World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Research Article)

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Flood risk assessment of the river Benue catchment in Adamawa State Nigeria

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World Journal of Advanced Research and Reviews, 2023, 19(01), 347–368

Publication history: Received on 27 May 2023; revised on 04 July 2023; accepted on 06 July 2023

Article DOI: https://doi.org/10.30574/wjarr.2023.19.1.1298

Abstract

Floods are one of the most devastating natural disasters that occur globally, causing loss of life and property. Adamawa, a state located in north-eastern Nigeria, is prone to flooding due to its location within the floodplains of the River Benue. The research examines the spatial distribution of flood risk, the role of altitude in determining flood risk levels, and the implications for population exposure. The investigation was carried out in the following local government areas, namely Yola-South, Demsa, Numan, Lamurde, Guyuk, Shelleng and Song. The study used a combination of remote sensing and geographic information systems (GIS) techniques to analyze the flood risks extent and exposure within the catchment. SRTM 30 Meters resolution Digital Elevation Model (DEM) data was used to derive catchment boundaries, stream networks and watershed characteristics. 500 years return period flood hazard raster along with a population raster of the settlements within the region of interest were also used. The findings reveal varying flood risk extents, with areas at lower elevations exhibiting higher flood risks. Additionally, the study identifies specific wards within each locality that are situated in different flood risk zones, highlighting the need for localized flood risk assessments. The results demonstrate a correlation between flood risk levels and the percentage of the population exposed to these risks. The study aligns with existing literature on flood risk, altitude, and population vulnerability, emphasizing the importance of considering these factors in flood risk management strategies. The findings contribute to a better understanding of flood risk patterns and can guide policymakers and stakeholders in implementing targeted interventions and developing effective disaster response plans. However, it is essential to contextualize the findings within the specific study areas and complement them with site-specific assessments and further research.

Keywords: Flood; Risk; Exposure; Catchment; Population; Mitigation

1. Introduction

Flooding is a major natural disaster with attendant serious social, economic, and environmental consequences for communities around the world (UNISDR, 2019). Flooding incidences have increased in recent times probably due to the uncontrolled activities of man within his environment with significant impact on climate regime that transcends into extreme weather events with disastrous consequences. One of such events is rainfall of high intensity with long duration, which is capable of increasing the streams, sea, river and even the artificial ponds levels and inundates adjacent lands. It is no doubt that Floods can cause detrimental consequences on our societies, properties, economy and on the environment of many parts of the world.

Records show that on the average, approximately 21 million individuals worldwide are affected by either pluvial or fluvial floods yearly (Luo, et al., 2013). Over 3700 flood tragedies are recorded in the EM-DAT database, covering the period 1985 to 2014 (EM-DAT 2014). These events were responsible for hundreds of thousands of deaths mainly in

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Asia (particularly China, Thailand and Bangladesh) and unfavorably affected billions of people mostly through homelessness, mortality principally through drowning, bodily wounds or injuries, fecal-oral and rodent-borne diseases, vector-borne diseases largely in tropical areas and psychological conditions through depression, anxiety and post-traumatic stress (Ahern et al. 2005, Hunter 2003, Few et al. 2004, Tapsell & Tunstall 2008, Clerk, et al., 2018; Chen, et al., 2019; Hall et al., 2020).

Notably, the effects of inundations are remarkably severe in developing or low-income countries due to their susceptibility to the incidence of these occurrences. Inundations may be seen as local, only impacting local communities, or they may be very large, affecting an entire nation (Mohammad and Atu, 2018). It might be caused by regular localized heavy downpours, occasional severe storms, or by many other causes (Smith et al., 2018). Outside climate change for the concern of floods, is the concern of rapid population growth and urbanization, the level of awareness of flood risk, the limited efforts towards flood disaster risk reduction in many places and the exposure and susceptibilities of large numbers of human population (Peduzzi et al. 2011, Gill et al. 2004, Action aid 2006, Raaijmakers et al. 2008; Johnson and Brown, 2016). Flooding is thus one of the most devastating hazards in the world claiming lives and properties (Ologunorisa, 2006). Effective flood risk assessment is therefore critical for helping communities to anticipate and prepare for potential flood events and to implement appropriate flood risk management strategies (UNISDR, 2019).

Empirical methodologies involve the use of statistical techniques to analyze relationships between flood risk factors and flood events based on historical data (Merz et al., 2013; Thompson et al. 2015). These methodologies can be used to identify patterns and trends in flood risk over time, and to develop predictive models that can be used to forecast flood risk in the future (Merz et al., 2013). To assess flood risk, researchers have used a variety of methods. For example, Ogah et al. (2019) used a hydrological model rainfall, topography, land use, and soil type to simulate the impact of different rainfall scenarios on flood risk in the region and showed that flood risk is highly variable, with some areas being more prone to flooding than others. Usman et al., (2018) however, focused on the social and economic impacts of flooding and found that flood events have led to significant losses in terms of crop damage, loss of infrastructure, and loss of human life with a disproportionately effect on marginalized communities, women and children.

In the past decade in Nigeria, thousands of lives and property worth millions of naira have been lost directly or indirectly to flooding every year. In most urban centers of Nigeria such as Lagos, Kano, Abuja, Lokoja, Port Harcourt, and Yola, human population is constantly on the increase, thus resulting to exploding cities (Oyesiku, 2009). This results in the growth and proliferation of unplanned cities due to congestion of people and buildings leading to increased risk of flooding. Flooding in urban areas and river basins is intensifying due to rapid urbanization, which is causing a major change in rainfall-runoff phenomenon and the drainage system as well. Flooding primarily occurs because of drainage congestion of inland flow and/or over bank flow of river during severe rainfall event. The overland flow pattern is becoming complex due to huge structural development, and therefore, the correct prediction of surface runoff is becoming a challenging issue (Ologunorisa, 2006).

Several studies have highlighted the importance of considering land use and land management practices in flood risk assessment (Cilliers, 2019; Muhammad et al., 2018; Clerk, et al., 2018; Pham et al., 2013; Jha et al., 2012). Factors related to topography, hydro-meteorology, and land use and land management practices can alter the hydrological cycle and increase the amount of water that is available to flow into rivers and streams, which can increase flood risk, affecting the vulnerability of communities to flood events (Cilliers, 2019; Muhammad et al., 2018; Jha et al., 2012). Obeta (2014), in his research on "flooding impact in Nigeria" noted that "flooding and solutions to its impacts are critical issues". Thus, the importance of exploring more realistic flood risk mitigation measures for Nigeria should be paramount (OCHA 2012). Flooding in Nigeria are mostly fluvial (resulting from rivers overtopping their natural and manmade defenses), and pluvial (flash, arriving unannounced following a heavy storm) in nature and have been a major cause of concern for rural areas and cities within the country (Bashir et al. 2012). At the same time as government with stakeholders' efforts towards confronting the hazard have not yielded satisfactory results, they have been criticized as ad-hoc, poorly harmonized, non-generalizable and not well recognized (Obeta 2014). Nevertheless, in the light of 'best practices' in flood risk assessment on and 'lessons learned' from other countries' experiences of flooding, it can be debated that such stake holders' determinations are limited due to lack of quality information or data, that are necessary to systematically confront flooding, poor sensitivity of flooding among the general populace, lack of funds and enhanced technology as well as poor political will power that will help enact laws that can address flooding.

The rising number of flood fatalities and the constrained sustainable development posed by flooding suggest that much of what is identified regarding flooding is deficient on remedies especially in the developing parts of the world. More dangerous is the subject-matter of Nigeria being one of the most populated countries in sub-Saharan Africa with population size estimated at over 200 million people (World Bank 2020). In view of the notion that future population growth will drive future flood risk, this population size along with future evaluations enticements interest towards building the capacities of human populations to handle with flooding. Considering the current-state-of-art on the accuracy of rainfall forecasts, only flood warnings are feasible and further studies in such area are needed to improve their prediction skills.

In recent years, Adamawa, a state in Nigeria, has experienced several severe flood events that have caused significant damage to infrastructure, crops, and homes (Adamawa State Ministry of Environment, 2019). These flood events have been associated with heavy rainfall and the failure of river banks and levees, as well as with the inadequate capacity of drainage systems to cope with large volumes of water (Adamawa State Ministry of Environment, 2019). The impact of flood events in Adamawa is likely to be exacerbated by climate change, which is expected to increase the frequency and severity of extreme weather events in the region (IPCC, 2018).

Despite the importance of flood risk assessment for catchments in Adamawa State, there is a lack of comprehensive and up-to-date spatial information on flood risk extent and the percentage of the population in a specific catchment that are exposed to flood hazards. This lack of information makes it difficult for policy makers and decision makers to effectively mitigate the impacts of flooding and protect vulnerable communities. Consequently, this study assesses flood risks in the spatial context and the exposure of the population to flood hazards in the River Benue catchment of Adamawa State, Northeastern Nigeria.

2. Materials and Methods

The study was conducted in Adamawa state. The study area is the upper River Benue basin catchment (Figure 1) that traversed Fufore, Yola North, Yola South, Girei, Song, Demsa, Numan, Lamurde, Guyuk, and Shelleng local government areas of Adamawa State, with a major tributary called the Gongola river that flows along the boundary between Guyuk and Shelleng local government areas. Figure 2 shows the wards of the 10 local government areas that make up the River Benue catchment.

