DROUGHT AND FLOOD RISK ASSESSMENT ON MANYAME RIVER BASIN, ZIMBABWE UNDER CLIMATE CHANGE

Author :* RUKARWA Lorraine (MEE15632)

Supervisor: ** GUYSEV, Maksym HASEGAWA, Akira

ABSTRACT

This study was focused on analysis of the magnitude, frequency and severity of the historical, current and future water related disaster risks in Manyame catchment of Zimbabwe. It involved the analysis of historical and future precipitation trends, frequencies and severities using several climatological and standardised indices, and numerical models. For the future climate analysis daily precipitation from the 20-km grid MRI-AGCM3.2S for the past (1979-2003) and future (2075-2099) was used. The historical damages of floods and droughts were correlated to the rainfall anomalies by use of Standardised indices (SPI, SPEI, and SOI). The results of the present precipitation analysis indicate an increasing trend of the wet conditions by 15% and also 33% increase in dry conditions particularly the mid-season droughts a situation that is going to be reversed in future climate projections considering RCP8.5. The future climate show the 100% increase of the flood risk and 42% increase in drought risk. There is therefore need employ both software and hardware measures to reduce the impact of flood and drought in the basin.

Keywords: *Floods, Droughts, Frequencies, Climate change, Risk*

INTRODUCTION

Water related disasters are the most common and frequent natural hazards constituting 90% of the total disasters in the world (UNDP, 2014). This is aattributed to spatial and temporal variability of precipitation whose extremes alternatively culminate as of flood and drought both dreadful hydro-meteorological disasters. In Africa water related disasters contribute to 92% of the natural disasters casualties (CRED, 2016) with floods causing the greatest fatalities and damages while drought affects the largest number of people at a time. Accordingly, Zimbabwe is a vulnerable country in sub-Saharan Africa to the devastating effects of floods and droughts. In March 2000 the country was hit by tropical cyclone Eline, which swept away roads, destroyed infrastructure and homes worth over 300 million USD, led to the death of over 200 people and left 40,000 people homeless (CRED, 2016). The country experience recurrent drought due to its semi-arid climate with the 1992 drought being the worst in recorded history. In 1992, cereal production dropped to 25% of the annual requirement crippling food security in the country, worse still most water resources dried up resulting in unconceivable consequences such as starvation, hunger and thirst of over 80% of the population (Tobaiwa, 1993). Apparently, occurrence, frequency and intensity of the extreme precipitation events have been on the increase over the past 25 years (Meehl *et al.*, 2000) causing more death and damage to property thus

*Irigation Engineer, Department of Irrigation, Zimbabwe
**Research Specialists ICHARM, PWRI, Japan

posing major obstructions to the attainment of human security and sustainable socio-economic development in the world. This study was therefore aimed at characterising the past and present trends, frequencies and severities of floods and droughts in Manyame catchment of Zimbabwe one of the main economically important basins in Zimbabwe. It also estimated the future flood and drought risk in order to create a basis for decision making about the management of water resources in an integrated way that will achieve a balance between flood control and drought management. The study was done in Manyame river basin (Figure 1a) located north of Zimbabwe, measuring 25,497 km^2 covering about 15% of Zimbabwe. The study incorporated the areas that drain into Manyame river which springs from the central Zimbabwe flowing in a northerly direction into Lake Cahora Bassa along Zambezi River in Mozambique. The Manyame basin is a sub-basin of Zambezi river basin (Figure 1b) which is the 4th largest basin in Africa measuring 1,390,000 km^2 covering 4.5% of Africa and 54.6% of Zimbabwe spreading over eight southern African countries. The Manyame basin has many dams that can be used to control the impacts of floods in the catchment such as Mazvikadei and Darwendale dam. The Manyame catchment outlet lies low lying flood prone area of the middle Zambezi basin between Kariba and Cahora Bassa dams and a confluence of 4 big rivers.

