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AN ASSESSMENT OF FLOOD RISK IN THE GAMBIA: A DATA-DRIVEN APPROACH TO FLOOD RISK MANAGEMENT AND PREVENTION

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ABSTRACT: *Coastal African countries, including Gambia, are increasingly vulnerable to a range of natural disasters, notably flooding, which poses significant challenges to sustainable development and safety. This study set out to comprehensively assess the flood risk in Gambia using a data-driven approach, aiming to enhance flood risk management and prevention strategies. Utilizing geospatial data and Geographic Information System (GIS) techniques, the research involved mapping and categorizing flood risk zones across various regions. The analysis focused on the identification and categorization of flood risk zones, assessment of the vulnerability of key infrastructures, health facilities, road networks, and settlements to flooding. The findings reveal that a total of 2,721 square kilometers of land is at flood risk categorized as either high or very high. This constitutes 26.89 percent of the country's of terrestrial area. A total of 25 critical health infrastructure were in areas of this high flood risk categorization – ranging from general hospitals to clinics. Up to 24.5% of the nation's road network was found to be in this flood risk zone. Of the country's five administrative regions, the West Coast Region which is home to most of its urban centers was most at risk of flooding. Here, of the 353 settlements in this region, 172 of them fell under the high to very high-risk flood zone categorization, constituting 48.7% of the settlements at a significant level of flood vulnerability. This study enhances the understanding of flood hazards in Gambia, providing essential perspectives for decision makers, city planners, and emergency response teams. This research highlights the need for using data-driven methods in identifying and managing environmental risks. It also advocates for the adoption of long-term strategic planning, infrastructure enhancements, and community-based activities to reduce the effects of floods.*

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INTRODUCTION

Flood vulnerability represents a critical challenge to human development, impacting social, economic, and environmental dimensions in susceptible areas. In the Gambia, its main hydrologic artery (the River Gambia, Figure 1) plays a pivotal role in the physical geography of the Gambia, significantly influencing the occurrence of floods in the country. Originating from the Fouta Djallon highlands in Guinea, the river bisects the country into a narrow strip of land, with its lower valley constituting over 35% of the total land area, making it prone to floods. The country's subtropical climate, with wet seasons from June to October, contributes to the river's overflow, particularly when coupled with high tides and sea level rise. These factors, combined with human activities such as deforestation and poor farming, exacerbate the vulnerability to river and coastal flooding, affecting a significant portion of the population living near the river and coastal areas.

The multifaceted impacts of flooding range from disrupting livelihoods to causing extensive damage to infrastructure and ecosystems (UNDRR, 2019). In the Gambia, these effects are amplified due to the nation's limited adaptive capacity and high dependence on agriculture, a sector extremely vulnerable to climatic variations. Climate change exacerbates this vulnerability, with increased frequency and severity of flooding expected, thereby heightening the risk for Gambian communities. According to Belford et al. (Belford et al., 2023), climate change poses a significant threat to the Gambia's agriculture sector, with projections indicating a considerable decline in agricultural production and an increase in the economic vulnerability of the sector. This situation underscores the urgency of developing effective flood management and mitigation strategies in the face of economic constraints and increasing climatic risks.

Addressing these challenges necessitates a comprehensive approach, encompassing climate change adaptation planning, strategic policy development, and livelihood diversification. Adaptation strategies should be context-specific, emphasizing the enhancement of community resilience and the promotion of sustainable economic practices. The Gambia's strategic response to flooding requires the integration of climate projections and risk assessments into national development plans, aligning infrastructure and urban planning with flood mitigation objectives. Enhancing livelihoods through diversification is also crucial. As noted by UNCDF (UNCDF, 2023), initiatives like several national initiatives, have demonstrated the potential of collective efforts in building climate resilience and promoting sustainable agricultural practices among smallholder farmers in the Gambia. These efforts not only mitigate the economic impacts of climate change but also contribute to strengthening local capacities in dealing with environmental stresses.

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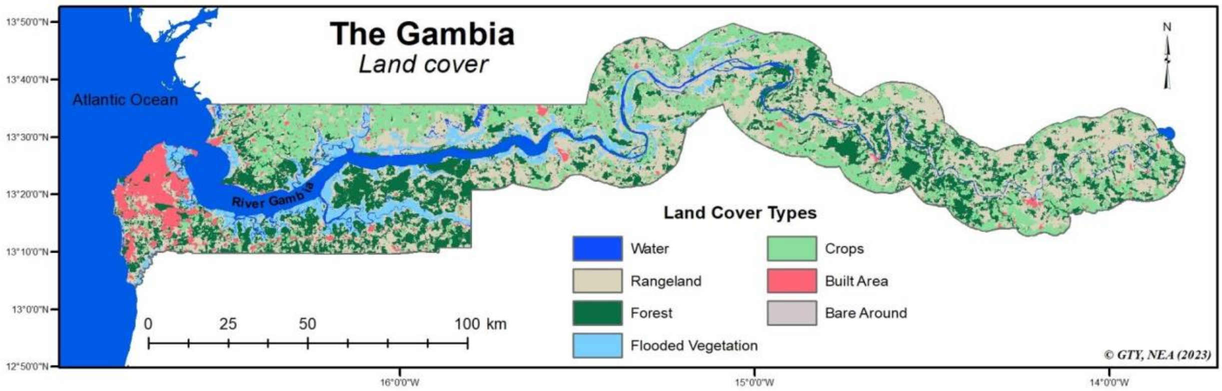

Figure 1. Map of The Gambia showing the dominant role played by the River Gambia in the geography of the country as well as the country's major land cover types (Source: K. Karra et al., 2021)(Karra et al., 2021)

Major Types of Floods Affecting the Gambia

The Gambia is vulnerable to diverse flood types, including river, flash, coastal, and pluvial floods. Riverine floods, triggered by excessive surface water runoff in the Gambia river basin, during heavy rains particularly, threaten the region as many live near the river (GFDRR, 2022; UNESCO, 2023). These floods, which can have devastating effects on livelihoods, are anticipated to recur within the next decade. Flash floods, another prevalent type, arise from rapid rainfall runoff that overwhelms both soil absorption and drainage systems, a situation exacerbated by rapid urbanization and inadequate infrastructure (ReliefWeb, 2022). Although specific instances were not detailed, the Gambia's low-lying coastal geography, coupled with heavy rainfall, indicates a high potential for coastal floods during storm surges and extreme weather events. Lastly, urban areas, notably the capital Banjul and Kanifing Local Government Area, are prone to pluvial floods caused by rainfall that fails to infiltrate impermeable urban surfaces, further aggravating the flooding issues (FloodList, 2022).

Principal Factors That Increase Exposure, Vulnerability, and Risk in the Gambia

Urban flooding presents a complex challenge for African countries as it is intricately linked to socio-economic, infrastructural, and environmental factors. This complexity is evident in the factors that increase the exposure and vulnerability to flood risks in the Gambia.

Poverty: Poorer people often live on low-value lands in areas more exposed to hazards. This includes frequent low-intensity hazards, and these populations typically receive less protection from public infrastructure and services. Their dwellings are often more fragile and they have fewer resources to invest in disaster preparedness and risk reduction. In the Gambia, poverty is a significant factor that increases vulnerability to flooding. As of 2022, the poverty rate climbed to 53.4% largely due to the impacts of COVID-19. Before the pandemic, the national poverty rate declined from 48.6% in 2015 to 45.8% in 2019 but has since risen, implying that about 1.1 million Gambians were poor in 2020 (Touray, 2022; Bank, 2020).

Poorly Managed Urbanization: Unplanned and informal settlements expand into coastal and river floodplains that lack adequate housing, infrastructure, and service provision. Where laws

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and regulations exist to control construction, they are often not enforced due to economic, political, or capacity constraints, leading to development in at-risk areas. The urbanization rate in the Gambia is currently at 4.2%, with the urban population constituting 63.85% of the total population in 2022. This rapid urbanization without adequate planning and infrastructure development leads to expansion into flood-prone areas (O'Neill, 2023).

Inadequate Solid Waste Management: Solid waste frequently blocks drainage channels and fills flood water retention ponds, contributing to flood risk. In many cities, waste is dumped into drainage channels, creating resistance to the flow of water and causing overspilling during flood events. Proper waste management is crucial in mitigating flood risks, as clogged drainage can exacerbate flooding conditions. The Gambia's solid waste management challenges contribute to its vulnerability to urban flooding.

Climate Change: Climate change in the Gambia is characterized by a clear warming trend over the last half-century. The Climate Change Knowledge Portal notes that the most recent years have seen the hottest months in this period, indicating a rise in temperatures. Such a trend is significant because it can lead to more intense and frequent extreme weather events, including heavy rainfall and storms, which are primary contributors to flooding. As temperatures continue to rise, the intensity and frequency of these events are likely to increase, exacerbating the risk and impact of flooding across the country (Bank, 2021).

