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REVIEW ARTICLE

Temporal Assessment of the Effect of Flooding Vulnerability on Agricultural Land Use in the Gambia

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Abstract Flooding is a significant environmental problem, projected to intensify from 2010 to 2030. This natural disaster has affected several regions globally, leading to loss of life and property, community disruption, economic loss, injuries, and deaths. Factors contributing to flooding include heavy rainfall, rising sea levels, lowlands, waterways, climatic variations, wetlands, soil types, and unplanned urban settlements. The most severe case in the history of the Gambia struck in 2022. Therefore, this study aimed to identify areas vulnerable to flooding and the effect on agricultural land in the Gambia, as well as suggest preventive measures. The method adopted included the collection of secondary data from Landsat ETM imagery, Digital Elevation Model, rainfall data, Copernicus Global Land Services (CGLS), and Food Agricultural Organisation soil maps. The satellite imageries were processed and classified using ArcGIS 10.7.1, generating land use and land cover, slope, drainage density, rainfall, and soil maps. ArcGIS, combined with the Analytic Hierarchy Process (AHP), was used to integrate these maps to produce a vulnerability map for the study. The results showed areas with very high, high, moderate, low, and very low vulnerability. Based on the classification, coastal and lowland regions were in the high category. Therefore, this study recommended the construction of water barricades in vulnerable coastal areas to mitigate the disaster.

1. Introduction

Flooding is a major environmental problem worldwide, manifesting in regions susceptible to rainfall or coastal hazards. Furthermore, it has resulted in the destruction of lives and properties through excess water flow onto the dry lands. Over recent years, the reincidence of floodings has posed a serious threat to human existence, destruction of farmlands, coastal shores, and buildings, and loss of lives. The multifaceted causes of this disaster include heavy rainfall, sea-level rise, soil moisture regime, operations of dams, construction in waterways, overpopulation, global warming, and climate change. The occurrence is not limited to specific geographical locations, it is prevalent around the largest rivers worldwide and typically during the onset of spring. This phenomenon arises when river levels surge beyond their banks. Flooding can be defined as the inundation of land by excess water or inflow of tide onto land, essentially the misplacement of water causing the collapse of land along coastal shores. Factors contributing to this natural disaster are heavy rain, thunderstorms, and rapid surface water flow on dry land.

In the Gambia, flooding is a frequent and common occurrence, categorized as coastal or fluvial. It occurred in many parts of the country and the worst in memory was in 2022, which affected 50,378 people and displaced 7,404 in regions including North Bank Region, West Coast Region, Kanifing Municipality, and Banjul (Humanitarian Response, 2022). The onset of the rainy season in July increases the situation, leading to widespread water contamination and annual disturbance due to heavy rainfall. Meanwhile, contributors to river flooding in the country were sea level, wind, and tributary forcings. According to Jaiteh and Sarr (2011), the rise in sea level tends to increase towards the inner part of the river estuary, particularly affecting the river Gambia. Wind, as a forcing factor, significantly impacts water levels, causing the pressure of the water to intensify its tributary forces. It remains uncertain whether these factors represent the entirety of the problem. This study aim to address these gaps and identify vulnerable areas, thereby aiding in decision-making processes. The results obtained are expected to contribute valuable insights for future investigations on flooding in the Gambia. The methodology focuses on utilizing maps and climatic data to unveil areas at risk. GIS and remote sensing will be integral components in modeling the vulnerability, offering a comprehensive understanding of the dynamics.

Flooding can be effectively measured using GIS, which generates risk maps highlighting communities at risk. These maps play a crucial role in future planning to mitigate potential loss of lives and property. In the assessment and prediction of this natural disaster, providing solutions and sustainable environmental management has become imperative. Flooding vulnerability is measured through GIS by considering various factors in risk identification, including slope orientation, elevation, rainfall, proximity of built-up areas to drainages, extent of inundation, as well as cultural practices and perceptions (Eguaroje et al., 2015). Accurate vulnerability mapping plays a crucial role in land use planning, aiding in the implementation of effective mitigation measures. The inclusion of charts and maps is instrumental in facilitating the identification of vulnerable areas, empowering planners to prioritize their mitigation efforts (Forkuo, 2011). Flooding management is important in minimizing extensive damages to society and optimizing land usage and management. However, achieving this goal is not technically feasible without the utilization of well-crafted flooding hazard and risk maps (Balica et al., 2012). Societal vulnerability to this natural disaster is determined by three primary factors, namely exposure, susceptibility, and resilience. In this study, The Gambia is assumed to be vulnerable due to these three factors. The integration of spatial analysis and remote sensing provides valuable insights into the level of vulnerability in any given area.

