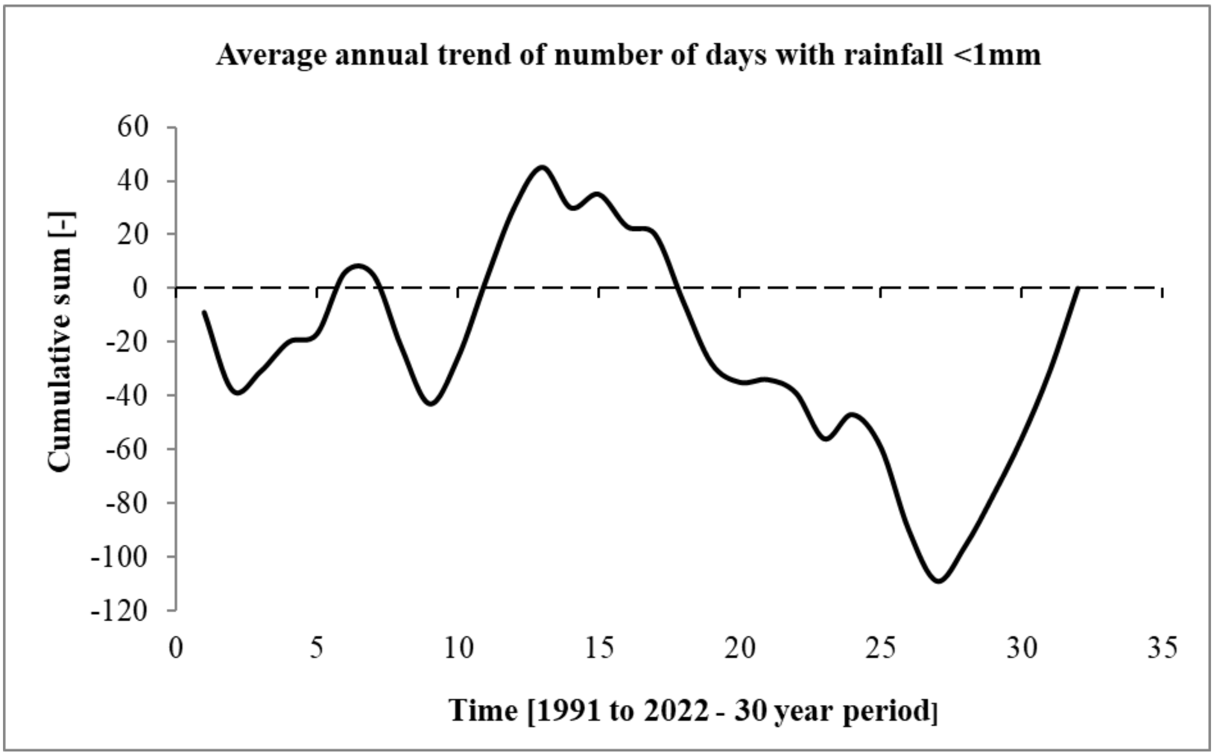


Fig 2. 48: Average annual variability in number of days with rainfall less than 1mm

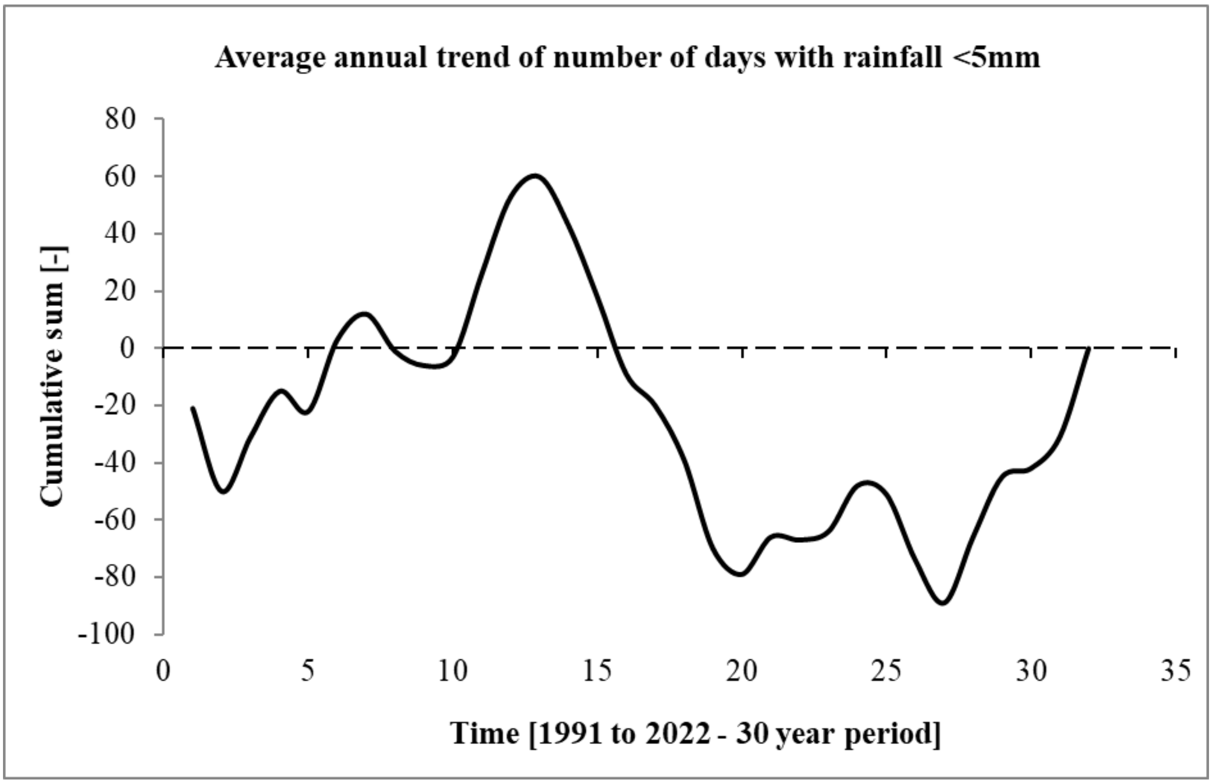


Fig 2. 49: Average annual variability in number of days with rainfall less than 5mm

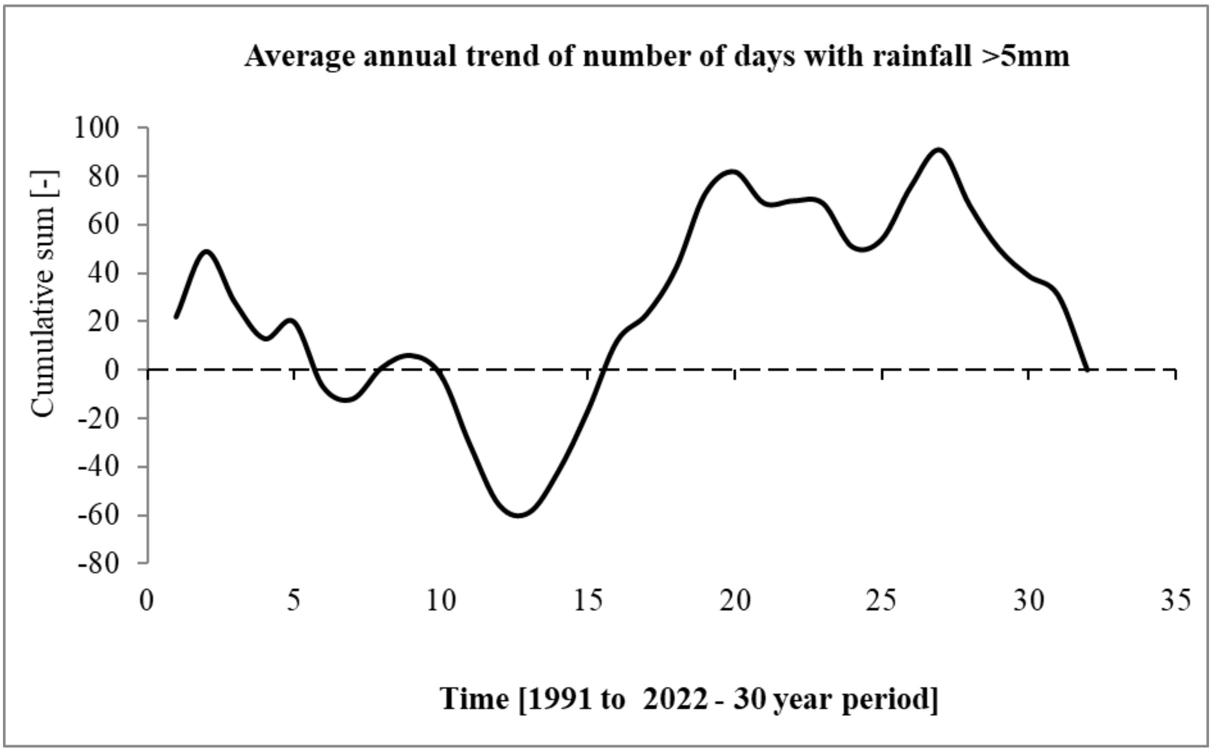


Fig 2. 50: Average annual variability in number of days with rainfall greater than 5mm

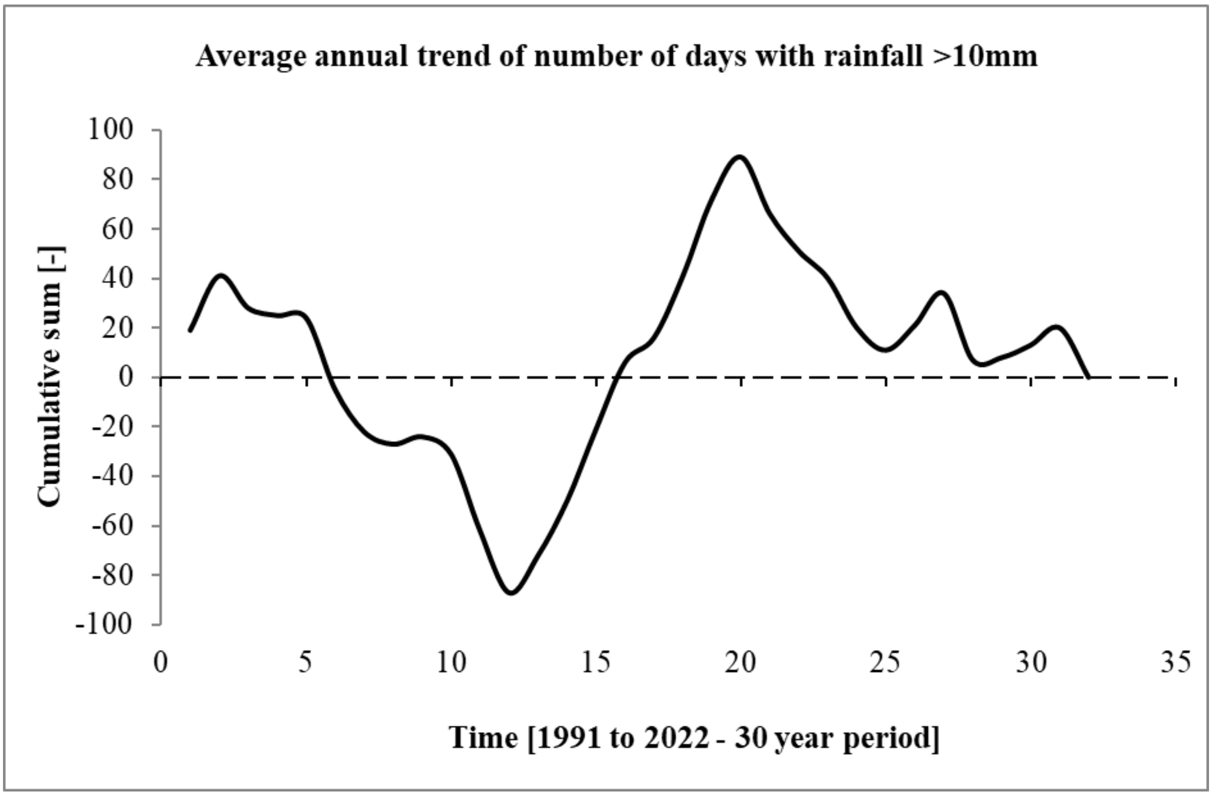


Fig 2. 51: Average annual variability in number of days with rainfall greater than 10mm

2.6 Sub Conclusion one

- **To analyse trend in rainfall and determine the significance of change**

The maximum and average annual daily rainfall across the catchment exhibited negative trend over the 30-year period (1991-2022). This downward trend in the maximum and average annual daily rainfall can be explained by the negative trend in the maximum annual daily rainfall anomaly, though the change is not so significant.

CHAPTER THREE: DETERMINATION OF THE CURRENT AND PLANNED WATER USE AND PROJECTED FUTURE DEMAND

3.1 Introduction

According to the Uganda Water Resources Assessment Report, 2013, the per capita consumption rate was taken as 20 l/d for small towns, 35 l/d for medium towns and 50 l/d for large towns as provided in the Directorate of Water Development Water Supply Design Manual, 2013. Water use and future demand assessment started with the delineation of the proposed area/ catchment, followed by a socio-economic baseline survey to establish the total population/ number of water consumers. Since it was impractical to take a count of all the water users, we used statistical methods, sampling, and demographic data from the Uganda Bureau of Statistics (UBOS**).** Data from the respective districts and local councils (LCs) was used to validate/ improve the estimates. Fig 1.1 shows the extent and composition of the Mpanga catchment.

3.2 General objective

The main objective of this study was to obtain the current and planned water demand in the Mpanga catchment, as well as the projected water demand for the research period of 40 years.

3.2.1 Specific objectives

a) Determining the current, planned and projected Domestic demand
b) Determining the current, planned and projected Livestock demand
c) Determining the current, planned and projected Fisheries demand
d) Determining the current, planned and projected Hydropower demand
e) Determining the current, planned and projected Irrigation demand
f) Determining the current, planned and projected Industrial demand
g) Computing the current and future demand for Environmental flow

3.3 Literature review two

3.3.1 Current demand

Water demand has been studied by a wide scope of scholars. It is generally defined as the volume of water needed by several users for their satisfaction. It is obtained as the summation of water demand from different service levels, which is domestic demand, livestock demand, fisheries demand, Hydropower, Irrigation, environmental flow and industrial demand. According to Y. Saketa (Water Supply, 2022), water demand at a demand site is calculated as;

Total water demand = Total activity level* Water use rate

3.3.2 Planned water demand

The Albert Water Management Zone Water Resources Assessment Report obtains the planned water demand by compiling the water demand from planned facilities such as industrial parks, institutions, hydropower plants. This information was obtained from the National Planning Authorities, sister government parastatals and district Local Governments development plans.

3.3.3 Projected Water demand

Projected water demand is the amount of water required by the various water users in the ultimate year of the design period. The DWD water supply design manual (DWD, 2013) stipulates the process of computing the future demand. For each demand category, the annual growth rate was used to project the current water demand using the equation;

$$Q_n = Q_0 (1+r)^n$$

Where Q_n is the demand after n years, Q_0 is the demand in the current year, r is the annual growth/ expansion rate and n is the number of years considered.

3.4 Methods and materials two

3.4.1 Data source

The population based on 2014 National Population and Housing Census (NPHC) was obtained from Uganda Bureau of Statistics (UBOS).k

3.4.1.1 Population

The current projected population was computed using equation 7 below;

$$P_n = P(1+r)^n \qquad (7)$$

Where, P_n is the population after n years; P the base population and r is the annual growth rates (%) for the respective Sub- Counties in each District. The base population was derived from the UBOS projections of the 2014 NPHC. Therefore, current domestic water demand for each district was estimated by multiplying the projected 2023 population with a per capita consumption. As can be seen in table 3.2 below, the districts Bundibugyo, Bunyangabu and Buhweju were found to be insignificant to the catchment in terms of the area in the catchment, and therefore were not considered during the analysis.

3.4.1.2 Water use

Water is a vital input for many economic activities, and it is important for us to clearly understand the available supply and the level of utilization by the different sectors of the economy, more so in the Mpanga catchment. This is with the view to establishing whether, there is room for increased utilization within the framework of Integrated Water Resources Management. Since there are no existing water use registers/ data bases for the Mpanga catchment, this study was especially important as a building block in establishing the water demand/ use patterns.

3.4.1.3 Water users

Integrated water resources management within the Mpanga catchment requires an essential component of assessing water demand, which involves estimating the amount of water needed to meet the requirements of various users and sectors. They were categorized as either consumptive or non-consumptive. Consumptive users such as domestic, irrigation, livestock, and industrial users consume water, reducing the amount of water accessible to downstream users and ecosystems.

However, non-consumptive users such as hydropower, environmental flow, and fisheries use water in a way that does not significantly reduce the amount of water available for downstream users and ecosystems. Water demand assessment assists in identifying both present and future water needs as well as the potential for water scarcity and conflicts among different users.

3.4.2 Research design

This study mainly followed a quantitative approach. This involved the collection and analysis of numerical data. The obtained data was analysed to obtain patterns and averages, as well as make predictions and generalized results for the areas where numerical data was not readily available. Through this, the study was able to draw rational conclusions on some of the conceptions about the Water demand patterns in the Mpanga Catchment.

3.4.3 Research approach

The water demand was determined through two broad steps;

a) Determining the number of water consumers lying in each category
b) Determining the average day unit water demands for each of category
c) Computation of the current daily and annual water demand, with 2023 as the current year.
d) Projection of the daily and annual water demand to the future period 2063.

The study considered the following consumer categories;

- Domestic demand
- Livestock demand
- Fisheries demand
- Hydropower demand
- Irrigation demand
- Industrial demand
- Environmental flow

The above datasets were obtained from the gazetted statistics of the Uganda Bureau of Statistics (UBOS) as well as district Local Governments within the catchment. Analysis was done based on the provisions of various design manuals, publications and international standards.

3.5 Findings and discussion

3.5.1 Current and projected domestic water demand

Table 3. 1 summarises the current (2023) population and domestic water demand (m^3/year) for the Mpanga catchment. The estimated total current water demand is 28,881m^3per day. The largest (25%) and smallest (7 %) percentage volumes of domestic water are demanded by Ibanda and Mbarara districts respectively.

The current water demand was determined through two broad steps;

a) Determining the number of consumers lying in each category
b) Determining the average daily unit water demands for each consumer category. The consumer categories considered are as highlighted in section 3.4.3 above.

Table 3. 1: Population projections

S/N	Name	Admin	2015	2020	% Growth	2023	2063
1	Kabarole	District	257,200	285,700	2.13	304,241	704,804
2	Kyenjojo	District	185,200	223,700	3.85	250,583	1,138,077
3	Kamwengye	District	191,200	230,100	3.77	257,132	1,131,008
4	Kitagwenda	District	118,100	142,200	3.78	158,963	702,690
5	Ibanda	District	253,200	277,300	1.87	292,804	605,213
6	Mbarara	District	129,200	144,000	2.20	153,739	368,106
7	Kazo	District	157,600	188,200	3.60	209,222	859,281
8	Kiruhura	District	138,300	165,300	3.65	183,934	764,441
	Total		**1,430,000**	**1,656,500**	**3.11**	**1,810,618**	**6,273,620**

Table 3. 2: District area within the catchment

District	Total Area (A) Km^2	Area in Catchment (a)	Fraction of district lying in the Catchment (a /A)	% Composition of the catchment
Kabarole	1,312.0	455.7	35%	8.8%
Kyenjojo	2,350.1	574.9	24%	11.1%
Kamwengye	1,693.0	595.5	35%	11.4%
Kitagwenda	715.6	283.4	40%	5.4%
Ibanda	964.8	864.4	90%	16.6%
Buhweju	687.1	23.5	3%	0.5%
Bundibugyo	848.2	0.0	0%	0.0%
Mbarara	1,242.0	362.4	29%	7.0%
Kazo	1,556	889.1	57%	17.1%
Bunyangabu	498.3	2.2	0%	0.0%
Kiruhura	4,605	1151.3	25%	22.1%
Total	**16,472.1**	**5,202.4**	**32%**	**100%**

Table 3. 3: Current and projected domestic water demand

District	2023 (m^3/day)	2063 (m^3/day)
Kabarole	5,710	13,166
Kyenjojo	2,739	12,485
Kamwengye	3,157	13,793
Kitagwenda	2,067	9,188
Ibanda	7,293	15,168
Mbarara	2,018	4,789
Kazo	3,408	13,950
Kiruhura	2,489	10,385
Total	28,881	92,926

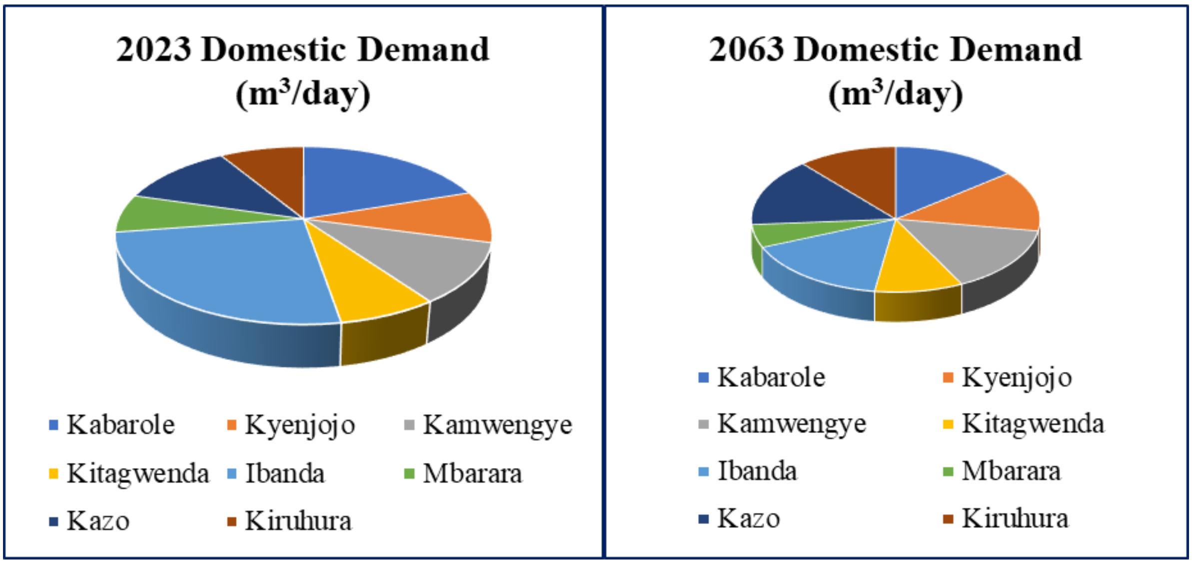


Fig 3. 1: Current and projected domestic daily water demand

From fig 3.1 above, it can be deduced that the average population growth in the Mpanga catchment is 3.11 which ranges from 1.87% in Ibanda to 3.85% in Kyenjojo.

The estimated total current water demand is 29,000 CM per day. The largest (25%) and smallest (7 %) percentage volumes of domestic water are demanded by the Ibanda and Mbarara districts respectively.

The estimated future domestic water demand is 93,000 CM per day. The districts Ibanda and Kazo demand the largest percentage volume of domestic water.

3.5.2 Livestock demand

The current livestock water demand for each district was computed by summing the water demands for all livestock types i.e., cattle, goats, sheep, pigs and poultry. The current water demand for each livestock type was estimated using the following formula: $WD_{LT} = L_n \times WD_{TLU} \times L_c$ where: WD_L is the water demand for each livestock type, L_n is the current livestock count for each livestock type, WD_{TLU} is unit water demand for one (1) Tropical Livestock Unit (TLU), and L_c is the livestock coefficient.

Table 3. 4: Total livestock and water demand conversion factor

District	Cattle	Goats	Sheep	Pigs	Chicken	Ducks	Turkey
Kabarole	67,115	155,264	13,510	40,781	352,530	8,990	1,742
Mbarara	149,992	176,464	22,588	12,243	239,470	5,966	711
Greater Kamwenge	120,906	154,422	26,239	34,280	339,191	11,237	363
Kyenjojo	184,537	254,966	38,235	73,345	579,743	6,712	598
Ibanda	55,126	89,704	13,997	12,164	144,301	6,851	153
Greater Kiruhura	342,315	188,686	28,017	3,967	142,459	4,719	235
Total	**919,991**	**1,019,506**	**142,586**	**176,780**	**1,797,694**	**44,475**	**3,802**

Category	Cattle	Goats	Sheep	Pigs	Chicken	Ducks	Turkey
Conversion Factor	0.7	0.2	0.2	0.4	0.1	0.1	0.1
Annual growth rate %	0.2	-0.4	-4.8	6.1	3.1	3.1	3.1

According to DWD, (2000) one Total Livestock Unit (TLU) needs 50 litres/day; one head of cattle, one goat, one sheep, and one pig shall be deemed 0.7, 0.15, 0.15 and 0.4 of a TLU respectively. The conversion factor for poultry is 0.1.

The current (2023) livestock counts (Table 3. 5) were projected from UBOS's 2008 livestock census (Table 3. 4) using the following formula: $L_n = L\ (1 + r)^n$ where, L_n is the livestock count after n years; L the baseline (2008) livestock count and r is the annual growth rate (%). A similar study in the sub-Saharan region recommends growth rates of 0.002, -0.041, -0.048, 0.061 for cattle, goats, sheep, and pigs respectively.

According to FAO, (2010) the poultry growth rate in Africa is 3.1%. The negative growth rates applied for goats and sheep depict an annual reduction in those livestock types, though in general, all annual growth rates for all livestock types apart from poultry are close to zero. In relation to the Ugandan context, the growth rates for cattle, goats, sheep, pigs and poultry based on UBOS's livestock census for 2002 and 2008 were 10%, 16%, 14%, 27% and 19% respectively. The sub-Saharan growth rates were adopted since they depict an equilibrium in livestock production and consumption.

Table 3. 5: 2023 Livestock Counts- Projected UBOS data

District	Cattle	Goats	Sheep	Pigs	Chicken	Ducks	Turkey	Total Livestock Units
Kabarole	69,157	146,205	6,460	99,126	557,283	14,211	2,754	139,672
Mbarara	154,555	166,168	10,800	29,759	378,557	9,431	1,124	166,093
Greater Kamwenge	124,584	145,412	12,546	83,324	536,197	17,764	574	171,959
Kyenjojo	190,151	240,089	18,282	178,279	916,464	10,610	945	289,574
Ibanda	56,803	84,470	6,693	29,567	228,113	10,830	242	77,223
Greater Kiruhura	352,729	177,676	13,396	9,643	225,201	7,460	371	291,080
Total	**947,980**	**960,019**	**68,176**	**429,699**	**2,841,815**	**70,307**	**6,010**	**1,135,602**

Error! Not a valid bookmark self-reference.5 above summarizes the livestock counts for each district. Since UBOS data could not be obtained for the livestock counts of Kitagwenda and Kazo, the projections and analysis were considered as for greater Kamwengye and greater Kiruhura from which Kitagwenda and Kazo were respectively curved. For a total of 1.1 million livestock units projected for 2023, the water demand was analysed as follows;

Livestock Water demand = Percentage of district in the catchment* Livestock Units* Per capita consumption i.e., 0.05 m^3/ unit/day.

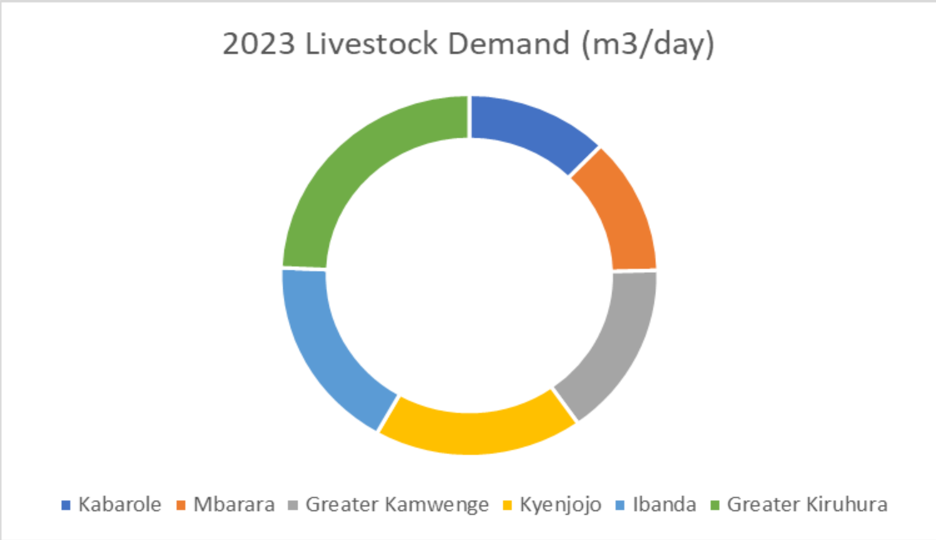
Since the districts do not lie wholly within the catchment, a fraction (%) was applied when analysing the demand, assuming a uniform distribution of livestock over the entire catchment. The livestock demand per district is as summarized in the table below;

Table 3. 6: Current (2023) and future (2063) livestock daily water demand

District	Percentage in Catchment	2023 Livestock Units	2023 Livestock Demand (m3/day)	2063 Livestock Units	2063 Livestock Demand (m3/day)
Kabarole	35%	139,672	2,425	592,133	10,283
Mbarara	29%	166,093	2,423	331,770	4,840
Greater Kamwenge	36%	171,959	3,095	563,332	10,140
Kyenjojo	24%	289,574	3,542	1,094,282	13,385
Ibanda	90%	77,223	3,459	220,883	9,895
Greater Kiruhura	33%	291,080	4,803	371,148	6,124
		1,135,602	**19,748**	**3,173,548**	**54,667**

Total livestock demand for the current year 2023 was obtained as approximately **20,000 CM** per day, with the highest contributors being Greater Kiruhura, Ibanda and Kyenjojo.