Inadequate Drainage Systems: In developing urban areas, the drainage infrastructure is often outdated and maintenance is limited, which is a challenge faced by many cities in the Gambia as they contend with rapid growth. For example, in Kanifing, there are plans to construct a new comprehensive stormwater and waste drainage system along the Kotu River from Abuko to help reduce flooding exacerbated by climate change. The financial negotiations for this project were set to take place in December 2022, indicating ongoing efforts to improve drainage infrastructure (Magoum, 2022). The capital city, Banjul, and its environs have been plagued by poor drainage, particularly during the rainy season, leading to widespread flooding and some areas becoming inaccessible. This has been a persistent issue for years, underscoring the urgent need for proper drainage systems in urban centers. There is a broad initiative, the Drainage, Sanitation & Waste Management project, which aims at improving the drainage system across the Gambia. This includes the rehabilitation of existing systems and the creation of new infrastructure like culverts and ditches, indicating an acknowledgment of the inadequacy of current facilities and a concerted effort to address these challenges (Cooperation, 2010). A call to action has been made for authorities in various regions of the Gambia, such as KMC and the West Coast Region, as well as the Ministry of Works and National Roads Authority, to work collaboratively on creating adequate drainage facilities. This collaboration is crucial for areas like Westfield and Churchill's Town, which have been highlighted as needing significant improvements in their drainage systems.

Hardening of Catchment Areas: As urban areas expand and hard surfaces increase, the ability of the land to absorb rainfall diminishes, leading to greater runoff and heightened risk of flooding. This is a common issue in rapidly urbanizing regions like the Gambia.

Importance of Flood Risk Assessment and Management

Flood risk assessment and management are crucial for protecting lives, infrastructure, and the environment in flood-prone regions like the Gambia. By identifying flood hazards, assessing

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vulnerability, and evaluating potential impacts, flood risk assessments can inform decision-makers and stakeholders in the development of effective strategies for flood risk reduction.

Protecting human lives is a priority, as floods can lead to fatalities, injuries, and displacements. By pinpointing high-risk areas and implementing mitigation measures, such management can save lives and alleviate human suffering (Doorn, 2014). Economically, floods can inflict considerable damage to infrastructure, housing, and businesses, resulting in significant losses (Kind, 2014). Proper flood risk management strategies can minimize these economic losses and bolster economic resilience amidst escalating flood risks. In terms of infrastructure, flood risk management identifies and protects critical infrastructure at risk from flooding, through improved design, flood-resistant building practices, and early warning systems (Lumbroso, 2020). Environmentally, it is crucial for conserving ecosystems and minimizing flood-induced damages like soil erosion, water pollution, and habitat loss (Long'or Lokidor et al. 2023). Additionally, with climate change exacerbating flood frequency and intensity, effective flood risk management is increasingly essential for resilience, especially in vulnerable regions (Raadgever et al., 2018). Incorporating climate change projections into flood risk assessments informs adaptation strategies, preparing the Gambia for future challenges.

Aims of the Study

The primary objectives of this study are twofold: firstly, to conduct a comprehensive assessment and identification of areas in the Gambia vulnerable to flooding, categorizing the level of vulnerability within these regions. Secondly, the study aims to ascertain the degree to which key infrastructures and population settlements are susceptible to flood risks. By doing so, the study will pinpoint specific regions that should be prioritized for flood risk mitigation efforts. Such information will provide a data-driven basis for developing targeted strategies for flood risk management, encompassing infrastructure improvements, strategic land-use planning, and community-focused initiatives, all guided by the findings of the hazard assessments and vulnerability evaluations.

DATA SOURCES AND METHODS

ArcGIS Desktop was used to conduct a geospatial analysis that included the following datasets: CHIRPS precipitation data, land cover, a digital elevation model (DEM), slope data derived from the DEM, soil type map data, and geology map data in order to identify flood vulnerability zones in the Gambia.

Data Sources

The procedures used with these datasets are described in the sections below:

Precipitation Dataset from CHIRPS

A quasi-global rainfall dataset that extends over 35 years and covers latitudes between 50°S and 50°N is called the Climate Hazards Group InfraRed Precipitation with station data (CHIRPS) (Funk et al., 2015). The Climate Hazards Group at the University of California, Santa Barbara and the United States Geological Survey (USGS) generated this dataset. Three primary elements are incorporated by CHIRPS into its process: (i) the Climate Hazards Group Precipitation Climatology (CHPclim), a superior monthly rainfall climatology with near-global

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extent and 0.05° resolution (Funk, Peterson et al., 2015); (ii) satellite-based 0.05° resolution imagery; and (iii) in-situ station data to produce gridded rainfall time series for various applications, such as trend analysis and seasonal drought monitoring. The high spatial and temporal resolution, which takes into account regional variations in the correlations between various datasets, is one of the main benefits of CHIRPS. Furthermore, it offers an almost instantaneous record from 1981 to the present (López-Bermeo et al., 2022).

Land Cover

The ESRI 2020 Global Land Use Land Cover (LULC) dataset (Karra et al., 2021) was used to generate the land cover data that was used in this investigation. Based on high-resolution (10m) ESA Sentinel-2 imagery, this dataset displays a world map of different LULC kinds. A deep learning algorithm that has been trained on more than 5 billion manually tagged Sentinel-2 pixels from more than 20,000 sites globally is used to create the map. Six bands of Sentinel-2 surface reflectance data—visible blue, green, red, near-infrared, and two shortwave infrared bands—are processed by the deep learning model. In order to extract a subset of these classes for this study, The Gambia's national borders were hidden in the global dataset.

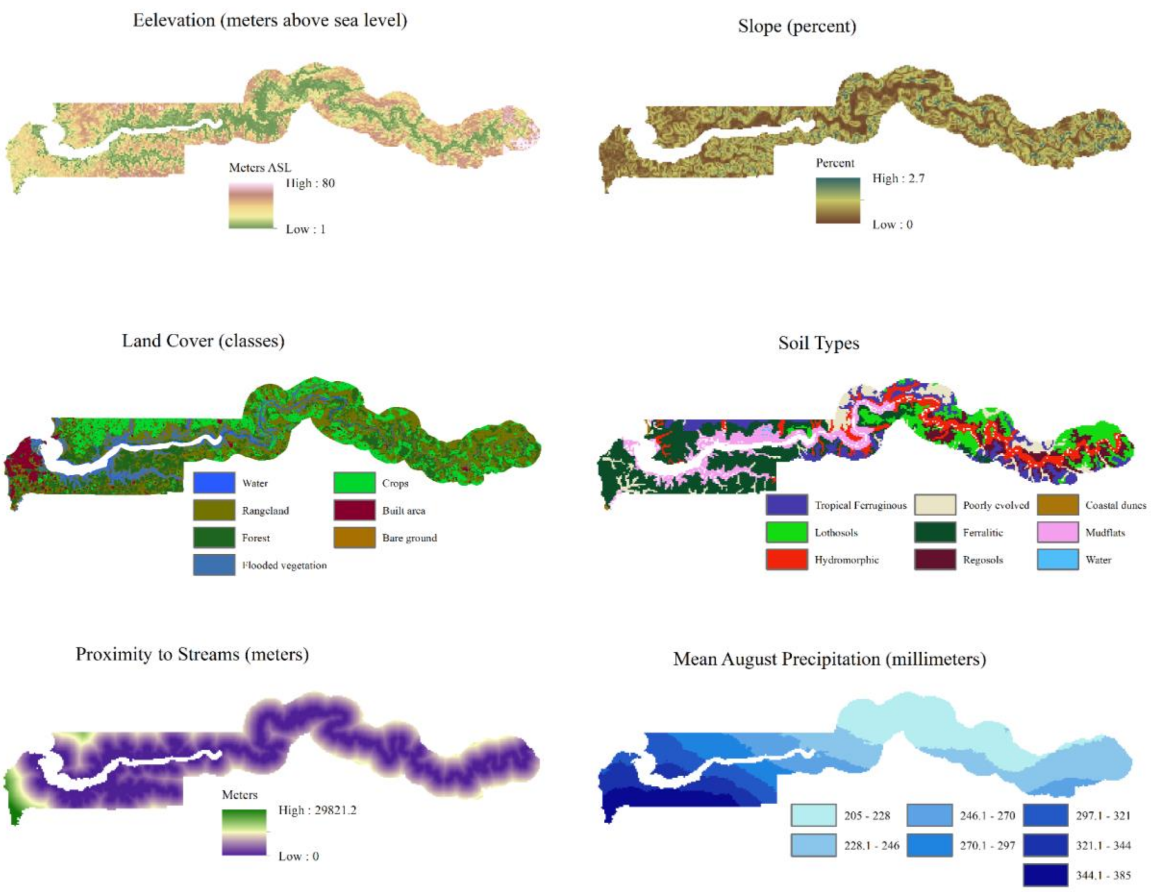

Figure 2. Datasets used for the assessment of flood risk.