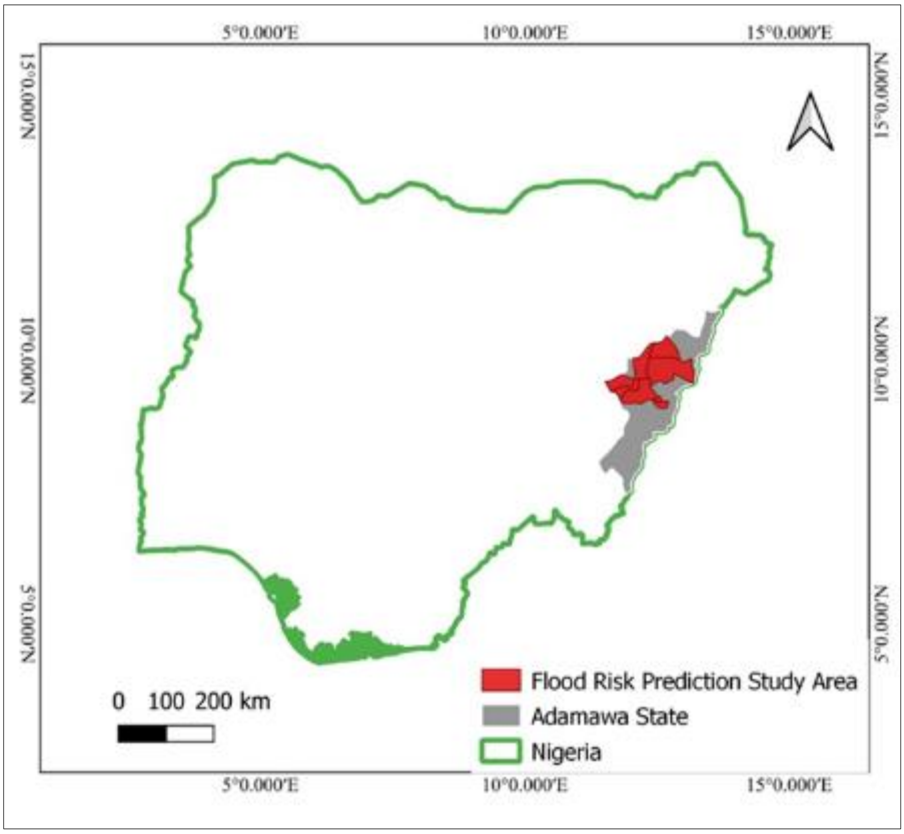

Figure 1 Map of Nigeria showing the study area in Adamawa State

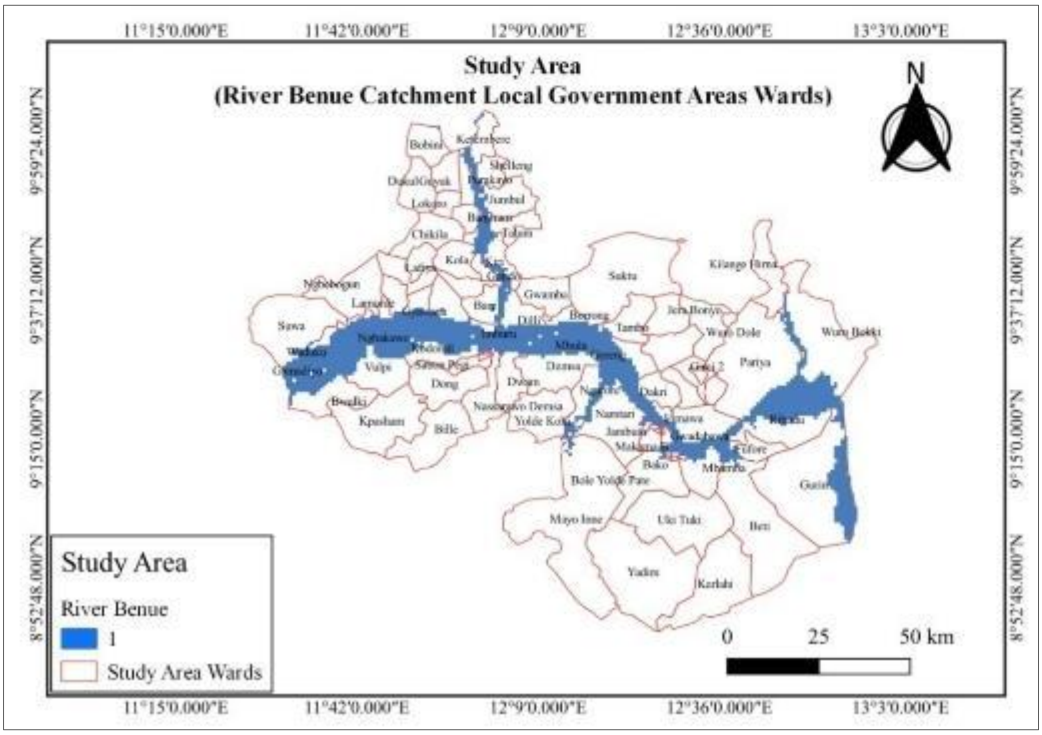

Figure 2 River Benue Catchment Local Government Areas Wards

2.1. Population

The study area has a projected total population of the study is 252,370. The projection was based on 3% growth rate using the 2006 National Population Census data from the National Population Commission of Nigeria. The population by local government areas that make up the study area is presented in Table 1.

Table 1 Population of the study area

S/N	Local Government	Population
1	Fufore	323000
2	Yola-South	302500
3	Yola-North	307900
4	Girei	200200
5	Demsa	275100
6	Numan	141200
7	Lamurde	171600
8	Guyuk	272200
9	Shelleng	229000
10	Song	301000
		2523700

2.2. Data Collection

a. Topographic Data: A 30 Meters resolution Shuttle Radar Topographic Mission (SRTM) Digital Elevation Models (DEMs) were obtained from reliable sources to assess the altitude and elevation characteristics of the study areas.

b. Land Cover Data: Satellite imagery and land cover maps from the Global Land Cover Facility (glcf.umd.edu) were utilized to identify the land cover types within the study areas, which influenced the infiltration and runoff processes.

c. Hydrological Data: Stream gauging stations and river discharge data were collected to understand the hydrological characteristics and drainage patterns.

2.3. Flood Risk Assessment

- Flood Hazard Mapping: Flood hazard maps were created by integrating the topographic data, land cover information, flood hazard data, precipitation data, and hydrological data. This process involved analyzing the elevation, slope, and flow direction to identify areas susceptible to flooding.
- Population Data: Population data, including demographic information and population distribution, were obtained from (sedac.ciesin.columbia.edu/data/collection/gpw-v4).
- Exposure Analysis: The flood hazard maps were overlaid with population distribution data to assess the population exposure to flood risks. This analysis involved quantifying the percentage of the population residing in different flood risk zones.

2.4. Data Analysis

In terms of spatial analysis, Geographical Information System (GIS) techniques were employed to analyze and visualize the spatial patterns of flood risk levels and population exposure across the study areas. The Quantum GIS software (QGIS) version 3.26 was used in this study.

In terms of statistical analysis, descriptive statistics, including mean, range, and percentage calculations, were used to summarize the flood risk extents, altitude ranges, and population exposure percentages within each flood risk category.

3. Results

3.1. Flood Risk Analysis

A flood risk analysis was carried out to determine the categories of flood inundation extent prevailing in the study area. The result is presented in Figure 3.

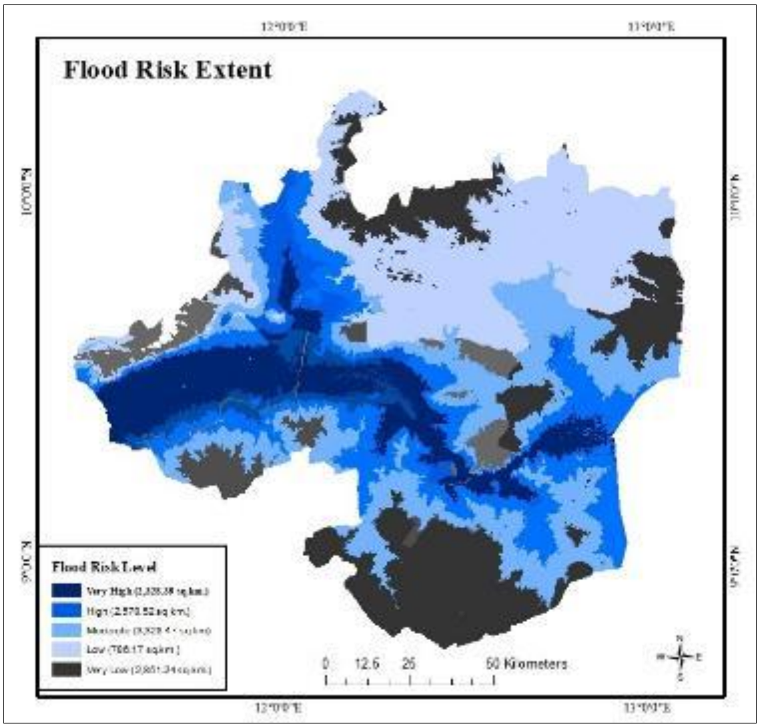

Figure 3 River Benue Catchment Flood Risk Extent

The result of the Flood Risk extent for the River Benue catchment as a whole is shown in Figure 3, which indicated that the study area is exposed to varying levels of flood risk. The flood risk was categorized into five distinct levels based on both the extent of inundation and the altitude above sea level. The categories are as follows:

- Category 1: Very High Flood Risk shows areas that are susceptible to flood hazards covering an area of 2,328.39 km^2, and characterized by an altitude below 170meters above sea level. The presence of a significant portion of the study area suggests a high susceptibility to flooding and the fact that human infrastructure located within this zone is highly vulnerable to the characteristic annual flood cycle of the River Benue. It highlights the urgent need for mitigation measures.
- Category 2: High Flood Risk encompasses an area of 2,570.52square kilometers, representing a slightly higher altitude range of 171m to 200m above sea level. The inclusion of additional land in this category indicates a broader area at risk of flooding.
- Category 3: Moderate Flood Risk is a zone covering an area of 3,328.47square kilometers and extends over an altitude range of 201meters to 250meters above sea level. While flood risk is slightly lower than in the previous categories, a significant portion of the study area still remains susceptible.
- Category 4: Low Flood Risk zone spans an area of 786.17km^2 and includes an altitude range of 251meters to 550meters above sea level. Although the flood risk is relatively lower compared to the previous categories, it is essential to consider appropriate measures to protect the areas falling within this range.
- Category 5: Very Low Flood Risk zone is the largest category in terms of area covering 2,351.24 square kilometers. It is characterized by an altitude above 550meters above sea level. While the flood risk is minimal within this category, it is important to note that it does not imply complete immunity to potential flooding events.

3.2. Flood Exposure Analysis

The exposure of the population in the various settlements across the study area to flood was also analyzed. The analysis of the population exposed to flood hazards revealed significant findings at both the local government area and ward levels within the study area. This analysis provides crucial insights into the vulnerability of the population to flood hazards, categorized into five exposure levels. The result is presented in Figure 4.

At the Study area level, the following exposure categories were identified in the River Benue catchment (Figure 4), and seems to correspond to the analyzed flood risk extent categorization in Figure 3 viz: Very High Population Exposure (50% to 100%); High Population Exposure (26%-50%); Moderate Population Exposure (13% to 26%); Low Population Exposure (5.7% to 13%) and Very Low Population Exposure (0% to 5.7%).

3.2.1. Category 1: Very High Population Percentage Exposure of 50%-100%.

In Fufore local government area, Gurin ward exhibited very high population exposure to flood hazards. Similarly, Makama A and Namtari wards in Yola-South local government area; Borrong, Mbula, Dilli, and Dwam wards in Demsa local government area; Bare, Imburu, and Kodomti wards in Numan local government area, and Gundu ward in Shelleng local government area.

3.2.2. Category 2: High Population Percentage Exposure of 26%-50%.

Local area wards that fall within the High Population Exposure category are: Ribadu ward in Fufore, Jambutu in Yola South, Makama "B" in Yola North, Dakri and Gereng wards in Girei, Demsa and Nassarawo Demsa in Demsa Area; Bwalki and Numan 2 in Numan area; Waduku, Rigange and Gyawana in Lamurde area; Gundo, Kiri, Talum, Jubul, Shelleng, and Ketembere wards in Shelleng area.

3.2.3. Category 3: Moderate Percentage Population Exposure (13%-25%)

Local area wards with moderate population that are affected/exposed to flood hazards are: Fufore and Wouro-Boki wards in Fufore local government area; Adarawo, Mbamba, Mayo-Ine, Ngurore and Yolde-Kohi wards in Yola-South area; Gwadabawa and Damare in Yola-North local government area; Girei 2 ward in Girei local government area; Gyawana, ward in Lamurde local government area; Banjiram, ward in Guyuk local government area; Jera-Bonyo in Song local government area.