The total future livestock demand is approximately **55,000 CM/day**, with the biggest percentage being demanded by Kyenjojo district, while the smallest percentage will be demanded by Mbarara as depicted in Fig 3. 2 below;



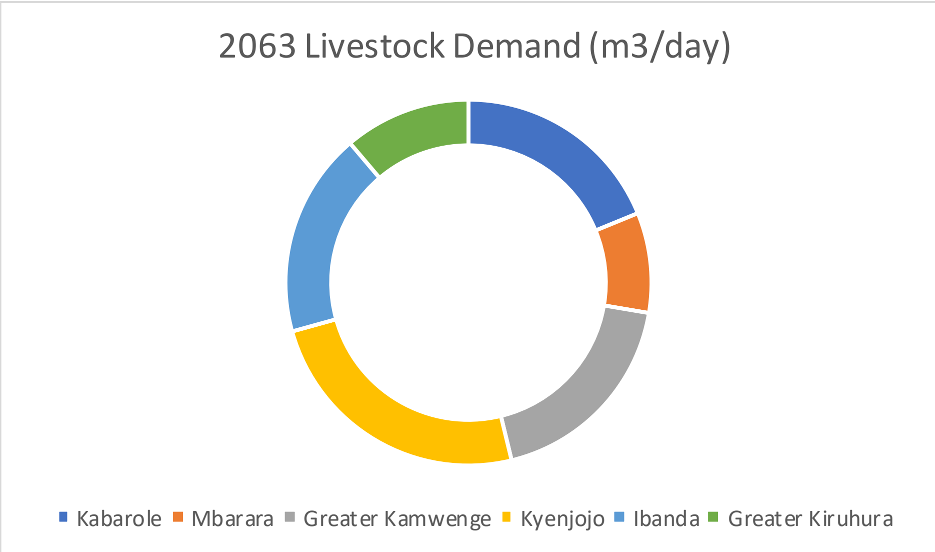


Fig 3. 2: Current (2023) and future (2063) livestock daily water demand

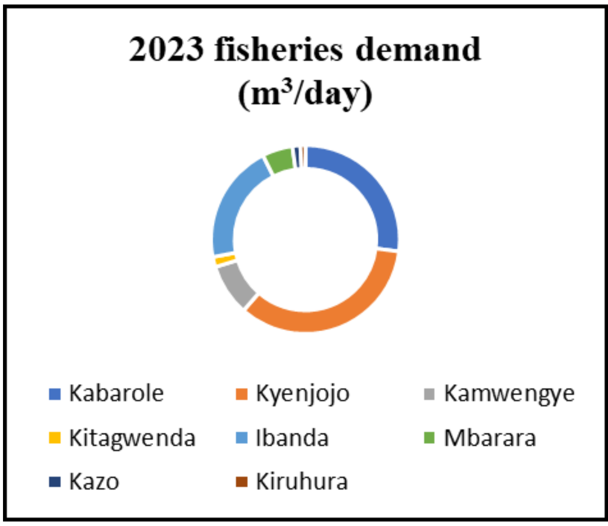
3.5.3 Fisheries water demand

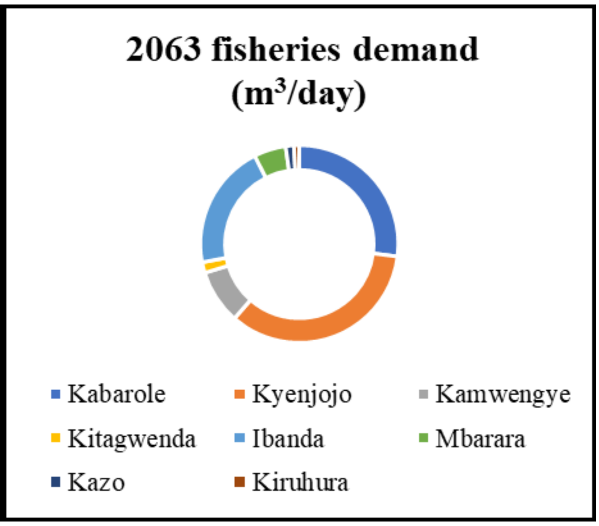
The Mpanga catchment is viable for aquaculture due to the existing water and wetland resources in the catchment. The current water requirement was determined based on the volume of the fishponds in each district and the regime of cleaning the ponds bi-yearly, assuming there was no external flow of water in and out of the pond system. The number of fishponds within the catchment was obtained using datasets from District Local Governments and FAO. In order to estimate the volume of the fishponds, an average depth of 1.5 m and surface area of 500m^2 was assumed (FAO, 2013). The water demand the current year, 2023 was projected to 2063, using the annual growth rate of 33.56% for aquaculture production in Uganda (FAO, 2020). The details of the fishponds from which the demand estimation was derived are captured in Table 3. 7 below.

Table 3. 7: Fisheries current (2023) and future (2063) daily and annual water demand

			2023 Demand		2063 Demand		
District	**Area of district in catchment**	**Number of Fish ponds**	**(m^3/day)**	**m^3/year**	**(m^3/day)**	**(m^3/day)**	**% Demand**
Kabarole	31%	265	69,028	138,056	7,346,510,565	14,693,021,130	27%
Kyenjojo	50%	479	87,885	175,771	9,353,486,228	18,706,972,455	34%
Kamwengye	43%	86	22,687	45,374	2,414,547,940	4,829,095,880	9%
Kitagwenda	52%	15	4,455	8,910	474,121,239	948,242,478	2%
Ibanda	37%	78	52,414	104,829	5,578,363,709	11,156,727,418	21%
Mbarara	60%	61	13,348	26,697	1,420,636,432	2,841,272,863	5%
Kazo	73%	8	3,429	6,857	364,889,104	729,778,207	1%
Kiruhura	43%	12	2,250	4,500	239,475,140	478,950,280	1%
TOTAL	**48%**	**1,004**	**255,497**	**510,993**	**27,192,030,356**	**54,384,060,712**	**100%**

The total current fisheries demand is 255,000m^3/day (Table 3. 7) and of which the biggest percentage (34%) is demanded by Kyenjojo while the smallest demand is from Kazo and Kiruhura districts, as shown by the pie charts below;





3.5.4 Industrial water demand

Over the past 20 years, Uganda has encountered substantial economic growth, with growth rates varying between 4% to 8% per annum. The Country's GDP growth was around 6.8% between 2001-04 and then rose to 8% between 2005-08. The manufacturing sector contributes 9% to GDP, while the mining sector contributes 0.8% as of 2006 (MWE, 2013). Establishment of industries in this catchment has continued to provide a source of livelihood to the population. The dominant industrial activities include, grain milling, tea, coffee and dairy processing. These industries require large volumes of water for various purposes, such as heating, cleaning, transporting substances, cooling, and raw materials. As more industries continue to be established in the region, accurately estimating the actual water demand has become a challenge.

As presented below, a number of process plants and manufacturing industries were identified in Mpanga catchment during the field investigations. The calculated current industrial water use was adopted for the current Industrial water demand since information on water consumed (m^3) per unit of product produced as well as production levels was not readily available.

In addition, there are plans to develop or establish an industrial park within the catchment by the Uganda Investment Authority or private developers, as can be seen in the table below.

Table 3. 8: Kabarole industrial demand

No.	District	Area (ha)	Status	Sectors targeted
1.	Kabarole	203.15	Planned	Dairy processing, tea processing, fruit processing, wood processing industries.

Source: Uganda Investment Authority website

3.5.4.1 Current and Future Industrial Water Demand

The current industrial water demand, as obtained from the AWMZ water permit records indicated a total daily abstraction of **3,086 m^3** for the currently documented industries in Kabarole, Kyenjojo and Kamwengye districts. Since the exact location could not be plotted on the GIS maps, the water demand/ abstraction obtained per district was multiplied by the fraction of the district lying in the catchment, as summarized in the table below;

District	Industrial abstraction (m3/day)	Percentage lying in the catchment	Effective Industrial demand (m3/day)
Kabarole	426	35%	148
Kyenjojo	450	24%	110
Kamwengye	2210	35%	777
TOTAL	**3,086**		**1,035**

The annual rate of industrial growth was estimated at 8.7% as according to the Uganda Vision 2040 publication.

In addition to this, the current and future water demand for the industrial park located in Kabarole (Table 3. 8) was estimated using the consumptive unit rates as per the DWD Water Supply and Design manual. The manual differentiates between medium scale (water intensive), medium scale (medium water intensive) and small scale (dry) industry types. For analysis purposes, the industrial park was classified as a small-scale macro industry, developed to 10% in 2023, and fully developed by the year 2063. The different levels of development shown in **Error! Not a valid bookmark self-reference.** for the different industrial types were used to project the future industrial water demand.

Table 3. 9: Water demand per industrial type

Industry type	Water Demand (m^3/ha/d)	Level of development (%)				
		2022	2025	2030	2040	2063
Medium Scale (water intensive)	40	6	10	20	30	60
Medium Scale (medium water intensive)	15	20	30	40	55	75
Small scale (dry)	5	10	15	25	60	100

(*Source,* DWD-MWE, 2013)

The current and future water demand for industrial park within the Albert WMZ sub-zones districts is summarized in Table 3. 10 below.

Table 3. 10: Industrial Park current and future water demand

Current Demand in m^3/day. (2023)		Future Demand in m^3/day. (2063)	
AWMZ Data base	**Industrial Park**	**AWMZ Data base**	**Industrial Park**
1,035	102	29,126	1,016
TOTAL	**1,137**	**TOTAL**	**30,142**

From the above table, it can be deduced that the total current demand is 1, 137 m^3/day while the future industrial water demand is 30,142 m^3/day.

3.5.5 Hydroelectric power generation water demand

Currently, there is only one hydropower station operating in the Mpanga Catchment. The EMS Mpanga Hydropower Plant draws 1,382,400 m^3/day. This was considered as the Current Hydropower demand, as well as Future demand, since there was no available data on the planned Hydropower plants in this catchment.

3.5.6 Irrigation

Agriculture is the main economic activity within the Mpanga Catchment and AWMZ as a whole, and provides livelihood for most of the rural communities in the area as most people practice small subsistence farming. In general, the Mpanga catchment experiences two rainy seasons throughout the year. However, dry spells can occur during critical periods of plant growth, resulting in soil moisture deficits (MWE, 2013). In such a situation, adoption of irrigation has the potential to increase yields by reducing on crop losses and improving crop's physiology, thereby enhancing its ability to harness nutrients, overcome diseases and other stress. According to MAAIF (2017), Uganda aspires to transform agriculture from subsistence to commercial agriculture through both mechanization and introduction of modern irrigation systems.

The Ministry of Water and Environment, under the Water for Production department has invested towards setting up several small-scale solar-powered irrigation schemes in different districts in the Mpanga Catchment. The tables below list several irrigation schemes set up by the Ministry of Water and Environment within the AWMZ.

Table 3. 11: List of irrigation schemes and daily water abstraction rate

Name of scheme	Details	District	Abstraction m^3 per day	Source
Dott Services Ltd - Mpanga	Permit data base	Kabarole	6,580	Mpanga
Kicuna Small Scale Irrigation Scheme	Records provided by Water for Production, MWE- Mbarara regional office	Kabarole	216	Kasoma Stream
Rwengaaju Modal Village Irrigation Schemes	Records provided by Water for Production, MWE- Mbarara regional office	Kabarole	7,171	R.Mpanga. By gravity
Masongora Small Scale Irrigation scheme		Kabarole	240	Sogahi stream
Biguli Small scale irrigation scheme		Kamwenge	168	Swamp
Karubuguma Scheme		Kitagwenda	50	R. Mayanja
Nyamareebe Small scale irrigation scheme		Ibanda	1,896	Swamp
Rwentanga Farm Institute	U-GIFT microscale Irrigation perogram	Mbarara	5	Pond
Rutooma Parish, Ankole Diocese	U-GIFT microscale Irrigation perogram	Mbarara	8	Pond
TOTAL			**16,334**	

In addition to the large schemes, there are several small irrigation schemes in the Mpanga Catchment. According to the National Irrigation Masterplan for Uganda (2010-2035), the average annual gross irrigation water use in Uganda is 7,500 m3/ha/year. With this estimate, the water demand for irrigation of the small unclassified irrigation sites was obtained as a product of the land acreage in hectares, and the average annual gross irrigation water use as seen in the tables below;

3.5.6.1 Current Irrigation Water Demand

Water demand for crop irrigation was based on the existing irrigation schemes in the. The potential irrigable area within the zone was determined using the figures in the National irrigation Masterplan for Uganda 2010-2015. The potential for Irrigation in the Mpanga catchment is based on the Water Classification Action of 1995. Generally, All the land within the AWMZ, where the Mpanga catchment lies was classified as Type A and Type B. Area A is the area with favorable soil conditions close to the main water sources as identified in previous studies as the irrigation potential (Irrigation Masterplan, 2010). Area B irrigation potential is defined as the arable land that could be irrigated provided bulk water supplies including water storage in the dry season would be available (MWE, 2013).

According to the National Irrigation Masterplan for Uganda (2010-2035), the average annual gross irrigation water use in Uganda is 7,500 m^3/ha/year. Hence, the current potential irrigation water demand (m^3/year) was estimated by multiplying the irrigable areas for the various irrigation schemes in the zone with the average annual gross irrigation water use.

The Ministry of Water and Environment, under the Water for Production department has invested towards setting up several small-scale solar-powered irrigation schemes in different districts in the Mpanga Catchment. The total current demand was obtained by summing the data from the irrigation schemes as summarized below;

DISTRICT	**Irrigation demand (m^3/day)**
Ibanda	1,143
kitagwenda	271
kazo	21
kiruhura	312
Kyenjojo	687
Kabarole	4,364
Kamwengye	72
Mbarara	8
TOTAL	**6,878**

The data obtained indicates that Kabarole, Ibanda and Kitagwenda districts contributed most to the current irrigation demand in this catchment. Although the data analyzed had gaps, it can be observed that Mbarara, Kazo and Kamwengye have the least irrgation water demand as can be seen in the graph below;

3.5.6.2 Future Irrigation Water Demand

The projected irrigable areas in the Albert WMZ were determined using the formula;

$$A_n = A_o (1+r)^n$$

Where A_n is the potential irrigable area after n years, r is the estimated irrigation expansion rate and A_o is the current potential irrigable area. According to the National Irrigation Masterplan for Uganda (2010-2035), the country's irrigation expansion rate, was estimated to be less than 0.05%.

Consequently, the calculation of future irrigation water demand was done by multiplying the projected irrigable areas by the annual gross irrigation water usage of 7,500m^3/ha/year. Therefore, the future irrigation water demand can be observed to increase minimally to a total of 7,017 m^3/day, with similar distribution among the districts as shown in the table below;

Table 3. 12: Current and future Irrigation water demand

DISTRICT	Current Irrigation demand 2023 (m^3/day)	Future Irrigation demand 2063 (m^3/day)
Ibanda	1,143	1,166
kitagwenda	271	276
kazo	21	21
kiruhura	312	318
Kyenjojo	687	701
Kabarole	4,364	4,452
Kamwengye	72	73
Mbarara	8	8
TOTAL	**6,878**	**7,017**

3.5.7 Environmental flow demand

Environmental flow water demand refers to the amount of water required to maintain the ecological health of a watercourse. The environmental flows have been taken as 10% of the average baseline monthly flow within the Mpanga Catchment. The computed values will thereafter be allocated to environmental flow water demand.

3.5.8 Total water demand

The aggregated daily demand was obtained as a summation of the water demand for the different service levels. As can be observed from the table below, the hydro power sector requires the highest amount of water per day for continued operation during the current year 2023, and fisheries will require the highest quantity during the future year, owing to the large expansion growth rate of 33.56% for aquaculture production in Uganda, according to the FAO report of 2020.The future daily demand was obtained by projecting the current daily demand to the year 2063 (a period of 40 years).The annual water demand for each service level is computed by multiplying the daily demand by 365 days for domestic, livestock, livestock and irrigation.

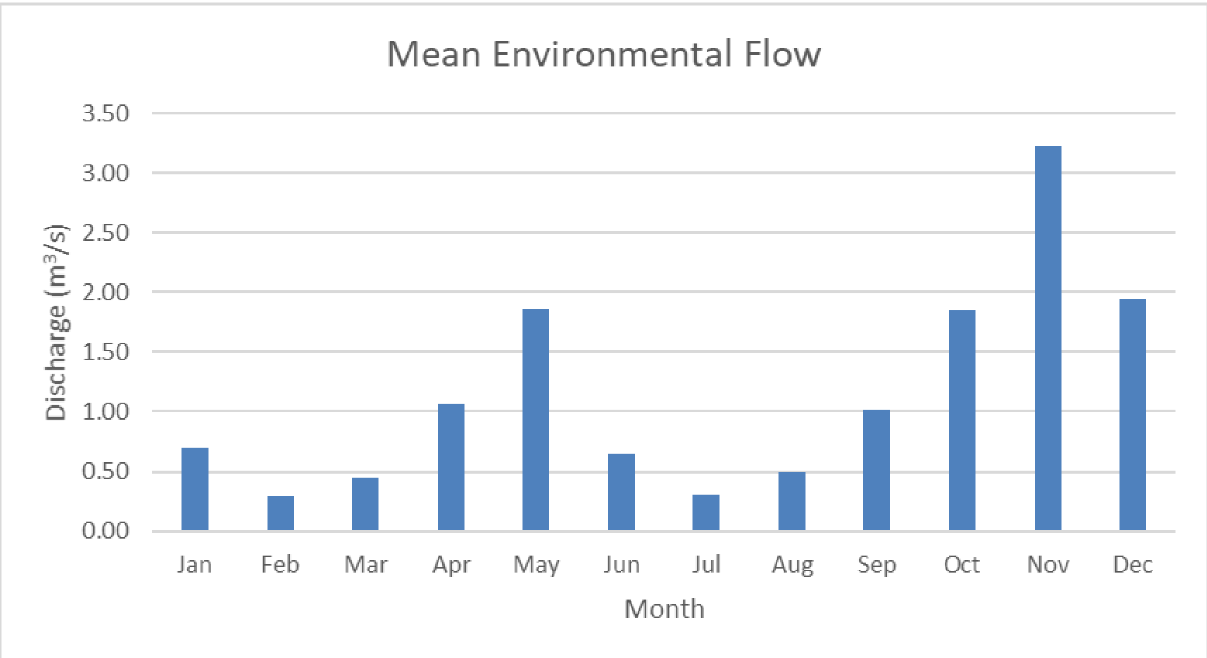
However, since the Hydropower plant is non-consumptive, the annual demand obtained equals the daily water demand. Similarly, for fisheries, the assumption is that the fish ponds are stocked twice in a year, and that there is no leakage of water in the ponds. Consequently, the annual water demand was obtained by multiplying the daily water demand by two stocking regimes. The annual water demand for the different service levels is as summarized below;

TOTAL DEMAND	2023		2063	
Category	**(m^3/day)**	**(m^3/year)**	**(m^3/day)**	**(m^3/year)**
Domestic	28,881	10,541,565	92,926	33,917,990
Livestock	19,748	7,208,020	54,667	19,953,455
Fisheries	510,993	1,021,986	54,384,060,712	108,768,121,424
Industrial demand	1,137	415,005	30,142	11,001,830
Hydropower	1,382,400	1,382,400	1,382,400	1,382,400
Irrigation	6,878	2,510,470	7,017	2,561,205
E-Flow	–		–	–

E-Flow was generated from the modelling stage using the MIKE HYDRO tool as detailed in the next chapter. The environmental flows were taken as 10% of the average baseline monthly flow within the catchment. The average flows in the catchment from 1999 to the year 2006 were considered as shown below;

Month	Environmental Flow	
	(m3/s)	(m3/day)
Jan	0.69	59,742.14
Feb	0.29	24,863.60
Mar	0.45	38,998.17
Apr	1.07	92,444.50
May	1.86	160,863.46
Jun	0.64	55,708.66
Jul	0.30	26,208.15
Aug	0.50	43,182.20
Sep	1.02	88,207.41
Oct	1.85	159,515.50
Nov	3.23	278,850.90
Dec	1.94	167,803.61

This can be depicted in the graph below;



Consequently, the total demand in the catchment was computed for the period 2023 and 2063 as shown on the table below;

2023	Domestic	Livestock	Fisheries	Industrial	Hydropower	Irrigation	E-Flow	TOTAL
Jan	28,881	19,748	510,993	1,137	1,382,400	6,878	59,742	**2,009,779**
Feb	28,881	19,748	510,993	1,137	1,382,400	6,878	24,864	**1,974,901**
Mar	28,881	19,748	510,993	1,137	1,382,400	6,878	38,998	**1,989,035**
Apr	28,881	19,748	510,993	1,137	1,382,400	6,878	92,445	**2,042,482**
May	28,881	19,748	510,993	1,137	1,382,400	6,878	160,863	**2,110,900**
Jun	28,881	19,748	510,993	1,137	1,382,400	6,878	55,709	**2,005,746**
Jul	28,881	19,748	510,993	1,137	1,382,400	6,878	26,208	**1,976,245**
Aug	28,881	19,748	510,993	1,137	1,382,400	6,878	43,182	**1,993,219**
Sep	28,881	19,748	510,993	1,137	1,382,400	6,878	88,207	**2,038,244**
Oct	28,881	19,748	510,993	1,137	1,382,400	6,878	159,516	**2,109,553**
Nov	28,881	19,748	510,993	1,137	1,382,400	6,878	278,851	**2,228,888**
Dec	28,881	19,748	510,993	1,137	1,382,400	6,878	167,804	**2,117,841**

A table showing the daily water demand for the year 2023

2063	Domestic	Livestock	Fisheries	Industrial	Hydropower	Irrigation	E-Flow	TOTAL
Jan	92,926	54,667	54,384,060,712	30,142	1,382,400	7,017	59,742	**54,385,687,606**
Feb	92,926	54,667	54,384,060,712	30,142	1,382,400	7,017	24,864	**54,385,652,728**
Mar	92,926	54,667	54,384,060,712	30,142	1,382,400	7,017	38,998	**54,385,666,862**
Apr	92,926	54,667	54,384,060,712	30,142	1,382,400	7,017	92,445	**54,385,720,309**
May	92,926	54,667	54,384,060,712	30,142	1,382,400	7,017	160,863	**54,385,788,727**
Jun	92,926	54,667	54,384,060,712	30,142	1,382,400	7,017	55,709	**54,385,683,573**
Jul	92,926	54,667	54,384,060,712	30,142	1,382,400	7,017	26,208	**54,385,654,072**
Aug	92,926	54,667	54,384,060,712	30,142	1,382,400	7,017	43,182	**54,385,671,046**
Sep	92,926	54,667	54,384,060,712	30,142	1,382,400	7,017	88,207	**54,385,716,071**
Oct	92,926	54,667	54,384,060,712	30,142	1,382,400	7,017	159,516	**54,385,787,380**
Nov	92,926	54,667	54,384,060,712	30,142	1,382,400	7,017	278,851	**54,385,906,715**
Dec	92,926	54,667	54,384,060,712	30,142	1,382,400	7,017	167,804	**54,385,795,668**

A table showing the daily water demand for the year 2063

Sub conclusion two

Based on the study conducted, the objective has been accomplished to a fair extent. In this study, the water demand for different service levels has been computed at catchment level using design manuals and district databases. The UBOS database was central to data concerning population characteristics in each district, up to sub-county level. The water demand computations informed the water allocation, using the MIKE BASIN MODEL.

This study is especially vital for the Mpanga catchment, which is under massive pressure, especially due to high rates of population growth, which have fuelled catchment degradation. The study indicates the extent to which the respective service levels abstract/ utilize water from the catchment, and thus serves as a building block to effective planning and sustainable usage of the available water resources. Particular attention should be accorded to the fisheries sector since it is observed to grow at an exponential rate, and whose future demand will require strategic planning and management of the catchment.

In conclusion, the computation and analysis of water demand in the Mpanga catchment is very critical in ensuring that the water resources in the Mpanga catchment are sustainably managed. Attention should be drawn to optimum and innovative use of the water resources If not, the water resources in this catchment may not be sufficient for future generations.

CHAPTER FOUR: EVALUATION OF WATER DEMAND MANAGEMENT OPTIONS AND ALLOCATION UNDER DIFFERENT SCENARIOS IN A SUSTAINABLE MANNER

4.1 Introduction

This chapter primarily presents the spatial-temporal assessment of the availability of surface water in the Mpanga Catchment for both current and projected demands.

Having quantified water demand for both the current and projected scenarios, water allocation based on available water could be assessed according to the allocation principle that domestic water is given priority. In the context of catchment management planning guidelines for Uganda, water balance is the difference between the available water and demand. The available water was determined using the MikeHydro Basin model. Upon successful run of the simulation, the results obtained were analysed to determine the average monthly-unallocated water.

4.2 General objective

The primary objective of the study was to evaluate water demand management options and allocation under different scenarios in a sustainable manner.

4.2.1 Specific objectives

The specific objectives of the water resources assessment are as follows:

a) To assess water availability
b) To assess water demand
c) To build a MikeHydro Basin model showing the exisiting scenario
d) To calibrate and validate the model
e) To evaluate water demand management measures.

4.3 Literature review three

4.3.1 Water Resources Availability

Water availability is influenced by factors such as climate patterns, land use changes and human activities. All these factors were taken into consideration during the research.

Surface water availability in a given catchment can easily be assessed using river flow data. The flow data that was obtained was characterized by gaps of missing data for long periods. Therefore, rainfall runoff modelling was adopted as a more accurate method of estimating stream flow by simulating rainfall runoff from the catchment. A NAM rainfall runoff model developed in MIKE HYDRO Basin was used to model runoff from the sub-catchments in the Mpanga Catchment.

4.3.2 Integration of Mike Hydro in water resources studies

MIKE Hydro Basin requires long-term naturalised streamflow sequences at key locations within the larger water resource system for yield and water balance analyses. This is necessary for specific catchment development scenarios. For this rainfall-runoff component of the modelling, the NAM model was used. NAM is a physically based rainfall-runoff model in the MIKE Hydro Basin suite. NAM is used to simulate the runoff response of individual sub-catchments and then to route the runoff through an interlinked system of sub-catchments, river reaches, reservoirs and wetlands.

The model the physically-based parameters of the NAM model were calibrated against recorded historical stream flows and then utilising the calibrated parameters in conjunction with long-term monthly rainfall records, the required long-term naturalised streamflow sequences were generated at key locations within the larger water resource system.

4.3.3 Water Resources Allocation Strategies

Unallocated water (also known as water balance) is the difference between the available water and demand. In this study, the demand was determined as shown in the previous section. The demand was classified as domestic, industrial, institutional, irrigation, etc.

The surface water available within the catchment was also determined using historical streamflow data. The demand allocation was undertaken using the Mike Hydro model with domestic demand taking first priority, water for agriculture was given second priority with environmental flow taken as 10% of the average stream flow.

The primary objective during the water allocation process is to ensure the provision of enough water in terms of quantity and quality of water for domestic needs. Subsequently, the water allocation for other purposes such as irrigation, livestock, and industrial use and so on considers the economic, social, and environmental importance of water. This approach aligns with the principles stated in the Uganda National Water Policy of 1999, which emphasizes a comprehensive evaluation of water allocation based on its multiple values.

According to the MoWLE (1999) guidelines, water allocation in Uganda is prioritised as shown below.

a) Domestic Water Demand
b) Irrigation and Livestock Water Demand
c) Environmental Flow Demand
d) Industrial and Commercial Water Demand
e) Institutional Water Demand
f) Fisheries Water Demand
g) Hydropower Water Demand

Having assessed the availability of surface water in the Mpanga Catchment, a comparison was undertaken between the overall available water resources and the combined water demands that the water resources can support across all sectors. The goal of the water balance is to enable water resource planners and managers to make informed decisions on water allocation, conservation practices, and water resources development projects e.g., inter-catchment transfers or storage in dams to improve water security and assurance of supply.

4.4 Methods and materials three

4.4.1 Data source

Reliable hydro-meteorological data is an essential component of surface water assessments. In this study, river flow data were collected from the Directorate of Water Resources Management (DWRM) and the Uganda National Meteorological Authority (UNMA). These two institutions remain the primary sources of hydro-meteorological data in the country. Rainfall data was sourced for the stations in or near the study area indicated in Fig 4. 1.