Floodings are an annual environmental phenomenon in the Gambia, causing destruction to lives and properties and the extent of its damage varies. It has made many homeless, and farmless and caused the spread of diseases owing to waterborne diseases. Aids has been provided for victims by both International and National organizations. Despite the recurrent cases, there has been limited study on flooding in the area. Various factors contribute to natural disasters, including excess rainfall, poor drainage systems, sea level increases, wind forces, and tributary forces. While the rainy season could potentially benefit farmlands in the region, it remains unclear whether there are other contributing causes. Furthermore, strategies for mitigating future occurrences are not well-documented. Therefore, this study aimed to determine the causes, impacts, and mitigation strategies.

This study on temporal assessment of the effects of flooding vulnerability on agricultural land use in the Gambia aimed to identify flooding-prone areas, explore contributing factors and analyze trends in flooding vulnerability. Furthermore, it provided awareness and new developments into vulnerability on agricultural land use and offered valuable information for land planners, the Gambian government, as well as International agencies for future investigations and planning purposes.

Heavy rainfall and extreme climate are often cited as the primary factors behind flooding in the Gambia. Vulnerable areas include lowlands, waterways, wetlands, and unplanned urban settlements. According to the Gambia Bureau of Statistics, the documented origin of flooding dates back to 1948. Some significant years of its events were 1954, 1955, 1956, 1988, 1999, 2002, 2003, 2004 to 2011, 2012 to 2014, 2015 and 2022. A cultural belief surrounding this natural disaster was rooted in the Gambia folk tales of Ninki Nanka by an elderly man. In 1947, there was a large reptile-like beast (dragon) in the swamp, whenever it wanted to move, heavy rainfall ensued, causing water to flow into town and facilitating the journey of the animal to the high sea. This event marked the onset of the natural disaster in Ebo Town, the Gambia. Despite this folk tale, scholars disagreed that the origin can be solely attributed to sea level rise, stagnant water, and rain. Based on their contention, this natural disaster is a combination of many environmental factors in the area. These include sea level rise, waterlogging clay soils, shallow water tables, lowlands, coastal erosion, and deficiency in non-urban sewage systems (National Disaster Management Agency, 2011).

Despite being one of the few countries with a low population exposed to flooding, an average of 12,700 people are affected yearly. River (fluvial) and flash flooding are prevalent types, often triggered by heavy rainfall, rise in sea level, and lowlands conditions. High rainfall affects agricultural lands leading to an increase in prices of goods and services and an increase in government expenditure (Ceesay, 2020). Between 2002 and 2006, the Gambia witnessed 65 cases, leading to 13 deaths and 450 cases of cholera in 2005. In 2010, farmlands were submerged by floodings, affecting 26,000 people, and leaving over 7,000 homeless, while in 2012, 13 deaths due to flooding and high windstorms were observed. The National Disaster Management Agency (2010) reported partial damage to 2,090 houses were partially damaged, the destruction of 561 houses, and the displacement of 7,640 people. The Kanifing Municipal Council and Western Region suffered damages to roads, bridges, water facilities, health facilities, schools, and electricity poles, with some areas contaminated by flooded toilets and stagnant water. In 2022, the Gambia experienced its most significant case in decades, with 276mm of rainfall resulting in flash flooding from July 30th to August 5th. A total of 50,378 people were affected, 7,404 were displaced, and severe damage occurred to schools, health facilities, roads, and other infrastructure. The aftermath included reports of reptiles in homes, blocked drainage systems, leakage of toxic chemicals, and overflow of excess water.

Remote sensing has gained international recognition as a valuable tool for assessing flooding vulnerability to manage the hazards (Kumar and Bhattacharjya, 2020); (Lee and Choi,2018). These modern studies identify flooding-prone areas, while the effectiveness of the different remote sensing methods was compared. In combination with statistical and weighted allocation approaches, these methods were used to analyze the socio-economic impacts of the natural disaster (Ogato et al, 2020). Additionally, some studies incorporate field observation in conjunction with the aforementioned methods (Diaz-Sarachaga and Jato-Espino, 2020). This investigation applied remote sensing, statistical, and weighted allocation approaches to identify flooding-vulnerable areas and suggest effective strategies for management.

