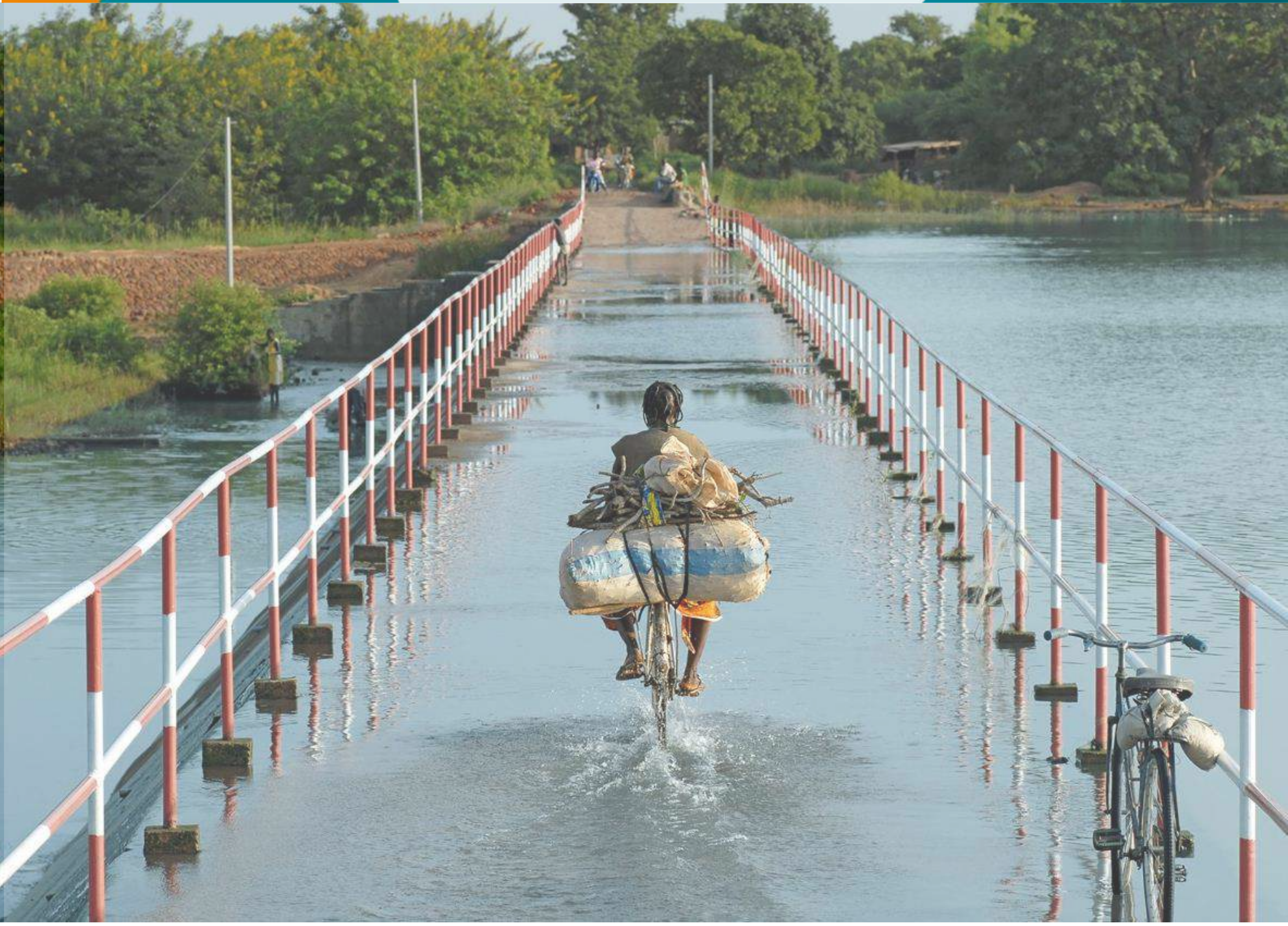
InsuResilience Solutions Fund



Development of a Sovereign Parametric Risk Transfer Scheme for Urban Floods in Lagos State, Nigeria

Prepared by

Insurance Development Forum

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funded by KFW

on behalf of Federal Ministry for Economic Cooperation and Development

managed by Frankfurt School of Finance & Management – German Excellence. Global Relevance.

part of InsuResilience Global Partnership

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Abbreviations and Acronyms

AAR	-	Annual Average Rainfall
AED	-	Annual Expected Damage
AMO	-	Atlantic Multidecadal Oscillation
AMSL	-	Above mean sea level
BMZ	-	Federal Ministry of Economic Cooperation and Development
CDRFI	-	Climate and Disaster Risk Financing and Insurance
CHIRPS	-	Climate Hazards Group InfraRed Precipitation
CEMS	-	Copernicus Emergency Management Service
CMIP6	-	Coupled Model Intercomparison Project Phase 6
DRM	-	Disaster Risk Management
DTM	-	Digital Terrain Model
ECMWF	-	Medium-Range Weather Forecasts
EMA	-	Emergency Management Agencies; federal (N), state (S), local (L) level
ENSO	-	El Niño-Southern Oscillation
FFP	-	Flood Footprint
GCM RCM	-	Global climate and reanalysis models
GFDRR	-	Global Facility for Disaster Reduction and Recovery
GHCNd	-	Global Historical Climatology Network daily
GIZ	-	Deutsche Gesellschaft für Internationale Zusammenarbeit
GLOFAS	-	Global Flood Awareness System
GPM	-	Global Precipitation Measurement
GTSM	-	Global Tide and Surge Model
GWP	-	Gross written premiums
IDF	-	Insurance Development Forum
IDF	-	Intensity-duration-frequency
IPO	-	Interdecadal Pacific Oscillation
IRFF	-	Insurance Risk Finance Facility
ISF	-	InsuResilience Solutions Fund
ITCZ	-	Inter-tropical convergence zone
JRC	-	Joint Research Centre
KPI	-	Key performance indicator
LASAMBUS	-	Lagos State Ambulance Services
LASEMA	-	Lagos State Emergency Management Agency
LASRO	-	Lagos State Resilience Office
LCAP	-	Lagos Climate Adaptation Plan
LCRA	-	Lagos Climate Risk Assessment
LGA	-	Local Government Area

LiDAR - Light detection and ranging
LRS - Lagos Resilience Strategy
LS - Lagos State
LS MoF - Lagos State Ministry of Finance
MCSs - Mesoscale Convective Systems
ME - Mean error
MEIV2 - Multivariate ENSO Index Version 2
MoF - Ministry of Finance
MJO - Madden-Julian Oscillation
NAO - North Atlantic Oscillation
NASDRA - National Space Research and Development Agency
NCEI - National Centers for Environmental Information
NDMF - National Disaster Management Framework
NIA - Nigerian Insurance Association
NIC - National Insurance Commission
NIHSA - Nigerian Hydrological Service Agency
NiMet - Nigerian Meteorological Office
O-ORBDA - Ogun-Osun River Basin Development Authority
PVHH - Poor and vulnerable households
RoL - Rate on-line
RSML - Root squared mean error
SAR - Synthetic Aperture Radar
SDG - Sustainable Development Goals
UNDP IRFF - United Nations Development Program, Insurance and Risk Finance Facility
WAM - West African Monsoon
XSR - Excess rainfall

Executive Summary

Flooding poses a major threat to Lagos State, disproportionately affecting poor and vulnerable populations. To address this challenge, this project was developed with the primary objective of designing a parametric flood insurance product that provides rapid financial relief to those most at risk. The insurance scheme offers a structured, data-driven approach to disaster risk financing, ensuring timely payouts and strengthening Lagos State's capacity to respond effectively to severe urban flood events.

A key focus of the project was the selection of a reliable flood-related index. Two main index options were evaluated: an excess-rainfall-based index and a flood footprint index. Following rigorous testing, the flood footprint index was identified as the most reliable and suitable for the local context. The selected trigger is based on the total area flooded with depths of 50 cm or more. In its first year, the insurance product will cover approximately four million people across seven local government areas (LGAs).

To support the insurance product, a robust parametric pricing model was developed. The pricing methodology is based on a stochastic flood event catalogue from JBA, covering pluvial, fluvial, and coastal flooding risks. During the risk period, flooding in the covered areas is continuously monitored using satellite imagery and other data sources, which are consolidated to generate a detailed flood depth footprint. This footprint identifies areas where flood depths exceed 50 cm, providing an objective assessment of the event's severity. By overlaying this flood footprint with a population exposure layer, the number of people affected by the event can be accurately estimated. A fixed payout of USD 17 per affected person has been established for the preferred structuring option, allowing for the straightforward calculation of the total payout for each monitored event. ICEYE has been selected as the favored data provider due to its ability to deliver high-resolution satellite imagery and near real-time flood monitoring.

Following a structured legal and regulatory process, the insurance product is currently undergoing approval by the National Insurance Commission (NAICOM). Policy documents have been finalized, and the necessary guidelines for a competitive tender process to place the product in the insurance and reinsurance market have been established. The sustainability of the insurance scheme is expected to be supported by a phased premium subsidy approach. Lagos State, with support from UNDP, has approached donor(s) to subsidize up to 90% of the insurance premium in the first year of the policy and is aiming to have the subsidy gradually decrease every year over a three-year period while a disaster fund is set up internally to finance the premium in the long term.

By integrating real-time flood monitoring, advanced insurance modelling, and a clear implementation roadmap, this project lays the foundation for a scalable and sustainable

disaster risk financing mechanism. It enhances Lagos State's financial resilience, ensures timely assistance to affected populations, and strengthens institutional capacity for long-term flood risk management.

A. Introduction

A.1. Flood risk context in Lagos State

Lagos State, one of the most populous and economically significant regions in Africa, faces an escalating risk of flooding. This coastal megacity, located on the shores of the Atlantic Ocean and encompassing a network of lagoons and water bodies, is characterized by a low-lying topography, rapid urbanization, and a tropical wet-and-dry climate. These factors, compounded by the impacts of climate change, significantly heighten Lagos' vulnerability to various types of flooding, including pluvial, fluvial, and coastal flooding. The rainy season, spanning from April to October in a bimodal fashion, presents the most pronounced flood risks, as the city's infrastructure struggles to cope with the increased water levels.

Lagos is exposed to a range of flood hazards driven by natural and anthropogenic factors. Extreme precipitation events during the rainy season frequently overwhelm the city's drainage systems, resulting in flash floods and prolonged waterlogging. Rising sea levels and storm surges, exacerbated by Lagos' coastal location, further threaten the city's resilience, as do the expanding waterways that are prone to overflow during heavy rainfall in upstream river basins. Climate change has intensified these challenges, contributing to more frequent and severe hydroclimatic events, unpredictable weather patterns, and sustained environmental stress on flood defenses. The lack of sufficient flood protection infrastructure and inadequate maintenance of existing drainage systems further compounds the city's exposure to flood hazards.

Lagos has experienced unprecedented population growth in recent decades, driven by rural-to-urban migration and socioeconomic opportunities. The city's population, now exceeding 20 million, has led to rapid urbanization, often occurring in an unplanned and unregulated manner. Informal settlements and overcrowded neighborhoods have proliferated, with many of these communities situated in flood-prone areas due to the scarcity of affordable and suitable land. These developments increase the city's overall exposure to flooding, as critical urban infrastructure, residential zones, and economic hubs face heightened risk during flood events.

The vulnerability of Lagos to flooding is further amplified by underlying socioeconomic and structural factors. A significant portion of the population resides in informal settlements, such as slums and shantytowns, where housing structures are poorly constructed and lack resilience against extreme weather events. These areas often lack basic infrastructure, including adequate drainage, sanitation, and waste management systems, leaving residents particularly exposed to the adverse effects of flooding. High poverty levels limit the ability of many individuals to relocate to safer areas or invest in flood-resilient measures, thereby perpetuating a cycle of vulnerability.

The consequences of flooding in Lagos extend beyond immediate damage to properties and infrastructure. Frequent flood events disrupt critical infrastructure, such as roads, bridges, and public transportation, leading to significant economic losses. The city's commercial and financial sectors, which are central to Nigeria's economy, are also at risk of operational interruptions during severe floods. Moreover, public health risks arise from stagnant floodwaters, which can serve as breeding grounds for waterborne diseases such as cholera and typhoid. Informal settlements, in particular, bear the brunt of these health crises, given their limited access to clean water and adequate sanitation facilities.

Addressing Lagos' flood risk requires a multifaceted approach that integrates physical, institutional, and socioeconomic measures:

- **Flood Mapping**: Comprehensive flood risk assessment and mapping are essential to identify vulnerable areas and develop effective flood preparedness and response plans.
- **Coastal Defense**: Coastal flooding risks can be mitigated through the construction and maintenance of coastal defense structures and the preservation of natural buffers, such as mangroves.
- **Early Warning Systems**: Effective flood early warning systems can help communities prepare for and respond to flood events, reducing the impact on lives and property.
- **Infrastructure Resilience**: Ensuring critical infrastructure, including dams and drainage systems, is resilient to extreme weather events and regularly maintained is vital for preventing catastrophic failures such as dam breaches and overtopping.
- **Climate Change Adaptation**: Long-term strategies that account for climate change impacts, such as rising sea levels and altered rainfall patterns, are essential for managing future flood risks. These include physical adaptation and mitigation measures with high cost-benefit ratios for frequent flood events.
- **Risk Transfer Schemes**: In addition to physical measures, risk transfer mechanisms like insurance are crucial for enabling Lagos State to recover from medium to high-impact flood events. These strategies should be implemented through collaborative public-private partnerships to ensure an effective and holistic risk management framework.

By integrating sustainable urban planning, robust flood defenses, and comprehensive adaptation strategies, Lagos can build resilience to flooding and safeguard its residents, infrastructure, and economy from the escalating challenges posed by climate change and urbanization (Figure 1).

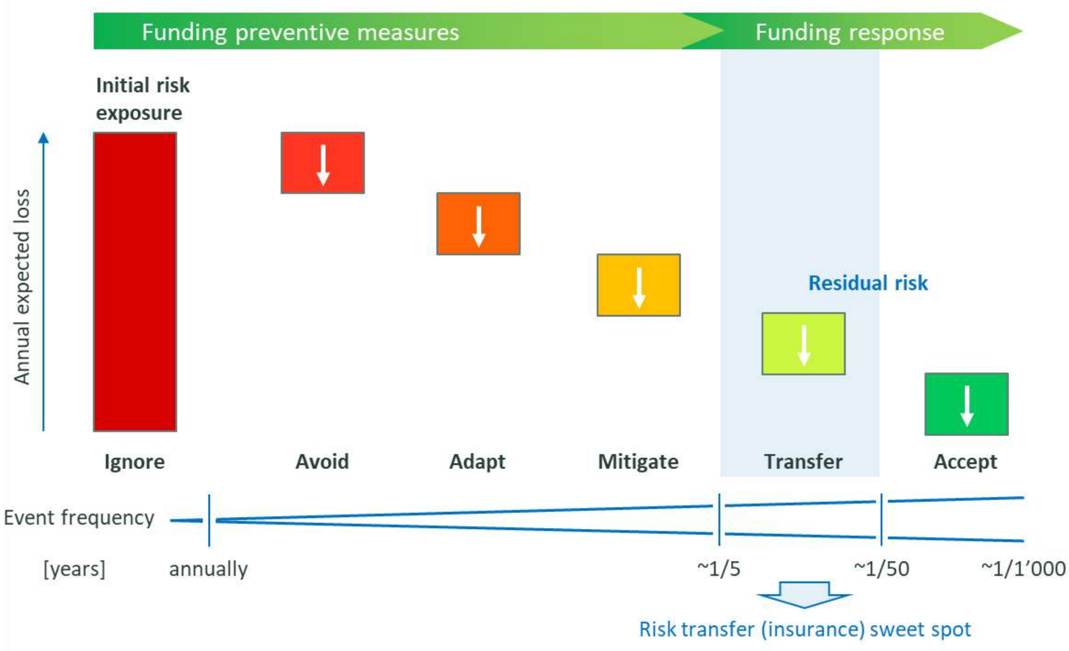


Figure 1: To reduce initial risk exposure, several concepts must be applied. After implementing physical measures that reduce more frequent events, risk transfer, i.e. insurance, is most efficient to support the financing response to residual risk. Figure generated by SwissRe.

A.2. Flood risk adaptation initiatives

Over the past two decades, both Nigeria's federal government and Lagos State have undertaken various initiatives to address the city's flood risks. The following timeline highlights key efforts [1]:

- **1999**: The Federal Government, alongside the National Emergency Relief Agency (now NEMA), established Emergency Management Agencies at federal (NEMA), state (SEMA), and local (LEMA) levels to improve disaster management. This culminated in the creation of the National Disaster Management Framework (NDMF) in 2010.
- **2006–2013**: Lagos State launched several structural projects to combat flooding. These included constructing 69 kilometers of secondary stormwater drains for coastal flood management; initiating the *Great Wall of Lagos* with Dutch engineers in 2009 (a project still ongoing); conducting shoreline protection works; draining 100'000 hectares of land; dredging and maintaining 32 rivers; implementing five channelization projects; citywide de-flooding; de-silting and maintaining existing drainage systems; and demolishing structures in flood-prone zones.
- **2007–2011**: To enhance flood mitigation capacity, the Lagos Ministry of the Environment increased its engineering staff in the Office of Drainage Services from 5 to 57, assigning engineers to monitor drainage systems in all local government areas. In 2009, the state introduced advanced topographic mapping using LiDAR and GIS for improved flood risk analysis. This complemented the efforts of national agencies such as National Space Research and Development Agency (NASDRA, founded in 2001 for

satellite data), NIMET (established in 2003 for meteorological analysis), and NIHSA (created in 2010 for hydrological services).

- **2010s**: Physical development in wetlands and areas prone to flooding was halted to reduce risk exposure.
- **2019**: The Lagos State Resilience Office (LASRO) was established in partnership with the Rockefeller Foundation's 100 Resilient Cities initiative. LASRO is a multidisciplinary unit responsible for developing a Lagos Resilience Strategy (LRS) to strengthen Lagos' capacity to withstand chronic and acute shocks, including flooding. It supports flood risk management through funding, research, and policy development.
- **2021**: Building on the LRS, the Lagos State Government commissioned the *Lagos Climate Risk Assessment (LCRA)* in 2021 to reinforce the resilience strategy and lay the groundwork for the *Lagos Climate Adaptation Plan (LCAP)*, released later that year. The LCRA offers a detailed analysis of climate risks to populations, assets, and infrastructure. It also assesses the vulnerability of various economic sectors to these risks, provides a record of historical flood events in Lagos, and outlines priority actions for adaptation. The plan emphasizes flood risk mitigation, social inclusion, effective governance, and ecosystem resilience as its foundational pillars.
- **2021**: The *Lagos Climate Adaptation Plan (LCAP)*, developed under the C40 Cities initiative in 2021, set ambitious objectives, including achieving a carbon-neutral Lagos by 2050 and enhancing the city's climate resilience.
- **2022**: Lagos State Government collaborated with Boston Consulting Group to refine the adaptation and resilience plan by identifying concrete initiatives, estimating investment needs, and identifying potential external funding partners. Key strategies identified include policy development, education and awareness campaigns, emergency response initiatives, social protection programs, early warning system improvements, and investment in public infrastructure for water and flood management. These measures aim to strengthen Lagos' overall climate resilience, with a particular focus on mitigating flood risks.

According to a study conducted by FSD Africa on flood risk management and resilience in Lagos [1], despite significant public sector efforts in infrastructure and capacity building, the city remains inadequately prepared to manage urban flood risks. Challenges such as limited coordination, lack of technical expertise, and insufficient data hinder both public and private sectors. Furthermore, the business and financial sectors have been largely excluded from flood risk management strategies, and risk finance has not played a substantial role. This highlights the need to better integrate the financial sector, particularly insurance providers, into existing frameworks like the National Disaster Management Framework (NDMF).

Currently, the insurance market in Nigeria offers limited flood risk coverage, mostly in the form of general property insurance. The lack of specific flood products stems from data challenges, insufficient technical expertise, and low demand for standalone flood insurance. Other obstacles include a general mistrust of the insurance sector, concerns about risk concentration, and the fact that flood risk is only recently being acknowledged as a major concern. Despite some demand from financial institutions for tailored flood protection, high premium costs remain a barrier. Greater awareness is needed across all stakeholders to address these issues.

Parametric flood insurance offers several key advantages that make it an effective tool for integrating into the disaster risk management framework of Lagos State (see also Section F). First, it provides rapid payouts based on predefined parameters, such as rainfall levels or flood depth thresholds, which can be triggered immediately after a flooding event, helping stakeholders respond swiftly to emergencies. This quick release of funds is especially valuable in a city like Lagos, where delays in recovery can exacerbate economic losses and human suffering.

Second, parametric insurance mitigates data and pricing challenges. By using objective, publicly available data to define risk parameters, it reduces the reliance on localized data collection, which can be scarce or unreliable. This makes it an accessible and transparent tool for insurers and stakeholders, especially in a market where traditional flood risk assessments can be costly and complex. Furthermore, parametric insurance can help improve flood resilience by encouraging proactive investment in flood risk management. Since the payouts are triggered automatically when the parameters are met, it incentivizes local governments, businesses, and individuals to invest in better flood mitigation and infrastructure to reduce the likelihood of triggering insurance claims.

Finally, integrating parametric flood insurance into the risk management strategy of Lagos State could help to build trust in the insurance sector. As the financial sector's involvement in disaster risk management grows, parametric products could serve as a bridge to more comprehensive insurance offerings, fostering a culture of risk preparedness and long-term resilience.

A.3. Integration of CDRFI instruments into the existing DRM framework

While ongoing and planned mitigation efforts will significantly reduce flood hazards and their impact, eliminating flood risk remains financially unfeasible and virtually unattainable. In this context, flood insurance serves as an essential tool for managing residual risk – those risks that persist despite all feasible mitigation and adaptation measures (as illustrated in Figure 2).

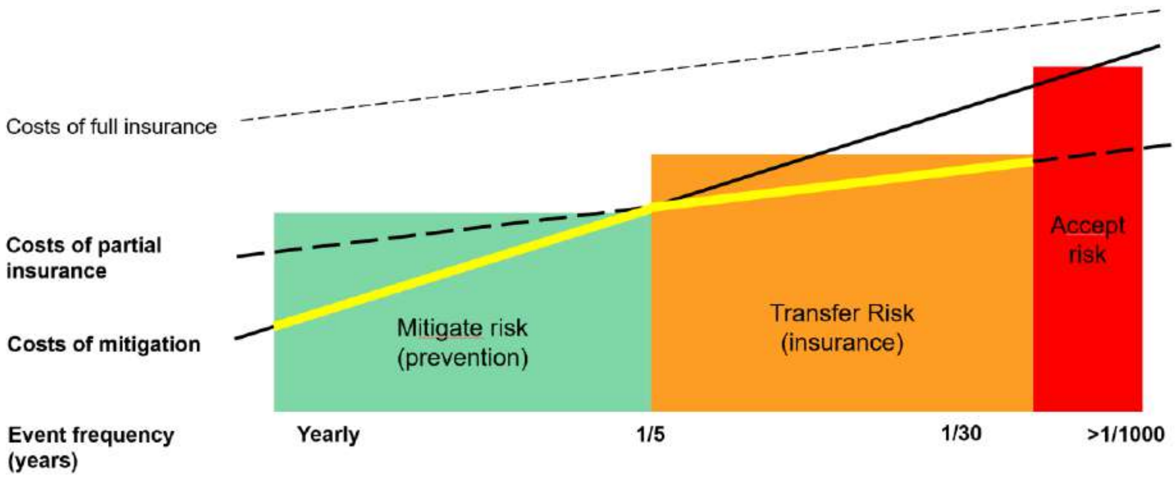


Figure 2: Holistic risk management, interplay between risk mitigation of higher frequency events and risk transfer for more remote catastrophes. Yellow line highlights pathway of costs for mitigation with ideal return of investment. Figure generated by SwissRe.

As depicted in the Figure 2, physical mitigation measures yield the highest return on investment for frequent events, while (partial) insurance is a more cost-effective tool for addressing the risks associated with less frequent, higher-impact events. Insurance is not effective on risks that occur too frequently, and residual risk must be accepted.

Building on past projects and utilizing advanced technologies, this initiative aims to create an innovative index-based flood insurance scheme for Lagos State, specifically designed to support emergency relief and post-flood recovery efforts, with an emphasis on aiding vulnerable populations. The insurance scheme was developed in close collaboration with the Lagos State Government, factoring in the necessary scale, event frequency, response costs, recovery needs, and budget limitations.

By offering quick and transparent payouts triggered by flood observations, the proposed product will serve as a financial safety net for the Lagos State Ministry of Finance (MoF), the Lagos State Emergency Management Agency (LASEMA), and other relevant government agencies, enhancing their capacity to manage flood-related disasters. This will not only support vulnerable populations but also expedite the recovery of economic activity. This project acts as a model for designing and implementing parametric urban flood insurance, with the potential for replication in other urban areas across Nigeria, West Africa, and beyond.

A.4. Project objectives

The project focuses on enhancing LASEMA's and Lagos State Government stakeholders' capacity to respond effectively to severe urban flood events by emphasizing data acquisition, insurance development, and capacity building. The project's objectives were achieved through the following activities:

1. **Data and Monitoring**:
    - Identify and source essential data.
    - Develop a historical flood event record.
    - Define a flood exposure dataset.
    - Gain comprehensive understanding of rainfall trends and climate scenario forecasts.
    - Evaluate rainfall indices to design excess rainfall parametric insurance products.
    - Integrate Lagos State into ICEYE's real-time flood monitoring system.
    - Test the feasibility of ICEYE's flood footprint data.
    - Quantify flood risk and event losses using stochastic flood event catalogs, exposure and vulnerability data.
2. **Insurance Development**:
    - Assess and select index triggers (e.g., rainfall, flood extent).
    - Underwrite and price parametric flood products.
    - Align payout processes with emergency contingency plans.
    - Engage stakeholders in participatory product development.
    - Present final product designs through workshops, incorporating stakeholder feedback and capacity building.
    - Draft policy templates and obtain approvals from the National Insurance Committee.
    - Prepare specifications for reinsurance broker public tender.
    - Determination of the ideal (re-)insurance set-up as desired by the government.
    - Supporting the go-live, including follow up discussions on premium financing support and more.
3. **Contingency Plan and Capacity Building:**
    - Facilitate participatory product development.
    - Develop a contingency plan and coordinate with local/state stakeholders to enable rapid and accurate payments for low-income urban communities.
    - Design a proactive disaster risk financing strategy that focuses on the poor and vulnerable population and restarts the economic activity of this population.
    - Support capacity building for LASEMA technical staff with a focus on flood hazard mapping, parametric insurance pricing and risk mitigation measures.
    - Support the coordination of the emergency plan with the disbursement process, including clear roles and responsibilities between LASEMA and local municipalities, the distribution of disbursement according to these roles and a control function to ensure that the proposed solution benefits the poor and vulnerable.

To achieve the key outcome of developing a tailored parametric flood cover and identifying the most appropriate solution, the project team set out to explore three trigger options:

- **Satellite-measured rainfall**: Uses gridded rainfall data (e.g., CHIRPS, ERA5).
- **Station-based rainfall**: Relies on data from existing (e.g., NiMet, NCEI) or new rainfall stations.
- **Flood footprint analysis**: Tracks maximum flooding extents via satellite imagery and other local sources (e.g., ICEYE).

The chosen trigger must meet risk profile requirements, align with budget constraints, and minimize basis risk, with government acceptance as a core success metric. Overall, the project aims to enhance financial resilience by integrating disaster risk financing strategies and building government capacity to manage flood risks effectively.

A.5. Deliverables

As part of the development of a sovereign parametric risk transfer scheme for urban floods in Lagos State, Nigeria, several key deliverables are being provided. These documents collectively support the design, implementation, and approval of the risk transfer mechanism. The deliverables include:

- **Technical Report**: This report presents the methodology, data, and analyses underpinning the parametric risk transfer scheme. It details the flood hazard assessment, exposure evaluation, risk modeling, and financial structuring of the insurance product.
- **Final Exposure Layer**: A geospatial dataset representing the population at risk from urban flooding in Lagos State.
- **Request for Proposal (RfP) – Reinsurance Broker & Advisory Services**: A document outlining the scope of work and requirements for selecting a reinsurance broker and advisory firm. This ensures the procurement of specialized expertise to facilitate market engagement, optimize coverage terms, and structure the reinsurance placement.
- **Insurance Package for Product Approval Process**: A comprehensive set of 11 documents prepared for regulatory approval and market engagement. This package includes key contractual and technical materials required to operationalize the sovereign parametric insurance scheme. The documentation covers aspects such as policy wording, trigger definitions, payout structures, governance framework, and financial mechanisms.

These deliverables provide a robust foundation for the successful implementation of the parametric risk transfer scheme, ensuring transparency, technical rigor, and alignment with regulatory and market requirements.

A.6. Stakeholder analysis

The project involves a diverse range of stakeholders, including public and private sector entities, international development organizations, and technical partners, each contributing to the design, implementation, and governance of the flood parametric insurance product for Lagos State (Figure 3).

The project was co-financed under the framework of the Tripartite Agreement between Insurance Development Forum (IDF) members – AXA Climate, Swiss Re and JBA – along with the United Nations Development Programme's Insurance and Risk Finance Facility (UNDP IRFF) and the German Federal Ministry for Economic Cooperation and Development (BMZ) through the InsuResilience Solutions Fund (ISF). These institutions provided the financial and strategic backing necessary for product development, aligning with the broader InsuResilience Vision 2025, which aims to extend climate and disaster risk protection to 500 million people worldwide.

The insurance product's technical design and structuring were led by AXA Climate and Swiss Re, leveraging their expertise in risk transfer and stakeholder engagement. Technical and service providers, such as JBA and ICEYE, contributed essential flood risk datasets and satellite-based flood monitoring to ensure accurate risk assessment and trigger mechanisms for parametric payouts. African Risk Capacity (ARC) played a pivotal role in designing the contingency plan to ensure swift and effective fund disbursement in the event of a disaster.

Key public-sector stakeholders in Lagos State provided regulatory oversight, data support, and policy implementation. The Lagos State Ministry of Finance (LS MoF) serves as the policyholder and financial oversight authority, ensuring the alignment of the insurance product with state financial strategies. The Lagos State Disaster Management Authority (LASEMA) is responsible for coordinating disaster response and validating the insurance product's technical parameters. The National Insurance Commission (NAICOM) ensures regulatory compliance, while the Nigerian Meteorological Agency (NiMet), Nigerian Hydrological Service Agency (NIHSA) and the Ogun-Osun River Basin Development Authority (O-ORBDA) provide hydrometeorological data to test potential insurance trigger mechanisms. Additionally, the Lagos State Operation Coordinating Unit (LASOCU) provides geolocated datasets on vulnerable populations, facilitating targeted disaster response.

At an international level, the UNDP Integrated Risk Financing and Insurance (IRFF) plays a key role in implementing projects by leveraging its expertise in disaster risk management and financial resilience. In this particular project, UNDP helps integrate risk transfer mechanisms into the broader financial strategy of Lagos State, ensuring alignment with national development goals and fostering stakeholder coordination. In Lagos State, the SDG Office ensures the initiative aligns with sustainability objectives, while UNDP strengthens this by embedding disaster risk financing within the state's development plans, contributing to long-term resilience-building.

By integrating expertise from insurance providers, regulatory agencies, technical specialists, and international development organizations, the project establishes a comprehensive approach to disaster risk financing. This multi-stakeholder collaboration not only enhances Lagos State's financial resilience but also contributes to a broader transformation of Nigeria's insurance market by embedding parametric risk transfer solutions into its disaster risk management framework.

Figure 3: Map of the stakeholder relationships in the project. Figure generated by AXA Climate.

Table 1: Summary of the project stakeholders' roles and responsibilities.

Institution	Role & Responsibility
Co-Financing & Partner Institution	
Insurance Global Partnership (IGP) & InsuResilience Solutions Fund[1] (ISF)	The IGP is a multi-stakeholder initiative focused on strengthening resilience in developing countries and protecting vulnerable populations from disaster impacts. The InsuResilience Vision 2025 aims to provide climate and disaster risk coverage to 500 million people by 2025. To support this goal, the German Government established the ISF to finance the development of insurance solutions, including this project.
Insurance Development Forum (IDF)[2]	Public-private partnership uniting the insurance industry, international organizations, and governments to enhance insurance and risk management for disaster resilience. It fosters collaboration among (re)insurers, policymakers, and development agencies to create innovative climate and disaster risk solutions. In this project, IDF is represented by AXA Climate, Swiss Re, and JBA.
Industry Partners	
AXA Climate	Project Co-Lead and Product Structurer– AXA Climate is a subsidiary of the AXA Group, focusing on providing climate risk management solutions and specialized in parametric insurance products. AXA Climate is responsible for driving stakeholder engagement, support with technical product design, and policy wording development.
Swiss Re	Project Co-Lead and Product Structurer - Swiss Re is a global reinsurance company that provides risk transfer, risk management, and insurance solutions to insurers, corporations, and governments. Alongside AXA Climate, Swiss Re is responsible for stakeholder engagement, supporting technical product design, and policy wording.
AXA Mansard	Local Project Manager – Facilitates dialogue with the insurance regulator and government stakeholders, and potentially will serve as the primary fronting insurer.
Technical Providers	
JBA	Flood Risk Data Provider – JBA provides flood datasets to assess Lagos State's risk, supporting the structuring and pricing of the parametric insurance product.
ICEYE	Satellite Data Provider – ICEYE provides 24/7 monitoring of Lagos State to capture flood events and assess flooding extent. This data determines payouts to policyholders based on the parametric insurance product. ICEYE will continue this role once the product is operational.
African Risk Capacity (ARC)	Contingency Plan Designer - ARC designs the contingency plan, outlining the process for disbursing funds from the insurer to the insured (Ministry of Finance). The plan ensures quick payouts for emergency response activities, improving the government's disaster management capabilities.
Key Public Partners	

Lagos State Ministry of Finance (LS MoF)	Policyholder and Financial Oversight Authority - The LS MoF is one of the Central Management Agencies of the Civil Service of Lagos State. The goal of the Ministry is to ensure efficient and effective management of the economy towards the attainment of upper middle-income status and poverty reduction.
Lagos State Emergency Management Authority (LASEMA)	Disaster Risk Coordination and Validation Authority - LASEMA manages disasters and similar emergencies in LS. It coordinates all relevant civil authorities at different administrative levels. LASEMA plays a key role in validating the technical terms of the flood parametric insurance product and the associated contingency plan.
Nigerian Meteorological Agency (NiMet)	Precipitation Data Provider - NiMet provides meteorological information in Nigeria by collecting, processing, archiving, and disseminating meteorological data to end-users. They have supplied precipitation data for Lagos and the Ogun Basin, which has been evaluated for its potential use as a parametric insurance trigger.
Nigerian Hydrological Service Agency (NIHSA)	River Data Provider - NIHSA is responsible for monitoring, assessing, and forecasting hydrological conditions, including river discharge and flood risks in Nigeria. Their role in the parametric insurance setup includes providing hydrological data, including river water levels and flow rates, to support flood risk assessment.
Ogun-Osun River Basin Development Authority (O-ORBDA)	River Data Provider - O-ORBDA manages the water resources within the Ogun-Osun River Basin, including dam operations and flood control measures. Their role in the parametric insurance setup includes providing data on river levels and discharges, reservoir levels, dam releases, and water management strategies.
National Insurance Commission (NAICOM)	Regulatory Authority and Insurance Oversight - NAICOM was established in 1997 by the National Insurance Commission Act 1997 with responsibility for ensuring the effective administration, supervision, regulation and control of insurance business in Nigeria and protection of insurance.[3]
Lagos State Operation Coordinating Unit (LASOCU)	Vulnerable Population Data Provider – LASOCU, under the Ministry of Economic Planning and Budget (MEPB), supplies geolocated datasets on poor and vulnerable populations to support targeted disaster response and insurance solutions.
Sustainable Development Goals (SDG) office	Sustainable Development Partner – Ensures project alignment with Lagos State's SDG priorities, fostering resilience and social impact through strategic investments.
International Development Organisation	
United Nations Development Program's Insurance and Risk Finance Facility (UNDP's IRFF)	Project Implementation Support - UNDP operates in 170 countries, reducing poverty and building resilience for the Sustainable Development Goals. The UNDP IRFF, active in 34 countries, aims to deliver protection solutions in 50 by 2025. In this project, it facilitates execution, aligns with national goals, and coordinates stakeholders.

[1] https://insuresilience-solutions-fund.org/about/about-isf
[2] https://www.insdevforum.org/mission-vision-history/
[3] https://www.naicom.gov.ng/

B. Methodology

Parametric insurance is based on a parameter or a constructed index that represents the financial need of the insured, which, however, depends solely on the occurrence of a natural phenomenon and can be measured objectively. If predetermined threshold values are reached (e.g. the flood area exceeds predetermined values), a predefined insured sum is paid out within a short period of time. Parametric products have been successfully developed and implemented for similar use cases.

Developing a parametric insurance product involves several key steps, as summarized in Figure 4. First, a main risk hazard, such as flooding, is identified and its parameters characterized. A technical analysis is then carried out of the risk to the areas, population and/or assets to be insured, as well as historical events and consequential damage. Based on these analyses, an index is defined (e.g. based on daily rainfall or direct flood observations) that should have a high correlation with economic losses. In other words, the so-called *basis risk* (i.e. risk that actual losses do not correlate with the index, see Section F.3.1) is minimized to an acceptable level. Finally, the sum insured and the payout structure are determined based on the needs and affordability of the insured. It is important to recognize that this product development process is not linear. The steps are interconnected and require frequent iterative reviews to refine calculations and product design (Figure 4).

In the finalization phase, legally binding policies must be drawn up that set out all the essential components of the insurance contract, the steps for calculating payouts and special conditions. The primary wording must be passed from the fronting insurer to the government, while the local and international re/insurance industry stands behind the fronting party to provide sufficient capacity through a reinsurance contract. Once this mediation process is completed (possibly through a public tender), the project will be put into operation. Monitoring of the parameter is initiated and carried out 24/7 and the calculation agent is ready to detect flooding events. Once an eligible flooding event is confirmed, funds will be disbursed expeditiously and used by the government as outlined in the emergency/contingency plan. All parties work on the extension of the program to ensure the sustainability, before expiration of the typically annual insurance period. Some of the steps described below will be repeated and improvements implemented if necessary.

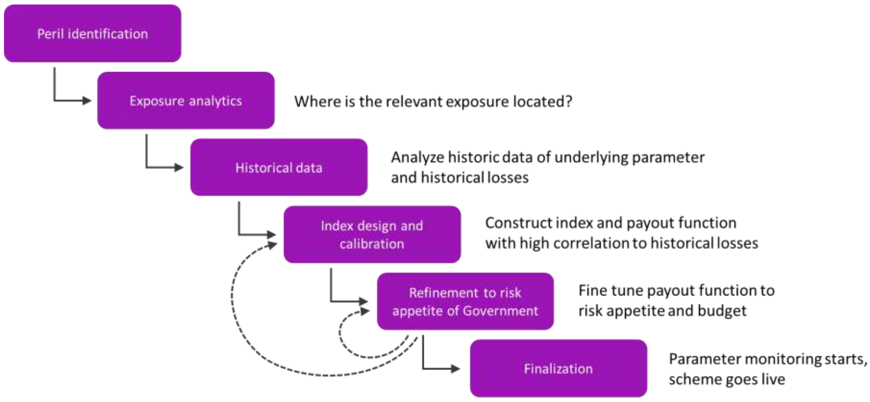


Figure 4: Parametric insurance product development, steps to implementation, simplified. Figure generated by SwissRe.