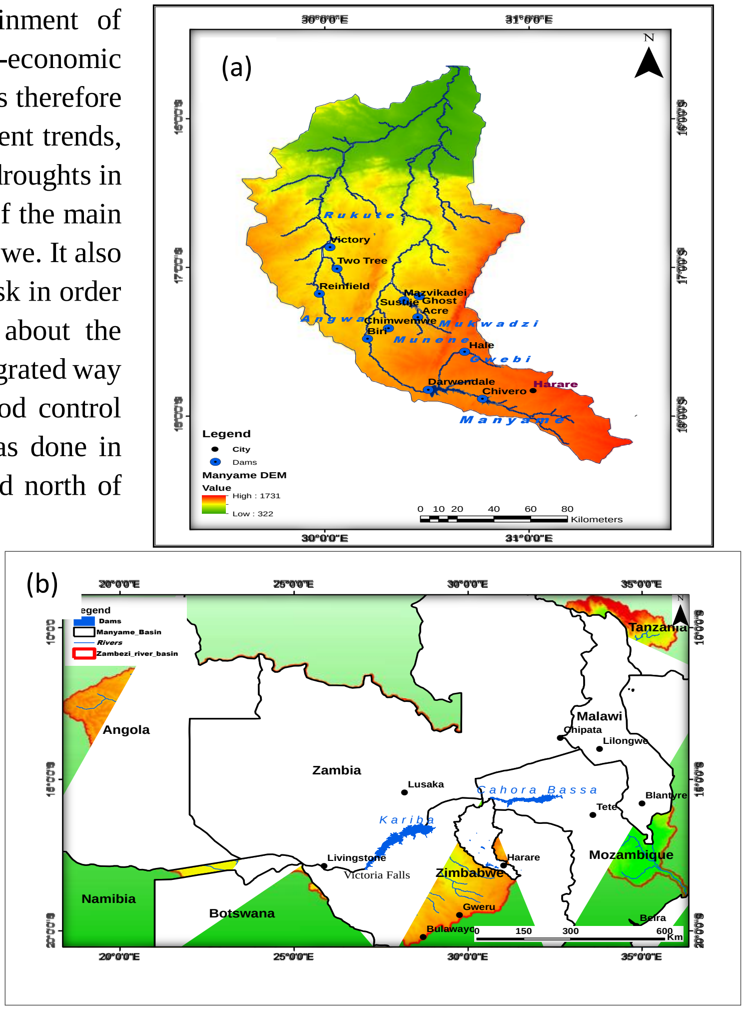

Figure 1: Location of the Study Area.

THEORY AND METHODOLOGY

The study established the water related disaster risk in Manyame river basin of Zimbabwe. Historical precipitation was analysed in order to ascertain trends and frequencies in precipitation anomalies. Extreme dry and wet precipitation was analysed with several climatological indices, namely mean rainy day index (RDI), consecutive dry days (CDD), consecutive wet days (CWD), maximum 5-day rainfall total (R5d), simple daily intensity index (SDII), annual maximum daily rainfall (R1d), and heavy precipitation (>10 mm) days, and two standardized indices such as Standardised Precipitation Index (SPI) (McKee *et al.*, 1993) and Standardised Precipitation and Evaporation Index (SPEI) (Vincete-Serano *et al.*, 2010). The historical damages of floods and droughts were correlated to the standardised indices in order to establish relationships that can be used to predict the disaster risk in the future using statistical methods. For the climate change assessment, the MRI-AGCM3.2S precipitation was bias corrected using daily PGF-AFDM precipitation dataset (Sheffield *et al.*, 2006) for the present and future Representative Concentration Pathway 8.5 (RCP8.5) scenario with 4 sea surface temperature distributions. Precipitation was analysed using the aforementioned climatological indices for the present and future climates while the comparative SPI (Hasegawa *et al.*, 2015) was used to evaluate future flood and drought frequency and severity based on the present climate conditions. The block-wise

TOPMODEL (BTOP) (Takeuchi *et al*., 2008) models was used to simulate past and future flood hazards after calibration and validation using the available river discharge data. The output was then analysed to quantify the future flood risk by comparing the changes in discharges indices such as mean flow rate, peak discharge, days above a threshold and days of low flow.

DATA

Daily and monthly precipitation data obtained from local weather stations was utilised for historical analysis of the Manyame Basin. For simulating flood risk for the Zambezi Basin, Princeton University Global Forcing (PGF) dataset (Sheffield *et al*., 2006) which has high resolution for Africa made for Flood and Drought Monitoring (AFDM) satellite rainfall was used. Topographical data downloaded from USGS HydroSHEDS website. For climate change simulations the daily precipitation datasets projected with MRI-AGCM3.2S were bias-corrected with PGF-AFDM reference dataset using a non-parametric method (Inomata *et al*, 2011).