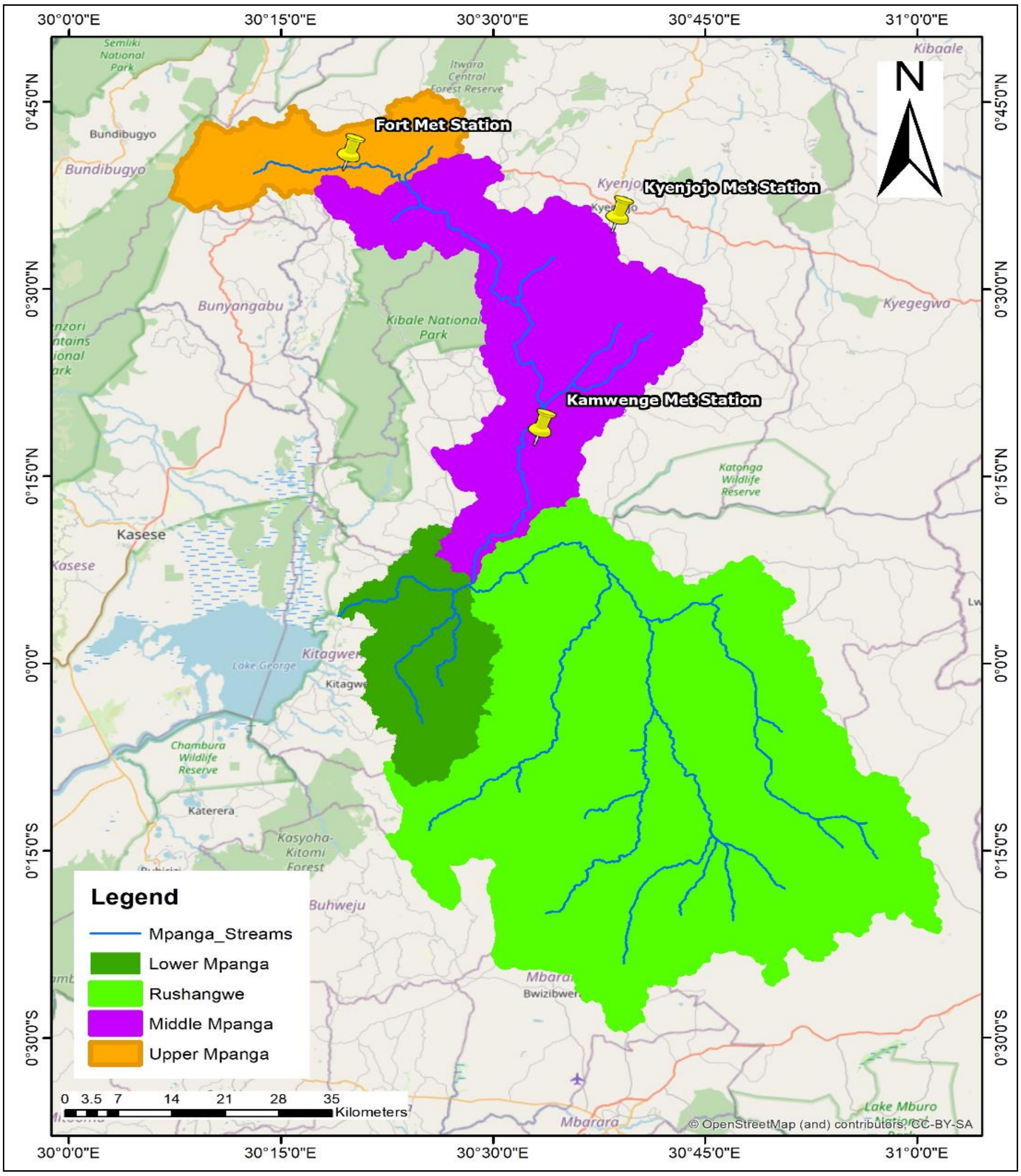


Fig 4. 1: Rainfall stations in or near the Catchment

4.4.2 Research design

The study used the available hydrological data to determine the availability of water resources within the Mpanga catchment. Demand allocation would then be undertaken in order to determine the quantity of unallocated water within the Mpanga catchment for the present and future scenarios.

4.4.3 Research approach

The primary objective of surface water resources assessment and allocation was to determine the availability of surface water in the Mpanga Catchment by considering various hydrological processes such as, precipitation, evaporation, rainfall runoff. This would be followed by the allocation of demand and then the estimation of the unallocated water within the catchment. The hydrological processes influence the amount of surface water discharge in the Mpanga River. The study aimed to integrate all the hydrological processes and assess the quantity of surface water available as well as the unallocated water in the Mpanga Catchment for the present and future scenario.

4.5 Findings and discussion

4.5.1 Water availability

Surface water availability in a given catchment can easily be assessed using river flow data. The flow data that was obtained was characterized by gaps of missing data for long periods. Therefore, rainfall runoff modelling was adopted as a more accurate method of estimating stream flow by simulating rainfall runoff from the catchment. A NAM rainfall runoff model developed in Mike Hydro Basin was used to model runoff from the sub-catchments in the Mpanga Catchment.

4.5.2 Rainfall

The Fort Portal and Kyenjojo Met Stations had sound data and this was considered for the rainfall pre-processing. We used the Kyenjojo data for gap filling the missing values from Fort Portal

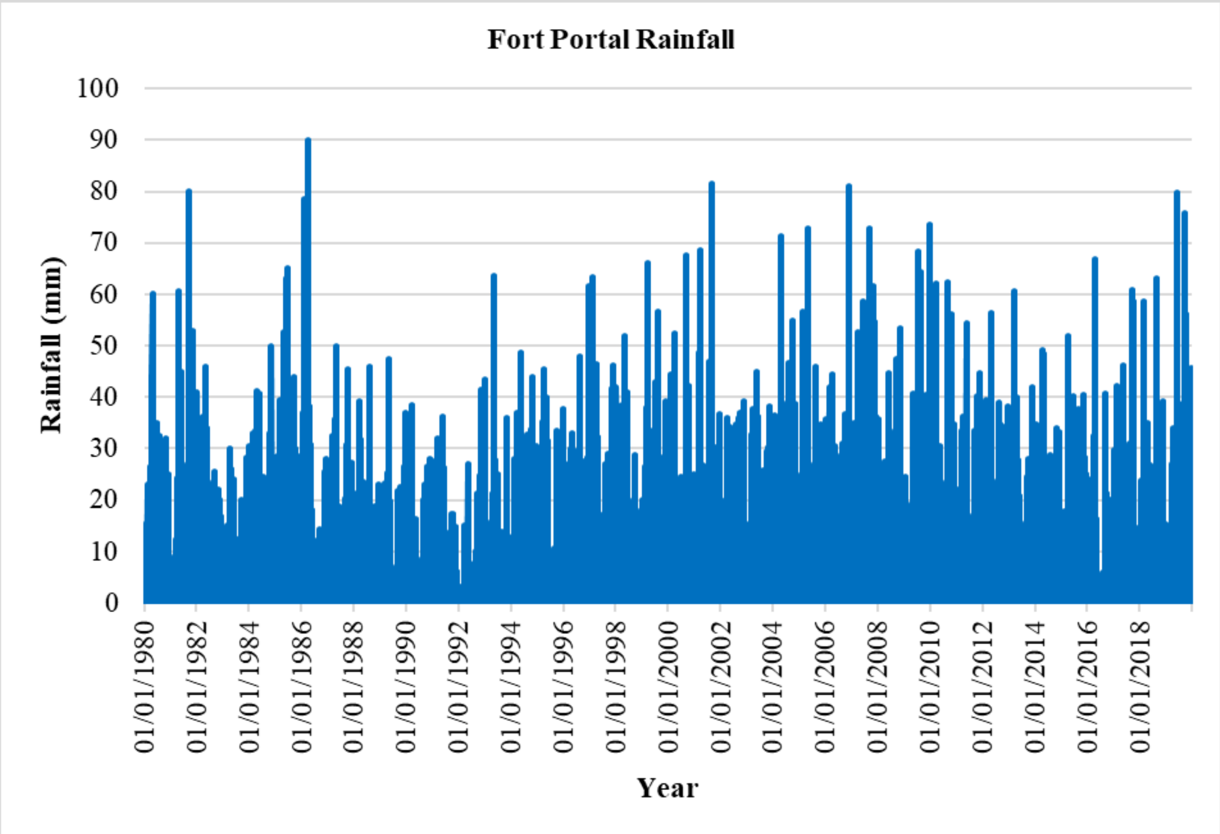


Fig 4. 2: Time series for the Fort Portal rainfall data

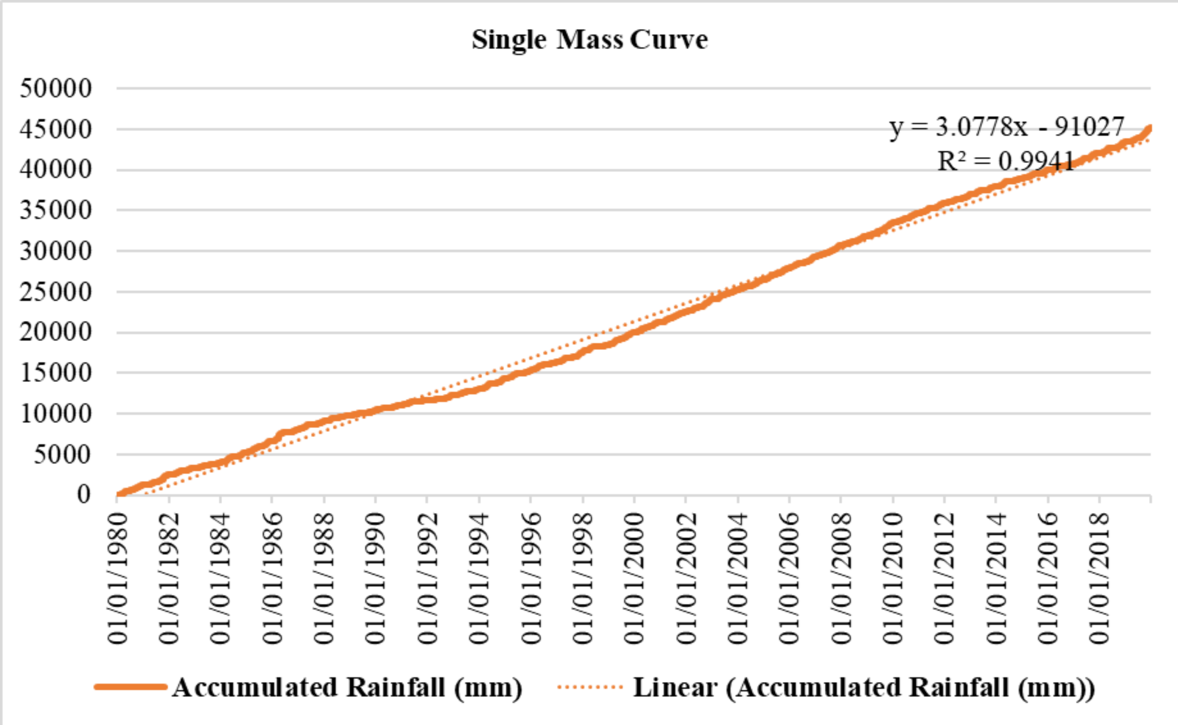


Fig 4. 3: Single-Mass check on stationarity of Fort Portal annual rainfall values

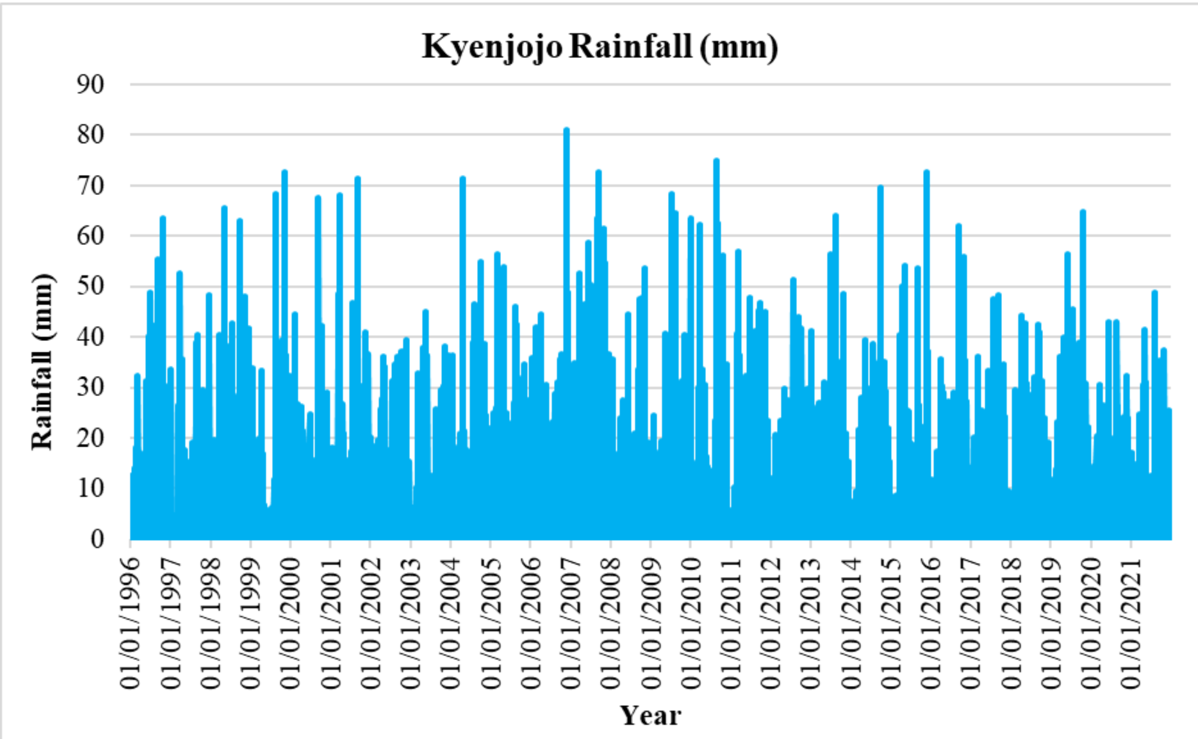


Fig 4. 4: Rainfall Time Series for the Kyenjojo Rainfall Data

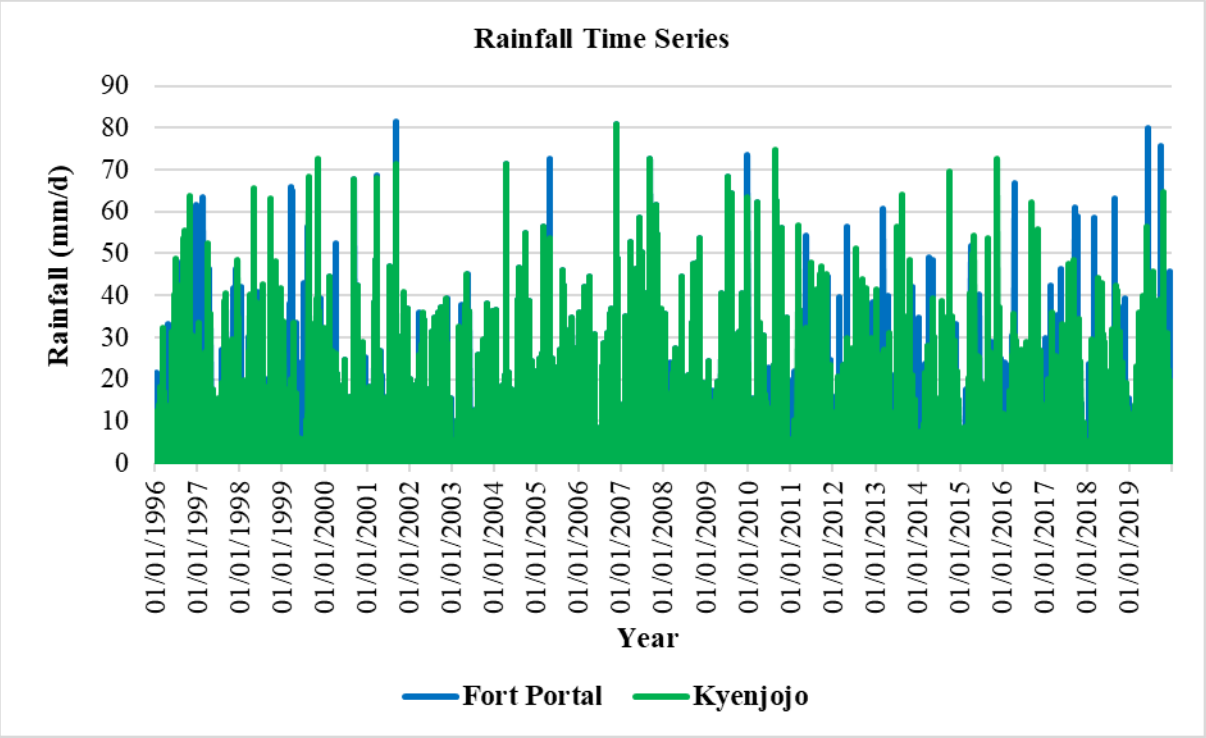


Fig 4. 5: Comparison of rainfall time series for Fort Portal and Kyenjojo

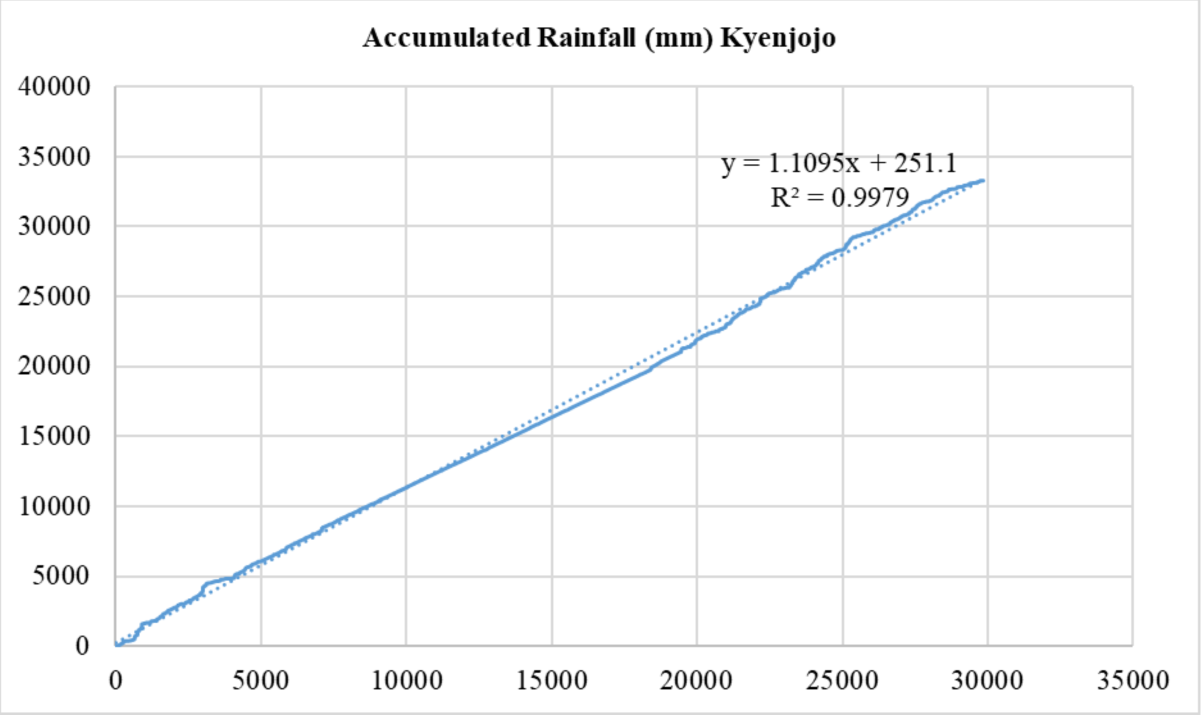


Fig 4. 6: Double-Mass check on stationarity of Kyenjojo annual rainfall values against Fort Portal

4.5.3 Evapotranspiration (ET)

Evapotranspiration data was computed using the FAO Penman Monteith Equation tool. Temperature values for the considered rainfall stations were determined from the NASA Data Access Viewer tool.

The NWRA of 2013 divided the country into ET zones indicated in the figure below. From the figure, it indicates that the Mpanga catchment has an approximate annual ET ranging between 1302 – 1392 mm/a

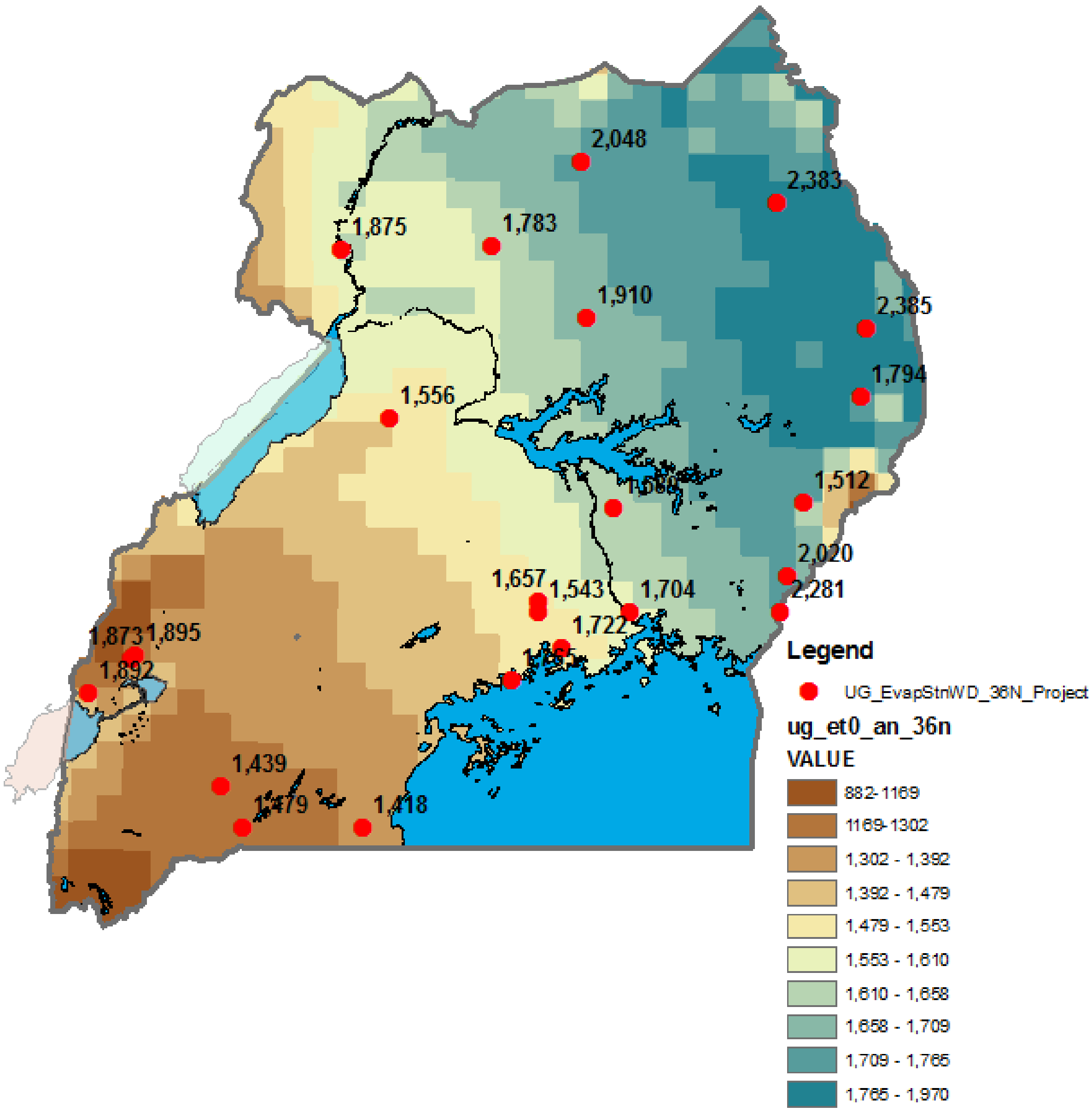


Fig 4. 7: ET Zones in Uganda (MWE, 2013)

4.5.4 Streamflow

4.5.4.1 Streamflow Data Availability

There are two operational gauging stations along the river Mpanga. The first gauging station 84215_Mpanga River spans the period 1954 to 2023, while the second station 84212_Mpanga River also spans the period 1954 to 2023. Both stations have missing values and repeated zero values; for the purpose of this study, a period with reliable data was considered for calibration and validation. The period between 1999 and 2006 was chosen for the analysis.

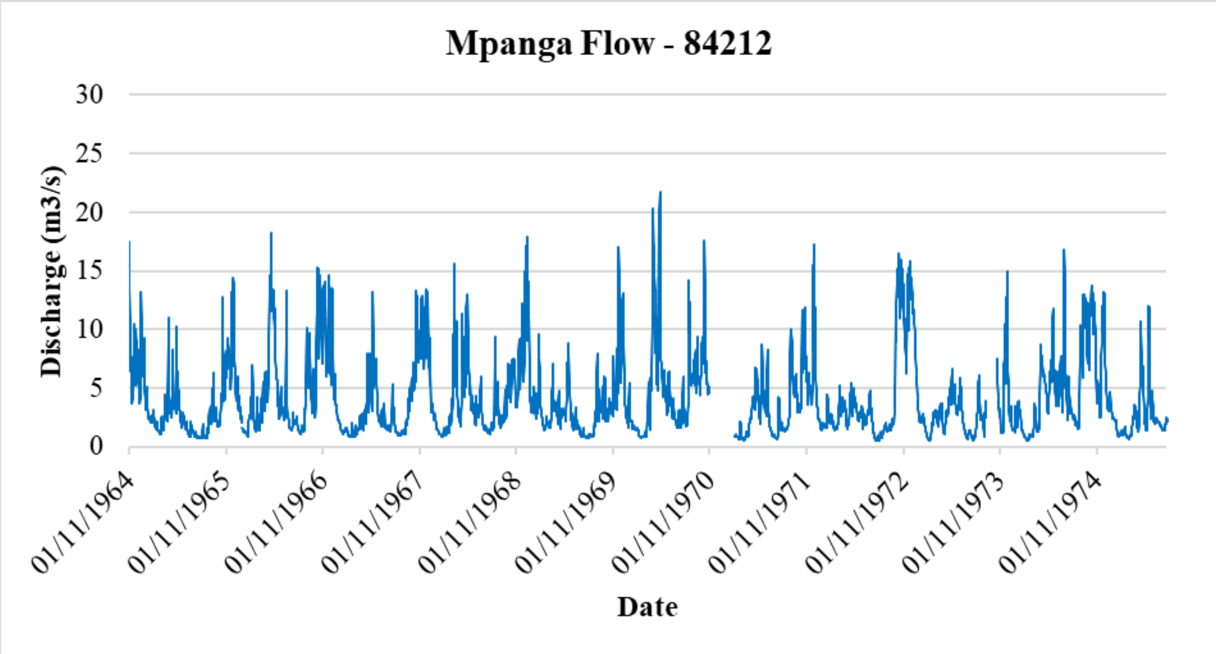


Fig 4. 8: Flow hydrograph for the Mpanga River at the 84212 gauging station

4.5.5 Rainfall-Runoff Modelling

A River Basin Model for the Mpanga river catchment was developed and calibrated against streamflow records for the period 1999-2006. The Mike Hydro framework was used to develop a rainfall-runoff model known as NAM, for all the sub-catchments in Mpanga Catchment. NAM is a lumped, conceptual rainfall-runoff model that simulates the overland flow, interflow, and base flow components of streamflow (DHI, 2023).

Comprehensive data processing and data quality checking of all available discharge records was done in preparation of running the Basin Model.

The figure below presents a comparison of this study's simulated discharge with the observed discharge from the Mpanga gauging stations for the period between 1999 to 2003. The coefficient of determination for the model calibrated at a daily time step is 0.191, which is not a good fit, but the FDCs indicate a sound fit of simulated daily discharges below about 4 m^3/s.

