



C5.23 ISF Project

## Development of a Sovereign Parametric Risk Transfer Scheme for Urban Floods in Accra, Ghana

# Technical Report

August 2024

*A project, co-funded by the InsuResilience Solutions Fund.*

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**Target audience:** Government of Ghana institutions, insurers.

**Input providers:** National Disaster Management Organisation (NADMO), Ghana Meteorological Agency (GMet), Ghana Hydrological Authority (HYDRO) and other government agencies

**Note:**

*In the project set-up, the insurance partners served as independent consultants, leveraging their technical knowledge and market understanding to develop a targeted parametric insurance solution for the Government of Ghana. The technical solution outlined in this report is a recommendation. It is up to the MoF to take a decision on implementation and approach the market in accordance with its procurement rules.*

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## Abbreviations and Acronyms

AAR	-	Annual Average Rainfall
AED	-	Annual Expected Damage
ARF	-	Area Reduction Factor
AMO	-	Atlantic Multidecadal Oscillation
BMZ	-	Federal Ministry of Economic Cooperation and Development
CCD	-	Cold Cloud Duration
CHIRPS	-	Climate Hazards Group InfraRed Precipitation
DTM	-	Digital Terrain Model
ENSO	-	El Niño-Southern Oscillation
FFP	-	Flood Footprint
GAMA	-	Greater Accra Metropolitan Area
GARID	-	Greater Accra Resilient and Integrated Development
GFDRR	-	Global Facility for Disaster Reduction and Recovery
GIA	-	Ghana Insurance Association
GIZ	-	Deutsche Gesellschaft für Internationale Zusammenarbeit
GPM	-	Global Precipitation Measurement
GMet	-	Ghana Meteorological Agency
IDF	-	Insurance Development Forum
IDF	-	Intensity-duration-frequency
IGP	-	Insurance Global Partnership
IPO	-	Interdecadal Pacific Oscillation
IQR	-	Interquartile range
IRFF	-	Insurance Risk Finance Facility
ISF	-	InsuResilience Solutions Fund
ITCZ	-	Inter-tropical convergence zone
KIAMO	-	Kotoka International Airport Meteorological Office
LiDAR	-	Light detection and ranging
MCSs	-	Mesoscale Convective Systems
MEIV2	-	Multivariate ENSO Index Version 2
MoF	-	Ministry of Finance
MJO	-	Madden-Julian Oscillation
MMDAs	-	Metropolitan, Municipal and District Assemblies
NADMO	-	National Disaster Management Organisation
NAO	-	North Atlantic Oscillation
NIC	-	National Insurance Commission
RCC	-	Regional Coordinating Council
RoL	-	Rate on-line
SAR	-	Synthetic Aperture Radar
UNDP	-	United Nations Development Programme
WAM	-	West African Monsoon
XSR	-	Excess rainfall

## Executive Summary

Ghana faces increasing vulnerability to climate change, with over 16 major floods since 1990, particularly affecting poor and vulnerable households.<sup>1</sup> These floods strain the Government's finances and resources, requiring urgent emergency response and recovery efforts.

The InsuResilience Solutions Fund (ISF) Ghana Project, launched in June 2022, aims to develop a parametric flood insurance cover, enabling timely payout of disaster relief funds. This is to enhance Ghana's response capacity to flood events, contributing to climate resilience for Greater Accra Metropolitan Area (GAMA). The parametric insurance solution intends to rebuild economic activity in low-income urban areas and strengthen the capacity of the National Disaster Management Organisation (NADMO) and other Government stakeholders. The project is conducted and co-financed under the framework of the Tripartite Agreement between Insurance Development Forum (IDF) members: Allianz and Swiss Re, United Nations Development Programme's Insurance and Risk Finance Facility (UNDP's IRFF) and the German Federal Ministry for Economic Cooperation and Development (BMZ) together with technical partners HKV, ICEYE, and FloodTags as well as local Government partners such as the Ministry of Finance (MoF), NADMO, National Insurance Commission (NIC), Ghana Meteorological Agency (GMet), and other Government agencies and selected civil society organisations.

Parametric insurance, also known as index-based insurance, is a type of coverage where the payout is determined based on pre-defined parameters, such as weather conditions. Unlike traditional insurance, which relies on individual loss assessments, the payout is triggered when the objective thresholds are met. As a result, parametric insurance provides swift financial protection for costs that may not be easily quantifiable or insurable through traditional insurance, such as relief funds needed in the aftermath of a disaster or other emergency situations.

The project team has developed two parametric insurance solutions: a traditional excess rainfall (XSR) product and a more innovative flood footprint product (FFP). For the XSR payout, the trigger is based on the amount of rainfall whereas in case of FFP, it is determined by water on the ground as observed by satellite-mounted radar. Due to higher accuracy and proven first applications elsewhere in the world, the project team recommends the FFP. Ghana would be a forerunner in climate risk mitigation specifically for urban flooding if the product developed is implemented.

The insured areas have been carefully selected to cover poor and vulnerable households in low-income residential areas and informal settlements. A contingency plan was collaboratively developed by NADMO and other key stakeholders with support from UNDP's Insurance Risk Finance Facility (UNDP's IRFF). The plan prioritizes how funds from payout will be deployed. Concretely the payout will be used for food relief, emergency shelter and non-food relief items, logistics services, environmental sanitation and hygiene promotion, restoration of livelihoods, restoration of teaching and learning, and restoration of critical infrastructure.

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<sup>1</sup> InsuResilience Solution Fund Annual Report 2022 ([https://insuresilience-solutions-fund.org/content/kfw-insuresilience-solutions-fund/7-publications/15-isf-annual-report-2022/isf\\_annual\\_report\\_2022.pdf](https://insuresilience-solutions-fund.org/content/kfw-insuresilience-solutions-fund/7-publications/15-isf-annual-report-2022/isf_annual_report_2022.pdf), p.33)

This technical report gives an overview of the project setup, scope, and methodology. It outlines the data analysis and hazard assessment that have been conducted and describes different parametric insurance options which were considered. Finally, it provides a recommendation for the solution that best fits the project's objectives, and shares lessons learned.

# 1. Introduction

## 1.1. Background and project genesis

Ghana is at significant risk of flooding from multiple sources, with 16 major floods recorded between 1990-2020, affecting over four million people nationwide (Tengan & Aigbavboa, 2016; World Bank, 2021) (Figure 1).

Both the frequency and impacts of floods have intensified in recent decades, fuelled by climate change, land use changes and compounding demographic and economic factors, including increasing rural poverty, rapid urbanisation, growth of informal settlements and poor urban governance (World Bank, 2021; Abass, et al., 2022). The situation is set to worsen; median model trends suggest near doubling of road exposure to floods under RCP6.0 between 2000 and 2080 (Röhrig, et al., 2019) while dedicated urban public asset exposure analyses predict doubling of annual expected damages (AED) between 2015 and 2050, primarily as a result of increased exposure and flooding frequency, rather than floods getting substantially more severe (Pleijter, Job, & Mantey, 2019). Responding to and recovering from increasingly frequent and impactful floods, places a significant strain on Government finances and resources.

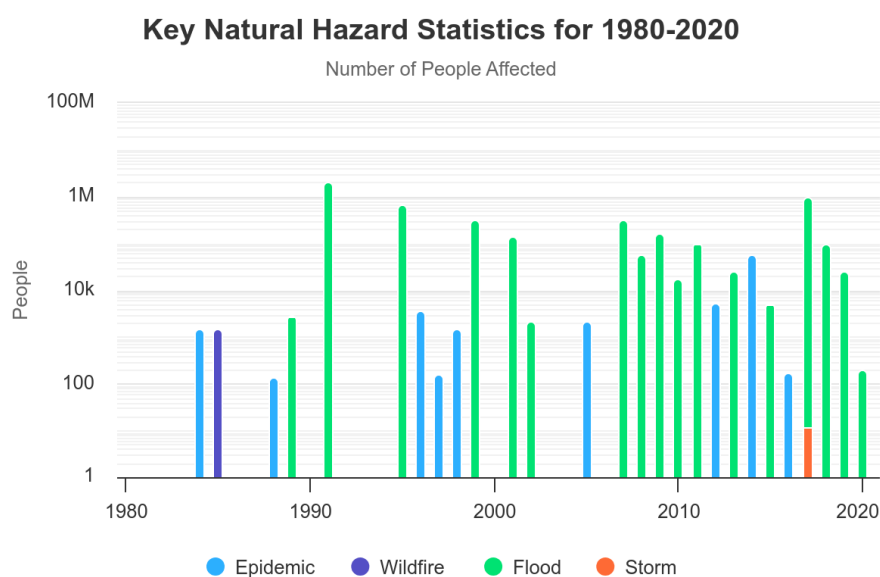


Figure 1: Key natural hazards impacting Ghana between 1980-2020: Number of people affected (World Bank, 2021).

