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Title: Advanced flood hazard zonation, risk profiling and Susceptibility mapping in Abuja, the Federal Capital Territory of Nigeria, using a Hybrid GloFAS-NASA DEM-MERIT HAND-socioeconomic vulnerability mapping Approach, validated using Sentinel-1 SAR in the Google Earth Engine computing environment.

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Abstract

Flood incidents in Abuja, the Federal Capital of Nigeria, are one of the most frequently occurring natural disasters in recent times, which poses significant threat to lives, infrastructure and buildings in Urban and semi-urban districts of the city. Despite significant research effort geared towards flood susceptibility mapping globally, limited success has been achieved in the global south, due to scarcity of data, as well as low integration of observed inundation and exposure into a comprehensive framework. The GloFAS developed by the EU Joint Research Centre in alignment with the ECMWF and Copernicus CEMS aims to protect the globe, especially in data-scarce regions, from the adverse effects of extreme hydrological events like floods and droughts. This study is conducted to assess the best combination of JRC water layers, SAR flood extents and terrain variables that provides the most accurate hazard classification in the Study area, evaluate the significance of spatially driven susceptibility mapping models validated against GloFAS-driven event modelling in enhancing flood zonation, using GloFAS LISFLOOD data, and to investigate the dynamic impact of social vulnerability on flood risk severity by overlaying flood hotspots on physical hazard maps. This is undertaken, using a Hybrid GloFAS-NASA DEM-MERIT HAND-socioeconomic vulnerability mapping Approach, while validation is done using Sentinel-1 SAR in the Google Earth Engine computing environment.

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LIST OF ABBREVIATIONS

GEE-Google Earth Engine

ECMWF- European Centre for Medium-Range Weather Forecasts

CEMS-Copernicus Emergency Management Services

Copernicus- EU's big satellite and Earth Observation program

GloFAS- Global Floods system: developed by the EU Joint Research Centre

JRC- European Union Joint Research Centre

GRFHM- Global River Flood Hazard Maps.

IFS- Supercomputer model for global weather daily prediction: rainfall, Temperature, Evaporation, Snowmelt

LISFLOOD - GIS-based distributed rainfall-runoff and river-routing model that simulates hydrological processes to forecast weather events within GloFAS. It can convert meteorological inputs into flood forecasts.

NASA – National Aeronautics and Space Administration

MERIT - Multi-Error Removed Improved Terrain

HAND - Height Above Nearest Drainage

DEM -Digital Elevation Model

SAR- Synthetic Aperture Radar

RP- Return Period for Rapid flood mapping and hazard catalogue: 10- 500 years

Sentinel-1 GRD VV- Ground Range Detected Vertical-Vertical Polarisation.

1.0 INTRODUCTION

Flood disaster remains one of the most damaging and frequently occurring disasters in the world today. Recent flood disasters in the Federal Capital of Nigeria, Abuja, such as floods in the Abuja Municipal Area Council's Lokogoma, Trademore, Pyakasa and Lugbe districts, have exposed vulnerable populations to varying degrees of risk, confirming that Nigeria is not isolated from this global trend (Bello et al., 2026). Recent literature on flood disasters justifies the use of the Global Flood Awareness System's GLoFAS dataset in Google Earth Engine, because it offers a strategic tool for advanced flood zonation and risk profiling (Odiji et al., 2026; Bello et al., 2026). The GLoFAS developed by the EU Joint Research Centre in alignment with the ECMWF and Copernicus CEMS aims to protect the globe, especially in data-scarce regions, from the adverse effects of extreme hydrological events like floods and droughts. Despite advances in the availability of data from open geospatial platforms, Nigeria and several African countries continue to suffer from data scarcity and lag in spatial data analysis and environmental risk assessment. Abuja's case is particularly significant because the city has made significant urbanization, increasing the risk of runoff, localized exposure arising from deviations in city planning compliance, and creating several hotspots for increased flood disaster risk across the length and breadth of the capital of Africa's most populous country (Hajj et al., 2025; Belay et al., 2025).

1.1 Background

Flood risk in the context of disaster risk management concerns itself with the evaluation of the probability of flooding and the associated resultant impact on people, infrastructure, assets, and ecosystems (Gemitzi et al., 2024). Evidence from recent literature shows that there is an increasing challenge of flood disaster risk across the globe, owing to the increasing intensity of rainfall associated with climate change in the last few decades, exposure of land cover, as well as low coping capacities and capabilities of disaster risk management teams in many regions (Tique et al., 2026; Hamidi et al., 2025).

Nigeria suffers from an acute flood risk; recent data show that the country is arguably the most exposed and vulnerable country in West Africa, with several recorded heavy-impact flood incidents in the last two decades in this region (Tique et al., 2026). This risk has been exacerbated by low coping capabilities, poor town planning, high population growth rates and increasing

rainfall extremes, as well as insufficient research aimed at conducting dense hydrometric observations. Several factors have been identified by nationwide, river basin and city-scale flood studies conducted in Nigeria as controls on susceptibility to flooding incidents in Nigeria, they include low elevation, intense rainfall, high drainage density, gentle slopes, land use change, as well as proximity to channels (Elujoba et al., 2025; Diriba et al., 2024).