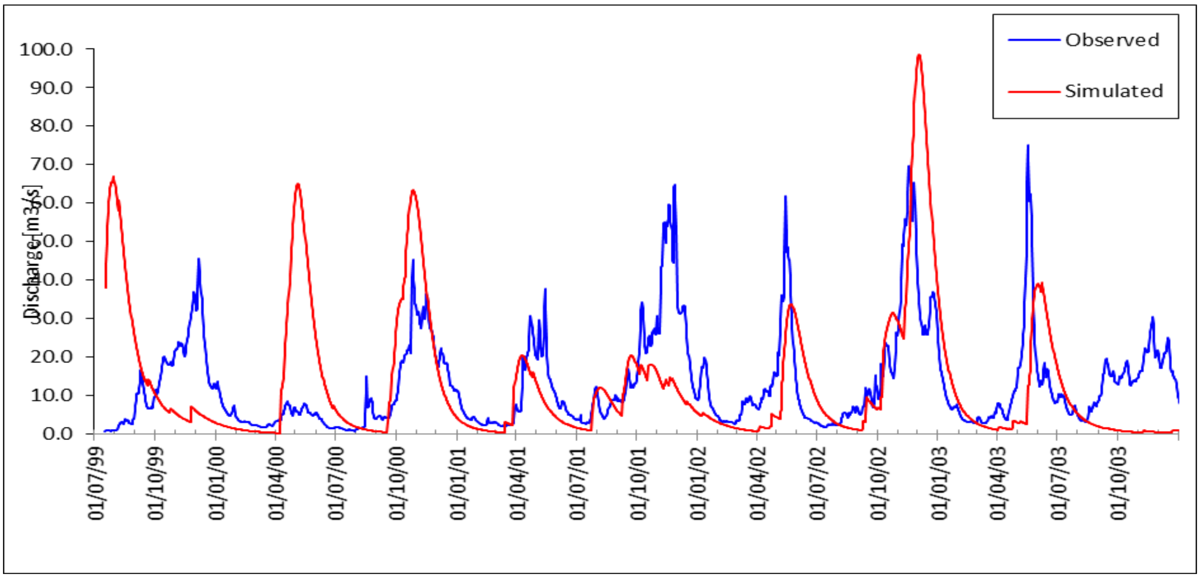


Fig 4. 9: Simulated daily discharge vs modelled daily discharge

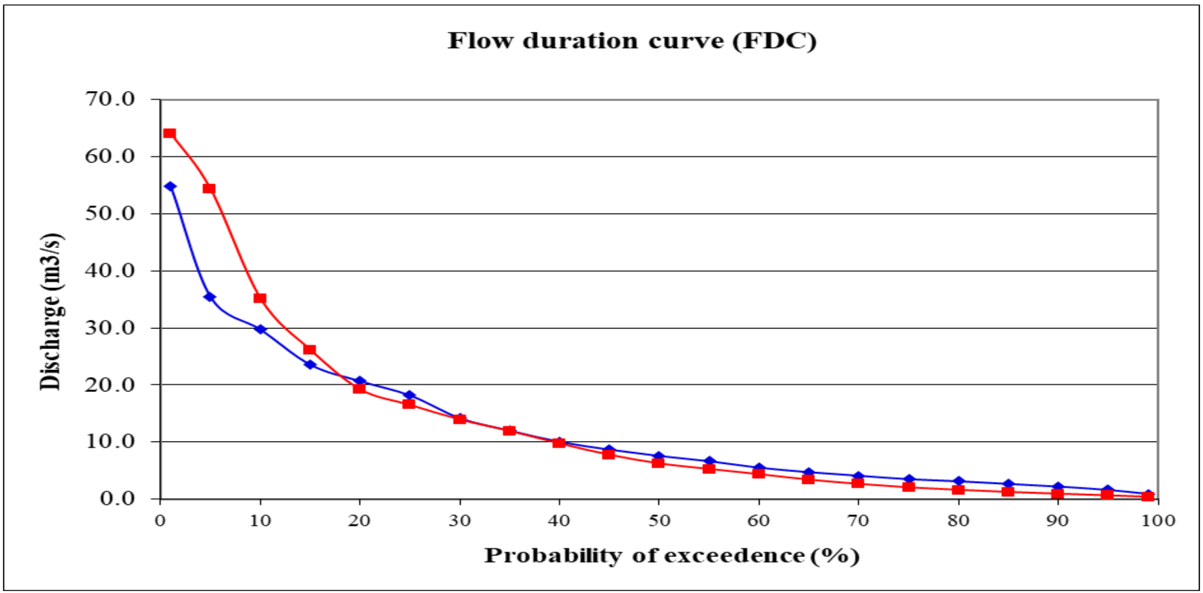


Fig 4. 10: Flow Duration Curves: Modelled discharge versus simulated discharge

The calibrated Mpanga Catchment rainfall-runoff model was then used in the process of the demand allocation.

4.5.6 Water demand

In the Mpanga River Basin, the total population was 1,810,618 million in 2023 (derived from the UBOS projections of the 2014 NPHC). In 2023, a total water demand was estimated at 28,881m^3/day. The main water user is fisheries, which accounts for 71% of the total water storage in the catchment and of which greater Kyenjojo demands the biggest percentage (34%). Domestic, livestock and irrigation demand was at 28881m^3/day (8%), 57,000m^3/day (14%) and 16,334m^3/day (5.6%) respectively. In order to mitigate conflicts between water supply and demand, in the near future, a number of measures should be taken including: water saving measures, allocation efficiency improvement. Both the recovery of the natural system in the upper Rushango sub catchment and a reasonable allocation for the water users in the Mpanga catchment are key aspects of water resources management.

4.5.7 Current Water Allocation and Balance

Water allocation for the current scenario considered the natural water availability and current water demand (including the mandatory Environmental Flow). The water balance was then computed as the difference between the availability and demand. This computation was done using the MikeHydro software. Generally, less water is available in the months of January, February, and March April for the upstream and intermediate sub-catchments as can be seen in Fig 4. 111 to Fig 4. 144.

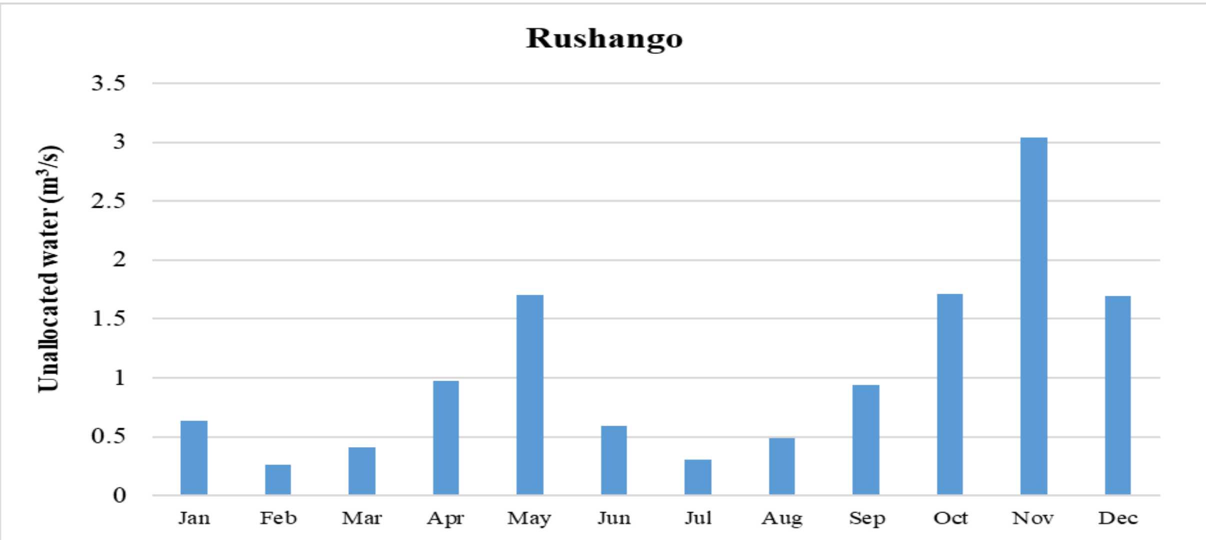


Fig 4. 11: Current water availability for the Rushango sub-catchment

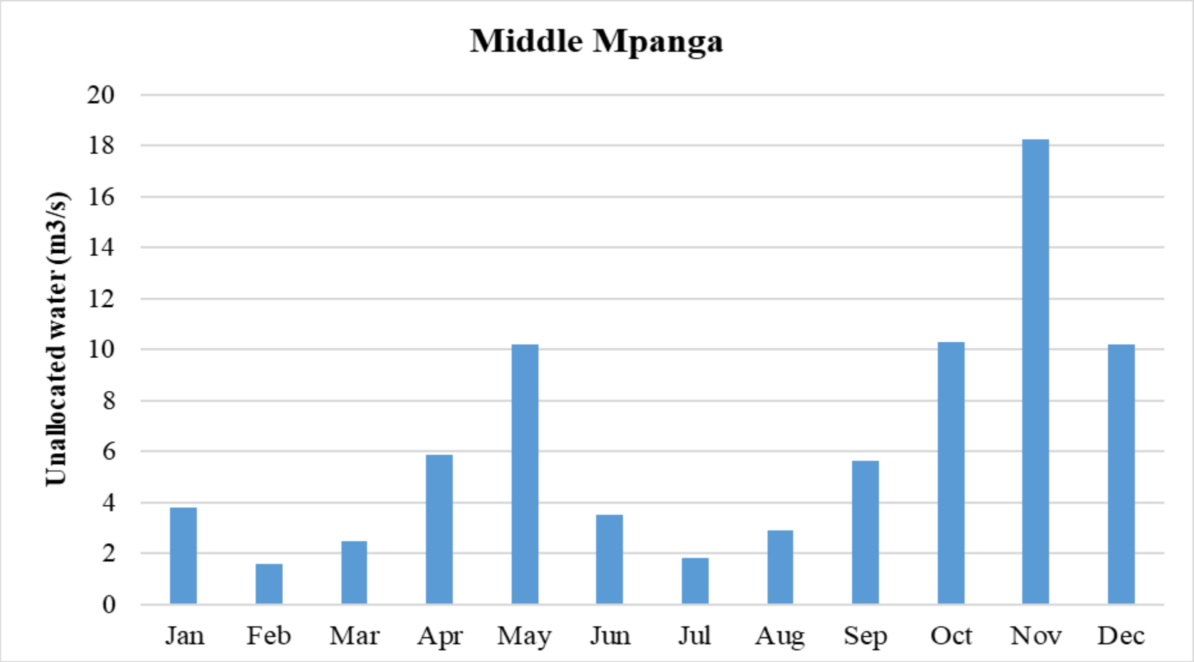


Fig 4. 12: Unallocated water for the Middle Mpanga sub-catchment at the current scenario

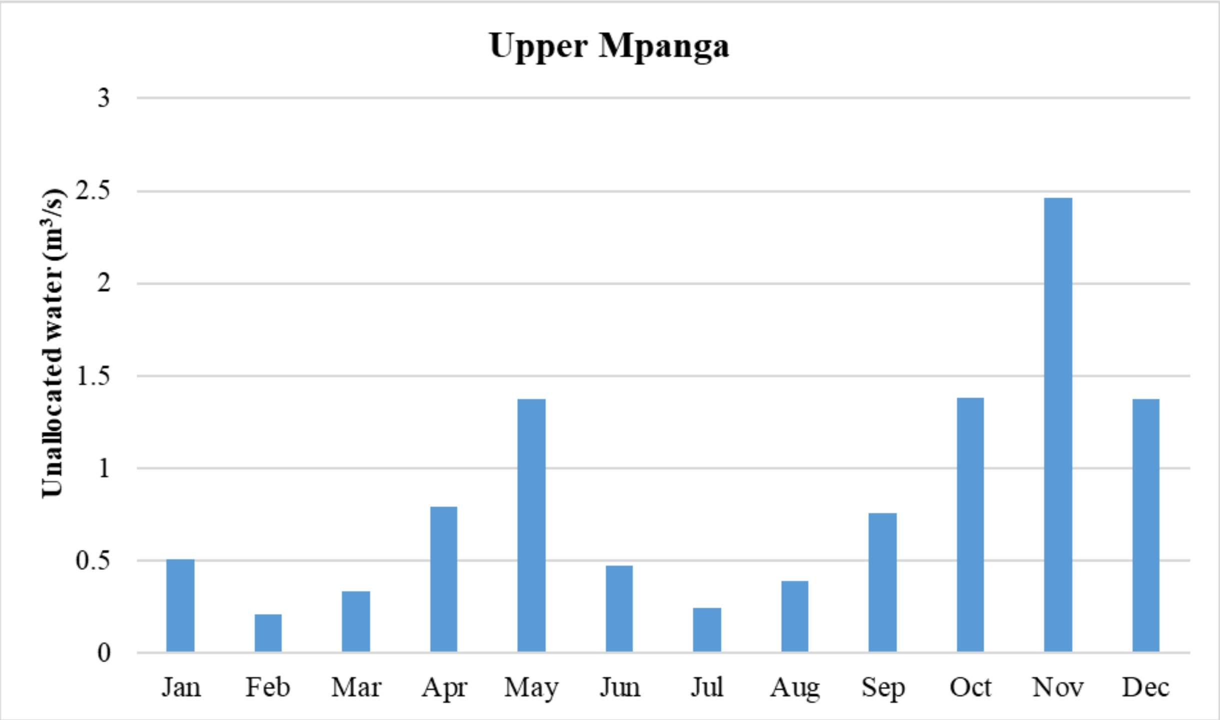


Fig 4. 13: Current water availability for Upper Mpanga sub-catchment

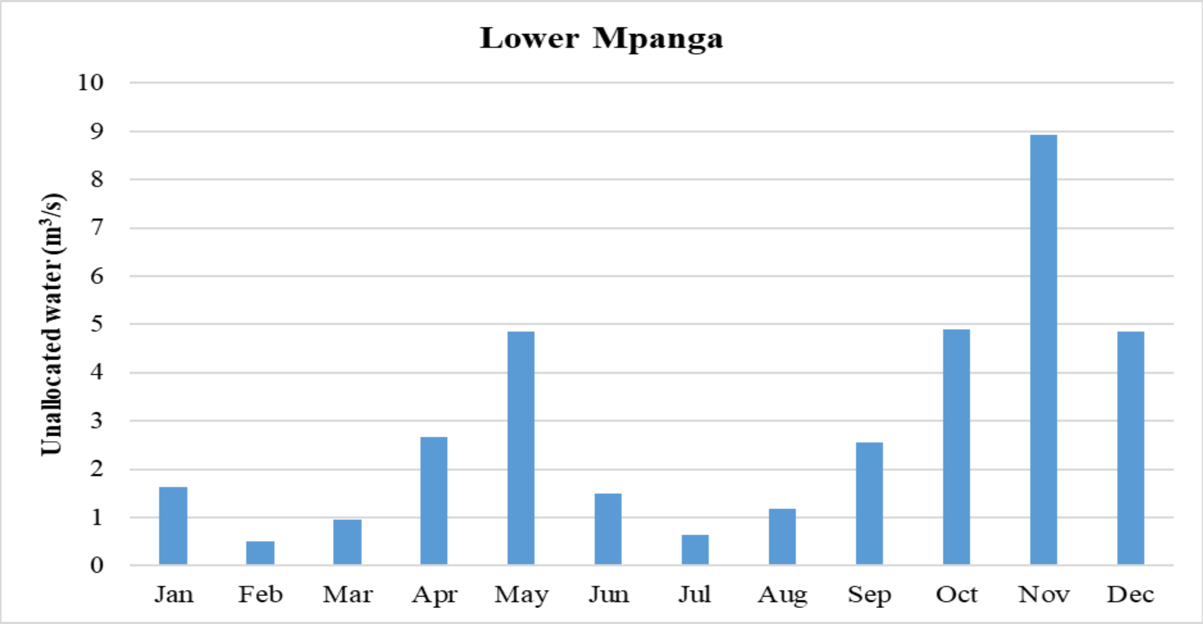


Fig 4. 14: Current water availability for the Lower Mpanga sub-catchment

Table 4. 1 showed the extracted monthly values for the unallocated water in cumecs for each sub-catchment.

Table 4. 1: Current average monthly-unallocated water for each sub-catchment

Sub-catchment	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rushangwe	5.17	1.53	2.99	8.60	15.78	4.75	2.01	3.74	8.19	15.90	29.10	15.76
Middle Mpanga	3.79	1.58	2.47	5.87	10.21	3.54	1.83	2.93	5.62	10.28	18.26	10.20
Upper Mpanga	0.51	0.21	0.33	0.79	1.38	0.48	0.25	0.39	0.76	1.39	2.46	1.37
Lower Mpanga	1.79	0.67	1.12	2.84	5.03	1.66	0.80	1.35	2.71	5.06	9.09	5.02

4.5.8 Projected Water Allocation and Balance

Water allocation for the 2063 scenario considered the current natural water availability and the 2063 projected water demand (including the mandatory Environmental Flow). The water balance was then computed as the difference between the availability and demand. This computation was done using MikeHydro software.

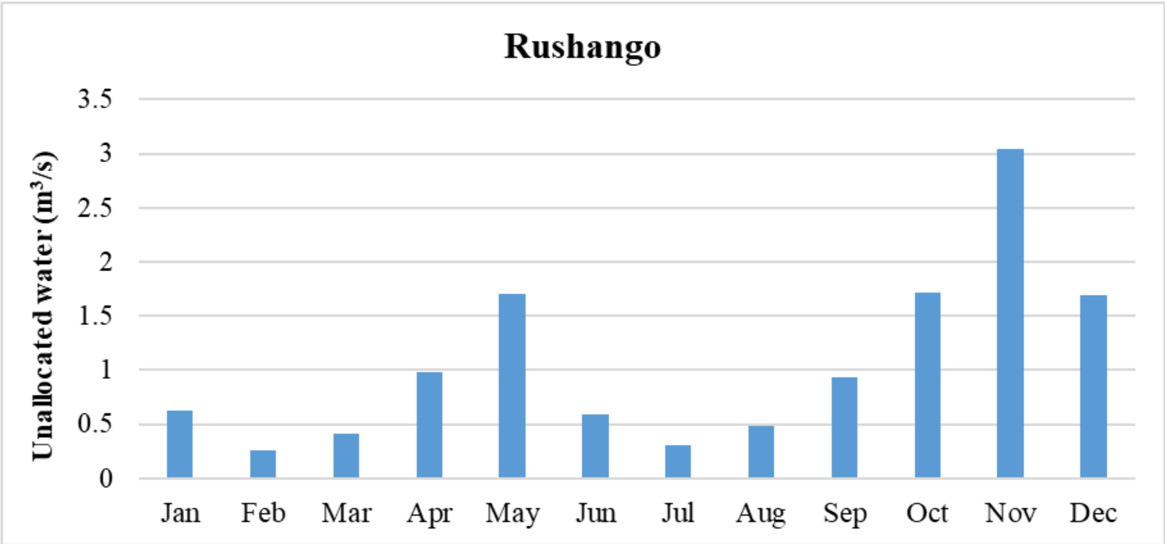


Fig 4. 15: Projected unallocated water for the Rushango sub-catchment

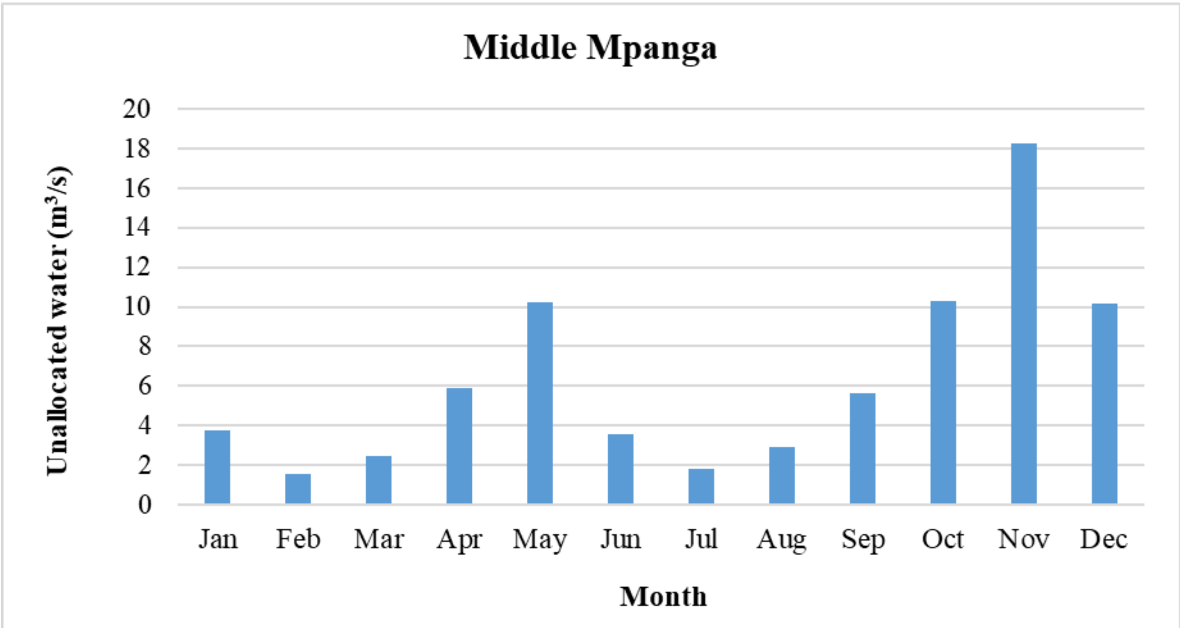


Fig 4. 16: Projected unallocated water for the Middle Mpanga sub-catchment

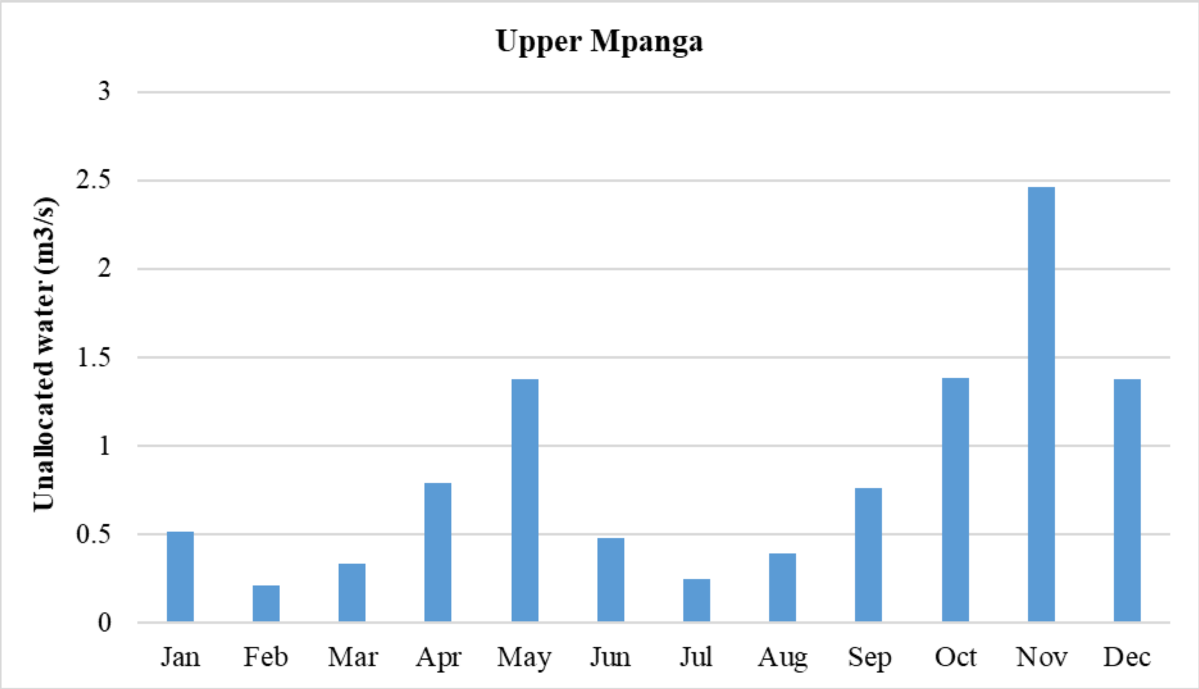


Fig 4. 17: Projected unallocated water for the Upper Mpanga sub-catchment

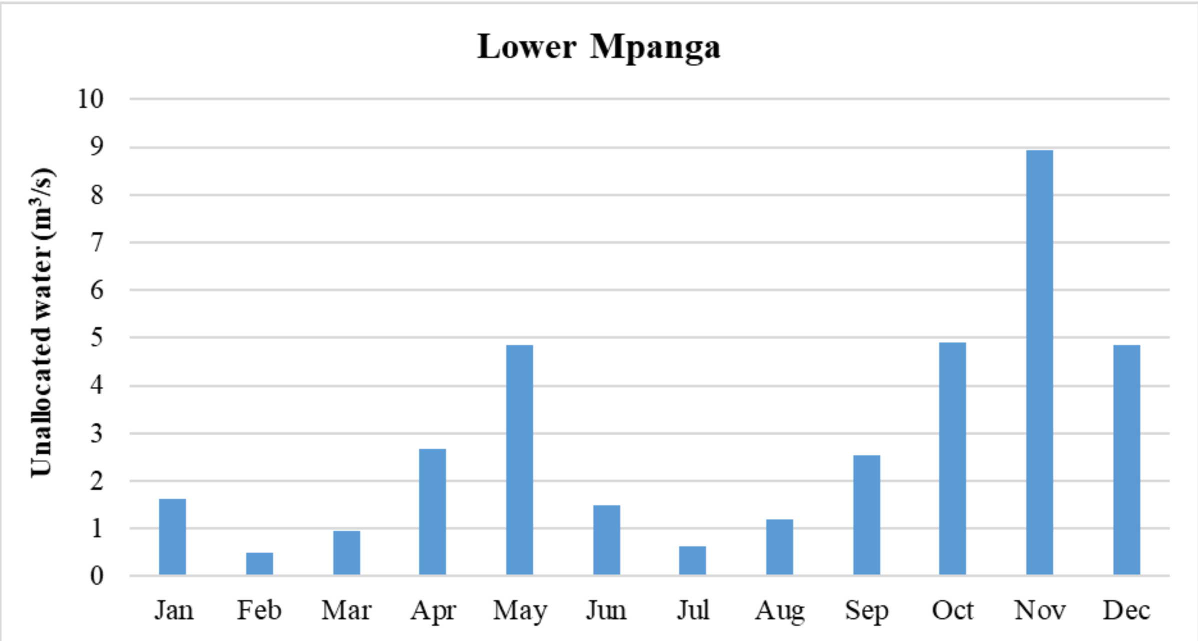


Fig 4. 18: Projected unallocated water for the Lower Mpanga sub-catchment

Table 4. 2 shows the extracted monthly values for the unallocated water for each sub-catchment

Table 4. 2: Average monthly-unallocated water for each sub catchment (m^3/s)

Subcatchment	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rushangwe	0.63	0.26	0.41	0.98	1.70	0.59	0.30	0.49	0.94	1.71	3.04	1.70
Middle Mpanga	3.79	1.58	2.47	5.87	10.21	3.54	1.83	2.93	5.62	10.28	18.26	10.20
Upper Mpanga	0.51	0.21	0.33	0.79	1.38	0.48	0.25	0.39	0.76	1.39	2.46	1.37
Lower Mpanga	1.62	0.51	0.95	2.67	4.86	1.49	0.64	1.18	2.54	4.90	8.93	4.85

4.5.9 Demand management measures

Water demand management looks at the real demand for water, which can be assessed through the willingness of users to pay for the water, in money or in kind (Savenije, 2001). In this study, we reviewed the current water allocation system, which give the impression that the existing water permit does not encourage efficient use of water. The fisheries activities as the biggest water user should be regulated to control demand in regards to storage. To implement demand management measures in Mpanga, both technical non-technical demand management measures such as institutional reform and water pricing adjustment to ensure sustainable operation of the water management system. Besides, a water allocation, decision support system will be used to experiment with the management measures at the Catchment Management Organization (CMO) levels to facilitate the decision making process.

4.5.9.1 Technical measures

Water saving: The irrigation system in the Mpanga catchment should be improved, especially in the upper sub catchment. Majority of farmers have adopted traditional irrigation method, such as flood and furrow methods, these methods have low costs of adoption, but are relatively inefficient with water use. A few farmers have adopted high-tech irrigation methods.

4.5.9.2 Non-technical measures

Non-technical measures are composed of institutional measures and water-pricing measures, besides that, the virtual water trade is a good instrument for water manager to solve water shortage problem.

4.5.9.2.1 Institutional measures

Institutional measures involve an appropriate legal framework and the establishment of implementing originations. Water allocation and permitting can be de-centralized within the CMOs following appropriate institutional reforms.

4.5.9.2.2 Legal framework

The Water Law is the basic law in the water sector, which regulates various water issues. In addition, specific laws, regulations and policies have been formulated addressing the actual need. At present, water laws passed and implemented include the Water Act, 1995, Water Resources Regulation, 1998, the Water (Waste discharge regulation), 1998. The Water Act, 1995 is under review and a number of reforms have been proposed which will include aspects of fees, establishment of CMOs aimed at addressing a new system on water allocation and emphasizing management of water resources in the catchment areas under their jurisdiction. As the basic law in water resources management, the Water Act, 1995 states that all rights to investigate, control, protect and manage water in Uganda for any use is vested in the Government and shall be exercised by the Minister and the director in accordance with this Part of the Act.

4.5.9.2.3 Water institutions

At present, a large number of national and local government institutions have responsibility for studying, monitoring, protecting and developing the water resources. Also, a numbers of governmental and non-governmental organizations have direct and indirect interests in the aspects of water resources development and conservation. The institutional framework has three levels: the decision-making level, the executive level and the users' level. In the decision-making level, the Ministries take place. Governmental organizations under the Ministries are at the executive level. Governmental and non-governmental organizations are at the water users' level for the implementation, operation and maintenance of the projects.