Accra, the capital city and economic hub of Ghana, stands as one of the area's most vulnerable to flooding across the country. Compound pluvial and fluvial flooding in Accra and its metropolitan area (the Greater Area Metropolitan Area, GAMA) is mostly triggered by seasonal rainfall and is exacerbated by occasional high sea levels, poor drainage, the accumulation of solid waste in waterways and the presence of low elevation settlements, particularly informal ones which frequently occupy flood plains (Amoako & Frimpong Boamah, 2015). To a lesser extent, GAMA is also susceptible to coastal flooding and 'man-made' flooding arising from spills from the Weija dam, which serves as

the main water supply for the area. GAMA is home to over 15% of Ghana's population<sup>2</sup>, employs more than a quarter of the workforce, and accounts for over half of the country's economic output (UK Aid, 2018). Flooding in the area therefore has the potential to disrupt millions of lives and destabilise the national economy. The looming of flood risk in GAMA further increases, (Padi, Foli, Nyadjro, Owusu, & Wiafe, 2022) (Addo & Adeyemi, 2013), alongside rapid growth<sup>3</sup>. It highlights the pressing need for comprehensive flood risk management strategies.

This urgency was illustrated by the devastating floods on 3 June 2015, reported amongst the ten deadliest worldwide that year. It marked a turning point, prompting thorough investigations and a series of initiatives to tackle flood risk in GAMA. Following this disaster, the Greater Accra Resilient and Integrated Development Project (GARID) was initiated in 2017, backed by the World Bank. GARID aims to mitigate flood risk in GAMA through a blend of structural and non-structural approaches, centred on three key areas: enhancing drainage infrastructure, improving solid waste management, and implementing a flood early warning system. Furthermore, the project earmarks funds to support communities in flood-prone areas, including through housing quality enhancements. To date, substantial progress has been made and actions such as regular dredging of the Odaw River and removal of solid waste from crucial drainage points have already led to a noticeable decrease in the occurrence of severe flooding. While ongoing and planned mitigation efforts will significantly reduce flood hazard and impact, eliminating flood risk is financially impractical and virtually unattainable. Here, flood insurance emerges as a useful tool for managing residual risk; that is, the risk that persists despite all reasonable and economically viable mitigation and adaptation strategies (Figure 2).

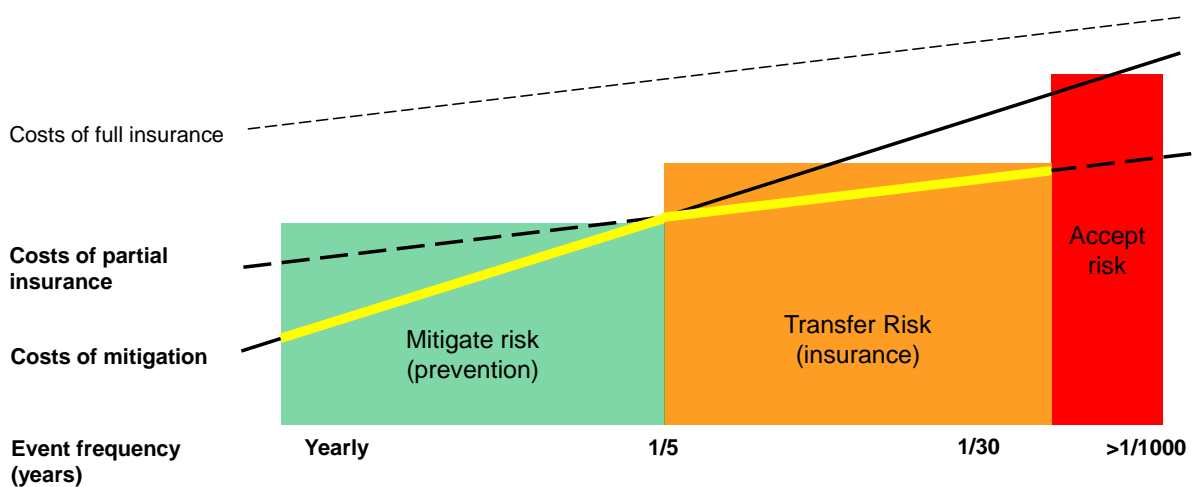


Figure 2: Holistic risk management, interplay between risk mitigation of higher frequency events and risk transfer for more remote catastrophes. Yellow pathway highlights pathway of costs for mitigation with ideal return of investment.

The illustration in Figure 2 shows the interplay between risk mitigation and transfer. As illustrated by the yellow line, physical mitigation measures have the highest return on investment to cope with frequent events, while (partial) insurance is a cost-efficient tool to cope with risks of more remote event return periods.

<sup>2</sup> As of 2021, GAMA's population was estimated at 4.99 million (Ghana Statistical Services, 2021).

<sup>3</sup> GAMA's population is predicted to double within 20 years from 2017 (UK Aid, 2018).

Against this backdrop and leveraging on previous projects<sup>4</sup> and cutting-edge technologies, this project aimed to design a state-of-the-art sovereign, index-based flood insurance cover for GAMA to finance post-flood emergency relief and recovery efforts with a focus on assisting the poor and vulnerable population. The insurance scheme was structured with support from UNDP's IRFF in collaboration with the Ghanaian Government, considering their requirements on magnitude and frequency of events to be insured for, associated response and recovery costs, and budget restrictions.

By offering rapid and transparent payouts triggered by flooding observations, the envisaged product will provide a financial safety net for Ghana's Ministry of Finance (MoF), National Disaster Management Organisation (NADMO) and other Government agencies, enhancing their response capacity and particularly, the ability to support the poor and vulnerable to speed up the re-establishment of their economic activity.

The project serves as a blueprint for the design and operation of parametric urban flooding insurance, with the potential for scalability not only across other urban areas in Ghana but also across other flood prone urban areas in Western Africa or around the world.

## 1.2. Project objectives and scope

The overall project objective was to enhance the response capacity of the National Disaster Management Organisation (NADMO) and other Government stakeholders after a severe flood event in the urban context, starting with Greater Accra Metropolitan Area.

The objectives of the project were achieved through the following activities:

1. Identification of data requirements;
2. Alignment on the methodology to develop an insurance product among key project stakeholders;
3. Assimilation of high-resolution flood maps based on satellite imagery for GAMA via engagement with ICEYE and its validation based on the HKV flood model;
4. Detailing of the HKV flood model based on the new outputs available including a time-series of historic events and their locations in Accra by FloodTags;
5. Evaluation of the feasibility of different index values (e.g., rainfall/river gauge triggers, flood extend, flood depth, mix of those, etc.) and test run of the most suitable options;
6. Correlation of the chosen index based on the HKV flood model;
7. Technical product design including definition of parametric trigger conditions;
8. Underwriting and costing of most suitable parametric flood product(s);
9. Design of the timely payout process and its alignment with contingency plan;
10. Presentation of the final product design(s) to the Government and incorporation of stakeholder feedback;
11. Drafting of insurance policy & wording templates for seamless placement;
12. Obtaining approval for the index product via National Insurance Committee; and
13. Preparation of product specifications for a potential public tender.

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<sup>4</sup> Including the Allianz-GIZ develoPPP project that targeted the municipality level via an indemnity-based product concept to cover aggregated public asset losses, and the Greater Accra Resilient and Integrated Development projects including (HKV, 2018).

In parallel to the activities listed above, a specific working cluster focused on capacity building and development of a contingency plan carried out by UNDP's IRFF. This includes the following activities:

1. Facilitation of participatory product development;
2. Development of a contingency plan and its alignment with local/sovereign actors to enable fast and accurate payments, targeting low-income urban communities;
3. Design of a proactive disaster risk finance strategy with a focus on poor and vulnerable population, and re-establishment of economic activities of such;
4. Support in capacity building for technical staff of Ghana Hydrological Authority (GHA), GMet and NADMO focused on flood hazard mapping and risk reduction measures; and
5. Support in the alignment of contingency plan with the payout process including clear roles and responsibilities between NADMO and local municipalities, distribution of the payout according to these roles and controlling function to ensure that the proposed solution benefits the poor and vulnerable.