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Digital Elevation Model (DEM)

A digital elevation model (DEM) depicts the topographic bare ground (bare earth) surface of the Earth, free of any surface items like trees and structures (San & Suzen 2005). This study made use of the Global Multi-resolution Terrain Elevation Data 2010 (GMTED, 2010) (Danielson & Gesch, 2011) DEM, downloaded from: https://earthexplorer.usgs.gov/. The GMTED2010 integrates the most up-to-date global elevation data and offers a new level of detail in global topographic data. It features seven new raster elevation products for each of the spatial resolutions of 30 arcseconds, 15 arcseconds, and 7.5 arcseconds. This dataset, which covers the countries of the Gambia, Guinea-Bissau, Mauritania, and Senegal, has a resolution of 7.5 arcseconds (Resource ID: 88dcf877-6d9c-432b-9613-0d42cc071c17; Spatial Reference System Identifier: EPSG:4326). The DEM was used to execute a number of operations on the DEM dataset for our hydrological research, including fill, flow direction, flow accumulation, and extract streams (Li, 2014) in ArcGIS software. The Calculate Slope tool in ArcGIS was used to create the slope dataset, which tracks how quickly elevation changes from one DEM cell to the next. Drainage density and river distance were also computed as crucial input factors for the hydrological research.

Slope

The slope dataset obtained from the DEM is crucial for evaluating flood susceptibility since it measures the percentage of land surface inclination, offering a comprehensive spatial depiction of terrain steepness throughout the entire country. Through the process of measuring the increase and decrease in height across a certain distance, it determines the level of steepness at every place on the map. The significance of its role in flood vulnerability assessment is manifold: it assists in forecasting water runoff, with locations that have a flatter topography being more susceptible to water accumulation, while areas with steeper slopes facilitate faster runoff. This dataset is essential for estimating the direction and velocity of floodwater flow, thereby aiding in the prediction of prospective flood courses and areas of impact. Furthermore, a comprehensive comprehension of slope gradients is crucial for the purpose of infrastructure development, as it guarantees that settlements are strategically located in safer regions to reduce the potential harm caused by floods. The slope data is also crucial in calculating the risk of soil erosion during floods, which is vital for measuring the long-term degradation of land and its environmental consequences.

Proximity to Streams

The dataset on proximity to streams is an essential tool for assessing the vulnerability to floods in Gambia. It quantifies the distance between land areas and neighboring streams or river systems, offering a spatial depiction of regions in relation to water bodies. This dataset is crucial for detecting places with a high risk of flooding, especially those located near streams, especially during periods of intense rainfall or increasing water levels. Additionally, it plays a crucial role in emergency response planning by identifying critical locations for prompt intervention and evacuation in the case of floods. When it comes to urban and rural development, it is crucial to have a clear awareness of the closeness to streams. This knowledge is necessary for effectively developing settlements and infrastructures, taking into account the necessary safety measures to prevent potential flood zones. Moreover, the dataset is of great value for conducting environmental impact studies, as it provides vital information on the

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relationship between land use, water bodies, and flood risks. This, in turn, helps in implementing comprehensive and sustainable land management techniques.

Soil Types

The "*Soil and Terrain Database for Senegal and the Gambia (version 1.0), at a scale of scale 1:1 million*" (Batjes, 2008; Dijkshoorn & Huting, 2014) was the source of the soil information used in this study. The FAO's Land Degradation Assessment in Drylands (LADA) program used upgraded soil data to create the Soil and Terrain database for Senegal and The Gambia primary data (version 1.0), at scale 1:1 million (SOTER_Senegal_Gambia). The *Institut National de Pédologie* Dakar provided the primary soil and topographic data for Senegal, while the *Centre de Suivi Ecologique (CSE)* provided the digital soil map (Dijkshoorn and Huting, 2014). The soils of the Gambia can be categorized into six primary types, as seen in the following excerpt from the more knowledgeable Senegal and Gambia GIS database (Batjes, 2008). The soils were given scores based on their susceptibility to floods with 1 being the least susceptible and 10 being the most susceptible, as shown in Appendix 1.1.

Gambia Health Facilities Dataset

The dataset utilized for assessing flood risks to health infrastructure in Gambia is sourced from the Humanitarian Data Exchange platform (https://data.humdata.org), specifically the Gambia Health Facilities. This dataset includes a comprehensive collection of health-related features tailored for GIS applications. The criteria for the data selection include any features in the area where the 'healthcare' attribute is not null or where the 'amenity' is specified as 'doctors', 'dentist', 'clinic', 'hospital', or 'pharmacy.' The attributes of these features include a range of critical details such as the type of amenity, building information, full address, healthcare specialty, operator type, general healthcare classification, capacity in terms of persons, city, data source, and the name of the facility. This rich dataset provides a detailed and georeferenced overview of health facilities in the Gambia, essential for assessing their vulnerability to flooding.

The datasets for roads and settlements in the Gambia, also sourced from the Humanitarian Data Exchange platform, provide an extensive spatial representation of the country's infrastructure. The settlements dataset, specifically titled 'Gambia - Settlements', encompasses the geographical locations of towns and villages, including national and regional capitals, at a scale of 1:1,000,000. Similarly, the roads dataset details the network of transportation routes across Gambia.

Data Analysis

The limits of the Gambia, the specific study area, were applied to all datasets. By ensuring that only data pertinent to the study region was taken into account, this phase cut down on the amount of computing needed and streamlined the analysis. To maintain consistency across all layers, the spatial resolutions and coordinate systems of the datasets were adjusted. During the geographical analysis, this phase is essential for correct dataset overlay and fusion. After being preprocessed, the datasets were imported into ArcGIS Desktop and put into a file geodatabase, giving the different layers a centralized location for storage and control. This configuration simplified the workflow for geospatial analysis and allowed for effective data handling.

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Hydrological Analysis

ArcGIS's hydrology toolbox was used to perform a number of operations on the DEM dataset in order to examine the hydrological characteristics of the study area and their implications for flood susceptibility. Fill, flow direction, flow accumulation, and stream extraction were among these operations.

- Filling Procedure: This procedure was used to remove minor flaws and depressions from the DEM that can potentially interfere with continuous flow routes.

- Flow Direction: To determine the direction of the sharpest descent from each DEM cell, the flow direction operation applied the D8 approach.

- Flow Accumulation: The flow accumulation operation was carried out to determine the accumulated flow, or the number of upstream cells that contribute to the flow of each cell, based on the flow direction raster.

- Stream Extraction: The stream extraction operation was used to draw the boundaries of the research area's stream networks using the flow accumulation raster. Map creation for flood vulnerability contributing factors.

Individual maps were created for each contributing element in order to thoroughly examine and display the spatial distribution of numerous factors impacting flood susceptibility in the Gambia. Precipitation, land cover, slope, soil type, and geology type were among the influences.

Reclassification of Maps of Causal Factors

Each contributing factor map was reclassified into a standardized numerical scale (0–10), with higher values indicating a stronger contribution to flood vulnerability, before the contributing factor maps were combined using the "Weighted Sum" tool. The ArcGIS "Reclassify" tool was used to reclassify the data (see Figure 3). Reclassification ensured that every map used the same scale, enabling the composite map to be created by meaningfully combining the various components.

Combining Maps Using "Weighted Sum"

Using the "Weighted Sum" tool in ArcGIS, a multi-criteria analysis was carried out to combine the flood vulnerability data from individual contributing factor maps. The reclassified maps were blended using ArcGIS's "Weighted Sum" tool in accordance with their respective weights. In order to construct a composite map, this method involved multiplying the value of each cell in each reclassified map by its appropriate weight and totaling the results. The combined impact of all influencing factors on flood susceptibility throughout the research region was depicted by this composite map. The mathematical formula used to operationalize ArcGIS's "Weighted Sum" tool is a linear weighted combination, which is defined as follows:

Weighted Sum = $\Sigma (W_i * R_i)$

where:

Σ denotes the summation across all layers (contributing factors),

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W_i represents the weight assigned to the i-th contributing factor (layer),

R_i is the reclassified value of each cell in the i-th layer.

For each cell in the output raster, the "Weighted Sum" tool calculates the weighted sum by multiplying the reclassified value (R_i) of the cell in each input raster (layer) by the corresponding weight (W_i) and then summing the products. This process is performed for all input layers to create the final composite map, which reflects the combined influence of all contributing factors on the phenomenon being analyzed (e.g., flood vulnerability). It is essential to ensure that the sum of all weights (ΣW_i) equals 1 to maintain the relative importance of each contributing factor in the final composite map.

The resulting composite map was examined to ensure that it accurately captured the spatial distribution of flood vulnerability in Gambia. Areas with higher composite values indicated a higher combined influence of contributing factors and, consequently, a higher vulnerability to floods.