3.2.4. Category 4: Low Population Exposure of 5.7%-13%

Local area wards with Low percentage of Population Affected/exposed to flood hazards are: Beti and Pariya in Fufore area; Bole-Yolde-Pate, and Modire in Yola-South area; Karewa, Gwadabawa, Limawa, and Luggere in Yola-North area;Gwamba ward in Demsa area; Sabon-Pegiand Dong in Numan area; Lamurde, Nbebogun and Suwa wards in Lamurde area;Dumna, Purokaryo and Bobini wards in Guyuk local area, and; Kilange-Hirna in Song local government area.

3.2.5. Category 5: Very Low Population Exposure of 0.5% to 5.7%.

Local government area wards with "Very Low Affected/exposed Population" are: Karlahi, Yadim and Uki-tuki in Fufore area; Girei-1, Jera-Bakari and Wuro-Dole wards in Girei area; Bille and Kpasham wards in Demsa area; Ngbakawo, and Lafiya wards in Lamurde area; Kola, Chikila, Dukul, Lokoro and Guyuk wards in Guyuk area and; Jera-Bakari, Wuro-Dole, Suktu, and Tambo wards in Song area.

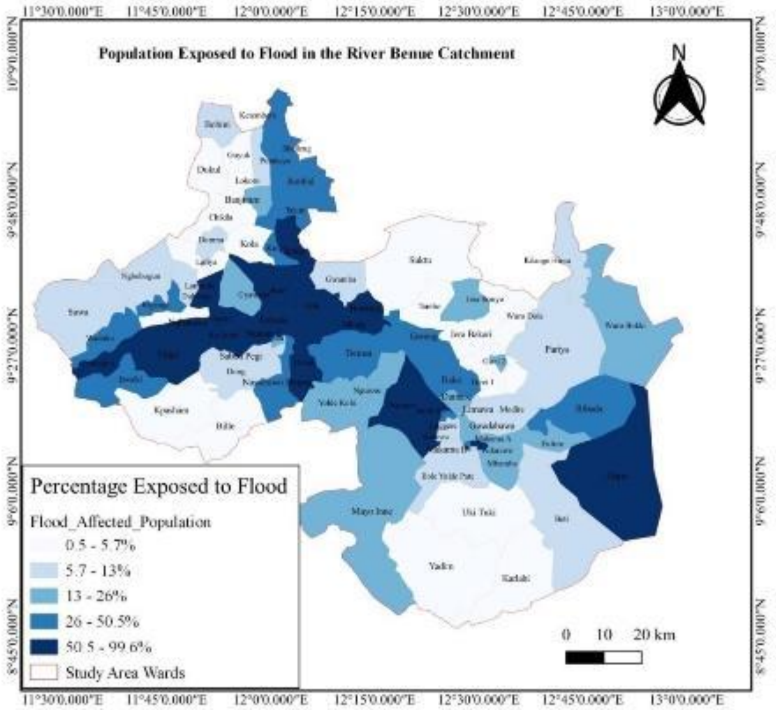

Figure 4 River Benue Catchment Percentage Population Exposed to Flood

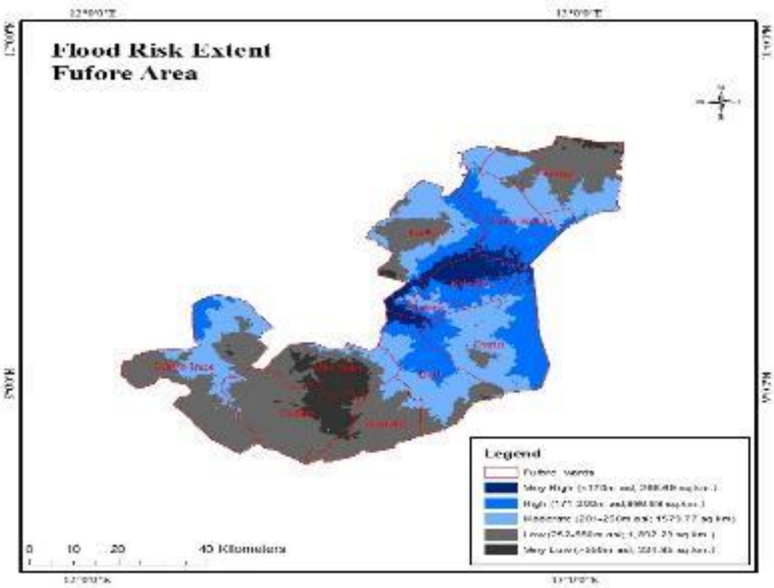

Figure 5a Flood Risk Level in Fufore Area

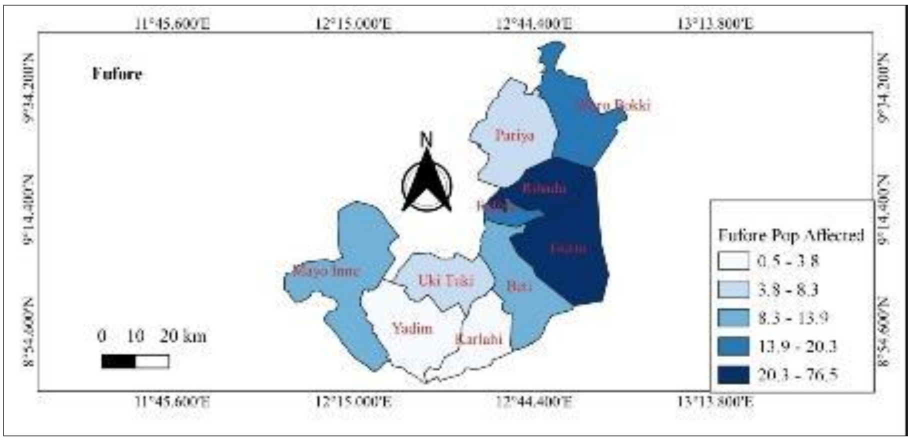

Figure 5b Percentage Population Exposed to Flood in Fufore Area

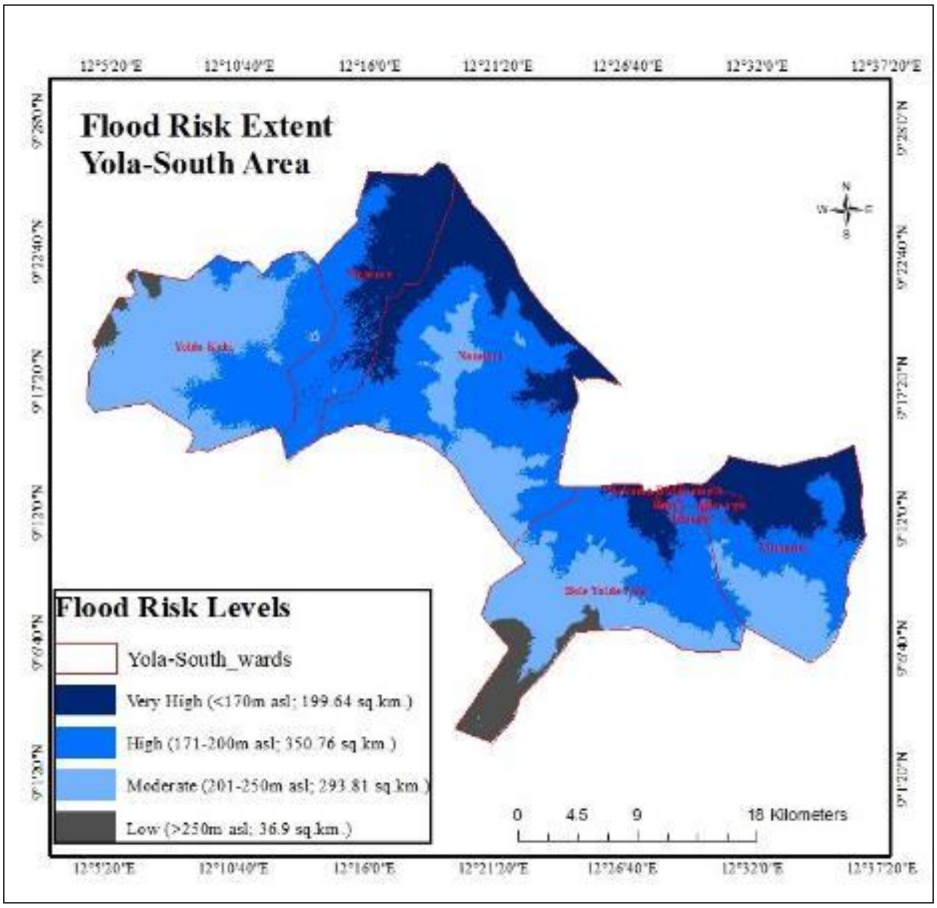

Figure 6a Flood Risk Levels in Yola South

Figure 5a-b presents the flood risk levels and corresponding population exposure across the wards in Fufore. The analysis reveals varying extents of flood risk and population exposure within the area, providing crucial insights into the vulnerability of different wards. The "Very High Flood Risk and Exposure" category in Fufore covers an area of 266.69 square kilometres (Figure 5a). These areas are characterized by an altitude of less than 170m above sea level. Gurin and Ribadu wards (Figure 5b) fall within this category and the percentage range of population exposure to flood hazards within this category ranges from 20.3% to 76.5%. The "High Flood Risk/Exposure" category encompasses an area of 966.69 square meters in Fufore (Figure 5a). These areas have an altitude range of 171 meters to 200 meters above sea level. Only Wuro-Boki ward belongs to this category, where according to Figure 5b 13.9% to 20.3% of its population is exposed to flood hazard annually. While the flood risk is slightly lower compared to the "Very High Risk" areas, it still indicates significant vulnerability. The "Moderate Flood Risk/Exposure" category, covering an area of

1579.77 square kilometers, is observed to lie within an altitude range of 201 meters to 250 meters above sea level (Figure 5a). Beti and Mayo-Ine are two wards within Fufore that belong to this category with between 8.3% and 13.9% of their population exposed to flood hazards on annual basis (Figure 5b). The Low Flood Risk/Exposure category is identified in an area spanning 1892.23 square kilometers that comprise Pariya and Uki-Tuki wards in Fufore (Figure 5). These wards are situated within an altitude range of 251 meters to 550 meters above sea level, with a population exposure range of 3.8% to 8.3%. While the flood risk is relatively lower in these two wards, it is crucial to note that even low-risk regions can experience occasional flooding events. In the "Very Low Flood Risk/Exposure" category is found to cover 334.95 square kilometers and situated at an altitude above 599m above sea level. Yadim and Karlahi wards in Fufore make up this category where between 0.5% to 3.8% of their population affected by flood hazards.