The project built on the deliverables and lessons learned from the Allianz-GIZ developPPP project (2018-09/2021) which targeted the municipality level via an indemnity-based product concept to cover aggregated losses of the public assets.

**Overall objective:**  
Enhance the response capacity of the NADMO and other Government stakeholders after a severe flood event in the urban context, starting with Greater Accra Metropolitan Area

**Outcome A:** A tailor made parametric flood cover developed with a focus to quickly re-establish economic activity of low-income urban areas

**Outcome B:** The financial resilience of Ghanaian Government against extreme flood events increased via targeted capacity building activities

**Output 1:**  
Innovative radar-based information and past event analysis are processed and evaluated

**Output 2:**  
Different index proxies are tested and the most suitable one is integrated in the product

**Output 3:**  
An insurance product concept is developed

**Output 4:** A process for timely payout is in place

**Output 5:**  
Participatory product development

**Output 6:**  
Improvement and alignment of contingency plans

**Output 7:**  
Technical staff of GMet and NADMO has increased knowledge on urban floods

To deliver output 1 requires following activities (summarized as component 1)

1. Calibrate the HKV model based on the FloodTags past event analysis and available ICEYE imagery by comparing those with the flood prone areas in the HKV flood model
2. Validate a generic risk tool by comparing its results with the damage of the June 2015 event for Odaw and longer-term post event analyses by FloodTags
3. Detail flood hazard maps of Greater Accra and calibrate on the available outputs from the abovementioned activities

To deliver output 2 requires following activities (summarized as component 2)

1. Evaluate the feasibility of the different index values (e.g., rainfall/river gauge triggers, flood extend, flood depth, mix of those, etc.)
2. Test run the selected indices and identify of the most suitable one
3. Define of a suitable trigger based on time series analyses of satellite rainfall products (appr. 20 years GPM data)
4. Validate the trigger based on the available time series of rainfall from GPM and ground data of GMet (if available)

To deliver output 3 requires following activities (summarized as component 3)

1. Based on the flood model and different return period layers, identify important flood prone areas for re-establishment of economic activities
2. Finalize an underwriting and pricing approach
3. Develop draft policy and wording
4. Present the product for the review of National Insurance Committee (NIC).

To deliver output 4 requires following activities (summarized as component 4)

1. Design the payout along the most efficient emergency response activities for re-establishing the economic activities in low-income areas in the contingency plan
2. Identify the frequency of payout
3. Establish a controlling mechanism for the payout reaching the end beneficiaries

To deliver output 5 requires following activities (summarized as component 5)

1. Identify the most frequent questions and concern related to the index-based products
2. Design one training concept focused on the proposed product design (focus on basis risk & technical product design)
3. Provide Government with enough product development information to make a decision regarding the public tender

To deliver output 6 requires following activities (summarized as component 6)

1. Identify the status quo and map clear roles and responsibilities under the contingency planning
2. Assist the Government in aligning contingency plans on both local and sovereign levels
3. Design and present to the Government a preventive disaster risk finance concept with focus on poor and vulnerable urban population

To deliver output 7 requires following activities (summarized as component 7)

1. Offer real-time flood monitoring on the basis of Twitter, News Media and YouTube with geo references displayed in a web interface by FloodTags (during the project run time – 2 years)
2. Design and offer to GMet and NADMO personnel a dedicated training suite to increase the understanding of flood hazard mapping and modelling
3. Introduce the flood monitoring system by FloodTags to GMet and NADMO through a dedicated knowledge exchange

Figure 3: Project objectives and potential outcome.

Figure 3 outlines the project's objective, outcomes, outputs and activities. In achieving the primary outcome of developing a tailor-made parametric flood cover and identifying the most suitable solution, the project team aimed to explore four options:

- (I) remote-sensed rainfall cover: a satellite-based gridded measurement of the amount of rainfall (e.g., CHIRPS);
- (II) station-based rainfall cover: a rainfall measurement of the amount of rainfall by comprehensive and long-time series from existing rainfall stations on the ground, potentially installing new rainfall gauging stations or sensors; and
- (III) remote-sensed flood footprint cover: a satellite-based monitoring of the actual extent of flooding (e.g., ICEYE).

The feasibility of these options depended on the Government's requirements regarding target risk profile (return period levels of attachment and full limit, that is the insurance layer) and basis risk. Government acceptance serves as key performance indicator (KPI) for evaluating the project design.

The secondary objective was to increase the financial resilience of the Ghanaian Government via targeted capacity building activities.

### 1.3. Stakeholders

The project was co-financed under the Tripartite Agreement between Insurance Development Forum (IDF) members: Allianz and Swiss Re, United Nations Development Programme's Insurance and Risk Finance Facility (UNDP's IRFF) and the German Federal Ministry for Economic Cooperation and Development (BMZ) through the InsuResilience Solutions Fund (ISF). The technical design was spearheaded by Allianz SE, Allianz Ghana, Swiss Re, and UNDP's IRFF, along with technical partners (HKV), service providers (ICEYE & FloodTags), and local Government stakeholders. The key Government stakeholders included Ministry of Finance, National Disaster Management Organisation, National Insurance Commission, Ghana Meteorological Agency and Ghana Hydrological Authority (GHA). Beyond its specific contribution to the project, the UNDP, through its Insurance Risk Finance Facility, is working closely with the Government of Ghana to enhance the country's long-term financial resilience by integrating risk transfer into its development strategy and fostering a transformation of the nation's insurance market (Figure 4 and Table 1).



Figure 4: Project stakeholders.

Institution	Role & Responsibility
<b>Co-Financing &amp; Partner Institution</b>	
<b>Insurance Global Partnership (IGP) &amp; InsuResilience Solutions Fund<sup>5</sup></b>	IGP is a multi-stakeholder initiative to strengthen the resilience of developing countries and protect the lives and livelihoods of poor and vulnerable people against the impacts of disasters. The InsuResilience Vision 2025 key target is that 500 million poor and vulnerable people should be covered against climate and disaster shocks by 2025. The German Government has set up the InsuResilience Solutions Fund (ISF) to finance the development of relevant insurance offerings.
<b>Insurance Development Forum (IDF)<sup>6</sup></b>	IDF convenes the insurance industry to work towards optimising and extending the use of insurance and its related risk management capabilities to build greater resilience and protection for people, communities, businesses, and public institutions that are vulnerable to disasters and their associated economic shocks. IDF's goal includes creating a platform for collaboration and innovation for (re)insurance companies to develop solutions.
<b>Industry Partners</b>	
<b>Allianz SE</b>	Insurance Company – Potential reinsurer and project lead, driving stakeholder engagement, support with technical product design, policy and wording.
<b>Swiss Re</b>	Reinsurance Company - Potential reinsurer and leading the technical product design, policy and wording, supporting stakeholder engagement.
<b>Allianz Ghana</b>	Hosting local project manager. Facilitating the dialogue with the insurance regulator and Government stakeholders. Potential primary fronting insurer.
<b>Technical Providers</b>	
<b>HKV</b>	Provider of the hydrological & hydraulic flood mode and vulnerability curves. Determination of peril frequency-severity and validation of the satellite imagery maps.
<b>ICEYE</b>	Satellite Data Provider - agreed to exceptionally contribute services at below commercial rates to align with ISF development mandate and expectation for in-kind contribution.
<b>FloodTags</b>	Provider of the past event analyses and real time monitoring based on the social and news media (during project run).
<b>Key Public Partners</b>	
<b>Ministry of Finance</b>	The MoF is one of the Central Management Agencies of the Civil Service of Ghana. 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. In the project context, the MoF is the customer. <sup>7</sup>
<b>National Disaster Management Organisation (NADMO)</b>	NADMO was established by act 517 of 1996 to manage disasters and similar emergencies in the country. It was structured and placed under the ministry of the interior, to enable it to coordinate all the relevant civil authorities at the national, regional and district levels. NADMO functions under a national secretariat, ten (10) Regional secretariats, two hundred and forty-three (243) Metropolitan, Municipal and District secretariat and over nine hundred (900) Zonal offices throughout the country. <sup>8</sup>
<b>Ghana Meteorological Agency (GMet)</b>	GMet exists to provide efficient and reliable meteorological information by collecting, processing, archiving and dissemination of meteorological information to end-users. <sup>9</sup>
<b>Ghana Hydrological Authority (HYDRO)</b>	HYDRO is responsible for the planning, design, execution, operation, and maintenance of flood control mechanisms, coastal engineering works, drainage improvement works, and operational and applied hydrology in the country.
<b>National Insurance Commission (NIC)</b>	The object of the Commission is to ensure effective administration, supervision, regulation and control the business of Insurance in Ghana. NIC is mandated to perform a wide spectrum of functions including licensing of entities, setting of standards and facilitating the setting of codes for practitioners. The Commission is also mandated to approve rates of insurance premiums and commissions, provide a bureau for the resolution of complaints and arbitrate insurance claims when disputes arise. <sup>10</sup>
<b>International Development Organisation</b>	
<b>United Nations Development Programme's Insurance and Risk Finance Facility</b>	UNDP works in 170 countries and territories to eradicate poverty and reduce inequality. We help countries to develop policies, leadership skills, partnering abilities, institutional capabilities, and to build resilience to achieve the Sustainable Development Goals. <sup>11</sup> UNDP Insurance and Risk Finance Facility deliver innovative protection solutions in 50 developing countries by 2025. Currently, the facility is operational in 34 countries. We support the development of innovative insurance products and services that are aimed towards vulnerable people and communities while also investing in the long-term transformation of insurance markets. <sup>12</sup>