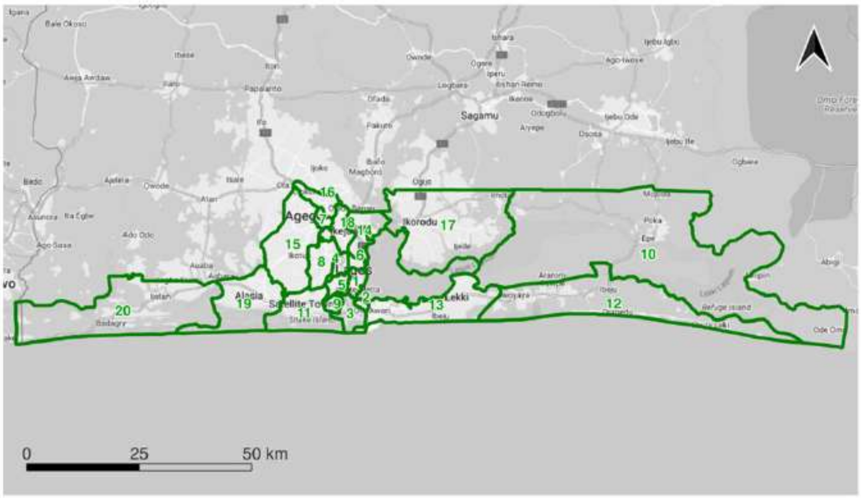
C. Geographical context

C.1. Project geographic scope: Lagos State

The geographical scope of the project is Lagos State (LS) (Figure 5). LS is dominated by the greater Lagos metropolitan area, but it is to be noted that the Lagos metropolitan area stretches even beyond the administrative boundaries of LS, and therefore beyond the scope of the project. The targeted beneficiaries are the poor and vulnerable population, fully in line with the mission of the InsuResilience program as the sponsor. This section of the report details the geographical scope of the project. Further contextual information on Lagos State's demographics, socioeconomics, topography, climatology and hydrology can be found in the following sections. Further details on hazards, exposure data sets and data analytics can be found Section D and E.

C.2. Administrative boundaries

Lagos State lies along the coastal plain of southwestern Nigeria on the Gulf of Guinea. Lagos State covers an area of ~3'580 km^2 and is made up of 20 Local Government Areas (LGAs, Figure 5). LGAs are further subdivided into Wards (Figure 6). The administrative boundaries have been extracted from GRID3 [2].



ID	lganame
1	Lagos Mainland
2	Lagos Island
3	Apapa
4	Mushin
5	Surulere
6	Shomolu
7	Agege
8	Oshodi/Isolo
9	Ajeromi/Ifelodun
10	Epe
11	Amuwo Odofin
12	Ibeju Lekki
13	Eti Osa
14	Kosofe
15	Alimosho
16	Ifako/Ijaye
17	Ikorodu
18	Ikeja
19	Ojo
20	Badagry

Figure 5: Lagos State subdivided into its 20 local government areas (LGA), also listed on the right-hand side [2]. Lagos State is located between latitudes 6°37'N and 6°70'N; and longitudes 2°71'E and 4°37'E. Figure generated by AXA Climate.

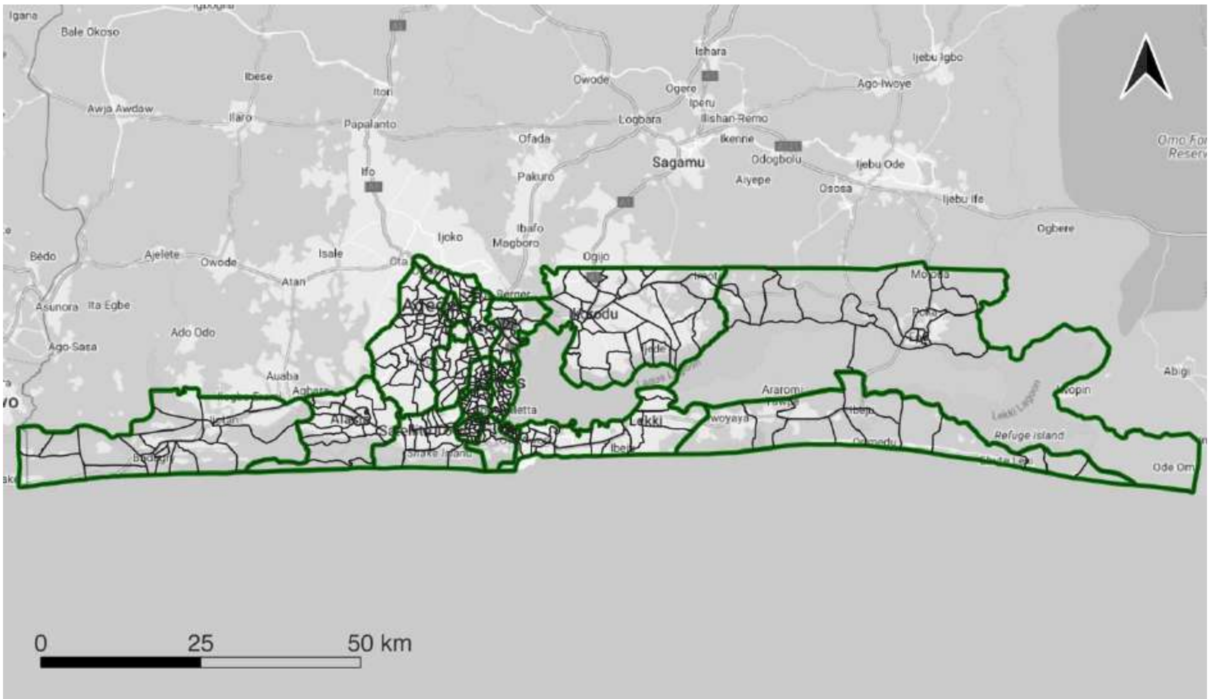


Figure 6: Division of Lagos State into Wards [2]. Figure generated by AXA Climate.

C.3. Demographics and socioeconomics

Lagos State, with the greater Lagos metropolitan area, is the economic heart of Nigeria and presents a dynamic and complex demographic and socio-economic profile.

C.3.1 Population distribution

Greater Lagos is the undisputed center of Lagos State. It is not only the largest city in Nigeria, but also one of the largest metropolitan areas in Africa and the world, currently estimated to be home to more than 16 million people [3]. It is also one of the fastest growing metropolitan areas, growing at about 3.7% every year. The densely populated urban area now extends far beyond the administrative boundaries of Lagos State into Ogun State, with about 9.7 million residents living withing the Lagos State's boundary.

Figure 7 shows the population density by LGA, Figure 8 the population size of Lagos State on a 100x100 meter grid and Table 2 lists all 20 LGAs and their population [4]. The aggregated population per LGA (as estimated by WorldPop) and the share of population of each LGA over the total is shown in Table 2. The average population density is 6'800 per km^2, with a large proportion living in informal settlements. The population of Greater Lagos is young, with large average family sizes of about 4 people per household.

Figure 7: Population of LS aggregated per LGA [4]. Figure generated by SwissRe.

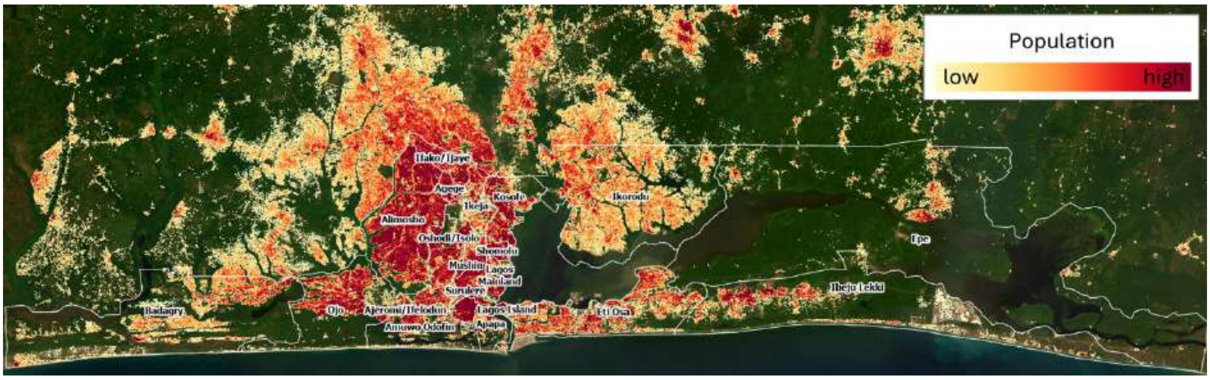


Figure 8: Population on 100x100 meter grid of the Lagos State and beyond [4], demonstrating the urban sprawl of the greater Lagos metropolitan area beyond its administrative boundaries. Figure generated by SwissRe.

Table 2: Lagos State's 20 LGAs, their population and share of total [4].

LGA	Population	Share of total
Agege	186'904	1.9%
Ajeromi/Ifelodun	215'738	2.2%
Alimosho	1'999'908	20.6%
Amuwo Odofin	409'457	4.2%
Apapa	130'247	1.3%
Badagry	580'558	6.0%
Epe	240'110	2.5%
Eti Osa	825'092	8.5%
Ibeju Lekki	456'509	4.7%
Ifako/Ijaye	404'027	4.2%
Ikeja	271'903	2.8%
Ikorodu	1'248'280	12.9%
Kosofe	513'890	5.3%
Lagos Island	73'585	0.8%
Lagos Mainland	245'092	2.5%
Mushin	181'779	1.9%
Ojo	729'257	7.5%
Oshodi/Isolo	576'389	5.9%
Shomolu	169'397	1.7%
Surulere	230'962	2.4%
Total	**9'689'083**	**100%**

C.3.2 Economy, income levels and disparities

Lagos State is the powerhouse of the country, generating about a quarter of the national economic output [5]. A large proportion of the workforce in Lagos State is engaged in the informal economy, highlighting the economic vulnerability of the poor and vulnerable. The rapid growth and urbanization of Lagos State has brought with it significant socio-economic challenges. Income inequality is a significant problem as a significant proportion of the population lives in informal settlements characterized by inadequate housing and limited access to basic services such as clean water and sanitation.

Low-income residential areas and informal settlements account for a significant proportion of the total population of Lagos State due to their high population density and abundance. They are often located along floodplains, exacerbating the impacts of flooding and increasing the vulnerability of these communities. In line with the IDF and ISF's missions, this project places great focus on the vulnerable population in Lagos State.

C.4. Topography and land cover

Lagos State's topography is characterized by a diverse and complex landscape shaped by its geographical location along the Gulf of Guinea in southwestern Nigeria. This topographical variation significantly influences the region's urban development, hydrology, and environmental dynamics. Lagos State's maximum elevation based on a recent LiDAR image [6] is ~70 meters Above Mean Sea Level (AMSL) in the Ifako/Ijaye LGA, its average elevation is around ~9 meters AMSL (Figure 9), while larger parts of LS land lie near sea level.

The southern and western portions of Lagos State are dominated by low-lying coastal plains that extend along the Atlantic Ocean. These coastal plains are relatively flat and consist of near sea level lagoons, estuaries, and sandy beaches. Lagos Lagoon and Lekki Lagoon are prominent features, and these areas are crucial for fishing and transportation. Moving inland from the coastal plains, Lagos State's topography transitions into elevated uplands. These uplands consist of undulating terrain with gentle slopes. They are mainly concentrated in the northern and eastern parts of the state. The elevation in these areas gradually rises, contributing to a more varied landscape.

Lagos State is home to extensive wetland areas, particularly in the coastal regions. Mangroves and swamps thrive in these low-lying wetlands, playing a vital role in coastal protection, wildlife habitat, and water quality maintenance. These environments are ecologically significant and support a diverse range of flora and fauna (Figure 10). Besides, these features are crucial for water storage and play a significant role in flood control during the wet season. However, the proximity to the coast also makes the region susceptible to coastal erosion and rising sea levels.

Lagos Island, located at the core of the City of Lagos, is characterized by relatively low-lying terrain, but it has been extensively modified due to urbanization and land reclamation. Ikoyi (part of the Eti Osa LGA), an affluent neighborhood, is situated on a sandbar that extends into the Lagos Lagoon. This area's topography has been altered to accommodate urban development.

The topography of Lagos State has a profound impact on urban planning and infrastructure development. The low-lying coastal plains require effective drainage systems and flood management strategies to address the challenges posed by heavy rainfall during the wet season. Urban development in elevated uplands needs to consider slope gradients and land stability.

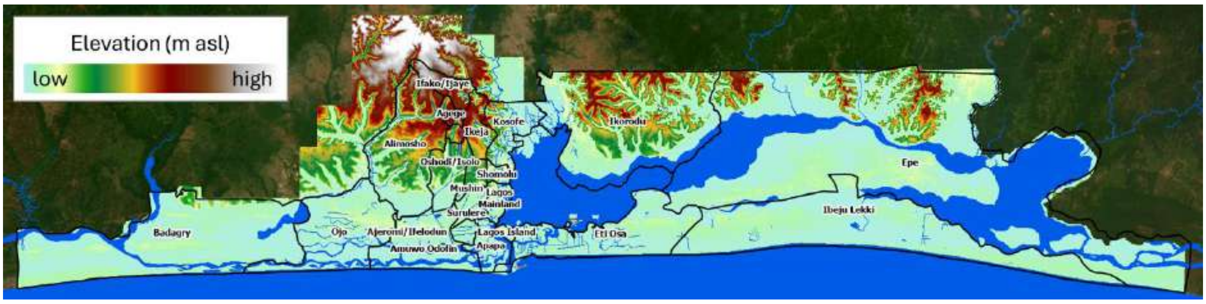


Figure 9: High resolution digital terrain model for Lagos State (LIDAR). Highest elevation above mean sea level at around 70 meters in the Ifako/Ijaye LGA [6]. *Figure generated by SwissRe.*

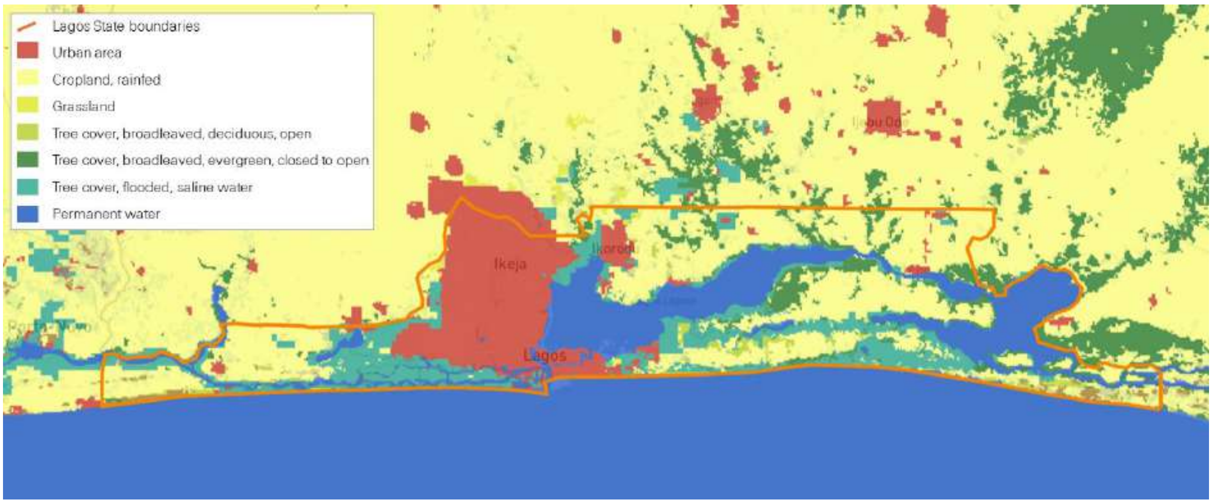


Figure 10: Land cover of Lagos State (orange outline) and its surroundings [7].

C.5. Climatology

Lagos State is situated in the southwestern region of Nigeria. It lies in the coastal equatorial climatic zone, characterized by a tropical equatorial savannah with drier winters climate as per the Köppen–Geiger climate classification 'Aw' [8], but is close to a tropical monsoon-style climate zone ('Am'). The annual average temperature is approximately 28.7°C, with mean monthly temperatures ranging from an average monthly minimum of ~24°C in August to monthly maxima of ~30°C in March [9] (Figure 11).

C.5.1 Precipitation and weather patterns

Lagos State's climate type and weather patterns are characterized by a distinct division into wet and dry seasons throughout the year, prominently influenced by the state's proximity to the Atlantic Ocean and the Equator. LS typically receives an annual average precipitation of approximately 1'700 millimeters (last 10-year average), rendering it one of the wetter regions in Nigeria [10]. Lagos State experiences a bimodal precipitation pattern characterized by two distinct rainy seasons within the calendar year. This unique climate feature significantly influences the region's agriculture, water resources, and overall way of life (Figure 11).

The first rainy season typically occurs from April to July. During this period, Lagos State receives the initial influx of rainfall after the dry season. The onset of the first rainy season brings relief from the dry and dusty conditions associated with the harmattan winds, which prevail during the preceding dry season months. Rainfall is frequent and gradually intensifies, peaking in June. This season is vital for the cultivation of crops and is considered the primary planting period for many agricultural activities. This first rainy season is often referred to as the *long rains*.

Following a brief smaller dry spell, Lagos experiences a second rainy season, which usually takes place from September to October. This season is shorter and less intense than the first, with lower rainfall totals. It provides a final opportunity for planting and crop maintenance. The second rainy season is often referred to as the 'minor' or *short rains*.

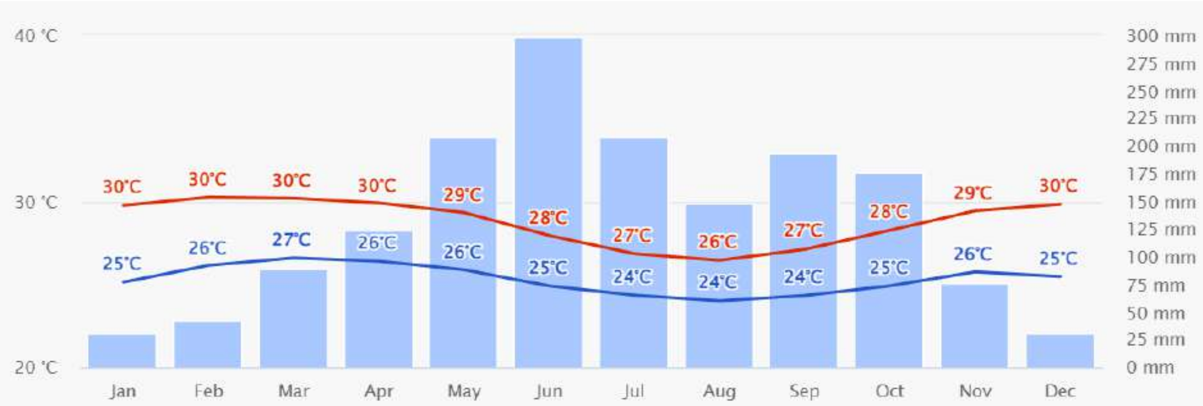


Figure 11: Distribution of monthly aggregated precipitation volumes (blue bars) and monthly average mean daily maximum (red line) and minimum temperature (blue line) in Lagos city at 6.45°N, 3.39°E (11 meters AMSL) as per ERA5T data [10].

Lagos State's bimodal precipitation pattern is of paramount importance to agriculture in its more rural areas. The two rainy seasons enable farmers to plant and harvest crops at different times of the year. The initial season allows for a wide variety of crops to be planted and cultivated, while the second season is critical for late season crops and enhancing overall agricultural productivity. Besides, the bimodal precipitation pattern plays a significant role in recharging water resources in Lagos State. The rainy seasons contribute to the replenishment of rivers, lakes, and aquifers, ensuring a consistent water supply for the region. Adequate water supply is vital for both agricultural and domestic use.

The unique rainfall distribution in Lagos State necessitates considerations in urban planning and infrastructure development. Proper drainage systems and flood management strategies are crucial to address the increased precipitation levels during the rainy seasons. Urban development projects must be designed to withstand the challenges posed by heavy rainfall. The bimodal precipitation pattern also emphasizes the importance of climate resilience in LS. Residents and authorities must be prepared to adapt to the alternating wet and dry seasons, which require effective flood management and infrastructure maintenance. Climate-conscious policies and practices are integral to the region's sustainability.

C.5.2 Large scale drivers of rainfall variability

Like any other place in the world, Lagos State is influenced by a range of global climate patterns and drivers that can greatly influence rainfall patterns. These must be analyzed and should be taken into account when underwriting the parametric flood insurance policy.

C.5.3 Madden-Julian oscillation

The Madden-Julian Oscillation (MJO) is an important factor in tropical climate variability, characterized by an eastward-moving 'pulse' of cloud and rainfall near the equator that typically recurs every 30 to 60 days. In equatorial West Africa, the MJO can influence the timing and intensity of rainfall events, particularly during the earlier spring rainy season (March-June), by modulating low-level wind anomalies and moisture transport from the Atlantic Ocean. Over large portions of equatorial West Africa, such as Lagos State, MJO impacts on rainfall constitute a difference on the order of 20% to 50% from average daily rain rates for the March-June period [11].

C.5.4 El Nino Southern Oscillation (ENSO)

El Niño-Southern Oscillation (ENSO) is characterized by fluctuations in sea surface temperatures and air pressure in the equatorial Pacific Ocean, occurring at irregular intervals typically of between two to seven years and which can significantly influence global weather patterns. ENSO has been found to impact weather and rainfall patterns in West Africa with El Niño events often resulting in warmer and drier conditions in the region due a weaker West African Monsoon (WAM). Conversely, La Niña events are typically associated with enhanced rainfall in the region (Figure 12). Observations also show that the timing of the ENSO is essential to the teleconnection process (i.e. the way ENSO impacts the WAM). Furthermore, a more recent study found a decadal time scale oscillation between ENSO and WAM[4] with the relationship believed to be physically linked and having strengthened significantly since 1980 [12]. Although ENSO probably has an influence on overall amounts of rainfall throughout the year, it might not have an influence on the actual precipitation extremes in LS.

[4] Meaning that the impact of ENSO on WAM intensifies and weakens on decadal cycles.

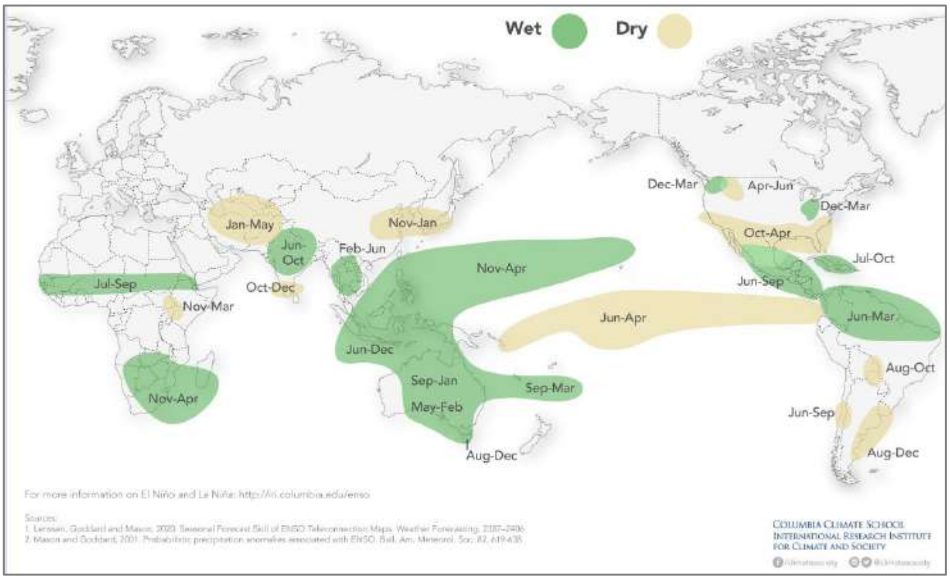


Figure 12: Typical but not guaranteed impacts of La Niña conditions which can result in generally wetter conditions in LS [13].

C.5.5 Atlantic Multidecadal Oscillation and Interdecadal Pacific Oscillation

Atlantic Multidecadal Oscillation (AMO) and Interdecadal Pacific Oscillation (IPO): on the decadal-to-multidecadal timescale, the WAM and rainfall across West Africa in general is influenced by the AMO and IPO [14]. The AMO is a cycle of long-duration changes in the sea surface temperature of the North Atlantic Ocean. It oscillates between *warm* and *cool* phases, typically over a period of 60 to 80 years, with each of the phases lasting for 20-40 years at a time. The IPO is a cycle of long-term fluctuations in the sea surface temperature across the Pacific Ocean. It alternates between *positive*, *negative*, and *neutral* phases, usually over a span of 15 to 30 years. Wet WAM anomalies are favored in the positive (warm) phase of the AMO and in the negative phase of the IPO, and vice-versa [14].

C.5.6 North Atlantic Oscillation (NAO)

The North Atlantic Oscillation (NAO) is characterized by the fluctuating sea-level pressure patterns in the North Atlantic region. It exhibits considerable inter-seasonal and inter-annual variability, with its phases lasting several months, while also showing significant multi-decadal variability (or circa 24 years). Its positive phase is typically associated with drier conditions in the Sahel, including parts of West Africa, while the negative phase can bring wetter conditions [15]

C.5.7 Summary of large-scale drivers of rainfall variability

The above paragraphs and high-level analysis show that although large-scale atmospheric circulations significantly affect precipitation patterns in Lagos State their interactions with each other and with local factors add complexity. Consequently, their influence on precipitation patterns in LS is neither systematic nor unambiguous. Furthermore, these large circulations, especially those operating on longer time scales on the order of years to decades, are observed to be better predictors of precipitation accumulations over longer periods, such as annual or seasonal totals, while their impact on short-term extremes is less clear, largely due to the significant role that local factors typically play in these events.

Accordingly, in the specific ENSO case, El Niño events are typically accompanied by rainfall that is below the annual average, while the opposite is true for La Niña events, although with some uncertainty. However, no clear patterns have been identified regarding the impact of ENSO on seasonal and especially daily precipitation, including extremes. Therefore, the occurrence or forecast of El Niño or La Niña events, as well as long-term forecasts in general, are not expected to materially affect the dynamics of purchasing or pricing parametric flood insurance (typically with annual contractual periods).

C.6. Climate trends

Understanding historical climate trends in the project area is critical to determining the time frame for product design. Additionally, insights into future climate can reveal possible shifts in flood risk due to climate change. The following initially provides an overview of current and future climate trends nationwide and regionally, including an analysis of the observed trends across Lagos State based on precipitation data. Finally, a summary of the results is provided with a focus on Lagos State.

C.6.1 Country and regional overview

For context, the following provides an overview of Nigeria's historical climate trends and future projections, primarily drawn from the World Bank [16], and supplemented by other local studies.

Key climate trends

Lagos State is expected to see a steady increase in average temperatures, although not as extreme as the northern parts of Nigeria. Regarding precipitation, annual averages remain similar but slight shifts in seasonal precipitation and in the magnitude and frequency of short-term extreme events can be expected.

Given the ongoing impacts of a changing climate, with expected further increases in rainfall volatility and intensification of extremes, continued monitoring and analysis of rainfall patterns in LS, as well as monitoring flood-exacerbating factors such as sea level rise, are critical. Particular attention should be paid to the short-term extremes that typically cause flooding in the Lagos metropolitan area. These insights could inform the design of future insurance schemes and possible updates to this or other parametric insurance products.

Temperature

Mean annual temperature for Nigeria is ~28.7°C for the period of 1991–2020, with average monthly temperatures ranging between 24°C (December, January) and 30°C (April), while the mean maximum annual temperature can reach 33.2°C [16]. For the country, temperature increases of 0.03°C per decade were observed between 1901–2016, with stronger increases occurring over the last 30 years of 0.19°C per decade Figure 13 [16].

According to studies quoted by the World Bank [16], temperatures across Nigeria are expected to increase by 2.9°C to as much as 5.7°C by end of the century (Figure 14). Nighttime temperatures are expected to increase by as much as 4.7°C. An increase in the duration of heat waves by a range of an additional 8 to 55 days are expected by the end of the century. Temperature increases are expected to be lower in the southern areas of the country but will increase much more rapidly in the interior and northern areas in comparison. Low temperatures are also expected to increase.

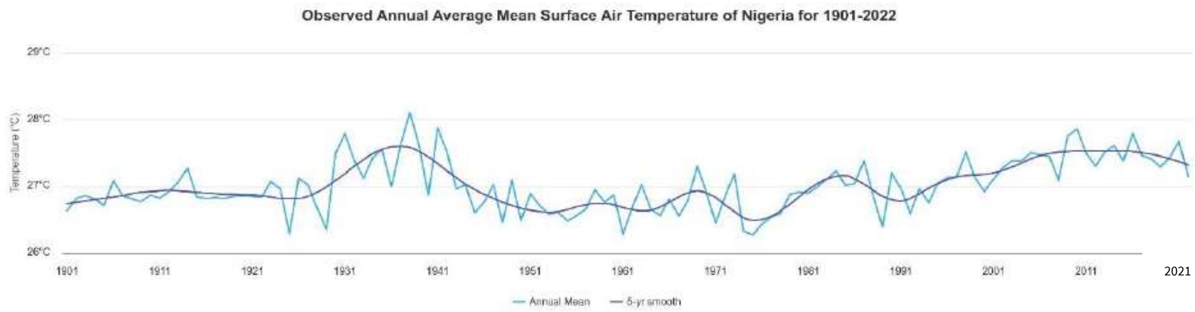


Figure 13: Observed annual average mean surface air temperature of Nigeria for 1901-2022 [17].

Precipitation

In Nigeria, rainfall trends show a high degree of variability and a decline in the predictability of seasonal rainfall has been observed across the country in recent decades. The amount of rainfall in the country varies greatly from a very humid coastal area to the Sahel in the northwest and northeast. The annual fluctuations in rainfall, especially in the northern parts, are large. Figure 14 shows the change in predicted annual average rainfall for Nigeria. On a nationally aggregated scale, annual average precipitation is expected to be like historical observations on average. However, across the country, rainfall is expected to decrease significantly in northern areas and increase in the south and along the coast where Lagos State sits.

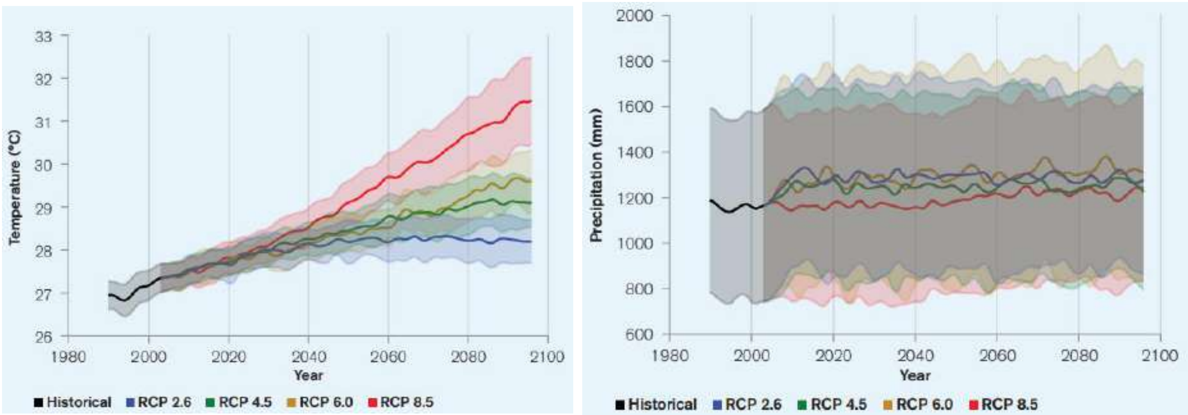


Figure 14: Historical and projected average temperature (left) and precipitation (right) for Nigeria from 1986 to 2099 (Reference Period, 1986–2005) [18].

In Lagos State, total rainfall appears to be relatively stable. Various satellite and reanalysis datasets (e.g. ERA5 and CHIRPS) are somewhat contradictory, showing either a slight increase or a slight decrease in the annual total (Figure 15). The annual number of dry days and days with more extreme rainfall also remain at a relatively stable level, however, show little correlation during historically important events. A more detailed analysis of all available precipitation data sets for Lagos State is given in Section E.1.2.

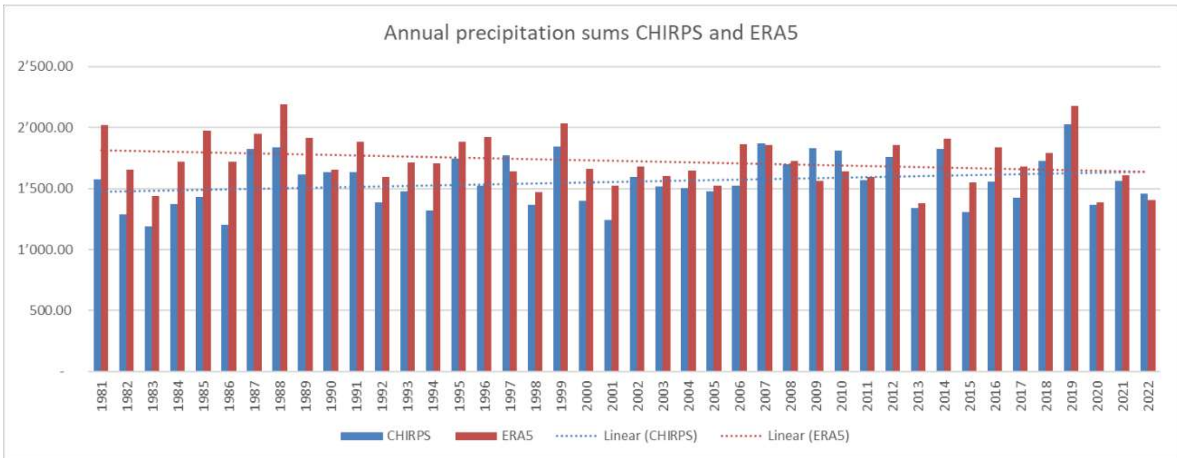


Figure 15: Annually aggregated precipitation from ERA5 and CHIRPS for Lagos State shows some variations between the two datasets, as expected. Over the past 40+ years, both datasets exhibit slightly contradictory linear trends. Figure generated by Swiss Re.

Figure 16: Location map of data points in the proximity of Lagos for ERA5 (left, ~25-kilometer resolution) and CHIRPS (right, ~5-kilometer resolution) as analysed in Figure 15. Figure generated by Swiss Re.

Sea level rise and coastal erosion

In line with Western African region trends, the sea level is expected to rise putting more people at risk of flooding in the near future [16]. Coastal erosion is a significant issue, which is projected to worsen.

C.7. Hydrology

The hydrology of Lagos State is closely linked to its unique topography, which includes coastal plains, wetlands, and various rivers and lagoons. Understanding the hydrological patterns in Lagos State and - west to east – the basins of the Yewa, Owo, Ogun, Ona (Aye), Oshun and Sasa rivers as well as all human-caused influences (e.g. man-made canals and dams) is essential for water resources management, flood protection and environmental protection.

Lagos State faces a multitude of flood risks originating from various sources, including river flooding, pluvial (rainfall-induced) flooding, coastal flooding. These risks are compounded by factors such as rapid urbanization, climate change, and the region's low-lying coastal topography. Dam releases at upstream reaches of the river systems draining into Lagos State also play a role in flooding extensive areas of the state.

C.7.1 River basins

Five main river basins drain into Lagos State (Figure 17). Heavy rainfall in these upstream areas can result in increased water discharge into Lagos State. This can lead to riverine flooding, particularly during the wet season, affecting communities along the riverbanks. The management of water resources and flood control in Lagos State and its upstream basins is essential for sustainable development. Properly functioning drainage systems, wetland preservation, and environmentally conscious practices are crucial to maintain ecological balance and adapt to the region's hydrological challenges.

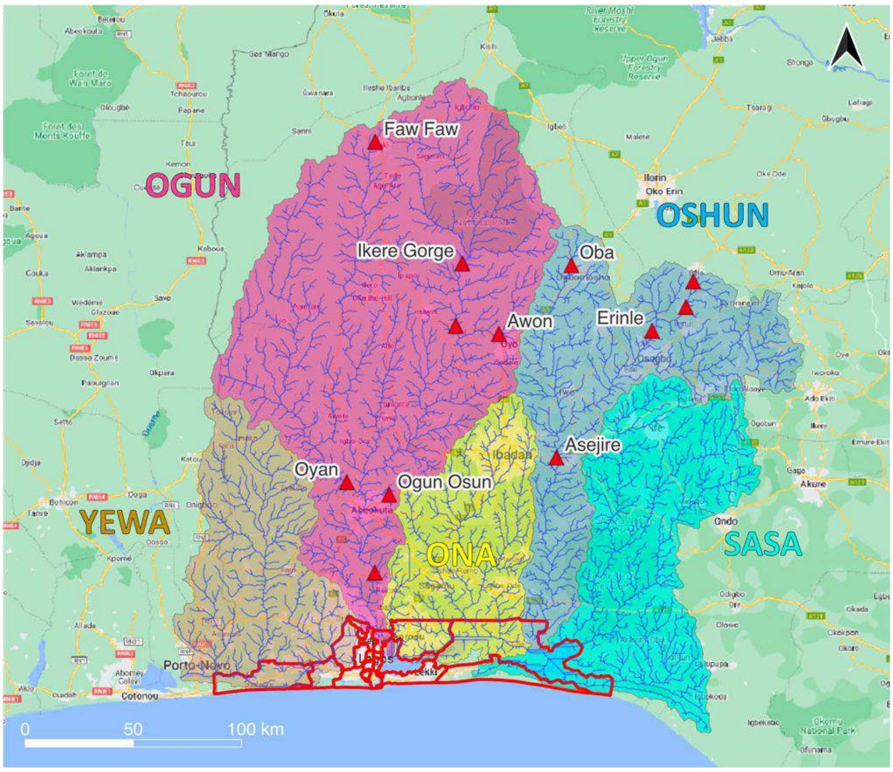


Figure 17: Main river basins draining into Lagos State. Larger water retaining structures are symbolized by red triangles [19]. Oyan Dam is located in the Ogun River basin, right upstream from the city of Abeokuta (Ogun State). Figure generated by AXA Climate.

A brief description of the five river basins draining into Lagos State is shown below:

- **Yewa River Basin:** It lies to the northwest of Lagos State, adjacent to the Nigerian-Benin border. The Yewa River is important for local agriculture, and its water levels vary with the rainy and dry seasons.
- **Ogun River Basin:** It is located to the northwest of Lagos State. It is one of the major river basins in the region. The Ogun River is essential for water supply in LS, agriculture, and hydroelectric power generation. Seasonal variability in rainfall significantly affects water levels in the Ogun River. Dams along the Ogun River are regulated, and water releases leads to frequent flooding situations in the Lagos State's Kosofe and Ikorodu LGAs downstream (see Section C.7.6).
- **Ona River Basin:** It covers an area of 6'800 km^2, with most of it in Ogun State, before ending in the Lagos Lagoon. The Ona Basin lies west of the Oshun River basin and the Owa, Ibu and Omi Rivers [20].
- **Oshun River Basin**: It is situated to the northeast of Lagos State. The Oshun River is characterized by its winding course and is subject to fluctuations in water levels, influenced by seasonal rainfall patterns. This river basin supports agricultural activities and water supply.
- **Sasa River Basin**: Draining into the northeast of Lagos State, it is smaller in scale compared to the Ogun and Oshun basins. It is primarily an agricultural region with seasonal variations in water flow.