Figure. 1 FCT Abuja-Lugbe district flood inundation 2021

The flood risk hazard is a major issue affecting Nigerian cities, in many of which densely populated low-lying districts have become the most vulnerable, due to an increasing concentration of compact areas, where urban growth has outpaced drainage provision and compliance in enforcing land use regulations has taken the back seat (Bello et al., 2026; Umar et al., 2026; Elujoba et al., 2026). Abuja, the nation's capital, is not exempt from this problem. Recent studies have shown that the city's expansion and corresponding vegetation loss have intensified surface runoff impact, leading to the development of district-level runoff hotspots, which ultimately disrupt the hydrological balance in this city (Odiji et al., 2026).

1.3 Problem Statement

Flood incidents in Abuja, the Federal Capital of Nigeria, are one of the most frequently occurring natural disasters in recent times, which poses significant threat to lives, infrastructure and buildings in Urban and semi-urban districts of the city. Despite significant research effort geared towards susceptibility mapping, limited success has been achieved due to scarcity of data, as well as low integration of observed inundation and exposure into a comprehensive framework. Despite overwhelming evidence of several flood risk drivers in the peri-urban settlements in Abuja, past studies have critically under-characterized risk in these areas. While some progress has been made in some Abuja-specific studies, there remains a huge gap in the application of GIS, remote sensing, cloud-based analytics, as well as globally proven hydrological products such as GloFAS-JRC, in flood zonation and risk profiling (Salaudeen et al., 2026). The implication of this is that current efforts have failed to dynamically convert the results of static hazard maps into actionable flood intelligence that can be useful in disaster risk management. This study addresses these gaps by taking advantage of a hybrid model to develop a dynamic integrated framework that can be useful in improving flood disaster preparedness, response and resilience planning.

1.4 Research Aim

The aim of this study is to conduct advanced flood hazard zonation, risk profiling and Susceptibility mapping in Abuja, the Federal Capital Territory of Nigeria, using a Hybrid GloFAS-NASA DEM-MERIT HAND-socioeconomic vulnerability mapping Approach, validated using Sentinel-1 SAR in the Google Earth Engine computing environment.

1.5 Research Objectives

- Assessing the best combination of JRC water layers, SAR flood extents and terrain variables that provides the most accurate hazard classification in the Study area.
- Evaluating the significance of spatially driven susceptibility mapping models validated against GloFAS-driven event modelling in enhancing flood zonation, using GloFAS LISFLOOD data.

- Investigating the dynamic impact of social vulnerability on flood risk severity by overlaying flood hotspots on physical hazard maps.

1.6 Research Questions

- What is the impact of the GloFAS dynamic river discharge on flood susceptibility zonation and improvement of real-time flood risk mapping?
- How does the spatial flood modelling observed flood susceptibility, derived using Sentinel-1 SAR, compare with the dynamic inundation thresholds simulated by GloFAS JRC, when validated against known flood events?
- How do social vulnerability factors such as congestion, poor planning and overpopulation affect changes in flood risk exposure in flood hotspots across different flood hazard locations in Abuja?

1.7 Relevance of study

The use of GloFAS has proved to be relevant in several studies conducted in the EU as well as other parts of the globe; its usefulness stems from its global applicability in hydrological analysis and forecasting, often filling in the gaps effectively in data-scarce scenarios where discharge records were either inconsistent, sparse or unavailable (Salaudeen et al., 2026; Prudhomme et al., 2024). Nigeria and many African countries suffer from technology deficits and data scarcity due to several political and socio-economic reasons; therefore, this study finds relevance in the African context. Therefore, for a study of this nature focused on Abuja, the Federal Capital of Nigeria, the combination of GloFAS with streamflow forecast information to predict inundation scenarios provides a veritable tool for flood risk anticipation (Hossain et al., 2023).

Developing countries such as Uganda, Bangladesh and Mozambique, with similar socio-economic and development indices to Nigeria, have benefited from GloFAS-based studies in improving flood forecasting, developing early action plans and improving flood disaster risk management (Hossain et al., 2023). Other benefits that have been recorded in practical application of GloFAS in data-scarce environments include hydrologic model parameterization as well as preliminary flood

assessment, subject to cautious interpretation in line with independent observed streamflow data, based on local context.

