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GIS-Based Flood Risk Mapping and Analysis ofJalingo Metropolis, Taraba State, Nigeria

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ABSTRACT: Assessment of rainfall events and their extreme values using statistical protocols is critical to understanding flood characteristics of any given place. This study analysed rainfall data from 1971-2021 for the Jalingo Metropolis in order to determine the rainfall patterns, frequency, and its consequent implications on flood occurrences.The results of the analysis indicated an annual rainfall range of 718.5 mm - 2531.5 mm. The years 2019, 2021, and 2014 were extremely wet, while the driest year was 2003. The month of September was the wettest, while January was the driest month.Highest variation in rainfall amount within the same month occurs in the month of September, with coefficient of variation (Cv) = 2.62), followed by June and July with Cv values of 2.17 and 2.13 respectively. The study reveals 4 stages of flood occurrences that agrees with the different elevations of the study area. 55% of Jalingo area falls under the stage 1 flood, and are susceptible to flooding, once a continuous rainfall magnitude exceeds 25.4 mm/day. Stages 2 and 3 covers 10% and 7% of Jalingo, respectively, representing plains areas having high risks and recurrent floods caused by progressively increasing rainfall amount without hydraulic structures in place. The stage 4 flood occurs in locations that cover only 5% of Jalingo area and is rarely flooded. This study generally reveals progressive increase in the amount of rainfall in the study area in the years to come, and possible flooding if necessary preventive measures are not implemented. Among the recommendations of this study is that residents and commercial activities in the flood-prone areas should vacate to non-vulnerable locations in the Jalingo area, and provision of adequate drainage systems for proper channeling of surface runoff waters against flood occurrences, should be made a priority.

KEYWORDS:GIS, Rainfall, Flood-risk analysis, Mapping, Jalingo

I. INTRODUCTION

Floods are mostly rainfall induced extreme weather events that results into large amounts of overland surface water flow that leads to temporary inundation of dry lands often accompanied with serious loss of lives and properties [1]. It is one of the most severe naturally and periodically occurring environmental disasters facing human settlements in the 21st Century. In Nigeria, flooding has affected over 11 million lives, with a total of 1100 deaths and property damages exceeding US$17 billion between 1985 and 2014 [2]. Taraba state is one of the Northeastern states that has witnessed several devastating flood incidences, where many of its flood prone settlements experienced varying degrees of flooding accompanied with huge losses. The reoccurring flooding in some communities along the River Benue trough explains the potential vulnerability of Taraba state to floods [3], [4]. This recurrent situation necessitates scientific initiatives for effective flood disaster monitoring and warning mechanisms in order to reduce the loss of human lives and properties from flooding. Unfortunately, in Taraba state, there is still dearth of information concerning rainfall trends, flood frequencies, and their requisite prevention measures.

Flood risk mapping is a crucial process in disaster management and urban planning, involving the assessment and visualization of areas susceptible to flooding. The primary objective of flood risk mapping is to provide a spatial representation of flood hazards, which helps in identifying regions at risk and formulating mitigation strategies [5]. By using Geographic Information Systems (GIS), flood risk maps can effectively combine multiple layers of data to analyze and visualize flood risk in a detailed and comprehensive manner [6].

Flood risk analysis is a comprehensive process aimed at understanding and quantifying the potential impacts of flooding on human lives, property, and the environment. This process involves the evaluation of flood hazards, the exposure of assets, and the vulnerability of those assets to flood damage [7]. The primary objective of flood risk analysis is to assess the likelihood and consequences of flood events. According to [8], the primary motive for flood-risk assessment is to produce a map that shows the various areas with high and low flood risks within an area. This involves using historical flood data, hydrological models, and climate projections to estimate the probability and severity of future floods [5].

A critical component of flood risk analysis is the assessment of vulnerability, which refers to the susceptibility of a community or system to flood damage. This includes evaluating physical, social, economic, and environmental factors that influence the ability to prepare for, respond to, and recover from flood events [9]. Vulnerability assessment helps to identify the most at-risk populations and infrastructure, guiding targeted interventions and resource allocation [10].

According to [11], information on the extent of flood inundation is important in order to understand societal exposure, water storage volumes, flood wave attenuation, future flood hazard, and other variables. Flood inundation maps provide information on the areal spread of a flood.