C.7.2 Coastal Plains and Lagoons

Lagos State's coastal plains are characterized by low-lying terrain, which includes lagoons and estuaries. Lagos Lagoon, Lekki Lagoon, and Badagry Lagoon are prominent features. These lagoons play a significant role in the hydrological system of the state, influencing water levels flow, tidal patterns, and the distribution of freshwater and saline water. The lagoons are subject to fluctuating water levels, which can result in overflow and inundation of nearby areas during strong onshore winds and heavy rainfall. Lagos State's coastal location, its proximity to the Atlantic Ocean, makes it vulnerable to coastal flooding. Rising sea levels and storm surges can result in coastal inundation. This can have severe consequences for communities along the coastline, including damage to infrastructure and displacement of residents.

C.7.3 Wetlands and Mangroves

Extensive wetlands and mangroves are located in the coastal areas of Lagos State. These environments serve as important ecological systems and impact the region's hydrology by providing water storage, habitat for wildlife, and coastal protection.

C.7.4 Rainfall and Seasonal Variability

Lagos State experiences a bimodal rainfall pattern (Section C.5.1), which significantly influences its hydrology. The wet season, from April to October, brings heavy rainfall, contributing to the replenishment of water bodies. The dry season, from November to March, is characterized by reduced precipitation levels.

C.7.5 Urbanization, drainages and waste management

The low-lying coastal plains and high population density make flood control a critical concern. Urbanization has altered natural drainage systems in Lagos State. Effective drainage and flood management systems are essential due to the challenges posed by heavy rainfall during the wet season. Further, consistent waste management is crucial for the cleanliness and effectiveness of drainages.

C.7.6 Dams

Lagos State has reservoir dams for various purposes, including water supply, hydroelectric power generation, and agriculture. The sudden release of water, breach or overtopping of these dams, often as a response due to extreme rainfall or structural and man-made issues, can lead to sudden and catastrophic flooding downstream. Adequate dam maintenance and monitoring are essential to mitigate this risk.

Dam breach or overtopping

Flooding in Lagos State is a complex phenomenon influenced by natural, urban and infrastructural factors. In addition to heavy rainfall, riverine flooding and sea level rise, the risk of flooding in the region is sometimes further increased by controlled releases of water from nearby dams. During periods of excessive rainfall further upstream, water levels in reservoirs may exceed safe thresholds, requiring controlled releases to protect the structural integrity of the dam and mitigate broader flood risks downstream. However, these controlled releases, although essential for safety, can worsen local flooding and lead to waterlogging in urban and coastal areas.

The flood dynamics affecting Lagos State are closely tied to the river systems upstream particularly the Ogun River and its associated water-retaining structures. Among these, the Oyan Dam plays a critical role, as it is the largest dam along the Ogun River before it reaches Lagos State. Built primarily for water supply and irrigation, the Oyan Dam also influences flood risk management within the region. While it serves as a buffer during periods of moderate rainfall, its management practices during peak flows – especially the timing and volume of controlled releases – can significantly impact downstream flood conditions. In the following sections, we will explore the role of the Oyan Dam in managing flood risk for Lagos State, as well as the implications of its operational decisions on the flood parametric insurance policy.

The Oyan Dam's Role in Flood Management for Lagos State

The Oyan Dam, located in Ogun State (see Figure 17), was built in the early 1980s along the Oyan River, a tributary of the Ogun River. It was developed by the Ogun-Osun River Basin Development Authority (O-ORBDA) primarily for water supply, irrigation, and hydroelectric power generation, but it also plays a key role in flood control, especially for Lagos and other areas downstream. In the Nigerian newspaper Daily Post, the managing director of O-ORBDA claimed that " *[…] without the dam, Isheri and some Abeokuta communities would not exist due to the high risk of flooding […]*" [21].

Built in the early 1980s, Oyan Dam was part of a broader initiative to harness Nigeria's water resources for multipurpose benefits – agriculture, potable water, and energy. Though initially constructed with a focus on water supply and irrigation, the dam also became integral in managing seasonal flooding in Lagos, a city heavily impacted by rainfall and river overflow.

The dam's reservoir has a capacity of about 270 million cubic meters and plays a critical role in mitigating flood risk by storing and controlling the release of water into the Ogun River, which flows south towards Lagos. During the rainy season, controlled releases from the dam help manage water levels downstream, reducing the flood risk for Lagos and its surrounding communities. However, the dam's flood control effectiveness is sometimes challenged by heavy and unpredictable rainfall, especially during the peak rainy season. When water levels exceed safe limits, controlled releases become necessary, but they can still contribute to downstream flooding if urban drainage in Lagos is inadequate.

In summary, the Oyan Dam is vital for both water supply and flood management in the Lagos region. Proper coordination and planning around its releases are essential for minimizing flood risk, especially as Lagos continues to grow and develop in low-lying areas that are highly vulnerable to flooding.

Historical events due to Oyan Dam releases

Below is presented a list of notable flood events in Lagos State that have been linked to releases from the Oyan Dam, often exacerbated by heavy rainfall. While precise records for every instance are not always available, here are some key years in which significant flooding was attributed in part to controlled releases from the dam:

- **2007:** Significant rainfall, potentially combined with releases from Oyan Dam, led to flooding in various parts of Lagos and Ogun States. Many communities faced property damage and displacement [22].
- **2010:** The release of water from Oyan Dam during high rainfall events worsened flooding in Lagos, impacting areas near the Ogun River and pushing authorities to address infrastructure and flood response needs [23].
- **2019:** High water levels led to Oyan Dam releases, resulting in flood risks in areas such as Mile 12, Isheri, and other Lagos neighborhoods. Residents again raised concerns about the regular impact of water releases from the dam on local communities [24].
- **2021:** Releases from Oyan Dam following heavy rains caused serious flooding, affecting various Lagos communities along the Ogun River. Local authorities issued warnings, but floodwaters still forced evacuations in flood-prone neighborhoods [25].
- **2022:** Continued rainfall and the release of water from Oyan Dam led to considerable flooding, especially impacting communities along the Ogun River in Lagos [26]. The government advised residents in vulnerable areas to evacuate as they faced risks of rising water levels.

Example for the October 2024 flooding event

During the October 2024 flood event, out of the four gates at Oyan Dam, only two were open, each at 12% capacity each [27]. For this situation, the release rate was quantified at 208 m^3/s, which means there was an approximate total release of 17.9 million m^3/day. Lagos State Government issued alerts to the residents of the Ogun riverbanks to relocate to higher grounds, which would indicate that floods can occur for such release rates of 17.9 million m^3/day. Another source [28] points out that the risk of flooding begins as soon as the release from the Oyan Dam exceeds 16.0 million m^3/day.

Dam exclusions in insurance

The presented flood parametric insurance product in this report covers flood losses in Lagos State due to dam release in dams located upstream catchments flowing into Lagos State. However, it is noted that in most occasions flooding due to dam releases is excluded from (parametric) flood insurance coverage because it represents a distinct risk with specific characteristics and often involves a controllable or regulated water source. Most critically the insured may be able to deviate the triggering conditions from natural behavior, i.e. a moral hazard.

Below a few reasons why insurers may exclude this type of flooding are explained in more detail:

- **Human Control and Negligence Risks:** Unlike natural flooding caused by heavy rainfall, dam releases are generally human-controlled, whether planned or emergency-driven. Insurers may see these events as preventable or linked to operational decisions, which could involve negligence or mismanagement, potentially complicating the liability. There is also a moral hazard component for a parametric FFP product covering a Governmental entity with influential power on the water authority that regulates the dam.
- **Different Risk Profile:** Dam releases can lead to very sudden and intense flooding, often with higher water velocities and depths than naturally occurring floods. This distinct risk profile may require specialized coverage or a different underwriting approach that reflects the potential scale and intensity of damages from such events.
- **Separate Liability and Coverage Frameworks:** Flooding from dam releases often falls under separate liability regimes, particularly if the dam is managed by a government entity or a private corporation. In these cases, the dam owner/operator may be liable for damages, and affected parties might seek compensation through other means (like litigation) rather than standard flood insurance.
- **Unpredictable Payout Exposure:** Insurers strive to predict and manage potential payouts based on natural flood patterns. However, dam release incidents can be hard to anticipate, and insurers might exclude them to maintain the predictability of their risk models.
- **Complexity of Policy Design:** Including dam-related flood risks would require tailored clauses that could complicate standard flood policies, often designed around natural perils. Separate policies or endorsements may be created for those who specifically want coverage for dam-induced flooding.

In some cases, it is possible to get separate or specialized insurance for dam-related flooding, either through an endorsement to a standard flood policy or through a policy specifically addressing dam failure or release risks. For the purpose of the product, we accounted for dam releases and explain the corresponding method in Section F.4.2.

D. Definition of the target areas for insurance coverage

As mentioned earlier, the index-based flood insurance product developed here is designed to support post-flood relief and reconstruction efforts, with a focus on supporting the poor and vulnerable households (PVHH) and accelerating the recovery of their economic activities following a flood event. Considering this background and following consultations with local stakeholders, it was decided to focus on LGAs where low-income neighborhoods are located and include them in the scope of the parametric program. The calculation of the exposure level of the points is done in two steps:

1. The first step is the selection of the LGAs that cluster a larger proportion of PVHH exposed to floods. The polygons of the LGAs (administrative level 2) of Lagos State are extracted from GRID3 [2].
2. The second step is the generation of exposure points with the number of insured persons per point in the selected LGAs, called from now on *calculation points*. Based on the Total Insured Value (TIV) agreed by Lagos State Government (i.e. sum insured for the first year of policy), a payout (in USD) per person covered is assigned.

D.1. LGA selection covered under the scheme

The Lagos State Emergency Management Agency (LASEMA) in collaboration with the Insurance Development Forum (IDF) selected the seven LGAs where the largest proportion of PVHH are exposed to floods. The selected LGAs are presented in Figure 18 and the distribution of the population across these LGAs is shown in Figure 19. Table 3 indicates the number of people covered per LGA, as extracted from WorldPop [4]. The total number of the covered population under this scheme across Lagos State is 4'020'322 people.

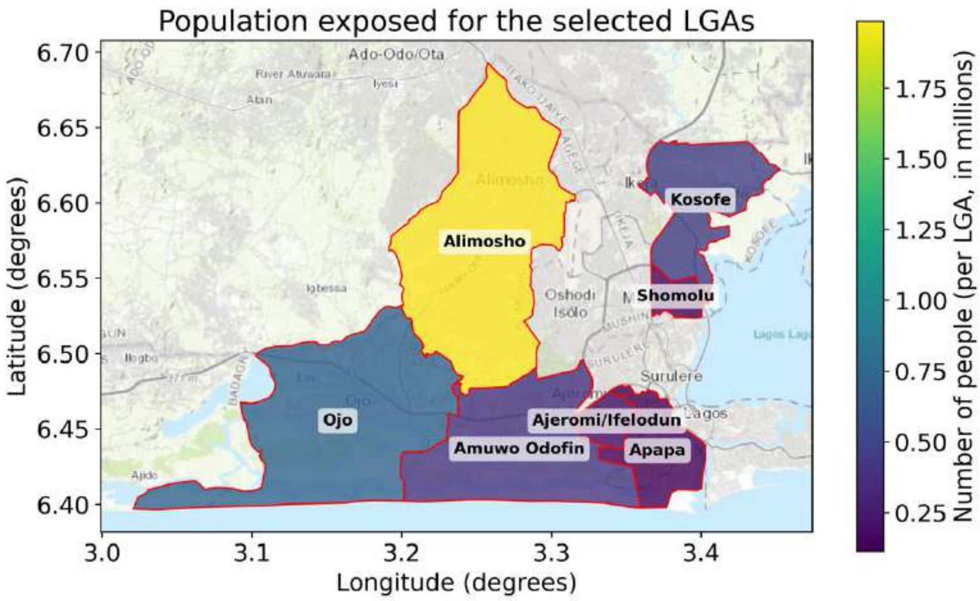


Figure 18: Purple marks the seven LGAs covered under the purpose of this project. Figure generated by AXA Climate.

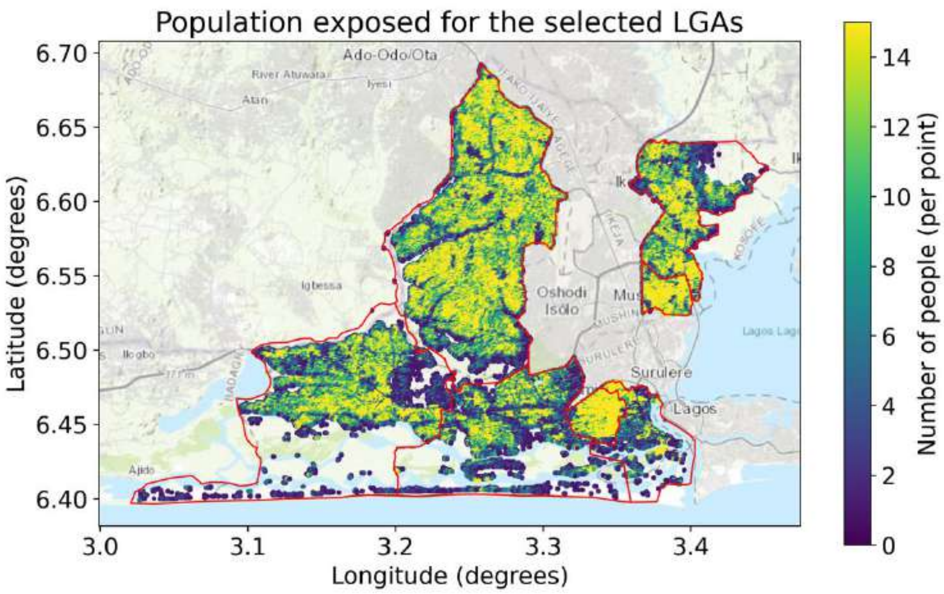


Figure 19: Population across the 7 selected LGAs. Blue outlines permanent water bodies. Figure generated by AXA Climate.

Table 3: Number of people in covered LGAs and share of the total [4] The number of people covered is slightly below the population shown in Table 3, as people living in permanent water bodies or in the immediate boundaries are not covered by the policy (see Figure 20*).*

LGA	Population	Share of total
Ajeromi/Ifelodun	194'273	4.8%
Alimosho	1'987'350	49.4%
Amuwi Odofin	397'045	9.9%
Apapa	113'848	2.8%
Kosofe	465'849	11.6%
Ojo	711'141	17.7%
Shomolu	150'816	3.8%
Total	**4'020'322**	**100%**

D.2. Specifications and applications of the exposure layer in the insurance product

The exposure layer is defined by an excel file (*.xslx* table) that includes 30-meter equispaced points distributed across the selected LGAs. The points located in permanent water bodies (such as rivers, canals, lagoons, etc.) were removed from the exposure layer, based on a permanent water bodies mask layer [29]. Each point of the exposure layer includes the population counts as attribute, extracted from WorldPop data [4].

In turn, a constant disbursement per person *flooded* is predefined for all the LGAs covered (e.g. USD 17), where *flood* meaning that the flood depth at individual calculation points exceed a certain threshold (e.g. 50 centimeters). For a certain flood event, if the flood depth exceeds the predefined threshold at a certain point, all the population counts at that point will be considered as *flooded,* and if the flood depth at that point does not exceed the predefined threshold, none of the population at that point would be considered as flooded (no payout for that point).

The exposure layer is contractual and is attached to the insurance policy. This layer is used by the insurer to perform the flood risk assessment, product structuring and pricing (see Section F.4), as well as by the calculation agent, who computes the payout to issue to the policy holder in case a flood event occurs. After the occurrence of a flood event during the policy period, the calculation agent computes the payout based on the maximum flood depth raster per event issued by a third-party data provider (ICEYE is suggested as data provider for this product). Such raster is generated by extracting the maximum flood depth for every pixel of the area interest, which has been surveyed along the entire development of a flood event. The horizontal resolution of the maximum flood depth raster as provided by ICEYE is 4x4 meters.

For such a flood event, the calculation agent identifies the pixels of the maximum flood depth raster that overlay each calculation point, assigning a maximum flood depth for each point. Based on the predefined flood depth threshold (e.g. 50 centimeters), the calculation agent will determine the points where the flood depth exceed the threshold, which will lead to the population counts *flooded* for that specific event. Subsequently, the resulting population *flooded* will be multiplied by the predefined disbursement per person *flooded* (e.g. USD 17) to compute the total payout to be issued to the policy holder.

Generation of the point exposure layer for the selected LGAs

To compute the points exposure layer for the selected LGAs, the following steps are conducted:

1. **Clip 100x100 meter resolution raster of population using the polygons of the 7 selected LGAs as mask:** In this case, the Bottom-up gridded population estimates for Nigeria dataset is used, as a new version of the WorldPop population raster dataset was made available on the WorldPop Open Population Repository during the execution of the project [3].

2. **Re-grid the 100x100 meter resolution clipped raster (i.e. 3 arcdeg) to a 33.33x33.33 meter resolution raster (i.e. 1 arcdeg):** From each pixel on the original raster, 9 pixels result from the re-gridding operation. The population counts of the 3 arcdeg pixels are uniformly distributed among the 9 resulting pixels of 1 arcdeg. This means that if a 3 arcdeg pixel had originally 99 people, each of the 9 resulting 1 arcdeg pixels will have 11 people.

3. **Extraction of the centroids of the 1 arcdeg resolution raster, with population counts concentrated in the centroid (i.e. exposure point, or calculation point) as attribute.**

4. **Removal of the calculation points falling in permanent water bodies:** Computation of the geospatial difference between the calculation points and the layer of permanent water bodies. The dataset used is the OSM Water Layer [29], which is a 3 arcsec resolution raster that includes permanent (surface) water features extracted from OpenStreetMap, such as large lakes and rivers, canals and minor streams. This raster is polygonised to perform the overlay with the calculation points. The final exposure layers cover points that are outside of permanent water bodies areas (see example in Figure 20). An extract of the tabular dataset is given in Table 4.

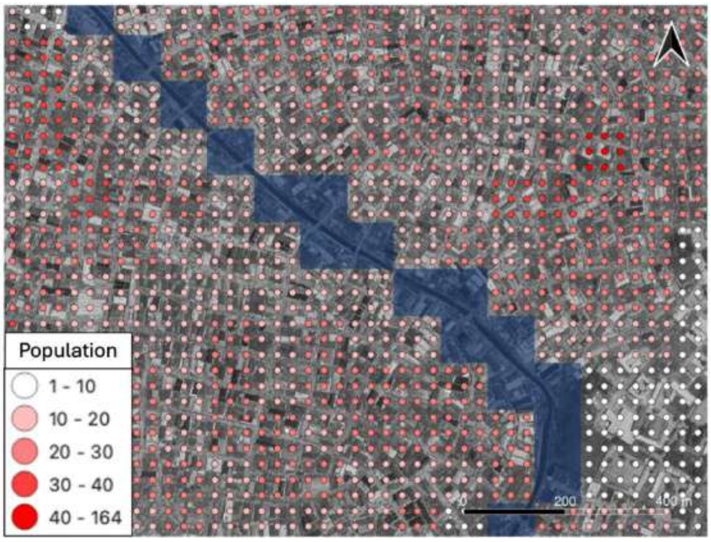


Figure 20: Illustration of an area covered where some population calculation points (exposure) have been removed, as they were intersected by permanent water bodies (in blue). Figure generated by AXA Climate.

Table 4: Example of a subset of two calculation points (only relevant columns are shown). Each point is clearly identified with a location number and georeferenced with a pair of coordinates. An attribute with the population counts is also provided.

ID	Longitude	Latitude	Population	State	LGA
414'620	3.30639	6.64722	7	Lagos	Agege
414'621	3.30667	6.64722	7	Lagos	Agege
...	...	...	...	...	...

D.3. Conclusion on the exposure layer

In this document, the methodology to generate the exposure file of points for the Lagos State parametric insurance product has been presented. Based on such methodology, the parametric insurance program will cover 4'020'322 people across seven (7) selected LGAs (Ajeromi/Ifelodun, Alimosho, Amuwo Odofin, Apapa, Kosofe, Ojo and Shomolu). The exposure layer of points (table presented in *.xlsx* format) will be attached to the insurance policy.

E. Flood hazard assessment

This section provides an inventory of datasets that can be used to quantify flood hazards, with the aim of selecting potential indices for structuring a flood parametric insurance cover. Additionally, an analysis of historical flood events is conducted to enhance the understanding and quantification of flood hazards and risks. The information and historical datasets presented in this section are critical for guiding and validating the product design.

E.1. Inventory of flood hazard datasets

This section reviews existing historical flood event records, as well as observed and modelled rainfall, river, and coastal data sources to identify those with sufficient quality, reliability, and robustness for developing an index to structure a parametric insurance product. The goal is to select data sources that can support both accurate policy pricing and objective, reliable monitoring of the chosen index.

E.1.1 Historical flood events in Lagos State

This subsection presents a timeline of historical flood events from 1968 to 2023, compiled from multiple sources, bringing together available information on associated rainfall and impacts. A summary of the key flood events is then presented, highlighting associated rainfall and reported losses. This is followed by a detailed analysis of the two most severe flood events, including an examination of event losses and government response costs. An exhaustive table with the historical flood events in Lagos State is shown in Appendix 5.

Data sources

Multiple sources that depict historical flooding in the Lagos State area have been reviewed, including reports by LASEMA, online portals, academic papers and information supplied by other local agencies. The main data sources are summarized in Table 5.

Table 5: Sources for construction of an historical losses database for Lagos State.

Source	Link	Description
Idowu, D.; Zhou, W. "Land Use and Land Cover Change Assessment in the Context of Flood Hazard in Lagos State, Nigeria.", Water 2021, 13, 1105.	https://doi.org/10.3390/w13081105	This review includes an extensive list of recorded flood events in various locations within Lagos State from 1968 to 2020 (by month) compiled based on literature and online news sources. However, no information about human losses and financial worth damages are mentioned.
FSD Africa Urban Flood Resilience Research Findings	FSD Africa Urban Flood Resilience Project	Data from FSD Africa (Financial Sector deepening) ranges from 1968 to 2012 in Lagos, it includes some figures on deaths, number displaced and economic losses for each event.
Dartmouth Flood Observatory data	https://floodobservatory.colorado.edu	Data from the Dartmouth Observatory gathers important historical floods in the Gulf of Guinea. Although the spatial distribution of the data is relatively scattered (at the country scale), it includes some figures about human losses and displaced from 1985 to 2018.
EMDAT database	https://www.emdat.be	Data from EMDAT ranges from 2000 to 2022 and includes flooding events in the Lagos State with precise details and figures (days, duration, quantitative estimation of the human and economic losses). The data is dated by month and the spatial extent of floodings is assessed by Adm1.
Lagos State Climate Risk Assessment (CRA)	https://moelagos.gov.ng/wp-content/uploads/2021/09/Geo-Solutions-Lagos-CRA-Feb-Final-Report-V4-April-23-2021.pdf	This news report about floodings in Lagos includes summaries of flooding events in numerous LGAs between March 2011 and September 2012. Although there isn't any figure, the data is granular, and the severity is well assessed by the testimonies.
Nkwunonwo, U. C., Whitworth, M., and Baily, B.: "*Review article: A review and critical analysis of the efforts towards urban flood risk management in the Lagos region of Nigeria*", Nat. Hazards Earth Syst. Sci., 16, 349–369, 2016	https://doi.org/10.5194/nhess-16-349-2016	This review article contains a detailed table summarizing floods in Lagos between 1968 and 2012 based on news reports. There are many figures like the number of people displaced, the human losses, economic losses and cause of each event. The data is dated by month and the spatial extent of floodings is assessed by LGA (if possible).

Standardization and compilation of historic flood events

We attempt to blend data sources and create a consistent historic flood timeline with a qualitative description that can be utilized for the calibration of the parametric insurance scheme.

The compilation method is based on two main hypotheses:

1. Flood severity is estimated through economic and human losses, as the available sources do not provide more precise metrics.
2. The mention of a flood in a report from a trustworthy source proves its actual occurrence.

First, six sources were used to create the most complete list of historical flood events in Lagos State for the period 1968-2023. When an event is mentioned in a source, the date is added to the database and the details given by that source are recorded in the corresponding cell of the database. For each flood event, data on human, material and financial losses were collected based on the six sources used. Individual events were then aggregated by year and LGA in the final tables from the various sources. The economic and human loss data were used to compare the severity of the floods and assign a severity index of 1 to 3, as described in Table 6 below. Finally, the database was checked and validated by LASEMA. The final format is a table showing the severity index by year and by LGA (Appendix 5).

Table 6: Qualitative description of the severity index used to characterize flood events in Lagos State.

Severity Index	Flood extent & depth	Number of deaths	Number of people affected	Example event descriptions
1	Relatively localized, <1 meter flood depth	0	Dozens to hundreds	2002 flood: >USD 2'500, 2 deaths, 200 displaced
2	Medium – several neighborhoods and considerable flood depth (typically >1 meter)	1-100	Thousands	2017 flood: USD 6 million, 20 deaths, 500 displaced
3	Widespread, deep and fast flood waters	>100	Thousands to millions	2012 flood: USD 5.2 billion, >350 deaths, thousands displaced

Next, the list of historical losses and the severity index assigned to each flood event were then subjected to several reviews by LASEMA. Events were reviewed sequentially to confirm the severity index values. Two minor events and one medium event were corrected.

The result is a total of 37 flood events from year 1968 to 2023, with:

- **Severity 1:** 28 events.
- **Severity 2:** 7 events.
- **Severity 3:** 2 events

Description of major flood events in recent history

Two years reach the maximum value for the severity index, as highlighted in Appendix 6:

- **2012 flood:** Three floods occurred on 2012, but the most severe one happened from July to October. This flood was triggered by flash rains during the rainy season, affecting all the LGAs in LS. The flood was exacerbated by the overflow of Lamingo dam and Lagdo reservoir in Cameroon. This devastating flood rocked the entire country, claiming hundreds of lives and affecting millions. The total estimated economical loss is USD 9.5 billion. According to the humanitarian ministry, Nigeria's last major flooding in 2012 killed 363 people and displaced 600'000 to 2'100'100 depending on sources. Nevertheless, the figures are given at the scale of the whole country, therefore it is difficult to understand how badly Lagos State was specifically affected. According to Mr Abayomi Oyegoke, from NiMet Central Forecast Unit, Oshodi, a total of 570 millimeter of rainfall had been recorded in Lagos State between January and June 2012.
- **2022 flood:** Although mentioned only once in the EM-DAT database [30], this flood, which occurred from May to October, was particularly devastating and claimed over 600 lives. All of Nigeria's metropolitan districts were affected. Unusually heavy rainfall, the likelihood of which is increasing due to climate change, was cited as the cause of the flooding. The economic damage was once again staggering, reaching USD 4.2 billion. The devastation in Nigeria was worse than the 2012 flood disaster with 34 out of 36 states and over 2.8 million people affected, including 2'500 injured. Several hundreds of thousands of hectares of land have been inundated, causing damage to more than 300 thousand homes and over half a million hectares of farmland. In Nigeria, the overflow of a dam in Cameroon also claimed lives in the corresponding catchment area. However, this flood was also a nationwide event, affecting several provinces – the figures do not only concern Lagos State.

The 2017 event should be mentioned too, as it is regularly cited on the internet as one of the worst historical floods in Lagos State. EMDAT recorded 20 deaths, 500 displaced and USD 6 million spent on reconstruction. All the LGAs were affected. The severity index value for this event is 2 out of 3 as the figures are less dramatic than for the 3 flood events mentioned before.

E.1.2 Rainfall datasets

Rainfall measured at meteorological stations

By means of rainfall gauges, it is possible to record rainfall volumes over time. Currently, there exist automatic rain gauges that can record volumes at a certain predefined frequency (example in Figure 21). The data is transmitted automatically to a linked device. Subsequently, data is typically validated by the gauge operator before it is made available for use. The availability of rainfall gauge data is variable depending on the geography, based on the development of the local rainfall network.

Figure 21: Weather station installed by the Trans-African Hydro-Meteorological Observatory (TAHMO) [31].

The advantage of rainfall gauge record is that they can directly measure precipitation volumes. The disadvantage is that they provide rainfall records at specific points, and several gauges installed over an area of interest are required to understand the spatial patterns of the rainfall in the area. Also, continuous maintenance of the rainfall gauge network is key to ensure the quality of the rainfall records. Rainfall gauges are commonly integrated in weather stations, which besides rainfall they also measure other variables, such as wind speed or relative humidity or solar radiation, among others.

Two data sources of rainfall at meteorological stations could be found:

- **Nigerian Meteorological Agency (NiMet)**: NiMet provided daily rainfall datasets for four river basins draining into Lagos State – Yewa, Sasa, Osun, and Ogun – along with data for Lagos State itself, covering the period from 2004 to 2023 [32] (Figure 22). However, the methodology used to generate these datasets remains unclear. Specifically, the sources of the rainfall data, the stations used, and the aggregation process applied to generate the daily rainfall totals at the basin or state level have not been specified. The identification of measurement locations is critical for monitoring a parametric insurance index. Due to the absence of these specifications, it has not been possible to use this dataset to establish an excess rainfall parametric insurance product. Without this clarity, it is difficult to ensure the data's reliability and applicability for such an insurance product.

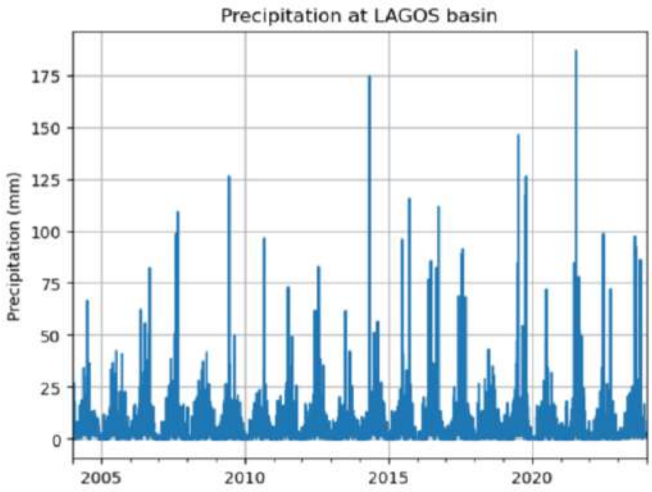


Figure 22: Daily precipitation for the period 2004-2023 for Lagos State [32]. Figure generated by AXA Climate.

- **National Centers for Environmental Information (NCEI):** The National Centers for Environmental Information (NCEI), an entity under National Oceanic and Atmospheric Administration (NOAA) in the United States, has established the Global Historical Climatology Network daily (GHCNd), which provides daily cumulative precipitation data from weather stations worldwide [33]. This data is freely accessible via an API. The only GHCNd station with historical precipitation records found in Lagos is located at the airport (Station ID: NIM00065201). However, this station appears to be highly unreliable, as over the past 30 years the maximum number of days with recorded data per year is only 70 (Figure 25). Due to the station's inconsistent data coverage, it has been disqualified as a viable source for structuring an excess rainfall parametric insurance product for Lagos State.

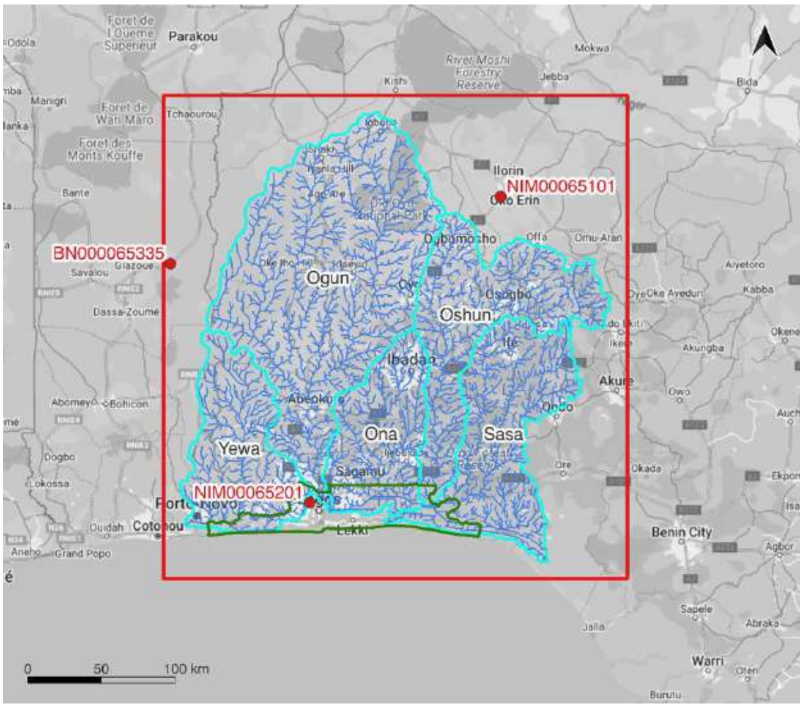


Figure 23: NCEI rainfall gauges available in the area of interest [33] (red). Lagos State is highlighted with a green boundary line, while the upstream river drainage basins are shown in blue. Figure generated by AXA Climate.

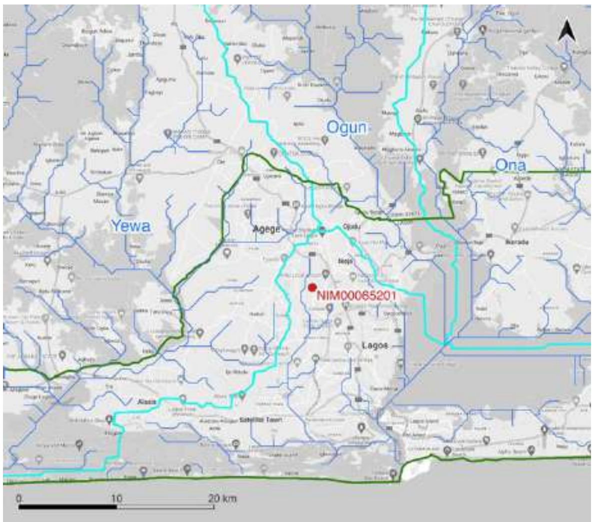


Figure 24: The available NCEI gauge is located at the Murtala Muhammed International Airport [33]. Figure generated by AXA Climate.

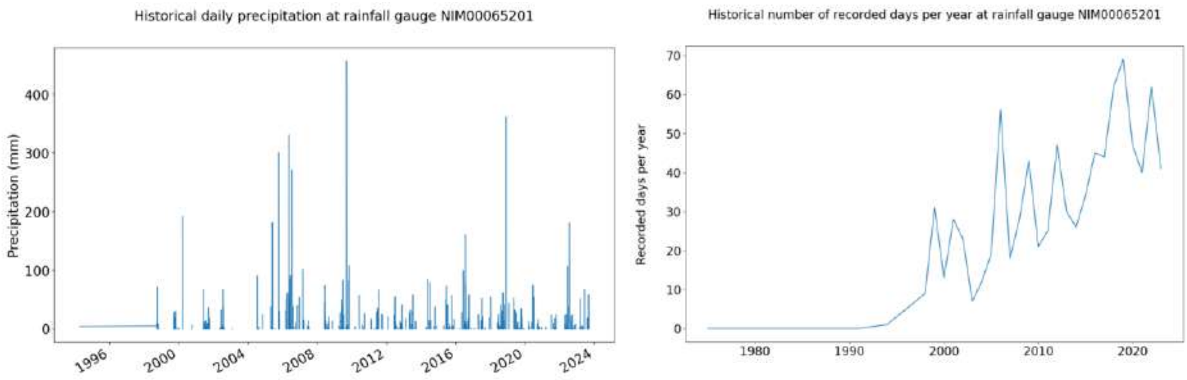


Figure 25: Historical daily precipitation at NCEI station (left) and number of recorded days per year (right) shows high unreliability [33]. Figure generated by AXA Climate.

<u>*Rainfall measured by satellite or generated by reanalysis (global) climate models*</u>

In the category of global data sources, rainfall data measured by satellites and generated by global climate and reanalysis models (GCM/RCM) are included. Several global rainfall datasets are freely accessible and are typically distributed in a gridded format (e.g., *.netcdf*).

Below it is presented a short description of the characteristics of satellite and reanalysis-derived rainfall datasets:

- **Satellite-derived rainfall**: A very scalable approach to measure rainfall across large areas appeared with the development of satellite technology. Devices such as infra-red, microwaves or radar gadgets are mounted on satellite constellations to record gridded rainfall at constant time-step globally or quasi-globally. Rainfall products such as GPM [34] gather rainfall values exclusively from satellite observations and are publicly available. In some cases, rainfall satellite observations are combined with observations recorded by gauges on the ground, in order to improve the accuracy of the dataset. Examples of such rainfall datasets are CHIRPS [35] and ARC2 [36], which are publicly available. However, it is important to mention that these datasets have some limitations, such as spatially variable biases, in some occasions poor correlation with ground gauges at short (~daily) time scales and poor representation of spatial variability over smaller catchments, and a tendency to underestimate heavy rainfall.

- **Reanalysis-derived rainfall**: To generate historical rainfall records, it is also possible to use numerical global climate models that are continuously calibrated with observations (Figure 26). These models solve fundamental physics equations to obtain variables such as temperature, humidity of different layers of the atmosphere and precipitation (rainfall, snowfall). Examples of these datasets are ERA5 [37] and ERA5-Land [38], and they are publicly available on the Copernicus Climate Data Store [39]. Same limitations as the ones described for the rainfall datasets generated by means of remote sensing techniques apply for the reanalysis datasets.

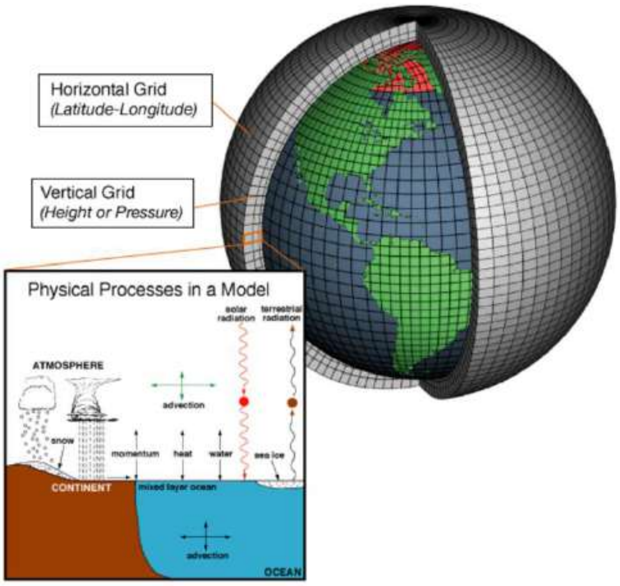


Figure 26: An example of how the Earth is broken down into cubes displaying some of the many different factors climate modelers consider when creating global climate models [40].

A summary table presenting the main features of four global rainfall datasets used in this project to analyze extreme rainfall in Lagos is provided in Table 7 below.

Table 7: Explored satellite and rainfall datasets for the area of study.

Data source	Spatial resolution	Available period	Temporal resolution	Latency
CHIRPS	0.05 x 0.05 deg	1981-Present	Daily	1 month
ERA5	0.25 x 0.25 deg	1940-Present	Hourly	5 days
GPM	0.1 x 0.1 deg	2000-Present	Half hourly	14 hours
TAMSAT	0.0375 x 0.0375 deg	1977-Present	Daily	5 days

In the following paragraphs, each of the datasets will be described and analyzed.