2. Methods

Study Area

The Gambia, situated between latitude 13.28^{0}N, 16.34°W and longitude **13.467^{0}N, 16.567^{0}W**, is located in West Africa, within an area of 11,295 km^2. Bordered by the Atlantic Ocean to the west and Senegal to the north, south, and east, the country experiences a hot and tropical climate with consistent heat throughout the year, resulting in distinct rainy and dry seasons. The rainy season spans 5 months, typically from June to mid-October, with annual rainfall ranging from 900mm and 1,300mm. Meanwhile, the dry season extends from November to May, with temperatures varying between 32^{0}C and 40^{0}C. Particularly, temperature differences exist between the coast and the inland areas. The geographical features include the Gambia River, numerous Atlantic coastline beaches, and a flat plain. Ibol (2022) described the Gambia River as the primary feature flowing across a plateau of Miocene-Pliocene stone formed approximately 23.7 to 1.6 million years ago. Narrow valleys divide flattish hills in the east, while in the west, small hills alternate with sand depressions, forming a flat plain. Houses in the region comprise brick, mud, and cemented houses, connected by both tarred and un-tarred roads. The diverse land use patterns include forestry, residential, open water, agriculture, academic, religious, commercial, health, government facilities, and open spaces. The soil composition

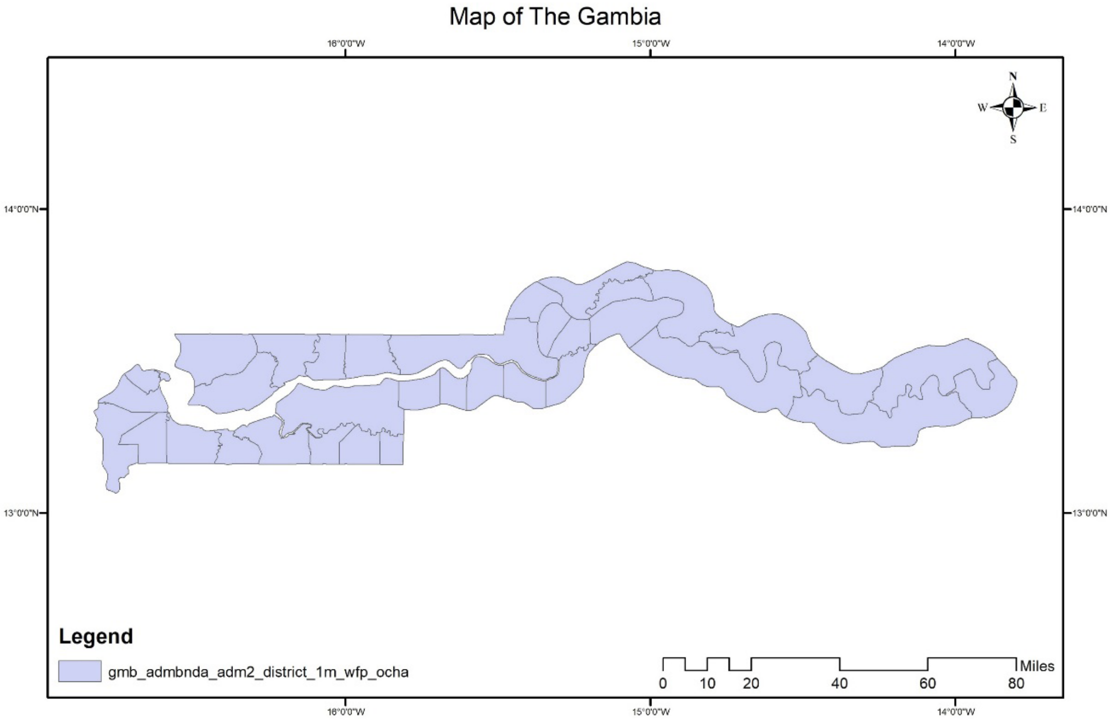

Figure 1. Map of the Gambia

consists of sandy, loamy, and clay textures, with savanna vegetation in the uplands, swamps in low-lying areas, and mangrove swamps near the brackish lower the Gambia River. Recognized as a tourist destination, the Gambia has many ecotourism sites, few wild animals, and more than 500 species of birds. The natural resources identified were fish, clay, silica, sand, titanium, tin, and zircon. The map of the Gambia is shown in Figure 1.

Sampling Techniques

Variables responsible for flooding, identified through literature and field surveys, were land use, slope, drainage density, elevation, river proximity, rainfall, and soil texture (Hagos, et al., 2022). Secondary data, including satellite imagery from Landsat ETM imagery, Digital Elevation Model (DEM), Food and Agricultural Organization, rainfall data, and Copernicus Global Land Services (CGLS) satellite imagery, were used to obtain these variables for the study. Utilizing ArcGIS 10.7.1, the imageries were processed to derive elevation, soil, rainfall, and land use maps. Satellite imagery was preferred for its accessibility and close resolution to earth observation. CGLS-acquired satellite images were digitized and classified into land cover categories such as forests, herbaceous vegetation, bare/ sparse vegetation, herbaceous wetlands, built-up areas, cropland, and permanent water bodies. The classification of the study area produced rainfall, soil, and elevation maps after rasterization with ArcGIS.