1.8 Justification

The need for this study to be conducted in Abuja is supported by three major identified gaps; Firstly, despite considerable progress achieved by some studies in susceptibility mapping, many others remain localized, relying on insufficient data and recording little success in integrating uncertainty, exposure and observed inundation into a single framework (Tique et al., 2026). Secondly, rapidly expanding semi-urban settlements surrounding the city remain under-characterized despite overwhelming evidence of major drivers of flood risk in these settlements (Umar et al., 2026). Thirdly, Abuja-specific studies have identified hotspot districts and runoff intensity as key areas of concern; however, there has been limited application of cloud-based analytics, global hydrological products, or advanced risk profiling tools to assess the exposure of people and infrastructure to hazards (Odiji et al., 2026).

This study uses GloFAS within the Google Earth Engine to address the identified gaps, with the objective of not only identifying flood-prone areas of Abuja, but also improving preparedness planning, emergency response, as well as resilience planning (Tique et al., 2026; Msusa et al., 2025). This study is positioned within an emerging research direction targeted at digitally transforming static hazard mapping into an integrated, dynamic and evidence-based, decision-oriented flood intelligence approach (Umar et al., 2026; Tique et al., 2026; Hamidi et al., 2025). In view of the identified challenges and gaps, advanced flood hazard zonation and risk profiling using GloFAS in Google Earth Engine is therefore both scientifically timely and operationally relevant.

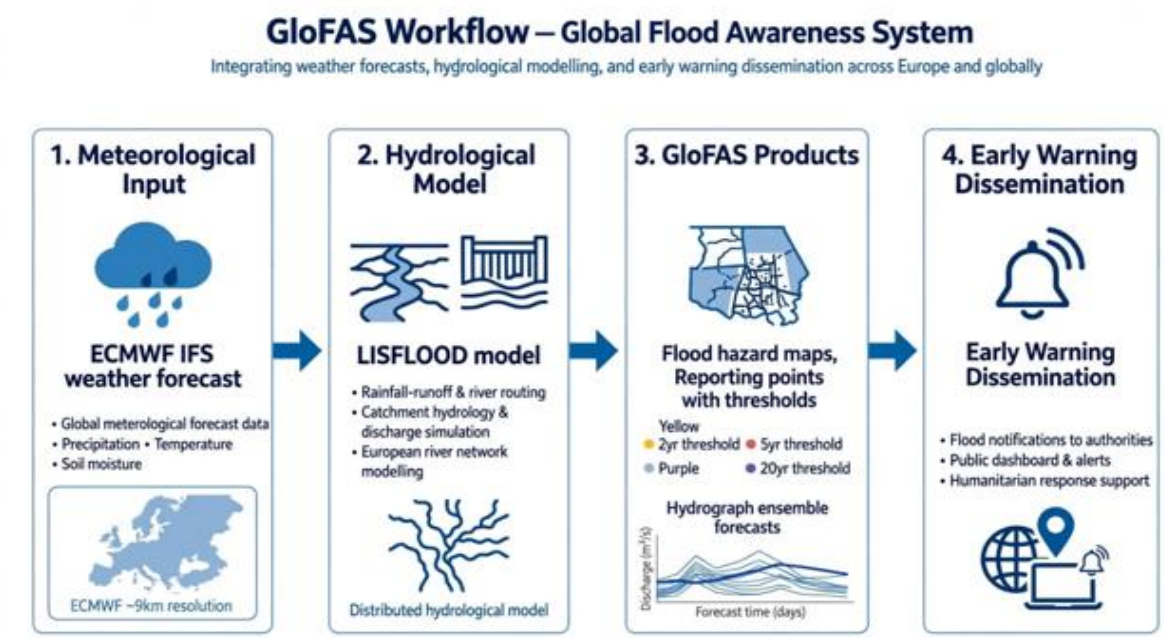


Figure 2. Global Flood Awareness System. Source: EU JRC/ ECMWF/Copernicus CEMS

2.0 METHODOLOGY

2.1 Study Area

The study area covers the entire geographic borders of the Federal Capital Territory of Nigeria and its structural, topographic and hydrological drainage characteristics (Etuk et al., 2022).

Geographic Setting of the Study Area

The FCT Abuja, covers approximately 8000 square kilometers (7298.37 Sqm), located in the North central region of the country, lying between latitudes 8*21'-9*18'N and longitudes 6*46'-7*37', with governance structure split into six separate administrative councils; Abuja Municipal Area Council: Most Urbanized administrative area, hosts majority of government institution, Bwari Area Council: which occupies the mountainous norther flank of the study area, Gwagwalada and Kuje Area councils: with features including a mix of rapidly urbanizing peri-urban clusters and extensive agricultural domains, as well as the Kwali and Abaji Area Councils which lie to the southwestern part of the study area characterized by sedimentary lowlands(Etuk et al., 2022). The Spatial map below shows a five-layered intrinsic vulnerability map of groundwater distribution in Abuja, with categories across districts from very high to very low.