- **CHIRPS**: It blends climatology data that incorporates satellite information to represent sparsely gauged locations, daily infrared Cold Cloud Duration (CCD)-based precipitation estimates and rainfall gauge data [35]. The CHIRPS algorithm uses a novel blending procedure incorporating the spatial correlation structure of CCD-estimates to assign interpolation weights. The specific CHIRPS product tested in this project is *CHIRPS-2.0/global_daily*. CHIRPS daily rainfall is available in *.netcdf* and raster format and can be downloaded from CHIRPS data site or using a Python script.

- **ERA5:** Reanalysis combines model data with observations from across the world into a globally complete and consistent dataset using the laws of physics [37]. ERA5 provides hourly estimates for a large number of atmospheric, ocean-wave and land-surface quantities. Despite providing data starting back to 1940, the uncertainty of model estimates grows as we go back in time, because the number of observations available to create a good quality atmospheric forcing is lower. In case that serious flaws are detected in this early release (called ERA5T), this data could be different from the final release 2 to 3 months later. In case that this occurs, users are notified. The specific ERA5 product tested in this project is ERA5 hourly data on single levels from 1940 to present, and the variable extracted is Total precipitation. ERA5 is downloadable in *.netcdf* format by means of an API request, using the *cdsapi* Python package (Figure 27 and Figure 29).

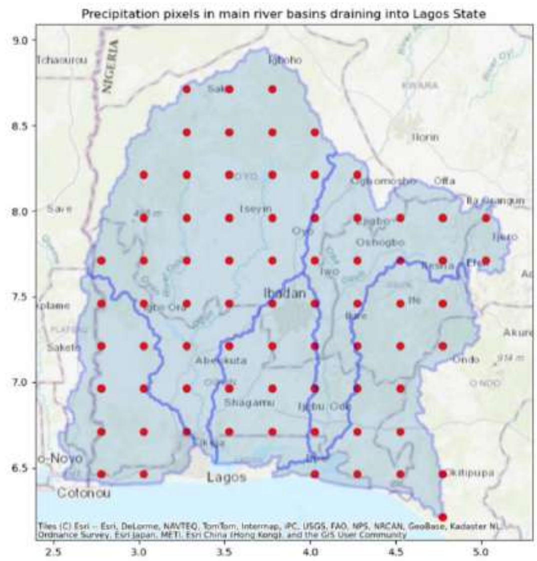


Figure 27: ERA5 pixel centroids for those within the polygon of upstream river basins draining into Lagos State. Figure generated by AXA Climate.

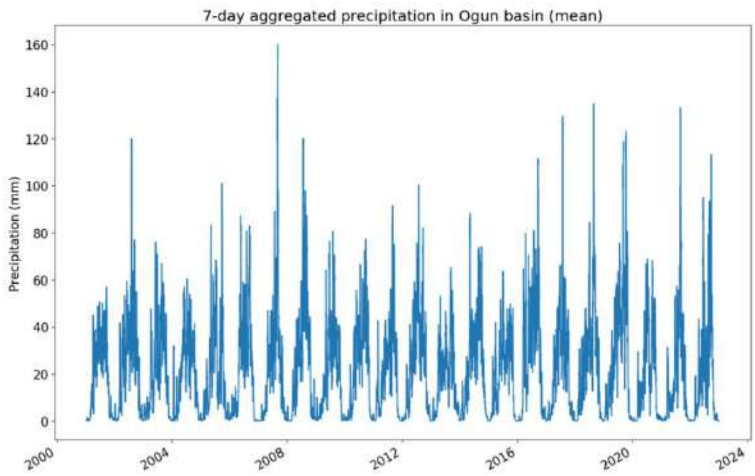


Figure 28: Spatially averaged 7-day ERA5 cumulative precipitation for the Ogun upstream basin. Figure generated by AXA Climate.

- **GPM:** The Global Precipitation Measurement (GPM) dataset is a consolidation of rainfall datasets gather by NASA-JAXA missions Tropical Rainfall Measuring Mission (1998 - May 2014) and GPM (June 2014 - Present) [34]. The dataset is generated from the combination of infrared, microwave and radar satellite signals. GPM was conceived as an extension of the TRMM to improve the precipitation estimates in tropical and subtropical areas, notably by extending the capabilities to capture light rain (<0.5 mm/h), solid precipitation and microphysical properties of precipitating particles (NASA, 2023). The specific GPM product tested in this project is entitled *GPM IMERG Late Precipitation L3 Half Hourly 0.1°x 0.1° V06 (GPM_3IMERGHHL)*, and the variable extracted is *Total precipitation*. Data can be downloaded from NASA EarthData data portal in *.netcdf* format.

- **TAMSAT:** Tropical Applications of Meteorology using Satellite data (TAMSAT) and ground-based observations enhances the capacity of African meteorological agencies and other organizations by providing and supporting the use of satellite-based rainfall estimates, soil moisture estimates and forecasts, and related data products [41]. Using satellite imagery, cold cloud duration (CCD) fields are calculated, where CCD is defined as the length of time the cloud top temperature is colder than Tt. For conversion into units of millimeters CCD is calibrated using rain gauges. Data can be downloaded from the University of Reading in *.netcdf* format.

E.1.3 River level and discharge datasets

River level or discharge indices could serve as the basis for a parametric insurance product designed to cover Local Government Areas (LGAs) at risk of fluvial flooding. It is important to note that only a subset of the LGAs face this type of risk. To comprehensively address the remaining LGAs and account for pluvial flood risk, a combination of river discharge or level indices and an excess rainfall index should be employed. In this context, two types of river datasets have been identified for Lagos State and its upstream river basins.

River levels or discharges measured at hydrometric stations

Hydrometric stations are located in rivers and water courses and bodies. Records of river levels or discharges are taken at a certain frequency (e.g. 1 hour). Available historical time-series of river levels and discharges at hydrometric stations located in river basins draining into Lagos State have been requested to the Ogun-Oshun River Basin Development Authority (O-ORBDA) [42], which have been able to provide the following datasets (river levels and discharge):

- River Ogun at Mokoloki (1980 - 2007, 2013 - 2018).
- River Ogun at Sepeteri (2001 - 2008, 2014 - 2018).
- River Yewa at Ajilete (1980 - 2012, 2003 - 2018).
- River Yewa at Ijaka Oke (1982 - 1999, 2003 - 2018).
- River Owena at Ladin/Ife-Ondo road (2009 - 2018).
- Osun River at Ede (2012 - 2018).
- O-ORBDA Oyan Dam Water Discharge (2020 - 2022).

Besides, O-ORBDA has provided a copy of the Hydrological Yearbook (2014 - 2016) and a Hydrological Drainage map of the river basins draining into Lagos State. The latter includes the location of the hydrological and rainfall stations, as well as the location of dams and river basins that drain into Lagos State (Figure 29).

The abovementioned list of historical discharges and water levels record reveals that most of the datasets have experienced interruptions spanning multiple years, with the latest recorded data for most stations dating back to 2018. This raises questions about whether these stations remain operational today. Additionally, the identified stations are located relatively far upstream from Lagos State, which increases the uncertainty in accurately capturing flood events within the state based on river discharge or level measurements from these distant stations. This uncertainty is further compounded by the presence of water-retaining structures such as dams (e.g., Oyan Dam). Consequently, it is concluded that the mentioned hydrometric stations and their associated datasets are not suitable for establishing a river discharge or level parametric trigger.

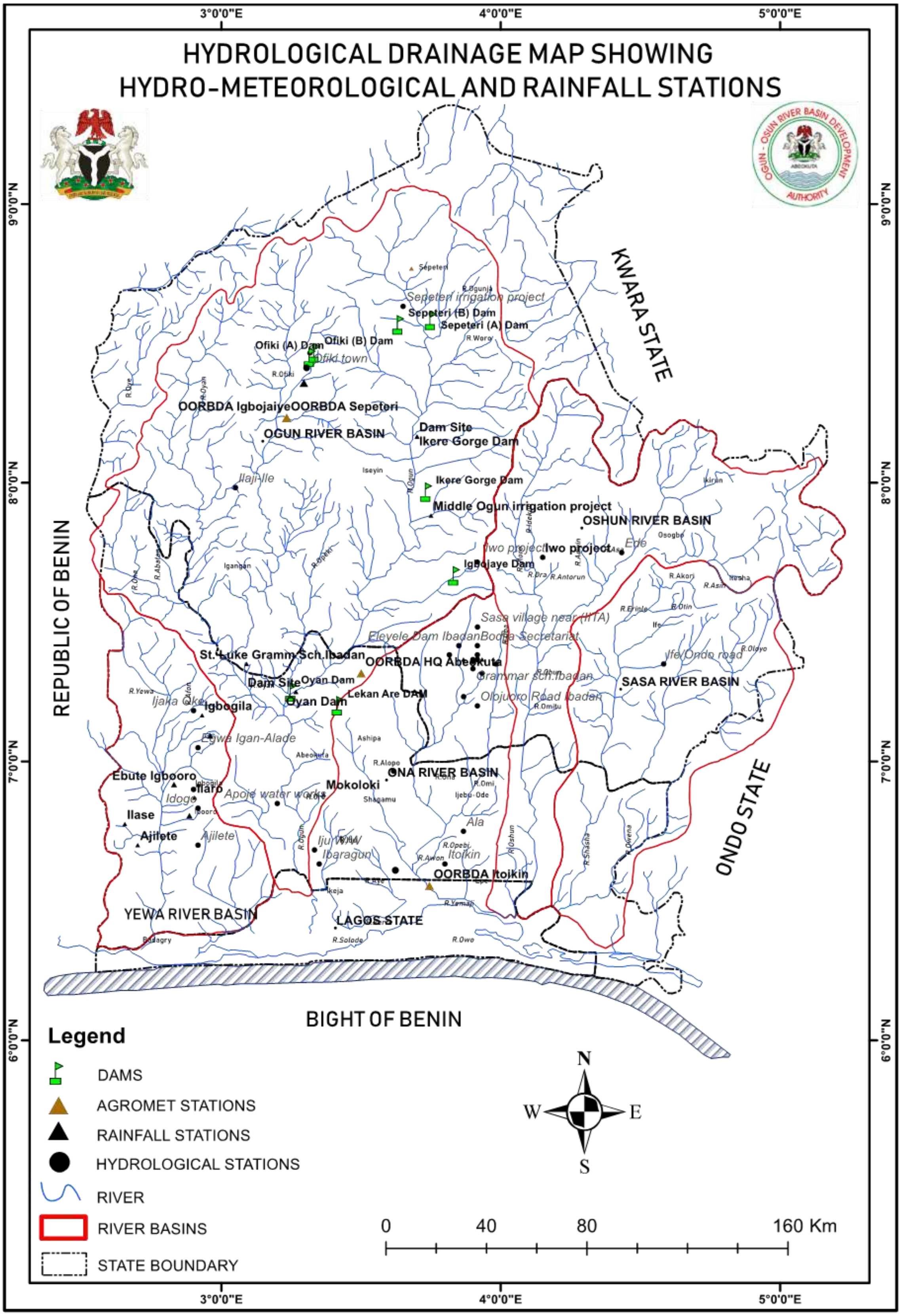


Figure 29: Map of the different river basins flowing into Lagos State, as well as rainfall and hydrological stations, and dams (green marker) [42].

Modelled river discharge datasets

The Global Flood Awareness System (GLOFAS) is a hydrological forecasting and monitoring service that provides global-scale insights into flood risks [43]. Developed through a collaboration between the European Centre for Medium-Range Weather Forecasts (ECMWF) and the European Commission's Joint Research Centre (JRC), GLOFAS is part of the Copernicus Emergency Management Service (CEMS). The system integrates weather forecasts with hydrological modeling to predict riverine floods and monitor river discharge worldwide. GLOFAS offers key features such as global spatial coverage, daily temporal resolution, and long-term historical simulations dating back to 1979. These simulations, alongside real-time forecasting, make it a useful tool for analyzing flood frequency and structuring parametric insurance products. A dataset description is provided in the figure below (Figure 30).

DATA DESCRIPTION	
Data type	Gridded
Projection	Regular latitude-longitude grid
Horizontal coverage	Global except for Antarctica (90N-60S, 180W-180E)
Horizontal resolution	0.05° x 0.05° for version 4.0, 0.1° x 0.1° for version 3.1 and older
Vertical resolution	Surface level for river discharge
Temporal coverage	1 January 1979 to near real time for v4.0, and various dates for legacy versions
Temporal resolution	Daily data
File format	GRIB2
Conventions	WMO standards for GRIB2
Versions	Operational version - GloFAS v4.0 released 2023-07-26. A new river discharge reanalysis will be published with every major update of the GloFAS system. For more information on versions, we refer to the documentation.
Update frequency	Updated daily

MAIN VARIABLES		
Name	Units	Description
River discharge in the last 24 hours	$m^3 s^{-1}$	Volume rate of water flow, including sediments, chemical and biological material, in the river channel averaged over a time step through a cross-section. The value is an average over a 24-hour period.

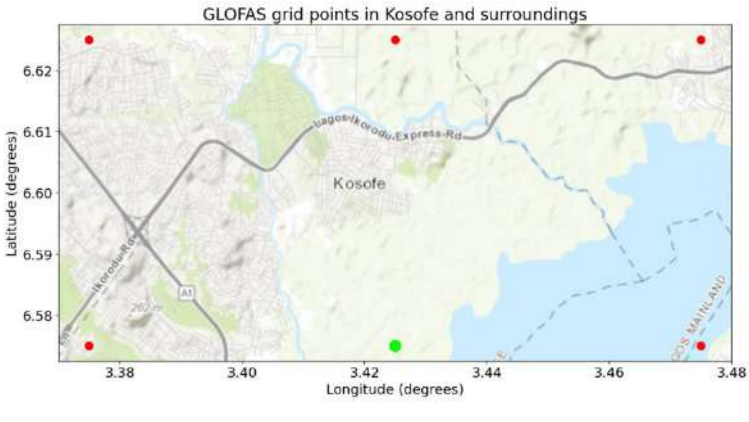
Figure 30: Technical description of the GloFAS river discharge dataset [43].

Given its historical dataset, GLOFAS can be leveraged to conduct a frequency analysis of river discharge. This analysis allows the identification of predefined flood thresholds based on the probabilities of specific river flow events, such as 10-year or 20-year floods. These thresholds can then serve as the triggers for a parametric insurance product. For Lagos State, which is susceptible to significant flood risks, this approach could provide a foundation for creating a transparent and data-driven insurance mechanism. The availability of consistent historical data since 1979 strengthens the reliability of the modelled triggers and ensures the parametric product is underpinned by robust statistical evidence.

While GLOFAS offers a robust framework for analyzing fluvial flood risk, several limitations must be addressed when considering its use for structuring a parametric insurance product for Lagos State. One of the main challenges lies in the diverse nature of flooding in Lagos, which includes pluvial (rainfall-induced urban), fluvial (riverine), and coastal flooding.

- **Coverage of Pluvial and Coastal Floods:** GLOFAS is primarily designed for modelling fluvial floods, focusing on river discharge and flow patterns. However, pluvial flooding, a frequent issue in Lagos caused by intense rainfall and inadequate drainage infrastructure, is not captured in GLOFAS outputs. Similarly, coastal flooding due to storm surges and tidal events – critical in a low-lying, coastal city like Lagos – falls outside the scope of GLOFAS, which does not account for marine or oceanographic dynamics.
- **Spatial Resolution Constraints:** The spatial resolution of GLOFAS, at approximately 0.1° (~10 kilometers), limits its ability to resolve localized flood events in densely populated urban areas. Lagos' heterogeneous landscape, with varying urban densities, drainage systems, and low-lying coastal zones, requires finer-scale modelling to accurately reflect flood impacts. The coarse resolution may result in an underrepresentation of flood risk in smaller basins or urban hotspots.
- **Temporal Resolution Challenges**: GLOFAS provides daily data, which may be insufficient for capturing rapid-onset pluvial floods that occur within hours of intense rainfall—a common phenomenon in Lagos. This temporal limitation makes it less suitable for triggering payouts in cases where sub-daily flood dynamics dominate.
- **Local Calibration Needs**: GLOFAS uses a global hydrological model (LISFLOOD) and may not be calibrated to local hydrological and environmental conditions in Lagos. Variations in rainfall-runoff relationships, river behavior, and urban drainage systems can result in discrepancies between GLOFAS outputs and actual flood occurrences, reducing its reliability for insurance triggers without local adjustments.
- **Historical Data Limitations**: Although GLOFAS provides a long historical dataset for discharge simulations, this dataset primarily reflects riverine flood patterns. Key flood risks in Lagos, such as pluvial and coastal flooding, are absent from the historical record, limiting the ability to develop a comprehensive multi-hazard parametric insurance product.

Below (Figure 31), it is shown as example the time-series of the discharge for the Ogun River at Kosofe (Lagos State) in 2022, as provided by GLOFAS. It can be observed in the graph that GLOFAS captured the peak of the September-October 2022 floods in the Ogun River.



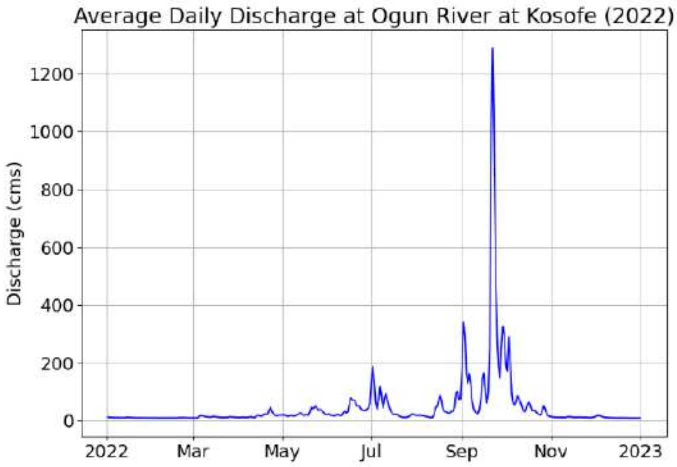


Figure 31: (Top) GLOFAS grid points in the surroundings of Kosofe (north of Lagos State) are shown in red. The green point is the one having the maximum river discharge, therefore supposedly representing the Ogun River. (Bottom) Time-series of Ogun River discharge in 2022. Figure generated by AXA Climate.

GLOFAS offers significant advantages for analyzing fluvial flood risk and structuring parametric insurance products, particularly through its long historical record of river discharge simulations. However, its limitations in addressing pluvial and coastal flooding, as well as its coarse spatial and temporal resolution, must be mitigated for effective application in Lagos State. By integrating GLOFAS with additional datasets and localized modeling efforts, a robust, multi-hazard parametric insurance product can be developed to address the diverse flood risks faced by the region. This combination of global and local tools will ensure that the product is both data-driven and responsive to the unique challenges of flood risk in Lagos.

E.1.4 Sea level datasets

Modelled sea level datasets

The dataset titled *Global sea level change time series from 1950 to 2050 derived from reanalysis and high resolution CMIP6 climate projections* [44] offers comprehensive data on sea level variations, encompassing tides, storm surges, and sea level rise over a century-long period. Developed through hydrodynamic simulations with the Deltares Global Tide and Surge Model (GTSM) version 3.0, it utilizes outputs from five climate models of the HighResMIP (High Resolution Model Intercomparison Project) multi-model ensemble, part of CMIP6 (Coupled Model Intercomparison Project Phase 6). This ensemble is specifically tailored for assessing climate extremes, benefiting from high-resolution models with at least 50 kilometer in the atmosphere and 0.25° in the ocean. The dataset spans from 1950 to 2050, with the historical period (1950-2014) largely constrained by observations, and the future period (2015-2050) corresponding with the high-emission scenario SSP5-8.5. Additionally, a reanalysis dataset is included, computed by forcing GTSM with ERA5 reanalysis from 1979-2018, providing recent historical water levels useful for examining specific extreme events in the past (Figure 32).

Data Description	
Dataset title	Global sea level change indicators from 1950 to 2050 derived from reanalysis and high resolution CMIP6 climate projections
Data type	Reanalysis / Climate projections
Topic category	Sea and coastal regions, Natural hazard
Sector	Coastal flood risk, integrated coastal zone management, harbor and port
Keyword	Extreme sea level, CMIP6, time series
Domain	Global
Horizontal resolution	Coastal grid points: 0.1° Ocean grid points: 0.25°, 0.5°, and 1° within 100 km, 500 km, and >500 km of the coastline, respectively
Temporal coverage	ERA5 reanalysis: from 1979 to 2018 Historical: from 1950 to 2014 Future (SSP5-8.5): from 2015 to 2050
Temporal resolution	10min (all), hourly and daily maximum (reanalysis only)
Vertical coverage	Surface
Update frequency	No updates expected
Version	1.0
Model	Global Tide and Surge Model (GTSM) version 3.0
Provider	Deltares (Kun Yan)
Terms of Use	Copernicus Product License

Figure 32: Overview of key characteristics of the water level change time series [45].

While the Global Sea Level Change dataset provides valuable insights, its limitations must be considered in the context of a parametric insurance product designed for Lagos State. Similar to GLOFAS, the dataset has constraints related to its focus, resolution, temporal scope, and applicability to local conditions.

- **Exclusion of Pluvial and Fluvial Flooding:** While GLOFAS neglects urban and coastal flooding, this dataset excludes riverine or rainfall-induced urban flooding, which are integral to the comprehensive flood risk in Lagos.
- **Regional-Level Data:** Despite its high resolution, the dataset may not provide sufficient detail to capture localized flood dynamics in Lagos, especially in urbanized or low-lying coastal areas with complex topography and land use. This limitation is similar to GLOFAS' inability to resolve small-scale flood events due to its coarse resolution.
- **Localized Variability:** Regional sea level variations influenced by land subsidence, shoreline dynamics, and sediment transport are not always adequately represented in global-scale models.

Given these limitations, the Global Sea Level Change dataset is not suitable for structuring a parametric insurance product for Lagos State.

E.1.5 Flood hazard models

Hydraulic (flood) models play a crucial role in structuring parametric flood insurance by simulating flood dynamics and generating flood depth and extent maps. These models use hydrological inputs such as rainfall, river discharge, and sea level data to estimate how water moves through landscapes, providing a detailed representation of flood-prone areas. By leveraging these simulations, parametric insurance products can be designed with clear, measurable triggers based on flood depth and extent thresholds. In the following paragraphs, we describe the JBA Flood Model, a widely used hydraulic modeling framework for flood risk assessment and insurance applications.

JBA's probabilistic Global Flood Model framework

A quarter of today's population is at risk of flood. With population centers likely to become even more vulnerable to flood events in coming years, insurance and risk management professionals need an understanding of potential flood frequencies and severities on which they can rely. Probabilistic flood models provide an important way to produce useful flood risk information for insurers, reinsurers, financial institutions and public sector bodies alike.

JBA's Global Flood Model is the first model to offer probabilistic modelling in every country worldwide. It incorporates JBA's global flood maps and global flood event set, providing users with a highly configurable probabilistic model capable of generating losses across 99.98% of the global landmass (excluding Greenland and Antarctica). Its features include:

- A global probabilistic river and surface model and the first flood model available in many countries worldwide.
- The ability to quantify flood risk, at high resolution, for any location in the world.
- Consistent comparison of loss across country and continental borders.
- 30 meter mapping of river and surface water in all territories, with the possibility to upgrade to JBA's 5 meter mapping in the US and Europe.
- Explicit modelling of tropical cyclone and non-cyclonic events.

The image below shows the different model components of JBA's probabilistic flood model framework, i.e. exposure, vulnerability and hazard (Figure 33). The latter component is further broken down into a stochastic event set and flood hazard maps. This enables FLY, JBA's revolutionary analysis engine, which is different to the traditional catastrophe model workflow, in that there is no upfront build process, permitting unprecedented user control and on-the-fly risk quantification for any given location worldwide.

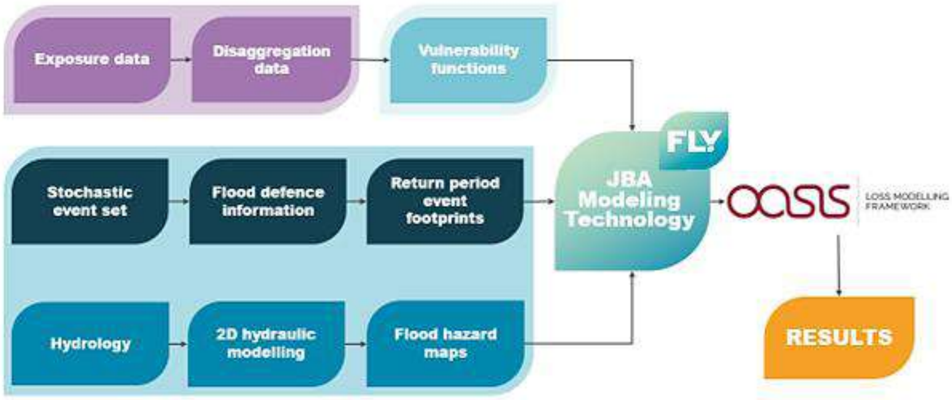


Figure 33: JBA Risk Management modelling framework. Figure generated by JBA.

Stochastic event-based simulation

JBA's Global Flood Event Set includes over 15 million simulated events across 16 independently modelled regions. The synthetic precipitation and streamflow in the event set are conditioned on a mix of available observations (historical data) and reanalysis data. Importantly, the Global Flood Event Set contains flood events that are more extreme (but still physically plausible) than have been observed in recent history. The modelling approach reflects the need to simulate catchment antecedent conditions (which influence river (fluvial) flooding) and extreme precipitation (which causes both river and surface water (pluvial) flooding). The regionally calibrated rainfall-runoff approach allows the generation of river flooding at locations without flow gauges. The results of the simulations are time series of daily intensities which are then grouped into events.

Detailed inundation mapping

Flood is an extremely localized peril, so aggregating data across large areas can have a detrimental impact on the quality of the loss calculation. The Global Flood Model fully exploits the high resolution of JBA's market-leading Global Flood Map without smoothing or summarizing the underlying data to shorten analysis run times or reduce data volumes. The Global Flood Map (Figure 34) provides river and surface water flood extents and depths at a 30-meter resolution for a variety of return periods (i.e. 20, 50, 100, 200, 500, 1500 years) and can be combined with defense information. The map is created by using observed river and rainfall data to generate extreme rainfall and river flow volumes and allowing those volumes to spread across the terrain using hydraulic modelling. River modelling captures flooding from larger rivers with a catchment area over 500 square kilometers and surface water modelling captures flooding from smaller rivers and locations where rainfall pools in topographical depressions.

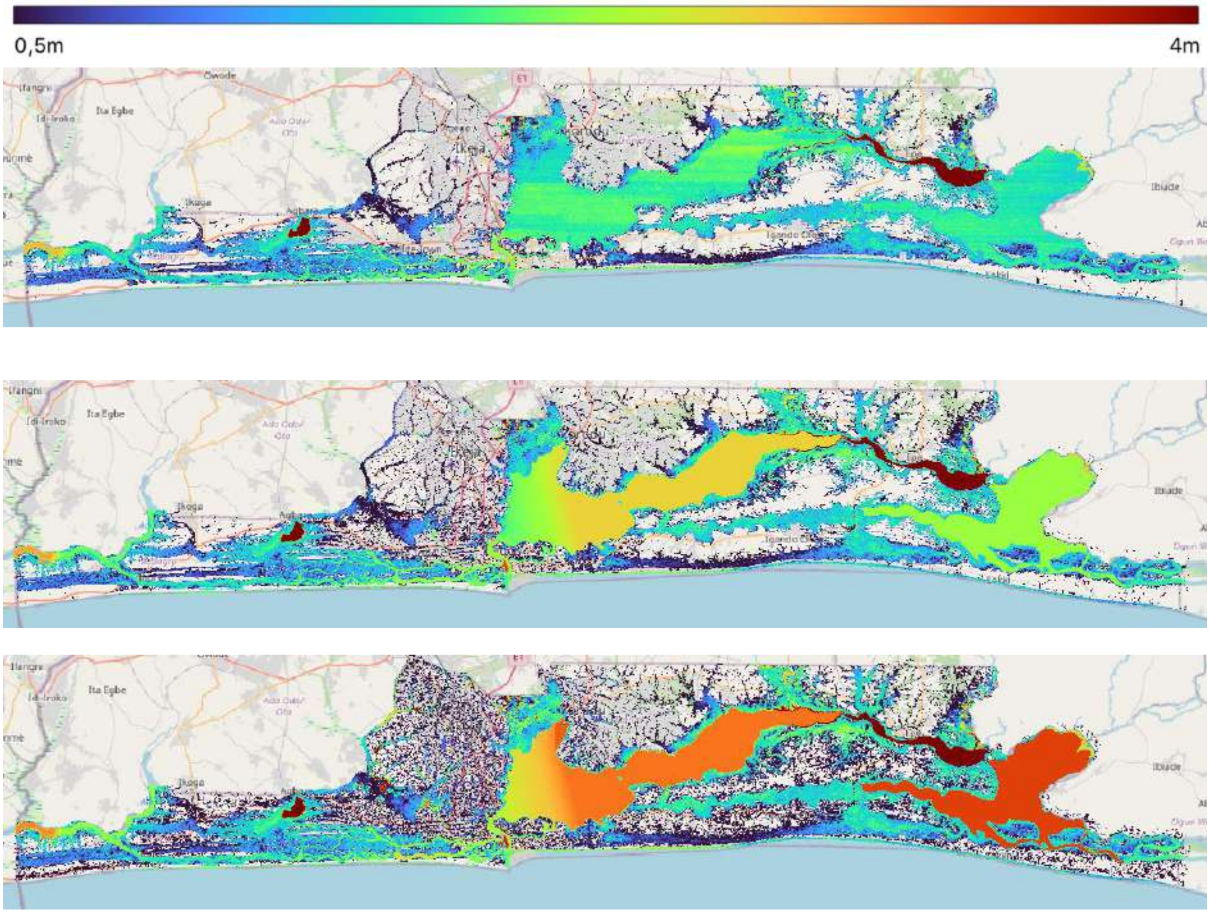


Figure 34: 20-, 100- and 1500-year return period flood depth map for Lagos State (fluvial, pluvial and coastal combined), with warm colors indicating higher inundation. Figure generated by JBA.

The coastal flood maps for Lagos State were specifically developed for this project using JBA's coastal projection modelling software. The process begins by using JBA's coastline to define a modelling area that extends both inland and offshore, ensuring that islands and any complex coastal topography are captured. Extreme Sea Levels (ESL), taken from a peer-reviewed global dataset, were projected across the modelling area. After an initial evaluation of two ESL datasets: CoDEC [46] and Coast-RP [47], the latter was selected. The modelling tool compares the projected extreme water level with land elevations, represented by an underlying Digital Terrain Model (DTM), ensuring any flooded areas are hydrologically connected to the sea. Initial tests were carried using Copernicus (30-meter resolution DSM, followed by the use of high-resolution (2.5 meter) LiDAR data provided by the Office of the Surveyor General, Lagos State. The final coastal flood map was produced in a format consistent with JBA's pluvial and fluvial flood maps, providing coastal flood extent and depth information for a range of return periods.

<u>*Loss estimation*</u>

FLY makes direct use of the location information in an insurance portfolio, like the people-based portfolio in this project, and combines this on the fly to generate a model that is customized for the portfolio. The user can bring a model into being at runtime directly from event set, hazard, vulnerability and other data of their choosing. In this example for Lagos State, the vulnerability component was implemented as a binary function where any exposure results in a full loss when affected by a flood depth equal or above 50 centimeters. The resulting analysis includes the best possible analysis resolution for the exposure data and at the same time offers markedly improved run times which was crucial during the policy pricing stage of the project.

E.2. Assessment of excess rainfall indices for parametric insurance product

This part explores the possibility of using rainfall indices for Lagos parametric insurance product. It is conducted in two parts:

- First, a comparison and correlation study between ground-based and satellite precipitation data. Since weather stations provide reliable precipitation measurements, this step assesses the performance of satellite and reanalysis data in accurately representing actual precipitation recorded on the ground.
- Second, a correlation study between satellite and reanalysis precipitation indices and historical flood losses. This analysis evaluates the ability of rainfall indices to capture flood events, particularly the most severe ones.

Finally, a conclusion on the relevance of excess rainfall indices for Lagos parametric insurance product will explain our choice to proceed with flood depth and extent parametric product.

E.2.1 Correlation analysis between satellite precipitation data and weather station data

To assess the reliability of satellite precipitation data, several satellite and reanalysis datasets (CHIRPS, ERA5, TAMSAT, and GPM) were compared against ground-based observations from a weather station at a specific location. This approach assumes that the weather station data represents the ground truth. The closest ground station to Lagos State with a satisfactory data completeness ratio in the Speedwell database [48] is the Cotonou station in Benin, as shown in

Figure 35.

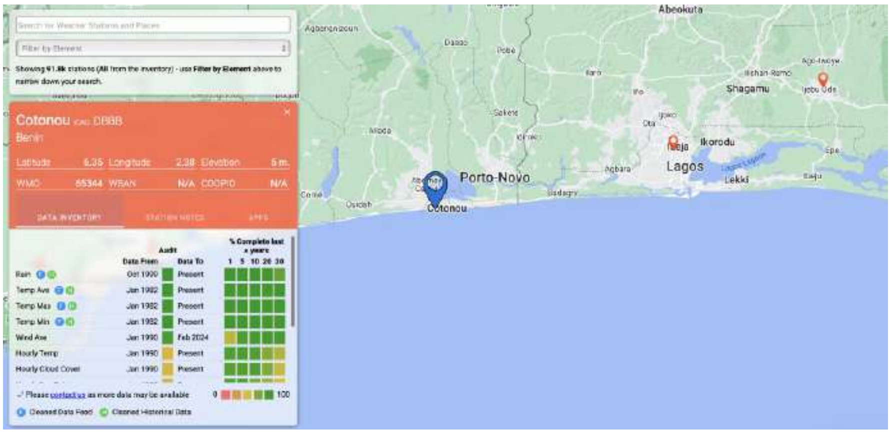


Figure 35: Screenshot from the Speedwell platform indicating the position of Cotonou ground station and the completion percentage for several climate variables, especially rainfall [48].

For the correlation study, different metrics were used to compare the gauge rainfall observation on the weather station in Cotonou and the satellite precipitation estimations at the pixel intersected, or closest by, the coordinates of the weather station. The equations defining the four metrics correlation, root squared mean error (RMSE), mean error (ME) and bias are given in Appendixes 7 and 8.

After conducting the comparison study, we obtain the results displayed on Table 8:

Table 8: Assessment of the performance of four different satellite and reanalysis data sources by comparing their daily precipitation estimates to the precipitation recorded by the weather station.

	Precipitation (ERA5)	**Precipitation (TAMSAT)**	**Precipitation (GPM)**	**Precipitation (CHIRPS)**
Correlation	25.3%	51.6%	41.4%	45.0%
RMSE	11.37	9.68	13.59	10.57
ME	0.003	-0.608	-0.881	-0.212
Bias	1.001	0.847	0.793	0.941

As observed in the table, the correlation remains low for daily rainfall, with a maximum of 51.6% and significant RMSE values. The analysis indicates that TAMSAT data best represents ground-measured rainfall, while GPM and CHIRPS also show acceptable performance. In contrast, ERA5 performs poorly and can be disregarded. Additionally, all three satellite sources tend to underestimate ground rainfall, with bias values below 1.

The low correlation between satellite-derived and ground-based daily precipitation is a well-documented issue, which our study in Porto-Novo confirms. However, this analysis focuses solely on daily values and does not assess the ability of satellite data to capture major flood events. It is possible that while satellite data may struggle with normal rainfall measurements, it could still provide a reasonable approximation of extreme precipitation through specific indices. The next subsection explores this aspect in detail.

E.2.2 Correlation analysis between satellite precipitation data and historical flood loss record

To assess the capacity of satellite and reanalysis-derived precipitation indices to capture historical flood events, a selection of indices commonly employed in excess rainfall parametric products was compared to reported historical floods. These indices are calculated for TAMSAT, GPM and CHIRPS (ERA5 has been disregarded based on proved poor reliability in previous analysis). The daily rainfall per dataset is computed as the average of the daily rainfall of all the pixels intersecting the polygon of Lagos State [2]. An example of the selected pixels for GPM is shown in Figure 36. The rest of the indexes are elaborated from the spatially aggregated daily rainfall for each data source. The risk period is the same for all the indices and runs from May 1st to August 31st.

The indices used for this exercise are:

- Maximum daily rainfall for the risk period.
- Cumulative daily rainfall for the risk period.
- Maximum 5-days cumulative rainfall for the risk period (daily rolling window).
- Maximum 10-days cumulative rainfall for the risk period (daily rolling window).

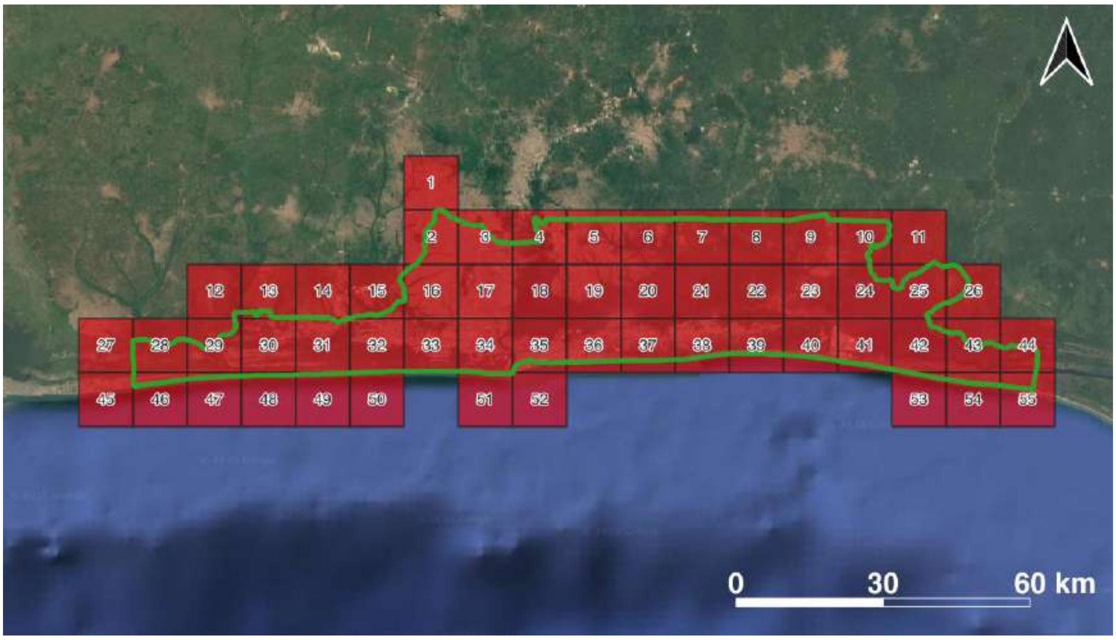


Figure 36: GPM pixels intersected by the polygon of Lagos State. The numbers represent the IDs of the pixels. Figure generated by AXA Climate.

Subsequently, the worst years identified by each index were selected, and the number of years aligning with recorded historical losses was calculated. Two hit rates were then computed: the first considering the nine most severe historical floods (severity levels 2 and 3), and the second focusing exclusively on the two most extreme events (severity level 3). The results are presented in Table 9 and Table 10 below.

Table 9: In red, annual maximum indices during the risk period May to August for different rainfall data sources and different temporal aggregation. In green, historical event severity levels.