Data Collection and Processing

The satellite data utilized for the study were collected on May 3, 2023. CGLS data at 100 m spatial resolution (CGLS-LC100) were selected for generating a comprehensive land use and land cover map to observe spatial and temporal changes within the study area. ArcGIS software was adopted to process satellite imagery and classify it into distinct categories, including forests, vegetation, wetlands, cropland, built-up areas, and water bodies. Land use land cover (LULC) describes the nature of soil deposits and the distribution of features such as forests, built-up areas, water bodies, cropland, shrubland, and grassland in a particular place. The interaction of these elements plays a crucial role in flooding dynamics. Changes in agricultural practices and increased urbanization, for instance, contribute to increased risks. Slope, indicating the degree of steepness to the horizontal plane, serves as a key indicator of vulnerability. Furthermore, water naturally flosses along slopes and accumulates on plain surfaces (Desalegn and Mulu, 2020). Slope and elevation maps for the study area were obtained from the digital elevation model (DEM) through the processing dataset of Shuttle Radar Topography Mission (SRTM) version 2 (90) using ArcGIS 10.7.1. The resulting data were classified into 5 distinct areas. A spatial analysis tool in ArcGIS 10.7.1 software on the dataset from SRTM, was applied to clip the study area to generate drainage density, a factor influenced by both slope and bedrock characteristics (Wondim, 2016). Drainage density, obtained from DEM in ArcGIS, allowed for the classification of the study area into 5 groups. To further enhance understanding, Food and Agricultural Organization data on the soil of the Gambia was scanned, processed, and geo-referenced with ArcGIS software to obtain a digitized soil map. Soil type significantly influences soil dynamics, impacting water infiltration and holding capacity. Rainfall, another critical factor, was analyzed using the spatial analysis tool in ArcGIS software, considering mean annual data from 2011 to 2022. The resulting map categorized the Gambia into five classes based on rainfall intensity.

The analytic Hierarchy Process (AHP), developed by Saaty in 1980, serves as a significant tool for assessing flooding vulnerability through the application of GIS. This method necessitates the determination of priority vectors or weights for various alternatives, guiding the decision-making process. To achieve this, problems are initially segmented into distinct issues, which are subsequently organized into a hierarchical structure. The arrangement shows the weights assigned to each element, facilitating a clearer understanding of the problem at hand. AHP proved instrumental in risk management and was applied widely in resource planning and mitigation. The culmination of weights assigned to elements and alternatives plays an essential role in arriving at the final decision. In the context of this study, the interrelationships and attributes comprising land use, elevation, rainfall, and soil maps were meticulously outlined. These relationships were then decomposed into thematic layers using AHP within the ArcGIS software. Saaty's scale was implemented in the pair-wise comparison matrices to indicate the pronounced importance of each attribute (Saaty, 1980).

3. Result and Discussion

Areas Vulnerable to Flooding

ArcGIS processed data was used to produce drainage density, slope, elevation, annual precipitation, land use, and land cover, as well as soil maps, as shown in Figures 2, 3, 4, 5, 6, and 7, respectively. These were used to derive the flooding vulnerability map in Figure 8. It is widely acknowledged that land use and land cover, alongside other factors, significantly contribute to flooding (Ogato, et al., 2020).