Table 1: Presents a concise summary of each project stakeholder, detailing their roles and responsibilities.

<sup>5</sup> <https://insuresilience-solutions-fund.org/about/about-isf>

<sup>6</sup> <https://www.insdevforum.org/mission-vision-history/>

<sup>7</sup> <https://mofep.gov.gh/about-mof>

<sup>8</sup> <https://www.nadmo.gov.gh/index.php/about/background>

<sup>9</sup> <https://www.meteo.gov.gh/gmet/welcome-to-the-ghana-meteorological-agency/>

<sup>10</sup> <https://nicgh.org/about-us/overview/>

<sup>11</sup> <https://www.undp.org/about-us>

<sup>12</sup> <https://irff.undp.org/about-us>

## 2. Methodology

Developing a parametric insurance product involves several key steps, as summarized in Figure 5. Initially, a key risk peril, such as flooding, is identified and its parameters are characterized. A technical analysis is then carried out of the exposure of the areas, population and/or assets to be insured as well as historic events and consequential losses. 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 losses. In other words, the so-called '*basis risk*' (risk that actual losses do not correlate with the index, see Section 6.2.1) is minimized to an acceptable level. Lastly, 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.

In the finalization phase, legally binding policies must be written that outline all essential elements of the insurance contract, the steps for calculating payouts and special conditions. The primary wording must be issued 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 agreement. Once this placement process is completed (possibly through a public tender), the project will go live. Monitoring of the parameter takes place 24/7 and the Calculation Agent stands by to detect flood events. Once an eligible event is confirmed, funds will be disbursed swiftly and used by the government as outlined in the emergency/contingency plan. After the contract period has expired, the program will come to its renewal. Some of the steps described above will be repeated and improvements implemented as necessary.

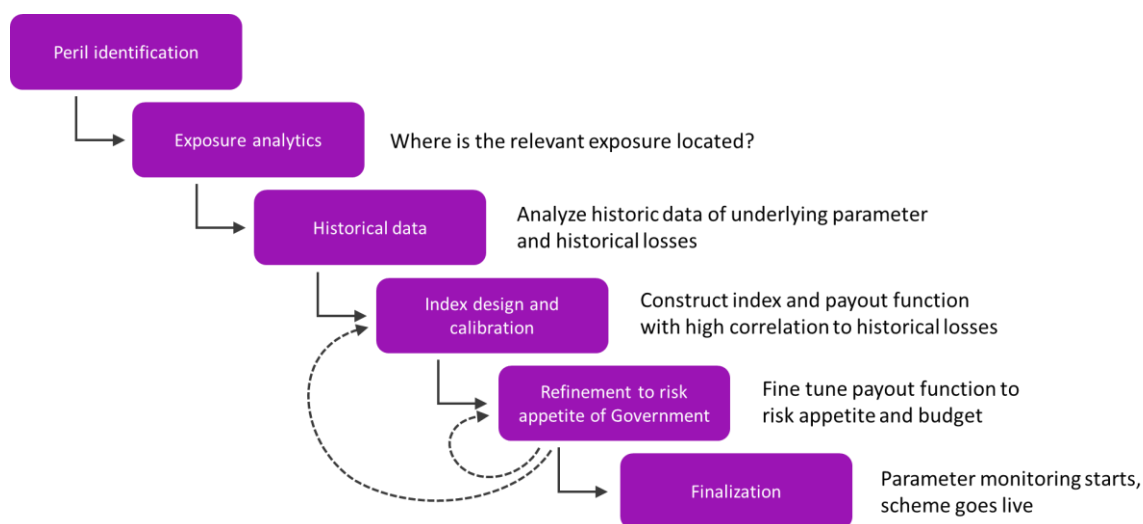


Figure 5: Parametric insurance product development, steps to implementation.

## 3. Geographic Context

### 3.1. Project geographic scope: the Greater Accra Metropolitan Area (GAMA)

The project geographic scope is the Greater Accra Metropolitan Area (GAMA), with the Weija dam and the area downstream of it excluded for parameter observation purposes (Figure 6). Target beneficiaries are the poor and vulnerable population, aligning with the InsuResilience program's mission. This sub-section details the geographic scope of the project. For context, additional information on GAMA's demographics, socio-economics, topography, climatology and hydrology can be found in the following sub-sections. Additional specifics on hazard and exposure datasets and analyses are presented in Sections 4 and 5.

GAMA is centred in Ghana's capital, Accra, and is a sub-area of the Greater Accra Region – one of Ghana's 16 administrative regions. It is located on the coastal plain of south-eastern Ghana, along the Gulf of Guinea. GAMA stretches over an area of 1'495 km<sup>2</sup> and comprises 25 of the 29 Metropolitan, Municipal and District Assemblies (MMDAs) that make up the Greater Accra Region.

A decision to adopt GAMA as boundary for product design was jointly made with local Government agencies, considering that it comprises the areas with highest concentration of population and assets, the main centres of both formal and informal economic activity, and the area's most susceptible to flooding (i.e. the Odaw and Sakumono basins) across the capital region.

Further, a decision was jointly made to exclude from the project scope the Weija dam and the area downstream of it (i.e., the Weija Gbawe Municipal District) given that flooding in the area is largely driven by dam discharges – a flooding mechanism very different from that of the rest of GAMA, and one that is largely influenced by man-controlled factors, making it hard to model and insure for, particularly in the absence of good quality, long-term hydrological and dam operational records. The proposed restriction simply limits the area across which the insurance parameter is observed and does not exclude the area in question from receiving emergency support financed with parametric insurance payouts. By removing this area from parameter observation, flood risk and insurance parameters across the remaining target area can be modelled more consistently, which ultimately reflects positively on the insurance product pricing and ability to attract coverage by the insurance market. The Government, as policyholder, can ultimately decide on payout allocation within and around the project scope area, in line with the contingency plan that is developed as part of this project.