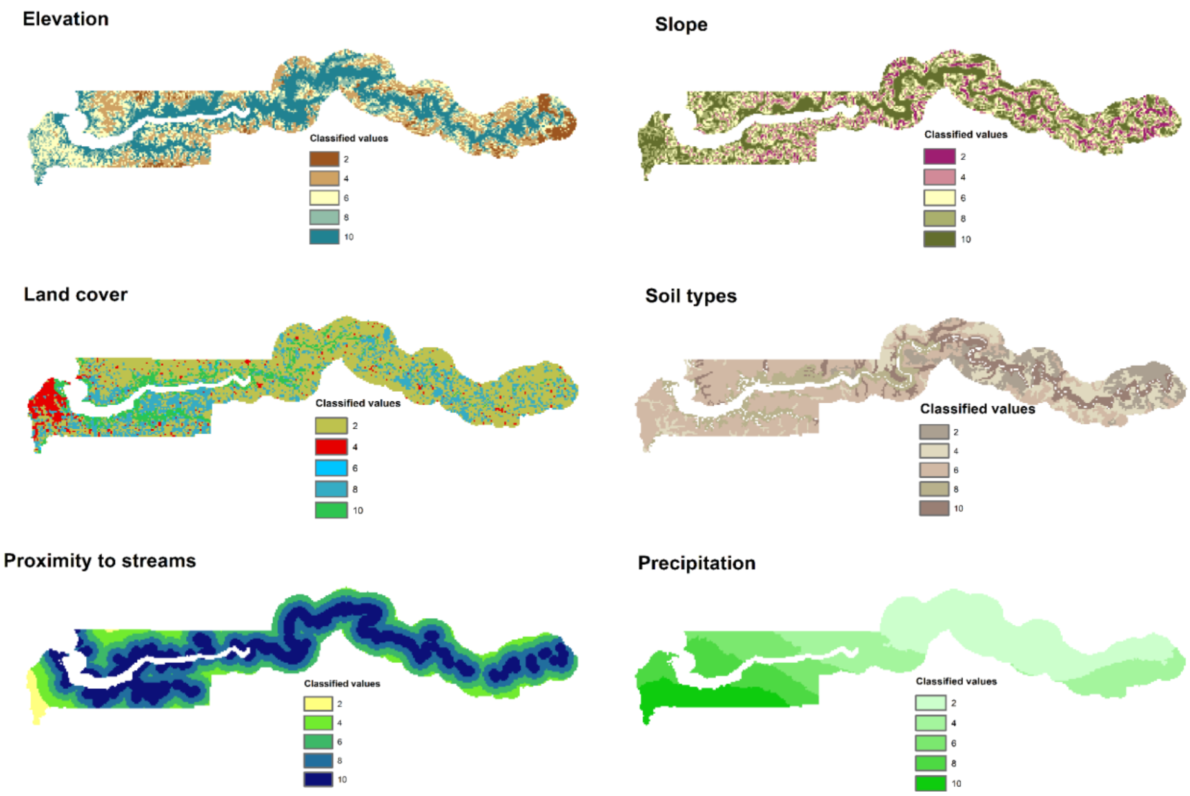

Figure 3. Datasets that were classified before being combined using a sum of weights.

Categorization of Risks

Based on the values of the combined components, the composite map was divided into various categories of flood susceptibility, described as: very low; low; medium; high; and very high (see Table 1). For area calculations for each type of vulnerability, the total area for each category of vulnerability was determined using the "Zonal Statistics" tool in ArcGIS.

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Assessing Health Infrastructure at Flood Risk

In the methodology to identify health infrastructure within varied flood risk zones using ArcGIS, a systematic approach was implemented. Initially, the Gambia Health Facilities dataset was integrated into ArcGIS, involving georeferencing the facilities based on spatial attributes. Subsequently, flood risk zones were delineated and georeferenced, utilizing data on topography, historical flood incidences, and hydrological models, categorizing these zones by their flooding probability and severity. An overlay analysis was then executed, superimposing the health facility dataset onto the flood risk zone map, facilitating a spatial correlation between the facilities' locations and identified flood risks. The subsequent phase involved the identification and categorization of health facilities, based on their spatial intersection with various flood risk zones. Finally, the categorization underwent validation and refinement through an examination of the facilities' attributes, ensuring the analysis accurately mirrored the actual conditions.

Roads and Settlements at Flood Risk

Utilizing the same methodological framework as applied to the health facilities, these datasets were integrated into ArcGIS for a comprehensive analysis. This involved the georeferencing of roads and settlements, mapping and categorizing flood risk zones based on various data sources, and conducting an overlay analysis to identify the spatial correlation between these infrastructures and the flood risk areas. The process culminated in the identification and categorization of roads and settlements within different flood risk zones, followed by a rigorous validation and refinement process to ensure accuracy in depicting their vulnerability to flooding.

RESULTS

This section provides evaluations of different elements crucial for comprehending flood hazards in the Gambia. This entails a comprehensive examination of areas prone to flooding, emphasizing the locations that are most susceptible to floods. The report also examines the vulnerable vital infrastructure that is at danger of flooding, identifying crucial facilities and systems that may be affected. Special focus is dedicated to healthcare facilities that are susceptible to floods, evaluating the potential hazards to these crucial medical institutes. In addition, the analysis involves scrutinizing both the main and subsidiary road networks to identify vulnerable areas and assess their possible effects on transportation and accessibility. Finally, the study assesses the vulnerability of settlements to flooding, with a specific focus on residential areas that are highly prone to flood hazards.

Areas at Risk of Flooding

Five levels of flood risk were identified (Figure 4) and the area of each flood risk category was computed and expressed in square kilometers (Table 1).

Very Low Risk: This category included 1,704 square kilometers of land. Due to suitable topography, efficient drainage systems, and low human density, these areas are characterized by reduced flood risks.

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Low Risk: There were 2,592 square kilometers of low-risk regions. Although there are certain flood risks in these areas, the risk is generally low because of things like the moderate topography, adequate drainage systems, and controlled population density.

Medium Risk: The areas with medium risk, which encompass 2,155 square kilometers, are defined by a balanced mix of risk characteristics, such as places with varied land use, moderate population density, and varying topography.

High Risk: There were 1,885 square kilometers of high-risk zones. Due to factors like a dense population, inadequate drainage systems, and adverse geography, these areas are vulnerable to frequent and severe flooding.

Very High Risk: This group included 836 square kilometers of territory. These areas have the worst topography, the highest population density, and the worst drainage systems, making them the most vulnerable

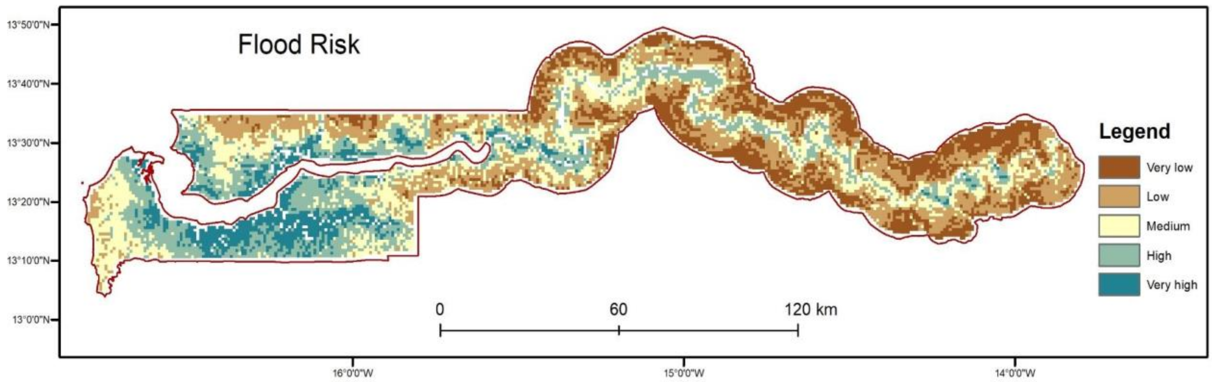

Figure 4. Vulnerability to floods in The Gambia.

Table 1. Areas (in square kilometers) under each flood risk category. Note that the total amount of area is 9,172 kilometers square even though the area of The Gambia is 11,300 km². This is because …

Flood Risk category	Area
Very low	1,704
Low	2,592
Medium	2,155
High	1,885
Very high	836

Critical Infrastructure under Flood Risk

In the context of disaster risk management, the vulnerability of critical infrastructure, such as health facilities and road networks to flooding is a significant area of concern. Health facilities are vital for providing immediate medical aid and ongoing care during and after a disaster, and

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their functionality can significantly influence the disaster's overall impact on human health. Similarly, road networks are crucial for enabling effective disaster response and recovery, including the transportation of relief supplies and personnel, evacuation procedures, and post-disaster reconstruction efforts. Therefore, assessing the vulnerability of these infrastructure to flooding can inform the development of effective strategies for disaster risk reduction and climate change adaptation.