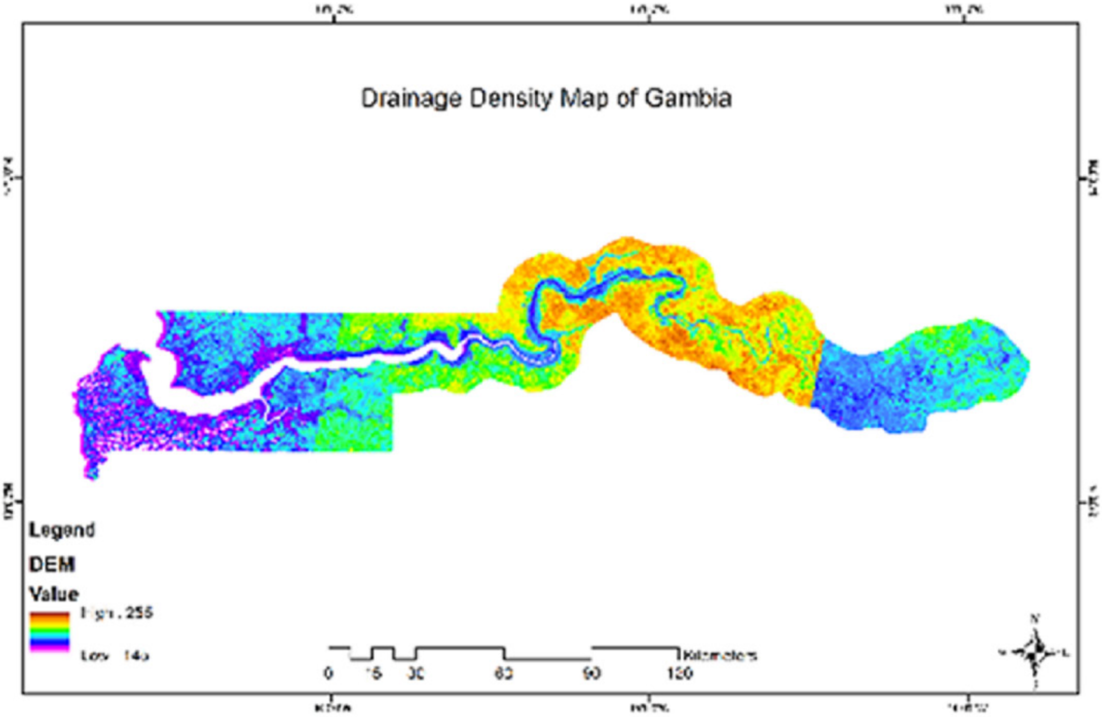

Figure 2. Drainage Density map of the Gambia

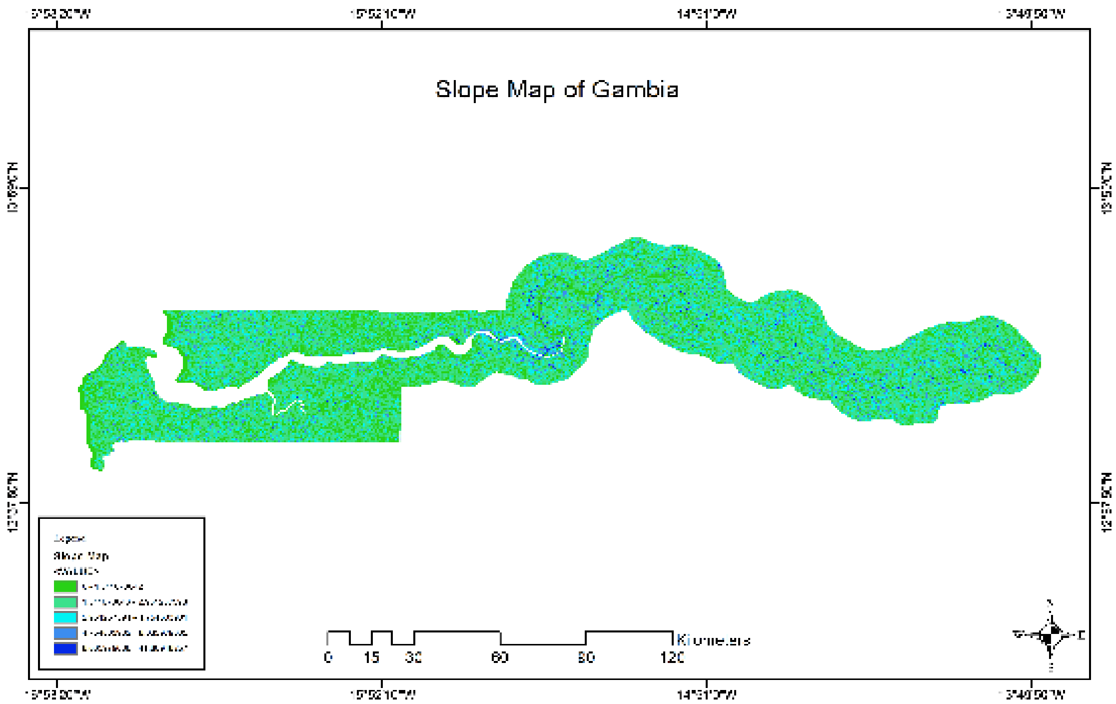

Figure 3. Slope map of the Gambia

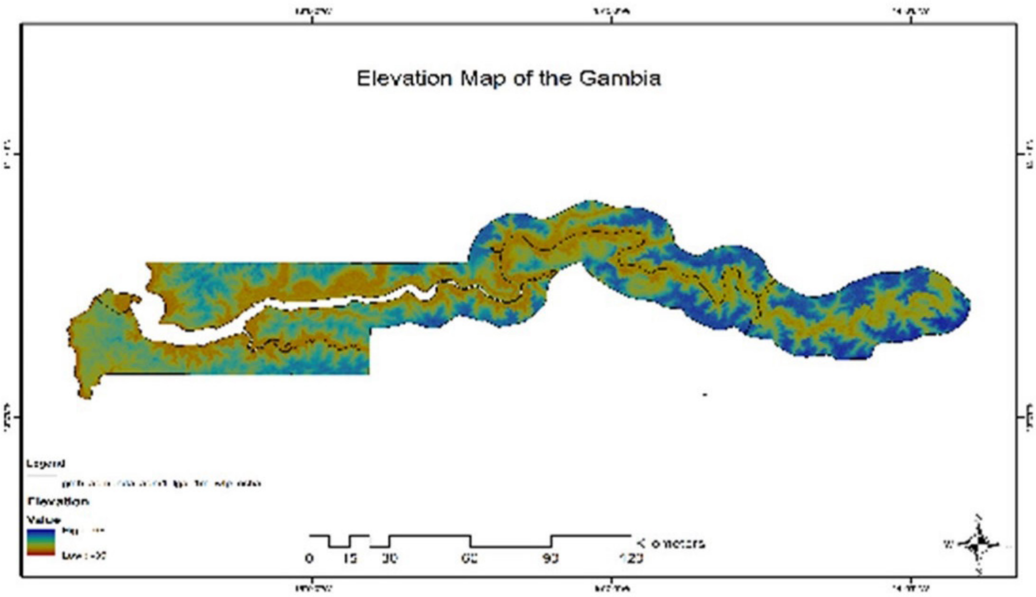

Figure 4. Elevation map of the Gambia

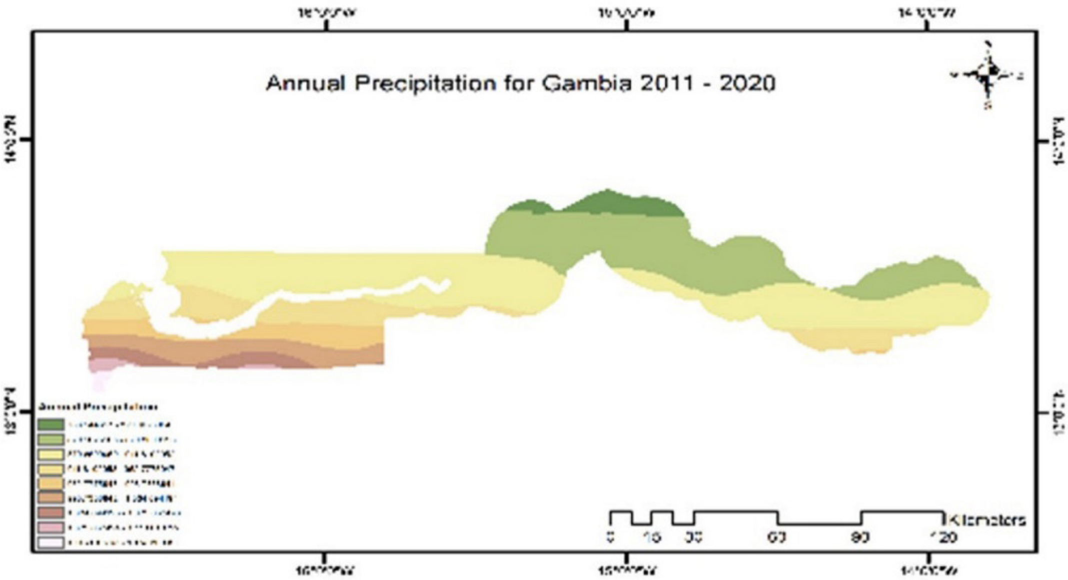

Figure 5. Annual Precipitation Map of the Gambia