RESULTS AND DISCUSSION

Present flood and drought risk

The results of the extreme precipitation analysis using climatological indices shows 33% increasing trend of dry conditions as signified by the decreasing trend of the RDI in a season by one day in 4 years and the reduction trend of the SDII The rainy season is therefore presently becoming dryer. The consequences of this scenario is a reduction in yield of corn by 16-60% thus compromise household and national food security (Bänziger *et al*., 2002). On the other hand, the extreme high rainfall precipitation are showing a slower increasing trend in frequencies and intensities with an average 15% increase in the extremes R1d, annual heavy precipitation days as well as CWD. The analysis of standardised indices clearly provide a visualisation of past flood and drought such as the 1982, and 1992 extreme drought as well as the 2000 floods (Figure 2). However, for the period after 2002, the SPI and SPEI are showing incongruity with the indices showing different patterns. This is an indication of the increase in seasonal variability temporal distribution of rainfall within the season. Furthermore, the past extreme precipitation have a strong corelation with the extreme Southern Oscillation Index (SOI) which is an indicator of the El Nino and La Nina phenomena which are presumed to be main cause of rainfal variability Southern Africa. Apparently, the standardised drought indices (SPI and SPI) and SOI showed a positive correlation of above 60% (Table 1). For the El Nino or La Nina years, the former has a stronger relationship of over 70%. Therefore, the phenomena can be used to predict the occurrence of drought and can be used as an early warning signal to reduce the impact of disaster.

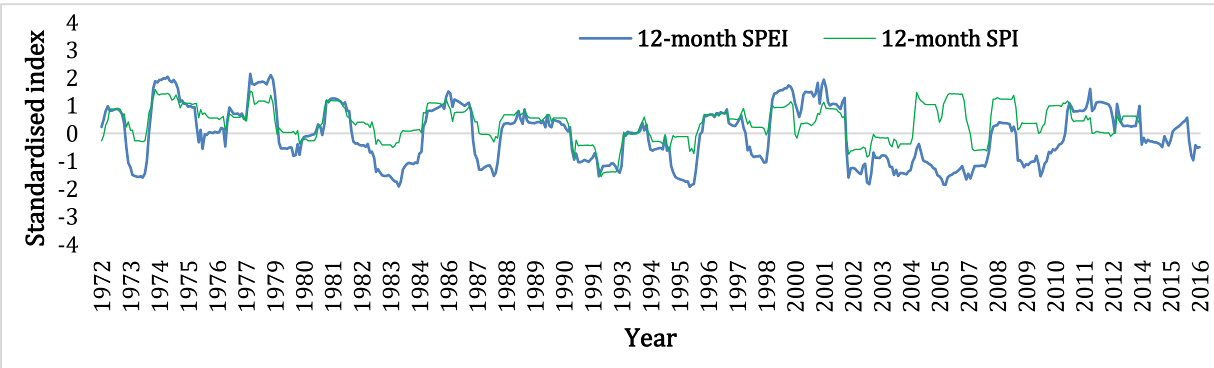

Figure 2: 12-month SPI and SPEI time series for Banket research station in Manyame catchment.

Table 1: Correlation coefficients between SST anomalies and drought indices.

	1-month SPEI	1-month SPI
Southern Oscilation Index (SOI)	0.67	0.52
La Nina	0.67	0.62
El Nino	0.72	0.70

The past extreme precipitation brought about several impacts including food and water shortages. Analysis of annual crop assessment and vulnerability assessments reports showed that SPEI and harvested area show a direct relationship (Figure 3) thus droughts have a significant effect on the area planted. However, the productivity as depicted by household cereal production exhibits a parabolic relationship with the productivity reducing during drought and also declining as the received rainfall exceeds the normal to severe wetness conditions signifying that both floods and drought have an effect on the productivity hence the need to manage them both simultaneously. The impact of these disasters