Health Facilities at Risk of Flooding

The assessment of flood vulnerability in the healthcare sector has revealed crucial insights into the potential impact of flooding on medical facilities. This includes one hospital, six minor health centers, 13 clinics, three major health centers, and two general hospitals, each facing varying degrees of risk (Figure 5). The implications of these findings are significant, as they affect facilities that provide everything from primary healthcare to specialized and emergency services, impacting the delivery of critical medical care to communities.

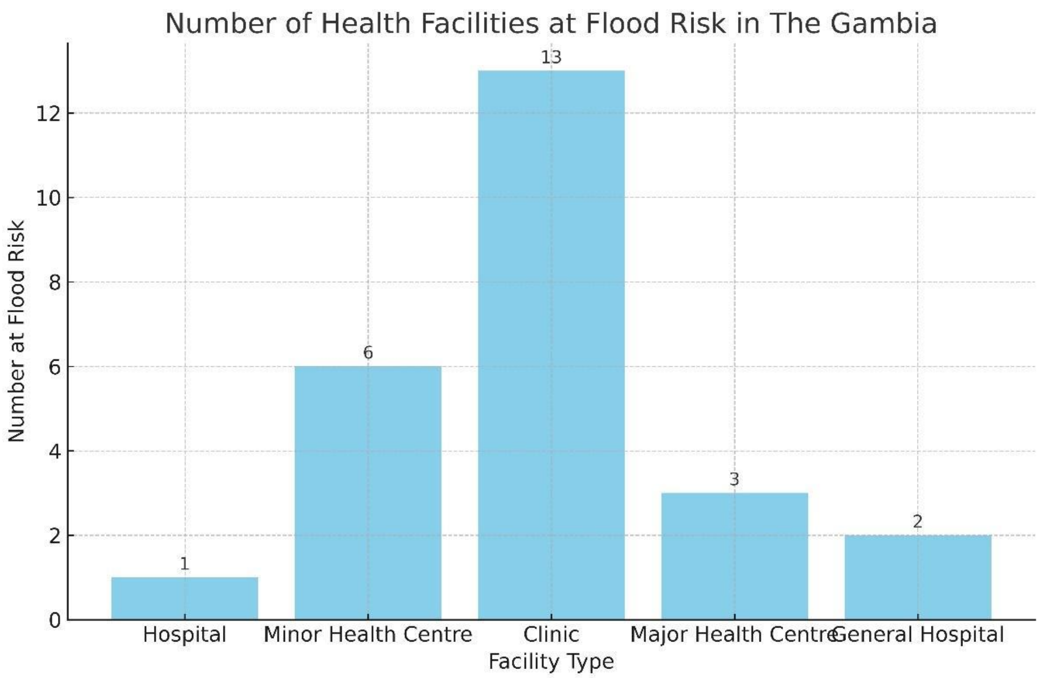

Figure 5. The number of different types of health facilities identified as vulnerable to flood hazards.

- Hospitals: One hospital was identified as being at danger of flooding based on the evaluation. This is a major issue because hospitals are often where severe and complex medical problems are treated and where essential medical equipment is kept. Flooding may prevent the delivery of vital medical services and perhaps put lives in danger.

- Minor Health Centers: Six minor health centers were noted as being susceptible to flooding. These facilities frequently offer local communities primary health care services, thus their closure would have a big influence on how easily people might obtain those services, especially in remote locations.

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- Clinics: According to the report, 13 clinics are vulnerable to flooding. Specialized outpatient treatments are frequently provided by clinics; if these services are disrupted, it may have an effect on the community's general health.

- Major Health Centers: Three important medical facilities were discovered to be at risk of floods. Compared to minor health centers, these facilities often offer a wider range of services, including emergency care. Flooding could prevent the delivery of essential services, which could raise morbidity and mortality.

- General Hospitals: There is a risk of flooding at two general hospitals. Large regions frequently rely on these institutions as their principal sources of healthcare: therefore, their disruption could have a severe impact on population health.

Primary and Secondary Road Networks at Risk

The study also assessed how susceptible the Gambia's road infrastructure is to flood dangers. Roads play a crucial role in the infrastructure of the nation by promoting trade, access to important services, and transportation. The evaluation concentrated on the primary and secondary types of roads. Secondary roads often link smaller towns and rural areas to the primary road network whereas primary roads are large motorways that connect major cities and towns. Based on the total of the lengths at risk, the susceptibility of these routes to flooding was determined.

- *Primary Roadways:* According to the report, there are 202 kilometers of primary roadways that could be flooded. This makes up a sizable chunk of the main thoroughfares in the nation. Interruption of trade and transportation due to flooding could result in financial losses and restricted access to vital services.

- *Secondary Roads:* Two hundred and thirteen (213) kilometers of secondary roads are at risk of flooding, according to the assessment. In rural areas, these roads frequently act as the main method of transportation. Road flooding could cut off access to vital services like healthcare and education and isolate these communities.

The length of all the country's roadways combined is 1691.8 kilometers. This indicates that about 24.5% of the nation's road network is susceptible to flooding. This high percentage illustrates the possible effects of floods on the nation's transportation system.

Settlements at Risk of Flooding

Additionally, the study evaluated how susceptible towns were to flood risks in several Gambia regions (Figure 6). Settlements are important because they house the population and a sizable component of the nation's infrastructure. Settlements include both urban and rural residential regions. The assessment concentrated on the overall number of populated areas in each region, the number of populated areas in danger, and the proportion of populated areas in danger.

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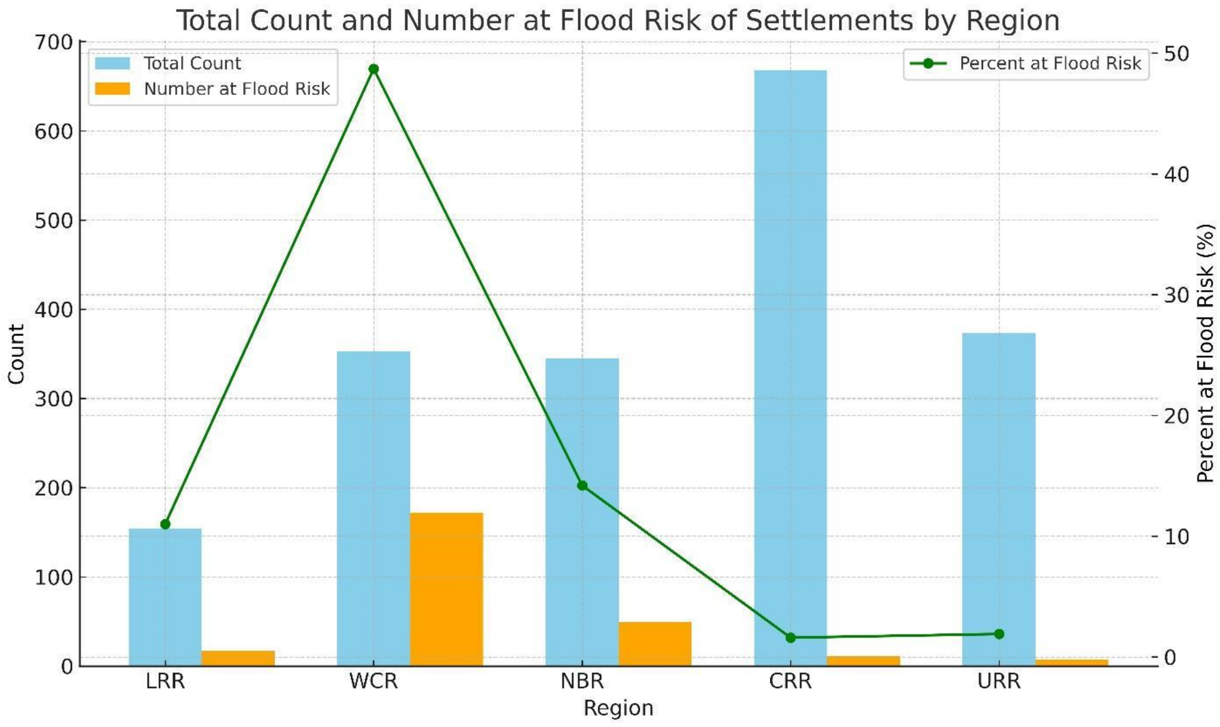

Figure 6. Comparative Analysis of Settlement Vulnerability to Flood Risk by Region in The Gambia. The left vertical axis represents the total count of settlements (blue bars) and the number of settlements at flood risk (orange bars), while the right vertical axis denotes the percentage of settlements at flood risk (green line), showcasing a significant variance across different regions. The Lower River Region (LRR) shows a moderate percentage at risk, whereas the West Coast Region (WCR) exhibits the highest proportion of settlements at risk. Conversely, the Central River Region (CRR) and Upper River Region (URR) have the lowest percentages, indicating a lesser degree of risk exposure.

- ***Lower River Region (LRR):*** Of the 154 communities that make up this region's total, 17 of them (or 11%) are at risk of flooding. This suggests a moderate degree of exposure to flood risks.