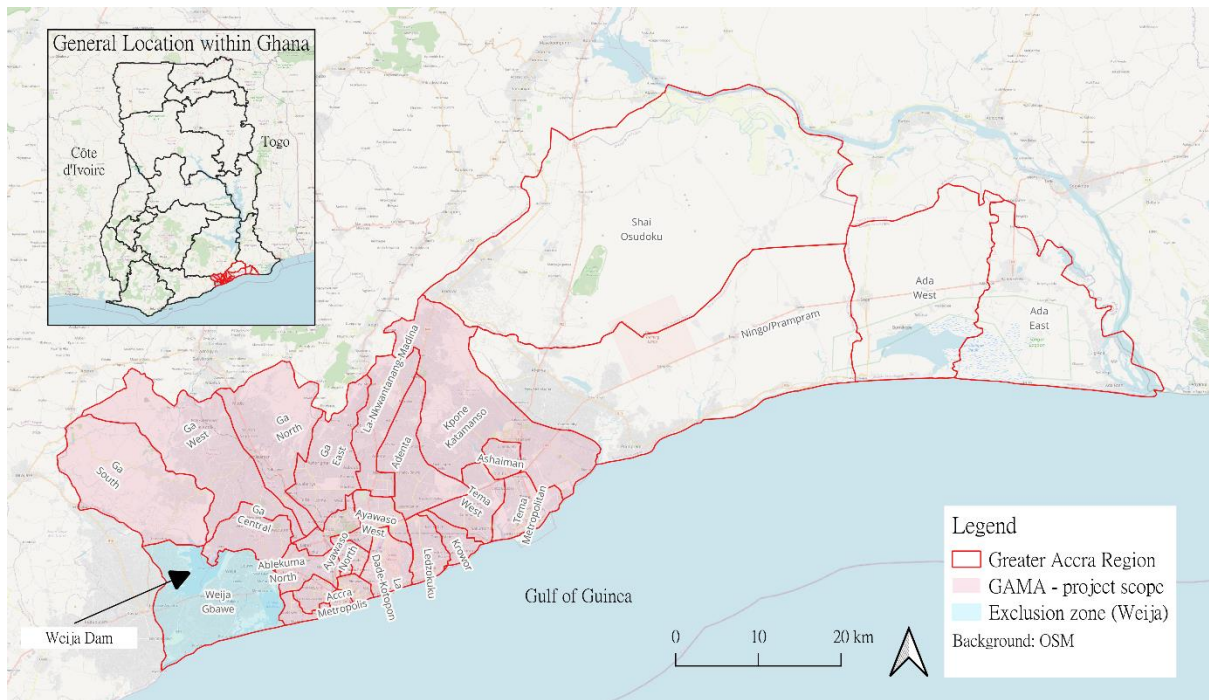


Figure 6: Project geographic scope with GAMA marked in red shading.

### 3.2. Demographics and Socioeconomics

GAMA, as the economic and administrative heart of Ghana, presents a dynamic and complex demographic and socio-economic profile.

#### 3.2.1. Population profile

As of 2021, GAMA's population stood at 4.99 million (Ghana Statistical Services, 2021), with an average population density of approximately 3'300 persons per km<sup>2</sup>, representing over 15% of Ghana's total population. The area is not only the most densely populated in Ghana but also its fastest growing, highlighting significant urban migration trends<sup>13</sup>. Population density reaches its highest in the Accra Metropolis area at 15'500 persons per km<sup>2</sup>, diminishing towards GAMA's outskirts but notably spiking in the Tema Metropolitan and Ashaiman Municipal Districts (Figure 7). In terms of demographics, GAMA boasts a youthful population, with 30% under the age of 15 and ~56% under the age of 24 years, and females constituting 49% (UN Habitat, 2009; Ghana Statistical Services, 2021).

<sup>13</sup> For reference, UN Habitat reported gross population densities for Accra Metropolitan Area (a sub-area of GAMA) of 623 persons per km<sup>2</sup> in 1970 and 1'003 persons per km<sup>2</sup> in 2009 (UN Habitat, 2009).

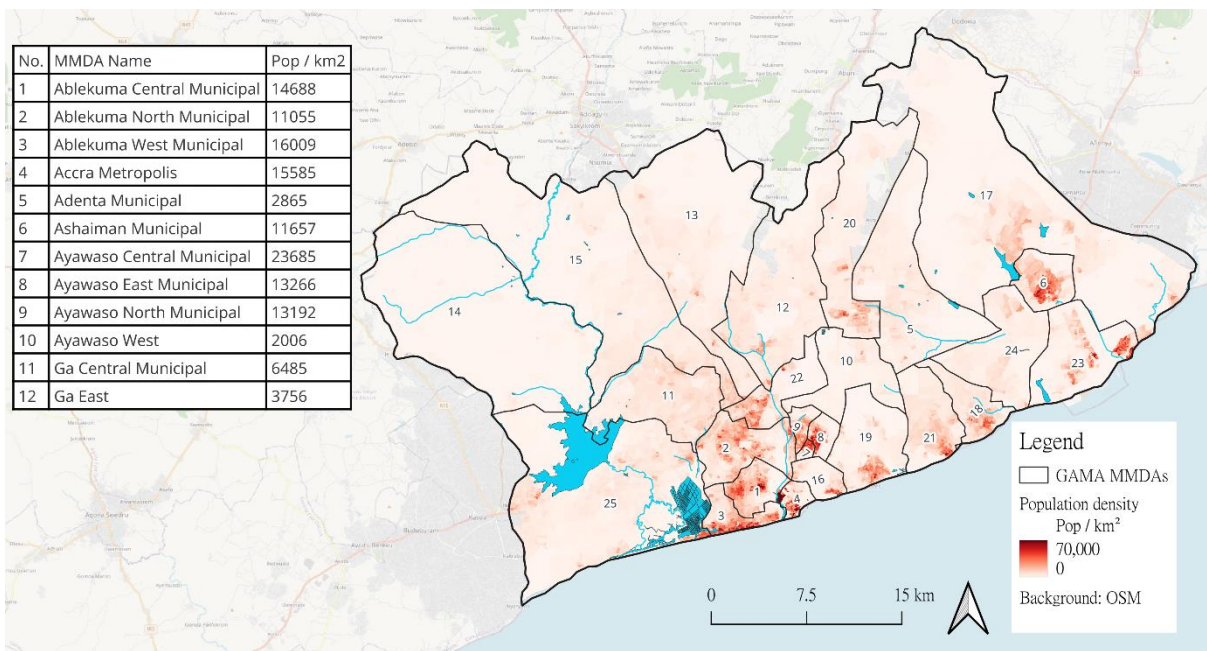


Figure 7: Population density distribution across GAMA. Source: 2021 Census (Ghana Statistical Services, 2021).

### 3.2.2. Economy

GAMA is the powerhouse of the country, generating over half the national economic output and employing more than a quarter of the workforce (UK Aid, 2018). The UN Economic Commission for Africa (ECA, 2021) reports that, from 2015 to 2020, the Accra Metropolitan District alone, which sits at the centre of GAMA, accounted for 34% to 39% of the nation's economy. Additionally, Accra's GDP per capita was found to be triple the national average, further highlighting its economic significance. About 65% of GAMA's employed workforce<sup>14</sup> is engaged in the informal economy, (Ghana Statistical Services, 2021), underscoring economic vulnerabilities, where table-top marketplaces play a key role in supporting the livelihoods of the poor and vulnerable. An example of a table-top market is shown in Figure 8.

<sup>14</sup> Among the population over 15 years old, an estimated 56% (1'963'000 people) are employed, 8% (286'000 people) are unemployed, and 36% (1'257'000 people) are outside the labour force.



Figure 8: Example of a typical table-top market in GAMA. Source: Job Udo (HKV).

### 3.2.3. Income levels and economic disparities

GAMA's rapid growth and urbanisation have brought about substantial socio-economic challenges. Income disparity is a notable issue, with a considerable portion of the population living in informal settlements characterised by inadequate housing and limited access to essential services such as clean water and sanitation. In addition, low income and informal settlements are often found along flood plains, exacerbating flooding impacts and increasing the vulnerability of these communities. HKV (2018) categorised GAMA's residential areas into four income levels—high, middle, low, and informal settlements—using land cover types derived from satellite imagery. This work was compared with another method developed by Swiss Re, and further validated and modified during stakeholder dialogues (Figure 9). Despite occupying a modest proportion of GAMA's surface land area low-income residential areas and informal settlements represent a significant portion of GAMA's total population due to their high population density<sup>15</sup>. More information on our standardized mapping methodology, with a focus on the target vulnerable population of the insurance product presented herewith is provided in Section 4.

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<sup>15</sup> Estimated based on 2021 census data (Ghana Statistical Services, 2021) across the income level categories derived by HKV and further reviewed with local stakeholders as part of the project.