Over the years, volumes of research works have been documented on both beneficial and destructive impacts of rainfalls, but without adequatedetails on rainfall pattern and its implications to flood occurrences in Taraba state, particularly Jalingo Metropolis, Taraba state, Nigeria. The aim of this research is to undertake flood mapping and analysis of Jalingometrololis, in Taraba state, Nigeria. This will be achieved through the generation of flood inundation map and flood water depth of the study area, using a fifty-one year rainfall record integrated into the GIS environment.

II. MATERIALS AND METHODS

Description of Study Area

Jalingo LGA is roughly located between latitudes 8^o 47‟ to 9^o 01‟N and longitudes 11^o 09‟ to 11^o 30‟E. It is bounded to the north by Lau Local Government Area (LGA), to the east by Yorro LGA, to the south and west by Ardo Kola LGA. It has a total land area of about 195km^2. Jalingo LGA has a population of 139,845 people according to the 2006 population census, with a projected growth rate of 3% per annum [12]. The major ethnic groups of Jalingo LGA are the Fulani, Jibu Kona and Mumuye, while other ethnic groups such as Hausa, Jenjo, Wurkum and Nyandangare also found. Hausa language is widely spoken as a medium of communication for social and economic interactions.The relief of Jalingo LGA consists of undulating plain interspersed with mountain ranges. Jalingo metropolis is drained by two major rivers Mayogwoi and Lamurde, which took their source from the mountain ranges in Yorro LGA and emptied there content into the Benue river system at Tau village. Jalingo LGA has tropical continental type of climate characterized by well-marked wet and dry seasons. The wet season usually begins around April and ends in October. The dry season begins in November and ends in March. The LGA has a mean annual rainfall of about 1,200mm and annual mean temperature of about 29^oC. Relative humidity ranges between 60-70% during the wet season to about 35-45% in the dry season.

Data Collection

The data collectedfor this research was primarily sourced from secondary sources, focusing on daily rainfall within Jalingo Metropolis. The specific datasets collected include daily rainfall data obtained from the Nigeria Meteorological Agency (NIMET), Jalingo, Taraba State, using a rainfall station (number 0.708.43) located at latitude 7° 41' N and longitude 8° 37' E. This data spans from 1971 to 2021.

Flood Mapping

The ArcGIS software package using digital elevation dataset from Shuttle Radar Topographical Mission (SRTM) was used to automatically create the topography and show the heights of each of the components of the terrain as well as the proximity to the rivers and the floodplain as presented in Figure 4. A composite image was generated from the Landsat TM image and then classified to extract the different land uses of the study area using the Box classifiers and the supervised classification algorithm.

The image was imported into the ArcGIS software, digitized and interpolated to generate a Digital Elevation Model (DTM). The rainfall data obtained from NIMET was analyzed to give information on the role of rainfall in the flooding of Jalingo metropolis. The methodology was automated using a Python script (FwDET) utilizing a number of ArcGIS tools and remote sensing data and a flood extent data of Jalingo falling within 1971 to 2021.

To identify the boundary cells, a flood inundation extent polygon was converted into a polyline layer using the ArcGIS "Polygon to Polyline" tool. A new raster layer was generated using a conditional raster calculation (ArcGIS Map Algebra) expression, in which cells corresponding to the boundary raster layer (from Step 1), which are

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not "No Data," receive the value of the underlying DEM . This was done to extract the elevation of boundary cells. A new raster layer was calculated in which each cell was assigned with the elevation of its nearest boundary cell. The rainfall data was converted to attribute data and applied in ArcGIS manipulation and overlay analysis to determine its interaction with other inputs themes such as relief. The floodwater depth was calculated using a raster calculation (ArcGIS Map Algebra) expression.

Flood analysis map

The map of flood risk zones was prepared using the DEM, rainfall data and drainage characteristic of Jalingo metropolis in a GIS environment. Soil characteristics and vegetation type were also considered. Rainfall amounts and other themes within the relief categories were analyzed using GIS overlay manipulations. This process resulted in the division of Jalingo metropolis into four successive flood stages, corresponding to the degree of flood vulnerability of the different parts of study area.

Data Analysis Techniques
Variability

According to [13], variability is a measure of how far a set of values is spread out. In nature, the distribution and occurrence of rainfall is not uniform; rather it has spatial as well as temporal variations, which makes rainfall occurrence very difficult to predict. Variability consists of mean deviation (M.D.), standard deviation (S), variance (S^2) and coefficient of variation (C_v). The measure of variability or dispersion of a probability distribution curve is given by the following parameters.