4.5.9.2.4 Governmental organization

Complicated management structure exists between the national, intermediate and local levels. Sometimes this has caused conflicts between management activities, such as different policies from different departments. At the intermediate level, the Directorate of Water Resources Management (DWRM), which was established under Ministry of Water and Environment (MWE), is the main Directorate responsible for management of water resources in the Mpanga catchment. This is being implemented through its deconcentrated structure under Albert Water Management Zone (AWMZ), for all purposes and responsible for implementation of catchment based integrated water resources management strategy of

MWE. However, the Mpanga catchment covers nine districts, with various differences, economically and water use practice. Water conflicts are very serious, benefit re-sharing is very complicated, and some problems of catchment management are very difficult to solve. Consequently, to intensify the catchment management, it is necessary to ensure that DWRM has the authority and capacity to co-ordinate water use effectively. A coordination mechanism should also be developed for delineating the duties and responsibilities of all parties concerned. To improve and strengthen the mediating ability of the CMO is an important task in the future.

4.5.9.2.5 Non-governmental organization

In this area, under supervision of the DWRM, which is in charge of water allocation from the water sources, Water User Associations (WUAs) needs to be formed for the fisheries groups. A storage agreement covering operation and maintenance (O&M) activities including permitting for those eligible is signed between AWMZ and WUAs. Any farmer in this specific fisheries area can be a member of the WUA after applying. The WUAs are responsible for the operation and maintenance of the storage facilities. However, water user participation is relatively new in the Mpanga catchment. Furthermore, an important issue is how to organize all farmers through a participatory process into WUAs.

4.5.9.2.6 Water pricing/fees

Apart from technological means, economical means are very important for the implementation of WDM. Appropriate pricing of water (i.e., implementing an increasing block rate pricing structure) has proven to be a very effective measure in changing the public behaviour towards water conservation and promoting economic efficiency and investment in new installations (Hanemann, 2001). An integrate part of a water pricing strategy is fee collection and the use of the economic incentives, such as subsidies.

Pricing/fees mechanism: The current annual fees for water abstraction is generally low and cannot support conservation and protection of the water sources. Since 1998, the regulation that stipulate the different fees has not changed despite continuous reduction in flows and increased water demand from different uses. Water prices/fees should be raised systematically until at least the cost of conservation and protection of water sources are recovered. However, due to low income of some users, the water price/fees should be raised in a gradual manner. Consideration for volumetric and basic part of fees may be charged according to the use. Attention should be paid here on the design of the first block for different water sectors, which satisfy the basic human need. The next block is applied for comparatively luxurious use. The precipitation is unevenly distributed in the Mpanga catchment, both in temporal and spatial distribution. The wet season is from March to May and September to November, which takes 86% of yearly rainfall. The dry season is from December to February and June to August 14% of the annual precipitation. However, the period in the dry season is a peak demand for irrigation, but the rainfall is limited. Overexploiting water in the upper catchment result to no water release to the middle and lower catchments and can cause significant dispute in these part of the catchment. A seasonal water fees is an effective way to help in solving seasonal water scarcity.

4.5.9.2.7 Water allocation decision support system

Besides the traditional water management practice, the development of hydro informatics provides the possibilities to use various tools to improve the water resources management, which is also known as a Decision Support System (DSS). A DSS is a combination of tools and approaches that are generally attributed to hydro informatics and that can help to understand and simulate a variety of management and hydrological aspects. These range from broad scale river catchment issues to detailed hydrological and hydrodynamic investigations in relation to water supply and development with respect to quantity and quality in river catchment. For the Mpanga catchment, the main problem is, given the available water resources and their natural variations, to identify to what extent the river catchment can be developed sustainably.

The following issues are to be considered: irrigation schemes, water supply scheme, reservoirs, avoiding unacceptable shortages for water users, especially the damage to the fragile ecological system; when and where conflicts between water users occur will; what combination of infrastructure and management measures will provide an optimum use of the available resources. The RIBASIM modelling tool developed by Delft Hydraulics (Krogt, 2003) is the core part of such a decision support system as well as the currently used Mike Hydro model hosted on the Nile Basin system. RIBASIM is a comprehensive and flexible tool to link the hydrologic inputs of water to the various water using activities in the basin and to evaluate a variety of measures related to infrastructure and operational management.

RIBASIM was used to build the water resources model, schematizing the river network, surface water and ground water and water users.

4.5.9.2.8 Simulation of demand management scenario

In order to evaluate the effectiveness of water demand management measures at least two models setup will be necessary, i.e., a ‘‘without-case’’ (pre-project) for the simulation of the water resources system without taking into account the measure or project; and a ‘‘with-case’’ (post-project) for a simulation run of the same water resources system with demand management measures. The differences between the results of these two runs will show the effects of the measure under consideration. The differences between the runs may pertain to water flows, water supply to individual water user or the overall water supply scenario. With additional information about the water pricing, cost for construction, operation and maintenance of the considered project, we can make an economic and financial evaluation of the entire project.

4.6 Sub conclusion three

The water scarcity in the Mpanga catchment is not only caused by the physical condition, but is also the result of lack of integrated river catchment management. Findings from the case study indicate that the water scarcity is largely caused by the excessive storage development in the middle catchment for fisheries activities, which breaks the balance between the water supply and demand in the river catchment. From the point of view of sustainable river catchment development, demand oriented measures are key issues to be addressed, which include the following: The government should promote public information and awareness by established monitoring and management information systems at all levels. Clear responsibility and co-ordination among institutions are necessary for water management. Water user associations play a critical role in water fee collection. However, they have not been involved in the water fees process, both in terms of the system of fee collection. Reform of water fees policy faces many technical, administrative and political constraints, but with increasing water scarcity, the need for financial sustainability and declining financial resources available for water resource management, reform of water fees is essential. A sharp increase of water abstraction fees is not suitable for the Mpanga catchment. A gradually increasing water abstraction fees is recommended. In order to implement an integrated conservation policy, the water fees mechanism should work together with other measures of water conservation. The construction of wastewater treatment plants is required for controlling water pollution and reusing the treated wastewater as well. Compliance on enforcement of waste discharge permit should be initiated to control industrial wastewater pollution. Industrial wastewater pre-treatment, recycling and reuse programs should be encouraged and seriously polluting enterprises should be shut down, merged or relocated. The availability of various hydro informatics tools, such as simulation models, optimization techniques, database management systems, Internet and GIS, provide an excellent basis for building a DSS. The experiments with the components of DSS built in the framework of this study, especially with RIBASIM, Mike Hydro give the possibility to say that DSS can considerably facilitate the integrated water resources management in this catchment.

CHAPTER FIVE: ASSESSMENT OF THE INFLUENCE OF ANTHROPOGENIC AND LAND USE ACTIVITIES ON WATER QUALITY OF RIVER MPANGA

5.1 Introduction

River Mpanga is a lifeline for an estimated 1.2 million people in Uganda. From its origin in the Rwenzori Mountains, the river flows through the Kabarole, Kamwenge and Kyenjojo districts before reaching Lake George. Over the past fifteen years, River Mpanga's flow and quality have been severely affected by human activity. Encroachment, sand and stone extraction, poor agricultural practices; and pollution have taken their toll and reduced its flow. Different organisations have united their efforts through the Watershed programme, creating a Catchment Management Committee and a Catchment Management Plan, that guide the management of River Mpanga. The river drains into Lake George through a network of hilly landscape characterised by increased incised channels arising from steep slopes stretching 12 to 15 km.

Direct impacts on the river come from multiple sources in a river catchment. The Mpanga catchment is bound by strong upstream–downstream relationships. The Rwenzori Mountains region is currently under high anthropogenic pressure due to high population growth rate and density and suffers a variety of poor land use practices such as deforestation of their steep slopes, mining (sand, gravel and stones) by the local communities (PROTOS and MWE 2011) water abstraction, poor waste disposal and agriculture. The human activities affect River Mpanda directly and/or indirectly as it flows through Fort Portal town to rural areas with various tea plantations (where large groundwater abstractions are operational) into Kibale Forest. The forest ecosystem in the catchment is one of the most important indigenous forests still present in Uganda and has high conservation value and Mpanga River plays a key role in its existence and conservation (PROTOS and MWE 2011). The river flows through different wetlands in Kamwenge District towards Lake George where heavy deforestation, cultivation of crops and livestock farming are common along the banks of the river. The red sandy-clay soils of Kiamara series in Mwenge, Kibale, Burahya and Bunyangabo counties and peaty clays along the Mpanga, are the most productive soils in the region (PROTOS and MWE 2011) favouring the cultivation of crops like banana, yam, sugar cane, vegetables and maize. River Mpanga flows into Lake George over Mpanga falls, a natural habitat for different species of fauna and flora, bordering Queen Elisabeth National Park. At this point, the river joins a wetland system Lake George classified as Ramsar site.

The main objective of this assessment was therefore to evaluate the determinate influence exerted by land use and anthropogenic pressures on the water quality of river Mpanga. The specific objectives were to verify land use types in the Mpanga catchment affecting its water quality and estimate the magnitude these effects on the water quality.

5.2 Water quality pressures – impacts from land use

Good water quality is an essential part of a healthy environment that benefits communities. Catchments with clean water systems help communities to thrive in multiple ways such as having a better quality of life and is a vital element of a thriving economy. However, far from this, there are a number of factors within river catchments that exert pressures hence affecting water quality and compromises their beneficial uses. Surface water systems are environmental receiving carriers, hence evaluating and quantifying how impacts occur between land use types and surface water quality is extremely important.

Land use change has a series of profound impacts on ecological process, surface runoff, and hydrological cycle, thereby affecting river water quality safety (Guo et al. 2021). As a result, determining water quality does require attention to human land use activities. Changes in water quality are assessed by measuring physical characteristics (pH, conductivity, turbidity and suspended solids); chemical properties ranging from major cations and anions, metals and organic parameters. In surface water systems, other parameters associate with pollution, impacts are measured. This includes, biochemical oxygen demand, chemical oxygen demand, nutrients (phosphorus and nitrogen). Furthermore, assessing impacts on water quality in surface water entails measuring stress factors that establishes ecological health of the system. Characterising benthic organisms and microbiological properties are pertinent in determining the magnitudes of the influencing factors.

Historically, decreasing arable land area and decreasing fertility has led to humans applying excessive amounts of pesticides and fertilizers to maintain crop growth rates and yields, which in many parts of the world has led to negative effects on regional water and environmental health (Chen et al. 2021). Rapid global changes including urbanization, population, socio-economy, energy demands, and climate have put unprecedented pressure on water resources and the associated systems. In response to population growth around the world, humans have built a large number of hydraulic structures to supply irrigation power and water resources (Bertone et al. 2016; Strehmel et al. 2016), yet in recent years the exponential growth of light and heavy industries around the world has consumed large amounts of water resources (Courtonne et al. 2016; Kosolapova et al. 2021). Global data indicate many studies on the relationship between land use types and water. Typical land use characteristics in the river Mpanga catchment are found to comprise the following;

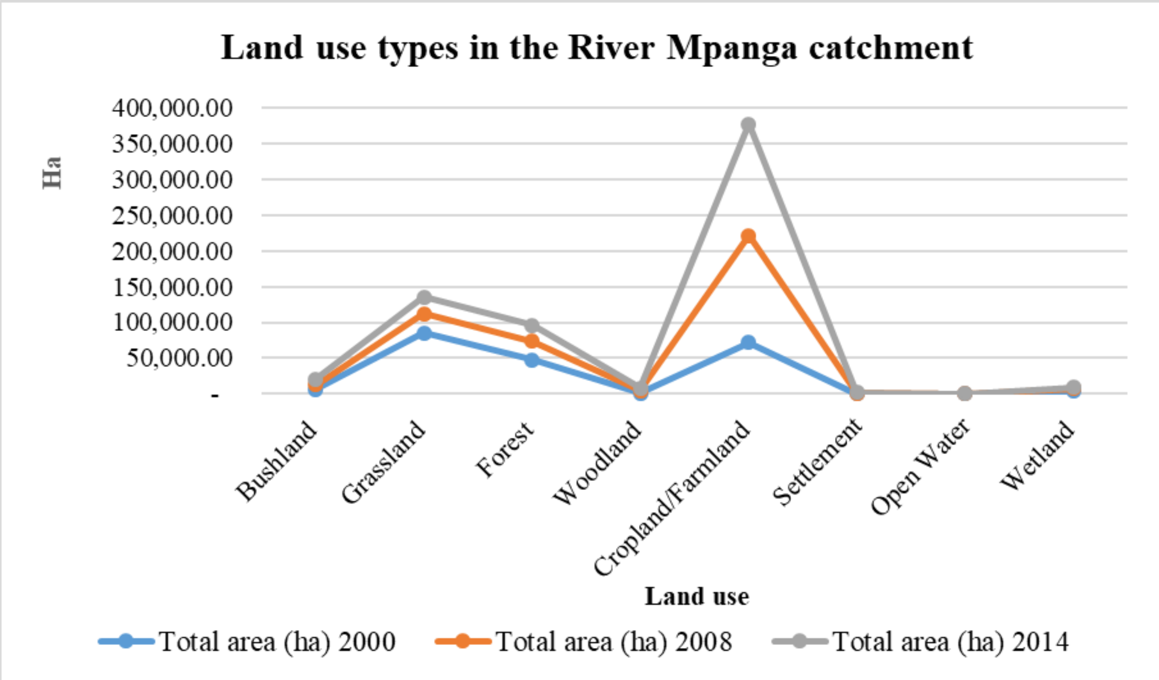


Fig 5. 1: Land use dynamics in the River Mpanga Catchment

Source: Onyutha et al., 2021

According to Onyutha et al., (2021), the proportion of land cover in the river Mpanga catchment comprised grassland (39.5%) as the major cover type, followed by cropland/farmland (33.0%), and forest (22.0%). The study further notes that increased pressures arise from the rapidly growing population. Moreover, the fractions of the catchment area covered by grassland, cropland/farmland, and forest became 10.4%, 72.2%, and 10.7%, respectively indicating that cropland or farming activities is the dominant land cover type. The reduction in forest cover followed an increase in cropland as shown in Figure 1. A deeper dive into the cause of increase in cropland/farmland is further shown to occur due to increase in population.

In a recent study (Onyutha et al., 2021), Kabarole district population increased by 32% from initial figure of 299,573 in 1999 to 469,236 in 2014. In Kamwenge there was an estimated increase of 51% from 201,654 in 1999 to 414,454 in 2014. While in Kyenjojo the population increased by 56% from 182,026 in 1999 to 422,204 in 2014(UBOS 1999 and 2014 Census). The being a rural setting, the increasing population goes hand in hand with exploitation of natural resources. As it is the case with urban cities, rural population migration to urban centres is equally on the rise. This creates the demand for water supply and sanitation services.

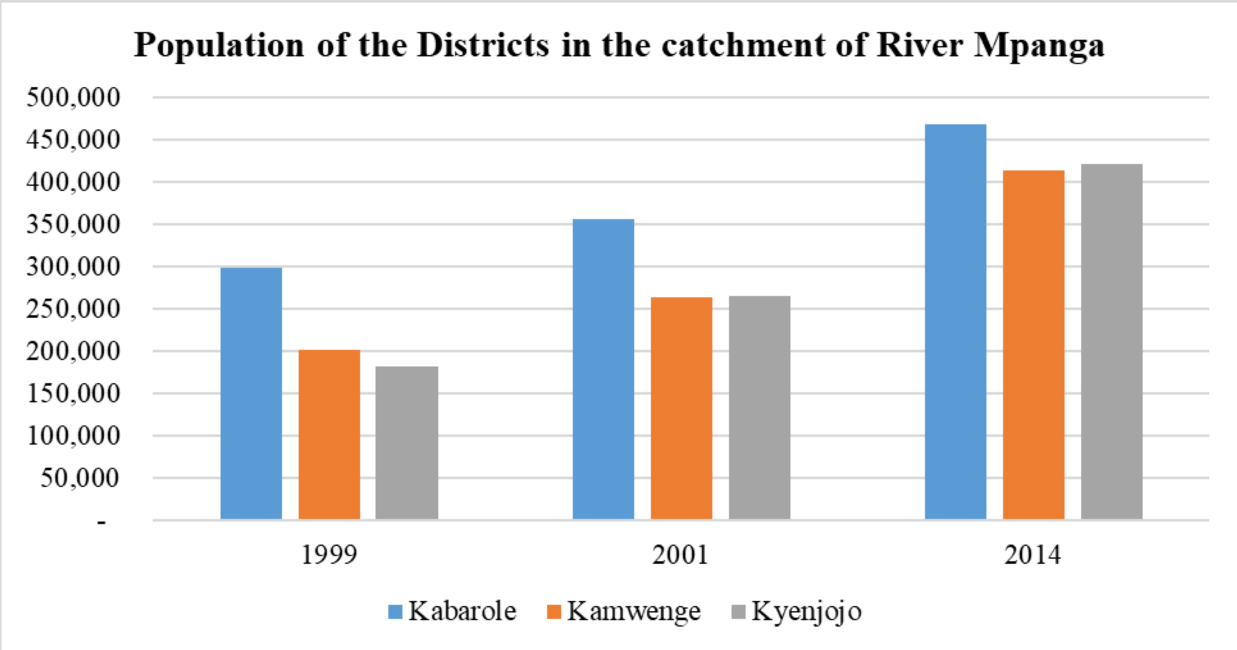


Fig 5. 2: Population of the three districts in the River Mpanga catchment

5.2.1 Impact of agricultural land on water quality

Stoate et al. (2009) claimed that agricultural land does negatively affect water quality which comes from planting, application inputs (fertilizers, agricultural chemicals), and agricultural irrigation. Many studies have shown that with the increase of agricultural land area and the decrease of water quality, habitat and biological combination, row crops, and other forms of intensive planting have a strong impact on river conditions (Dillon and Kirchner 1975; Wang et al. 2019a). It has been shown that as more land is reclaimed for agriculture, sediment, dissolved organic matter (DOM), total nitrogen (TN), and total phosphorus (TP) yields in surface water bodies in the area will increase (Ni et al. 2021). The ecological quality of highly agricultural rivers tends to be poor as evidenced by a decline in various ecological indices and riparian stability (Lacher et al. 2019). Previous studies in many countries have found that watersheds with a large proportion of farmland can emit more nitrogen and phosphorus (Gu et al. 2015; Neill 1989). Nitrogen and phosphorus fertilizers are often applied in large quantities during the growth of crops, and the phosphorus fertilizers that are not absorbed by crops are flushed into rivers by rainfall runoff, which in turn cause nitrification and denitrification reactions between different forms of nitrogen (Camara et al. 2019; Jaworski et al. 1992; Li et al. 2020).

5.2.2 Impact of urban land on water quality

Water quality degradation is most typical in areas experiencing rapid urbanization. With continuous rapid growth and urbanization, expanding construction land area and industry exert great impacts on the eco-landscape, water, and the soil (Dewan and Yamaguchi 2009; Lacher et al. 2019). Typical pollutants from urban areas such as nutrients, metals, medicinal drugs and toxic substances invariably end up flowing into rivers. In general, rapid urbanization often results in significant regional land use/cover changes, mainly due to increased impervious surfaces (Onyutha et al., 2021). Impervious surfaces cause changes in many ecological processes resulting from increased surface runoff into river systems discharged as non-point sources of pollution (Lin et al. 2020). Generally, where the percentage of impervious surface in an area reaches 10–15%, common pollutants in aquatic ecosystems, such as nitrogen, phosphorus, and heavy metals, will increase significantly, leading to a decline of water quality (Tasdighi et al. 2017).

Due to the differences in sewage treatment technology and nutrient removal efficiency, sewage discharge may also lead to spatial and temporal changes in nutrient fluxes in urbanized basins (Fashae et al. 2019). Like agricultural land, urban land is generally considered a key contributor to water quality changes in watersheds (Pankaj, 2021).

5.3 Methodology

River Mpanga stretches over 250km from the Rwenzori mountains, meandering past three districts, traversing town centres, forests, croplands including tea estates and grasslands with intense animal grazing. Its water enters Lake George after passing through the gorges with waterfalls and rapids. In order to assess whether human activity influence in the Mpanga Catchment influenced water quality of the river system, historical water quality data were obtained from the Albert Water Management Zone were analysed and typical parameters akin to different land use types were used.

5.3.1 Data analysis

The historical water quality data spanning between 1999 to 2018 was obtained from Regional Water Quality Laboratory Fort Portal for stations on River Mpanga within the Fort Portal Municipality, and two other stations viz., one at the bridge on road from Fort Portal to Kampala and the other at the bridge on the road from Kamwenge to Ibanda. The historical data had gaps in the sense that the monitoring was not regular and the aspects of seasonality was difficult to determine. A normal practice would be to sort the data and by so doing remove outliers. However, in our case, removal of outliers was not possible. Spikes in TSS and turbidity values were representative of samples collected during typical at peak flows over. Considering all dataset had an effect in determination of mean and standard deviation. Furthermore, the station within the Municipality had scanty data and more so, not all parameters selected for the assessment were measured. Furthermore, it was not possible to determine which data were collected over wet or dry season and, although spikes in suspended solids concentrations could have been used to isolate datasets over wet season, these were very few and instead could have been removed as outliers. In general., the following parameters were used to infer effects arising from land surfaces, nutrients from effluents sources and agricultural runoffs, changes in conductivity of the river, suspended solids as a measure of sediments from land surfaces and agricultural or croplands and grasslands with cattle grazing taking place. The Analysis of Variance (ANOVA) statistic was used to determine the variation in concentrations of the parameters. The means between the sites were compared and were significant differences occurred, post hoc test was used characterise variability among sites. For ease of visualization of the data, MS Excel was used to plot graphs. Given that all the sites were on the same river, a line graph was suitable to show mean variations of the selected parameters. In analysing the datasets, the stations within the municipality and any other dataset obtained from sites upstream of the municipality were considered as site number 1. The station on the bridge on Fort Portal-Kampala Road was considered as site number 2 and the site on the bridge on Kamwenge-Ibanda was considered site number 3. The parameters considered in this assessment included; Conductivity (µS/cm), pH (Unit), Turbidity (NTU), TSS at 105^{O}C (mg/l), Phosphates (mg/l), Nitrites (mg/l), Nitrates (mg/l), Total Phosphorus and Total nitrogen.

5.4 Results

5.4.1 Water quality datasets for determining the effect of Urbanization on the water quality of river Mpanga

This section presents the results as mean averages of the parameters, standard deviation, minimum, media and maximum concentrations. Only three land use types were considered based on the sample location to correspond to the datasets. Table 1 shows summary of water quality variables for the three sampling sites represented by 1(Fort Portal Municipality and upstream sites).

Table 5. 1: Mean variation of selected parameters in River Mpanga within Fort Portal, water abstraction point

Variable	N	Mean	Stdev	Minimum	Median	Maximum
Conductivity (µS/cm)	10	420	93.3	236	441	534
pH(Unit)	10	7.6	0.56	6.7	7.8	8.7
Turbidity (NTU)	9	6.12	7.18	0.01	2.29	18.7
TSS at 105OC (mg/l)	5	18	16	4	12	44
Phosphates (mg/l)	9	0.192	0.1	0.068	0.178	0.41
Nitrites (mg/l)	7	0.022	0.052	0.002	0.002	0.14
Nitrates (mg/l)	7	0.298	0.167	0.156	0.25	0.64
Total Phosphorus	3	1.21	1.24	0.22	0.81	2.6
Total nitrogen	3	1.55	0.38	1.159	1.58	1.92

Table 5. 2: Mean variation of selected parameters in R. Mpanga at Mubende – Fort Portal Road

Variable	N	Mean	Stdev	Minimum	Median	Maximum
Conductivity (µS/cm)	39	389.7	102	121	402	595
pH (Unit)	37	7.9	0.41	7	7.9	8.7
Turbidity (NTU)	31	37.09	35.04	3	27	128
TSS (mg/l)	25	16.12	12.9	2	11	49
Phosphates (mg/l)	26	0.24	0.38	0	0.17	2
Nitrates (mg/l)	30	0.35	0.71	0	0.09	3.26
Total nitrogen	16	4.4	4.45	0.79	2.63	17

Table 5. 3: Mean variation of selected parameters in R. Mpanga at Kamwenge - Ibanda road

Variable	N	Mean	Stdev	Minimum	Median	Maximum
Conductivity (µS/cm)	21	321.4	127.8	107	284	580
pH (Unit)	20	7.413	0.72	5.4	7.4	8.6
Turbidity (NTU)	21	55.2	91.2	0	20.8	392
TSS at 105^{O}C (mg/l)	20	21.3	26.04	5	12	94
Phosphates (mg/l)	16	2.69	9.97	0	0.2	40
Nitrites (mg/l)	19	0.008	0.012	0.002	0.004	0.054
Nitrates (mg/l)	19	0.2	0.43	0	0.06	1.89
Total Phosphorus	7	0.316	0.11	0.22	0.32	0.54
Total nitrogen	7	6.11	6.28	0.79	3.3	16

The measurements show some variability and possible nature in the datasets analysed of effects exerted by the three land use types. Detail description of the typical influence and implications of the chosen parameters are in the discussion section.

5.5 Discussion

5.5.1 Settlement/Urban effects on water quality of river Mpanga

The mean concentrations of water quality variables describing the status of the effects arising from Fort Portal Municipality and its environment are shown in Table 4. Among the parameters, conductivity mean concentration (420±93.3µS/cm) was higher and typically showed possible dilution from a brackish water. The Fort Portal site is upstream among the sites. The river from its source in the mountain through the town has not moved far enough to dissolve minerals responsible for increased conductivity in especially surface water system. More so, activities upstream are described as deforestation, sand mining and stone quarry.

Table 5. 4: Summary of datasets for the three major land use types

Variable	Urban/Settlement		Crop Farmland		Grassland/ Subsistence	
	N	Mean	N	Mean	N	Mean
Conductivity (µS/cm)	10	420	39	389.7	21	321.4
pH (Unit)	10	7.6	37	7.9	20	7.413
Turbidity (NTU)	9	6.12	31	37.09	21	55.2
TSS at 105OC (mg/l)	5	18	25	16.12	20	21.3
Phosphates (mg/l)	9	0.192	26	0.24	16	2.69
Nitrites (mg/l)	7	0.022		0.35	19	0.008
Nitrates (mg/l)	7	0.298	30	4.4	19	0.2
Total Phosphorus	3	1.21			7	0.316
Total nitrogen	3	1.55	16		7	6.11

It is therefore possible to state that the effluent from the municipal wastewater treatment plant and surface runoff from activities within the municipality increased the conductivity of the river. In surface water studies, conductivity is used as pollution tracer and therefore, elevated concentration depicts high dissolved solids, which is a sign that other pollutants are present in the river system in high concentrations. At the existing concentration, benthic organisms and other aquatic organisms sensitive to dissolved solids will not thrive in the water. However, other aquatic organisms tolerant to elevated conductivity will thrive in this type of water. In terms of human health, conductivity is among the determinant of salts in water and it imparts taste to water. Elevated concentration is generally no recommended for persons with hypertension conditions. However, the concentrations found in the river is far below the recommended standard in water for human consumption. In terms of water for plant use, moderate to high conductivity are not recommended for certain type of crops. Unlike other pollutants, conductivity in surface water systems is not easily removed. The only means to reduce the concentration is through dilution, which may come from surface runoff from rainwater as long as it falls on soil that has no or low mineral contents.

pH mean variation; 7.6±0.56 (Table 1 and Figure 1b) is typical of a neutral and balanced systems. Generally, surface water systems unless exposed to intense pollution will not have acid pH values less than 7. However, due to eutrophication, alkaline waters with pH values above 8 do occur. River Mpanga sample from within the municipality does no fall within the two extremes.

The nutrient parameters indicate presence of total phosphorus (1.21±1.24mg/l) and total nitrogen (1.55±0.38mg/l) pollutants which generally originated from the land surfaces, discharged from wastewater treatment or septic tanks or soak pits into the rivers. As opposed to wastewater effluents, natural surface water systems do not have standards upon which to concentrations or load are considered acceptable. Therefore, nutrient concentrations in surface water systems are determined based on the source type like lakes, reservoirs and rivers or streams. Judgement to determine acceptable levels are based on capacity to uptake in as much as presence of the nutrient would unlikely cause eutrophication of the resources. Natural system like River Mpanga in this scenario would act as carrier of nutrient to the downstream of Lake George. The simple forms of the nutrients (nitrates; 0.298±0.167 mg/l, nitrites; 0.022±0.052mg/l and orthophosphates; 0.192±0.1mg/l) are the readily available required by plants and responsible for proliferation of algae in surface water systems. While nitrites are the reduced form of nitrogen, nitrates is the oxidized form. Therefore, presence of nitrite at the site within the municipality indicates low dissolved oxygen due to the presence of organic matter.