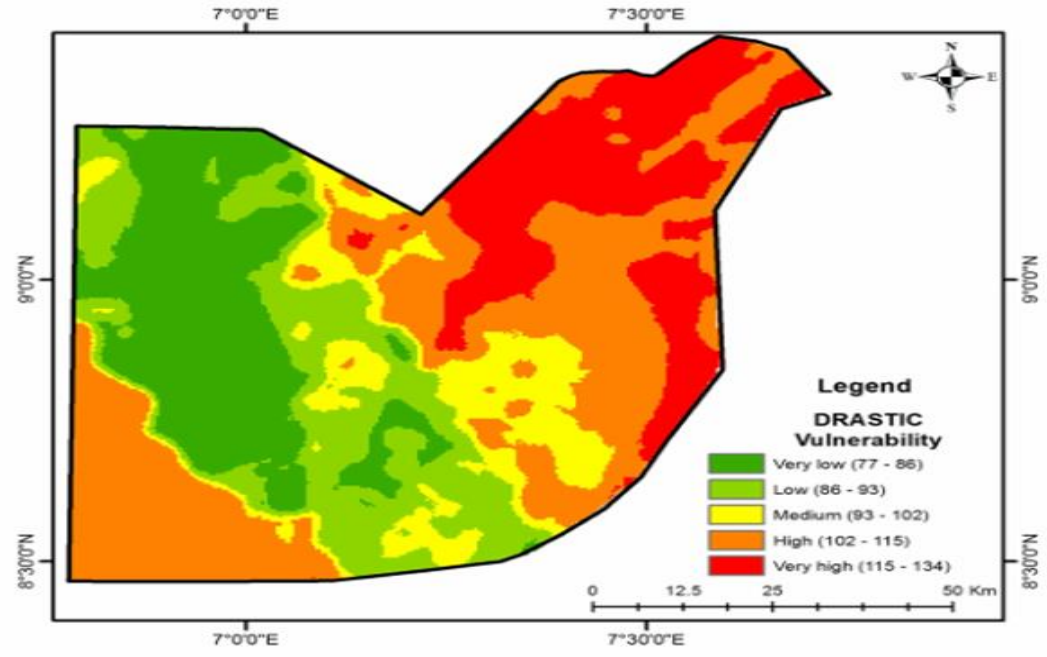


Figure 3: DRASTIC intrinsic Groundwater Vulnerability Map for Abuja FCT. (Etuk et al., 2022.)

The mean annual precipitation observed in the area has been found to fluctuate around 1,200 millimetres per annum, with peak periods occurring around April and October (Etuk et al., 2022). The area demonstrates a baseline drainage, controlled by surface morphology, with run-off and groundwater flow following a dominant northeast to southwest pattern that sustains stream baseflow.

2.2 Research Design

The study was conducted using a quantitative approach to data analysis, based on a geospatial, multi-source hybrid model, which combined the GloFAS return-period hazard scenario simulations with terrain data based on the NASA Digital Elevation Model (DEM), Sentinel-1 SAR validation, as well as OpenStreetMap OSM data and WorldPop population layers to characterise the extent and dimensions of hazard, exposure, susceptibility, as well as vulnerability in the study area. The Global Flood Awareness System (GloFAS), a technological product jointly developed by the ECMWF and JRC under the Copernicus Emergency Management Service of the EU, serves as the hazard backbone for this study (CEMS, 2024). This global framework for flood-hazard mapping derives a long-term daily river discharge, based on the LISFLOOD hydrological simulation model, to downscale the streamflow in a specified area into a high-resolution river network, which is based on two-dimensional hydrodynamic simulation, to deliver return-period (RP10-RP500) hazard maps at 30'' resolution for Rapid flood mapping and hazard cataloguing (Dottori et al., 2016).

Global Models such as the GLoFAS are particularly useful in studies situated in data-scarce regions, such as sub-Saharan Africa, where high-resolution hazard information may be insufficient or unavailable (Akintola, 2024; Dottori et al., 2016). The data analysis is conducted using the computational capacities of the Google Earth Engine coding environment. The boundaries of the study area (FCT Abuja) are derived externally from a GIS shapefile, uploaded as an asset into the GEE script environment. The outputs of data analysis represent a summary of the entire study area, broken down into different area councils, to identify flood hotspots (Akintola, 2024).