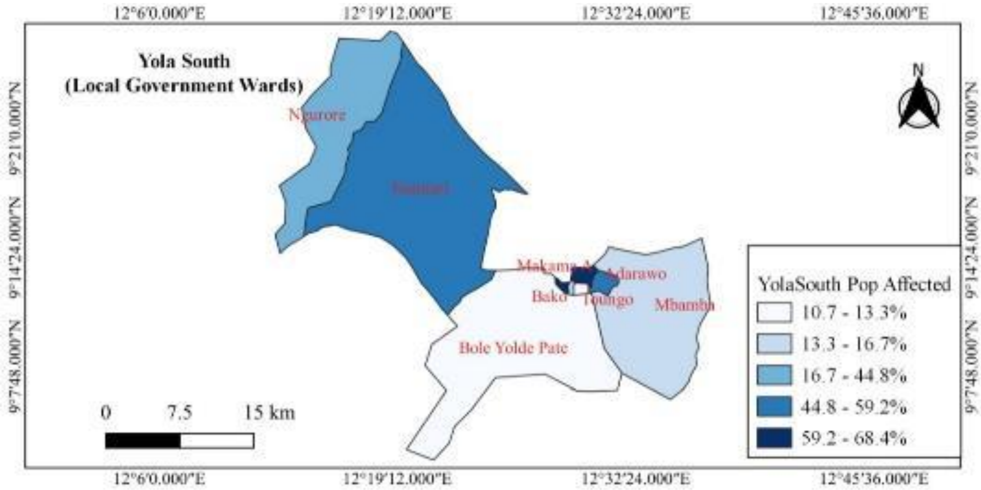

Figure 6b Population (%) Exposed to Flood in Yola-South Area

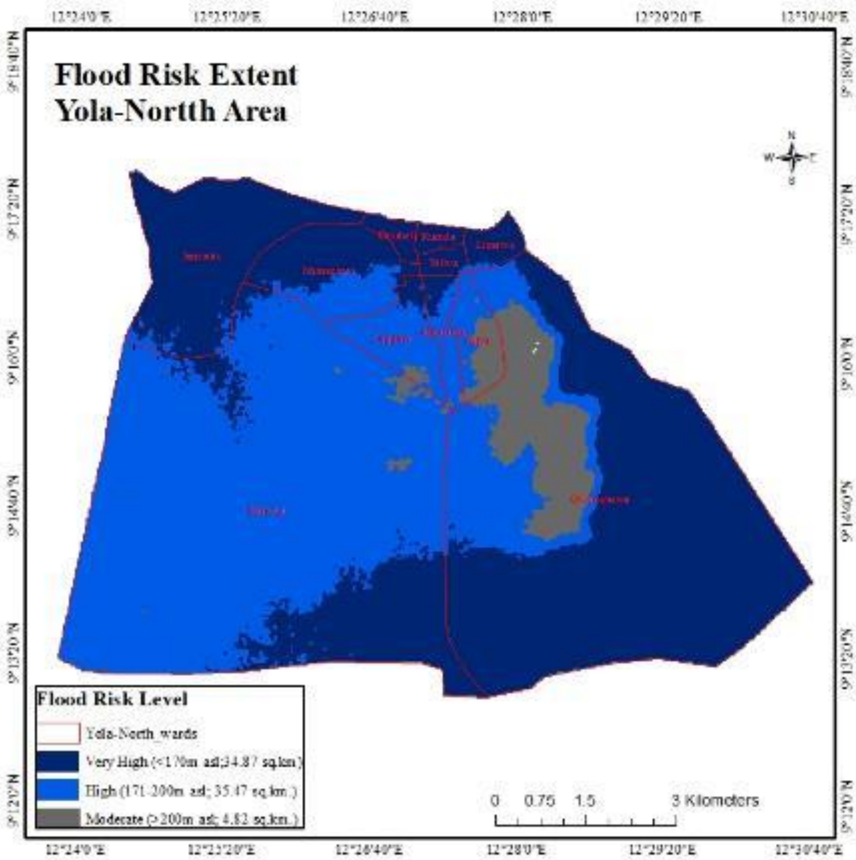

Figure 7a Flood Inundation Extent in Yola-North

Figure 6a-b presents the flood risk extent and corresponding population exposure across the wards in Yola-South local government area. The analysis shows varying levels of flood extent and population vulnerability in Yola-South, providing valuable insights into the wards at highest risk. The very high flood risk/exposure category covers an area of 199.64 square kilometers that make up Makama A and Bako wards of Yola South area. These wards are characterized by an altitude of less than 170m above sea level, with 59.2% to 68.4% of the population exposed to flood hazards. This high population exposure underscores the urgent need for targeted flood risk management strategies, evacuation plans and resilient infrastructure. The high flood risk/exposure category encompasses an area of 350.76 square kilometers in Yola South. This area lies within an altitude range of 171 meters to 200 meters above sea level. Namtari and Adarawo wards are located in this area, with 44.8% to 59.2% of the population affected by flood hazards. Low flood risk/population exposure category covers an area spanning 293.81 square kilometers. This area is situated within an altitude range of 201 meters to 250 meters above sea level. Mbamba and Ngurore wards belong to this category. The population affected by flood hazards in these wards range from 13.3% to 44.8%. In the very low flood risk/population exposure category, Figure 6 shows that it covers 36.9 square kilometers and situated at an altitude greater than 250 meters above sea levels. Bole-Yolde-Pate and Toungo wards belong to this category. The population exposure within this category ranges from 10.7% to 13.3%.

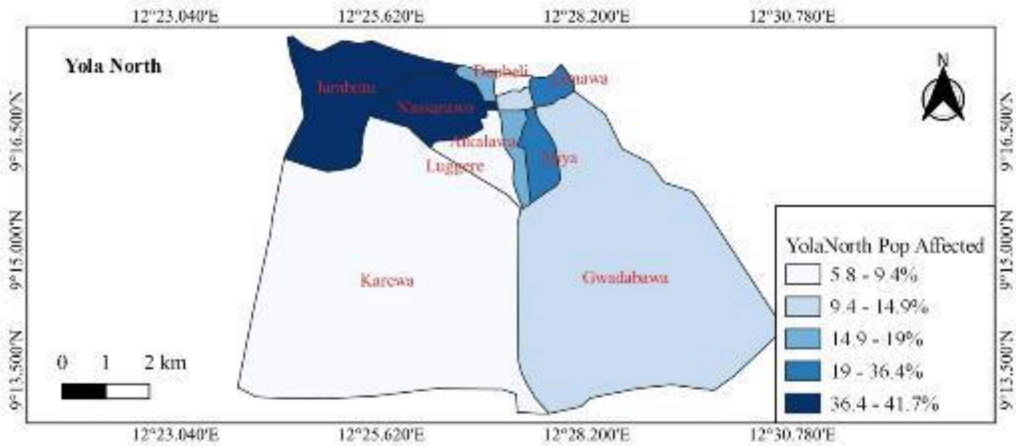

Figure 7b Population (%) Exposed to Flood in Yola-North

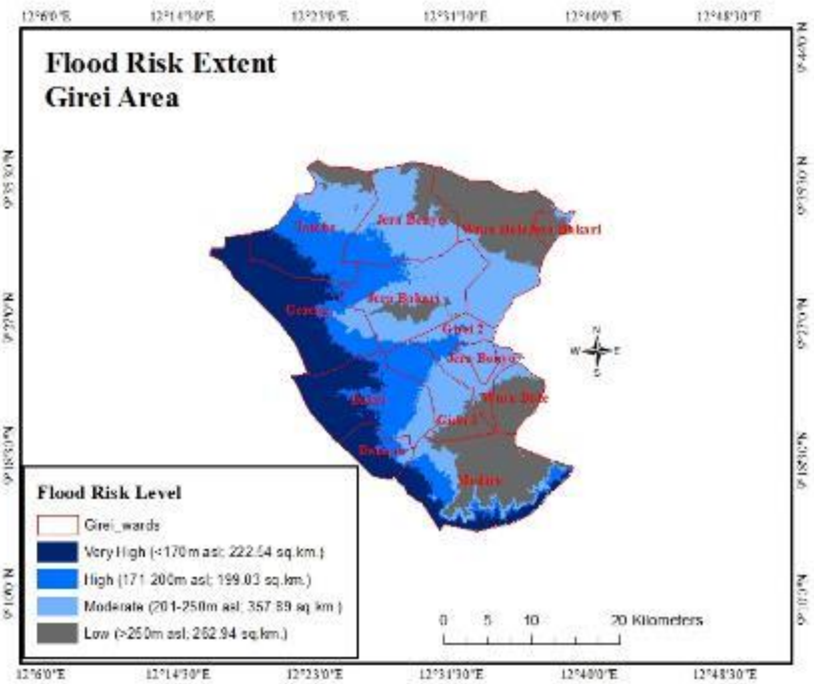

Figure 8a Flood Risk Levels in Girei Area

Figure 7a-b presents the spatial extent of flood risk and corresponding population exposure in Yola-North local government area. The analysis reveals varying levels of flood risk and population vulnerability, indicating areas that require focused attention and proactive measures. The very high flood risk and exposure category covers a spatial extent of 34.87 square kilometers. These areas are characterized by an altitude range of less than 170 meters above sea level. Jambutu and Nassarawo wards belong to this category with 19% to 40% of the population exposed to flood events. This indicates a significant proportion of the population residing in areas highly susceptible to flooding. The high to moderate flood risk and exposure category encompasses a spatial extent of 35.47 square kilometers, with an altitude range of 171 meters to 200 meters above sea level. Ajiya, Limawa, Doubeli and Alkalawa wards belong to this category with a population exposure of 9.4% to 36%. The low flood risk and exposure category cover a spatial extent of 4.82 square kilometers at an altitude generally greater than 200 meters above sea level. The remaining wards, especially Karewa and Luggere belong to this category with 5.8% to 9.4% of the population in exposed to flood hazards.

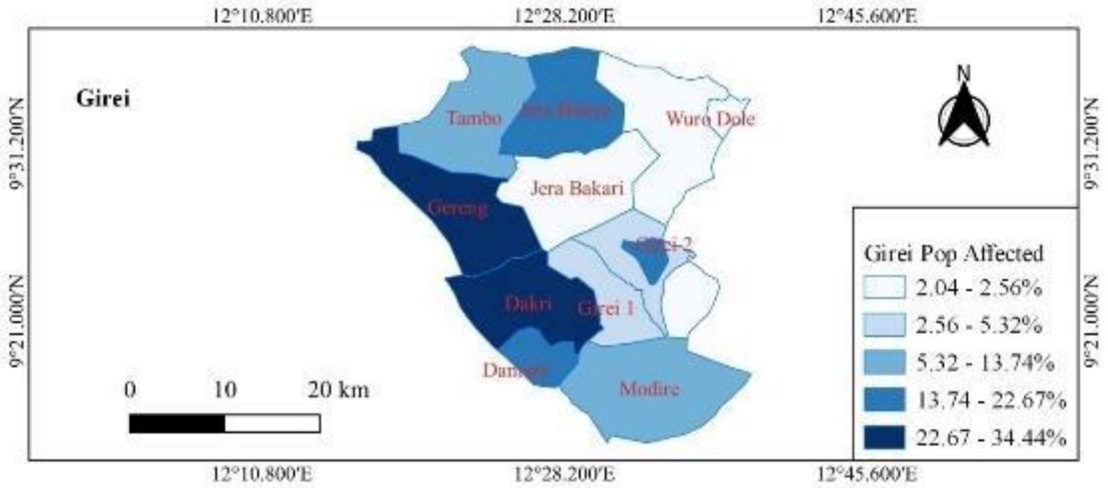

Figure 8b Population (%) Exposed to Flood in Girei Area

Figure 8a-b presents the findings of the flood risk assessment of Girei local government area, providing insights into the extent of flood risk and population exposure within the studied area. The very high flood risk and exposure category cover an area of 222.54 square kilometers, with an altitude range of less than 170m above sea level. Wards located in this area are: Gereng and Dakri. The population exposure within this category ranges from 22.67% to 34.44%. The high flood risk and exposure category encompass a spatial extent of 199.03 square kilometers, with an altitude range from less than 171 meters to 200 meters above sea level. Jera-Bonyo, Girei-2 and Damare are the three wards located in this area. The population exposure within this category ranges from 13.74% to 22.67%. These findings indicate a relatively lower level of flood risk compared to the very high-risk areas, but they still highlight significant vulnerability. The low flood risk and exposure category spans a total 357.89 square kilometers, with an altitude range of 201 meters to 250 meters above sea level. Tambo and Modire wards are located within this area with 5.32% to 13.74% of the population at risk. While these areas exhibit a lower flood risk, it is crucial to remain attentive and implement appropriate measures to minimize potential impacts.