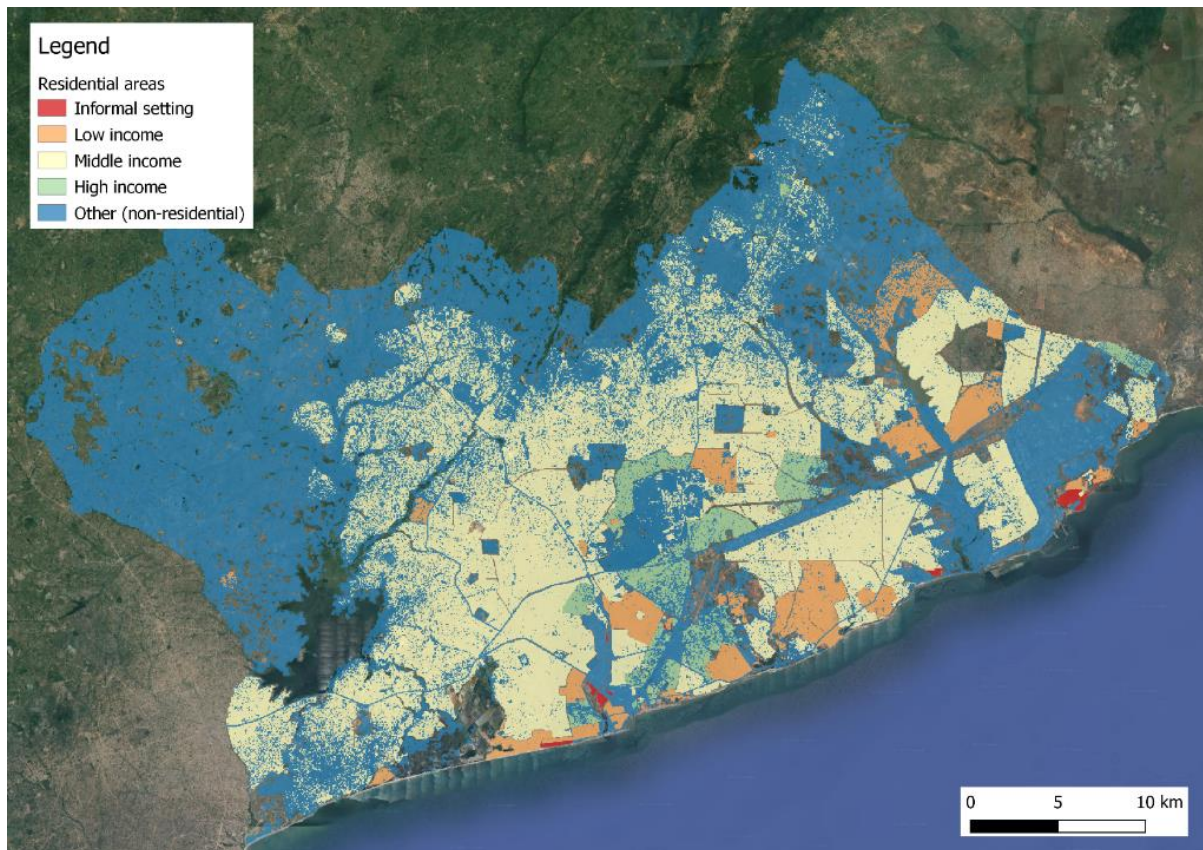


Figure 9: Classification of GAMA's residential areas into four income levels: informal settlements, low-, middle- and high-income areas. Source: (HKV, 2018).

### 3.3. Topography

GAMA's elevation ranges from sea level to approximately 360 metres above sea level, peaking in the foothills of the Akwapim Hills in the Sesemi locality in the north, and with an average elevation of around 50 metres. Characterised by low relief and gentle slopes, the landscape descends gradually from the surrounding hills to the Gulf of Guinea, interspersed with isolated hills and rock outcrops. This topographic configuration gives rise to 14 main watersheds which ultimately drain into the Atlantic Ocean. Figure 10 presents a Digital Terrain Model (DTM) of GAMA, developed as part of the GARID project<sup>16</sup>. The map also highlights the main river basins within GAMA as well as key topographic and hydrological features. GAMA's hydrology is further detailed in Section 3.6.

<sup>16</sup> Available at a grid resolution of 0.5 x 0.5 m<sup>2</sup> and with a vertical accuracy of 1.5 centimetres or better at control points, this LiDAR-based DTM aims to facilitate flood modelling efforts, thereby informing flood risk management strategies.

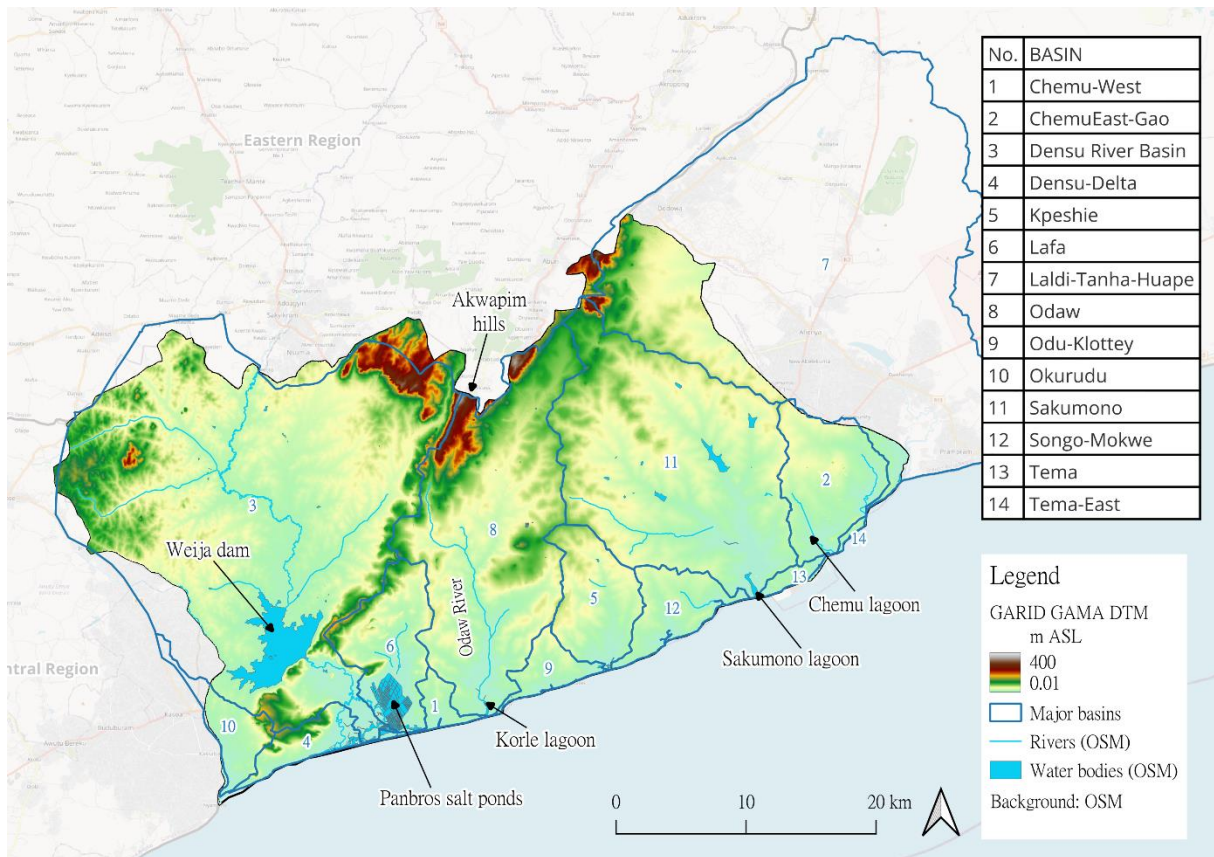


Figure 10: GAMA's elevation map, major river basins and key topographic and hydrological features (DTM source: GARID project). Note: the Densu basins extends further north; the boundary in the map was truncated to GAMA's boundary.

### 3.4. Climatology

#### 3.4.1. Overview

GAMA lies in the coastal equatorial climatic zone of Ghana and has a tropical wet and dry or savannah climate (Köppen–Geiger climate classification 'Aw') (Addae & Oppelt, 2019; Beck, et al., 2018; Bessah, et al., 2022). The annual average temperature is approximately 27°C, with mean monthly temperatures ranging from 25°C in August to 29°C in March<sup>17</sup> (Figure 11). Mean monthly relative humidity varies from 58% in January to 75% in June (Bessah, et al., 2022). The area receives an average annual rainfall of circa 740 millimetres, distributed across approximately 51 rainy days<sup>18</sup>.

#### 3.4.2. Rainfall patterns

Influenced by the West African Monsoon (WAM) and the movement of the inter-tropical convergence zone (ITCZ), and further modulated by large-scale circulations, local factors, and land-sea interactions, GAMA exhibits a bi-modal rainfall pattern. This pattern is marked by two rainy seasons separated by dry periods, as illustrated in Figure 11. The first and primary rainy season, spanning from March to July and peaking in June, is largely driven by the peak of the WAM. The second, minor rainy season occurs

<sup>17</sup> Values computed from minimum and maximum average monthly temperatures read from figures 5 and 6 in (Bessah, et al., 2022) and corroborated against web sources (e.g. (climate.top, 2024)).