The EC line plot (Figure 1) indicate that the mean concentrations is significantly different ($p=0.029$) from the sites at the fort Portal Kampala Road and Kamwenge-Ibanda road.

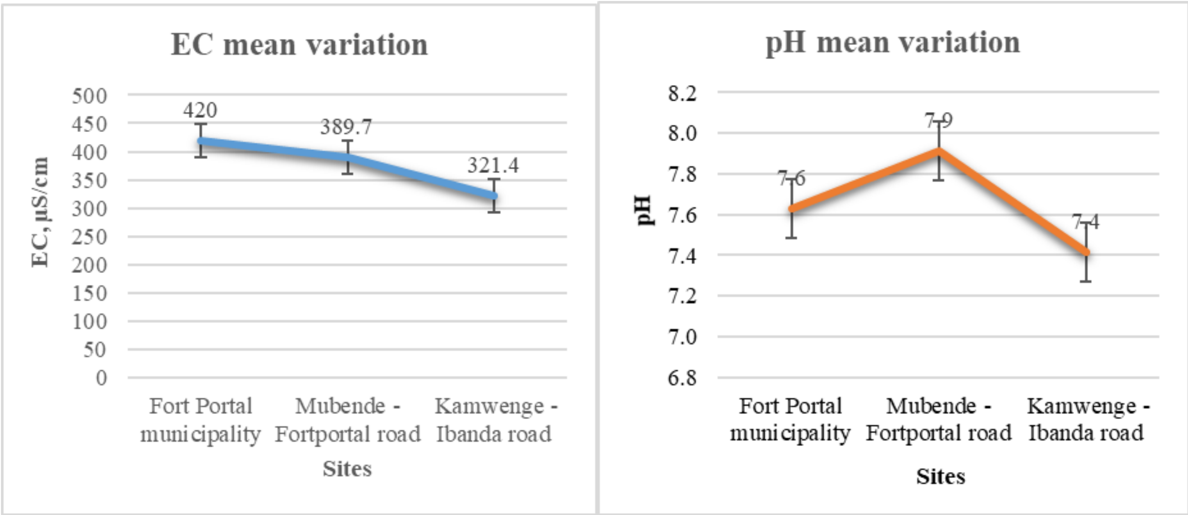


Fig 5. 3: Mean EC and pH variation at three separate sites on river Mpanga

Turbidity, mean variation (6.12±7.18NTU) as shown in table 1 and Figure 2a and b within the municipality show the river water is moderately ladened with suspended solids as also shown by the TSS mean concentration (18±16mg/l). Comparing the between sites. In natural systems, suspended solids to contribute to turbidity in water, which has the effect of light shielding effects. Suspended solids are also riders of other pollutants like trace organic residues and trace metals including bacterial organisms as these are retained onto the active sites in the case of trace elements (Berndtsson, R. 1990), or media for growth of microorganisms (Habeeb, S. A., & Nadhim, B. A. (2023).

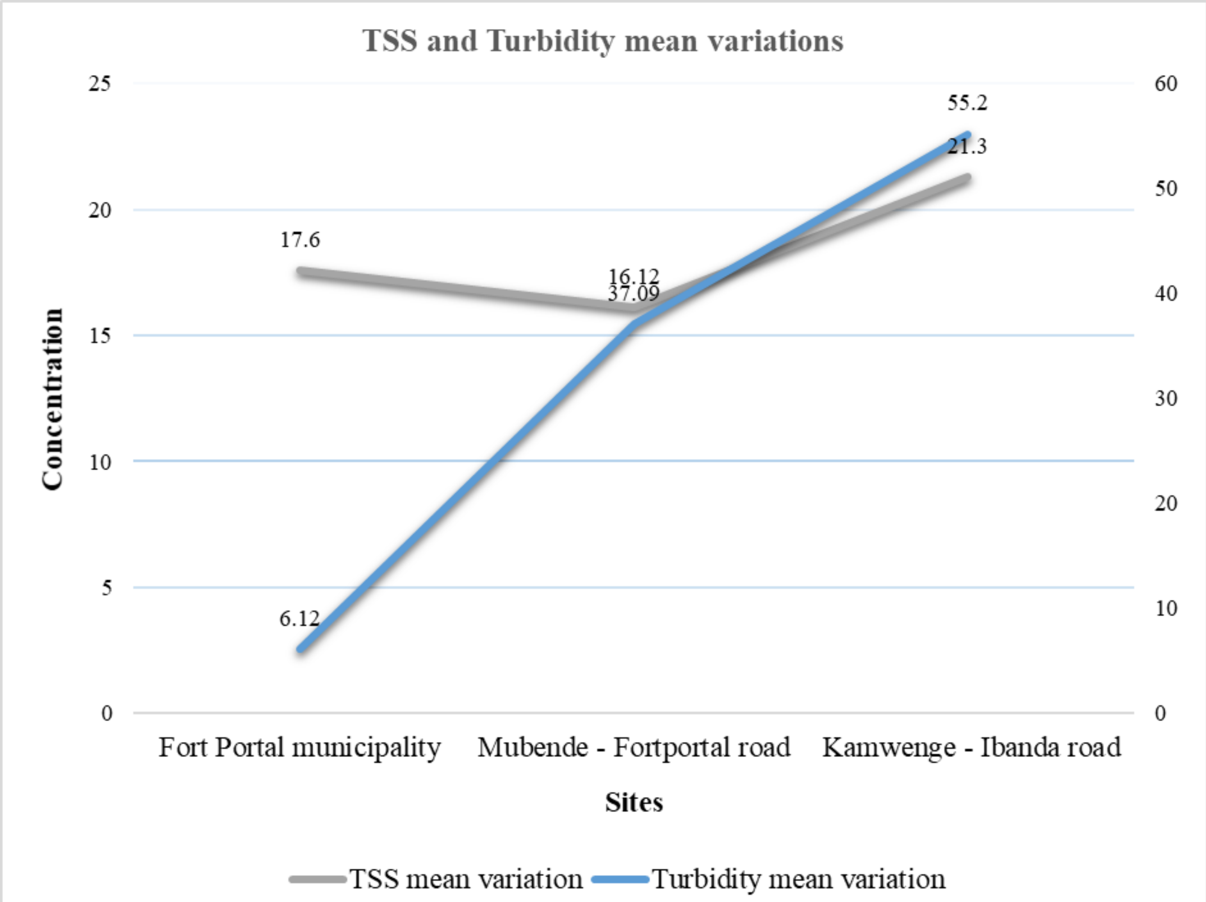


Fig 5. 4: Turbidity and Suspended solids mean variation from the three sites along river Mpanga

5.5.2 Agricultural land effects on river Mpanga

Assessing the effects of agricultural land use on water quality of river Mpanga was based water quality data obtained from the Fort Portal-Kampala Road bridge sampling point. Compared to the site within the municipality, the site along Kampala Road had fairy large amount of data (Table 2). The site is also second sampling point on the river after the Fort Portal site. Therefore, changes in water quality variation at this site depicts whether changes occurred for all the parameters assessed.

The mean Conductivity (389.7±102µS/cm) at this site was high but below the value at sampling site 1(Fort Portal Municipality). This mean conductivity value indicates a drop due dilution contributed to less saline water of the river. It also shows absence of other sources of water for example recharge from wetlands into the river up to this point. The river Mpanga at this point traversed extensive agricultural fields including tea plantations and subsistence agricultural lands.

Contribution from agricultural land use to water quality change in the river at this point were observed due to increased nutrients concentrations. Specifically, total nitrogen mean concentration (4.4±4.45mg/l) was higher than at site 1. The contribution to high total nitrogen is likely from agricultural inputs within the tea plantations. Nitrogen fertilizers are applied on farms where the crop output is the leaves. Tea is one such cash crop grown for its leaves; therefore, applying nitrogen-based fertilizers is primary requirement.

Agricultural land use furthermore generates high turbidity because of loose soils washed into runoffs from the fields. The observed turbidity mean value (37.09±35.04NTU) in the river was higher compared to the mean value from the site within the municipality. The turbidity mean concentration was compared to suspended solids at this point and the upstream point at the municipality. The mean TSS (16.12±12.9mg/l) was not significantly different between the two sites (p=0.121).

5.5.3 Subsistence agriculture effects on water quality of river Mpanga

The third site assessed for impacts on water quality of the river Mpanga was at the bridge along Kamwenge-Ibanda road. This site is downstream of the two sites, traversing mainly grassland, animal grazing zone and has subsistence agriculture. The soil formation in Kamwenge may not be comparable to the type in Kabarole and therefore the crop types are not similar. This further may require different agricultural inputs or intense use of it. Due to animal grazing, the use of acaricides for management of animal diseases was likely stress factor on the water quality. It is envisaged that despite variability in land use type, the effects on water quality may not vary for the same parameters are used.

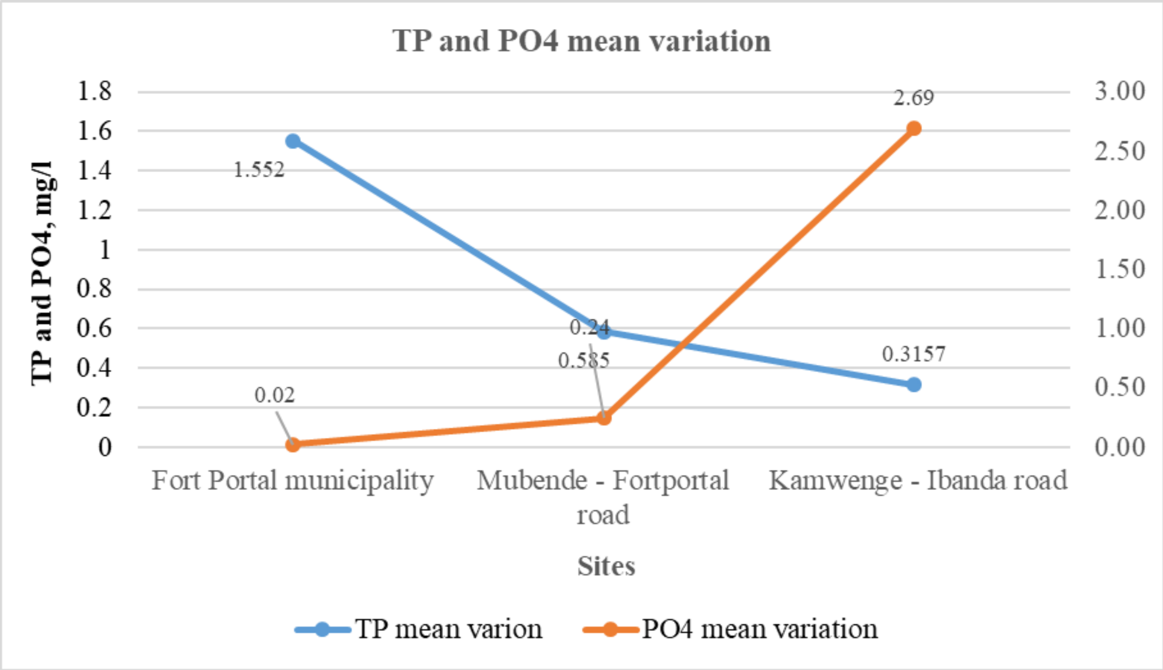


Fig 5. 5: Total Phosphorus and Orthophosphate concentration variations at three sites

Generally, the mean conductivity (321±127.8µS/cm) significantly different (p=0.029) from the value in the upstream sites. The mean conductivity (Table 3) depicts moderate salinity in the water. This value may present similar condition in as far as the ecological health of the river is concerned. As observed in the upstream, the variability in the conductivity may not cause marked change in aquatic macro-organisms' profile in the water as the difference is not large enough. As noted, intense use of agricultural inputs and other animal management regimes may have caused high total nitrogen mean concentration (6.11±6.28mg/l). Orthophosphates mean concentration (2.69mg/l) was higher than at the upstream sites within the municipality and at Kampala Road site. This difference is likely due to the variation in demand determined by the crop type in this particular catchment.

Moving longitudinally downstream, turbidity mean value (55.2NTU) and suspended solids (21.3mg/l) increased above the value in the upstream sites. This variation could have occurred due to soil type and animal grazing effects. The pH mean variation (7.4±0.72) indicated neutral water quality.

5.6 Sub conclusion four and recommendations

Sub conclusion

- Expanding urban settlement in Fort Portal has a negative effect on water quality of river Mpanga. Typical variable causing water quality change is conductivity which is assumed to originate from the wastewater treatment plant and surface runoff within the municipality
- Increased cropland and or farm areas under plantations has the potential to increase total nitrogen into the water.
- In the grassland/animal grazing areas, total phosphorus was found higher than in all the land use types.

Recommendations

- Noting that this assessment relied on historical water quality data and secondary information on land use, a detailed assessment study is therefore recommended. The study should be able to correlate land use pressures linking with current water quality of river Mpanga.
- For sustainable water quality management, dedicated sampling sites on the river should be reconstructed to monitor parameters comprehensively.
- As land use effects tend to correlate to increased effects of floods (causing dilution and sedimentation), monitoring of water quality should capture seasonality effects.
- Installation of hydrological equipment at all the sites of water quality sampling will enable determination of discharge measurements to compute pollution loads. Discharge measurements should be done on real time but also on specific days of water quality sampling.
- Expanding the range of water quality parameters should be considered. This includes, heavy metals, trace organics such as pesticides, pharmaceutical residues and plastic residues.

CHAPTER SIX: ASSESSMENT OF POPULACE PERCEPTION ON CONTROLLED ACTIVITIES WITHIN THE RIVER BUFFER ZONE IN MPANGA CATCHMENT

6.1 Introduction

6.1.1 Background

In India, the reports showed the encroachment of the Tons River and its tributaries in urbanized areas by about 0.73 km2 within a 50 m buffer [1]. The Mpanga catchment has several socio-economic/land-use activities being undertaken within by both the public and the private sectors. These include subsistence to large-scale commercial agriculture like tea; urbanization (towns and municipalities with resultant generation of sewage, solid waste and run-off from streets and garages); energy production (Hydroelectric power generation) and the Rwenzori Mountains Ranges [4]. The Mpanga min-hydropower plant of 18MW capacity was commissioned, but it is not able to generate power to its full capacity throughout the year due to erratic river flows. A water source protection plan should focus on the land management activities that cause soil erosion and loss of water storage in the catchment [6].

The River Mpanga Catchment Management Plan (RM-CMP) identifies and proposes suggestions of the possible interventions using the integrated water resources management approach. The plan takes into consideration the natural resources in the basin, their economic potential and identifies conservation threats from catchment wide processes by participatory [9,5]. River bank encroachment with wastes and plastics remains a serious issue, so efforts to raise awareness should continue as well as engaging with polluters along the river in order to get measures to save river Mpanga. This can only be done through collaborative advocacy and multi-stakeholder engagements [7,8]. CSOs, government and private sector actors should all work together to ultimately attain safe and sustainable water for domestic consumption and production.

Physically demarcate Protection Zones Experience in Uganda has shown that statutory zoning is rarely respected unless physically marked out so that people using the area can clearly see where they are or are not allowed to go. Fences and walls are commonly used to demarcate and protect land.

In many cases, excluding people from the land is not the aim – what is more important is to show the areas, such as riverbanks and lakeshores where particular activities are not allowed or strictly controlled. Markers can include metal or wooden posts or stone markers. There should be clear signage to explain what the zone means and what activities are and are not permitted. This should be done in English, the local language(s) and using symbols and pictures. When installed there should be awareness raising campaigns to inform people living near the zone perimeter about the new development and what the signs mean[2,3].

This research is based on the Ugandan regulations prescribed to protect the buffer zones. This reads as follows; "A person shall not, on any area of land within a distance of a hundred meters of a bank of any public river, cultivate or permit the cultivation of any crops, cut any tree, excavate any sand or in any manner conduct any activity likely to loosen the soil or diminish the quantity of water flowing in any part of a public stream" [10]. This entails that no activities should be done within 100m of any water resource.

However, despite the presence of these laws, many public streams have been encroached and are being degraded by communities living within these areas. Previous research has shown that enhanced knowledge coupled with effective implementation of existing laws and policies improves the attitudes and practices of communities towards water resource protection [11, 12, 13] which is the premise of this research.

6.1.2 Problem Statement

Buffer zones are essential for conserving and safeguarding against protected areas or sensitive areas; in Uganda, laws and policies have been set to protect buffers. One among them is the Environmental Management Act of 2019 [14], which prohibits conducting human activities within 100 m of the water source. There are increased socio-economic activities like agriculture within the 100 m strip of the riverbanks of Katonga, Semliki, Mpaga, Dura, Kagera, Nkusi, Muzizi, Lamia,and Ishasha. ; This violation can be termed an act of encroachment.

At Kazingo in Kichwamba Sub County, where river Mpanga passes, the communities have cultivated bananas, yams, sugar canes, vegetables on the riverbanks resulting into silting. In Fort Portal town, washing bays have been established 20 meters from the riverbanks and oils from the vehicles pour into the water, which is consumed by residents of the town. At

Mpanga Market, the toilets that are being used by the traders have been constructed along the river. Raw human waste is discharged directly into the river, whenever it rains.

Even though Uganda has had laws and procedures in place since 1902 (imported British law) to prevent encroachment on wetland and River resources [15], many rivers nevertheless appear to have been invaded, particularly those in townships. One such stream that has been negatively impacted by anthropogenic activities is the Mpanga stream in Fort-Portal, which has been subjected to infrastructure construction and riverbank cultivation.

The National Environment (Wetlands, Lake Shores and Riverbanks management) regulations of 2000 states that any activity carried out near a river should be one hundred (100) meters away from the riverbank.

Collaborative advocacy has created a multi-stakeholder platform involving political leaders, CSOs, utility companies like the National Water and Sewerage Corporation (NWSC- Fort Portal Area) among others to engage in restoration, preservation and regulatory activities to save river Mpanga. The Mpanga Catchment Management Committee was formed and is active under the political leadership of Mr. Richard Rwabuhinga, the Chairperson of Kabarole District. The Watershed partnership and regional actors led by Join for Water and Albert Water Management Zone of Ministry of Water and Environment from 11 -15 March 2019, commemorated Mpanga event in Kabarole.

However, information on the levels of encroachment and the activities undertaken in the buffer zone is scant or absent. Furthermore, the informed implementation of environmental legislation was envisaged to provide management needs for the sustainability of these rivers. Therefore, this paper aimed to assess community knowledge, perception and attitude with the river regulation and legislation governing buffer zones, and quantify institutional support in the management of the buffer zone.

6.2 Objectives

6.2.1 General objective

To assess populace perception on controlled activities within the river buffer zone, in accordance with the Environment act 2019.

6.2.2 Specific objectives

i. To assess the variability of community attitude towards river bank activity regulation and legislation.
ii. To evaluate community's perception and understanding of river buffer encroachment and regulation.
iii. To assess the level of Community awareness to institutional support and river buffer zone regulation.

6.3 Research question

i. What is the community attitude towards riverbank activity regulation and legislation?
ii. What is community's perception and understanding of river buffer encroachment and regulation?
iii. What is the level of Community awareness on institutional support and river buffer zone regulation?

6.4 Materials and Methods

6.4.1 Research Design

This study employed a mixed-methods strategy that combined qualitative and quantitative techniques. The mixed method approach was used in order to triangulate the information that was collected..

6.4.2 Study Population and Sample size

The study population included all households within the catchment of the 7 districts where river Mpanga flows. There are no current statistics available for the total households of the catchment area. Therefore, the sample was not calculated but purposively selected to include only those who own land within river Mpanga buffer zone of 100m.

Hence, a sample size of 121 households was surveyed and interviewed, in order to collect quantitative and qualitative data in assessing the perceptions, attitudes and awareness of buffer zone regulations of Uganda.

6.4.3 Data Collection Instruments

Key informants (Political leaders, Natural Resources officers, NGO's), ccommunity members and policy makers were interviewed using question guide and questionnaires. The structured and semi-structured questionnaire primarily focused on the demographic and economic information as well as the sample population's knowledge, perceptions, attitudes and awareness regarding the riverbank regulations.

6.4.4 Sampling techniques

Random sampling was used which gave each household within the buffer zone an equal chance of being selected.

6.4.5 Data Analysis

The study used Statistical Package for Social Sciences (SPSS) as well as Microsoft Excel to analyse the quantitative data. The qualitative data was analysed using Microsoft excel.

Sub objective one was analysed using descriptive analysis to determine the perceptions of the sample population on existing Ugandan laws and policies of riverbanks. The mode was determined to show the highest result. Tables and graphs were generated to show the results. The chi-square test for independence was used to test several hypotheses. Some of the hypotheses were, to test whether landownership type was statistically significantly related to occupation, gender or education.

Sub objective two was analysed using descriptive, and correlation analysis. This was done using contingency tables, which showed different relationships between variables. The analysis was done in SPSS.

Sub Objective three was analysed using both thematic and descriptive analysis. The data collected was put into themes and then graphs were used to show the results. The analysis was done using Microsoft Excel.

6.5 Findings

The outcomes of data collected and data analysis are presented in the following sections: The first section presents the demographics of the sample that was interviewed. The analysis of data based on the three objectives and their associated research questions come after the demographics.

6.5.1 Demographics

The social and economic characteristics of the sample population surveyed in Mpanga Catchment, Western Uganda, are displayed in Table 6. 1. 121 people in all were contacted for interviews using semi-structured questionnaires

Table 6. 1: Social and Economic Demographic Information of Sample Size

Variable	**Count**	**Valid Percent (%)**
Sex of respondent		
Male	74	61.2
Female	47	38.8
Age of respondent		
18-25 years	6	5
26-35 years	14	11.6
36-50 years	55	45.5
51-60 years	26	21.5
Above 60 years	20	16.6
Level of education		
None	54	44.6
Primary	51	42.2
Secondary	13	10.7
Tertiary	3	2.5
Occupation		
Farming	98	81
Small Business	20	16.5
Civil Servant	3	2.5
Length of residency in Mpanga		
1-5 years	17	14.4
6-14 years	19	16.1

15-24 years	27	22.3
Above 25 years	55	45.5
Sample population (n)=121		

6.5.2 Socio-economic information

Among the 121 individuals interviewed, 61% of the participants were men and 39% were women. Most of the participants, as seen in Table 1 above, were between the ages of 36 and 60, accounting for 67% of the River Mpanga Buffer zone dwellers. The majority (45%) of the people shown in Table 1 had no education, while 42% had completed primary school. Those employed in farming made up 81%.

First, the study assessed the knowledge of the residents of Mpanga catchment on the existing laws and policies on water resource buffer zone protection in Uganda. Regarding the understanding of meaning of buffer zone, 52% of people acknowledged that understand the meaning, while 48% did not know the meaning of a buffer zone. Although every participant was resident in the buffer zone, 33% of villagers said their land was not in the buffer zone.

A chi-square test of independence was analysed to test the Null Hypothesis that, "there no statistically significant relationship between a land owner "knowing the meaning of buffer zone" and "knowing that his/her land lies in a buffer zone". The following result was obtained. In Table 6. 13, the difference between the observed and the expected counts of the two variables has been displayed. It shows that the difference in counts is big, hence the likelihood of the Chi-square being small, and the possibility of rejecting the Null hypothesis.

6.5.3 Land ownership

Land ownership is largely free hold for more than 55% and family transfer type of land ownership accounting for 34% of the total land owned in the buffer zone of River Mpanga catchment. When land ownership type was cross tabulated with occupation type yielded the following results in the table below. In Table 6. 22 it is evident that the highest occupation was farming. A Chi square test was conducted to test the independence of land ownership and occupation.

Table 6. 2: Occupation and Landownership Cross tabulation

		Landownership				Total
		Communal	Family transfer	Freehold	Lease	
Occupation	Farming	2	35	58	3	98
	Small business	1	5	7	7	20
	Civil servant	0	1	2	0	3
Total		3	41	67	10	121

The Pearson Chi- square value p=0.001<0.05, refer to Table 6. 33. However, these statistics are not consistent with symmetric measures in Table 6. 33 below.

Table 6. 3: Chi-Square Tests

	Value	**df**	**Asymptotic Significance (2-sided)**
Pearson Chi-Square	23.807a	6	.001
Likelihood Ratio	17.524	6	.008
Linear-by-Linear Association	3.112	1	.078
N of Valid Cases	121		

Symmetric Measures

		Value	Asymptotic Standard Errora	Approximate Tb	Approximate Significance
Interval by Interval	Pearson's R	.161	.101	1.780	.078c
Ordinal by Ordinal	Spearman Correlation	.171	.105	1.898	.060c
N of Valid Cases		121			

The relationship between land ownership and occupation have a coefficient correlation r=0.161 which is very small and with a significant value of p=0.078>0.05. Since the statistic value is greater than the critical value, we conclude that there is no statistically significant relationship between land ownership and occupation hence land ownership and occupation are independent and so we do not reject the null hypothesis that there is no statistically significant relationship between land ownership and occupation.

6.5.4 Sub objective one

6.5.4.1 Negative attitudes towards river bank restoration actions

The study revealed that 61% of individuals were aware of the existing laws/ act/regulation about river buffer zone protection areas in Uganda, while 39% were not aware of any existing Laws. Despite having knowledge on the existing regulation about river buffer zone, residents of Mpanga catchment did not practice them.

The results have shown that irrespective of the awareness of the buffer zone regulation, 45% were still against riverbank restoration actions. Awareness is not adherence, and the level of adherence of the community to regulations governing the buffer zone was 55% adhered to, while those who did not adhere to these regulations comprised 45%.

Level of awareness and compliance with riverbank regulation

The results indicate that about 61% of the interviewed community members were aware of the regulations restricting the restricting riverbank activities along the buffer zones. Furthermore, 39% of the community was unaware of the buffer zone regulations (**Fig 6. 1**). Awareness is not adherence, and the level of adherence of the community to regulations governing the buffer zone was 55% adhered to, while those who did not adhere to these regulations comprised 45%.

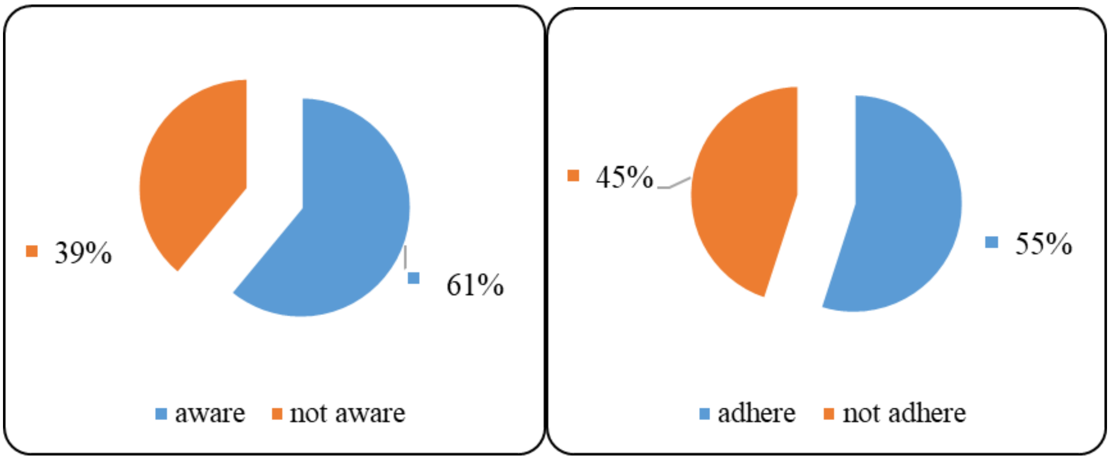


Fig 6. 1: Level of awareness and compliance with riverbank regulation

Findings indicated that awareness of the existing laws were got from community meetings as the biggest contributor (57% of information), followed by radio 43%.

The factors influencing attitudes against riverbank restoration were included the following; 21% argued that this is the only land for them to benefit from while 12% indicated complete lack of knowledge of river buffer zone regulation. Other negative attitudes against river bank restoration that were identified in this study included poverty 9.2%, strict use of demarcated land 4.2%, land entitlement 6.7% and meters too much 4.2%.

Pearson correlation was employ to investigate the relation between attitude of restoration and characteristics of respondents such as household size, age, occupation, length of residency and education. Pearson's correlation indicated positive relationship for different variables with R ranging from 0.04 to 0.151 (Table 6. 44). The relationship is weak for all the predictors, and not significant because the p values are all greater than 0.05. Only age was found to be a significant predictor variable for river bank restoration attitudes (Table 6. 55).