- ***West Coast Region (WCR):*** There are 353 settlements in the WCR, and 172 of them are at risk of flooding. With 48.7% of the settlements in this area at risk, this shows a significant level of vulnerability.

- ***The North Bank Region (NBR)*** comprises 345 villages overall, 49 of which are at risk of flooding. This accounts for 14.2% of the populated areas in the area, showing a moderate degree of risk.

- ***Central River Region (CRR):*** With 668 settlements, the CRR is home to the most people, but just 11 of them are at risk of flooding. Only 1.6% of the towns are vulnerable, which indicates a low level of vulnerability.

- ***The Upper River Region (URR)*** comprises 373 villages overall, 7 of which are at risk of floods. With only 1.9% of the towns vulnerable, this indicates a low level of vulnerability.

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DISCUSSION

This study set out to conduct a comprehensive assessment and identification of areas in the Gambia vulnerable to flooding, categorizing the level of vulnerability within these regions, as well as to ascertain the degree to which key infrastructures and population settlements are susceptible to flood risks.

Risks and Vulnerabilities Vary by Geography

The evaluation of flood vulnerabilities in the Gambia demonstrates a diverse range of risks in different regions, requiring customized approaches for flood risk management and catastrophe preparedness (Adger et al., 2005). In regions categorized as having a minimal risk, the populace's diminished awareness of the potential for floods, caused by few occurrences of such disasters, might result in a lack of vigilance in terms of readiness and reaction tactics. Nevertheless, the possibility of intermittent inundation in these regions necessitates a fundamental understanding of floods and the implementation of emergency protocols. In areas classified as medium and high-risk for flooding, it is crucial to actively include the community in preparing for floods. This includes implementing thorough evacuation plans, implementing steps to make buildings resistant to flooding, and conducting public awareness campaigns to reduce the risk (Kreibich et al., 2011). The situation is particularly dire in really high-risk regions, where communities are exposed to substantial peril. Strategies should prioritize more rigorous actions, such as moving people to safer areas, building flood defenses, and providing specialized emergency services for highly populated areas. Particular emphasis should be placed on vulnerable demographics such as the elderly and economically poor, as they are frequently subject to a disproportionate impact from floods (Birkmann et al., 2017).

The national disaster planning in the Gambia should be carefully coordinated with the different levels of flood risk. Within areas classified as high and extremely high-risk, the primary focus should be on establishing resilient emergency services and implementing comprehensive evacuation processes. On the other hand, in areas with lower levels of danger, the emphasis may be placed on surveillance, early detection systems, and educating the population to improve overall readiness. The inclusion of community-based disaster risk management can greatly bolster resilience, particularly in places with moderate to high levels of risk. This strategy utilizes local expertise in disaster planning and response, promoting a feeling of community ownership and accountability for disaster preparedness (Carabine, 2015). An efficient disaster planning strategy should possess adaptability and flexibility, enabling it to effectively address the ever-changing flood hazards and shifting climatic patterns.

The formulation of national policies and plans for climate change adaptation in the Gambia should take into account the diverse levels of flood vulnerability throughout the country. Adaptive solutions in places with high and very high risk could involve constructing flood defenses, implementing more stringent zoning rules, and enhancing urban drainage systems, with a focus on the most vulnerable areas prone to significant floods (Hallegatte et al., 2013). Conversely, in places with lower levels of risk, adaptation methods may prioritize landscape management, namely the conservation of wetlands and forests that naturally alleviate flooding. It is essential to incorporate flood risk assessment into development planning in all locations to prevent future growth from worsening flood hazards. In order to address the issue comprehensively, it is important to incorporate ongoing surveillance and revision of flood risk evaluations, implement efficient communication tactics that cater to various degrees of risk,

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and engage in partnerships with international organizations and non-governmental organizations to access extra resources and experience. This comprehensive approach seeks to achieve equilibrium between immediate requirements in high-risk regions and long-term resilience and adaptation methods throughout the Gambia, guaranteeing the safety and welfare of all its inhabitants in light of escalating flood hazards.

Vulnerability of Health Infrastructure

The evaluation of the Gambia's susceptibility to floods in terms of its health infrastructure has significant and diverse ramifications, highlighting the necessity for a comprehensive strategy in response. Hospitals, which play a crucial role in treating serious medical conditions and crises, are highly vulnerable to the dangers posed by flooding. Their vulnerability to floods has the potential to interrupt crucial medical services, put lives at risk, and put pressure on emergency response systems. Therefore, it is necessary to develop specific disaster planning and response strategies for these facilities. Of equal concern is the vulnerability of minor health centers and clinics, particularly in rural and remote regions, as they frequently serve as the main healthcare providers for local communities. Flooding can significantly impede access to crucial healthcare services, exacerbating health inequalities and potentially leading to a rise in untreated medical disorders (Alderman et al., 2012). In addition, the possibility of these facilities being closed or operating at a reduced capacity during floods could impose a substantial load on undamaged facilities, resulting in congestion, limited resources, and poor quality of care (Paterson et al., 2014).

Flooding amplifies public health hazards, including the transmission of waterborne illnesses and poor sanitation, intensifying public health difficulties and emphasizing the necessity for strong public health approaches in flood-prone regions. To improve the resilience of health infrastructure, it is crucial to make strategic investments. This involves reinforcing current facilities and taking into account the potential dangers of flooding while constructing new ones. In order to ensure a synchronized response to health difficulties caused by floods, it is imperative to incorporate these vulnerabilities into national health policies, catastrophe risk management plans, and climate change adaptation strategies (Birkmann et al., 2017). Ensuring the long-term strengthening of the health system is crucial. This includes providing training to healthcare staff in disaster response, creating contingency plans to ensure continuous care, and maintaining sufficient stockpiles of medical supplies. Overall, it is crucial to address the susceptibility of the Gambia's health facilities to flooding by implementing a comprehensive approach that includes strengthening infrastructure, enhancing emergency readiness, implementing public health strategies, and reforming policies. This is essential for protecting public health and ensuring the efficient provision of healthcare services in the midst of increasing climate-related difficulties.

Vulnerability of Road Infrastructure

The findings indicate a large susceptibility to floods, with approximately 24.5% of its roadways being exposed to risk. This poses noteworthy consequences for the nation's infrastructure, economy, and overall societal welfare. The possible inundation of 202 kilometers of main roads and 213 kilometers of secondary roads not only endangers crucial trade and commerce routes but also poses a significant risk of considerable economic damages and disruptions in the supply chain (Rowangould, 2013). The severity of this issue is worsened by the crucial function that secondary roads provide in linking rural regions to major cities. If these roads are damaged

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by floods, it could result in the isolation of populations, leading to significant consequences such as limited access to vital services like healthcare, education, and emergency assistance (CRED/UNISDR, 2015). The consequences of such isolation can have significant impacts on public health, education, and the overall ability of communities to recover from challenges, particularly in rural regions where these routes are crucial for survival.

This risk requires a comprehensive response that includes legislative interventions, infrastructure development, and strategic planning. There is an urgent requirement for policies and strategies that give priority to enhancing the ability of road networks to withstand and adapt to floods. This includes implementing construction standards that are resilient to climate change, enhancing drainage systems, and incorporating flood risk assessments into infrastructure design. Furthermore, the evaluation highlights the significance of adopting a comprehensive and forward-thinking strategy for infrastructure development, considering the growing effects of climate change. This approach should not only mitigate existing vulnerabilities but also strategically prepare for forthcoming difficulties, guaranteeing the economic stability of the nation, a continuous access to vital services, and an improved social resilience in response to growing climate-related threats (Field & Barros, 2014).

Regional Disparities Based on Settlements Affected

An evaluation of flood susceptibilities in different locations of the Gambia reveals a diverse range of risks in various settlements, which has substantial consequences for regional planning, emergency management, and sustainable development. The West Coast Region (WCR) has the highest susceptibility, with 48.7% of its settlements facing the possibility of flooding. This emphasizes the urgent requirement for focused flood prevention initiatives and strengthening of infrastructure in this region. In contrast, the Central River Region (CRR) and the Upper River Region (URR) exhibit less susceptibility, indicating that allocating resources and efforts towards prevention and preparedness measures in these regions may provide more beneficial outcomes. The presence of a moderate risk in the Lower River Region (LRR) and the North Bank Region (NBR) necessitates a well-rounded approach that combines both mitigation and preparedness techniques. The existence of this difference in flood risk emphasizes the need for a localized strategy in disaster management and urban planning in the Gambia. It is vital to prioritize places with higher susceptibility, such as the WCR, for infrastructure development, community education and early warning systems. Furthermore, our evaluation highlights the necessity of incorporating climate change adaptation into national development strategies, guaranteeing that future urban growth and rural advancement are carried out in a way that reduces the potential for flooding. Efficient handling of these vulnerabilities is crucial not just for safeguarding lives and property, but also for guaranteeing the economic stability and enduring growth of the Gambia.