Standard deviation (S)

It is the square root of the variance (S^2) as shown in Equation 10.

$$S(\sigma) = \sqrt{\frac{\sum_{i=0}^{n}(x-\bar{x})^2}{n}} \qquad (1)$$

where: $\bar{x}$ = the mean of all data point
i = ith data point
n = the total number of data points;
S2 = the variance;
M.D = the mean deviation
S or σ = standard deviation

Coefficient of variation

The coefficient of variation or coefficient of dispersion denoted by C_v is defined as a dimensionless dispersion parameter which is equal to the ratio of the standard deviation to the mean as given by Equation 11.

$$\text{Thus; } C_v = \frac{\sigma}{\bar{x}} \qquad (2)$$

where: C_v= the coefficient of variation
$\bar{x}$= the mean of all data points
σ= standard deviation

III. RESULTS AND DISCUSSION

Trend Analysis of Rainfall

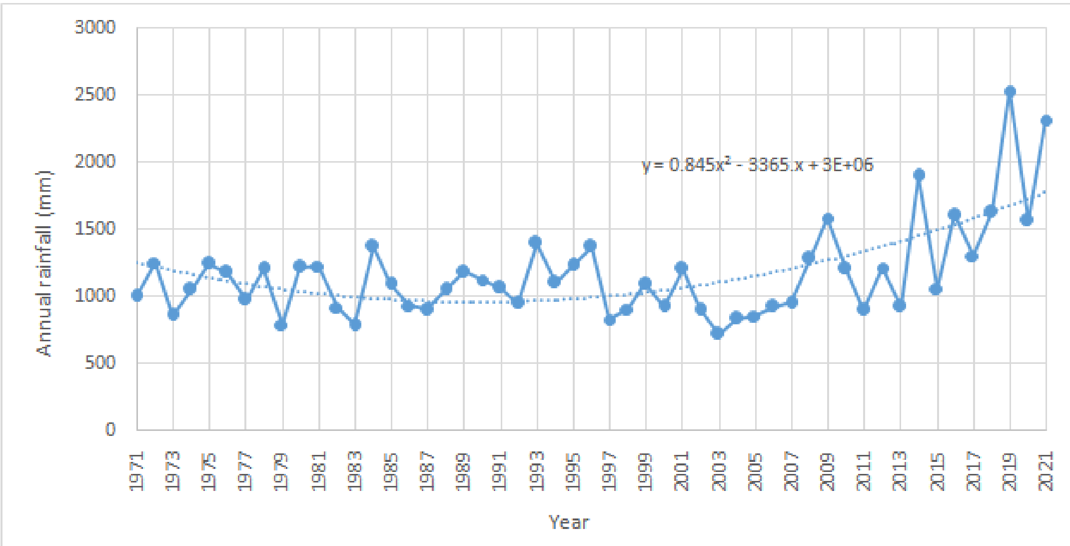

Figure 1: Time series plot of annual rainfall against year

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Figure 1 shows the annual trend of rainfall of Jalingo metropolis from 1971 to 2021. The maximum and minimum annual rainfalls for the studied period were 2531.50 mm and 718.50 mm, which occurred in the year 2019 and 2003, respectively. Figure 1 also reveals that year 2019, 2021, 2014 and 2009 recorded extremely wet rainfall annuals of 2532, 2315, 1898, and 1585 mm respectively, while the extreme dry years are 1979, 1983, and 2003, which witnessed annual rainfall amount of less than 800 mm. Between 1971 to 1983, the average annual rainfall was 1052. It increased marginally to 1134 mm between 1984 to 1996. There was a slight decrease in yearly rainfall between 1997 to 2007, which was followed by an upward trend, with average rainfall of 1500 mm between 2008 to 2021. The increasing trend in rainfall is consistent with the findings of [14], who reported that annual rainfall amounts in northern Nigeria have been on the increase, especially from the late 1990s.