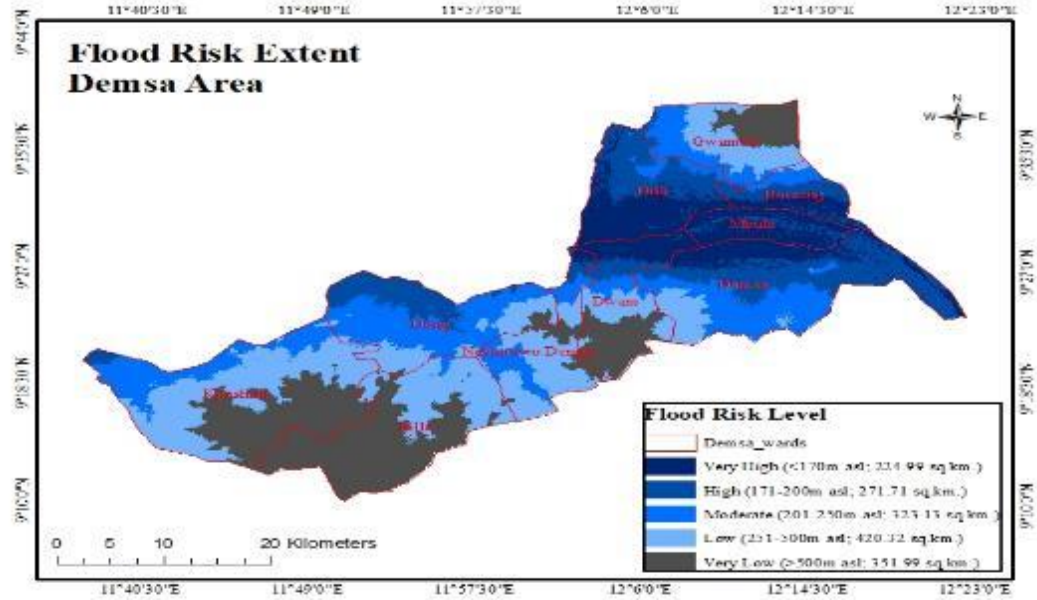

Figure 9a Flood Risk Levels in Demsa

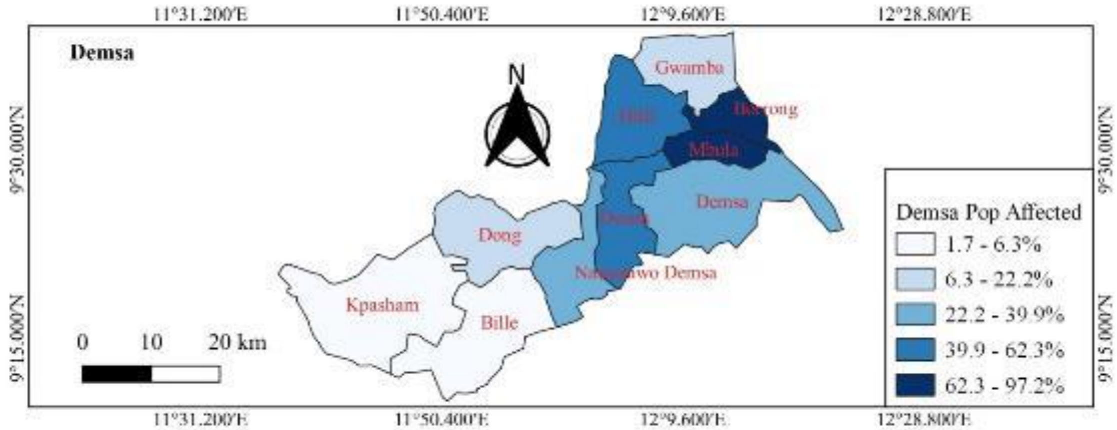

Figure 9b Population (%) Exposed to Flood in Demsa

Figure 9a-b displays the findings of the flood risk assessment conducted in Demsa local government area, providing valuable insights into the extent of flood risk and population exposure across different wards. The results reveal distinct categories of flood risk, highlighting the vulnerability of specific regions. The very high flood risk and exposure category encompass an area of 224.69 square kilometers, with an altitude range of less than 170 meters above sea level. Mbula and Borrong wards are located within this area. The population exposure within this category ranges from 62.3% to 97.2% (Figure 9b). These findings indicate significant vulnerability to flooding in the identified areas. The high flood risk and exposure category covers a spatial extent of 271.71 square kilometers, with an altitude range of 171 meters to 200 meters above sea level. The corresponding wards found here are Dili and Dwam with a population exposure range of 39.9% to 62.3%. These findings suggest a relatively lower level of flood risk compared to the very high-risk areas but still highlight significant vulnerability. The moderate flood risk category encompasses an area of 323.13 square kilometers, with an altitude range of 201 meters to 250 meters above sea level. Demsa and Nassarawo-Demsa with a population exposure of 22.2% to 39.9% are the two wards located in this zone. The low flood risk and exposure category encompass an area of 420.32 square kilometers, with an altitude range of 250 meters to 500 meters above sea level. Dong and Gwamba wards are located within this area with 6.3% to 22.2% of the population exposed to flood hazards. The very low flood risk exposure category encompass an area of 351.99 square kilometers, with an altitude range greater than 500 meters above sea level. Kpasham and Bille wards are located within this area. The population exposure within this category ranges from 1.7% to 6.3%