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CONCLUSION

The comprehensive assessment of flood vulnerabilities in the Gambia underscores the critical need for a multi-faceted and region-specific approach to flood risk management, disaster preparedness, healthcare service delivery, and infrastructure development. The varied levels of flood risk across different regions necessitate tailored strategies that balance immediate needs in high-risk areas with long-term resilience and adaptation strategies. This includes enhancing public awareness, emergency response plans, community engagement in preparedness, and robust policy interventions targeting the resilience and adaptation of crucial infrastructure like healthcare facilities and road networks. The significant risk to healthcare infrastructure, particularly hospitals, minor health centers, and clinics calls for strategic investments to bolster their resilience, ensuring uninterrupted healthcare service delivery even during floods. Additionally, the vulnerability of about 24.5% of the Gambia's road network to flooding, with its consequent economic, social, and public health impacts, demands urgent policy and infrastructural responses, incorporating climate-resilient construction standards and proactive planning against future climate change impacts. Furthermore, the varied risk across settlements, especially the high vulnerability in regions like the West Coast Region, highlights the need for focused mitigation strategies and infrastructure reinforcement, as well as the integration of climate change adaptation into national development policies. Addressing these challenges through coordinated efforts involving local knowledge, national policies, and international collaboration is paramount for safeguarding the nation's economic stability, public health, and overall societal resilience in the face of escalating flood risks and climate change challenges.

REFERENCES

ADGER, W. N., HUGHES, T. P., FOLKE, C., CARPENTER, S. R. & ROCKSTROM, J. 2005. Social-ecological resilience to coastal disasters. *Science,* 309**,** 1036-1039.

ALDERMAN, K., TURNER, L. R. & TONG, S. 2012. Floods and human health: a systematic review. *Environment international,* 47**,** 37-47.

BANK, W. 2020. Gambia - country profile. *Poverty and Inequality Platform.* Washington DC, USA: World Bank.

BANK, W. 2021. The Gambia - Trends & Variability - Historical. *Climate Change Knowledge Portal.* Washington DC, USA: World Bank.

BATJES, N. 2008. Soil parameter estimates for Senegal and the Gambia derived from SOTER and WISE (SOTWIS-Senegal, ver. 1.0). ISRIC-World Soil Information.

BELFORD, C., HUANG, D., AHMED, Y. N., CEESAY, E. & SANYANG, L. 2023. An economic assessment of the impact of climate change on the Gambia's agriculture sector: a CGE approach. *International Journal of Climate Change Strategies and Management,* 15**,** 322-352.

BIRKMANN, J., SORG, L. & WELLE, T. 2017. Disaster vulnerability. *The Palgrave handbook of unconventional risk transfer***,** 329-356.

CARABINE, E. 2015. Revitalising evidence-based policy for the Sendai Framework for Disaster Risk Reduction 2015-2030: lessons from existing international science partnerships. *PLoS currents,* 7.

COOPERATION, T. G.-E. 2010. Drainage, Sanitation & Waste Management. Banjul, The Gambia: National Authorising Officer Support Unit (NAOSU).

Article DOI: 10.52589/AJENSR-5YL0XG79
DOI URL: https://doi.org/10.52589/AJENSR-5YL0XG79

CRED/UNISDR 2015. The human cost of weather related disasters 1995–2015. Brussels, Belgium: Centre for Research on the Epidemiology of Disasters (CRED), UN Office for Disaster Risk Reduction (UNISDR).

DANIELSON, J. J. & GESCH, D. B. 2011. Global multi-resolution terrain elevation data 2010 (GMTED2010). South Dakota, USA: U.S. Geological Survey.

DIJKSHOORN, J. & HUTING, J. 2014. Soil and Terrain Database for Senegal and the Gambia (version 1.0)-scale 1: 1 million (SOTER_Senegal_Gambia).

DOORN, N. 2014. Rationality in flood risk management: the limitations of probabilistic risk assessment in the design and selection of flood protection strategies. *Journal of Flood Risk Management,* 7**,** 230-238.

FIELD, C. B. & BARROS, V. R. 2014. *Climate change 2014–Impacts, adaptation and vulnerability: Regional aspects*, Cambridge University Press.

FLOODLIST 2022. The Gambia – Floods Leave Homes and Roads Damaged, Two Fatalities. 03 August 2022 ed. Berlin, Germany: European Centre for Medium-Range Weather Forecasts (ECMWF).

FUNK, C., PETERSON, P., LANDSFELD, M., PEDREROS, D., VERDIN, J., SHUKLA, S., HUSAK, G., ROWLAND, J., HARRISON, L. & HOELL, A. 2015. The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. *Scientific data,* 2**,** 1-21.

GFDRR 2022. The Gambia - River flood. 10 June 2022 ed. Washington DC, USA: Global Facility for Disaster Reduction and Recovery (GFDRR); World Bank Headquarters.

HALLEGATTE, S., GREEN, C., NICHOLLS, R. J. & CORFEE-MORLOT, J. 2013. Future flood losses in major coastal cities. *Nature climate change,* 3**,** 802-806.

KARRA, K., KONTGIS, C., STATMAN-WEIL, Z., MAZZARIELLO, J. C., MATHIS, M. & BRUMBY, S. P. Global land use/land cover with Sentinel 2 and deep learning. 2021 IEEE international geoscience and remote sensing symposium IGARSS, 2021. IEEE, 4704-4707.

KIND, J. M. 2014. Economically efficient flood protection standards for the Netherlands. *Journal of Flood Risk Management,* 7**,** 103-117.

KREIBICH, H., SEIFERT, I., THIEKEN, A. H., LINDQUIST, E., WAGNER, K. & MERZ, B. 2011. Recent changes in flood preparedness of private households and businesses in Germany. *Regional environmental change,* 11**,** 59-71.

LI, Z. 2014. Watershed modeling using arc hydro based on DEMs: a case study in Jackpine watershed. *Environmental Systems Research,* 3**,** 1-12.

LONG'OR LOKIDOR, P., TAKA, M., LASHFORD, C. & CHARLESWORTH, S. 2023. Nature-based Solutions for sustainable flood management in East Africa. *Journal of Flood Risk Management,* n/a**,** e12954.

LÓPEZ-BERMEO, C., MONTOYA, R. D., CARO-LOPERA, F. J. & DÍAZ-GARCÍA, J. A. 2022. Validation of the accuracy of the CHIRPS precipitation dataset at representing climate variability in a tropical mountainous region of South America. *Physics and Chemistry of the Earth, Parts A/B/C,* 127**,** 103184.

LUMBROSO, D. 2020. Flood risk management in Africa. *Journal of Flood Risk Management,* 13**,** e12612.

MAGOUM, I. 2022. GAMBIA: Kanifing to get new drainage system to combat flooding. *Afrik21*.

O'NEILL, A. 2023. Gambia: Urbanization from 2012 to 2022. Hamburg, Germany: Statista.

Article DOI: 10.52589/AJENSR-5YL0XG79
DOI URL: https://doi.org/10.52589/AJENSR-5YL0XG79

RAADGEVER, G. T., BOOISTER, N. & STEENSTRA, M. K. 2018. Flood Risk Management Strategies. *In:* RAADGEVER, T. & HEGGER, D. (eds.) *Flood Risk Management Strategies and Governance.* Cham: Springer International Publishing.

RELIEFWEB 2022. Gambia 2022 Flash Floods Situational Report #005. 25 August 2022 ed. New York, USA: United Nations Office for the Coordination of Humanitarian Affairs (OCHA).

ROWANGOULD, G. M. 2013. A census of the US near-roadway population: Public health and environmental justice considerations. *Transportation Research Part D: Transport and Environment,* 25**,** 59-67.

TOURAY, S. 2022. World Bank Blogs. Poverty Trends in The Gambia: A Tale of Two Crises. *World Bank Blogs.* Washington DC, USA: World Bank.

UNCDF 2023. Enhancing livelihoods and increasing climate resilience of smallholder farmers in The Gambia. New York, USA: UN Capital Development Fund (UNCDF).

UNDRR 2019. Disaster risk profile - The Gambia. New York, USA: United Nations Office for Disaster Risk Reduction - Regional Office for Africa.

UNESCO 2023. Sentinels from above: how drones are helping The Gambia cope. 12 June 2023 ed. Paris, France: United Nations Educational, Scientific and Cultural Organization (UNESCO).

Article DOI: 10.52589/AJENSR-5YL0XG79
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Appendix 1

Appendix 1.1. Scores attributed to soil types based on their susceptibility to floods with 1 being the least susceptible and 10 being the most susceptible.