	Max			Cumulative			Max 5 days cumulative			Max 10 days cumulative			Historical losses
Year	GPM	TAMSAT	CHIRPS	GPM	TAMSAT	CHIRPS	GPM	TAMSAT	CHIRPS	GPM	TAMSAT	CHIRPS	Severity
2000	41,90	43,55	42,51	434,0	937,4	810,2	86,1	135,3	171,9	132,2	224,3	224,3	1
2001	59,43	39,49	39,74	678,7	778,5	741,2	116,4	77,6	85,0	150,1	131,8	139,0	
2002	59,65	48,48	63,79	731,9	1025,2	996,3	120,6	135,9	144,8	210,4	219,3	222,5	1
2003	44,72	36,86	33,97	528,5	787,0	610,8	109,8	104,4	92,1	171,4	162,7	141,5	
2004	76,97	41,57	42,77	844,2	745,8	713,3	145,2	92,1	121,1	186,4	155,6	156,1	1
2005	73,91	36,60	70,62	893,8	909,8	1001,0	143,2	90,0	160,4	194,6	165,2	262,0	2
2006	76,96	38,29	47,89	916,0	861,0	868,4	137,1	108,1	92,7	203,2	153,5	144,1	
2007	81,47	41,82	83,68	887,1	1066,1	1155,6	125,8	127,2	189,5	185,6	187,2	278,9	2
2008	69,95	38,76	43,55	918,1	1238,1	1065,1	106,6	113,7	103,7	147,2	186,6	182,8	1
2009	56,87	38,18	65,85	761,1	907,7	974,9	169,7	104,8	142,6	198,7	172,7	219,1	1
2010	69,66	48,40	54,90	1000,6	961,6	982,0	112,1	115,5	133,0	174,0	183,4	193,0	2
2011	128,46	44,92	55,29	1040,1	1167,3	920,8	188,2	121,3	130,2	267,0	214,0	191,9	2
2012	117,73	38,50	66,28	951,5	788,0	916,0	229,0	114,4	154,5	287,3	185,1	293,1	3
2013	51,13	29,22	42,55	782,1	855,1	679,2	94,8	86,0	74,6	138,8	128,6	105,8	
2014	67,94	41,93	55,64	1096,4	940,1	1020,4	126,6	98,7	119,6	201,0	181,4	205,4	1
2015	43,75	28,21	45,14	568,6	688,7	640,1	71,2	76,3	104,8	99,9	129,7	164,9	1
2016	78,56	47,74	51,11	731,2	834,9	734,9	137,3	114,1	100,6	187,8	196,1	190,3	1
2017	52,31	34,69	51,69	1112,9	1091,0	1027,4	165,0	123,3	116,9	232,9	199,0	196,7	2
2018	61,44	38,41	46,89	795,8	911,3	834,1	110,5	102,9	80,5	168,3	167,1	144,4	2
2019	64,16	35,18	51,08	788,4	993,2	883,1	100,0	87,3	122,8	157,0	146,8	163,4	1
2020	70,72	36,03	51,99	842,3	827,3	686,7	135,6	99,0	121,5	215,4	170,4	199,4	1
2021	69,91	35,40	48,13	829,5	903,0	765,0	88,2	82,8	93,4	168,8	151,2	144,9	2
2022	54,62	35,18	42,54	565,9	861,9	669,2	98,7	112,9	87,6	163,2	171,1	150,1	3
2023	62,17	34,68	49,12	770,2	942,9	910,3	93,5	109,1	120,2	143,5	137,7	190,6	1

Table 10: Hit rate on severity 2 and 3 events and hit rate on severity 3 events only calculated as the 9 (respectively 2) worst years according to the index overlapping with the 9 (respectively 2) historical flood events.

	Max			Cumulative			Max 5 days cumulative			Max 10 days cumulative		
Year	GPM	TAMSAT	CHIRPS	GPM	TAMSAT	CHIRPS	GPM	TAMSAT	CHIRPS	GPM	TAMSAT	CHIRPS
Hit rate on severity 2 and 3 events	0,44	0,33	0,56	0,67	0,44	0,56	0,44	0,56	0,56	0,44	0,56	0,44
Hit rate on severity 3 events only	0,50	0,00	0,00	0,00	0,00	0,00	0,50	0,00	0,00	0,50	0,00	0,50

From Table 9 and Table 10, it is evident that the best representations of historical losses are the GPM annual maximum daily precipitation, GPM maximum 5-day cumulative precipitation, and the GPM and CHIRPS maximum 10-day indices. However, the overall performance of these indices is poor, as the hit rates are generally low, ranging from 44% to 56%, with only one reaching 67%. None of the precipitation indices manage to capture the 2022 flood, and only four are able to capture the 2012 flood. Specifically, in Figure 37, which shows timeseries for the maximum daily per month and maximum 5-day cumulative indices, no peaks comparable to the 2012 flood are observed in 2022.

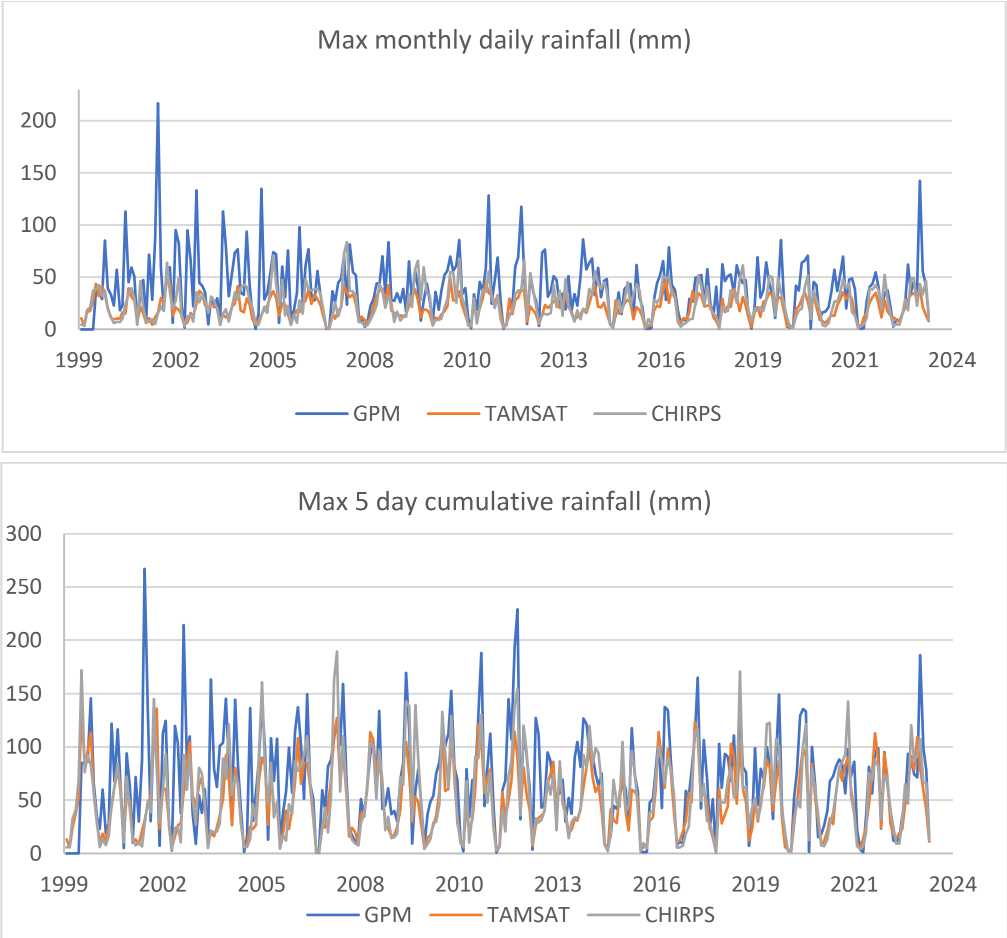


Figure 37: (Top) Rainfall timeseries from three different satellite and reanalysis data providers, for monthly maximum values, (bottom) and maximum over cumulative 5-day values. The timeseries run from 2000 to 2024, but do not show significant signals for the 2022 floods. Figure generated by AXA Climate.

E.2.3 Conclusion on the rainfall data analysis and product development

It has been decided not to proceed with an excess rainfall parametric insurance for the following reasons:

- **The correlation with the historical flood events is poor:** As shown in Table 10, the correlation between satellite data and weather station data is poor (scores between 25% and 52%).
- **The indexes fail to capture the severity of the floods:** Indeed, none of the proposed index manage to capture the 2022 flood event, and most of the indexes fail to capture 2012 flood event. This can be explained by the poor accuracy of strong local rainfall by satellite-based measurements, or by the dominance of other drivers of flood than precipitation in the historical flood events (such as man-made influence, for example the clogging of drainage channels).

To overcome the difficulties faced by the excess rainfall index, it is proposed to investigate the suitability of a flood depth and extent index for parametric insurance (Section E.3).

E.3. Assessment of flood depth and extent index for parametric insurance product

The above detailed analysis of all available rain data has shown that the rainfall parameter is not suitable for a qualitative parametric flood coverage. The project team does instead recommend basing the insurance scheme on a much more accurate data set that stems from actual observations of the occurrence of flood, a flood footprint. The reasoning for this recommendation is based on the following arguments:

- **Availability:** Flood footprint data now is available globally at very high temporal and spatial resolutions and successfully tested for Nigeria and the parametric use case.
- **Reduction of basis risk:** Flood monitoring and detection means that we directly observe the impact and make informed decisions about insurance payments. This is much closer to the problem setting compared to precipitation data, so we reduced basis risk.
- **Tailoring:** An insurance scheme based on accurate flood footprints can be tailored to the target population, the poor and vulnerable of Lagos State.
- **Costing accuracy:** Instead of developing the price of the insurance program based on historic data, this approach would support the utilization of probabilistic flood hazard models. This increases the trust in the underwriting process.
- **Additional data usage:** This solution will also allow other entities of Lagos State to make an informed decision on flood emergency relief, as the flood footprint data could be made available and integrated to their systems.

E.3.1 Experience with parametric flood insurance based on flood footprints

Fueled by technological advancements, a lot of progress has been made in the past years on the development of parametric flood insurance products. The data was tested successfully and some first pilot programs implemented.

Case study: New York City, USA

The area surrounding New York City is increasingly prone to sea level rise and floods. Currently, 780'000 of New York City residents live within or directly adjacent to the 500-year floodplain. Low- to moderate-income residents are disproportionately affected and struggle to access financial resources to recover after a flood. The Center for NYC Neighborhoods (CNYCN) in partnership with the Mayor's Office of Climate & Environmental Justice, the Environmental Defense Fund and SBP USA sought a solution to help better protect those residents from flood risk.

Swiss Re partnered with reinsurance broker, Guy Carpenter, and the data technology firm ICEYE to develop a parametric flood insurance policy that provides up to USD 1.1 million in emergency funding [49]. The solution leverages high-resolution data obtained through a mix of real-time satellite data, on-the-ground real-time sensors, and social media. When a flood occurs, the percentage of each insured neighborhood inundated by floodwaters is determined and if the percentage exceeds the agreed threshold, a payment is issued to CNYCN, who will subsequently distribute grants to households. This novel parametric insurance solution was awarded the Innovation Award at the 2023 Axco Global Insurance Awards.

If the policy is triggered, residents of flood-affected households who qualify are eligible to receive a grant from CNYCN of up to USD 15'000, intending to support affected low- to moderate-income communities recover more quickly after a severe flooding event. The pilot program incepted on February 1, 2023.

Case study: Accra, Ghana

Very similar to Nigeria, Ghana is a Western African country that is also very prone to flooding. Over 30 major floods affected more than 4.5 million people since 1955. In addition, the impact of rapid urbanization and climate change is exacerbating the risk of flooding in urban areas. The 2015 flood in Accra was reportedly amongst the ten deadliest disasters worldwide. Poor and vulnerable households are disproportionately affected from disaster losses due to their high exposure and lack of financial protection.

In 2022, Insurance Development Forum (IDF) members Allianz and Swiss Re, the United Nations Development Program (UNDP) and the German government launched a project with Ghana's Ministry of Finance to design a potential risk transfer mechanism for urban floods using a parametric insurance cover [50]. This is a sister project to the one in Lagos State, however started a little earlier. Similarly, the core beneficiaries are the poor and vulnerable residents in the Greater Accra Metropolitan Area.

For this project ICEYE's satellite technology was extensively tested against historic events and flood models. It was concluded that, similar to Lagos State, a parametric flood footprint solution based on ICEYE's data is the recommendation to the government.

While developing a potential insurance solution for major floods, the project also aimed to enhance the disaster response capacity of Ghanaian institutions through increased access to data, detailed risk insights, and activation of contingency protocols.

Case study: Comparison of Modelled and Observed flood extent in Australia (JBA)

Advancements in earth observation technology and flood modeling have significantly contributed to the development of parametric flood insurance products. While these innovations offer promising solutions, they also pose challenges, particularly in ensuring robust historical data for probabilistic modeling. Many of these technologies have been in use for less than a decade, limiting the availability of long-term hazard data needed to construct stochastic event sets spanning thousands of years. This makes it essential to validate the correlation between model-based flood risk assessments used for pricing and structuring parametric products and the real-time earth observation data used for triggering payouts.

A relevant case study in Australia (Figure 38) illustrates how model-generated flood extent compares with satellite-derived observations. JBA's probabilistic flood model, developed using its 2D hydraulic modeling software JFlow, produces flood maps for key return periods, detailing both flood depth and extent. Meanwhile, ICEYE's flood footprint, derived from synthetic aperture radar (SAR) data, provides real-time measurements of the same parameters. A comparative analysis between these two datasets for a flood event in Windsor and Richmond, Australia, revealed a strong match, suggesting that both methods rely on similar digital elevation models and share comparable levels of resolution and accuracy.

For the Sovereign Parametric Risk Transfer Scheme for Urban Floods in Lagos State, maximum flood extent at a pre-defined flood depth level serves as the hazard severity trigger. While a direct comparison between ICEYE's event footprint and JBA's flood hazard maps could not be performed for Lagos due to data limitations (no significant flood had been observed during the development phase), similar comparative analyses in Europe, Latin America, and the UAE demonstrated a satisfactory alignment between modeled and observed flood extents. These findings support the robustness of using flood footprint data as a trigger mechanism and indicate that basis risk from a hazard perspective is not a significant concern.

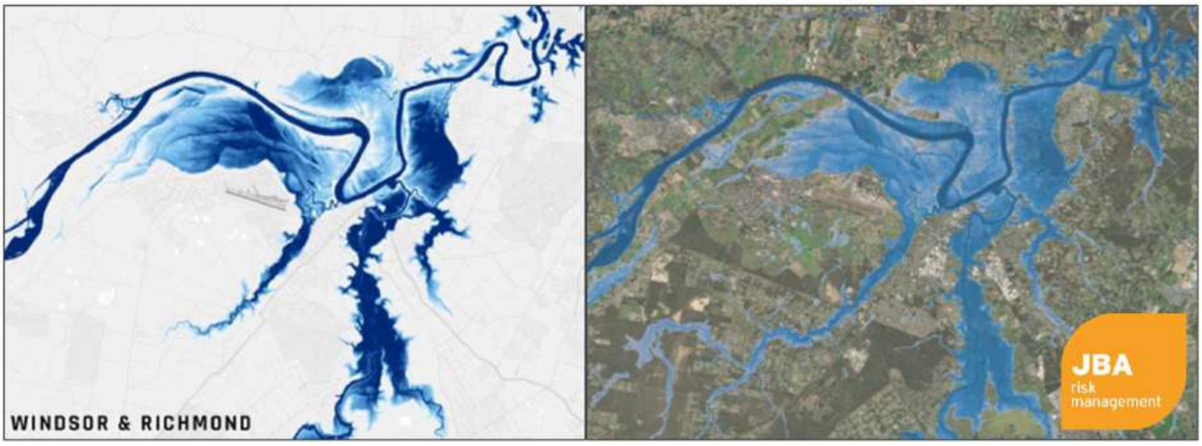


Figure 38: Visual comparison between ICEYE observation footprint and JBA's 100 yr river flood return period flood map for the area of Windsor and Richmond in Australia. Figure generated by JBA and ICEYE.

F. Parametric insurance options

F.1. Introduction to parametric flood risk transfer solutions

Parametric insurance enables quick cash disbursements to the insured because it can be triggered solely by measurement of a naturally occurring parameter. No lengthy loss adjustment is needed, and the payment proceeds can be used flexibly. Parametric insurance can therefore meet fundamental needs that traditional indemnity-based insurance cannot. It can be a suitable instrument to transfer the risk of traditionally uninsurable cost items, such as the immediate costs of emergency relief measures. For this project, it was decided to assess and develop the possibilities of parametric insurance, specifically adapted to the vulnerable population of LS. Assessing the feasibility of different parametric trigger options and the technology that reliably monitors the parameters are critical elements during the design phase of any parametric scheme.

Therefore, when designing well-structured schemes, two main dimensions must be considered:

- The parameters must be measured independently and consistently by a neutral third party and accepted as contractually binding trigger by insurer and insured, i.e. reflect the insured's needs at specified levels of risk.
- For accurate pricing, insurers must well understand probabilities of breaching critical trigger levels, either by (i) long enough consistent historic data of the parameter for an experienced-based costing model, or by (ii) state-of-the-art probabilistic hazard models.

Due to the project team extensive technical experience with parametric insurance, it was initially possible to consider a wide array of parametric insurance options for this project. The spectrum of trigger options ranges from more indirect, simple but established triggers to more direct, state-of-the-art satellite-based triggers. Each trigger type presented different benefits and challenges in terms of accuracy, reliability, risk assessment and implementation.

Below, it is provided a summary of the two distinct groups of trigger mechanism types that were considered:

- **Option 1: Rainfall or river runoff** are among the most used and tested options. Such parametric triggers are based on precipitation or river measurement data and the principle that heavy rainfall or increased river discharge can indicate flooding (proxy data). Over the past decades, the availability and quality of data have significantly improved the correlation of such proxy data to flooding. Rainfall or river runoff triggers have proven useful because their simplicity makes them relatively easy to develop, easy to understand and easy to communicate. However, problems with data quality and increased basis risk often still exist (see Section F.3.1). During the course of this project, such indices have been tested intensively and found deemed unsuitable for our purpose (Section E.2).

- **Option 2: Flood footprint data**, i.e. the direct observation of non-permanent and standing water on the ground, is more directly related to flood damage. Due to the complex nature of the peril, precise flood observations require specialized infrastructure that leverage remote sensed technology to detect and delineate inundated areas accurately. This means that data tends to be new and there is usually relatively little history available. Determination of the right level of risk, the occurrence likelihood of impactful floods, related to this trigger option, requires access to high-resolution flood hazard models. Flood footprint triggers are therefore often perceived to be less transparent, and their novelty can make it more challenging for underwriters. If structured and modelled properly, however, this second option offers a great advancement over proxy data, helping minimize basis risk further.

Table 11: Summary of key available technologies that may be considered as a basis for parametric flood insurance triggers. For this project, the two options highlighted in green were fully developed.

		Technology	Short description	Historic data availability	Basis risk	Price
Option 1	**Precipitation**	Remote sensing	Rainfall measurements based on satellite technology on a coarser, typically global grid.	Typically, good historic data.	High	Most data free of charge.
		Weather stations	Rainfall measurements on high temporal resolution at irregular points (where available).	Can have good historic data, but not guaranteed.	Low at station location, high the further away from the stations.	Some data free of charge, some commercially available.
	River	River gauges	River flow measurements on high temporal resolution at irregular points (where available).	Can have good historic data, but not guaranteed.	Low at point, high the further away.	Most data free of charge.
Option 2	**Flood observation**	Remote sensing (optical)	Measurements of non-permanent water based on optical satellite technology. Various public and private sources, typically available globally.	Can have good historic data, but not guaranteed.	Medium	Some data free of charge, some commercially available.
		Remote sensing (radar)	**Measurements of non-permanent water based on radar satellite technology. Various**	**Can have good historic data, but high-resolution data**	**Low**	**Some data free of charge, high-resolution data**

			public and private sources, typically available globally. Results often enhanced with auxiliary data.	**is only recently available.**		**is commercially available.**
		Water sensors	Measurements of non-permanent water based on specialized sensors at irregular points (where available).	Often no established networks available.	Very low at sensor location, high the further away from the sensors.	Usually, expensive and installation can be challenging.
		Ground reports, social media	Detection of non-permanent water based on georeferenced images by private and official resources.	Some historic data available, but highly variable and decreasing quality the further back in history.	Medium, varies case-by-case	Some data free of charge, typically commercially available.
		Modelled flood	Flood footprint as result of model output from specialized hydrological agencies.	Typically based on rainfall input, i.e. historic data often available.	Medium	Mostly commercially available.

For urban areas, accurate and timely flood detection is particularly challenging. Localized and intense rainfall often results in flash flooding which can significantly impact the typically dense concentration of assets in urban areas. An ever-increasing trend towards urbanization is leading to complex and changing drainage of water runoff, as new buildings, infrastructure, means of transport and garbage can obstruct and constantly divert the flow of water. Overburdened sewage systems can also lead to flooding in unpredictable places. In general, monitoring is very difficult as remote sensing needs to consistently penetrate to street level from all angles or, alternatively, a large network of flood detection sensors needs to be installed or maintained. As a result, insurers sometimes shy away from underwriting parametric flood in urban areas. This often is due to unsuitable flood hazard models.

The project team had to consider the appetite of the insurance market and, for the reasons outlined above, decided to offer two different solutions at the broad end of available technologies. Despite some technicalities, both parametric trigger options were kept as simple as possible.

At the start of the project most of the available options, as shown in Table 11, were considered. After extensive testing the project team determined that two are the most suitable for the purpose of the project (highlighted in Table 12). Detailed work on both trigger options contributed to improving the general knowledge of the flood situation in LS, and during the structuring and calibration process both options also informed each other. The submission of this report lays the foundation for the government to implement the preferred trigger option based on flood footprint data (Section E.3).

Table 12: Main technical features of the two trigger options developed for this project.

Features	Excess rain (XSR) trigger	Flood Footprint (FFP) trigger
Parameter	Station-based rainfall amounts.	Radar satellite-based flood extent, enhanced with auxiliary data.
Index	Maximum rainfall (millimeters) accumulated over various periods	Maximum flood extent of equal or higher than 50 centimeters of water depth, measured at critical points.
Trigger	Pre-defined stepped rainfall thresholds as per defined return period bands.	Pre-defined stepped payout levels as per number of affected (weighted) grid cells for defined return period bands.
Trigger calibration and risk assessment	Extreme signals of historic rainfall data calibrated to actual loss events.	Trigger level assessment through flood hazard model.
Benefits of solution	Solid and established data, lower model risk, simple and transparent design.	Lower basis risk, potential for high customization and tailoring of index, technological advancement.
Drawbacks of solution	Higher basis risk, as precipitation is only one driver of flood, and no hydrological runoff model is utilized: limited tailoring possible for complex urban setting.	More complex development and risk assessment required; higher model risk, more stakeholder education required.
Data availability	If there are no man-made errors, data is generally available for every day of the year.	Data is only available for larger and more catastrophic flood extents, not for shorter flash floods. This means typically ≥12 hours of non-permanent standing water, over affected areas of ≥300x300 meters and ≥30 centimeters of flood depth.
Pricing of insurance scheme	Similar prices for both solutions at market standard rates, due to adjustment of trigger levels to target risk profile.	
Running costs for the technology	Small subscription-like costs to access station data in near real-time from national meteorological service.	Small service fee for 24/7 monitoring, as provider is commercial entity.
Feasibility for implementation	Product fully developed, policy wording draft established, sufficient insurance capacity pledged.	Product fully developed, policy wording draft established, sufficient insurance capacity pledged.

Trigger recommendation

In most cases, an XSR trigger can be a simple but effective parametric risk transfer solution but is typically less suitable for urban areas due to the elevated basis risk. Although still less commonly established, the FFP trigger utilizes the latest advances in flood detection technology. It reduced basis risk significantly and can be much more tailored to the stated project goals of managing an urban flooding situation.

Due to the very poor correlation of heavy precipitation with flood loss events and the associated high basic risk, we unfortunately cannot recommend a suitable parametric trigger mechanism based on precipitation. In the remainder of this report, we will not explore an XSR option in more detail.

The project team recommends that Lagos State pilots a novel and innovative FFP. The following sections state some key advantages to working with ICEYE as flood footprint data provider, explain basic elements of the parametric structure as well as the details of the structuring of the FFP trigger option.

F.2. Key advantages of ICEYE as flood footprint data provider

The project team engaged ICEYE Oy as data provider for the development of this novel parametric urban flood scheme, and recommends working with an ICEYE-based solution going forward:

- **Data quality:** Of all remote sensed flood footprint data providers ICEYE proved capable of the most state-of-the-art, at the highest temporal and spatial resolution, tailored to flood impact on building level at a 24/7 observation.
- **Track record:** ICEYE owns the largest specialized satellite constellation and is constantly improving their output. Their data is already widely used by government agencies around the globe, and currently backs a pilot parametric flood transaction and several proposals.
- **Availability for Nigeria:** Flood footprint data is available and already tested in Nigeria. Lagos State is monitored around the clock.
- **Experienced reporting agent:** Established and automated post event calculation methods and data delivery. A specialized team of flood analysts will create and distribute flood footprint data in a timely manner.
- **Transparency:** The data will be made available to all parties involved in the insurance transaction. Upon request, other government agencies may also receive this data to a certain extent.

Further information on the quality and suitability of ICEYE's flood footprint data is given in Section E.3.1.

F.3. Critical structuring items

In this section, some critical items that must be considered in any parametric insurance scheme, regardless of the trigger type, are presented.

F.3.1 Basis risk

Basis risk is commonly defined as *the risk that an insurance payout deviates from the actual incurred losses*. With a potential payout depending upon a chosen event parameter rather than the actual loss itself, it is likely that the payout received from a parametric insurance may thus (+) reimburse more than needed for the loss sustained or (-) not fully reimburse.

- (+) **Positive basis risk:** for example, there is heavy rain, but no significant flood losses. Coverage pays but is not needed.
- (-) **Negative basis risk:** for example, there is insignificant rain, but substantial flood losses. Coverage does not pay but would be needed.

While basis risk can never be fully eliminated when it comes to parametric/index-based insurance, it can be minimized through careful structuring or more sophisticated trigger conditions, such as stepped or linear payout functions, or with the application of technological advancements and high-resolution data.

F.3.2 Parametric payout functions

To minimize basis risk of any parametric insurance scheme (as described in Section F.3.1), so-called stepped or linear parametric payout functions can be implemented. Here we have chosen to work with a linear payout function that covers a wide range of event recurrence probabilities. This payout function responds with initial smaller payments for more frequently occurring medium-sized events and pays in a linearly increasing fashion up to the full limit, corresponding to more impactful events with higher recurrence periods.

Linear (and stepped) parametric payout functions have become mainstream in the industry because they allow seamless adjustment to the insured's target risk profile while being easy to communicate and understand for all parties involved (Figure 39). The linear nature achieves two goals: (1) limit hit-or-miss situations and smooth very sudden changes, while (2) at the same time avoiding overly complex and impractical payout patterns.

During the structuring process, we used exposure data, input from all stakeholders, auxiliary rainfall data and all available flood hazard maps and models to determine suitable payout threshold levels for the FFP trigger. Multiple options were calibrated to reflect the government's desired target risk profile and budget within acceptable ranges.

The attachment and full limit payout probabilities, also often referred to as the insured *layer*, have a direct impact on the price. Any payout pattern that pays out more frequently is of course more expensive. The higher the insured layer sits, the lower the probability of a full limit payment and the lower the price because of that.

As with any insurance scheme it is highly advisable to optimize premium spend: the Government should ideally transfer the risk of catastrophic events with high budgetary consequences, while smaller and more frequent events with less financial impact should be retained.

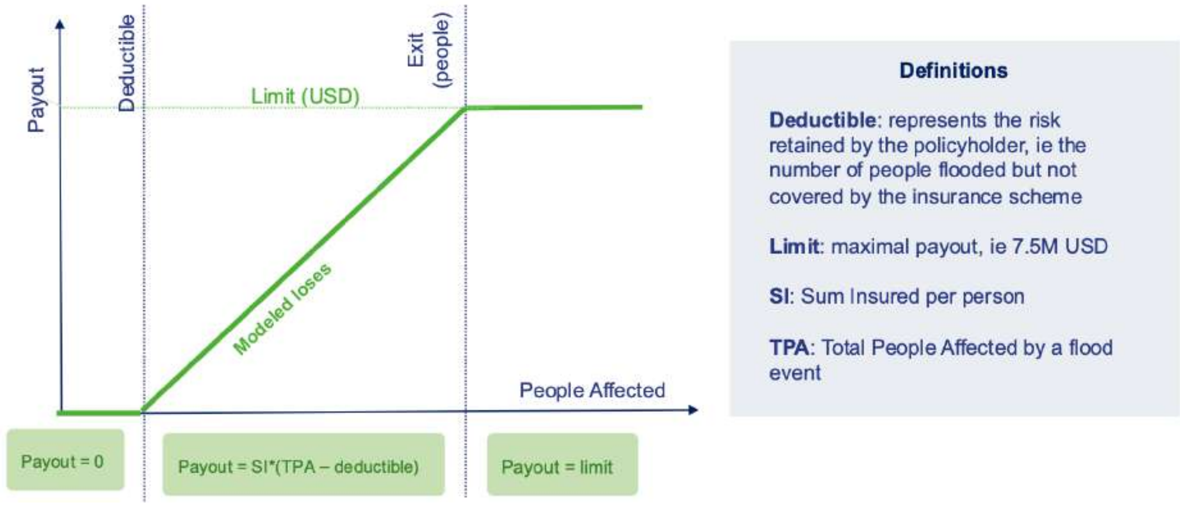


Figure 39: Conceptual linear parametric payout function, based on people affected by floods and a insured total limit of a USD 7.5 million equivalent. Each additional person flooded above the deductible adds to the parametric payout. Figure generated by AXA Climate.

F.3.3 Determining the payout limit and the payout per person affected

In designing this parametric insurance product for Lagos State, we carefully considered historical flood impacts, emergency response costs, and humanitarian aid benchmarks. The objective was to provide meaningful financial relief to the most vulnerable populations while ensuring that the coverage remains practical and sustainable. It is noted that the final decision on the insurance limits must in any case be made by Lagos State Government.

Policy Limit Determination

Lagos has experienced several severe floods in recent decades, leading to significant financial and social consequences. The 2012 and 2022 floods caused total damages in the USD billions. Such economic loss numbers are difficult to break down to LS's individuals LGAs and this proposed insurance policy only covers 7 rather low-income LGAs out of 20 total. Still, damages in the ≥USD 10 million range can be expected.

Beyond historical losses, the financial needs of LASEMA were also taken into account. LASEMA's annual operating budget is between USD 1 million and USD 1.5 million, with additional expenditures on relief efforts each year. In major flood events, these resources can quickly become overstretched, making external financial support critical.

To ensure that the policy is both cost-effective and capable of covering key response costs, the total insured sum needed to be at least USD 5 million. Lower amounts would not be financially viable due to the high costs associated with policy development, administration, and placement. Conversely, setting the policy limit too high – above USD 50 million – could be inefficient, as the government may struggle to immediately allocate such funds effectively, and securing risk transfer capacity for such volumes would be challenging.

After stakeholder consultation, a policy limit of USD 7.5 million was determined to be efficient and chosen for this pilot policy, which amounts of ~NGN 11.5 billion. This limit strikes a balance between ensuring sufficient coverage for flood-affected communities and maintaining financial sustainability. It aligns with historical losses, emergency response costs, and the practical implementation capacity of the government. Ideally, this amount scales upwards over time after a successful start of the program.

Payout per Person Flooded

To determine an appropriate payout per person, past humanitarian relief efforts in Nigeria were analyzed. The Red Cross Disaster Response Emergency Fund (DREF) operations provided a useful benchmark. During the 2011 floods, the Red Cross allocated USD 300'000 to assist 12'500 people, amounting to approximately USD 160 per household. Similarly, past DREF cash assistance programs in Nigeria typically provided between USD 80 and USD 100 per household.

With an average household size of 3.9 persons in Lagos, this equates to an estimated USD 20-25 per person. However, after taking into account budget constraints, risk modelling considerations and the need to ensure much broader coverage, the payout per person for this program, for a '*balanced*' option, has been set at the equivalent of USD 17. This amount provides a meaningful level of support while ensuring the financial sustainability of the insurance product over time.

Conclusion

The recommended policy limit of USD 7.5 million is based on historical flood damages, emergency response needs, and cost-effectiveness considerations. This ensures that the insurance provides timely financial assistance while remaining practical for implementation. Additionally, the payout of an equivalent of USD 17 per person (for a '*balanced*' option) is informed by past humanitarian relief efforts and calibrated to support affected households without straining the policy's financial capacity. Together, these parameters create an effective safety net for vulnerable populations in Lagos State, ensuring rapid support when it is needed most.

F.3.4 Structuring a well-balanced insurance product

To design the most effective insurance coverage, it should ideally:

- Be triggered frequently, ensuring regular payouts.
- Cover as many people as possible.
- Provide high compensation per insured individual.
- Maintain a low premium.

However, maximizing one of these objectives can negatively impact the others. For example, if coverage triggers more often, includes more people, and provides higher payouts, the overall risk increases, leading to higher premiums. Conversely, lowering the premium requires reducing at least one of the other three factors: the frequency of payouts, the number of people covered, or the compensation amount.

This interplay creates what we call the *insurance incompatibility square* (Figure 40), illustrating the inherent trade-offs in insurance design.

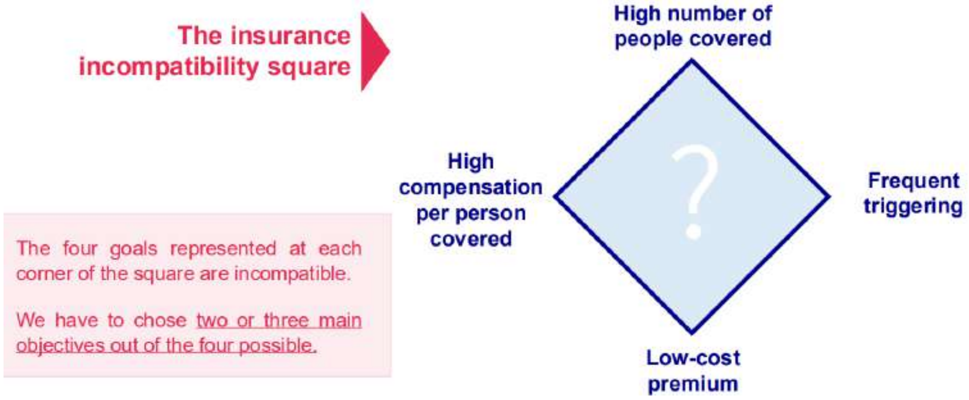
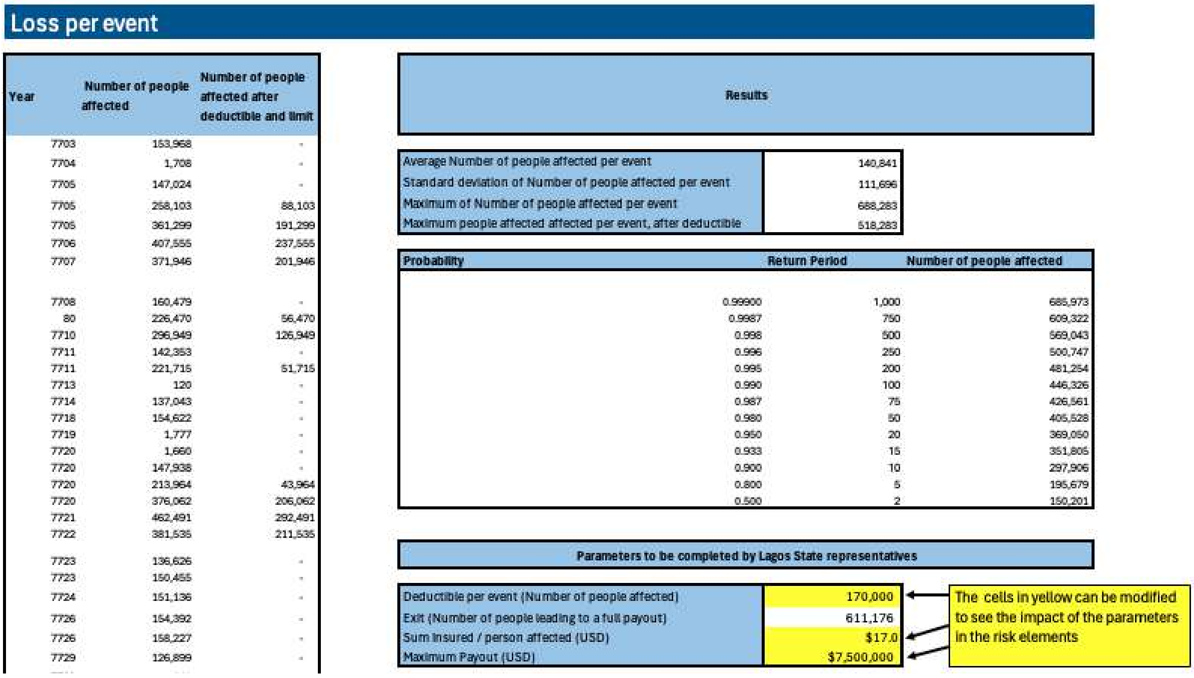


Figure 40: During the development of a parametric risk transfer scheme the structurers must strike the right balance between competing objectives. Figure generated by AXA Climate.

Throughout the project, the objective of the project team was to show this interdependence to Lagos State representatives so that they could choose the most suitable balance for their cover needs. To facilitate this, an interactive Excel tool was developed, presented, and shared with stakeholders (Figure 41). This tool allowed them to explore different scenarios, adjusting key variables such as deductible per event, compensation per person affected and maximum payout to find the most suitable balance for their specific requirements.



Loss per event

Year	Number of people affected	Number of people affected after deductible and limit
7703	153,968	-
7704	1,708	-
7705	147,024	-
7705	258,103	88,103
7705	361,299	191,299
7706	407,555	237,555
7707	371,946	201,946
7708	160,479	-
80	226,470	56,470
7710	296,949	126,949
7711	142,353	-
7711	221,715	51,715
7713	120	-
7714	137,043	-
7718	154,622	-
7719	1,777	-
7720	1,660	-
7720	147,938	-
7720	213,964	43,964
7720	376,062	206,062
7721	462,491	292,491
7722	381,535	211,535
7723	136,626	-
7723	150,455	-
7724	151,136	-
7726	154,392	-
7726	158,227	-
7729	126,899	-

Results

Average Number of people affected per event	140,841
Standard deviation of Number of people affected per event	111,696
Maximum of Number of people affected per event	688,283
Maximum people affected affected per event, after deductible	518,283

Probability	Return Period	Number of people affected
0.99900	1,000	685,973
0.9987	750	609,322
0.998	500	569,043
0.996	250	500,747
0.995	200	481,254
0.990	100	446,326
0.987	75	426,561
0.980	50	405,528
0.950	20	369,050
0.933	15	351,805
0.900	10	297,906
0.800	5	195,679
0.500	2	150,201

Parameters to be completed by Lagos State representatives

Deductible per event (Number of people affected)	170,000
Exit (Number of people leading to a full payout)	611,176
Sum insured / person affected (USD)	$17.0
Maximum Payout (USD)	$7,500,000

Figure 41: Screenshot of the interactive pricing tool shared with Lagos State representatives. Figure generated by AXA Climate.