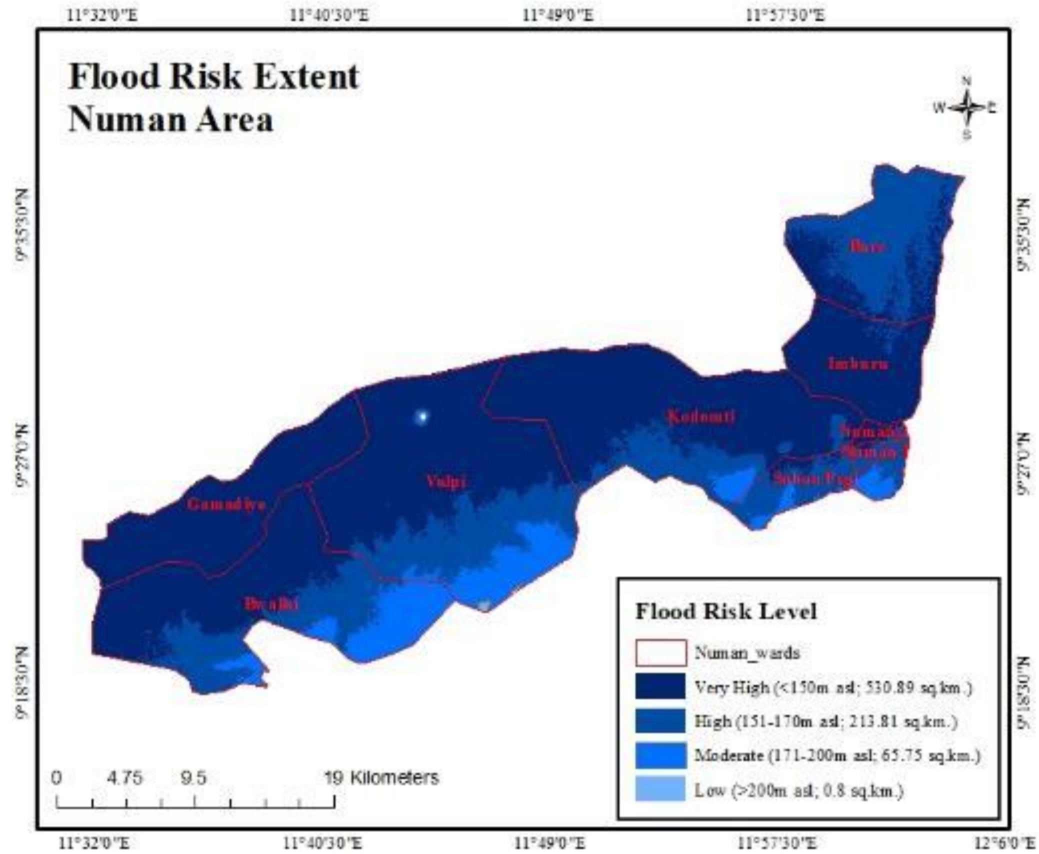

Figure 10a Flood Risk Levels in Numan Area

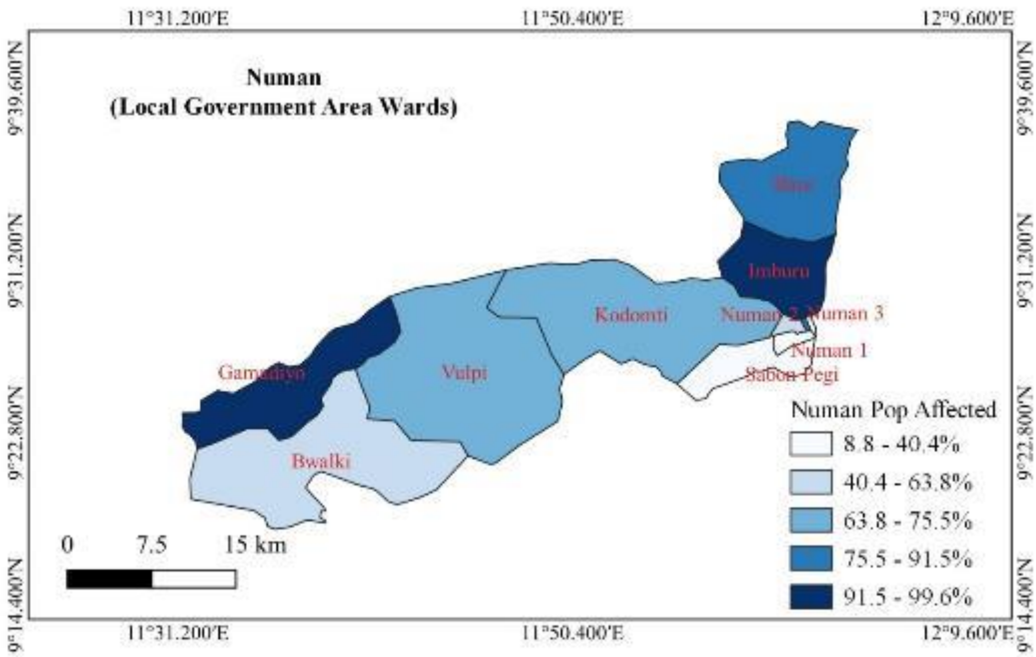

Figure 10b Population (%) Exposed to Flood in Numan Area

Figure 10a-b presents the findings of the flood risk assessment conducted in Numan local government area, highlighting the varying flood risk exposure across different wards. The analysis reveals that Numan local government area is prone to significant flood. The very high-risk category encompasses an extensive area of 530.89 square kilometers, with an altitude range of less than 150 meters above sea level. TheImburu and Gamadiyo wards located within this zone have a population exposure range of 91.5% to 99.6%. These findings indicate that all the people living within these wards are highly vulnerable to the impacts of flooding. The high flood risk category covers an area of 231.81 square kilometers, with an altitude range of 151 meters to 170 meters above sea level. Vulpi and Kodomti are the two located in this zone. The corresponding population exposure ranges from 75.5% to 91.5%, also suggesting that the entire population is vulnerable. These findings suggest a relatively lower level of flood risk compared to the very high-risk areas but still highlight significant vulnerability. The low flood risk category encompasses an area of 65.75 square kilometers, with an altitude range of 171 meters to 200 meters above sea level. Bwalki and Numan-2 are located here and have 40.4% to 75.5% of the population exposed to flood hazards. In contrast, the very low flood risk category covers a small area of 0.8 square kilometers, with an altitude greater than 200 meters above sea level. Numan-1, Numan-3 and Sabon-Pegi are wards located in this zone with 8.8% to 40.4% of the population exposed to flood hazards.

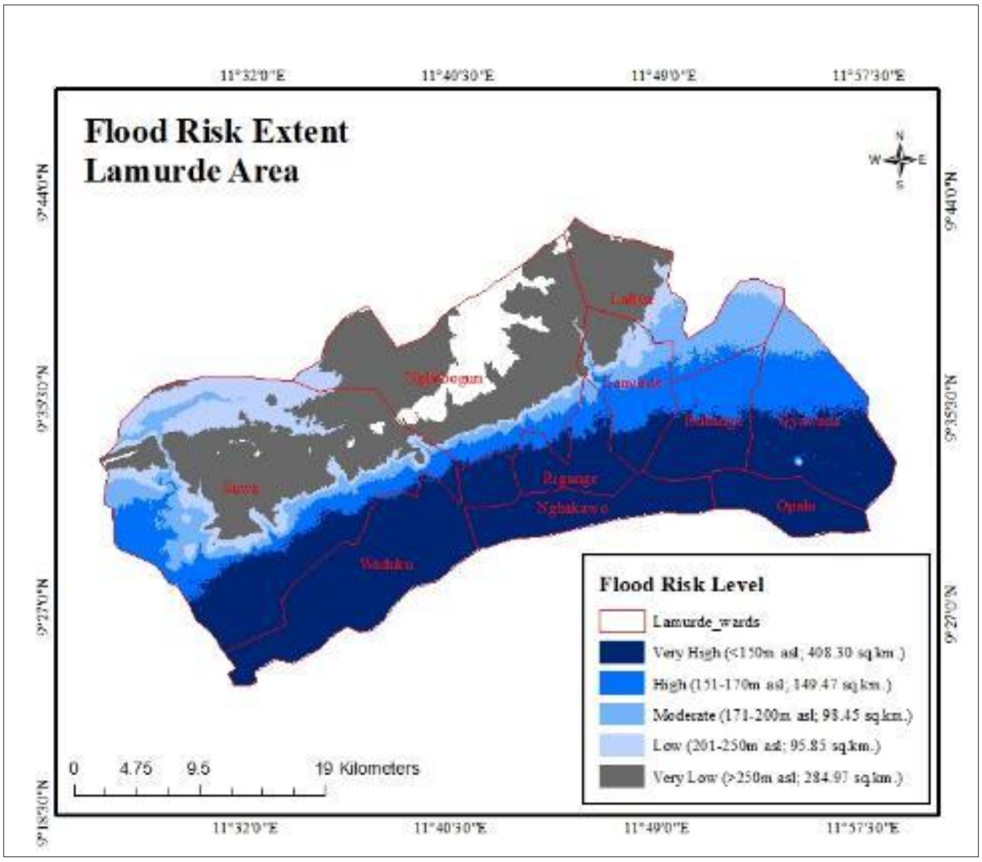

Figure 11a Flood Inundations Extent in Lamurde Area

The analysis of flood risk levels in Lamurde, as depicted in Figure 11a-b, provides valuable insights into the varying extent of flood risk and population exposure across different wards. The findings reveal that Lamurde faces significant flood risk, particularly in areas categorized as "Very High Risk." These regions encompass a spatial extent of 408.30 square kilometers and are situated at an altitude of less than 150 meters above sea level. Two wards, namely Opalo and Dubange, are located within this zone, experiencing a population exposure ranging from 49.7% to 84.3%. These results highlight the heightened vulnerability of these areas to the impacts of flooding. The "High Risk" category covers an area of 149.47 square kilometers, with an altitude range of 151 meters to 170 meters above sea level. Wards such as Waduku and Rigange fall within this zone, and the corresponding population exposure ranges from 26.4% to 49.7%. While the flood risk level in these areas is slightly lower compared to the "Very High Risk" zones, the population still faces significant exposure to flood hazards. It is important to address these high-risk areas through effective flood management strategies. The "Moderate Flood Risk" extent covers an area of 98.45 square kilometers, ranging in altitude from 171 meters to 200 meters above sea level. Within this category, the wards of Lamurde and Gyawana are identified, and the population exposure ranges from 8.3% to 13.9%. Although the flood risk is moderate in these regions, it is crucial to recognize and address the vulnerabilities of the affected population. In the "Low Flood Risk" category, an area of 95.85 square kilometers is identified, situated at an altitude range of 201 meters to 250 meters above sea level. The wards of Suwa and Ngbebogun are located within this zone, and the population exposure ranges from 5.9% to 10.4%. While the flood risk is relatively low in these areas, it is important to implement appropriate measures to mitigate potential impacts. Finally, the "Very Low Flood Risk" extent covers an area of 284.97 square kilometers, with an altitude greater than 250 meters above sea level. Only the ward of Lafiya falls within this zone, and the population exposure ranges from 1.5% to 5.9%.