2.3 Data Presentation and Harmonization

The static flood-depth scenario modelling was conducted using the JRC/Copernicus EMS Global Flood Awareness System's flood hazard dataset, using two return period bands (RP10 and RP100) to represent different scenarios in the GEE coding/computational environment. The output represents multi-criteria hazard modelling of future possible outcomes, as opposed to a specific forecast of a future event. The study covers the entire geographic space of the FCT Abuja; however, since the GloFAS product captures mainly larger transboundary river basins and their drainages (In the study context: Usuma River and tributaries; Gwagwalada and Jabi Rivers), interpretation of the data analysis will be guided by coverage over Abuja. The study takes cognizance of the fact that terrain dataset quality can significantly impair the outcomes of large-scale hazard maps when urban areas are treated as bare-earth elevations; hence, the GLO-30 surface model is harnessed to integrate building and vegetation data (Dottori et al., 2016). Building on this perspective, the NASA Digital Elevation Model is used to supply slope data to integrate terrain impact on the soil wetness index, as well as MERIT Hydro Height Above Nearest Drainage (HAND) to evaluate the impact of drainage-relative indicators, consistent with past relevant studies which have successfully adopted the HAND-based susceptibility model for mapping river basins in Nigeria (Komolafe et al., 2020). The Population in the mapped area was derived using the WorldPop raster 2025 data to overlay the flood mask of the inundated study area. However, this approach is limited by the fact that the data represent total study area count, rather than population density. This limitation is minimized by comparison of results with available municipal council population estimates. Gridded population estimates using population layers (such as GHS-POP and WorldPop) have been successfully harnessed in quantification of exposure in African settings (Tique et al., 2026). Population estimates derived from this analysis represent the modelled estimates of susceptible people and not the count of households.

2.4 Hazard Exposure and event-based Validation

The inundation footprint and flood depth are derived for the modelled Return periods (RP10 and RP100); the images are fitted and clipped based on pre-defined thresholds (example >0.1 m) to arrive at modelled inundated area footprints. The extent and area coverage of these areas are estimated in pixels. Locations that overlap identified hazard footprints and fall below the pre-defined elevation threshold were flagged using a separate terrain screening. Sentinel-1 GRD imagery was used to conduct an event-based screening based on data from recorded recent flood

events in the study area (for the Abuja 2023 & 2026 flood events). The pre- and post-event dates used were based on the documented event chronicles. Multiple ranges are selected to ensure robustness of inundation screening using observed change as opposed to a single-image threshold (Tupas et al., 2023). This approach is selected due to Sentinel-1's resilience and practical remote sensing capabilities, even under cloud interference, making it ideal for flood delineation; however, the double-bounce effect between water and buildings will be taken into account (Islam and Meng, 2022)

Component	Data Source (Primary)	Analytical Model	Key Considerations
Hazard Scenarios	GLoFAS RP10/100 depth	Modelled inundation footprint and Area coverage in Km2	Static return-period zonation, not an actual forecast (Dottori et al., 2016)
Topological Consideration (Terrain)	Copernicus GLO-30; NASADEM slope; MERIT HAND	Low-lying area screening, slope mask	Surface model used, not bare earth (Dottori et al., 2016)
Event Validation / Screening	Sentinel-1 GRD Change detection	Observed-event candidate inundation	Urban double-bounce and image backscatter (Islam and Meng 2022)
Vulnerability Exposure	WorldPop countsl Open Street Mapping OSM for built up areas	Population and structure exposure	Modelled estimates and use of partial proxy (Akintola, 2024; Tique et al., 2026).

Table. 1. Research method summary

The population exposure was computed using the derived flood mask and the provided population value from the WorldPop raster. The process involved masking the population raster with scenario-based inundation. Similarly, building exposure footprint was derived by overlaying the inundated area with OSM-derived building footprints; however, this data does not articulate critical infrastructure such as hospitals, schools, etc., which could represent flood disaster coping infrastructure within captured building footprints. In light of these constraints, this study will frame population exposure as a partial vulnerability proxy, in line with advocacy for greater integration of social vulnerability into wider flood risk research context (Fox et al., 2024).

2.5 Validation, Uncertainty and Reporting

Validation will be based on documented significant historical flood events, using Sentinel-1 observations as well as secondary data from independent references for the FCT Abuja. This approach is supported by opinions of past studies, which maintain that validation may be challenging when using global systems in data-sparse regions where reference data and physical

ground measurements may be scarce or divergent in opinions (Revilla-Romero et al., 2015). Building on this perspective, the comparison between Sentinel SAR-derived extents and Static GloFAS scenarios will be treated as complementary. Furthermore, interpretation and mirroring of findings between large spatial datasets and modelled 100-year flood extents has been asserted to overlap only partially; therefore, this study will be guided in the interpretation of findings. The final output will include hazard, exposure, observed event screening and partial susceptibility.

3.0 DATA PRESENTATION AND ANALYSIS

3.1 Hazard Zonation and Exposure

The results from the GloFAS-JRC dynamic discharge framework, using a 100-year return period, produced an inundation footprint of 143.08 km2, which represents 1.96% of the study area. Similarly, results from the RP10 scenario produced a smaller footprint of 128.75km2 of inundated area, with a mean depth of 3.50m and a 14.42m maximum depth. This hazard mapping method aligns with the standard GloFAS depth differentiation zonation mapping methodology, which uses a long- term river discharge to develop a high-resolution river network to produce a 2D hydrodynamic simulation per return period (Dottori et al., 2016).