In addition, three structuring options were particularly highlighted as referenced further below in Table 15.

F.3.5 Contingency plan for Emergency Relief

To ensure that the funds from the parametric insurance payouts are utilized effectively, a comprehensive contingency plan has been developed under the lead of the African Risk Capacity (ARC) and UNDP. This plan identifies the key emergency relief activities and thematic areas where financial resources will be allocated in response to a severe flood event in Lagos State. The primary objective of this contingency plan is to provide timely and effective assistance to affected communities, mitigate the immediate impacts of flooding, and support early recovery efforts.

The contingency plan is structured around key thematic areas that reflect the critical needs of flood-affected populations. These include water access, provision of food and non-food items, healthcare, temporary shelter, infrastructure repair, and agricultural support. The plan also considers the operational requirements of emergency response agencies such as LASEMA and LASAMBUS (Lagos State Ambulance Services) to ensure a coordinated and efficient response.

In the event of a severe flood that triggers the maximum insurance payout of USD 7.5 million, the financial resources will be distributed across the thematic areas as outlined in Table 13.

Table 13: Thematic areas and envisaged allocated costs of the contingency plan. FX-Rate: 1'528.5 Naira/USD.

Thematic Areas	Budget (NGN)	Explanatory Notes
Water access	227'000'000	Ensuring availability of clean drinking water in affected areas.
Non-Food items (LASEMA Relief Camp)	4'540'000'000	Support for three relief camps (Agbowa, Ikosi-Ejirin, and Igando).
Health	567'500'000	Provision of consumables and medical kits for LASEMA and LASAMBUS (39 ambulances).
Construction	1'135'000'000	Repair and reconstruction of public offices and structures damaged by floods.
Temporary shelter	227'000'000	Emergency accommodation for displaced populations.
Water resources management and infrastructure access	1'135'000'000	Drainage reconstruction, desilting, and maintenance of existing canals.
Agricultural inputs	227'000'000	Support for farmers affected by flooding.
Food kits distribution	3'405'000'000	Emergency food aid for flood-affected households.
Total (USD 7.5 million)	**11'463'500'000**	**Total estimated cost of emergency relief actions.**

The emergency relief activities will be coordinated by the relevant government agencies, including LASEMA, LASAMBUS and other key stakeholders involved in disaster response. The contingency plan ensures that funds are distributed efficiently and in a timely manner to support rapid emergency response and early recovery.

A more detailed breakdown of the contingency plan, including specific implementation strategies, operational guidelines, and logistical arrangements, will be provided in a dedicated document (Appendix 4). This will ensure full transparency and accountability in the use of insurance payouts for emergency relief efforts. By having a well-defined contingency plan, Lagos State can enhance its resilience to flood events, protect vulnerable populations, and ensure that financial resources are used effectively to mitigate the impacts of disasters.

One caveat is that, as the local vulnerability data (where the low income and most vulnerable are located) is not up to date nor comprehensive, the current contingency plan could not pre-target vulnerable beneficiaries. Rather, the existing LASEMA method will be used to identify who the vulnerable population impacted are by on the ground surveys after the flood hits. LASEMA will be able to increase its activities in the seven covered LGAS for these affected populations with the knowledge that these additional activities will be financed by an insurance payout.

F.3.6 Insurance premium support

To support the initial rollout of the parametric flood insurance product in Lagos State, various avenues for premium financing have been explored by the UNDP to ensure affordability during the early years. Applications for premium subsidy support have been submitted to potential donors, including the InsuResilience Solutions Fund (ISF), which aligns with the goals of climate resilience and disaster risk financing. Engagement with ISF is ongoing, and this effort is part of a broader strategy to secure concessional funding and reduce initial costs for the government.

A formal application to ISF Pillar IV has been executed with a request for a total budget of USD 2 million to support the insurance policy over the next three years. Within this budget, ~USD 170'000 are included to accommodate potential increases in premium costs during policy renewals in the second and third years. This proactive approach ensures that any fluctuations in pricing can be managed without compromising the financial sustainability of the insurance program. At the time of writing, the final decision from ISF had not yet been received.

In the first year of the policy, Lagos State is requesting a subsidy to cover 90% of the total premium cost (amounting to approximately USD 686'600 as described in later sections). The financial contribution from donor(s) is expected to decrease over the following years, with 80% coverage in the second year (2026) and 70% in the third year (2027). This phased reduction in subsidy is designed to enable a smooth transition towards full premium coverage by Lagos State in the long term through a disaster fund that is being set up internally.

The Green Climate Fund (GCF) was also approached for a potential donor, with a concept note submitted for premium subsidies by UNDP. However, no response was received, and practical challenges limited further pursuit of this option. UNDP is open to further exploring this avenue if it becomes relevant in the future. Additionally, discussions with FSD Africa confirmed that premium financing would not be feasible for this project.

The Ministry of Finance of Lagos State, with the support of UNDP, is responsible for managing the application and disbursement process for donor(s) funding. Their role includes securing funds, ensuring compliance with donor(s) requirements, and coordinating with relevant stakeholders to sustain the program beyond the initial funding period. This structured premium support mechanism would provide the necessary financial foundation for the insurance product to be successfully launched and maintained while progressively integrating it into the State's long-term disaster risk financing strategy.

F.3.7 Exchange rate

Currency exchange rate (FX) for all subsequent calculations was set for Naira to dollars at NGN 1545.5 to USD 1 as per the Nigerian central bank's rate on the 1st of January 2025.

F.4. Structuring of the parametric Flood Footprint Product (FFP)

F.4.1 Basic function of the FFP product

Before the start of the insurance contract the area of interest, or the schedule of critical assets or population locations, must be determined. Representative calculation points will be defined, each with a set of coordinates. During the policy period the independent reporting agent ICEYE will observe and report on any significant flood event in the area. Upon detection of an eligible flood a predefined payout function will be applied. The more calculation points are flooded the higher the insurance payout to the policy holder, above a deductible and up to an agreed limit (Figure 42).

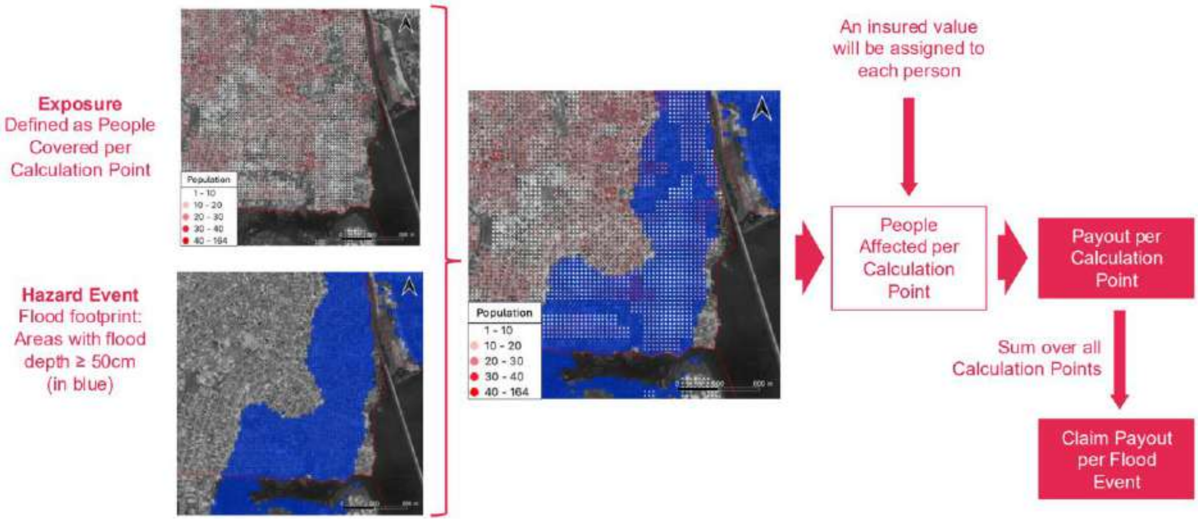


Figure 42: General workings of the flood footprint insurance product, tailored to cover poor and vulnerable population. Figure generated by AXA Climate.

The main advantage of a flood footprint solution over a trigger based on precipitation is a significant decrease of basis risk, i.e. the risk that payouts from the parametric product do not match the actual losses suffered on the ground (see Section F.3.1).

On the downside, given there is limited historic data available from ICEYE's footprint database for Nigeria, potential capacity providers must apply a so-called *decoupled* pricing approach to determine the right price to participate in the FFP solution. This means that the risk is calculated by use of probabilistic flood models, while real-time monitoring of the parameter is carried out by the independent third-party data provider ICEYE, i.e. *decoupled*. It is therefore essential to ensure that the flood models and the flood footprints are aligned (see Section E.3.1).

Underwriters require a state-of-the-art probabilistic flood model in order to determine the right price of this rather novel solution. This can be an obstacle, especially for smaller capacity providers with less experience in parametric risk transfer. Further, flood footprints are typically not available for temporarily and spatially smaller flooding events, which means this product is only suitable for mid- to large-scale flood events.

The following sections describe flood hazard models used to develop and structure the parametric FFP solution, as well as the entire calibration process used to determine the technical rate.

F.4.2 Product structuring and costing

Risk profiling components

Risks can be decomposed into three components:

- **Hazard**: It is the climate threat or danger, in this project it is flooding.
- **Exposure**: The population or assets which could be affected by the hazard.
- **Vulnerability**: It is the susceptibility of the exposure to a hazard.

The risk is the combination of the hazard, the exposure and the vulnerability, and it is alternatively expressed as the annual average loss due to such hazard (in monetary units per year, such as NGN per year). The description of the risk components is represented in Figure 43.

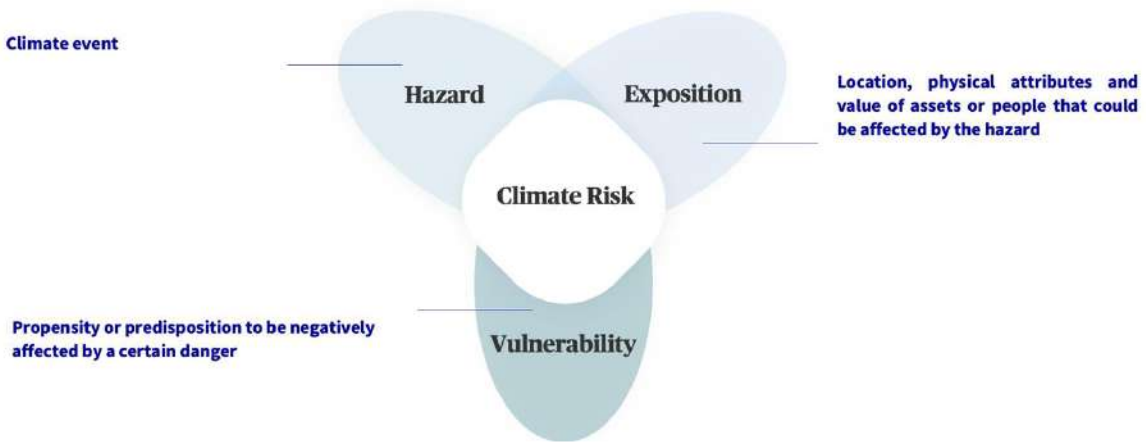


Figure 43: Representation of the risk decomposition analysis. Figure generated by AXA Climate.

In the following sections, the methodologies to generate the flood hazard, exposure, vulnerability and risk are presented.

Hazard

The hazard layer consists in 30x30 meter horizontal resolution maps of maximum flood depth per event run. JBA, the provider of this product, ran 10'000 years of stochastic flood events, considering pluvial, costal and fluvial floods, with the possibility of having several floods during the same year. Figure 34 displays probabilistic flood extents and depth for return periods of 20, 100 and 1'500 years.

Exposure

Out of the 20 existing LGAs in Lagos, in agreement with Lagos State Government it has been decided to cover the 7 LGAs with the most vulnerable population. The methodology used to obtain the exposure layer is described in Section D. The total population covered across the 7 targeted LGAs is 4'020'322 people.

Vulnerability

Based on the Joint Research Commission (JRC) Flood Depth-Damage Functions [51] and other related literature sources [52], flood depths of 50 centimeters in residential buildings in Africa could cause more than 20% of the maximum damage due to a flood, up to 50% for non-engineered buildings (Figure 44, Figure 45). For this flood depth residential properties experience substantial damage, including structural components and interior finishes, leading to costly repairs. A threshold of 50-centimeter flood depth is also commonly considered to compromise human safety. For this flood depth, flow velocities can generally reach values above 2 meters per second, which is the universal human stability threshold found in literature [53].

In this project a threshold of 50-centimeter flood depth is selected to consider that a pixel (grid cell) is flooded and that the corresponding people assigned to that grid cell are affected. Moreover, ICEYE accuracy increases with flood depth: choosing 50 centimeters at least decrease the basis risk on misdetection of flooded pixels. Therefore, it is considered a binary payout per pixel such that if the flood depth is below 50 centimeters the people attached to that pixel are not affected and if the flood depth is greater or equal to 50 centimeters there is a full damage on that pixel.

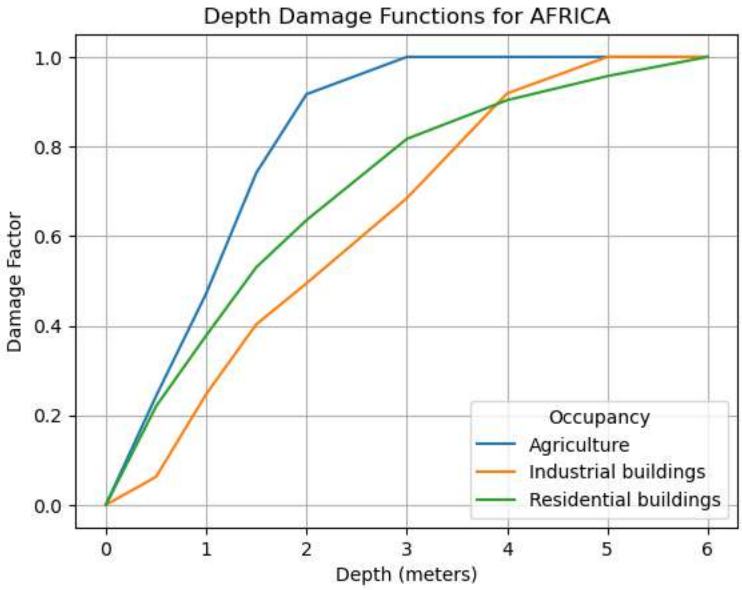


Figure 44: Flood damage function for residential, industrial and agricultural occupancies in Africa [51].

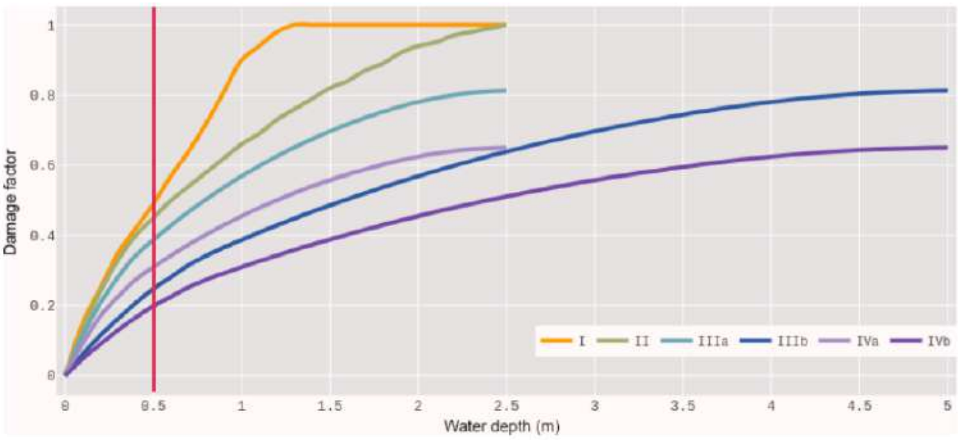


Figure 45: Stage-damage curves for four building-material-based vulnerability classes [52]. Class I consists of non-engineered buildings built with materials such as compacted mud, (non-cemented) adobe blocks, and other traditional materials found in the natural environment or informal buildings. Class II consists of wooden buildings. Class III consists of unreinforced masonry/concrete buildings with walls of burnt bricks or stone or concrete blocks. Class IV represents engineered reinforced masonry/concrete and steel buildings.

<u>*Risk modelling*</u>

JBA developed a 10'000-year stochastic catalogue of flood events to estimate potential losses per event, considering the possibility of multiple flood events occurring within a single year. For each event, JBA overlaid the maximum flood depth (hazard) layer, exposure, and vulnerability to determine the number of people affected. However, the stochastic catalogue does not account for the Oyan Dam and flood events caused by controlled water releases. To address this, an assumption is made to integrate the impact of dam releases into the flood risk assessment.

Due to their proximity to the Ogun River parts of the Kosofe LGAs are particularly flood prone as a result of controlled releases from the Oyan Dam (as explained in Section C.7.6). Seven wards within Kosofe have been identified as at risk due to these water releases (Figure 46, Table 14).

Table 14: Wards and their population at high risk from man-made flooding due to water release of dams upstream the Ogun River (see also map in Figure 46).

LGA	Ward	Population
Kosofe	Isheri / Olowora	172'898
Kosofe	Ikosi Isheri	29'548
Kosofe	Shangisha / Magodo	174'355
Kosofe	Idera	31'870
Kosofe	Orile-Ketu	52'815
Kosofe	Odo-Ogun / Ajegunle	128'790
Ikorodu (outside the covered area)	Majidun	35'419
	Total	**625'694**

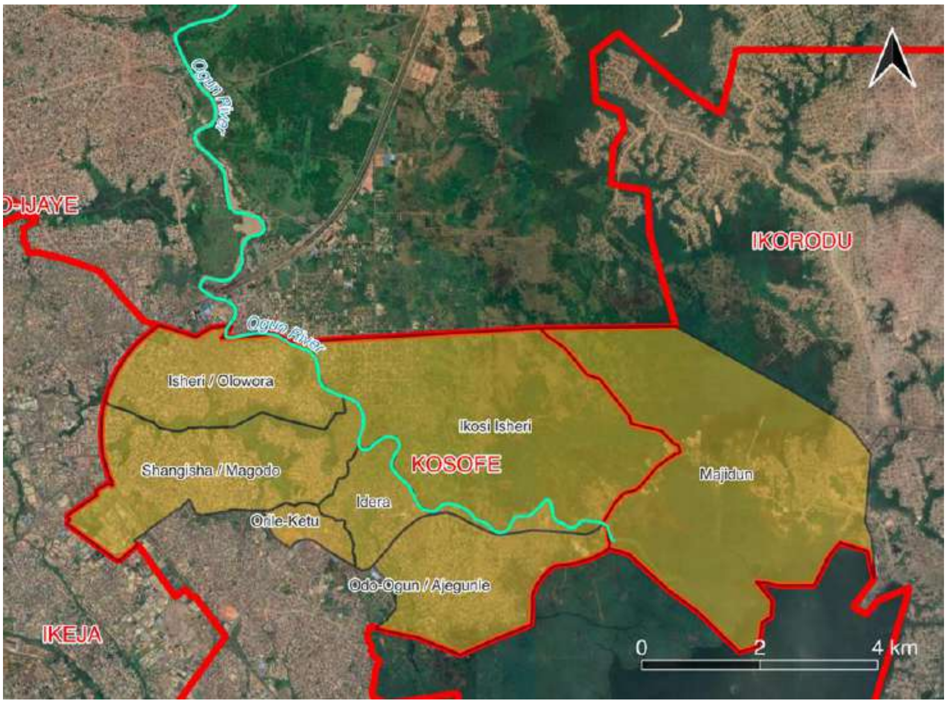


Figure 46: Map of wards at high risk from man-made flooding (marked yellow) due to water release of dams upstream the Ogun River (see also Table 14). Figure generated by AXA Climate.

A total of 625'694 people within the seven identified LGAs are potentially affected by floods resulting from dam releases. This represents approximately 3% of the total ~4 million people covered by the parametric insurance cover.

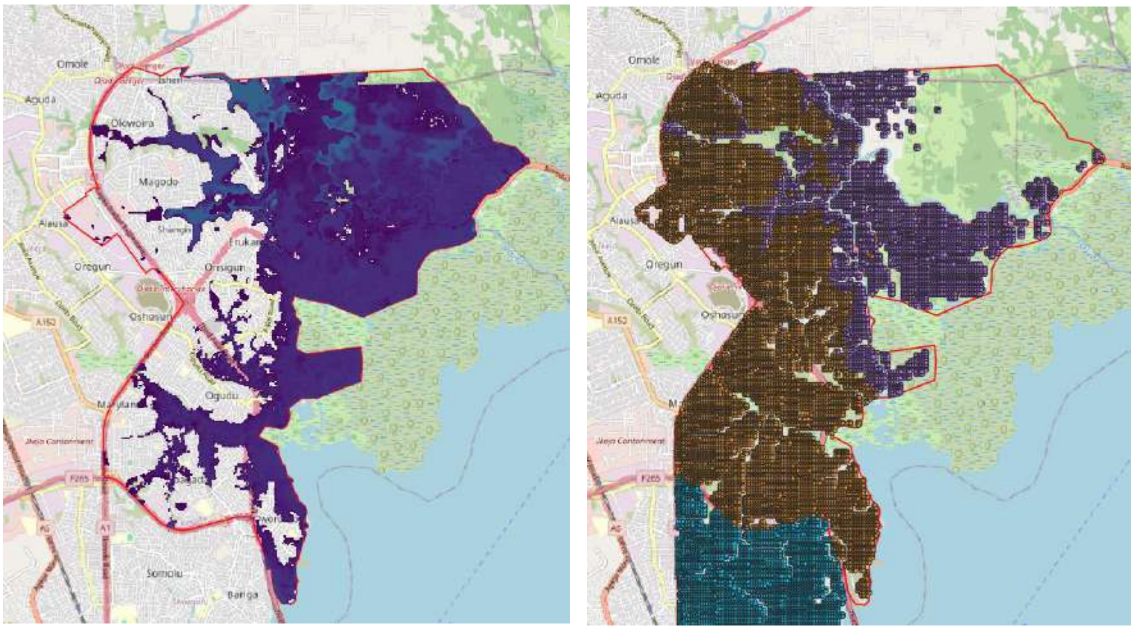


Figure 47: (left) 20-year river flood hazard map for Kosofe, (right) population points outside the flood hazard mask in orange and within the river flood hazard mask in purple. Figure generated by AXA Climate.

To account for the impact of dam releases, it is assumed that any water release corresponding to a return period within the 1 in 20-years flood hazard zones affects the population living inside the flood-prone areas (Figure 47). In Kosofe, the number of endangered individuals of dam releases is estimated at 104'758 people, representing the total population at risk for the purpose of this project.

To refine the assessment and account for the man-made releases of water of upstream dams, a reconstructed flood catalogue is developed. This catalogue is obtained by considering that 104'758 people are flooded in Kosofe and surrounding when it is affected by a flood. Due to the approximately 1 in 3-year frequency of dam releases, we consider those 104’758 are fully flooded once every three years (see Section C.7.6). The reconstructed dataset is then used to calculate the Occurrence Exceedance Probability (OEP) and Annual Exceedance Probability (AEP) curves, providing a more comprehensive flood risk analysis.

<u>*Occurrence Exceedance Probability (OEP) and Annual Exceedance Probability (AEP) curves*</u>

Once the reconstructed 10'000-year flood catalogue is obtained, the flood footprint of each flood event is overlaid with the exposure layer and the number of people affected is computed for each event:

$$Total\ people\ affected\ (TPA) = \sum_{Calculation\ Locations} Number\ of\ People\ Affected$$

The deductible and limit are applied following the formula below:

$$Payout(people) = \begin{cases} 0 \text{ if } TPA < deductible \\ TPA\ - deductible \text{ if } deductible < TPA < limit \\ limit - deductible \text{ if } TPA > limit \end{cases}$$

where TPA are the total number of people affected, deductible is the trigger threshold (minimum number of people to be affected per event before triggering a payout), and limit is the maximum payout per event. Multiplying the payout by the sum insured per person flooded gives a loss in dollars (USD $) per event, which essentially represents a linear parametric payout function:

$$\text{SI}_{\text{per person}}(\$/\text{people}) = \frac{\text{Maximum payout } (\$)}{\text{limit threshold (people)} - deductible\ (people)}$$

After having calculated the losses for each event, it is possible to construct:

- **The Occurrence Exceedance Probability (OEP) curve** (Figure 48): is a graph representing the cumulative probability of losses per event. It is usually represented with the losses for the x-axis and the probability for the y-axis (which ranges from 0 to 1).
- **The Annual Exceedance Probability (AEP) curve** (Figure 49): is a graph similar to the OEP curve, but this time it represents the cumulative probability of losses per year. The losses corresponding to events of the same year are summed to obtain annual losses. The AEP curve is usually represented with the losses for the x-axis and the probability for the y-axis.

The OEP curve is presented in Figure 48 for both the regular catalogue and the reconstructed catalogue, which accounts for dam releases. The curve of the reconstructed catalogue lies below that of the regular catalogue, indicating a more conservative estimate of the flood losses per event (i.e. higher losses per event compared to not considering dam releases, for a given event frequency). For the same number of affected individuals, the reconstructed catalogue assigns a lower cumulative probability (and therefore a higher probability of exceedance of a certain number of people flooded), reflecting the additional consideration of dam-related flooding.

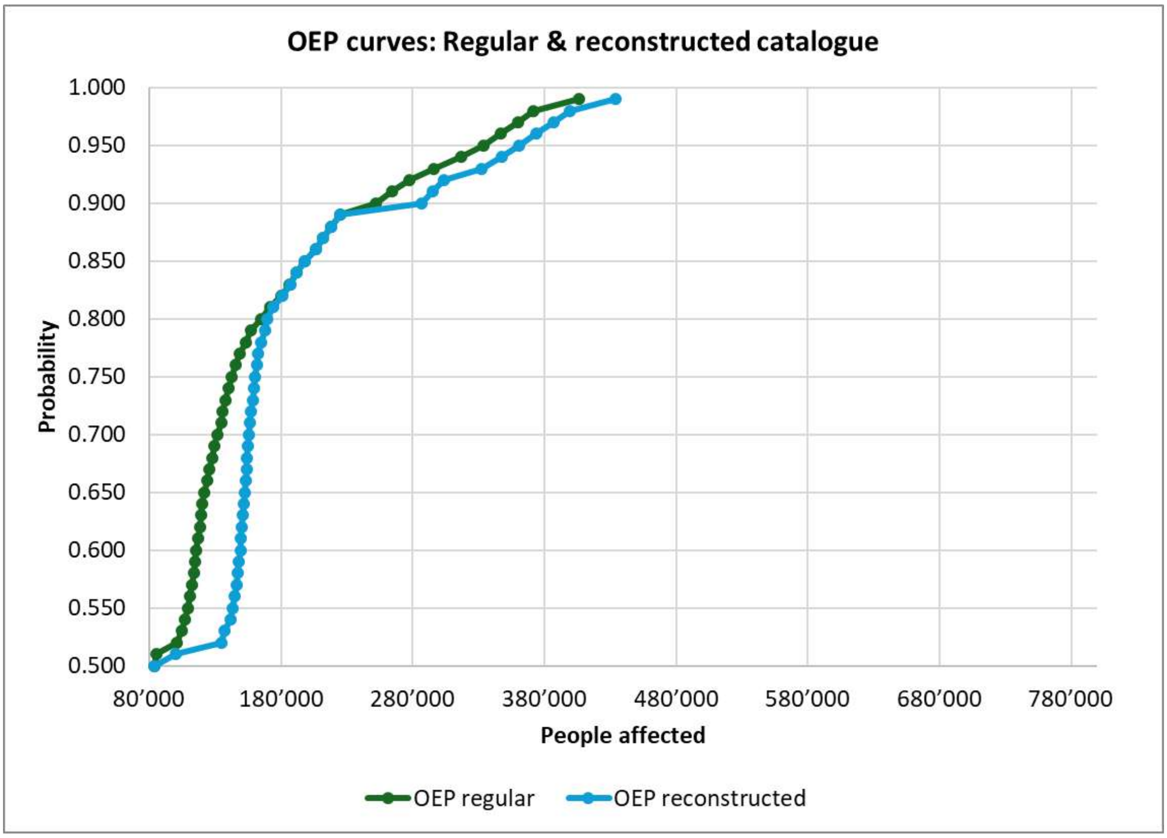


Figure 48: Occurrence Exceedance Probability (OEP) giving the probability of exceedance associated to the number of people flooded (with equal or more than 50 cm water depth), for the regular event catalogue (green) and the reconstructed (blue). Figure generated by AXA Climate.

The AEP curve is derived from the OEP by summing the total losses for each year over a period of 10,000 years. In Figure 49, the AEP curve and the reconstructed AEP curve are calculated using the annual losses from the occurrences catalogue and the reconstructed occurrences catalogue (considering the dam influence), respectively.

Notably, the AEP curve for the reconstructed catalogue lies below that of the original (regular) catalogue. This indicates that, for any given number of people affected per year, the probability of exceedance is higher in the reconstructed distribution than in the original one. In other words, severe events are more likely to occur in the reconstructed distribution. As a result, the reconstructed AEP curve is more conservative compared to the original JBA distribution.

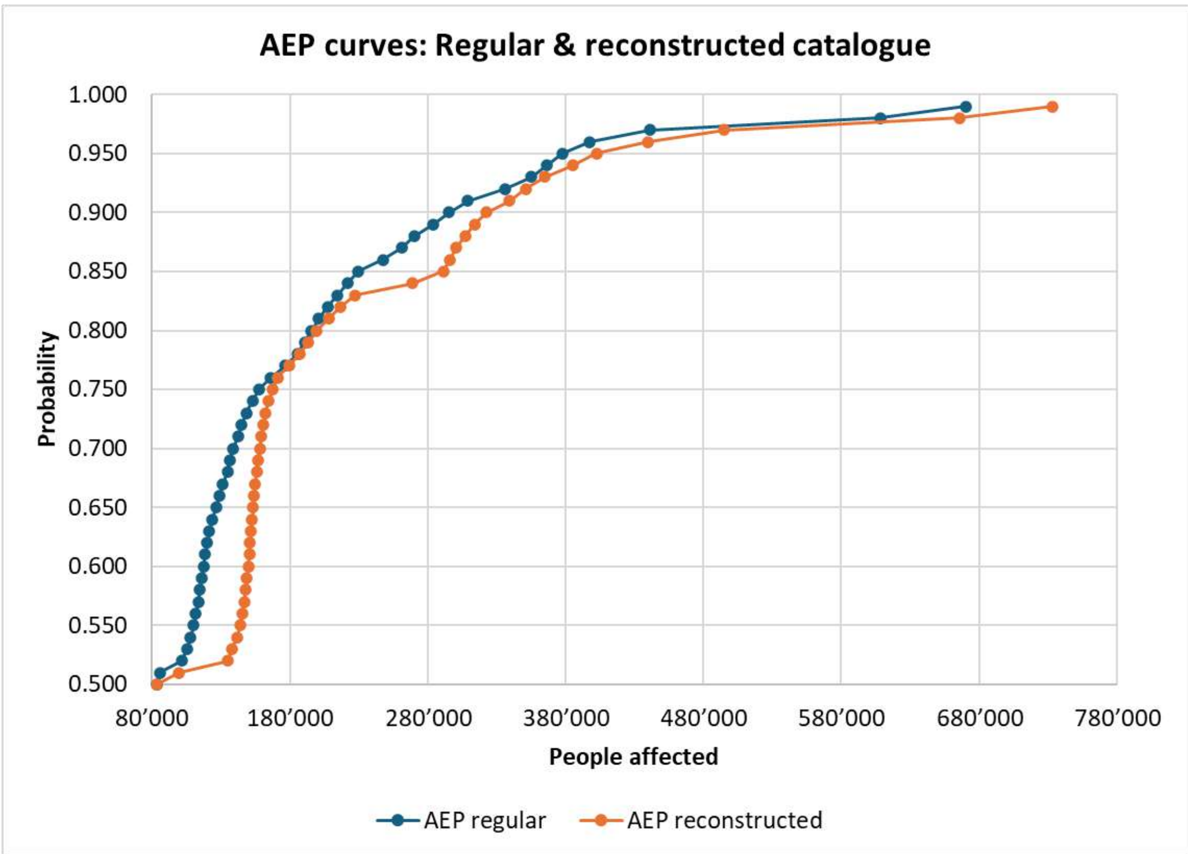


Figure 49: Annual Exceedance Probability (AEP) showing the total number of people affected over a full year and the (cumulative) probability associated. Regular catalogue in blue and reconstructed catalogue in orange. Figure generated by AXA Climate.

Product structure

It was decided to prepare three structure options for the parametric insurance coverage for further discussions. This gives LS and all stakeholders a wider range to choose from, accounting for the desired risk appetite, coverage limit and budget availability. The three proposed product structures factor in the three key items of any insurance product: deductible, limit, and sum insured.

- **Deductible**: The deductible represents the risk retained by the policyholder, i.e., the number of people who are affected by flooding but not covered by the insurance policy in each event. This deductible is defined as a threshold (in terms of the number of people affected), above which the insurance policy will start covering damages.
- **Limit**: The limit refers to the maximum coverage the policyholder can obtain under the policy in a given year. In this case, the agreed limit is USD 7'500'000 per year and per event (Section F.3.3).
- **Sum Insured (per insured person)**: The amount paid by the insurance policy for each person affected by the flood, once the deductible is surpassed. This is essentially a

linear payout function, i.e. every further person affected contributes to the insurance payment. It varies across the proposed structure options, as the total insured limit was set to be a fix value of USD 7.5 million.

The three product options outlined in Table 15 correspond to different combinations of deductibles and per-person sums insured (i.e. the number of people covered), keeping the total sum insured constant.

Table 15: Deductible, ICEYE's capabilities to detect floods, limit thresholds, sum insured per person and probability of triggering and full loss for the 3 different structure options.

	Option 1: ***Frequent trigger***	**Option 2:** ***Balanced***	**Option 3:** ***Pure catastrophic***
Deductible, number of people (% of people covered)	155'000 (3.86%)	170'000 (4.23%)	215'000 (5.35%)
ICEYE's capability to detect the attaching events	Not ideal	OK	Good
Full limit, number of people	655'000	611'176	515'000
Sum insured per person (USD)	15.00	17.00	25.00
Sum Insured per person (Naira)	23'182	26'274	38'637
Probability of triggering, attachment (return period)	31% (RP=3.3 years)	20% (RP=5.0 years)	13% (RP=8.0 years)
Probability of full loss, exit (return period)	0.09% (RP=1'111 years)	0.10% (RP=1'000 years)	0.26% (RP=385 years)

The sum insured per person for the three options range from USD 15 to USD 25. For example, the *Pure catastrophic* option 3, which focuses on catastrophic flooding only, provides higher payouts per person but triggers less frequently. Conversely, scenarios that trigger more often have lower per-person payouts, ensuring the total premium values remain manageable and of a similar magnitude.

The number of affected people to reach the full limit has been set between 515'000 and 655'000 for the three proposed options, aligning with the stochastic catalogue estimate of 685'973 people affected by a 1'000-year return period flood. This ensures consistency with the total flood-prone population.

It is important to note that ICEYE, for claim monitoring, cannot reliably detect very small and local events. Attaching at very frequent flood event return periods below three years are not in scope. This means the 3-year RP is the minimum feasible threshold, as any event below carries a high basis risk of non-detection. This is also a reason that the project team does not recommend option 1. Table 16 shows the losses in USD values for the different return periods after application of deductible and limit, for the three options outlined in Table 15.

Table 16: Losses in USD for different return period levels for the three presented options.

Return Period (years)	Option 1, loss in USD	Option 2, loss in USD	Option 3, loss in USD
10'000	7'500'000	7'500'000	7'500'000
1'000	6'988'563	7'499'987	7'500'000
750	6'645'076	7'276'086	7'500'000
500	5'942'281	6'388'544	7'500'000
250	5'149'803	5'532'921	7'004'586
200	4'891'337	5'277'587	6'542'665
100	4'609'934	4'769'942	5'582'952
75	4'431'022	4'630'656	5'157'862
50	4'179'786	4'343'952	4'741'417
20	3'284'276	3'415'557	3'673'803
15	2'752'300	2'864'274	3'072'150
10	1'977'213	1'983'965	1'789'546
8	911'231	774'250	5'235
5	216'859	-	-
2	-	-	-

The reader can observe that for option 1, the maximum payout is reached for a return period of 1'111 years. In option 2, the full limit would be reached at (almost) a 1'000-year return period and reached at 96% for a 750-year return period. Finally, in option 3 the maximum payout is reached already at a 385-year return period. It is noted that under all three options the maximum payout is reached at least for one event among the 10'000-year event set.

This is consistent with the choice of the limit return period level (or exit/exhaustion) for each options: as the exhaustion probability for option 3 is lower than for option 1, the maximal payout is therefore already reached at a lower return period level. However, option 3 only starts to pay at a later return period level given the deductible is higher. The choice of a higher deductible and lower exit for option 3 compared to option 1 allows to have a bigger sum insured per person, which is more suitable to deal with significant disasters.

The main metrics for the three considered options are summarized in the Table 17 below:

Table 17: Average annual number of affected people, annual expected loss and standard deviation for the three options.

	Option 1: *Frequent trigger*	**Option 2: *Balanced***	**Option 3: *Pure catastrophic***
Average annual number of people affected	120'292	120'292	120'292
Average annual number of people affected, after deductible	27'484	23'478	15'298
Annual Expected Loss (USD)	412'260	399'126	382'450
Annual Expected Loss (Naira)	637'147'830	616'849'233	591'076'475
Expected loss rate	5.50%	5.32%	5.10%
Standard Deviation (USD)	1'054'621	1'099'399	1'209'793
Standard Deviation (Naira)	1'629'916'756	1'699'121'155	1'869'735'082

Indicative net Premium calculation

Just like in any other insurance contract, the price of the proposed parametric coverage has to include insurance loadings. This section outlines the premium calculation process to get from a technical rate to the net premium. The metrics used for the calculation are:

- **Annual Expected Loss (EL)**: It is based on the average number of people affected per year from our loss computation with the 10'000-year stochastic flood event catalogue. The EL in USD value is subsequently computed as the product of the average number of people affected and the sum insured per person affected.
- **Standard Deviation (SD)**: It is the Pearson standard deviation of the loss (in USD) for the 10'000-year event simulated losses. It characterizes the volatility of the losses: A high standard deviation indicates that the probability of losses is greater or less than the mean.
- **Net Loss Ratio (NLR)**: It gives an indication on the profitability of the insurance product. For a NLR higher than 100%, the insurer is paying more out on average than what he receives in premium. For a loss ratio lower than 100%, the insurer receives more premium on average than what he pays out. This means insurance can be profitable (if other expenses are accounted for). The NLR is calculated using the following formula:

$$\mathrm{NLR} = \frac{\mathrm{EL}}{\mathrm{Net\ Premium}}$$

- **Net Premium (NP)**: corresponds due to the risk carrier, here mainly the retrocessioner

$$\mathrm{NP} = \frac{\mathrm{EL}}{\mathrm{Net\ Loss\ Ratio}}$$

- **Probability of triggering (attachment probability)**: It indicates the probability of receiving a payment in a given year. It is computed as the number of years with payments over the full 10'000 years of the simulated event catalogue.

- **Probability of full loss (full limit probability, or exit/exhaust)**: It indicates the probability of exhausting the limit of the policy in a given year, and it is computed as the number of years with maximum payout over the simulated 10'000 years of the event catalogue.