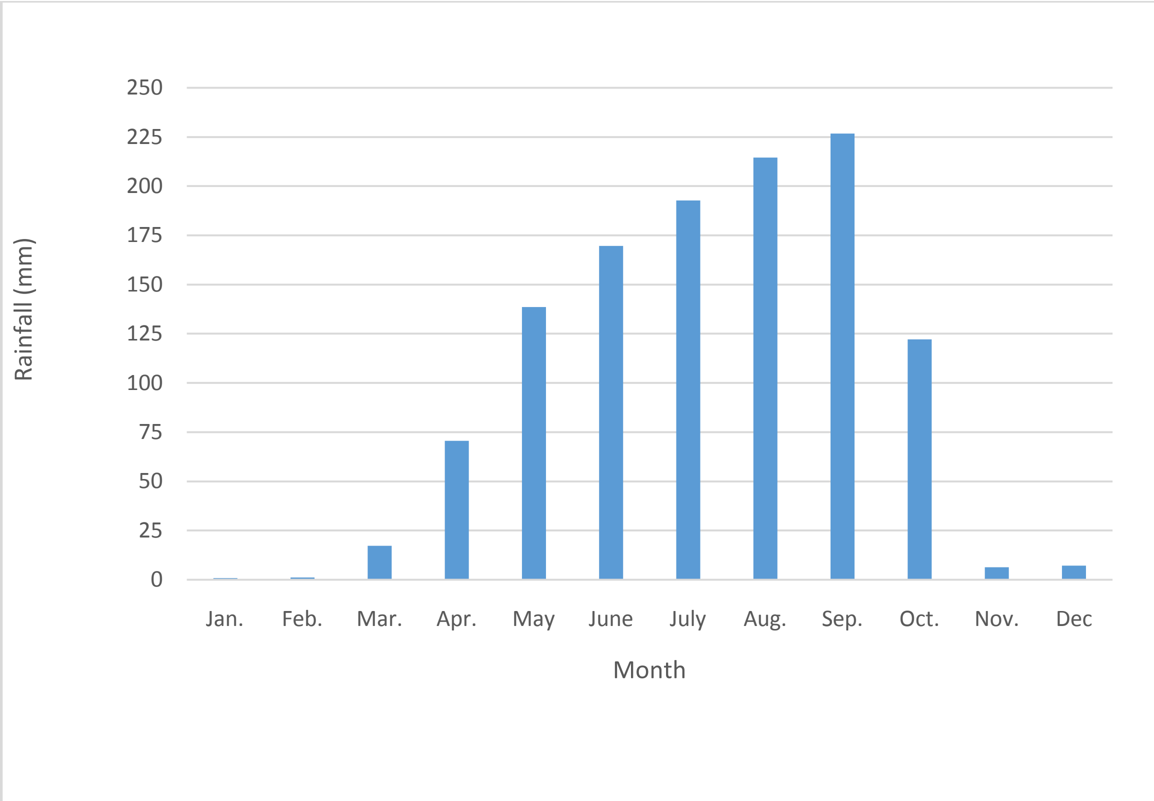

Figure 2: Average monthly rainfall pattern of Jalingo metropolis

Figure 2 shows the average monthly rainfall of the study area. Rainfall commences at the end of the first quarter of the year, and increases in amount till it peaks around September to about 225 mm. There is a sharp decrease in rainfall amount in October, signalling the end of the rainy season, and this becomes more pronounced in November and December when the dry season sets in.

Table 1: Descriptive statistics of Jalingo monthly rainfall data

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Annual (mm)	40.1	61.4	880	3603.7	7064.7	8650.6	9826.4	10942.6	11561.9	6232	320	367.7
Mean (mm)	0.79	12	17.3	70.7	138.5	169.5	192.7	214.6	226.7	122.2	6.27	7.21
Cv	0.20	0.35	0.69	1.13	1.87	2.17	2.13	2.06	2.62	1.45	0.40	0.24

Table 1 shows that the months of August and September receives the highest rainfall with monthly averages of 214.6 mm and 226.7 mm respectively, while the driest month is January with < 1.0 mm average monthly rainfall. It is also deduced from Table 1 that, for the period under study, rainfall amounts vary for the same month for the various years, as indicated by the coefficient of variation. While the dry season months of December, January and February show least variation in the amount of rainfall for the various yeas (Cv< 0.4), this is not the same for the rainy season months. Results of Table 1 shows that as rainfall amount increases from March to September, the coefficient of variation also increases. This is an indication of the unprecedented nature of tropical storm, especially during the raiany season. Highest variation in rainfall amount within the same month occurs in the month of September (Cv = 2.62), followed by June and July with Cv values of 2.17 and 2.13 respectively.