- Building exposure: approximately 4,957 building pixels were found to intersect with the RP100 flood mask against a total building OSM footprint of 1,201,674 (Confidence>=0.7), a small but significant share of the total built stock.
- Population Exposure: approximately 186,700 exposed people were found to fall within the RP100 mask, a figure close in scale to an estimated population of 230,000 obtained from a Kano study using a 100-year return period (Aldrees et al., 2024).
- Discharge skill caveat: Some studies assert that the GloFAS reanalysis shows up to 86% effectiveness in mapping global river catchments; however, systematic positive bias has been observed across Africa, leading to possible inflation of flood-modelled extents across Africa (Harigan et al., 2020).

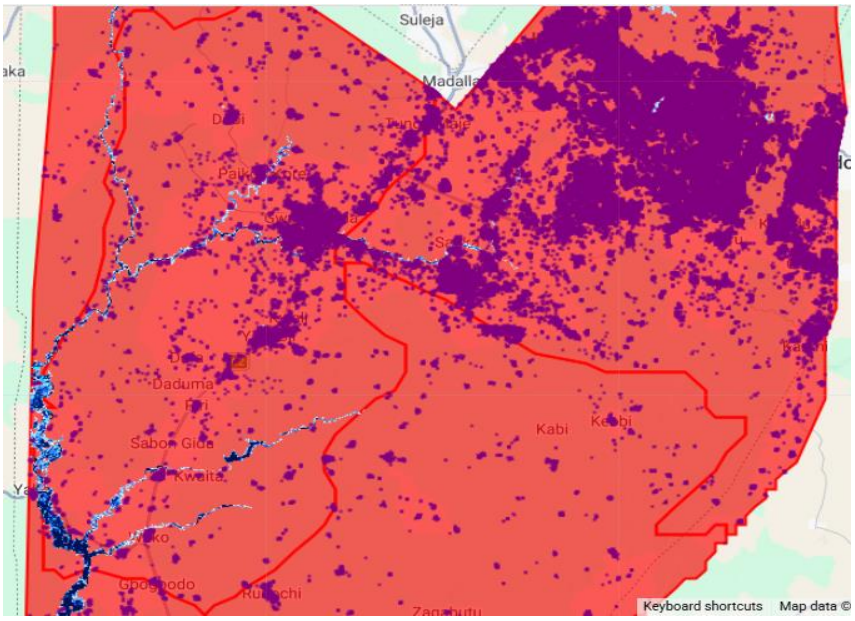


Figure 3: Sar inundation+ Population in RP 100 pixel+ Building exposed footprint

3.2 Sentinel-1 Validation Against GloFAS

The Sentinel-1 change detection was conducted using 2 post-event and 2 pre-event scenes from recent floods in Abuja occurring mainly in the AMAC area council. The results showed an observed flood extent of 12.86km2, which represents an area of about 0.176% of the total 7, 298 km2 study area. This figure amounts to roughly 9% of the total inundated RP100 modelled footprint. This observed gap is consistent with documented limitations from past studies involving the use of both approaches; whereas GloFAS-based hydrodynamic analysis has been observed to produce overestimation of flood extent, where discharge is biased high (Dottori et al., 2016; Sadana et al., 2026), SAR mapping has proved to be constrained by polarization choice and revisit timing (Roth et al., 2025; Tarpanelli et al., 2022).

Metric	GLoFAS-JRC RP100	Sentinel-1 SAR
Inundated area (km2)	143.08	12.86
Percentage of study area	1.96%	0.18%
Mean depth (m)	3.50	n/a (extent only)
Max depth (m)	15.78	n/a

Table 2. Validation metrics

The discrepancy observed is methodological because, despite the fact that Bayesian and threshold SAR-based algorithms have recorded up to 85- 95% accuracy when compared with physical reference maps (Roth et al., 2025), SAR only captures the instantaneous wetted surface at overpass, often missing peak or receded extents (Tarpanelli, 2022). Additionally, the efficiency of the GLoFAS-driven model has been observed to improve with basin size (notably, CSI 0.42 for basins> 1000 km2 compared to CSI of 0.29 for basins<50 km2), with significant sensitivity to DEM resolution (Sadana et al., 2026).

3.3 Social Vulnerability and Differential Exposure

The results show that there is an uneven distribution of exposed population across the six councils. The Abaji and Gwagwalada areas recorded the highest exposure, despite a lower population density of less than 500,000, compared with the Abuja Municipal Area Council, with an estimated population of about 2.5 million. The Bwari Area Council showed the least exposure, while Areas such as Karshi and Asokoro in AMAC showed low vulnerability. Parts of AMAC such as Lugbe showed a high level of vulnerability to flood risk, making it one of the top 3 most exposed councils.