Soil	Score	Explanation
Regosols	4	These are poorly developed soils that typically have good drainage due to their coarse texture, which can reduce their propensity to contribute to flooding. However, they can contribute to higher runoff due to low water retention capacity, leading to a moderate propensity for flooding.
Ferralitic soils	6	These are typically well-drained due to their granular structure, reducing their propensity to contribute to flooding. However, their nutrient-poor nature may lead to low vegetative cover, which could increase runoff and thus their propensity to contribute to flooding.
Tropical ferruginous soils	6	Similar to Ferralitic soils, they are well-drained but can be prone to runoff due to their nutrient-poor nature and potential for low vegetative cover.
Hydromorphic soils	10	These soils are typically found in waterlogged areas and have poor drainage, leading to a high propensity to contribute to flooding.
Lithosols	2	These shallow, rocky soils have excellent drainage and are unlikely to contribute to flooding unless the underlying rock is impermeable, leading to runoff.
Mudflats	8	These areas are typically found along coastlines or riverbanks and can contribute to flooding due to their flat topography and fine soil texture, which can lead to poor drainage.
Coastal dunes	4	These sandy soils typically have good drainage, reducing their propensity to contribute to flooding. However, they can contribute to higher runoff due to their coarse texture and low water retention capacity.
Poorly developed soils	4	Like Regosols, these soils typically have good drainage due to their coarse texture but can contribute to higher runoff due to low water retention capacity.

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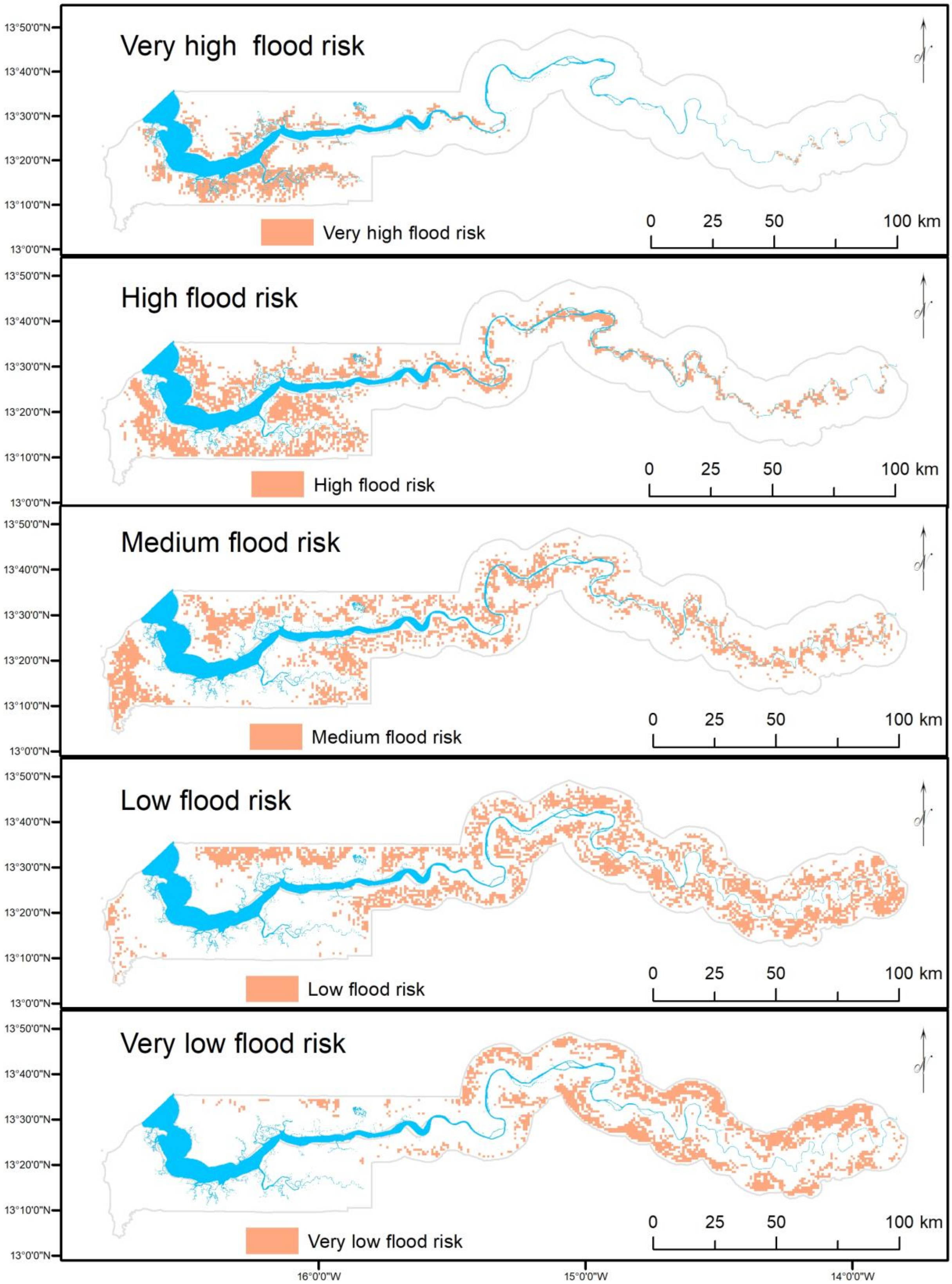
Appendix 1.2. The distribution of identified flood risk categories.



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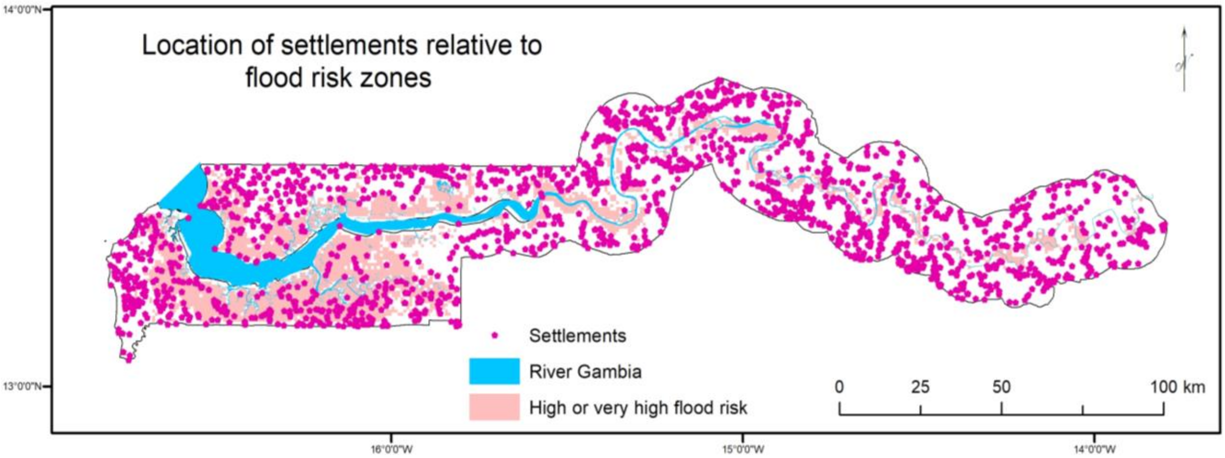
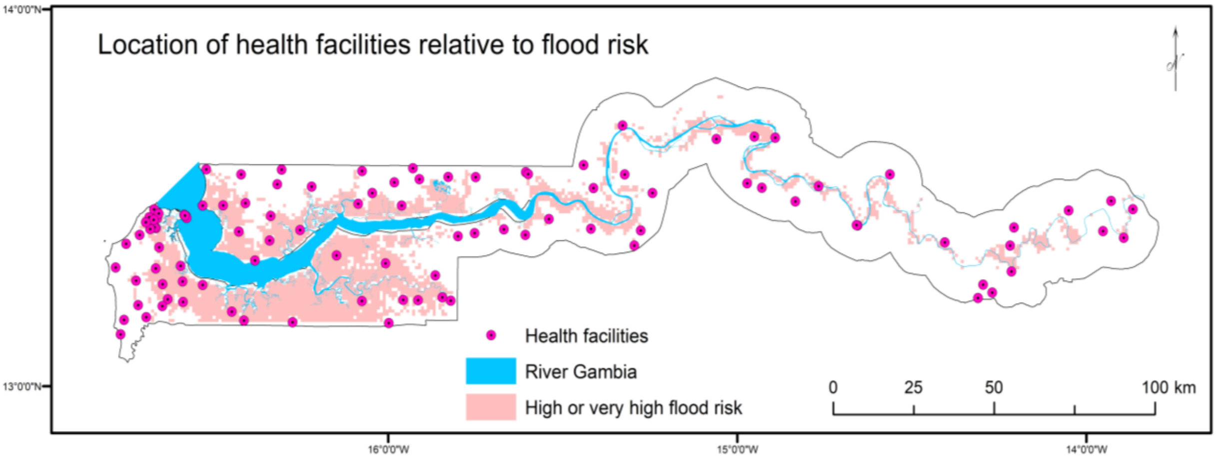
Appendix 1.3. All settlements relative to flood risk in the "High" or "Very High" category.



Appendix 1.4. All health facilities relative to flood risk in the "High" or "Very High" category.



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