Flood Analysis and Elevation of Study Area

Figures 3 and 4 show the flood analysis and the elevation maps of Jalingo metropolis respectively.

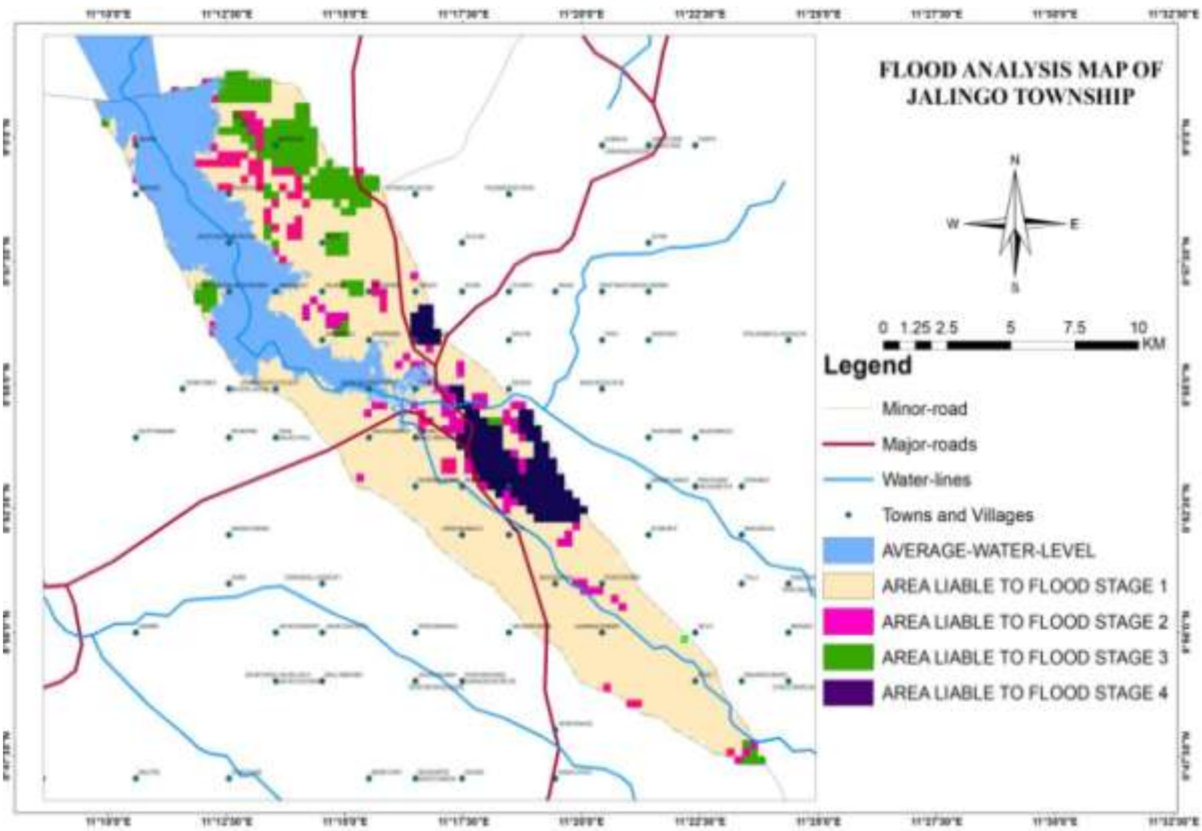

Figure 3**:** Maps showingFlood Analysis map of Jalingo Township.
Source: Research Results