Factors such as poor planning in the less urbanized southern councils of Abuja account for the higher flood exposure in these suburban councils, leading to an inverse relationship between population size and vulnerability in the context of this study. Key considerations responsible for unequal distribution of vulnerability and flood risk exposure include;

- Congestion, high population density and poor urban planning: high exposure amplified by dependence on subsistence agriculture on marginal land in peri-urban settlements such as Kwali and Abaji. Consequently, leading to a high population who could lose livelihood in case of floods (Owolabi and Fagbohunka 2026).
- Poverty as a key driver and a consequence: unequal concentration of wealth, resources, opportunities such as government jobs, social care services, as well as resources and capabilities for coping in the AMAC, suggests that even though flood risk and vulnerability are not a function of poverty, the poor residents of peri-urban areas of the FCT are more

exposed, due to lower coping mechanisms and response capacities (Moller-Jensen et al., 2022).

- Institutional gaps: inadequate level of inter-agency cooperation and coordination, poor implementation of city plans in built-up areas of the peri-urban settlements, inadequate drainage, as well as insufficient early warning systems.

The observed pattern in this data aligns with evidence that several factors impact flood risk vulnerability, arising from a multiplicity of multi-dimensional factors such as economic, institutional and social factors, rather than physical environmental hazard alone.

4.0 DISCUSSION AND CONCLUSION

4.1 Model performance and limits

The GloFAS-JRC framework produced results that were observed to be consistent with results from similar Nigerian-based urban flood mapping studies for the 100-year return period; however, the 9% ratio of inundated area obtained through the Sentinel SAR validation (12.86 km2) as compared to the modelled output (143.08 km2) necessitates further scientific investigation and enquiry, rather than dismissal. A possible explanation for this GAP, suggests a methodological constraint, such as suggestions from Dottori et al. (2016), which opine that the GloFAS-driven hydrodynamic model was prone to overestimating flood extent in cases where discharge is biased high. Similarly, the reanalysis skill of the GloFAS model has been found to be weakest in Africa-based studies; whereas it has shown about 86% global efficiency, it has shown a high positive bias across Africa-based studies (Harrigan et al., 2020).

Furthermore, the replacement of simulated discharge data with observed data in a U.S. study was observed to increase CSI from 0.37 to 0.67, while higher-resolution DEMs were also observed to increase CSI outputs from 0.37 to 0.57, suggesting that input quality may lead to significant distortion of results, more than modal structure (Sardana et al., 2026). Likewise, SAR is also constrained by the fact that Sentinel-1 was only able to capture an average of ~58% of flood events, while Sentinel-2 outputs were less accurate, capturing only about ~28% in some weather conditions on average when revisited (Tarpanelli et al., 2022). Apart from weather or cloud cover, other factors such as orbit geometry, vegetation cover, as well as wind play significant roles. Despite the fact that Bayesian and threshold-based methods produce up to 85-90% accuracy when validated using in-situ data, scarcity of physical reference flood maps remains a constraint in sub-Saharan Africa (Roth et al., 2025). Liang & Liu (2019) suggest that the implementation of local threshold data for flood zonation is 4- 13% above global thresholds; however, the use of only two event validations in this study suggests under-sampling of past floods in comparison to the RP100 scenario, rather than invalidating the results.

Source of Divergence	Evidence	Implications for Study
Discharge bias (Niger basin)	(Dottori et al., 2016)	RP 100/10 extents maybe

		Inflated
DEM Resolution	(Sadana et al., 2026)	30 m DEM smoothening of Channels
Limitations of SAR Revisit	(Tarpanelli et al., 2022)	Under-performance in capturing peak extents
Polarization choice	(Roth et al., 2025)	VV misses vegetated floods

Table 3: Summary of model performance and limits

4.2 Social Vulnerability and implication for disaster management governance

The distribution of population exposed to flood risk in this study reveals interesting trend of exposure not being proportionate to population density, AMAC, the post populous area council comes fifth in exposure ranking, despite its high population density. This finding aligns with the perspectives of past studies that suggest that socio-economic vulnerability is the outcome of a plethora of factors, which are multi-dimensional in nature (Moller-Jensen et al., 2022). Some of these factors include the distribution of private and public health facilities and educational institutions, the concentration of government agencies, a higher concentration of private economic hubs e.g. markets, opportunities and resources, and improved drainage and waste management as a result of better and stricter implementation of the city master plan in the urbanized Abuja Municipal Area Council, compared to peri-urban councils such as Abaji. This heavy concentration of public and private institutions suggests a critical level of inequality in the distribution of coping capacity and capabilities for reduction of vulnerability. Thus, in the context of this study, the unequal distribution of the urban poor (People surviving on less than two dollars a day) and subsistence agricultural populace surviving on marginal lands across the different councils reveals that poverty is both a driver and a consequence of flood risk in Abuja.