Additional cost items

The placement of the product in the market is possible thanks to the service provided by multiple actors. Each of these stakeholders receive a predefined fee amount upon placement in line with market standards, which can be an absolute amount or an amount proportional to the gross written premiums (GWP). The final GWP corresponds to the net premium, plus all the additional intermediary costs, and constitutes the actual amount paid by the policyholder, i.e. Lagos State.

The additional intermediary costs items to be factored into the GWP are explained below:

- **Reinsurance Commission**: A retention on the GWP by the insurer as compensation for fronting the risk.
- **Retrocession Commission**: A retention on the GWP by the reinsurer as compensation for fronting the risk.
- **Primary Flood Footprint Data Provider Fee**: A charge for forecasting and real-time monitoring of flood events during the policy period, including the generation of maximum flood depth and extent layers after flood events. ICEYE is proposed as the data provider.
- **Fallback Flood Footprint Data Provider Fee**: A fee for producing maximum flood depth and extent layers using physical flood models and other simulation sources. This service is activated only in the unlikely event if the primary data provider is unable to deliver but requires a small stand-by fee. The consortium recommends JBA for this role.
- **Calculation Agent Fee**: A charge for calculating losses from the parametric product, based on the calculation methodology of the live policy and the flood footprint data provided by the primary or fallback data provider. The consortium recommends JBA for this role.
- **NAICOM Fees**: Regulatory charges paid to Nigeria's National Insurance Commission (NAICOM). These fees ensure compliance with insurance regulations and support oversight services.
- **Taxes**: Nil (NAICOM fees are the only tax-like expenses to be paid).
- **Brokerage Fee**: A payment to the insurance broker for facilitating policy placement, negotiation, and management on behalf of Lagos State.

Gross Written Premium (GWP)

The capacity providers who will underwrite this product will determine their own net premium rates individually. The net premium includes capacity costs and expenses that insurers must consider, but which vary in each case. At this stage we can therefore only state an indicative GWP value, based on the experience of the project team.

The net premium is deduced from the targeted loss ratio, and with the Intermediary cost items as described above (reinsurance, brokerage, data provider, etc.) the GWP is computed:

$$\text{GWP} \quad = \frac{\textit{Net Premium}}{1 - \text{commissions}}$$

Another consideration is the fact that Lagos State and UNDP has applied for a 90% premium subsidy for the first year (and 80% and 70% for the following) that the ISF will consider. The below tables therefore indicate the GWP values for each option before and after subsidy – showing the real costs that LS has to pay.

Table 18: Illustrative rounded gross pricing (GWP) for option 1, with estimated intermediary cost items and subsidies considered. Nominal values are also shown with 90% premium subsidy.

	Option 1: *Frequent trigger*
Indicative gross Rate on Line (RoL)	9.99%
Indicative GWP (USD)	749'000
Indicative GWP (Naira)	1'157'544'000
Indicative GWP (USD) after 90% subsidy	74'900
Indicative GWP (Naira) after 90% subsidy	115'754'000

Table 19: Illustrative rounded gross pricing (GWP) for option 2, with estimated intermediary cost items and subsidies considered. Nominal values are also shown with 90% premium subsidy.

	Option 2: *Balanced*
Indicative gross Rate on Line (RoL)	9.69%
Indicative GWP (USD)	727'000
Indicative GWP (Naira)	1'122'789'000
Indicative GWP (USD) after 90% subsidy	72'700
Indicative GWP (Naira) after 90% subsidy	112'279'000

Table 20: Illustrative rounded gross pricing (GWP) for option 3, with estimated intermediary cost items and subsidies considered. Nominal values are also shown with 90% premium subsidy.

	Option 3: *Pure catastrophe*
Indicative gross Rate on Line (RoL)	9.31%
Indicative GWP (USD)	698'000
Indicative GWP (Naira)	1'078'676'000
Indicative GWP (USD) after 90% subsidy	69'800
Indicative GWP (Naira) after 90% subsidy	107'868'000

Lagos State representatives' preferred structure selection

After a number of consultation rounds, the Lagos State Technical committee integrated by LASEMA, Insurance Department of the Ministry of Finance of Lagos State and SDG Secretary selected the second option as the preferred choice. All details of option 2 ('*Balanced*') are summarized Table 21.

Table 21: Summary of the selected option number 2 ('Balanced').

	Option 2: *Balanced*
Deductible, number of people (equivalent return period)	170'000 (=4.23% of total covered population) (RP=5 years)
Flood depth threshold for trigger	50 cm
ICEYE's capability to detect the attaching events	OK
Full limit, number of people	611'176
Sum insured per person (USD)	17.00
Sum insured per person (Naira)	26'273.5
Indicative gross Rate on Line (GWP/Limit)	9.69%
Indicative GWP (USD)	727'000
Indicative GWP (Naira)	1'122'789'000
Indicative GWP after 90% subsidy (USD)	72'700
Indicative GWP after 90% subsidy (Naira)	112'279'000

F.4.3 Real-time monitoring of the index

Introduction to ICEYE Flood Solutions

ICEYE delivers unmatched persistent monitoring capabilities for any location on earth. Owning the world's largest synthetic-aperture radar satellite constellation, the company enables objective, data-driven decisions for its customers in sectors such as insurance, natural catastrophe response and recovery, security, maritime monitoring and finance. ICEYE's imagery can be collected day or night, and even through cloud cover. By focusing on monitoring natural disasters and combining the cutting-edge SAR technology with machine learning processes and auxiliary data, ICEYE produces high-resolution, rapid actionable insights – including data on floods (Flood Insights).

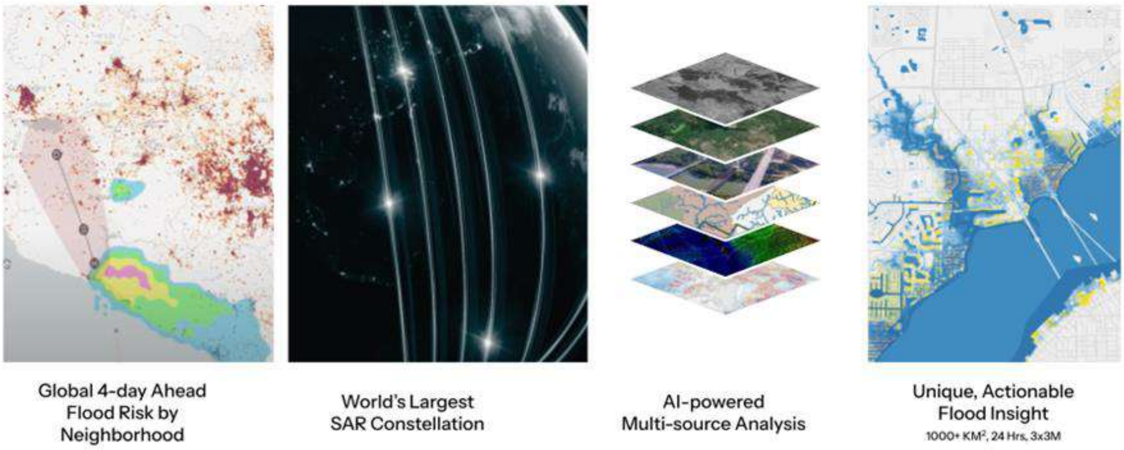


Figure 50: Basic pillars that make up the generation of ICEYE's flood footprints. Figure generated by ICEYE.

Flood Footprint generation: an end-to-end process

To produce Flood Insights, ICEYE has had to develop individual sub-teams with different tasks and roles in the analysis process, from forecasting floods to analyzing floods to delivering floods – and everything in between.

The first step to producing Flood Insights involves forecasting and monitoring for floods globally. In this step, ICEYE's team of meteorologists across multiple time zones views different data sources, most aggregated on an internal platform, to predict the most likely areas for flooding in the coming hours and days. These data sources include deterministic and ensemble weather prediction models (e.g. GFS, ECMWF, CMC), precipitation forecasts, excessive rainfall outlooks, flood propensity maps, tropical weather guidance (e.g. track and intensity forecasts, storm surge predictions), anomalous antecedent rainfall, and river/tidal gauge forecasts. In addition, the team will monitor globally where flooding is currently ongoing through additional data sources like individual state and nation flood warnings, current river gauge levels, radar, and even social media.

Once the meteorologists identify areas of concern (whether in the future or current), they look to match them up with population density and critical infrastructure to predict where the greatest impacts to life and property will be. They then align these areas of concern with the orbital paths of the world's largest (SAR) satellite constellation – which can see through clouds and at night – to capture acquisitions up to 3 days in advance of the threat of flooding and will adjust them throughout an event to reflect the latest thinking, including making adjustments during the flood itself. Since ICEYE owns and operates its own satellite constellation, the team takes an agile approach to targeting floods – with the ability to adjust an upcoming satellite pass or task a completely new one in only a matter of a couple of hours before time of acquisition.

As the SAR imagery is being collected, a separate team begins the search for all other sources of flood information in the event area that the meteorology team has designated for flood potential. This flood information may come in the form of river gauges or buoys, or in the form of images verifying the existence of flooding. If the auxiliary data is an image, it may come from social media, Government sources, or news reports – but can also come from publicly available satellite or aerial imagery.

The collection of auxiliary imagery is only part of this second step to the process – once that team finds it, they work to geolocate those data points and, if possible, identify approximate water depth in them. These data points serve as points of validation and calibration for the flood analysts to use in analysis beyond just the SAR imagery when producing flood extents/depths (Figure 51).

A third team, the flood analysis team, prepares all the collected data (satellite-, aerial-, and ground-based) for analysis simultaneous to the other teams continuing to collect more data. This includes preparing the latest digital elevation models (DEMs) ICEYE's data and engineering team has ingested to make it analysis-ready and defining analysis areas of interest (AOIs).

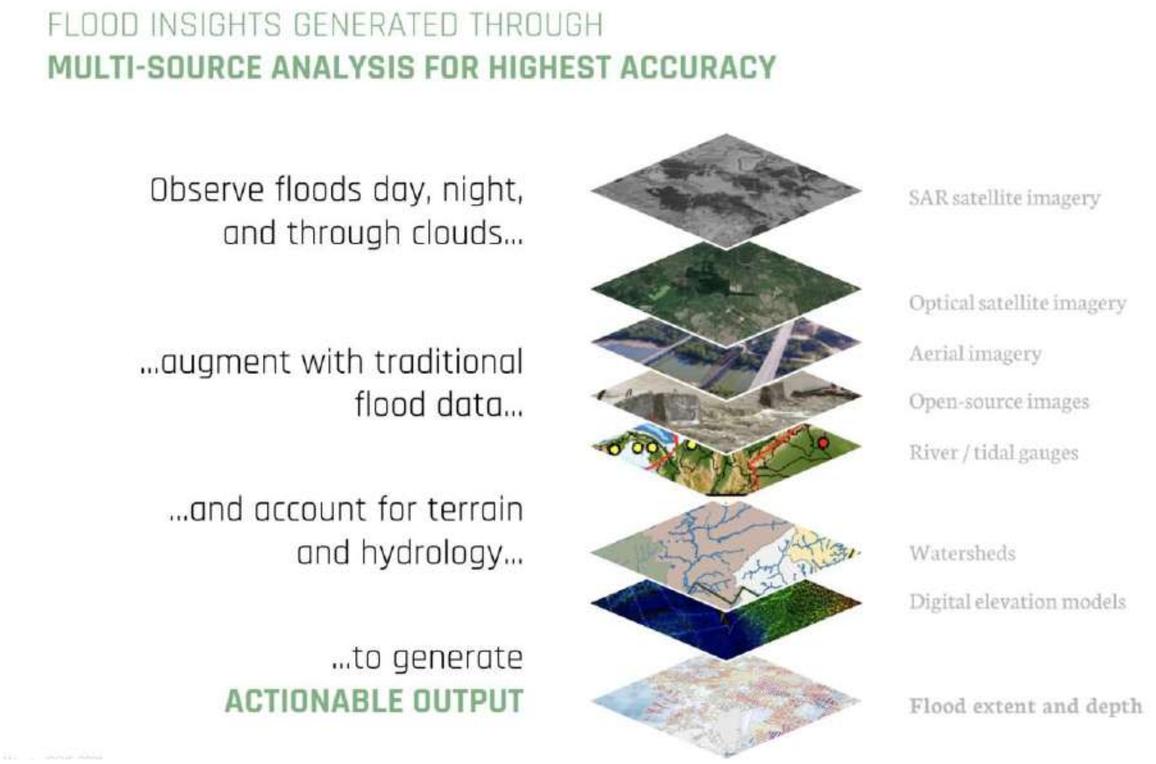


Figure 51: Further auxiliary data sources that augment the SAR imagery for the final maximum flood extent footprint. Figure generated by ICEYE.

Once data has been acquired that indicates flooding has reached critical thresholds for analysis (typically floods that last at least 12 hours and impact 100 buildings with equal or greater than 30 centimeters of water on average) and the auxiliary data has been prepped, the flood team activates to produce an analysis. During this analysis, the team collates all different data points that indicate flooding (e.g. ICEYE imagery, optical satellite imagery, geolocated visual observations, river gauges) and produces a water height surface within each analysis AOI. Once finalized, that water height surface is layered on top of the highest-resolution DEM(s) within the AOI, and the flood depth raster is produced. The flood depth raster is then quality controlled by checking it against the input data sources to ensure the outputs align to the flood observation data.

Analysis release includes a set of geospatial files consisting of extent vector, depth raster, and associated release notes – which are all supposed to be representative of the peak of the flood (agnostic to time). This data is at approximately 4-meter horizontal resolution (with discrete depth values at centimeter intervals). The accuracy of both the depth and the extent is largely dependent on the underlying datasets, including the number and quality of SAR images indicating flooding, the number of auxiliary images showing flooding, and the DEM used in the analysis. ICEYE aims to deliver Flood Insights in a timely fashion – in the case of Nigeria, the current aim would be to produce a single release of data within 7 days of the event peak.

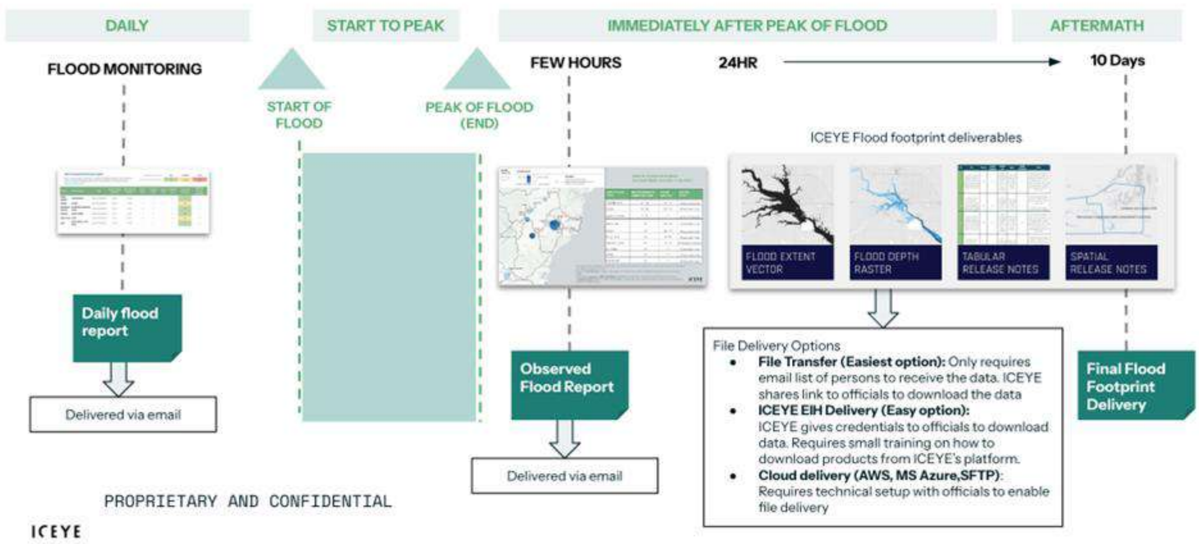


Figure 52: Timeline of different Flood Solution Deliverables. Figure generated by ICEYE.

Flood types and ICEYE flood events

The ICEYE Flood Insights product strives to produce analyses for all flood events – and for all areas that have been impacted by a flood event that reaches the threshold. However, floods are complex events that differ as a function of terrain and weather. Those differences have an impact on the performance characteristics of the delivered data product and whether ICEYE can analyze successfully. As there is no international standard for flood event definition, ICEYE monitors for floods using forecast data and meteorological warnings. ICEYE then characterizes floods internally. Characterization is based on the type of flooding, the area of the flood, and the duration of flooding. These three factors (geographic size, temporal duration, and type of flood) can dramatically impact ICEYE's ability to produce an analysis for a flood.

Generally speaking, small footprint (e.g. single neighborhood-level), short-duration floods (<3-6 hours) such as urban flash floods can be challenging to forecast and plan for imagery acquisition and thus, can be challenging to analyze. Conversely, large and long-duration events such as tropical systems or large-scale riverine flooding are generally well forecasted, easily imaged, and therefore can be more successfully analyzed. Nonetheless, through incorporating multiple data sources, including those not dependent on satellite passes, and the work of all teams together, ICEYE has demonstrated a capability to produce analyses for even small flash floods in some geographies.

ICEYE Flood Mapping Capabilities in Nigeria: Example

Flooding case study: September 2024 flood, Maiduguri, Nigeria

In September 2024, rains shifted unusually far north in Africa, causing riverine flooding in parts of northern Nigeria and southern Niger and Chad. This also caused pressure on local dams and in some cases, even dam failures. While the area is not normally covered by ICEYE's Flood Insights monitoring operations, the team decided to task imagery proactively to see what was possible. In this imagery, flooding was detected in over Maiduguri, Nigeria (Figure 53).

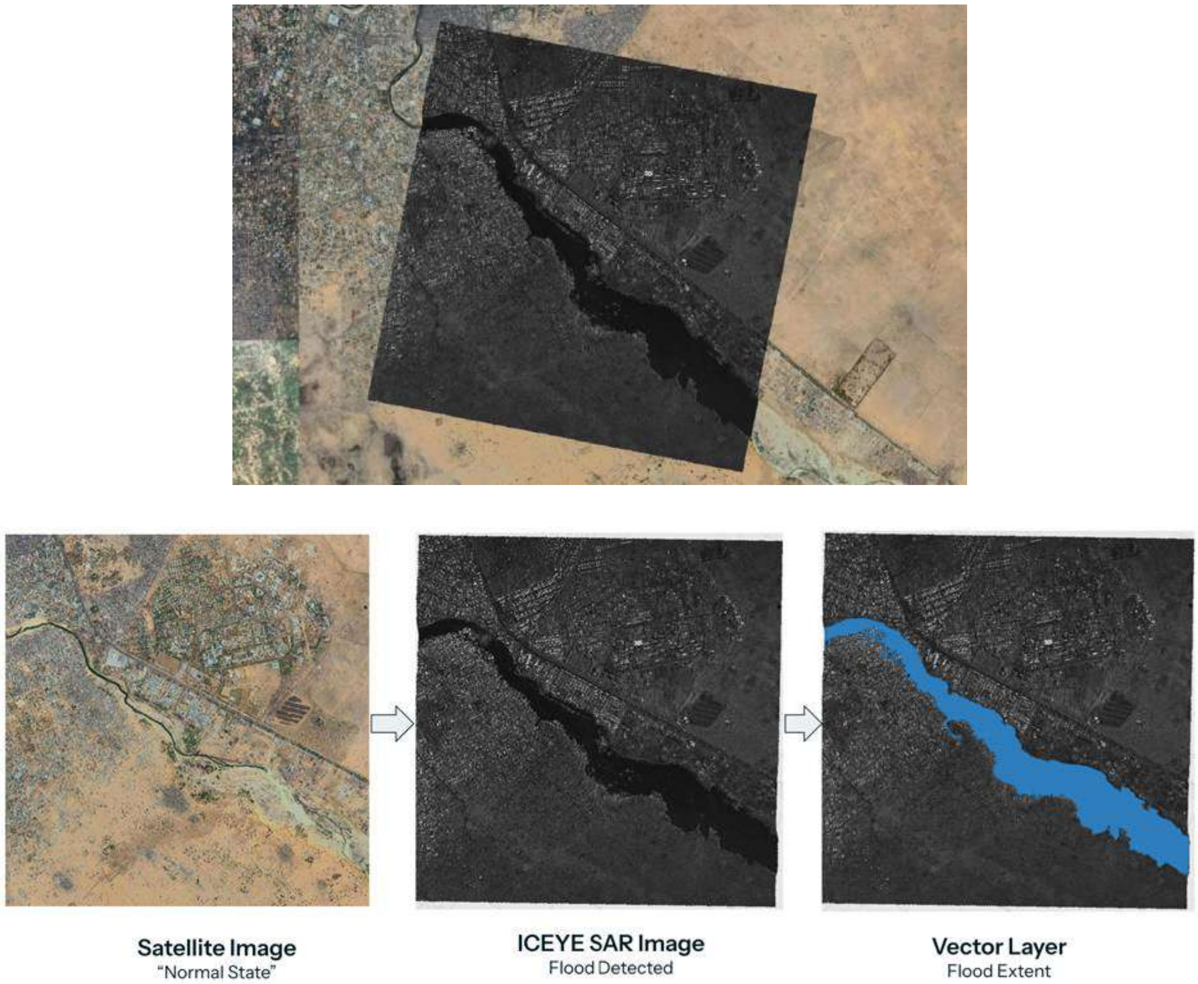


Figure 53: (Top) ICEYE DWELL SAR Image (0.5 m) from Maiduguri, north-east Nigeria, September 2024. (Bottom) Flood mask extracted from ICEYE SAR imagery. Figure generated by ICEYE.

ICEYE Flood Validation

While ICEYE did not collect auxiliary data for this event, nor endeavor to produce a full analysis, for the purposes of demonstrating the value of SAR imagery in flood analysis in Nigeria, it did produce the below image. This image below shows comparisons of a flood mask from ICEYE SAR imagery with visual confirmations of flooding from the same event – indicating close correlation between the observations and flood detected in ICEYE's SAR image in Maiduguri, Nigeria (Figure 54).

Figure 54: Comparisons of a flood mask from ICEYE SAR imagery with visual confirmations of flooding from the same event in Maiduguri, Nigeria. Figure generated by ICEYE.

ICEYE Flood Insights validation

The images in Figure 55 show comparisons of the ICEYE Flood Insights data with visual confirmations of flooding from the floods in Accra, Ghana, in May 2022 – indicating close correlation between the observations and ICEYE's flood footprint analysis. Note the analysis covered multiple areas within the larger Accra area and captured both urban and river flooding.

Figure 55: Details of ICEYE's Flood Output of the May 2022 Accra Floods. Blue color scheme shows details of the maximum flood extent in left image. Marked location coordinates are 5.563386, -0.227861, determined at water depth of 76 centimeters. Right top images show the

location's street with and without floods. Bottom right satellite image for reference. Figure generated by ICEYE.

Costs for monitoring services

The parametric FFP solution will benefit from the highest resolution flood footprint data currently available in the market. ICEYE's technology enables a tailored parametric flood insurance scheme at lower levels of basis risk. In addition to the risk transfer scheme itself, which would be a 'first', ICEYE will also make its data available to all of Lagos State's authorities involved in direct disaster relief after floods. This is an extra service that is delivered exclusively with this FFP solution backed by ICEYE. The project team believes the flood footprint data will bring additional benefits and there are reasons to think that the Government's response efficiency will improve as a result.

This fee varies depending on the risk profile LS choses to insure for and a pricing lever based on additional operational use cases considered (e.g. for response and recovery). Such levers depend on how widely the data is to be shared within the State Government, how many disaster management agencies are involved, the geographic scope of the monitoring area, and the length of time the data needs to be delivered.

F.4.4 FFP fallback options

In the event that ICEYE's technology fails, sensible fallback options for the primary reporting agency to parametric insurance coverage must be specified in the contract and agreed between the insured and the insurer. Modelled flood footprints are common practice and are often viewed as a workaround to similar parametric flood footprint schemes elsewhere. Provided JBA has supplied the high-resolution flood maps used the probabilistic model used for pricing, post-event footprints generated from the same dataset are the preferred fallback option. Although the flood event is not directly observed, such a modelled footprint is close to reality and can serve as a basis for determining a triggering event.

The development process of JBA's post-event flood footprint starts with the creation of a validation layer to convey confidence and uncertainty in the footprint by highlighting areas in which confidence that the resulting footprint is accurate. If river and rainfall gauge time series data is available, a return period analysis can be conducted to estimate the hazard return period of the event. Satellite imagery from publicly available sources to estimate the extent of the event and images from the media are sourced to estimate the depth of flood waters.

Once depth and extent estimates have been derived a return period is assigned that corresponds to JBA's return period flood hazard maps. The return periods are then assigned to Hydrological Accumulation Zone (HAZ) polygons. The flood hazard maps are mosaicked based on the polygon return period assignment. At this stage defense layers can be applied to the footprint. If the return period assignment of the footprint section is less than the standard of protection of the defense, the defended area is removed from the footprint as the area behind the defense is protected.

The footprints are produced as a raster depth, raster extent and vector extent files. They undergo quality control before release. When all validation tests are concluded successfully, the final footprint, consisting of raster cells with a flood depth equal or greater than 50 centimeters, will be intersected with the portfolio of people at risk in Lagos Sate to identify the final number of people impacted by the event.

F.5. Regulatory considerations

Parametric insurance currently lacks a regulatory framework in Nigeria. As a result, it is necessary to submit the product for approval through a product approval process. Several stakeholders were involved to clarify this process, including:

- **NAICOM**: The Nigerian Insurance Regulator.
- **Insurance Department of the Ministry of Finance, Lagos State**: Represented by Mr. Oluwole Gbenga.
- **AXA Mansard**: Acting as the sponsor of the product.

Following these meetings, various initiatives were launched.

F.5.1 Product Approval Process

NAICOM requires a product submission process to ensure that the insurance parametric product complies with Nigerian regulations. To facilitate timely approval, multiple interactions were scheduled with the regulator (NAICOM):

- **April 2023**: AXA Mansard sent a Letter of Introduction titled '*IDF Project on Transferring Flood Risk in Lagos State*' to NAICOM.
- **March 2024**: A Letter of Update was submitted, outlining key milestones achieved in the flood risk project and requesting the appointment of NAICOM staff dedicated to the initiative.
- **December 2024**: The Product Package for NAICOM Approval was informally submitted to the assigned NAICOM representative, who provided feedback. These inputs were incorporated into the final submission.
- **February 2024**: The final product package was officially uploaded to the NAICOM platform by AXA Mansard.

Close coordination among key stakeholders – including AXA Mansard, the Insurance Department of Lagos State, and IDF technical partners – was essential throughout the process.

- Document 1 – Application letter

- Document 2 – Receipt of payment for application fee
- Document 3 – Draft Policy Wordings Documentation
- Document 4 – Proposal and quotation form for flood
- Document 5 – Certification of loss + Claim form to be received from the insured
- Document 6 – Full product briefings and plan for all stakeholders
- Document 7 – Actuarial notes
- Document 8 – Letter of comfort and support from Africa Re
- Document 9 – Product business plan
- Document 10 – Standard KYC Proposal form
- Document 11 – Specimen Certificate

While the product is still in process of approval at the time of writing, there has a continuous communication with the regulator to anticipate unexpected constraints, to ensure the decisions are taken in terms of placement and policy drafting stay compliant with Nigerian regulation.

F.5.2 Insurance set-up and risk cession scheme

Two Nigerian brokers, QuickLink Insurance Brokers Ltd. And Sunlight Insurance Brokers, were appointed by the Insured to establish the local insurance setup. As per the Insured's mandate, four local insurers were invited and accepted to participate in the scheme (AXA Mansard, Cornerstone, Leadway, Lasaco). Africa Re will be the preferred provider of reinsurance capacity (see Section F.5.4).

Table 22: Proposed retained limit by the local insurers.

	Total
Share of the risk	100%
Local Retention	25.45%
Retained limit (USD)	1'908'825
Total limit (USD)	7'500'000
Retained limit (Naira)	2'950'089'038
Total limit (Naira)	11'591'250'000

For further clarity, scheme in Figure 56 summarized the stakeholder and flow of funds for the insurance set up.

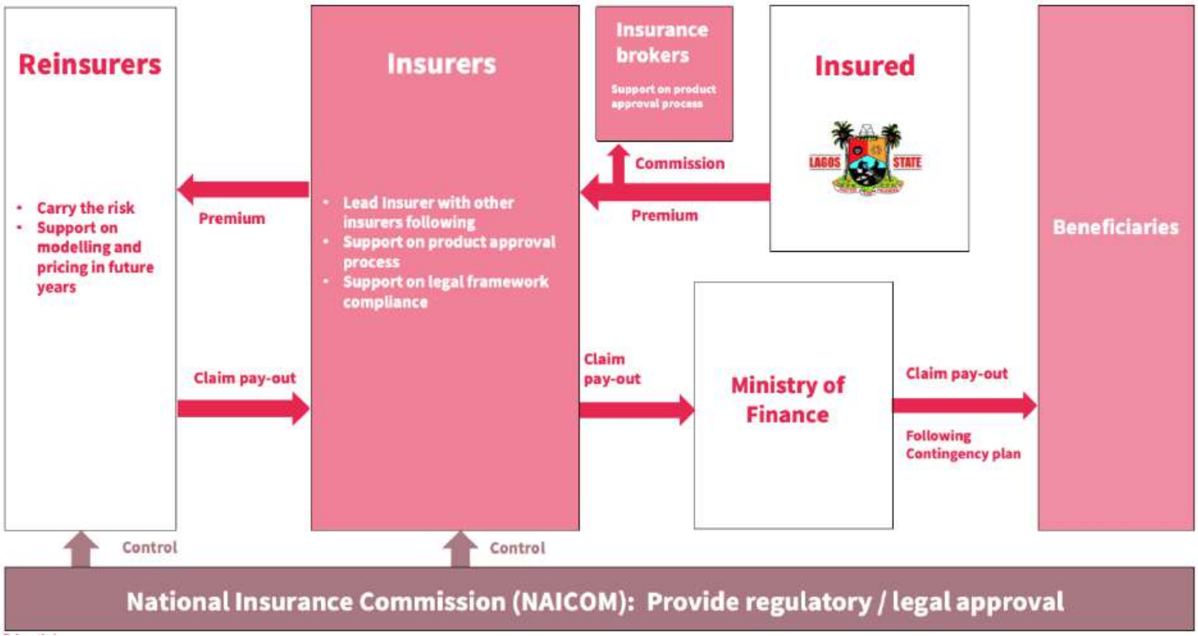


Figure 56: Insurance set-up and flow of funds. Figure generated by AXA Climate.

F.5.3 Policy wording drafting

The policy wording was developed by the consortium members, drawing inspiration from previous flood footprint policy wordings.

The first draft was submitted to AXA Mansard, which provided feedback to ensure compliance with Nigerian regulations. The policy was also shared with NAICOM during both the informal product packaging submission stage and the formal upload to the NAICOM platform.

Additionally, the policy was widely shared with local brokers and the Insured, who did not provide any comments or revisions.

F.5.4 Reinsurance

In Nigeria, international reinsurers are generally prohibited from underwriting reinsurance in or from Nigeria. Africa Re is considered a local reinsurer and other reinsurers like Zep Re and Continental Re have received letters of exception.

All participating insurers turned to Africa Re to secure the necessary capacity for their respective shares. Africa Re confirmed its interest in supporting the deal on an individual facultative reinsurance basis and issued letters of comfort and support to each local insurer.

At present, Africa Re is expected to provide reinsurance for this product, though discussions on finalizing this arrangement are still ongoing.

F.5.5 Insurance and Reinsurance Brokerage

Recognizing the need to ensure the sustainability of the program and promote an open market process, it was proposed to establish a tendering process for the appointment of a reinsurance broker.

The IDF Technical Team developed Terms of Reference, which were shared with key parametric industry brokers. As a result, several proposals were received from:

- Willis Towers Watson
- Guy Carpenter
- Howden

However, after reviewing the proposals and associated service costs, the Ministry of Finance decided not to proceed with appointing a reinsurance broker.

F.5.6 Taxes

Insurance taxes are a critical component of final premium budgeting. In Nigeria, parametric insurance products are subject to a 1% NAICOM fee on Gross Written Premium. This was confirmed by different local insurers.

F.5.7 Conclusions

This section describes the regulatory and placement aspects of the project. Policy development and regulatory coordination were key tasks of the IDF consortium and were carried out throughout the project. Emphasis was placed on communication with the main stakeholders, namely AXA Mansard and NAICOM. We also discuss setup considerations. While the placement process is ongoing, the IDF consortium has ensured broad participation by engaging four local insurers and initiating a tender process for a reinsurance broker. All these efforts were undertaken with the preferences course insured LS in mind, who retain ultimate decision-making power.

G. Conclusions, limitations and outlook

Lagos, Nigeria, faces a growing flood risk due to a combination of geographical, climatic, and urbanization factors. Addressing this risk is critical for the city's sustainable development, public health, and economic stability. With concerted efforts from government, communities, and various stakeholders, Lagos can take steps to become more resilient to the challenges posed by flooding.

G.1. Limitations of the current product and process

G.1.1 Basis risk considerations

The payout of a parametric insurance is pre-defined based on the exceedance probabilities of naturally occurring parameters. With parametric solutions, there is always some discrepancy between the payout and the actual financial losses in a flood disaster that needs to be dealt with (so-called *basis risk*, Section F.3.1). However, the project team determined the FFP solution is the best choice, standing out positively compared to other solutions. Floods are directly observed in areas that are attributed to the poor and vulnerable population in Lagos. This reduces a significant amount of the basis risk compared to more conventional XSR product – as precipitation measurements can be faulty and are not directly indicating the occurrence of a flood. XSR is only a proxy data, and its resolution and complex hydrologic settings make it less accurate to indicate actual flooding. Additionally, the FFP solution utilizes probabilistic flood models, while precipitation-based triggers only rely on the available history of data. This helps to increase underwriting confidence.

Remaining sources of basis risk for FFP solutions arise from:

1. The definition of the PVHHs. It is clear that in the event of a flood the city as a whole will be affected, to some degree, and the clear boundary between covered PVHH under this scheme and the rest of the population will be difficult.
2. The quality of the flood hazard models and their consistency with respect to the monitoring technology.
3. On the trigger side there is a risk of intermittent or erroneous satellite observation. ICEYE must ensure it tasks its satellites in time to capture the peak of a flood. With the help of weather forecasts and by continuous expansion of their constellation, they are confident that they can fulfil this task. However, due to force majeure, a small uncertainty will always remain, which is why we consider a fallback triggering option.

G.1.2 Data quality and availability

The development of a parametric insurance product for protecting poor and vulnerable populations from floods in Lagos relies on various datasets and modeling techniques. However, several limitations in data quality and availability impact the accuracy, reliability, and transparency of the insurance mechanism, and add to *basis risk* (Section G.1.1). These limitations must be acknowledged to guide future improvements and ensure the product remains both effective and equitable.

- **Data gaps in informal settlements**: A significant challenge in designing an equitable parametric insurance product is the lack of accurate and up-to-date data on informal settlements. Many vulnerable populations reside in unplanned urban areas, where housing structures are not properly mapped, and exposure data is incomplete. Since these communities are among the most affected by floods, improving data collection on informal settlements is essential to ensure that flood risk assessments and payout calculations accurately reflect the realities on the ground. This could involve leveraging high-resolution satellite imagery, crowd-sourced mapping efforts, and community-based data collection.

  It is also important to note that a clear cut of the PVHH, as roughly defined for the purpose of this project, and the rest of the population in Lagos is close to impossible. PVHH can be found everywhere in the city, also outside the covered LGAs. This project however presents a flexible risk transfer product whose potential payouts can still be used elsewhere.

- **Limitations in flood risk modelling**: The flood risk assessment underpinning the parametric insurance product is based on JBA flood models, which provide high-resolution flood hazard maps. However, these models require further calibration and validation to better reflect the specific hydrological and urban conditions of Lagos. Enhancing the calibration process with local flood event data, ground observations, and improved hydrodynamic modelling will help refine the accuracy of risk estimates. Additionally, as climate change is expected to alter flood patterns, the inclusion of future flood events and updated hydrological assessments will be necessary to maintain the model's relevance over time.

  Another limitation is the exclusion of critical urban and infrastructure factors affecting flood dynamics. The performance of Lagos' drainage system, waste management practices, and dam management operations significantly influence flood severity and extent. Blocked drains due to improper waste disposal exacerbate urban flooding, while reservoir releases from upstream dams can contribute to sudden water level rises. Currently, these elements are not fully integrated into the flood modelling framework, limiting the accuracy of projected flood extents and potential insurance payouts. Incorporating these factors into the model would provide a more realistic representation of flood risk.

- **Challenges in flood footprint identification and transparency**: The calculation of insurance payouts depends on the ability to accurately and transparently determine the areas affected by flooding. Currently, flood footprints are generated using satellite imagery and other data sources. However, challenges remain in ensuring the reproducibility and consistency of footprint generation methods. There is a need for standardized methodologies that improve transparency in flood extent determination, reduce dependency on proprietary products, and allow for independent verification of payouts. Further, the more accurate data will be made available, the more suitable they are to capture highly dynamic urban floods, and the lower the basis risk.

Addressing these limitations through data improvements, model enhancements, and transparent methodologies will strengthen the effectiveness of the parametric insurance product, ensuring that payouts are fair, timely, and accurately reflect the needs of flood-affected communities.

G.1.3 Public opinion and political risk

The implementation of a parametric insurance product for flood protection in Lagos faces several challenges related to public perception and political dynamics. These challenges could influence the acceptance, sustainability, and effectiveness of the insurance mechanism. Addressing these risks proactively through transparent communication, stakeholder engagement, and strong governance measures will be key to ensuring long-term success.

- **Coverage of some LGAs and exclusion of others:** The insurance product is designed to cover specific Local Government Areas (LGAs) based on historical flood risk assessments and financial constraints. However, this selective coverage may generate dissatisfaction among residents and local leaders in excluded LGAs. Communities outside the insured areas may perceive the policy as unfair, leading to political pressure for broader coverage, even if risk assessments do not justify it. Managing these expectations through clear communication on the selection criteria will be crucial.

- **Role of the insurance industry and perceptions of private sector involvement**: The involvement of private insurance companies may be met with skepticism from the public and policymakers, particularly if there are concerns about profit motives overriding the social protection objectives of the policy. If not properly managed, the perception that the insurance industry benefits at the expense of vulnerable populations could undermine public trust. Ensuring transparency in pricing, claims processing, and fund utilization will help mitigate these concerns.

- **Corruption and misallocation of funds:** The risk of corruption in fund distribution and relief efforts is a significant concern. If insurance payouts are not transparently managed and equitably allocated, public trust in the mechanism could be eroded. Strong oversight, independent audits, and clear accountability mechanisms should be implemented to prevent fund mismanagement and ensure that the insurance serves its intended purpose.

- **Political influence and changing government priorities:** Political leadership changes at the state or national level may impact the continuity of the insurance program. New administrations may have different priorities, potentially leading to reduced financial support or modifications in policy design. Ensuring institutional commitment beyond individual political cycles by embedding the insurance product into long-term disaster risk management frameworks will be essential.

- **Public perception of insurance-based assistance:** There may be misunderstandings about how parametric insurance works, particularly regarding payout triggers and the absence of traditional damage assessments. If communities expect direct compensation for all flood losses rather than predefined parametric payouts, dissatisfaction could arise. Public awareness campaigns and stakeholder engagement will be necessary to align expectations with the insurance mechanism.