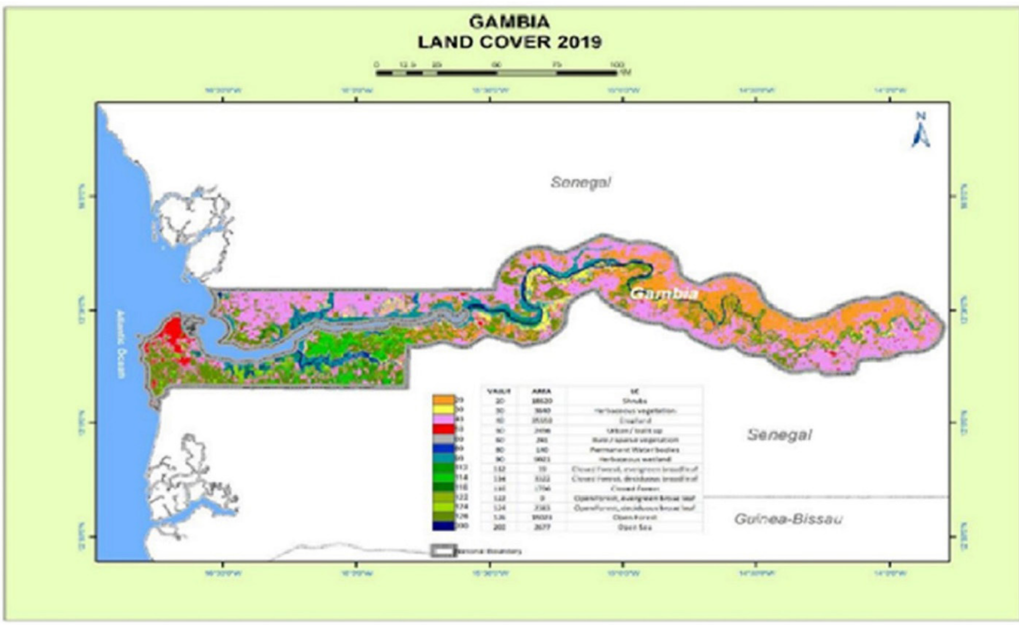

Figure 6. Land Use Land Cover map of the Gambia

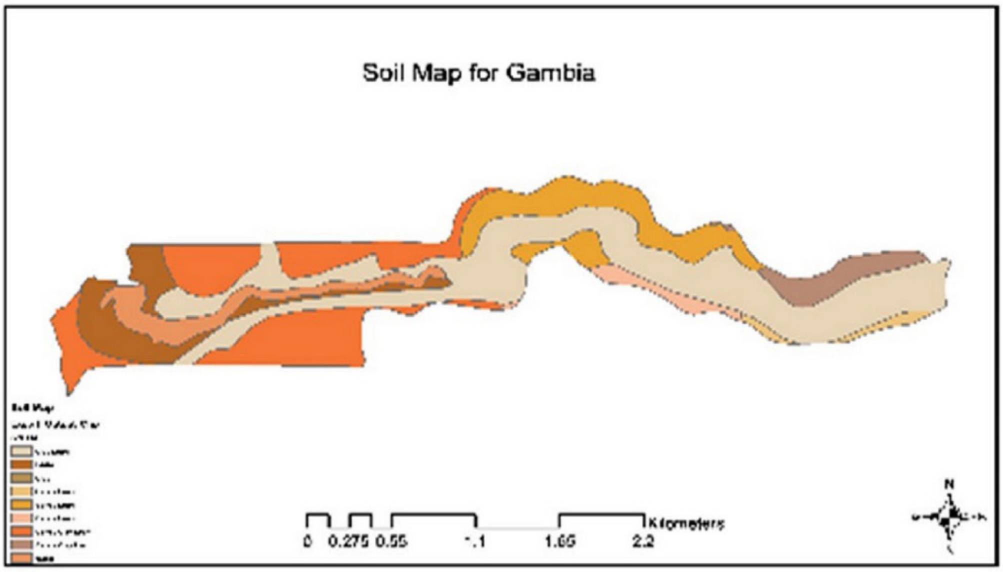

Figure 7. Soil map of the Gambia

Table I. Flooding vulnerable areas

Vulnerability level	Areas
Very low	Jane Kunda, Sambang, Bambali, Burena, Pakali Ba, Kuntaur, Kantali Kunda, Fatoto, Diabugu, Darsilami, Badja Kunda, Kulari, Basse Santa Su
Low	Ndungu Kebbe, Jowara, Kinteh Kunda, Nja Kunda, Njau, Sotokoi, Dankunku, Sabi
Moderate	Brikama, Manduar, Soma, Kalaf, Kwinella, Kerewan, Fass, Kau-ur, Farafenni
High	Kartung, Gunjur, Brikama, Faraba, Barta, Kalagi, Bondali Joda, Sintet, Manduar, Sibanor, Bessi, Kafata, Bwiam
Very High	Coastal areas of Kartung and Gunjur