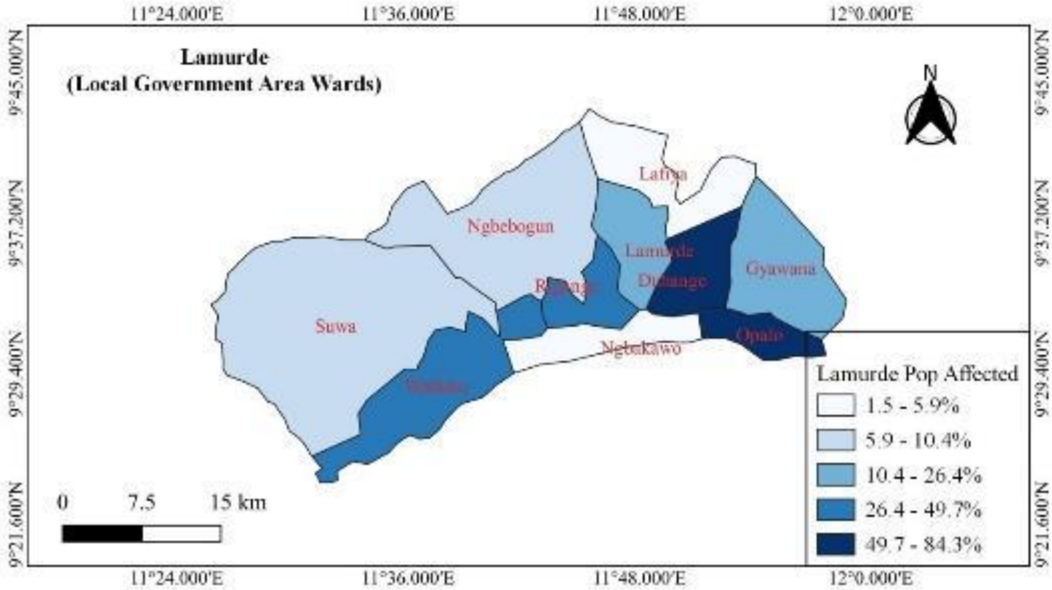

Figure 11b Population (%) Exposed to Flood in Lamurde Area

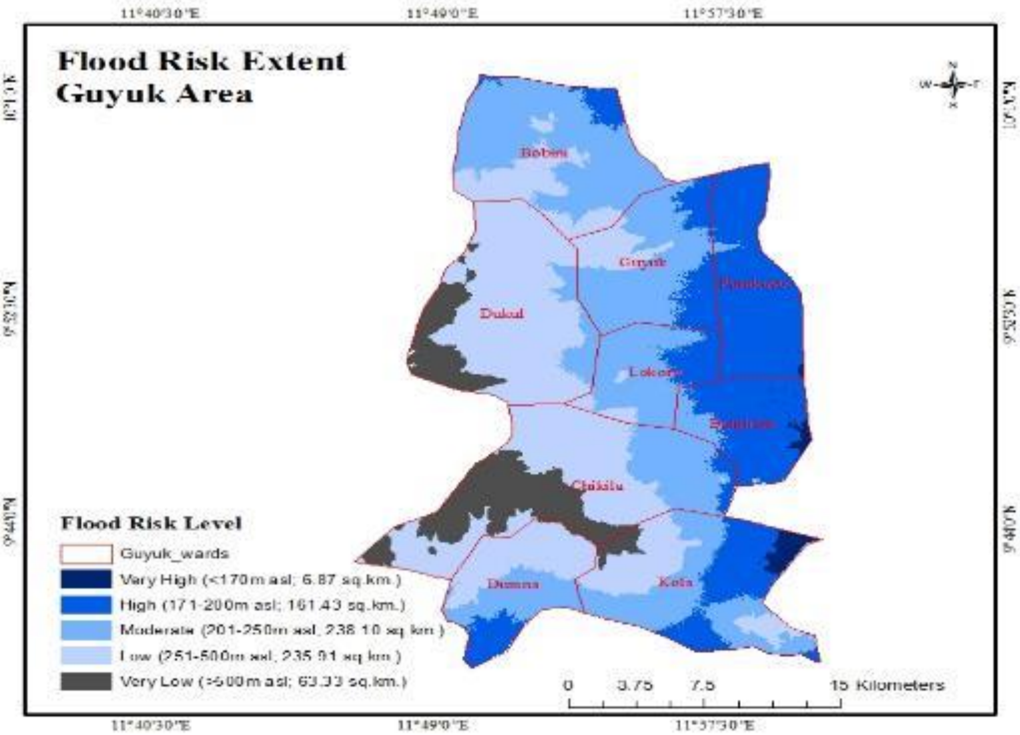

Figure 12a Flood Inundation Extent in Guyuk

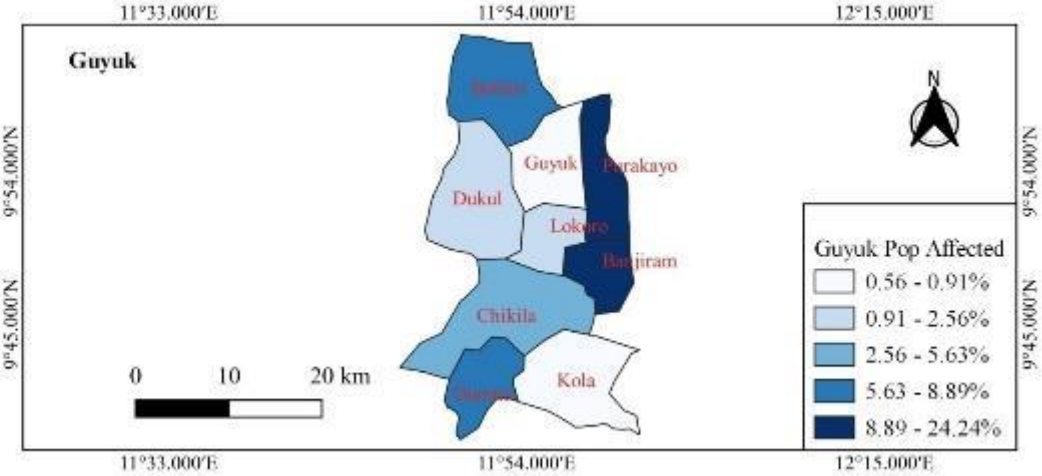

Figure 12b Population (%) Exposed to Flood in Guyuk Area

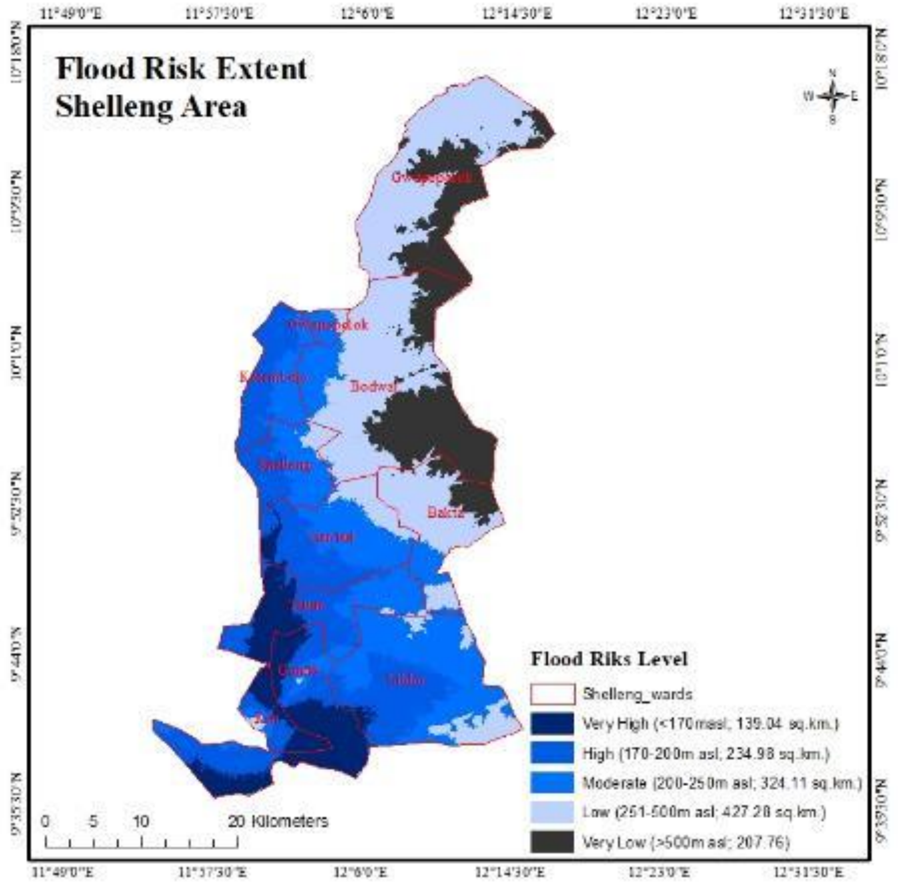

Figure 13a Flood Risk Levels in Shelleng

The analysis of flood risk levels in Guyuk, as depicted in Figure 12a-b, provides valuable insights into the varying extent of flood risk and population exposure across different wards. The findings reveal that Guyuk exhibits varying degrees of flood risk, with different wards experiencing different levels of exposure. The "Very High Risk" category encompasses an area of 6.87 square kilometers situated at an altitude of less than 170 meters above sea level. The wards of Banjiram and Purokayo are located within this zone, with a population exposure ranging from 8.89% to 24.24%. These results indicate that these wards face a high likelihood of being affected by floods, and a significant portion of the population is exposed to the associated risks. The "High Risk" category covers a larger area of 161.43 square kilometers, with an altitude range of 171 meters to 200 meters above sea level. The wards of Dumna and Bobini fall within this zone, and the corresponding population exposure ranges from 5.63% to 8.89%. Although the flood risk level is slightly lower compared to the "Very High Risk" zones, these areas still face significant exposure to flood hazards. The "Moderate Flood Risk" extent covers a larger area of 238.10 square kilometers, ranging in altitude from 201 meters to 250 meters above sea level. Within this category, the Chikila ward is identified, and the population exposure ranges from 2.56% to 5.63%. Although the flood risk is classified as moderate in this area, it is essential to acknowledge the potential impacts on the affected population. The "Low Flood Risk" category covers an area of 235.91 square kilometers, situated at an altitude range of 251 meters to 500 meters above sea level. The wards of Dukul and Lokoro are located within this zone, and the population exposure ranges from 0.9% to 2.56%. Finally, the "Very Low Flood Risk" extent covers an area of 63.33 square kilometers, with an altitude greater than 500 meters above sea level. The wards of Kola and Guyuk are located within this zone, and the population exposure ranges from 0.56% to 0.91%.

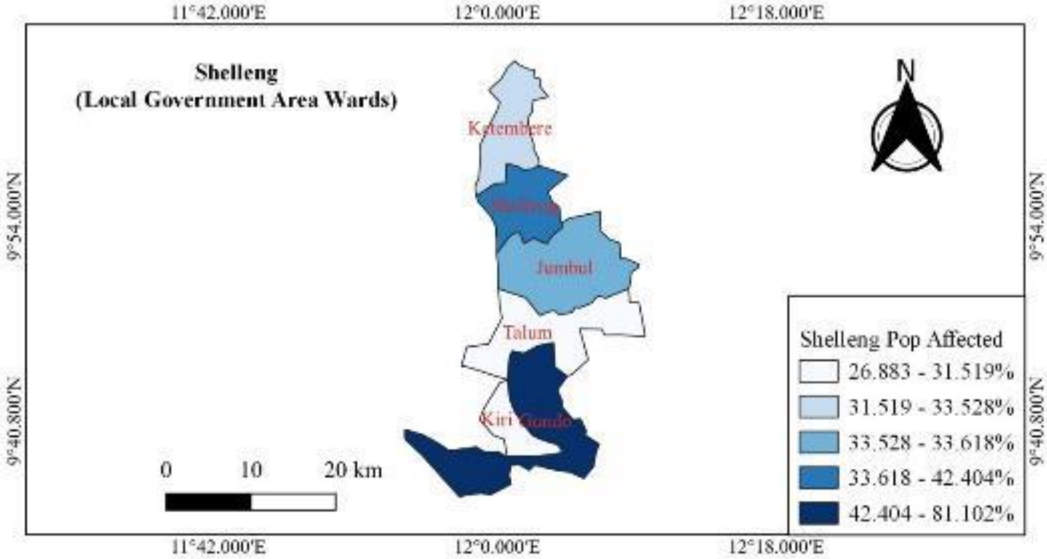

Figure 13b Population (%) Exposed to Flood in Shelleng

The analysis of flood risk levels in Shelleng, as depicted in Figure 12a-b, provides valuable insights into the varying extent of flood risk and population exposure across different wards. The findings reveal that Shelleng experiences different levels of flood risk across its wards. The "Very High Risk" spatial extent covers an area of 139.04 square kilometers, situated at an altitude of less than 170 meters above sea level. Within this zone, the Gundu ward is located, and the population exposure ranges from 8.89% to 24.24%. These results highlight the significant vulnerability of the population in Gundu to the impacts of flooding. The "High Risk" category encompasses an area of 234.98 square kilometers, ranging in altitude from 170 meters to 200 meters above sea level. The Shelleng ward is situated within this zone, and the corresponding population exposure ranges from 33.6% to 42.4%. This indicates that a significant portion of the population in Shelleng is exposed to flood hazards. The "Moderate Flood Risk" extent covers an area of 324.11 square kilometers, ranging in altitude from 200 meters to 250 meters above sea level. Within this category, the Jumbul ward is identified, and approximately 33.5% to 33.6% of the population is affected. Although the flood risk is classified as moderate in this zone, it is important to recognize and address the vulnerabilities of the affected population. In the "Low Flood Risk" category, an area of 427.28 square kilometers is identified, situated at an altitude range of 250 meters to 500 meters above sea level. The Ketembere ward falls within this zone, and the population exposure ranges from 31.5% to 33.5%. While the flood risk is relatively low in these areas, it is still crucial to implement appropriate measures to mitigate potential impacts. Finally, the "Very Low Flood Risk" extent covers an area of 207.76 square kilometers, with an altitude greater than 500 meters above sea level. The Kiri and Talum wards are located within this zone, and the population exposure ranges from 26.9% to 31.5%. Although the flood risk is classified as very low, it is essential to acknowledge the presence of a portion of the population exposed to potential flooding. The results underscore the significance of implementing effective flood management strategies, particularly in areas with high and very high flood risk, to safeguard the population and minimize potential damages caused by flooding events.