By anticipating these challenges and addressing them through effective communication, governance, and stakeholder involvement, the parametric insurance product can gain greater public trust and political stability, ensuring its long-term viability in Lagos.

G.2. Recommendations for improvement

Considering these limitations, the following recommendations are suggested for improving both the product itself and the operational components.

Product improvements:

Flood risk model	In a few years, the flood model should be reassessed to consider whether climate change is increasing the risk.
Exposure layer	Update population data to disaggregate vulnerable/low-income people including in informal settlements. Extend exposure layer to cover all LGAs but filter only these disaggregated vulnerable populations. Extend exposure layer in future to cover critical public assets.
Flood monitoring	Update the satellite-based monitoring of floods whenever new satellites, sensors or other data is available, making sure ever smaller and more frequent floods can be captured accurately.
Calibration	If there is a flood-triggered payout, use this data to calibrate the model.

Operational improvements:

Contingency Plan	If an updated vulnerable population mapping becomes available, the contingency plan should be updated so that payouts can be much more targeted to address this population.
Sustainable Premium	Ensure a budget line is put into the State budget for premium over the long term (multiple years) and a dedicated fund set up if needed for this purpose.
Insurance Setup	Open the insurance program to other insurers over time if it grows sufficiently. This would allow more of the risk to be retained in the country rather than flowing to non-Nigerian reinsurers.
Capacity Building	Ensure there is annual capacity building done with the relevant Ministries (SDGs, Finance and LASEMA) as well as local participating insurers and NAICOM.
M&E	Set up an audit and a separate account to track how the insurance payouts were used and to ensure they had as much impact as they were supposed to.

G.3. Potential next steps

G.3.1 Roadmap for implementation

With delivery of this report, the product development is completed, and the mandate of this project team ends. For the insurance solution to be implemented, the project team is working towards a placement of the product beginning of May 2025. Figure 57 illustrates the remaining steps of the product to be life.

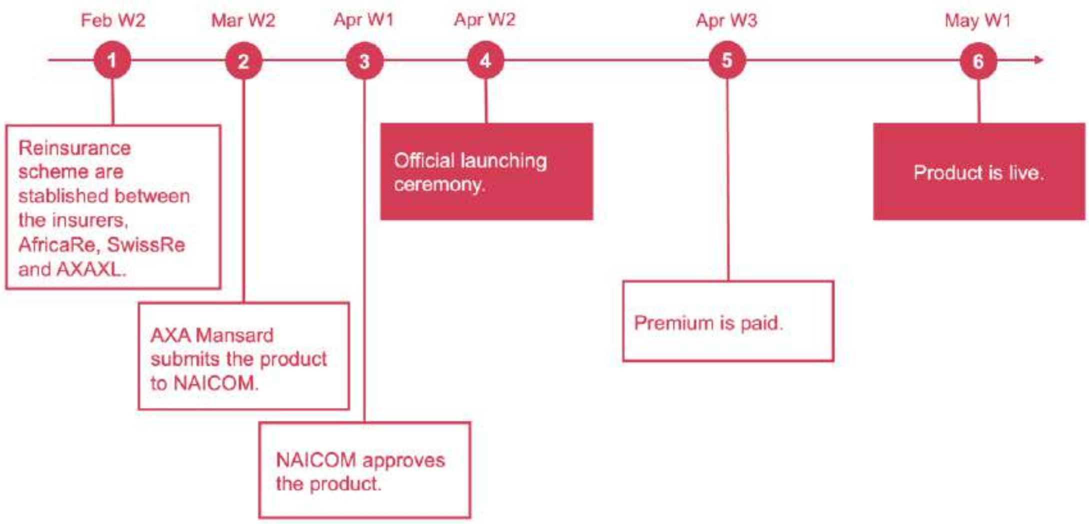


Figure 57: Expected timeline for the placement of the program. Figure generated by AXA Climate.

G.3.2 Sustainability of the insurance scheme

Ensuring the long-term sustainability of the parametric insurance scheme is critical for maintaining its effectiveness in providing financial resilience to vulnerable populations in Lagos. Sustainability depends on financial, operational, and institutional factors that must be continuously assessed and improved. Given that the policy is already in place and has been accepted by the regulator (NAICOM), efforts should now focus on ensuring its long-term viability and effectiveness.

- **Gradual Reduction of Donor Support and Transition to Local Funding**: The InsuResilience Solutions Fund (ISF) has committed substantial premium support in the initial years, covering 90% of the first year's premium, 80% in the second year, and 70% in the third year. While this provides a strong foundation, a strategy must be developed to ensure financial independence beyond this period. The Lagos State Government, through the Ministry of Finance and in collaboration with UNDP, should explore long-term financing mechanisms such as state budget allocations, risk pooling with other Nigerian states, and a sustainable premium financing strategy. LASEMA had mentioned that the Governor of Lagos had approved a new fund to be set up to increase the Agency's budget with a potential new tax creating revenue for the fund. This is a possible avenue that could be explored for the future premium payments.

- **Strengthening Public-Private Partnerships:** Engaging private insurers, reinsurers, and financial institutions is crucial for the scheme's long-term sustainability. These partnerships can support premium affordability, facilitate product innovation, and provide additional capital for payouts. Encouraging local insurers to assume greater responsibility in underwriting and managing parametric insurance products will enhance local capacity and reduce dependency on external partners.

- **Exploring Alternative Risk Financing Mechanisms:** To ensure the scheme remains viable beyond donor support, alternative risk financing strategies should be explored, including sovereign risk pools (to reduce the overall cost through risk pooling) and, potentially, microinsurance schemes targeting at-risk populations (to shift some of the cost to communities at risk). Developing a reserve fund or establishing a risk-sharing agreement with financial institutions can provide additional financial stability. By integrating these alternative risk financing mechanisms, the parametric insurance scheme can transition from donor reliance to a self-sustaining financial model.

- **Government Commitment and Institutionalization:** Integrating the parametric insurance scheme into Lagos State's disaster risk management framework will enhance its sustainability. A formal policy recognizing parametric insurance as a key financial resilience tool can help secure long-term government backing. Capacity-building programs for government agencies, insurers, and risk modelers will ensure proper implementation and long-term adaptation.

- **Public Awareness and Policyholder Engagement:** Building trust and awareness among beneficiaries is essential for sustainability. Campaigns should highlight the scheme's benefits, clarify payout mechanisms, and encourage community participation. Establishing transparent governance structures for claims processing and fund allocation will reinforce confidence in the scheme.

By addressing these key areas, the insurance scheme can transition from donor dependency to a sustainable, locally driven risk financing mechanism, ensuring continued protection for vulnerable populations in Lagos.

G.3.3 Further enhancement of the products

As the insurance scheme matures, opportunities arise for expansion and refinement to better address emerging risks, improve coverage, and enhance disaster response capabilities. With the policy soon in place and accepted by NAICOM, the focus should shift to optimizing and expanding the product.

- **Expansion to Additional Local Government Areas (LGAs):** Currently, coverage is limited to specific LGAs based on flood risk assessments. Expanding to other vulnerable areas will ensure broader protection for at-risk populations. Future expansion should be data-driven, using updated flood risk maps that incorporate historical and projected climate risks.

- **Integration of Public Facilities into the Exposure Model:** Including public infrastructure such as schools, hospitals, and emergency shelters in the exposure model will improve overall disaster resilience. The contingency plan should be adapted to prioritize the rapid restoration of essential public services following flood events.

- **Expansion to Other States in Nigeria:** Given Lagos State's pioneering role in parametric insurance, scaling up the initiative to other flood-prone states could enhance national disaster resilience. Coordination with federal agencies, insurers, and development partners is necessary to ensure replicability and financial viability in other regions.

- **Gender Inclusion Policy:** Women and marginalized communities often face disproportionate impacts from flooding. A gender-sensitive approach will ensure payouts and emergency relief efforts address their specific needs. Engaging women-led organizations in disaster response planning can enhance inclusivity and effectiveness.

- **Strengthening Industry Partnerships and Capacity Building:** Expanding the network of industry partners, including insurers, risk modelers, and financial institutions, can strengthen financial stability and operational efficiency. Training programs for insurers, government officials, and disaster risk professionals will ensure effective product management, policy renewals, and risk pricing improvements.

- **Enhancing Data Quality and Risk Modelling:** Improving flood risk modelling by integrating real-time satellite imagery, drainage system performance data, and climate projections will enhance payout accuracy. Investments in transparent and reproducible flood footprint generation will strengthen confidence in the scheme. But a key data improvement would be getting accurate vulnerability data to understand where the lowest income and most vulnerable people live and being able to add such a disaggregated exposure layer into the flood risk model.

- **Establishing a Long-Term Sustainability Plan:** Developing a clear roadmap for premium affordability, government backing, and risk-sharing strategies is essential for long-term success. Exploring additional risk financing instruments, such as regional risk pools, can provide financial buffers against extreme weather events.

By implementing these enhancements, the parametric insurance product can evolve into a comprehensive and sustainable disaster risk financing tool, fostering greater resilience across Lagos and beyond.

G.4. Lessons learned

G.4.1 Strong local collaboration is key

A local project manager is essential to fostering close alignment between the project team and government stakeholders. This is especially important for facilitating the smooth exchange of information and data between government institutions and the project team, as well as for the organization of workshops and bilateral in-person meetings.

G.4.2 Data sharing and cost considerations

Local government institutions sometimes questioned whether the project team should pay for data sharing. This should generally not be the case. The project is supported by the ISF and (partially in-kind) by the industry, and the beneficiary is Lagos State. More and better data means less uncertainty and therefore a smaller risk margin for which the government would ultimately have to pay. Only in one case and after consultation with ISF was it agreed to reimburse a small amount to cover administrative/data extraction costs.

G.4.3 Data drives success

The quality of the final insurance products depends heavily on the available historical claims data, as well as qualitative data on rainfall, river flows and flooding. Compiling a comprehensive data inventory early, perhaps even as part of the final grant application, will help determine the required timeline and potential for success of the project.

G.4.4 Early stakeholder onboarding

Early collaboration with regulatory authorities and national insurance associations is beneficial. Ideally, this should be done as soon as the technical product design has reached the draft stage (e.g. about a year before project completion).

Figure 58: (top and bottom) The project team organized several workshops to update all stakeholders and consider their feedback. Photographs from October 2023.

G.4.5 Continuous stakeholder engagement

It is important to schedule an in-person kick-off workshop in the first 6 months, once data collection is complete and product design has begun. After the personal kick-off workshop in Lagos, it took around six months for the project team and local stakeholders to agree on a common goal and project scope. In addition, all important local partners should be regularly informed about the latest status of the project (see also below).

A final product presentation workshop was organized by UNDP and the ISF Technical partners mid-February 2025 to present the product, hand it over and ensure capacity building. Beyond the original mandate, the placement with local insurers was also initiated by the product team.


UNDP
Lagos Flood Risk Transfer Scheme
Technical Capacity Workshop
on
Galaxy A14
11 February 2025 12:52


final technical workshop
Collaboration
UN
DP
Transfer Scheme
Product for Lagos State.
Galaxy A14
11 February 2025 10:23


Galaxy A14
11 February 2025 10:26

Figure 59: Impressions from the final technical workshop and product hand-over that was held in Lagos 11-12 February 2025.

G.4.6 Communication and feedback

Frequent (e.g. 6-weekly or bi-monthly) roundtable discussions with all local stakeholders are valuable for sharing progress and gathering feedback.

G.4.7 Transparency is paramount

It is critical to explain and reiterate to all stakeholders the role of insurance in catastrophe risk management at an early stage and throughout the project:

- Risk transfer should always be viewed as part of a holistic risk management strategy. The initial funds spent could be better allocated to physical mitigation and adaptation measures (e.g. building and cleaning sewers), while residual risk could be transferred

(Figure 1, Figure 2).

- The insurance 'sweet spot' ranges from medium-sized to more catastrophic disasters. It is important to have clarity about the cost-benefit ratio of insurance and appropriate risk profiles.
- The insured entity should try to clarify their own financial needs in the event of larger catastrophes, and its budget situation. Stakeholders should be aware that only a portion of the total economic costs of a disaster can be meaningfully insured. A parametric program can contribute quick money but only covers part of the total financial need.
- Insurance premiums should be pre-arranged and budgeted for in the annual financial planning.
- Insurance is not an instrument for financing new measures; it fundamentally reduces economic volatility and creates financial budget stability.
- On average, there are always net costs for insurance.
- Basis risk of parametric insurance will never be eliminated and must be minimized by careful structuring and with learnings from triggering events.

G.4.8 Planning for political shifts

Anticipation and accounting for political changes, such as elections, is essential for the sustainability of the programme, as they often cause delays due to onboarding requirements of new stakeholders.

G.4.9 Government champions

The active participation of some key government 'champions' significantly strengthens the project. These champions must have decision-making authority, facilitate data sharing with other institutions, be comfortable with policy complexities, and have a strong interest in representing the project's goals at a high level. It is highly advisable to regularly contact the champions and provide updates, include them in recurring update calls and assign them prominent roles and speaking slots in workshops.

G.4.10 Early discussions on implementation, funding flows and premium financing

Initiating discussions with the government regarding implementation decision criteria (public procurement regulation) and premium funding at an early stage is highly advisable. This includes discussions about premium subsidies from donors, such as the ISF. Premium payments must be budgeted for in the financial planning of the government. There should also be clarity on which specific bank account a payout would flow to (this is typically within Treasury) and what the process would be for this to then be released to LASEMA (or the receiving agency) – this is usually a bottle neck that can slow down the financing flows for many months or even years.

G.4.11 Contingency plan and product alignment

As the product needs to be closely aligned to the purpose of the insurance payout, there is a critical dependency on the contingency plan. It is important that a strong project partner starts clarifying critical elements of the contingency plan at an early stage and keeps updated about the product design. It is important to ensure that the contingency plan is closely aligned with the parametric product and follows the product structure. The implementing agency must be closely consulted. The contingency plan was created by ARC and UDNP and can be found in Appendix 4.

G.4.12 Project administration

Time and budget can be saved if the project's administration (e.g. time spent per project step) is simplified and centralized right from the start. Some flexibility should be allowed and small changes to the budget allocation should be possible.

Acknowledgements

The successful development and implementation of this parametric insurance scheme would not have been possible without the invaluable contributions, expertise, and dedication of multiple stakeholders. Their collective efforts have helped strengthen financial resilience against flood risks in Lagos, ensuring that vulnerable communities have access to timely and effective disaster response mechanisms.

First and foremost, we extend our sincere appreciation to the InsuResilience Solutions Fund (ISF), supported by the German Federal Ministry for Economic Cooperation and Development (BMZ) and managed by the Frankfurt School, for their critical financial and technical support. The premium subsidies provided through ISF have laid the foundation for an accessible and sustainable insurance solution, while their ongoing collaboration has ensured the long-term viability of the scheme.

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We acknowledge the crucial role of the African Risk Capacity (ARC) in supporting risk financing solutions that enhance disaster preparedness and response. Their engagement in this initiative has helped integrate global best practices into the design and implementation of the scheme.

A special thank you to UNDP, in particular Mr. Henry Akwitti and the entire team, for their unwavering dedication in facilitating coordination between stakeholders, supporting capacity-building efforts, and ensuring that the insurance scheme aligns with broader disaster risk management strategies in Lagos.

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Finally, we extend our thanks to FSD Africa for their role in strengthening the financial resilience of communities. Their contributions in evaluating different disaster risk management strategies and assessing the feasibility of parametric insurance in the local context provided critical background for the development of this initiative.

This initiative is the result of a collaborative effort, and we deeply appreciate the commitment of all partners who have played a role in making it a reality. Their continued engagement will be crucial in further enhancing the insurance scheme and expanding its impact across Lagos and beyond.

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www.insuresilience-solutions-fund.org

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Appendices

Appendix 1: Geographic boundaries

File names:

- *C5.25_AdminBoundaries_Wards.geojson*
- *C5.25_AdminBoundaries_States.geojson*
- *C5.25_AdminBoundaries_LGA.geojson*

Appendix 2: FFP calculation points of PVHH in target LGAs and their insured values

File name: *C5.25_exposure_calculationpoints.csv*

Appendix 3: FFP wording template – please do not share

File name: *C5.25_FloodFootprintWordingDraft_CONFIDENTIAL.docx*

Appendix 4: Contingency plan

File name: *C5.25_ContingencyPlan.pdf*

Appendix 5: Literature review of the available historical flood records in Lagos State

Date	Source 1: FSD Africa[5]	Source 2: LS CRA[6]	Source 3: Nkwunonwo et al. (2016)[7]	Source 4: Dartmouth Observatory[8]	Source 5: EMDAT[9]	Other	LGA affected	Death	Loss (USD)	Severity
Sep-00				-	0.5k displaced, USD 8.17m damage cost		**2**		**8.17 million**	**1**
Mar-02					200 displaced (not only in LS)		**2**		**-**	**1**
Jul-02	200 displaced, 2 deaths		200 displaced, 2 deaths, millions of Naira, many houses affected	2 deaths			**2**	**2**	**2.5k to millions**	**1**
Jun-04	1k displaced, millions of Naira		1k displaced, millions of Naira, drainages affected	No casualties	1k displaced		**2**	**0**	**million(s)**	**1**
Feb-05					1k displaced		**1**			**1**
Jul-05	3k displaced, 25 deaths, millions of Naira		3k displaced, 25 deaths, millions of Naira				**2**	**25**	**million(s)**	**2**
Aug-07			5k displaced, 17 deaths, millions of Naira, 5k houses affected	5k displaced, 6 deaths	5k displaced (11 provinces affected)		**5**	**17**	**million(s)**	**2**
Oct-08	Millions of Naira		Millions of Naira, many houses affected, traffic interruptions				**2**	**0**	**million(s)**	**1**
Jul-09	Thousands displaced, Millions of Naira		Many displaced, millions of Naira, many houses affected		-		**2**	**0**	**million(s)**	**1**
Oct-10	Dam leakage (no rainfall?)		Thousands displaced, 20 deaths, millions Naira, many houses affected and traffic interruptions				**4**	**20**	**million(s)**	**2**
Jul-11	10k displaced, 100 deaths, USD 200m	Million of people affected, 300-1'100 mm in the north and 1'200-1'700 mm in the south for 2011 cumulative rainfall	10k displaced, 100 deaths, millions Naira, many houses affected 'the July 2011 flooding event, which affected approximately 5k people and resulted in about 25 deaths. The direct economic losses resulting from the event totalled about 50b Naira (i.e. USD 250m). Public utilities including road networks, bridges, and schools were destroyed. In addition, houses collapsed, private homes were submerged, and several cars were swept away by flood water (IFRC, 2011; Oladunjoye, 2011).'		20 deaths, 27'000 displaced (only 2 provinces affected)		**15**	**25**	**200 million**	**2**
Oct-11					10 deaths		**1**			**1**
Feb-12		6 deaths, big property/public damage			15 deaths, 15k displaced, USD 1.275m damage (only LS)		**4**	**10**	**1.275 million**	**1**

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Jun-12						7 feared dead. Worst hit areas include: Popo Igunnu, Jimoh and Ago-Hausa Streets, Okokomaiko, Iba LCDA; Jakande in Oto-Awori LCDA; Sango, Igi Avenue, GRA Ikeja, Gbolahan Bankole Street in Igando LCDA, Aboru; Ipaja-Ayobo, Shogunle, Apapa, among others. Aiyepe Street in Itire, Canal Pepple Road, Shomolu, Agbado-Ijaiye, Ikola, Agbado-Okeodo LCDA, Akintan, Cele, Bakery Bus Stop, all in Ejigbo LCDA; The bridge linking Lagos and Ogun states at Ayobo, in Ayobo/Ipaja Local Council Development Area, was submerged[10].	**1**	**7**		**1**
July - October 2012	7.7 million affected, 64k displaced, 363 deaths, (USD +9.5b all over Nigeria)	Huge flood records throughough the city	Thousands displaced, >50 deaths, millions of Naira, many houses affected and traffic interruption		7m affected (or displaced), 378 deaths, 900 injured, USD 640m (on 18 provinces)	Flooding began in early July when Lagos experienced severe disruption. Ibadan, just north of Lagos, was badly affected by flood waters in mid-July. By end July, 39 people were killed in the central Northern Plateau state, which saw another 33 fatalities in mid-August after more torrential rain washed away homes, roads and bridges[11].	**2**	**>350**	**5.02 billion**	**3**
Jun-15							**10**		**-**	**1**
Jul-17					20 deaths, 500 displaced, USD 6m Reconstruction cost (on 15 provinces)	Residents in Lekki and Victoria Island suburbs woke up with their homes and their cars submerged under water[12]. Massive floods leave at least 20 dead in capital Lagos. The floods ravaged parts of Victoria Island, Lekki, Ikoyi, Ajah, Oniru and adjoining suburbs of Lagos. NOAA's Climate Prediction Center estimated southwest Nigeria, incl. Lagos, picked up generally 100 to 150 mm (3.9 to 5.9 inches) of rain between July 2 and 8[13].	**3**	**20**	**6 million**	**2**
May-18				48 deaths?			**4**		**-**	**2**
Oct-19							**7**		**-**	**1**
Jun-20							**6**		**-**	**1**
July - August 2021					7'500 displaced (7 provinces)		**1**		**-**	**2**
July - October 2022					603 deaths, 2'500 injured, 2.8m affected (or displaced), USD 4.2b (16 provinces)		**1**	**>600**	**4.2 billion**	**3**
8 - 16 Sept 2023						Flooding from heavy rainfall recorded between 8 and 16 September in different parts of Nigeria's commercial capital city, has wreaked havoc on infrastructure, businesses and properties. Affected areas include Trade fair, Alaba, Isolo, LASU-Igando road, Lagos-Badagry expressway, Lagos Benin expressway, Lekki, Agege, among others.	**2**			**1**

[10] https://www.vanguardngr.com/2012/06/7-feared-dead-as-flood-sweeps-lagos/

[11] https://www.aljazeera.com/news/2012/10/12/nigeria-hit-by-worst-flooding-in-a-generation

[12] https://edition.cnn.com/2017/07/09/africa/lagos-flood-storms/index.html

[13] https://watchers.news/2017/07/11/nigeria-lagos-flood-july-2017/

Appendix 6: Alternative method to calculate vulnerable population

The following paragraph describes an alternative method for a consistent method to map vulnerable informal settlements. This method can be applied independent of official census data.

The following data sets form the basis for the mapping:

- Building density: Gridded map (100m) obtained from WorldPop[14]
    - *NGA_Buildings_v1_1*
- Population density: Gridded map (100m) obtained from WorldPop[15]
    - *NGA_population_v2_0_gridded*

Additionally, a literature search was conducted to find specific maps of vulnerable areas in Lagos.

The following sources were found and considered:

(1) The Atlas of Informality (Figure 60, left)[16].
(2) Map showing blighted areas and slums in Lagos [54][17].
(3) Map of Lagos showing the major segments of the city and informal settlements [55][18].
(4) Makoko slum mapping from Open Street Map[19].

[14] https://wopr.worldpop.org/?NGA/
[15] https://wopr.worldpop.org/?NGA/Population
[16] https://www.atlasofinformality.com/
[17] Map showing blighted areas/slums in Lagos Source: SNC-Lavalin (1995). | Download Scientific Diagram (researchgate.net)
[18] https://www.semanticscholar.org/paper/Exploring-Social-Vulnerability-to-Natural-Disasters-Nsorfon/e7a8a5a2fe71c72f87db160e59c76743e2d814e4
[19] https://www.openstreetmap.org/relation/7349917#map=16/6.4964/3.3921

Figure 60: (left) Map of Lagos City showing the major segments of the city and informal settlements, (center) Makoko slum mapping, (right) Polygonised slum areas.

The building and population datasets (WorldPop) were compared to these georeferenced maps (Figure 60) and polygonised slum areas to define thresholds for building and population counts. Pixels with values above these thresholds are considered informal settlements. In addition, the thresholds were adjusted by visually comparing the areas with Google Earth satellite images.

The thresholds were defined as following:

- Buildings: 30 (pixel with count ≥30 considered as 'informal settlement')
- Population: 210 (pixel with count ≥210 considered as 'informal settlement')

Both the population and building maps were reclassified using these thresholds. All pixels with a value equal or larger the thresholds were assigned a value of 1. All pixels with a value smaller than the thresholds were assigned a value of 0. As a next step, the sum of both those reclassified maps was calculated (= 'population' + 'building'), resulting in a map with pixel values of 0 (not an informal settlement), 1 (either population or building count above threshold) and 2 (both population and building count above threshold). The map was filtered to remove isolated pixels. The final map of informal settlements is shown below in Figure 61. Famous low-income neighborhoods such as Makkoko show up clearly in the mapping method.

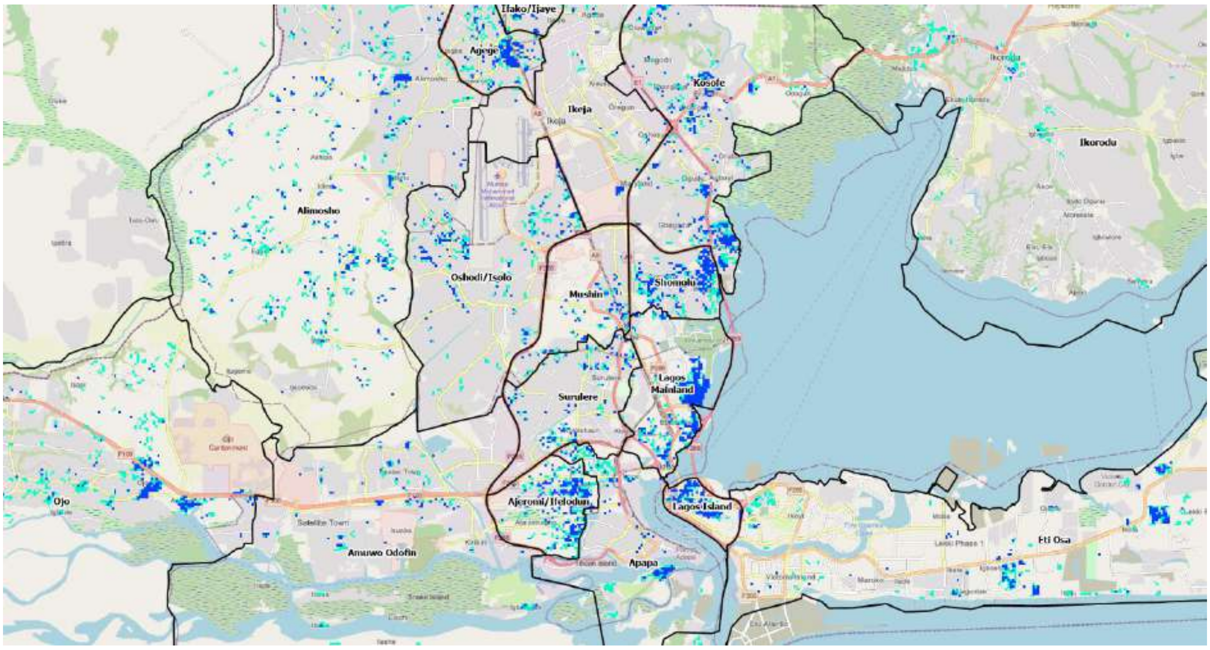

Figure 61: Informal settlements in central Lagos as per alternative mapping method. Vulnerability class 1 (light blue): either population or building count above threshold.

Vulnerability class 2 (dark blue): both population and building count above threshold. Figure generated by SwissRe.

The slum map was also compared with Google Earth Satellite Imagery (Figure 62).

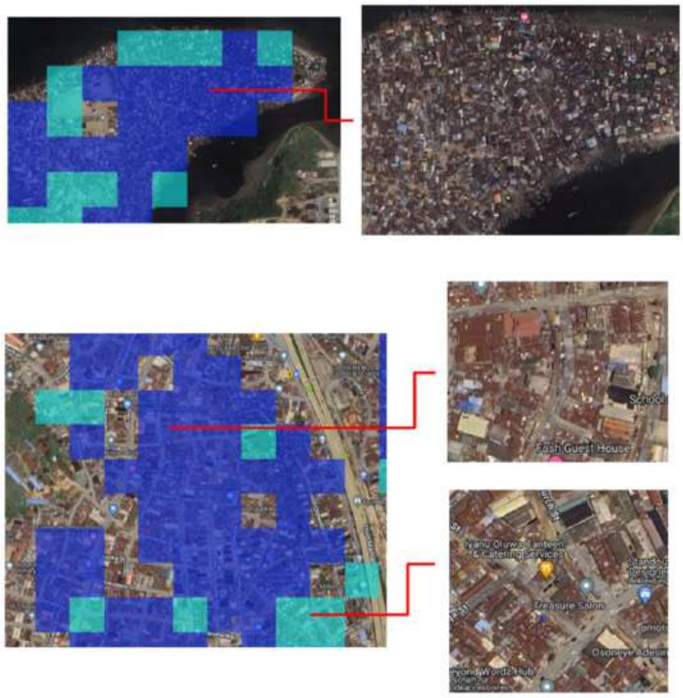

Figure 62: Comparison of the map of informal settlements with Google Earth Satellite Imagery. Blue pixels coincide with informal settlements. Source: Google. Figure generated by SwissRe.

A dataset containing ~700'000 points of poor and vulnerable households (PVHH) was provided by LASOCU. According to LASOCU, the dataset is 70% complete and missing ~30% of the point locations. Data points are randomly distributed throughout Lagos State. The PVHH dataset was explored and compared with the building and population datasets from WorldPop. For this, the PVHH point data was rasterized to the same 100m grid as the WorldPop data (calculating the sum of points per pixel). Figure 63 shows the rasterized data.

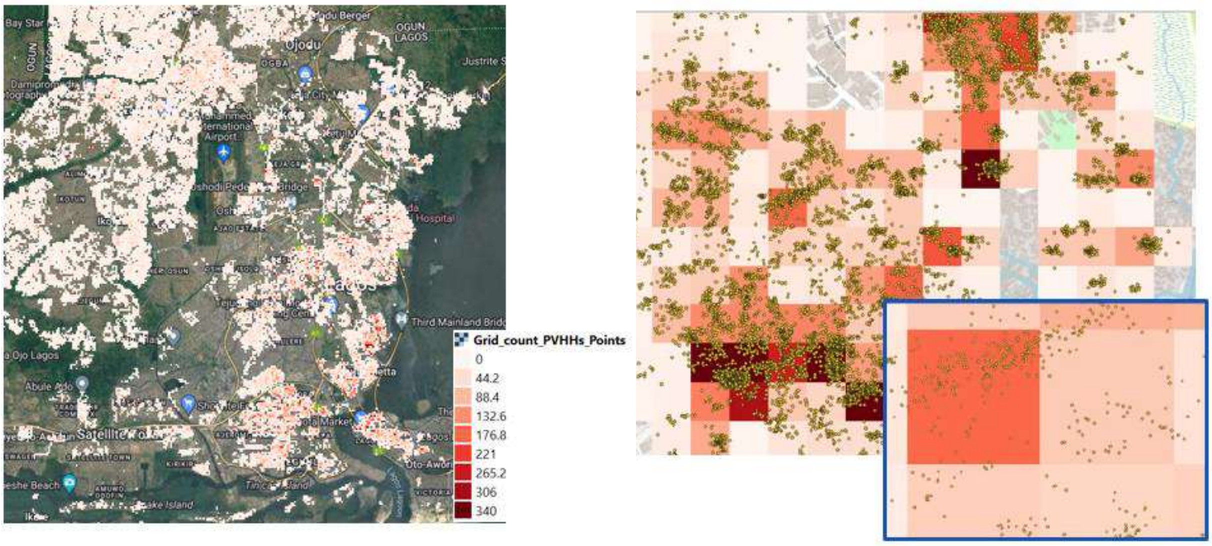

Figure 63: Rasterized PVHH point data (100m grid) and insert showing some agreement to the location points from LASOCU's database. Figure generated by SwissRe.

Figure 64 shows the correlation of the building, population and gridded PVHH data. The building and population counts from WorldPop are well correlated. However, the building/population and PVHH from LASOCU's database are not well correlated.

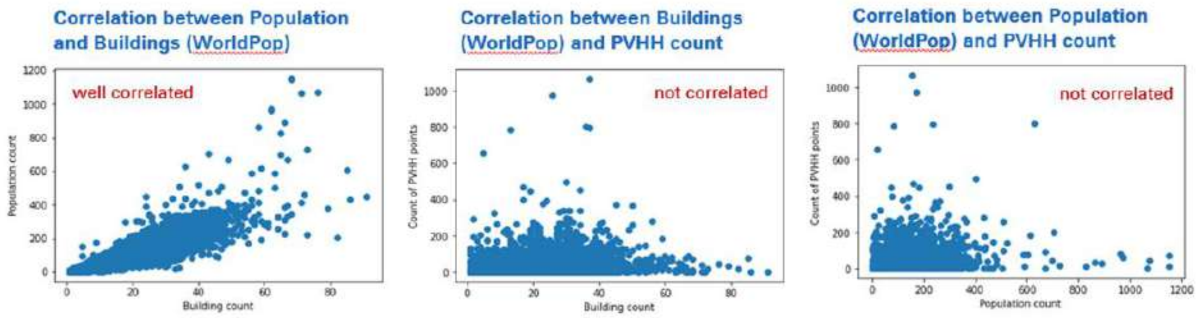

Figure 64: Correlation analysis of the population (WorldPop), building (WorldPop) and LASOCU's PVHH database. Figure generated by SwissRe.

Therefore, it was concluded that the PVHH points from LASOCU's database cannot be used to calibrate the building/population thresholds (as described above). However, they can be used as a comparison with the derived map of informal settlements. Figure 65 shows the map of informal settlements along with the gridded PVHH count from LASOCU (without threshold) and the PVHH count from LASOCU with only pixel counts >45 displayed. This map compares reasonably well with the map of informal settlements, with similar regions considered to be vulnerable. LASOCU's data hence increases confidence in the informal settlements map created using WorldPop building and population data.

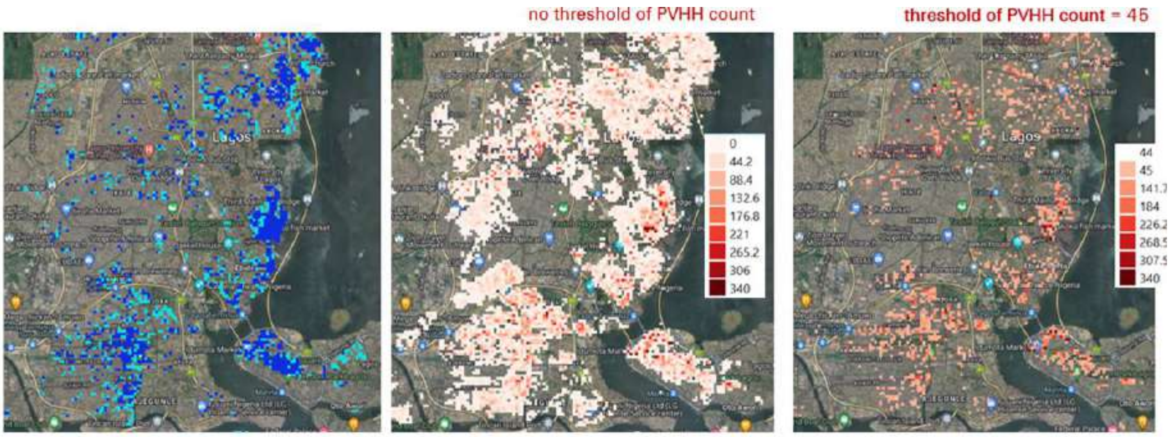

Figure 65: Comparison of Slum Map with rasterized PVHH from LASOCU database without threshold and with >45 threshold. Figure generated by SwissRe.

The number of PVP per LGA as per this alternative method was used to estimate the ranking of all LGAs in terms of % of PVP out of total population per LGA. This metric to some degree reflects the level of poverty of each LGA (Table 23).

Table 23: LGA ranked with respect to the estimated percentage of poor and vulnerable people (PVP) as per the presented methodology.

LGA	%PVP
Lagos-Island	31.4%
Shomolu	23.0%
Ajeromi-Ifelodun	19.2%
Agege	17.0%
Lagos-Mainland	14.0%
Apapa	10.9%
Kosofe	9.6%
Ifako-Ijaye	8.5%
Ojo	7.7%
Alimosho	7.0%
Oshodi-Isolo	5.1%
Surulere-Lagos	4.6%
Mushin	4.4%
Eti-Osa	4.2%
Ikeja	2.7%
Ikorodu	2.2%
Badagry	2.1%
Ibeju-Lekki	2.0%
Epe	1.5%
Amuwo-Odofin	1.4%
Total	**100%**

Definitions of developmental stages:

- **Informal settlements:** Very dense built-up area without visible streets, no cars, no vegetation.
- **Low income:** Buildings in zones with very little vegetation and almost no cars.
- **Middle income:** Education infrastructure, buildings in zones with considerable amount of trees and cars, police stations, more vegetation, colored roofs.
- **High income:** Buildings in zones with considerable amount of trees and cars, colored roofs, churches, hospitals, ministries, parliament, residential houses with larger surrounding space, fences, presence of civil and cultural infrastructure, fire departments.

Appendix 7: Correlation analysis between satellite precipitation data and weather station data

Let G_i be the ground value for precipitation on day i, and S_i be the satellite estimation of precipitation on day i.

Pearson correlation coefficient: for two random variables having a finite variance, the expression of this coefficient is given by the formula:

$$r = \frac{\mathrm{Cov}(G_i, S_i)}{\sigma_{G_i}\sigma_{S_i}}$$

$$\frac{\mathrm{Cov}(G_i, S_i)}{\sigma_{G_i}\sigma_{S_i}}$$

Where σ_{G_i} and σ_{S_i} are respectively G and S standard deviation. The perfect value for covariance is 100%.

The Root Mean Squared Error (RMSE): this metric is used to measure the 'distance' between actual observation points (weather station) and estimated points (satellite). The perfect value for the RMSE is 0. For N points, the formula is given by:

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{N}(G_i - S_i)^2}{N}}$$

The Mean Error (ME): it is very similar to RMSE also giving a 'distance' between true values and prediction points. The perfect value for ME is 0. For N points, its formula is given by:

$$\mathrm{ME} = \frac{\sum_{i=1}^{N} S_i - G_i}{N}$$

The bias: expressed here as the ratio between the satellite rainfall estimation expected value over the gauge rainfall estimation expected value. The perfect value for the bias is 1.

$$\mathrm{Bias} = \frac{\sum_{i=1}^{N} S_i}{\sum_{i=1}^{N} G_i}$$

Appendix 8: Correlation analysis between satellite precipitation data and historical flood loss record

Let p_i represent the precipitation measured on day i. We define the following indices:

- Maximum value over the risk period, referred as *Max*:

$$Max = maximum((p_i)_{i \in risk\ period}$$

- Cumulative value over the risk period, referred as *Cumulative*:

$$Cumulative = \sum_{i \in risk\ period} p_i$$

- Maximum cumulative value over 5 days, referred as *Max 5 days cumulative*:

$$Max\ 5 - days\ cumulative = \max\left(\sum_{k=i-4}^{i} p_i\right)_{i \in risk\ period}$$

- Maximum cumulative value over 10 days, referred as *Max 10 days cumulative*:

$$Max\ 10 - days\ cumulative = \max\left(\sum_{k=i-9}^{i} p_i\right)_{i \in risk\ period}$$

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