<sup>18</sup> Long-term annual average rainfall and rainy days computed from GMet records at Kotoka International Airport Meteorological Office (KIAMO) and Tema stations for the period 1960-2022, whereby rainy days are defined as days with total rainfall >1 millimetre.

from September to November. It is chiefly driven by the southward retreat of the ITCZ (also known as the tropical rain belt), which moves closer to the equator, and the weakening of the monsoon circulation.

Rainfall in GAMA is typically characterised by intense, short-lived convective storms. Storms during the first rainy season are particularly intense, frequently resulting in flooding, including the most severe historical flood events. The second season, though milder, also experiences heavy rainfall, with several high-severity flooding events recorded during this period. In this region, larger scale systems alongside local convection processes often lead to sequences of days with downpours. The occurrence of downpours over successive days can result in substantial multi-day rainfall accumulations, leading to reduced catchment storage capacity and often exacerbating flooding. While antecedent conditions and multi-day rainfall accumulation play a role in the initiation and severity of flooding, analyses of major flooding incidents undertaken in this project indicate that intense storms of sub daily- duration (typically lasting a couple of hours) are the primary triggers for flooding onset in GAMA and are the main determinants of flooding severity. This is confirmed by the analyses and diurnal rainfall profiles of extreme events reported by (Atiah, Amekudzi, & Danuor, 2023) (Figure 12).

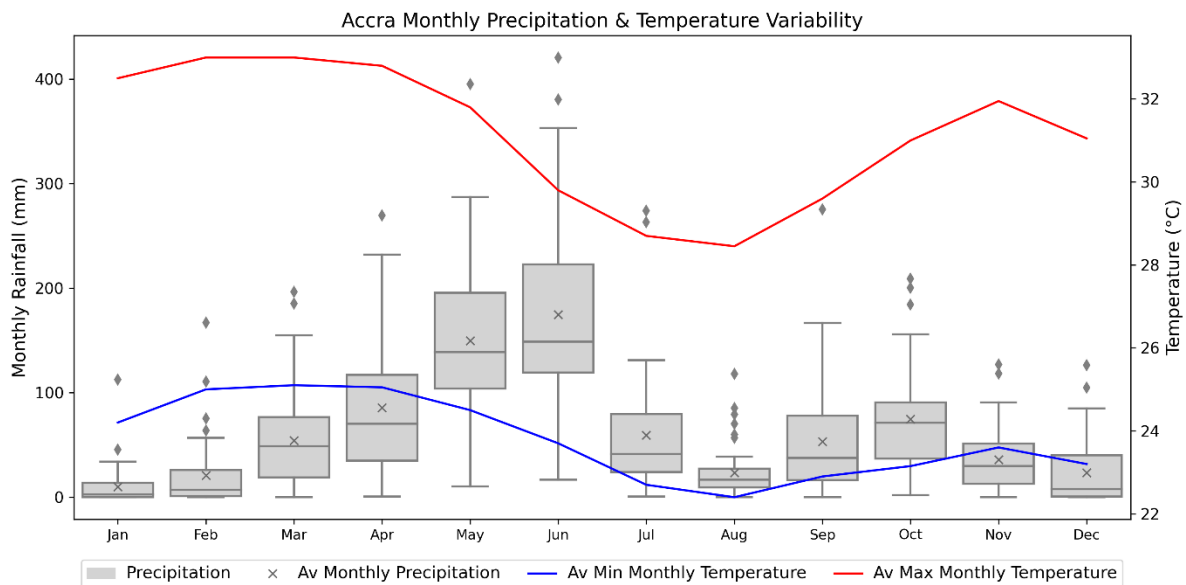


Figure 11: Accra's monthly precipitation distribution<sup>19</sup> and mean monthly temperature variability. Data sources: Precipitation values are based on GMet records at the Kotoka International Airport station (KIAMO) between 1980-2022; temperature values were extracted from (Bessah, et al., 2022) and are reportedly based on GMet records between 1976-2018.

<sup>19</sup> The boxplot visualises the distribution of rainfall accumulations for each calendar month, based on historical records. The box represents the interquartile range (IQR), which contains the middle 50% of the data. The horizontal line within the box indicates the median. The whiskers extend to the furthest data points within 1.5 times the IQR from the box, highlighting the range of the data. Points beyond this are plotted as outliers.

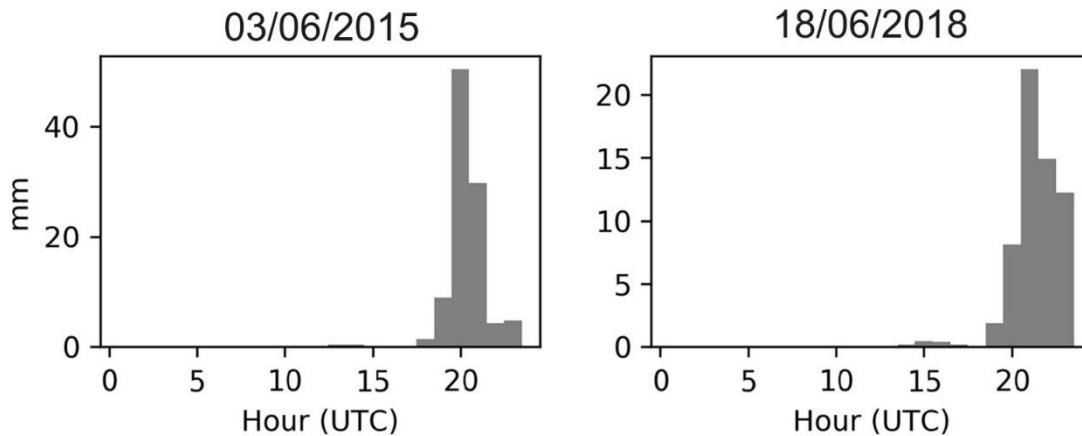


Figure 12: Diurnal rainfall profile for significant historical flood events in GAMA based on IMERG rainfall data. Source: (Atiah, Amekudzi, & Danuor, 2023).

### 3.4.3. Large scale drivers of rainfall variability

As previously mentioned, GAMA's bi-modal rainfall pattern is primarily driven by the West African Monsoon (WAM) which is a large-scale circulation characterised by a seasonal reversal in wind direction and the movement of the inter-tropical convergence zone (ITCZ, also known as the tropical rain belt) (Quagraine, Nkrumah, Klein, Klutse, & Quagraine, 2020). During the warmer months, south-westerly winds bring moisture from the Atlantic Ocean, leading to the main rainy season, while north-easterly winds prevail during the cooler months. This pattern is further modulated by local factors (such as local topography, land cover and urban heat island), land-sea interactions and large-scale atmospheric circulations, which can induce inter-annual and multi-annual rainfall variability. One of the main large scale circulations influencing rainfall patterns in Ghana is the El Niño Southern Oscillation (ENSO) (GFDRR, 2011; Owusu, Darkey, & Boadi, 2019). An overview of this and other large-scale circulations impacting rainfall patterns in West Africa, including GAMA, is given below, noting a non-exhaustive investigation. Understanding their mechanisms, temporal scales and predictability can provide insights into how these drivers may impact parametric flood insurance dynamics (e.g. premium loadings, policy acquisition or termination based on seasonal forecasts) and can inform complementary weather risk management strategies such as forecast-based financing. A summary of this high-level investigation is included at the end.

### 3.4.4. Madden-Julian Oscillation

The Madden-Julian Oscillation (MJO) is an important factor in tropical climate variability, characterised by an eastward-moving 'pulse' of cloud and rainfall near the equator that typically recurs every 30 to 60 days. In West Africa, the MJO can influence the timing and intensity of rainfall events, particularly during the 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 GAMA, MJO impacts on rainfall constitute a difference on the order of 20% to 50% from average daily rain rates for the March-June season (Berhane, Zaitchik, & Badr, 2015).