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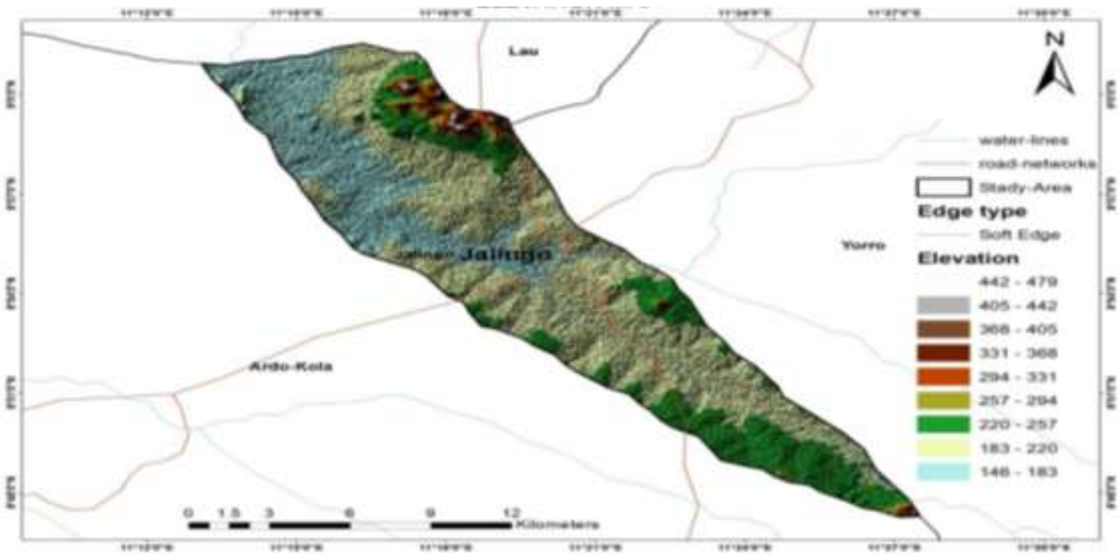

Figure 4: 3D view of the elevation of Jalingo area

Figure 3 shows the division of Jalingo metropolis into four successive flood stages, corresponding to the degree of flood vulnerability of the different parts of the city. The successive flood stages are:

Stage 1: This area had the highest risk and expected to be having recurrent flooding. The area falling under this zone constitutes of about 55% coverage of Jalingo and is highly prone to flash floods. Comparison of Figures 3 and 4 shows that the area under this category falls within the low-lying part of the study area, with elevation ranging from 183–257 m. These areas also share close proximity to the river. The parts of Jalingo Metropolis under this zone include JauroBanvo, Jenbambu, Janbargu, Gbazanabajun, and Bassabasa. This scenario is in agreement with the findings of [15], who reported that high flood vulnerability zones are primarily concentrated in the watershed's center and lower reaches, and are usually distinguished by flat areas with low slope gradient, lower elevation, low drainage density and proximity to the river, all of which are significant conditioning variables for flood hazard. Similarly, [8] recommended GIS as a functional tool for flood-risk mapping, and that distance to streams and elevation are highly responsible for flood occurrences.

Stage 2: This zone is considered to be under the second stage of flood risk. The area constitutes about 10% coverage of Jalingo, and situates on a relatively higher elevation than the stage 1 risk zone. The zone is at the risk of being flooded, if the draining process of the study area is not sufficient for the amount of water/rainfall received.The notable locations in this zone are Jaurovoti, Bazinpam, Abare, and Mayodasa.

Stage 3: The stage 3 flood zone constitutes of only about 7% coverage of the Jalingo Metropolis. The areas are on a much higher elevations and are not easily floodable. The notable locations under this zone are such as Murkuni and Baza areas.

Stage 4: The stage 4 flood zone occurs on the most highly elevated grounds and constitutes a considerable portion of about 23% of the Jalingo area. The location in this flood zone is such as JalingoBardel, and is hardly inundated.

IV CONCLUSION

Successful prevention and mitigation of flood disaster can be achieved if requisite knowledge about the expected frequency and level of vulnerability to people and infrastructures is available and utilized. The visualization of flood-risk zones can aid in easy mitigation and planning of flood management. The results of this study have revealed that about 55 % of Jalingo metropolis is highly prone to flooding under the current and future rainfall predictions. This area falls under stage 1 flood risk and is expected to be having recurrent flooding. Annual rainfall amount has progressively increased in the last four decades, with highest amount occurring in the month of September. A strong relationship between extreme rainfalls and floods existed during the study period of 1971 – 2021. From the results, the following recommendations have been proposed:

1. It is recommended that residents and commercial activities in the flood prone areas (stage 1) are advised to vacate and/or relocate to other locations not vulnerable to floods in the Jalingo area.

2. There is the need for provision of appropriate and adequate drainage systems such as drains and culverts for proper channeling of surface runoff waters from excessive accumulation.
3. A community-based advocacy approach for public awareness on such as flood alerts or early warning mechanisms about flood risk and its associated hazards to be extensively advocated in the Jalingo area, in order to ensure the safety of the vulnerable settlers and their economy.

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