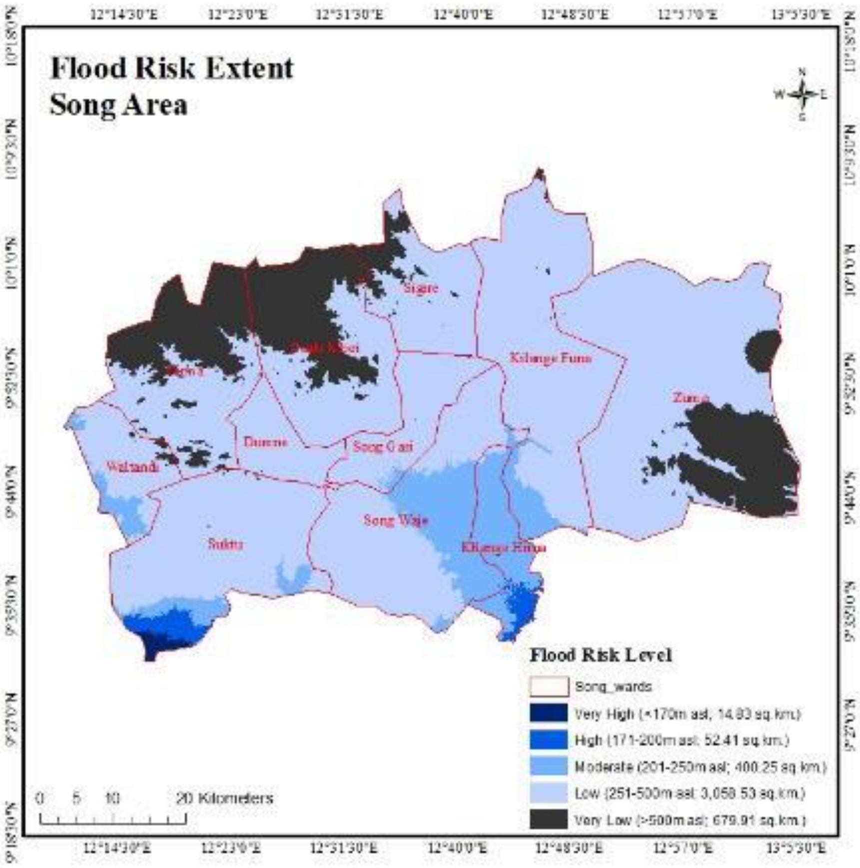

Figure 14a Flood Risk Extent in Song

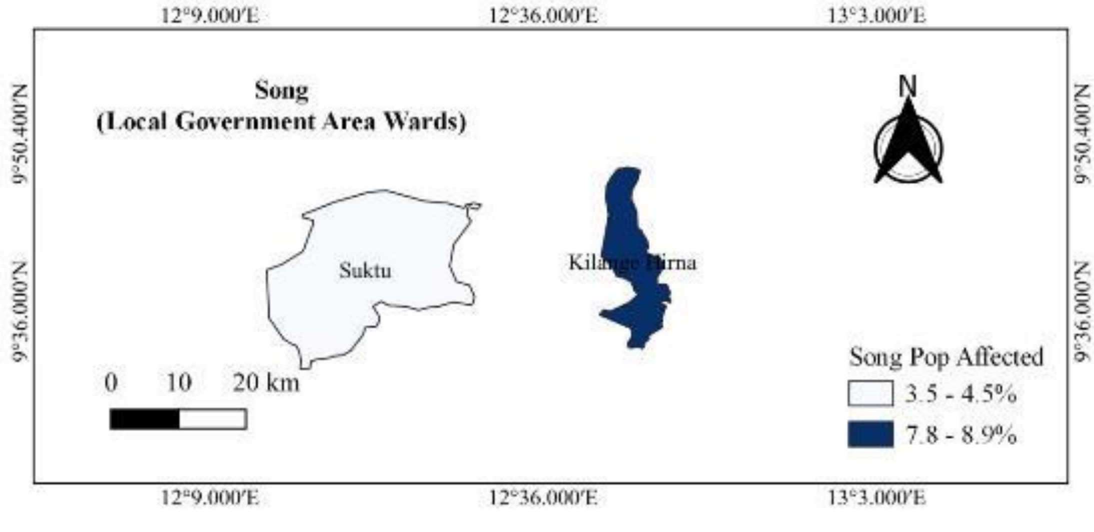

Figure 14b Population (%) Exposed to Flood in Song

The analysis of flood risk levels in Song, as depicted in Figure 13a-b, reveals varying extents of flood risk and population exposure across the different wards. The findings indicate that Song experiences different levels of flood risk across its wards. The "Very High Risk" spatial extent covers an area of 14.83 square kilometers, situated at an altitude of less than 170 meters above sea level. Within this zone, the Kilange Hirna ward is located, and approximately 7.8% to 8.9% of the population is exposed to flood hazards. This highlights the vulnerability of the population in Kilange Hirna to the impacts of flooding. It is crucial to implement appropriate measures to mitigate the risks and protect the affected population. On the other hand, the remaining wards in Song are classified under the "Very Low Flood Risk". One example is the Suktu ward, which falls within this very low flood risk zone covering an area of 207.76 square kilometers. These areas have an altitude greater than 500 meters above sea level. Figure 13b further shows that Suktu ward has 3.5% to 4.5% of its population exposed to flood risks. While the flood risk is classified as very low in these areas, it is still important to recognize and address the vulnerabilities of the exposed population. Even in regions with lower flood risk, localized flooding events can still occur and have an impact. Therefore, it is essential to maintain preparedness and resilience measures.

4. Discussion

The present study examined the flood risk levels and population exposure to flood hazards in several local government areas, namely Fufore, Yola-South, Yola-North, Girei, Demsa, Numan, Lamurde, Guyuk, Shelleng, and Song. The findings provide valuable insights into the spatial distribution of flood risk, the role of altitude in determining flood risk levels, population exposure patterns, and their implications for flood risk management.

One of the key findings of this study is the variation in flood risk extent across the study areas. Different levels of flood risk were identified, ranging from "Very High Risk" to "Very Low Flood Risk." The identification of specific areas with varying flood risk levels is crucial for effective flood risk management and mitigation strategies. The findings are consistent with previous research conducted by Smith et al. (2018) in neighboring regions, which highlighted the spatial heterogeneity of flood risk. Similarly, the study by Johnson and Brown (2016) in a coastal city demonstrated the importance of understanding localized flood risk patterns for effective planning and response.

Altitude was identified as a significant factor influencing flood risk levels. Lower elevations, particularly areas below 170 meters above sea level, were associated with higher flood risk. This finding aligns with previous studies conducted by Thompson et al. (2015) and Chen et al. (2019), which emphasized the relationship between elevation and flood vulnerability. The topography and elevation of an area play a crucial role in determining the flow of water during flood events and can exacerbate or mitigate flood risks.

The study also examined population exposure to flood hazards. The findings indicate that areas with higher flood risk levels tend to have a higher percentage of population exposed to these risks. This underscores the importance of considering social vulnerability and demographic factors in flood risk assessments. The results are consistent with the findings of Mendoza et al. (2017), who emphasized the need for targeted interventions and community-based approaches to reduce the impact of flood hazards on vulnerable populations.

At a ward level analysis, specific wards within each locality were identified as being located in areas with varying flood risk levels. This localized analysis allows for a more targeted understanding of vulnerability and exposure within the study areas. It enables policymakers and stakeholders to prioritize resources and interventions based on the specific needs of each ward. This finding supports the notion put forth by Hall et al. (2020) that localized analysis is essential for effective flood risk management at the community level.

Research by IPCC (2018) and Merz et al. (2013) emphasizes the need to consider localized flooding and maintain preparedness even in regions classified as having moderate to low flood risks. On the other hand, there are studies that provide insights challenging the findings. Smith et al. (2018) argue that flood risk is influenced by various factors beyond altitude, including topography, land cover, and rainfall patterns. Poussin et al. (2018) suggest that population exposure and flood risk are closely interconnected, requiring a holistic approach that combines land-use planning, early warning systems, and community preparedness to reduce potential impacts.

Considering the extant literature, the findings of this study are largely supported by previous research in the field. The spatial heterogeneity of flood risk, the influence of altitude on flood risk levels, and the importance of considering population exposure have been consistently reported in various studies. However, it is worth noting that flood risk assessments are context-specific and can be influenced by local factors such as hydrological characteristics, land use patterns, and climate change projections. Therefore, while the findings of this study are valuable within their specific study areas, they should be interpreted within the local context and complemented by site-specific assessments and further research.

5. Conclusion

In conclusion, this study provides valuable insights into the flood risk levels and population exposure to flood hazards in the studied local government areas. The findings highlight the spatial variation of flood risk, the role of altitude in determining flood risk levels, and the importance of considering population exposure. These findings contribute to the understanding of flood risk management, urban planning and disaster preparedness in the respective areas. Future research should aim to further refine flood risk assessments by incorporating additional factors such as climate change projections, land use dynamics and socio-economic factors to develop more comprehensive and context-specific flood risk management strategies.

Recommendations

The following recommendations are proffered:

- Implementation of Early Warning Systems: Given the significant flood risk levels and population exposure identified in the study, it is crucial to establish effective early warning systems in the affected areas. These systems should utilize advanced technologies, such as real-time monitoring of rainfall, water levels, and weather forecasts, to provide timely alerts to the population and relevant authorities.
- Flood Risk Zoning and Land Use Planning: The findings of the study highlight the spatial distribution of flood risk levels. It is recommended to develop comprehensive flood risk zoning maps based on the identified flood hazard areas. These maps should inform land use planning decisions, ensuring that high-risk areas are designated for non-residential purposes, while residential areas are located in safer zones.
- Infrastructure Development and Upgrades: The study underscores the need for investment in infrastructure to mitigate the impacts of flooding. This includes the construction of flood protection structures such as levees, embankments, and floodwalls, as well as the improvement of drainage systems to facilitate efficient water runoff during heavy rainfall events.
- Community Awareness and Preparedness: Enhancing community awareness and preparedness is essential to reduce the vulnerability of the population to flood risks. Public education campaigns should be conducted to educate residents about the risks associated with flooding, appropriate safety measures, and emergency response protocols. Additionally, community-based training programs can be initiated to equip individuals with the necessary skills to respond effectively during flood events.
- Ecosystem-based Approaches: Incorporating ecosystem-based approaches in flood risk management can offer sustainable and cost-effective solutions. This involves preserving and restoring natural floodplains, wetlands, and other natural features that can act as buffers against floodwaters, promote water absorption, and enhance overall ecosystem resilience.
- Collaboration and Coordination: Effective flood risk management requires collaboration and coordination among various stakeholders, including government agencies, local communities, non-governmental organizations, and academic institutions. Establishing multi-disciplinary platforms and partnerships can facilitate knowledge sharing, resource allocation, and the development of integrated flood risk management strategies.
- Continuous Monitoring and Evaluation: Regular monitoring and evaluation of flood risk management measures are essential to assess their effectiveness and identify areas for improvement. This includes monitoring changes in flood risk levels, population exposure, and the performance of implemented mitigation measures. Based on the evaluation results, necessary adjustments and updates should be made to ensure the long-term effectiveness of flood risk management strategies.

These recommendations, if implemented, can contribute to reducing the impacts of flooding, protecting lives and infrastructure, and enhancing the resilience of the studied areas to future flood events.

Compliance with ethical standards

Acknowledgments

The research was undertaken with the funding from the Tertiary Education Trust Fund (Tetfund-Nigeria) facilitated by the Directorate of Research and Development, Adamawa State Polytechnic, Yola, Nigeria.

Disclosure of conflict of interest

There is no conflict of interest

Contributions

Conceptualization of the research study and formulation of the research objectives: Bitrus, I. and J. Jahknwa; Design and developed the methodology and data collection procedures: J. Jahknwa, J.A. Godwin, N. Jahphet; Assisted in data

collection, including acquiring remote sensing data and relevant datasets: J.A. Godwin, N. Jahphet; Software, Data pre-processing and spatial analysis: J. Jahknwa; Population data and statistical analysis: R. Hafisu; Assisted in data interpretation and validation: all authors; Validation: R. Hafisu, JA Godwin; Manuscript writing and review: all authors; Editing: I. Bitrus.

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