This perspective is consistent with several Nigerian studies, which hold that inadequate drainage, encroachment on floodplains, poor town planning, and waste dumping are dominant drivers of vulnerability (Owolabi and Fagbohunka, 2026). Thus, residential and farmland encroachment on floodplains in high-hazard zones increases vulnerability and exacerbates flood risk. Invariably, the failure of government institutions compounds exposure, and as such, there is a need for improved planning and coordination between city planning agencies, waste management agencies, as well as National emergency management services in order to develop efficient early community warning systems and interventions.

4.3 Conclusion

The Hybrid GEE workflow showed that the GloFAS dynamic discharge is a veritable tool for the conduct of operational territory-scale flood hazard zonation, proving to be immensely beneficial in cases where gauges and field data are absent, thus filling the observational gaps that may ordinarily prevent early warning in the Global South (Prudhomme et al., 2024). Its return period-based mapping outputs represent an operational envelope scenario, as opposed to an actual forecast. The method is limited by documented constraints such as discharge bias as well as DEM sensitivity (Sadana et al., 2026). Similarly, the Sentinel-1 validation method remains a relevant method; however, its output is constrained by revisit accuracy and polarization (Roth et al., 2025; Tarpanelli et al., 2022).

The following key recommendations are useful for future studies. First, the adoption of higher-resolution DEMs to minimize channel dimension error, integrated with standard observed or derived bathymetry. Second, the integration of participatory vulnerability assessment based on cultural indices and institutional drivers with hazard layers. Thirdly, improvement of inter-agency coordination, institutionalization of early warning frameworks and disaster-conscious city development planning to improve socially informed flood risk governance (Moller-Jensen et al., 2022).

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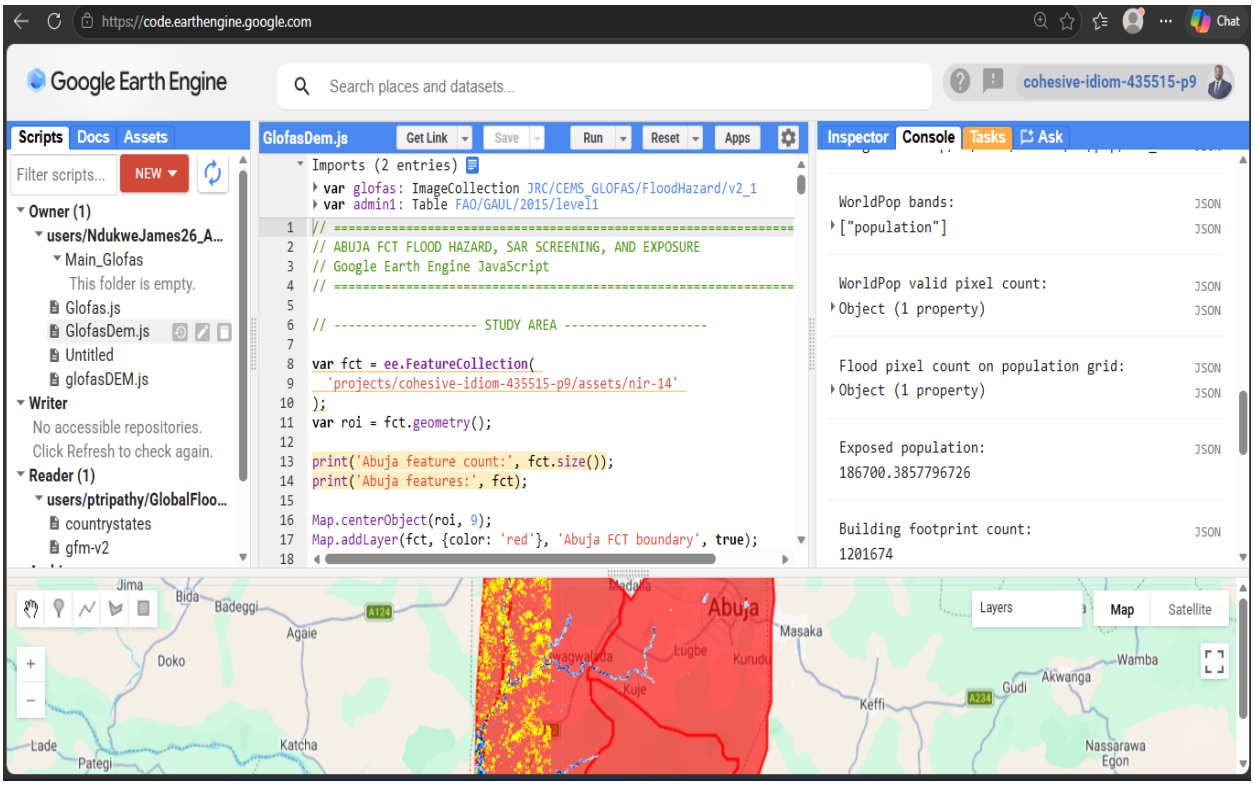
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7.0 APPENDIX



CODE LINK-GlofasDEM.js

https://code.earthengine.google.com/8fed992d24064eea25faeda6027abda7