Table 6. 4: Pearson Correlation

`		Education	Occupation	Age	What is your Family size	Are there individuals/communities against river bank restoration
Education	Pearson Correlation	1	.294**	-.194*	-0.041	0.108

	Sig. (2-tailed)		0.001	0.033	0.653	0.24
	N	121	121	121	121	119
Occupation	Pearson Correlation	.294**	1	0.007	-0.012	0.151
	Sig. (2-tailed)	0.001		0.94	0.898	0.102
	N	121	121	121	121	119
Age	Pearson Correlation	-.194*	0.007	1	.289**	0.046
	Sig. (2-tailed)	0.033	0.94		0.001	0.617
	N	121	121	121	121	119
What is your Family size	Pearson Correlation	-0.041	-0.012	.289**	1	0.122
	Sig. (2-tailed)	0.653	0.898	0.001		0.186
	N	121	121	121	121	119
Are there individuals/ communities against river bank restoration	Pearson Correlation	0.108	0.151	0.046	0.122	1
	Sig. (2-tailed)	0.24	0.102	0.617	0.186	
	N	119	119	119	119	119

[a]*Significant at p = 0.05*

Table 6. 5: Logistic regression predicting likelihood of residents' favourable river buffer zone protection attitudes

		B	S.E.	Wald	Df	Sig.	Exp(B)
Step 1[a]	Age			1.189	4	0.88	
	Age(1)	-20.948	13153.497	0	1	0.999	0
	Age(2)	0.653	0.854	0.586	1	0.444	1.922
	Age(3)	-0.134	0.623	0.046	1	0.83	0.875
	Age(4)	0.112	0.697	0.026	1	0.873	1.118
	Education			3.254	3	0.354	

	Education(1)	-41.792	22309.037	0	1	0.999	0
	Education(2)	-41.215	22309.037	0	1	0.999	0
	Education(3)	-42.425	22309.037	0	1	0.998	0
	Occupation			1.238	2	0.538	
	Occupation(1)	-20.293	19790.409	0	1	0.999	0
	Occupation(2)	-19.636	19790.409	0	1	0.999	0
	Family size			0.613	2	0.736	
	Family size(1)	-0.429	0.697	0.378	1	0.538	0.651
	Family size(2)	-0.387	0.526	0.542	1	0.462	0.679
	Utilization years			2.644	3	0.45	
	Utilization years(1)	-0.573	0.703	0.665	1	0.415	0.564
	Utilization years(2)	0.701	0.672	1.087	1	0.297	2.015
	Utilization years(3)	0.203	0.543	0.14	1	0.708	1.225
	Constant	61.841	29821.946	0	1	0.998	7.2E+26

[a]*Significant at p = 0.05*

Logistic regression analysis (Table 6. 5) was employed to test for variables predictive ability on the dependent variable. The whole model explained the variance of riverbank protection attitudes between 27.4 and 32.7% (R square) and correctly classified 74.5% of the cases. Among the predictor variables: age, length of residency, and education significantly explained the attitude towards riverbank restoration. Among the significant predictors, age emerged as the strongest predictor of holding favourable riverbank restoration attitudes, followed by the length of residency.

Since the coefficient of age was positive, the likelihood of having favourable attitudes towards riverbank restoration increased with age. The coefficients of the length of residence were also significantly positive. It suggests that the riverbank restoration attitudes were increasing with an increase in length of residency. In addition, the number of years of schooling also has a positive effect on the riverbank restoration attitude of the people. As the education level increases, awareness increases leading to a higher consent to the riverbank restoration of wetlands in the sample. Table 6.5 above shows the logistic regression predicting the likelihood of having favourable riverbank restoration

Furthermore, community attitude towards change of their negativity would highly be addressed by MWE, local leaders, cultural religious leaders, and NGOs, which were ranked at 50%, 41.5%, 7.3% and 1.2% respectively.

6.5.4.2 Positive attitude towards Riverbank restoration action

59.2% said the demarcation is good, while 40.8% said it is not good. Those who do not support demarcation had several reasons such as fear for losing their businesses like fish farming 93.5% and bee keeping (87.5%). Others (93.3%) argued that buffer zone of 100m is too much. Other people's attitude included poverty among people (96.7%) that they have to fight by using the river buffer land, negative mind set on demarcation (92.5%) and strict use of demarcation (96.7%). Other fears included lack of provision of alternative land (93.25%), being the only land they own (92.5%) and the restoration of riverbank would reduce personal land (94.5%).

Those who said demarcation is good preferred the following methods to be used; concrete pillars 62.7%, live fencing 21.4%, chain link fencing 15.7%. The results indicated that 59.7% supported restoration of degraded river buffer zone, while 40.3% do not support restoration of degraded river buffer zone. Those who support the restoration of degraded river buffer zone considered the following activities tree growing 54.2%, bee keeping 12.5%, fish farming 6.7%.

6.5.4.3 Attitudes towards river bank activity regulation and legislation

A higher number (47%) living within the buffer zone were in agreement with government of Uganda protecting the buffer zone as stated in the environmental Act 2019. However, 45% did not think that the Government of Uganda as stated in the environment Act 2019 should protect the buffer zone. The 8% were not sure whether buffer zone should be protected or not.

This could be largely because 53% had the opinion that the buffer zone belongs to individuals while only 33% had the opinion that it belongs to the Government.

However, the dwellers (49%) had the opinion that local communities are the best in protecting the protected buffer zone, although some percentage of dwellers (35%) believed that Government would be the best to manage the protected buffer zone.

In general, community believes that the best way of protecting Buffer zone without conflicting with the communities/ Government is by collaboration. Over 80% agree that collaboration is the best strategy in this endeavour. They further suggested that in employing collaboration, Government and Local communities should use the criteria of bottom up approach in order to protect the river buffer zones.

Over 76% of the buffer zone dwellers held the opinion of bottom up approach. The study reported that the key stakeholders that mostly influence the protection of buffer zone to the community, is actually the local community itself. This attitude was held by more than 70% of the river buffer zone dwellers. Those who suggested that Central Government and politicians also influenced the protection of buffer zones were 17% and 8% respectively.

6.5.5 Sub objective two

60.9% of the 121 respondents said they rented the homes they lived in, as compared to 39.1% who said they owned the homes they occupied. The majority of those surveyed (67.8%) said they had resided and utilized land in Mpanga Buffer for at least fifteen years as seen in table 6.6.

Table 6. 6: Years of utilized land in the buffer zone

Variable	Count	Valid Percent (%)
1-5 years	17	14.4
6-14 years	19	16.1
15-24 years	27	22.3
Above 25 years	55	45.5

First, the study assessed the knowledge of the residents of Mpanga catchment on the existing laws and policies on water resource buffer zone protection in Uganda. Regarding the understanding of meaning of buffer zone, 52% of people acknowledged that they understand the meaning, while 48% did not know the meaning of a buffer zone. Although every participant was resident in the buffer zone, 33% of the encroachers said their land was not in the buffer zone. Table 6.7 shows that 67.2% of the 121 respondents that said their land was in Buffer zone.

Table 6. 7: Is your land in Buffer zone

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	39	32.2	32.8	32.8
	Yes	80	66.1	67.2	100.0
	Total	119	98.3	100.0	
Missing	System	2	1.7		
Total		**121**	**100.0**		

6.5.5.1 Hypothesis testing for objective Two

A chi-square test of independence was analyzed to test the Null Hypothesis that, "there no statistically significant relationship between being knowledgeable about a buffer zone and utilizing land in the buffer zone (or the categorical variables are independent of one another). The following result was obtained; In table 6.8, the difference between the observed and the expected counts of the two variables has been displayed. It shows that the difference in counts is big, hence the two variables are not independent, and that is, there is an association between them. Hence, we rejecting the Null hypothesis.

Table 6. 8: Cross tabulation of land owned in the buffer zone and knowledge of buffer zone

			Do you understand Buffer zone meaning		Total
			No	Yes	
Is your land in	No	Count	24	14	38

Buffer zone		Expected Count	18.0	20.0	38.0
		% within Is your land in Buffer zone	63.2%	36.8%	100.0%
	Yes	Count	31	47	78
		Expected Count	37.0	41.0	78.0
		% within Is your land in Buffer zone	39.7%	60.3%	100.0%

However, in table 6.9 below, the Pearson Chi-Square=5.618 tests for independence at one-degree of freedom shows $p=0.018<0.05$ is significant. Hence, we reject the null hypothesis. 36.8% were knowledgeable about buffer zone but utilize land in the buffer zone.

Table 6. 9: Chi-Square Tests

	Value	**df**	**Asymp. Sig. (2-sided)**	**Exact Sig. (2-sided)**	**Exact Sig. (1-sided)**
Pearson Chi-Square	5.618[a]	1	.018		
Continuity Correction[b]	4.718	1	.030		
Likelihood Ratio	5.658	1	.017		
Fisher's Exact Test				.029	.015
Linear-by-Linear Association	5.570	1	.018		
N of Valid Cases	116				

Furthermore, table 6.10 shows an eta value η =0.22 and so eta-square η^2 =0.05 which indicates a medium impact of one "knowing the meaning of buffer zone" on "knowing that his/her land lies in a buffer zone".

· **Table 6. 10: Directional Measures**

			Value
Nominal by Interval	Eta	Is your land in Buffer zone Dependent	.220
		Do you understand Bufferzone meaning Independent	.220

We further interpreted the symmetric measures Table 6. 1111 below, for Phi and Cremer's V. Since the p-value of 0.018<0.05, we reject the Null hypothesis.

Table 6. 11: Symmetric Measures

		Value	**Approx. Sig.**
Nominal by Nominal	Phi	.220	.018
	Cramer's V	.220	.018
N of Valid Cases		116	

To crown it up all, the analysis looked at Fig 6. 22 below. It indicated that, there is a large difference between the lengths of the bars. So we reject the null hypothesis, and conclude that there is an association between the two variables, or the two variables are dependent, that is, not independent of each other. If one knows the meaning of buffer zone, then there are also high chances of knowing that his/her land lies in a buffer zone is high. Conversely, if one did not know the meaning of buffer zone, then there are also high chances of no knowing that his/her land lies in a buffer zone is high.

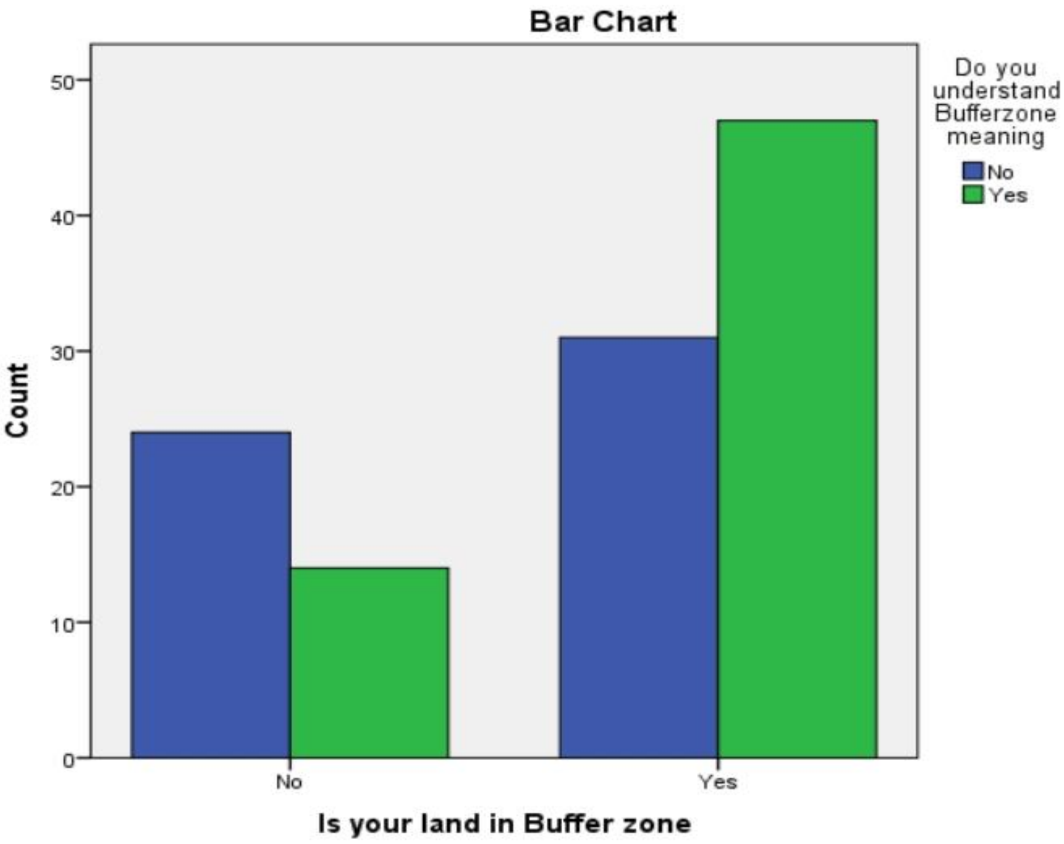


Fig 6. 2: Understanding buffer zone

Hence, all the above tests have proved that there is enough evidence to reject the null hypothesis and accept the alternative. Hence, the two categorical variables above mentioned are not independent.

6.5.5.2 Activities which are currently practiced in the Buffer zone

6.5.5.2.1 Restricted Activities

The survey data shows that crop farming and animal grazing are considered the most serious activities currently practiced within Mpanga Buffer zone in Western Uganda. 76% and 41% of dwellers practice crop farming and animal grazing respectively (figure 6.3).

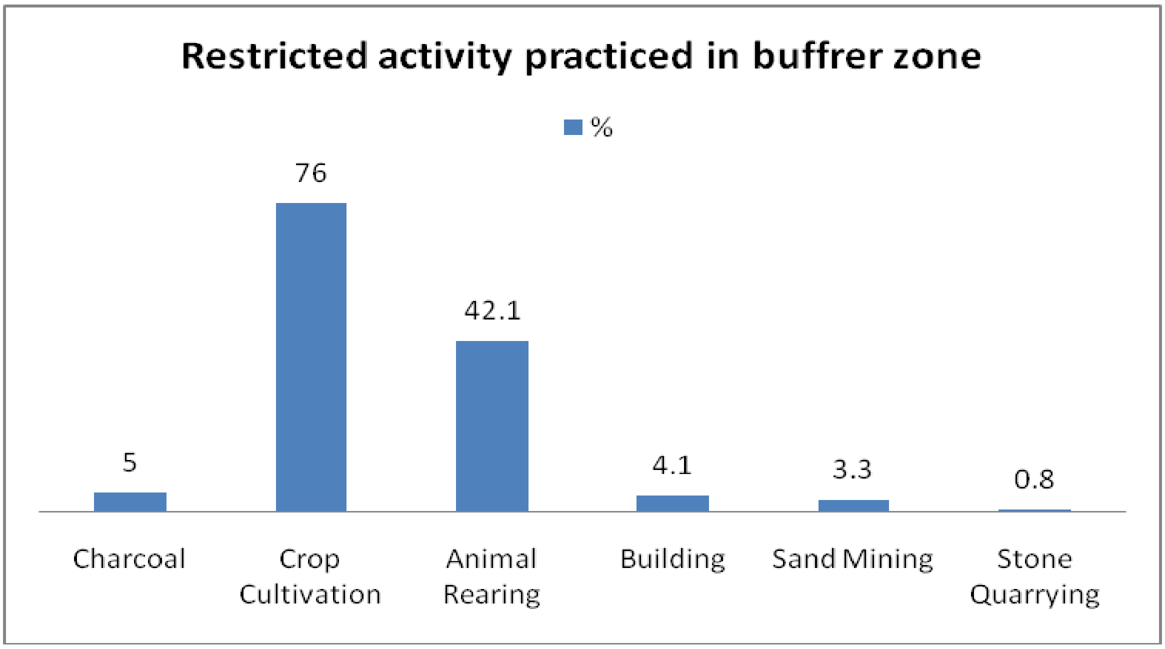


Fig 6. 3: Restricted activities in Buffer zone

While tree growing was, the most seriously regulated activity practiced in the buffer zone. This was reported by 12.4% (fig. 6.4).

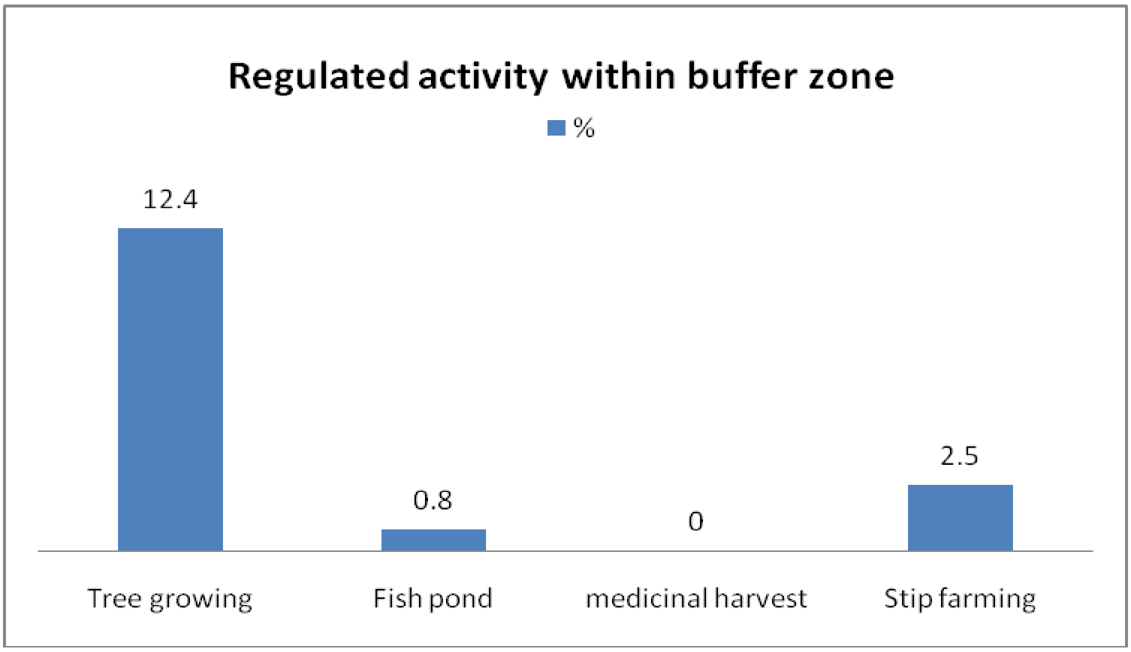


Fig 6. 4: Regulated activities in Buffer zone

6.5.5.3 Perceptions of causes of riverbank encroachment

People's knowledge about riverbank encroachment was very high (nearly 100%) as indicated in table 6.12. They defined encroachment in terms of cultivation near riverbank and illegal activities in demarcated area.

Table 6. 12: What do you understand by riverbank encroachment?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Cultivation near the river	60	49.6	65.2	65.2
	planting Eucalyptus near river/ deforestation	3	2.5	3.3	68.5
	illegal activities in demarcated area	24	19.8	26.1	94.6
	cutting down trees	5	4.1	5.4	100.0
	Total	92	76.0	100.0	
	Missing	29	24.0		
Total		**121**	**100.0**		

The question " do you think there is river bank encroachment in your area?" was asked and 65.5% said yes, while 34.5% said no, yet all respondents surveyed live within 100m river buffer zone. This further confirmed that the knowledge of knowing what a buffer zone is was still lacking among some people.

Participants were asked why there is riverbank encroachment and the following responses were obtained: The survey data shows that farming for food and need for income are considered the most serious activities for Mpanga river encroachment. Agricultural activities are considered as one of the essential factors causing buffer zone threat while 76% of people think that this activity causes very serious impact, as a restricted activity. Animal grazing accounted for 58% among encroaching activities.

However, 73% of the main encroachers were male and 27% of the encroachers were female. Respondents were asked to suggest what should be done to stop riverbank encroachment. Sensitization and alternative livelihood were suggested as major remedies to encroachment, each accounting for 24% and 26% of the respondents respectively.

6.5.5.4 Perceptions of the effects of river bank encroachment

The effects of the riverbank encroachment were surveyed and results are as shown in Fig 6. 55. Water pollution, drought, silting, soil erosion and flooding respectively were perceived as the greatest effects of riverbank encroachment. Other effects though not noticeable, were ecosystem loss and collapse of riverbanks. These changes have been noticed seasonally.

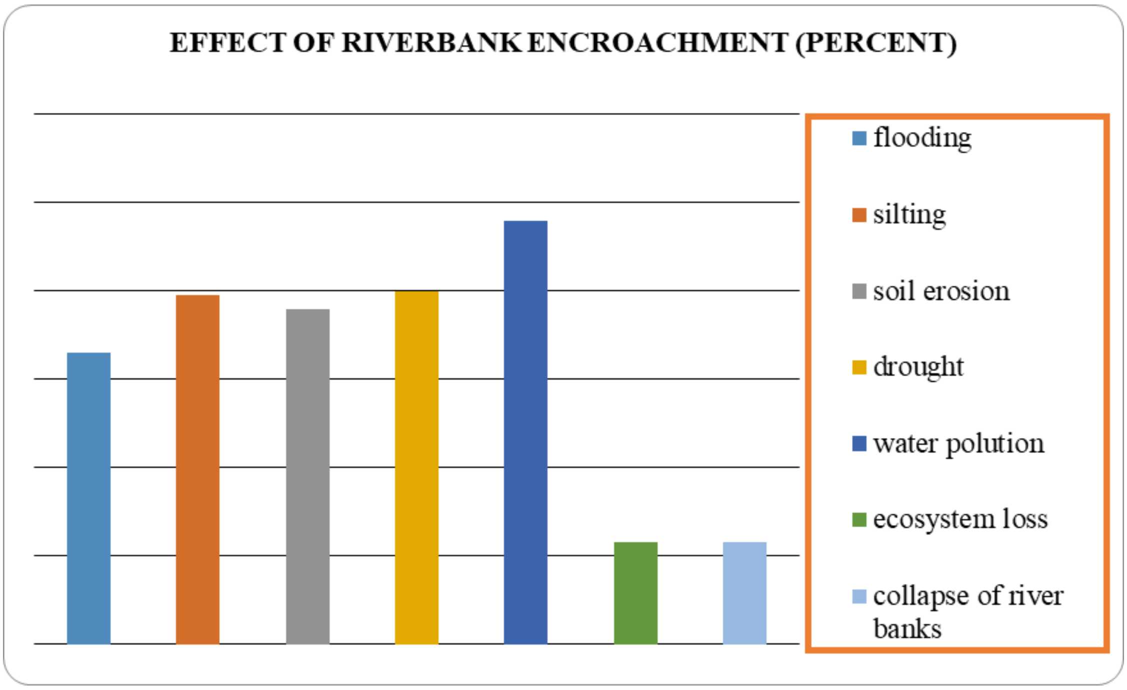


Fig 6. 5: Perception on the effect of riverbank encroachment

Fig 6. 66 shows individual proposal to mitigation of riverbank encroachment. As seen in the figure above, 20%, 14%, 9%, and 4% of those living in buffer zone suggested to respect the reserved buffer, tree planting, follow government officials advise and sensitization as the best solution to mitigate buffer zone encroachment.

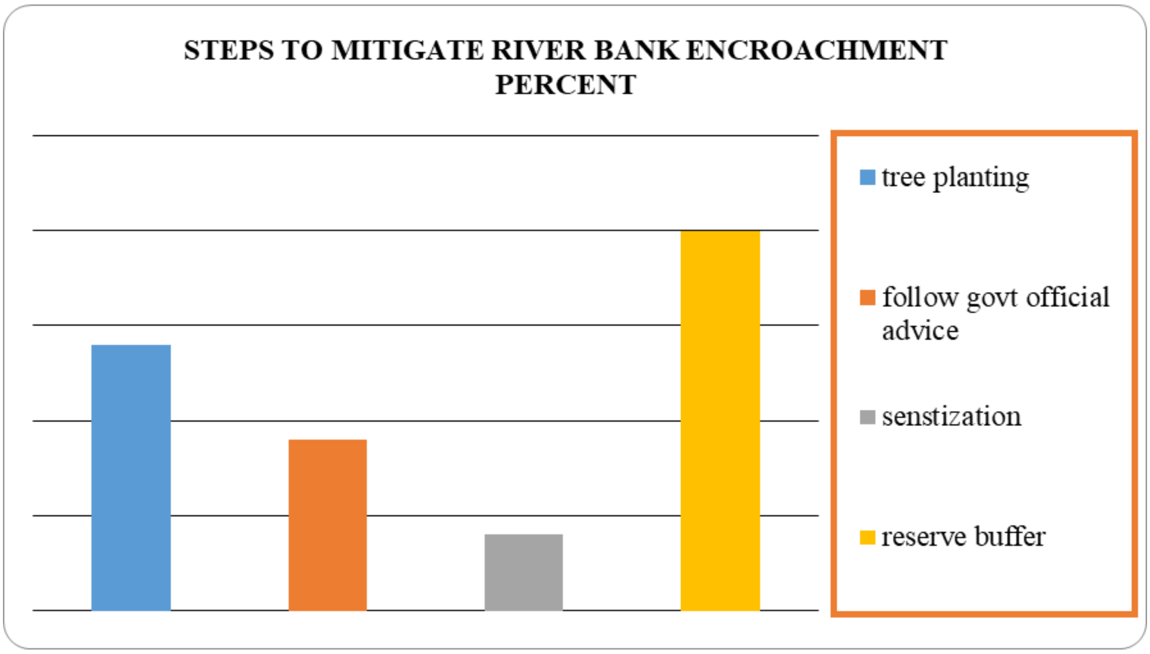


Fig 6. 6: Proposed mitigation for riverbank encroachment

Table 6. 13: Percentage of knowledge and land ownership on buffer zone

			Do you understand Buffer zone meaning		**Total**
			No	**Yes**	
Is your land in Buffer zone	No	Count	24	14	38
		Expected Count	18.0	20.0	38.0
		% within Is your land in Buffer zone	63.2%	36.8%	100.0 %
	Yes	Count	31	47	78
		Expected Count	37.0	41.0	78.0
		% within Is your land in Buffer zone	39.7%	60.3%	100.0 %
Total		Count	55	61	116
		Expected Count	55.0	61.0	116.0
		% within Is your land in Buffer zone	47.4%	52.6%	100.0 %

6.5.6 Sub objective 3

6.5.6.1 Riverbank regulation awareness

Buffer zone protection increases water quality and quantity in River Mpanga. This was agreed by over 30.4% and strongly agreed by over 61.4%. In general, about 92% agreed that buffer zone protection increases water quality and quantity of River Mpanga. Over 76% of the buffer zone dwellers equally agreed that river buffer zone protection reduces floods and their effects.

The environment Act of 2019 specifies that river Mpanga has to have a buffer zone protection area of 100m. This was disagreed by over 34% and strongly disagreed by over 61% and of the buffer dwellers. In general, about 95% do not wish to have a buffer zone protection area of 100m. Only 1.7% and 12.6% strongly agreed and agreed respectively, that the environment Act of 2019 specifies a buffer zone protection area of 100m.

Several of those that generally disagreed with a buffer zone protection area of 100m as stated had divergent views on the number of metres that should be reserved as buffer zone for River Mpanga. However, all of them (100%) suggested less than 100m, as there was none who suggested over 100m buffer zone. Majority (34%) of the buffer zone dwellers suggested a buffer zone of 50m, and a lower number (21%) suggested a buffer zone of 30m.

Of those who suggested a special consideration for towns and other developments, 23%, 27%, and 19% suggested a buffer zone of 10m, 20m and 15m respectively.

6.5.6.2 Awareness of river bank and surrounding area sustainable management practices

Regarding the advantages of buffer zone protection in improving the surrounding environment conditions like purifying the air, cool conditions, soil fertility and others, 48% strongly agreed and 39% agreed that buffer zone improves the surrounding environment conditions. Accordingly 31% and 43% agreed and strongly agreed respectively that buffer zone protection reduces the effects of climate change. The climate change effects reduced by buffer zone protection in Mpanga catchment were found to be the maintenance of water volumes, which was reported by 88%, rainfall patterns reported by 85.5%, temperature moderations by 79.7% and prolonged sunshine reported by 79.5%.

6.5.6.3 Institutional supports

Local Council 1 (L.C I) Environmental committees do exist in the area, although only 34.5% were aware of this phenomenon, whereas 65.5% were not aware of their existence. Of those who reported being aware of LC1 environmental committee, majority (73%) said that the committee does not consider concerns of people's ideas when it comes to environment management especially in the buffer zone.

The study reported that whenever there are intervention activity in the area, 67% were never consulted while 32.5% were always consulted. However, of the 32.5% who said were always consulted, 67%, 23% and 9.3% are consulted at the start, while ongoing and at the end of the intervention activity respectively. However, of the 67.5% said are not consulted, 16% reported that they are engaged in the awareness meetings, and 6% are engaged in-group benefits.