Source: Secondary data processing

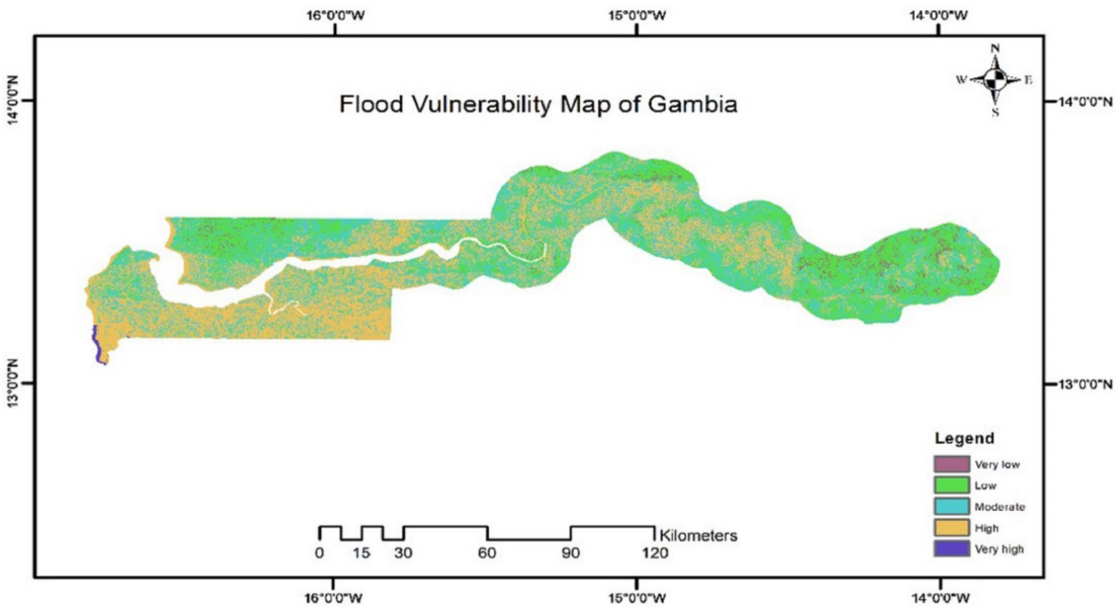

Figure 8. Flooding Vulnerability Map of the Gambia

In the study area, there is a lack of specific investigation on flooding vulnerability maps for validation. Table I shows areas that are vulnerable to flooding in the Gambia, complemented by the vulnerability map in Figure 8. The vulnerability level was categorized into 5 groups, namely very low, low, moderate, high, and very high. According to a report by Humanitarian Response (2022), the Kanifing Municipal Council and West Coast Region experienced the highest impact with 1,657 and 1,483 households affected, respectively. This study was in line with the report and further explained that these regions were under the high and moderate category. The coastal areas of Kartung and part of Gunjur had a very high vulnerability.

Some of the areas with high vulnerability include Kartung, Gunjur, Brikama, Faraba, Bondali, and Bwiam. Areas in the moderate category were Brikama, Manduar, Soma, Kalaf, Fass, and Farafemi. Certain places such as Ndungu Kebbe, Jowara, Kinteh Kunda, Njah Kunda, and Sotokoi, have low vulnerability. The areas with very low vulnerability were Jane Kunda, Sambang, Bambali, Burena, Pakali Ba, Kuntaur, Kantali Kunda, and Basse Santa Su.

The flooding vulnerability map showed that 35.25% of the study area was under high risk, while 32.48 and 30.4%, were low and moderate, respectively. Approximately 1.66% and 0.21 percent of the area was under the very low and very high risk. The percentage of areas with very high flooding vulnerability was higher as compared to a study by Thapa and Thapa (2021) where it was stated that areas with very high risk were 24%. The flooding vulnerability map was also classified into 5, namely higher risk, high risk, medium risk, low risk, and very low-risk areas. The locations of the high-risk and very high-risk areas were provided to help in deciding on disaster management. Results showed that the percentage of areas with high vulnerability was 43.28% in Ethiopia, as stated by Hagos, et. al (2022) and areas with very high vulnerability was 13.0%. Ali, et al (2022) observed that only watershed regions were prone to a high risk of 12.45%. These three studies indicated higher values for areas with very high flooding vulnerability compared to the Gambia.

The lowlands near the coast are major factors in flooding vulnerability. The vulnerability map showed that the coastal region had high risk. The high flooding areas can further be divided into very high and high risk with 20 and 80%. Specifically, from Kartong to Banjul comprises 80%, with Gunjur and Kartong constituting the remaining 20%. The low flat land near the coast of Gunjur and Kartong areas makes it very highly vulnerable. In contrast, karting to Banjul has undulating high and lowlands. Areas near River Gambia have high vulnerability and those far from the river have moderate, low, and very low vulnerability. The result from Rincon, et al (2018) disagreed with this study that areas in Toronto closer to the stream had very high vulnerability. However, areas with a high buffer distance from the stream had a high risk. Ceesay (2020) observed that climate variability was responsible for natural disasters, affecting the productivity of plants and animals and causing land and socio-economic damages.

4. Conclusion

In conclusion, this study focused on the temporal assessment of flooding vulnerability on agricultural land use in the Gambia. The results generated a map for the Gambia which was classified into very low, low, moderate, high, and very high vulnerable areas. Approximately 0.21 and 35.25% of the study locations were classified as very high and high, respectively. Based on observations, areas with moderate, low, and very low vulnerability had percentages of 30.4, 32.48, and 1.66 respectively. This information will help for better planning and management in the future, hence, urbanization should be controlled.

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