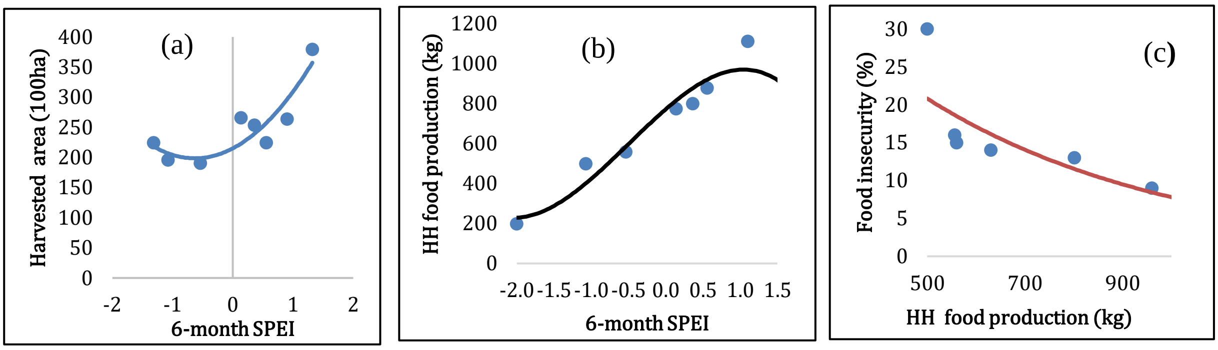

Figure 3: (a) SPEI vs harvested area, (b) SPEI vs household food production, and (c) Household food production vs food insecurity.

is shown by the prevalence of food insecurity among all the households. During drought years the catchment can only on average produce less than 40% of the household cereal requirements leading to high levels of food insecurity.

Future flood and drought risk

The results of the Pav analysis shows an average increase of 7.85% in in future considering the RCP8.5 scenario. The extreme precipitation analysis results in Table 2 also show an increase in extreme precipitation indices such as heavy precipitation days, CWD and R5d. On the other hand, the severity of dry conditions will increase as evidenced by the increase in CDD in a season which will rise to unprecedented levels with maximum increasing from of 28 to 32 days per year. Moreover, the 12- month cSPI median is showing a shift towards wetter condition with other shorter scales individually showing a shift towards the dry conditions. Notably, a greater median shift is in the 3-month cSPI of February-April signifying in dry conditions in the late summer season hence the need to craft the cropping calendar that can escape this dry period. According to the 1-month cSPI analysis there is going to that 33% of the floods in the years 2075-2099 will be experienced in January representing a shift from the present scenario where the peaks are usually experienced in February. This was complimented by the numerical model output (Table 3) where the river discharge is also showing an increase in the days above a threshold of 900 m^3/s which are going to be increase by 42% from an average of 43 to 61 days per year. The average days of low flow (<150 m^3/s) are going to be 6% lower. In addition, the maximum days of low flow per year is also going to decrease by 12%. Hence there is need to match the growing flood risk and the prevailing drought risk in order to achieve absolute water security in Manyame catchment.

Table 2: Ensemble average of future extreme precipitation analysis for Banket research station.

Index	Present	% Change	Future mean
R1d (mm)	143.6	-13.7	124.0
Pav (mm)	615.2	7.85	636.5
Rainy days	49.0	5.6	51.8
SDII (mm)	11.4	-1.3	11.3
Annual heavy rainfall days	18.0	9.7	19.8
CDD	28.0	17.0	32.8
R5d (mm)	173.9	34.6	234.0
CWD	10.1	20.2	12.2
12-month cSPI median	0.1	-	0.3
3-month cSPI Median(Feb-April)	-0.1	-	-0.5

Table 3: Future discharge analysis using BTOP output for Mhangura gauging station.

Index	Mean % change	Present	RCP 8.5	RCP 8.5 C1	RCP 8.5 C2	RCP 8.5 C3
Mean discharge (m^3/s)	40	2399	3750	3535	2935	3246
Max discharge (m^3/s)	69	4902	9809	7584	7149	8568
Min discharge (m^3/s)	10	688	619	566	549	743
Mean days (>900 m^3/s)	45	44	21	26	19	14
Max days (>900 m^3/s)	42	104	66	77	58	42
Mean days (<150 m^3/s)	-6	93	97	90	105	106
Max days (<150 m^3/s)	-12	126	145	146	159	142

CONCLUSIONS AND RECOMMENDATIONS

Water related disasters in Manyame catchment have a remarkable effect on food security which is a major deterrent of economic and societal growth. Based on the results there is going to be an increased risk of flood in the future in a country which already have a high risk of drought .Flooding is a growing problem that needs to be dealt with to reduce its effects. The timing of the floods and drought in future is going to shift from the traditional February to January instigating the need to put in place appropriate measures that comply with the future extreme rainfall patterns Although rainfall patterns are the major drivers of flooding in Manyame catchment, dam operation is also playing a role in the disaster, therefore, there is need for an integrated dam management system as well as revision of dam operation rules so as to reduce the flooding in the low lying areas of the basin. This can be complimented with the improvement of community's vulnerability awareness, and enhancement of early warning systems in order to improve society's coping capacity and resilience. Mechanical methods such as retardation pond can be done to save the communities of lower Manyame from flooding.

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