The dwellers (49%) in the area reported that they get Government assistance while 50% reported that they do never have any Government assistance. The kind of support got from the Government as reported by the riverbank dwellers is summarized in the bar chart (Figure 6.7) below:

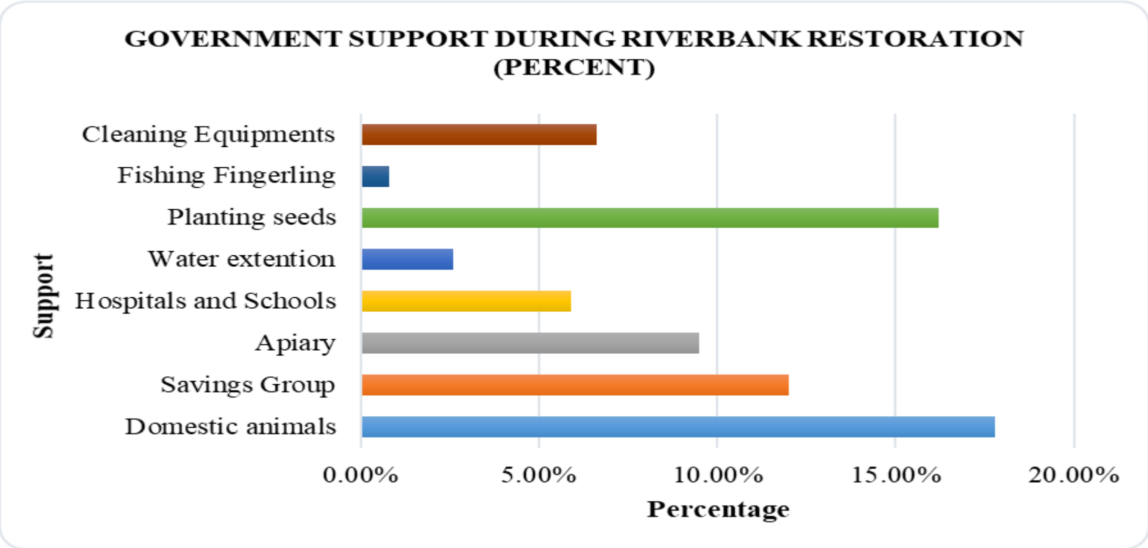


Fig 6. 7: Types of Government support during riverbank restoration programme

According to figure 6.7 above, Government supports the riverbank households with domestic animals for rearing on a rotational basis whereby after every parity the mother animal is transferred to another household while living behind the calf to support the predecessor household.

It was reported (Fig 6. 8) that planting seeds are sometimes supplied to households towards the planting season as Government support. The rest of the support as seen in figure 11 include starting saving groups and Apiary.

Below (Fig 6. 88) is a chart showing the Government institutions that normally give the above assistance to the dwellers of Mpanga river catchment. The vertical axis shows the percentage of people who reported the government institutions (multiple responses) that support the area.

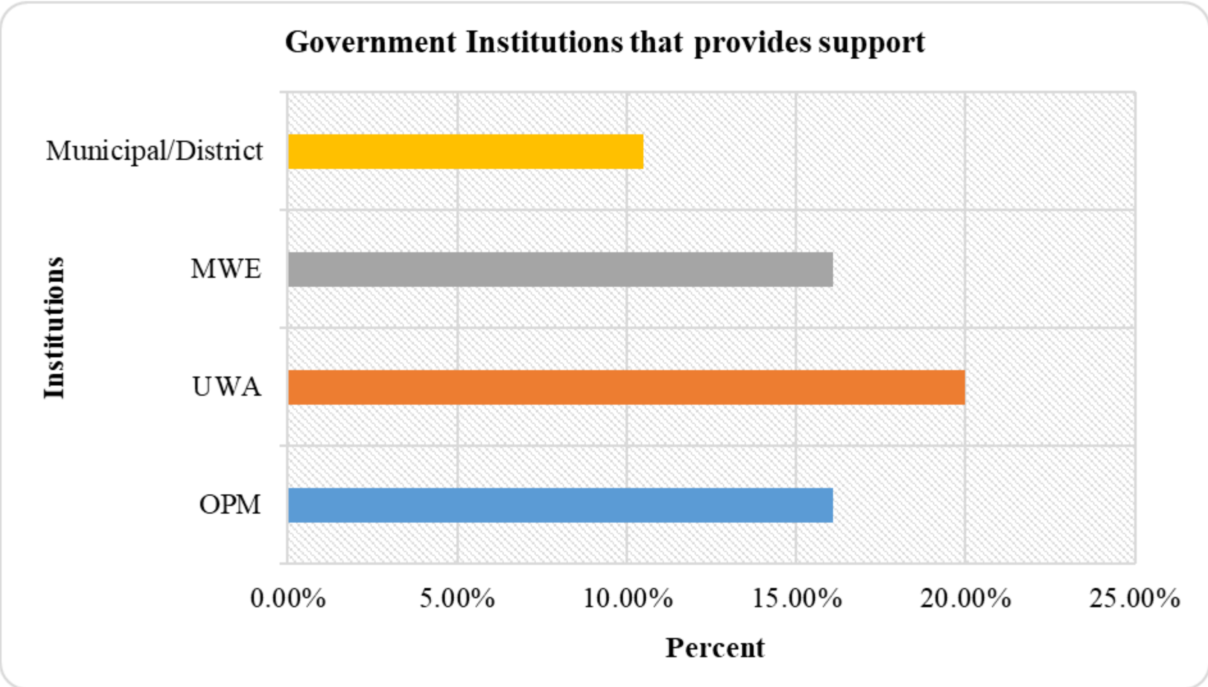


Fig 6. 8: Known Government Institutions that provide support to communities for riverbank restoration

From fig 6. 9 above, it can be seen that Uganda Wildlife Authority (UWA) tops the list of Government institutions support providers followed by Office of the Prime Minister (OPM) and Ministry of water and environment (MWE).

Fig 6. 10 showed the NGOs that normally give the above assistance to the dwellers of Mpanga river catchment. The vertical axis shows the percentage of people who reported the NGOs that support the area.

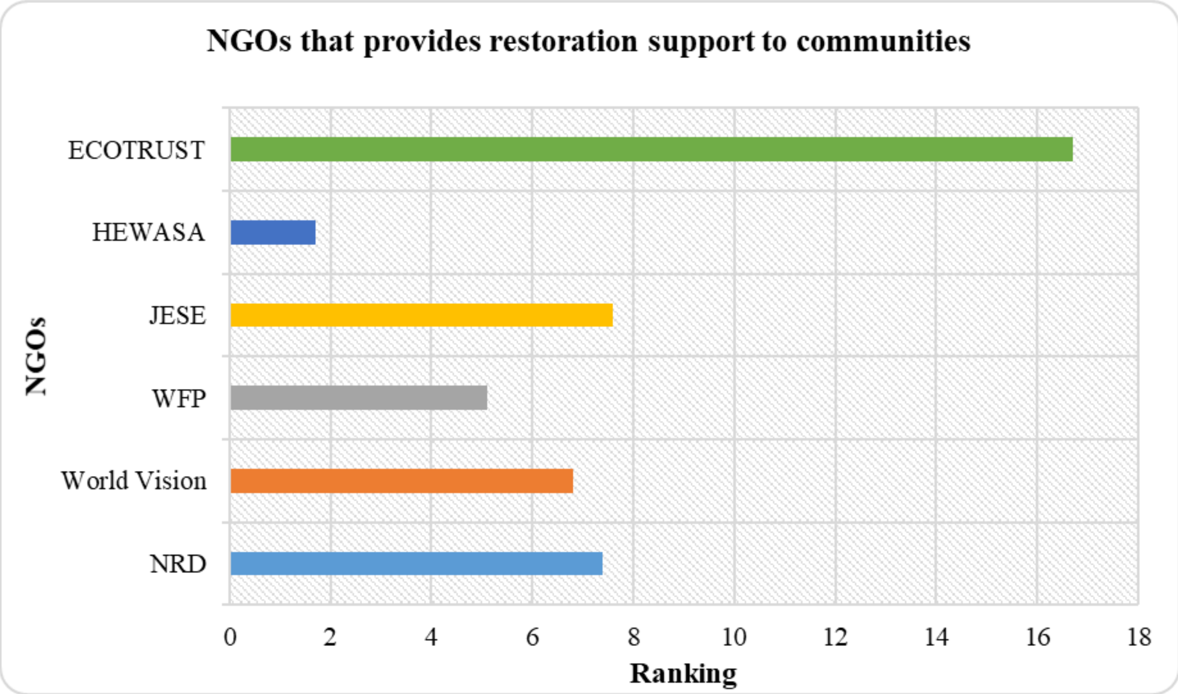


Fig 6. 10: Known NGOs that provide support to communities for riverbank restoration

NGOs equally play a pivot role in providing support to the buffer zone dwellers (Figure 10). ECOTRUST tops the list, followed by JESE (joint effort to save the environment) a local NGO in Fort Portal and NRD.

Dwellers suggested the following measures to increase Government and NGOs support for buffer zone protection in the area:

Collaboration with local leaders (38%) was the most prominent measure suggested by dwellers in this study. This was followed by a suggestion to organize the community into groups/teams (15%) to monitor and patrol the riverbank zones.

The suggestions made by the community on how to ensure the Laws about protection of buffer zone included, most notable was sensitization to the community(by 50%) and enforcement of the Laws (20%). Other suggestions include taking personal responsibility and regular monitoring of the buffer zone.

Fig 6. 1111 showed the percentage reported by dwellers as measures to increase Government and NGOs support in terms of buffer zone protection in the area.

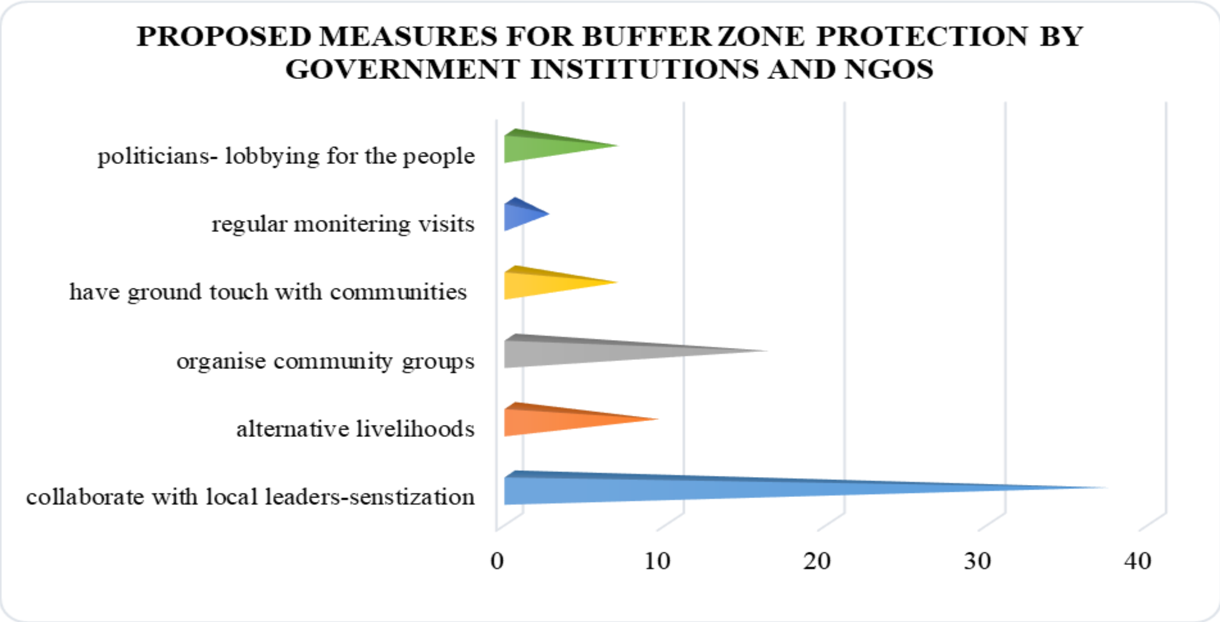


Fig 6. 11: Proposed measures for increased Government and NGOs on buffer zone protection

Fig 6. 12 showed proposed approaches by the community on enforcement of river buffer zone protection laws.

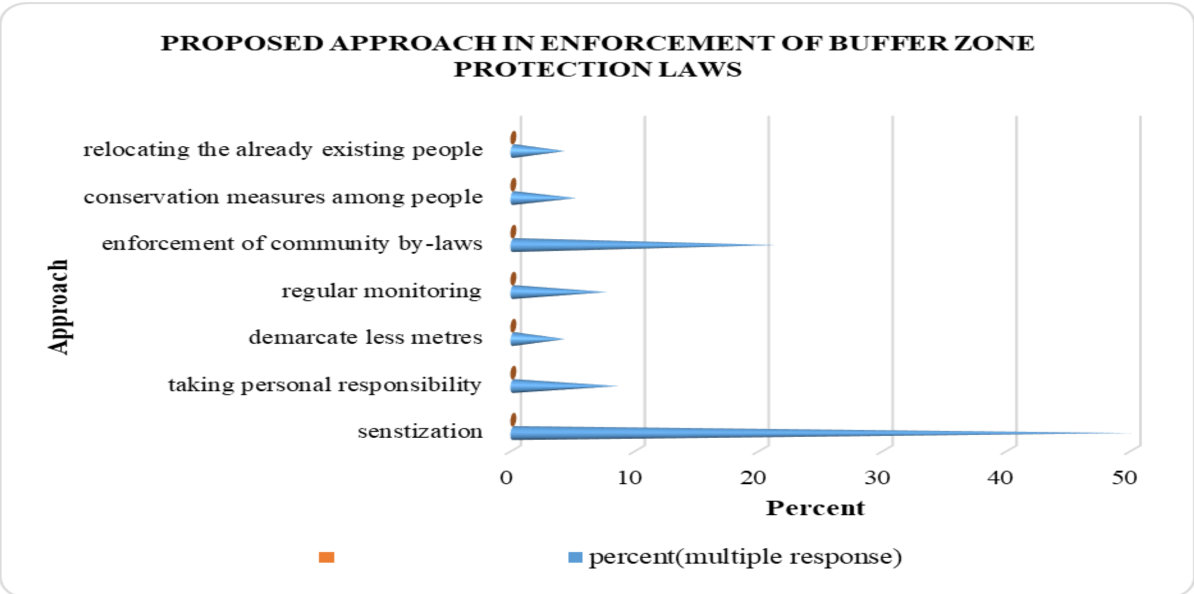


Fig 6. 12: Proposed approach to enforcement of river buffer zone

6.6 Discussion

This section interpreted and discussed the results presented in the previous chapters.

6.6.1 *Objective 1: To assess the variability of community attitude towards river bank activity regulation and legislation*

The results showed that there are low awareness levels on River bank protection, as the majority of the respondents indicated that they had not had anyone share with them any knowledge on the topic. This was in line with findings from the research done by [7] whose study showed that there was a lack of awareness on environmental protection of buffer zones, which resulted into the degradation of the water quality and quantity of rivers in Uganda.

Most of the research done in the Mpanga River catchment had shown that the leading cause of degradation of the catchment had been because of anthropogenic activities [2], [11], [16]. References [7] [2] have attributed the prevalence in the vice to the lack of environmental management awareness of the communities. A study by [1] showed that environmental education can enhance the behavioural intention of the public to willingly participate in River management as well as positively change their attitudes and perceptions about water quality.

6.6.2 *Objective 2: To evaluate community's perception and understanding of river buffer encroachment and regulation*

These findings are consistent with the findings of Iza Chimbo et el (2023) who assessed knowledge and practices towards water source protection of River Ngombe residents in Zambia, who found out that the residents had the opinion of a 50m river buffer zone. The study found out that the 50m river buffer zone should be general along the river system. This was suggested by 79% as opposed by 21% who had the opinion that there should be special considerations in scenarios like cities, towns and other developments.

The link between education level and riverbank legislation awareness showed a linear increase in awareness as the level of education increased. About 70% and 48.1% of those with no formal education and those with primary education respectively aware of the regulations. In contrast, the level of awareness increased to 70% for those with a university/college education. This observation suggests that increasing awareness campaigns may reduce the rate of encroachment in Mpanga buffer zones.

The link between age and riverbank legislation awareness indicated that most people aged 15–29 and 30–44 years were more aware of riverbank legislation by 60% and 54.5%, respectively. However, significant proportions (40% and 45.5%) of this active group were still unaware of the riverbank regulation governing the buffer zones of rivers. This trend implies the need for intensive sensitization for sustainable buffer zone management in the future. However, for the elderly under the category above 45 years, only 37.5% of people were aware, and 62.5% were unaware. This triggers the need to extend sensitization training to the elderly group, which can be used to educate young ones in the villages.

6.6.3 Objective 3: To assess the level of Community awareness to institutional support and riverbank zone regulation

This research indicated that the majority of the respondents who were residents of Mpanga buffer zone were not aware of the existing laws and policies on water resource protection as very few of them had an idea of the importance of a buffer zone and on the prescribed minimum distance of 100m for a river buffer zone according to the Ugandan law. Some of the respondents, who reported that the prescribed minimum distance of a river should be 100m, based their response on a good guess. The knowledge on the prescribed distance was compared to the level of education attained by the respondents; the results revealed that the majority of the respondents who knew the prescribed distance had attained secondary level of education. However, some of the respondents who knew the prescribed distance of 100m indicated that they had never been to school yet they were able to give a correct answer. Similarly, most of the respondents who did not know the prescribed distance of 100m had not attained a secondary level of education. Furthermore, some of the respondents who knew about the prescribed distance of 100m indicated that they were educated on water resource protection through television and the Ministry of Water and Environment (MWE).

Most of the respondents who indicated that they knew the importance of a river buffer zone reported that it was necessary in order to prevent their houses from flooding and collapsing, very few of the respondents gave examples that directly related to water resource protection.

6.7 Sub conclusion five and recommendation

Regardless of the recently implemented efforts to limit encroachment activities, the incapacity to eliminate socio-economic activities along the buffer zones threatens the sustainability of these rivers. The persisting increase in socio-economic activities like agriculture along buffer zones imperils the river ecosystems, guaranteeing little survival for aquatic biodiversity. Eutrophication is one of the existing impacts of agricultural activities, which is likely to create anoxic conditions and thus lead to the loss of aquatic biodiversity. Increased artificial areas in buffer zones due to the collective demand for population growth and economic expansion affected river characteristics like river flow and flood attenuation. Rivers have become more susceptible to floods, stream perturbation, and sedimentation; far worse, some rivers are in the blink of disappearing due to drying. The corresponding increase in agricultural land and the built-up area in the buffer zone implies a significant decrease in forest cover and Shrub lands. Deforestation practices threatens the recharge capacity of rivers during dry seasons, considering the unreliable hydrologic patterns influenced by climate change. The removal of Shrub lands and forests threaten the disappearance of species like fig trees, alongside an increase in the sediment level and excess evapotranspiration from rivers. The surrounding community may also endure water stress scarcity in the near future. An increase in fallow land impaired fertile soils by exposing them to active agents of soil erosion like wind and water. The loss of soil fertility succumbed the soil to stress from manure and chemical fertilizers. The soil has also accumulated a questionable number of pesticides and herbicides that are used to kill weeds and pests. Deteriorating soil quality has also affected the compactness of soil particles and, thus, increased sediments. The authors recommend that water managers and decision-makers redefine the strategies that increase the effectiveness of governing buffer zones for sustainable management amid climate change. Further studies should focus on predicting future changes, which could occur due to encroachment activities and the cost that the government will experience in remediating these changes if quick measures are not implemented. The economic feasibility of implementing EMA, 2004 should be reviewed to identify its areas of weakness and to recognize the areas that require re-enforcement.

CHAPTER SEVEN: GENERAL CONCLUSION AND RECOMMENDATION

7.1 CONCLUSION

The main aim of the study was to assess the water resources availability, allocation and management along river Mpanga.

Objective 1: determination of the spatial and temporal distribution of available water resources, factoring the influence of climate change in the Mpanga Catchment

The trends in annual daily maximum and average rainfall across the catchment over the 30 years. There was a significant ($p<0.05$) decline in maximum and average annual daily rainfall across the entire catchment catchment. Analysis of variability in rainfall provides an opportunity to characterize changes in climatic wet conditions across the Mpanga catchment.

Based on the linkages between the variation in wet climatic conditions and climatic indices (NDD<1, NDD<5, NDD>5, NDD>10), it can be possible to predict an upcoming period of excess water for predictive storage and continuous water availability for use.

Objective 2: determination of the current and planned water use and project future demand

This study is timely for the Mpanga catchment, which is under massive pressure, due to high rates of population growth, that have further fuelled catchment degradation. The study points to the uncontrolled growth rates of all service levels. Particularly, a red flag should be raised for the fisheries sector, whose trend is very alarming.

Based on the

Objective 3: evaluation of water demand management options and allocation under different scenarios, in a sustainable manner

The unallocated water (available water) within each of the sub catchments was determined using the Mike Hydro Basin modelling. The inputs in this model are; precipitation data, evapotranspiration data and observed flow data. The results from the modelling indicated that less water is available within the months of January, February, and March, June, July and August. Due to the limited time in which this assignment was required to be completed, the following assumptions were made;

Objective 4: assessment of the influence of anthropogenic and land use activities on water quality

Expanding urban settlement in Fort Portal has a negative effect on water quality of river Mpanga. Typical variable causing water quality change is conductivity, which is assumed to originate from the wastewater treatment plant and surface runoff within the municipality.

Increased cropland and or farm areas under plantations has the potential to increase total nitrogen into the water.

In the grassland/animal grazing areas, total phosphorus was found higher than in all the land use types.

Objective 5: assessment of the populace perception on controlled activities within the river buffer zone, in accordance with the Environment act 2019

Objective 5.1:

61% of individuals were aware of the existing laws/ act/regulation of river buffer zone protection but only 55% adhere to these laws or others still practiced negatively impacting activities. Pearson's correlation coefficient indicated weak and insignificant relationship between attitude for restoration of buffer zone and social characteristics of respondents (such as household size, age, occupation and education). The study showed that local villagers generally hold positive attitudes towards river buffer zone protection. However, awareness of the effect of river buffer zone encroachment are not high. Age, length of residency, and schooling years are observed to be significantly influencing attitudes towards river buffer zone protection. 59.2% said the demarcation is good, and dwellers (49%) had the opinion that local communities are the best in protecting the protected buffer zone.

Objective 5.2:

People's knowledge about riverbank encroachment was very high (nearly 100%). 67.8% of the surveyed community had resided and utilized land in Mpanga Buffer for more than 15 years. Chi-square test of independence rejected the Null Hypothesis that, "there no statistically significant relationship between being knowledgeable about a buffer zone and utilizing land in the buffer zone.

Crop farming and animal rearing were the main restricted activities practiced in the buffer zone, while tree growing was the main regulated activity practiced in the buffer zone. 73% of the main encroachers were male and 27% of the encroachers were female. Water pollution, drought, silting, soil erosion and flooding respectively were perceived as the greatest effects of riverbank encroachment.

Objective 5.3

92% agreed that buffer zone protection increases water quality and quantity of River Mpanga. Over 76% of the buffer zone dwellers equally agreed that river buffer zone protection reduces floods and their effects. 39% agreed and 48% strongly agreed that buffer zone protection improves the surrounding environment conditions like purifying the air, cool conditions and soil fertility.

95% did not know that a buffer zone protection area is supposed to be 100m. However, (100%) suggested that less than 100m buffer zone protection area would be ideal. Majority (34%) of the buffer zone dwellers suggested a buffer zone of 50m, and (21%) suggested a buffer zone of 30m. Majority are not aware of the existence of LC1 environment committees, and rarely do those committees consult the local people on environmental concerns. However, about 50% of dwellers in the buffer zone catchment agree that Government and NGOs do extend support in terms of monetary, technical or in kind to champion river buffer protection.

Government and NGOs need to collaborate with local leaders in order to increase support to buffer zone protection. Sensitization to the community is main way to ensure that the law to protection of buffer zone followed. The findings of this study are useful for advancing regional and national policies and practices for sustainable water resource management.

7.2 RECOMMENDATIONS

Objective 1: determination of the spatial and temporal distribution of available water resources, factoring the influence of climate change in the Mpanga Catchment

This research recommends that, further studies in the future across the WMZs should focus on the following;

The predictive potential of changes in drought indices on a seasonal river system.

Analysis of the impact of variability in PET_o to catchment water losses across the Mpanga catchment.

Correlation in seasonal variation in temperature on extreme rainfall episodes.

Objective 2: determination of the current and planned water use and project future demand

Efficient and innovative use of the available water resources is encouraged, to lessen the pressure of human activities on the already endangered resources. These include rain water harvesting, Re-use of waste water for alternative activities, waste recycling,

There should be both preventive and corrective measures to safeguard the existing water resources through nature- based solutions to maintain and rejuvenate the Mpanga catchment. Only then can the quantity and quality of available water be sustained for the future.

There is need for government to enforce the water use laws so as to bring down the high rates of illegal and unpermitted water abstraction. Relatedly, there should be closer collaboration between the ministry of water and environment, and the technical officers at district level, to ensure robust and updated water use records.

Continued sensitisation among the water users is instrumental in creating paradigm shifts and mindset change. This is the most important step in fostering responsibility and a sense of ownership of water resources by the local masses.

Lastly, should resources be availed, this study should be furthered to the micro catchment and parish level. Through further research, the real challenges facing the water resources will be well contextualized, leading to well informed decisions and policies in the future.

Objective 3: evaluation of water demand management options and allocation under different scenarios, in a sustainable manner

There is a need for reliable and continuous hydro meteorological data in order to promote Integrated Water Resources Management in the Mpanga Catchment. Therefore, it is advisable to employ smart technologies to collect, share and analyse large volumes of data in real-time.

There is need to improve the current study by taking into consideration the effects of climate change, and the effects of increased urbanisation of the catchment.

There is need to improve the current study by adding more water allocation scenarios to the model rather than the current and future scenarios. This will provide for a more comprehensive study.

The effect of climate change in the future was not catered for; this significantly affects precipitation, temperature as well as evapotranspiration values.

The effect of changing land uses – particularly the urbanisation of smaller towns within the catchment was not considered. This would significantly increase the volume of runoff into the river.

The water availability was therefore majorly based on the demand estimation and projections.

Objective 4: assessment of the influence of anthropogenic and land use activities on water quality

Noting that this assessment relied on historical water quality data and secondary information on land use, a detailed assessment study is therefore recommended. The study should be able to correlate land use pressures linking with current water quality of river Mpanga.

For sustainable water quality management, dedicated sampling sites on the river should be reconstructed to monitor parameters comprehensively.

As land use effects tend to correlate to increased effects of floods (causing dilution and sedimentation), monitoring of water quality should capture seasonality effects.

Installation of hydrological equipment at all the sites of water quality sampling will enable determination of discharge measurements to compute pollution loads. Discharge measurements should be done on real time but also on specific days of water quality sampling.

Expanding the range of water quality parameters should be considered. This includes, heavy metals, trace organics such as pesticides, pharmaceutical residues and plastic residues.

Objective 5: assessment of the populace perception on controlled activities within the river buffer zone, in accordance with the Environment act 2019

Sub Objective 1: To assess the variability of community attitude towards river bank activity regulation and legislation.

Zoning is crucial for the management of R. Mpanga buffer zone. The absence of demarcation along the buffer zone of R. Mpanga, especially in Fort Portal City, resulted in some anthropogenic activities such as deforestation, gardening, brick molding, among others, along the buffer zone. The zones' functions and boundaries need to be clarified and made available to people, especially what can and cannot be done in each zone.

Demarcation should be done in consultation with local communities. From the results, we see that only about 14% were aware of the 100m buffer zone for rivers, while about 95% were not aware/disagreed with the 100m buffer zone for rivers. About 54% suggested a buffer zone of 30-50m, with 46% suggesting a buffer of less than 30m. This disillusion has a big implication when it comes to demarcation without consultation with local communities.

The core zone needs to be actively enforced by joint Local Government Authorities and village people, and communication should be implemented in the communities to understand the zones.

Sub Objective 2: To evaluate community's perception and understanding of river buffer encroachment and regulation.

Integrating knowledge about river buffer protection values into the curriculum of local high schools to raise awareness and attitudes of the younger generation. It was observed from the findings of this study that the level of awareness increased to 70% for those with a university/college education. This observation suggests that increasing awareness campaigns may reduce the rate of encroachment in Mpanga buffer zones.

Involve communities surrounding the River in the management of the buffer zone and ensure direct input into decisions made in their area. The link between age and riverbank legislation awareness indicated that the older people were more aware of riverbank legislation, hence the need for intensive sensitization for sustainable buffer zone management.

Villagers should be involved in the active patrolling and enforcement of their River buffer zone. Rules should be recognized at all levels of communities.

Involve villagers directly in the monitoring of the buffer zone. Whenever there are intervention activity in the area, villagers must be consulted by participatory. Majority (67%) reported that LC1 Environmental committees never consult them when it comes to environment management especially in the buffer zone.

Sub Objective 3: To assess the level of Community awareness to institutional support and riverbank zone regulation.

Enforcement should be improved with community participation. Over 76% of the buffer zone dwellers held the opinion of bottom up approach. They suggested employing collaboration between Government and Local communities. These should use the criteria of bottom up approach in order to protect the river buffer zones.

Setting up community conservation teams/groups to monitor river buffer zones.

Social network and social communication should be further promoted since it is an important and effective mechanism for river buffer protection awareness improvement of local people.

Involve communities surrounding the River in the management of the buffer zone and ensure direct input into decisions made in their area.

Villagers should be involved in the active patrolling and enforcement of their rules. Rules should be recognized at all levels of communities.

Involve villagers directly in the monitoring of the buffer zone.

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ANNEXES

Shall entail; the raw data, i.e., chemistry, un processed SPSS data