### 3.4.5. El Niño-Southern Oscillation

El Niño-Southern Oscillation (ENSO) is characterised 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 WAM (Bert, 2016; Losada, et al., 2010). Conversely, La Niña events are typically associated with enhanced rainfall in the region. Observations also show that the timing of the ENSO is essential to the teleconnection process (i.e. the way ENSO impacts the WAM) (Joly & Voltaire, 2009). Furthermore, a more recent study found a decadal time scale oscillation between ENSO and WAM<sup>20</sup> with the relationship believed to be physically linked and having strengthened significantly since 1980 (Srivastava, Chakraborty, & Nanjundiah, 2019). In the specific case of Ghana, ENSO is reportedly one of the main large scale circulations influencing rainfall patterns (GFDRR, 2011). A study looking at records between 1955 and 2015 across the Ho Municipality in Ghana's Volta Region showed that 15% of the variability in total annual rainfall is likely explained by ENSO (Owusu, Darkey, & Boadi, 2019). To our knowledge, no studies have specifically focused on the impact of ENSO on rainfall patterns in GAMA, including on the rainfall extremes of interest for this project.

Based on the Multivariate ENSO Index Version 2 (MEIV2)<sup>21</sup> and on rainfall records from two stations across GAMA (i.e. at Kotoka Airport (KIAMO) and Tema), a high-level investigation was undertaken on the impact of ENSO on rainfall variability, looking at annual (Figure 13), monthly/seasonal (Figure 14) and daily rainfall (Figure 15), as well as at the annual frequency of exceedance of daily extremes (Figure 16). As regards annual rainfall, in line with regional studies, significant El Niño events typically coincide or are followed by below average annual accumulations (e.g. in 1983, 1986-87, 1992-94 and 1998) while La Niña events are typically associated with above average annual rainfall (e.g. 1988, 1995-96 and, more noticeably, 2007-08, 2010-11 and 2022). However, there are several exceptions to note, e.g. above average annual rainfall during the 2015-2016 El Niño, during which one of the worst historical flooding events was observed. Also, below average rainfall during the 1999-2000 La Niña and the initial phase of the 2021-2022 La Niña (although 2021 records at GMet stations are irregular and 2022 are certainly above average). Further, an analysis of annual rainfall vs. annual average MEIV2 only revealed a weak negative correlation, where ENSO accounted for 1% of the observed variability ( $R^2 = 0.01$ ).

Similarly, analyses of monthly rainfall deviations from long-term averages vs. ENSO indices (Figure 14) uncovered no distinct patterns, revealing only a weak negative correlation between monthly rainfall during the peak rainy season (April-June) and monthly MEIV2, again with an  $R^2$  of 0.01.

Looking at daily rainfall (Figure 15), interestingly, three of the largest historical daily rainfall values have occurred in the transition from El Niño to La Niña, suggesting a potential link and further highlighting the importance of the ENSO timing in the teleconnection. Nonetheless, other significant events have occurred both during El Niño and La Niña events, with the catastrophic event of June 2015 event occurring during a strong El Niño. Interestingly, there appears to be a lower incidence of high

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<sup>20</sup> Meaning that the impact of ENSO on WAM intensifies and weakens on decadal cycles.

<sup>21</sup> Available from NOAA's Physical Sciences Laboratory: <https://psl.noaa.gov/enso/mei/>

extreme daily rainfall during ENSO neutral or mild periods; however, further investigation is needed to confirm these observations.

Lastly, in line with the daily analysis, no discernible patterns were identifiable in terms of the impact of ENSO on the annual frequency of exceedance of set high percentile rainfall values (see example plot for p99 exceedance at KIAMO station in Figure 16). Additional analyses were conducted for additional higher percentiles with no patterns identified.

The above analysis confirms that, while ENSO does impact rainfall patterns in GAMA, the impact is not straightforward and is influenced by additional factors. ENSO events mainly correlate with variations in annual rainfall accumulations, with some exceptions to note, and no clearly discernible patterns were identified of ENOS's impact on monthly and daily rain, including daily extremes. Note: These results should be interpreted cautiously, bearing in mind potential uncertainties in rainfall data and the broad, high-level scope of the analysis.

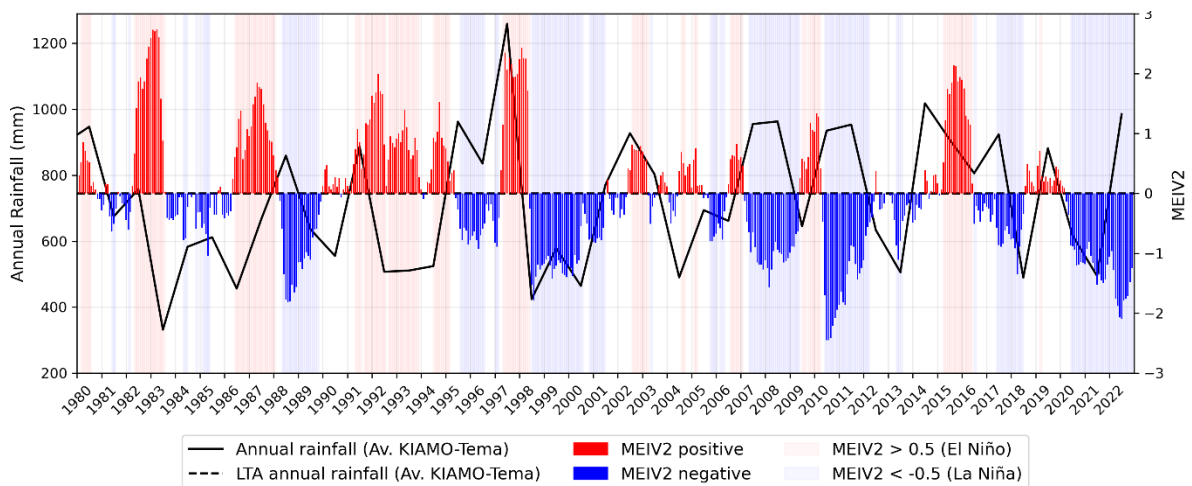


Figure 13: Time series analysis of ENSO indices and annual rainfall in GAMA across the period 1980-2022 (inclusive). Significant El Niño events (with MEIV2 > 0.5) are shaded in light blue, while La Niña events (MEIV2 < -0.5) are shaded in light red. N.B. annual rainfall was computed as the average of records at GMet's KIAMO and Tema stations.

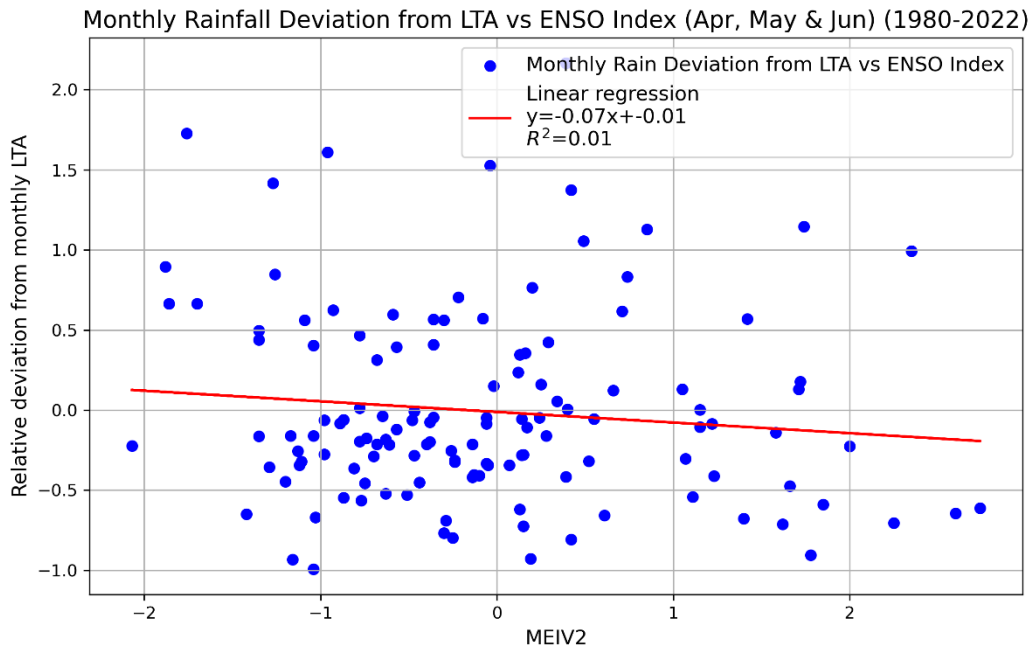


Figure 14: Scatterplot of monthly rainfall deviation from long-term average (LTA) vs. monthly ENSO index MEIV2 across the peak of GAMA's rainy season (Apr-Jun). Analysis conducted based on data at KIAMO station across period 1980-2022, inclusive.

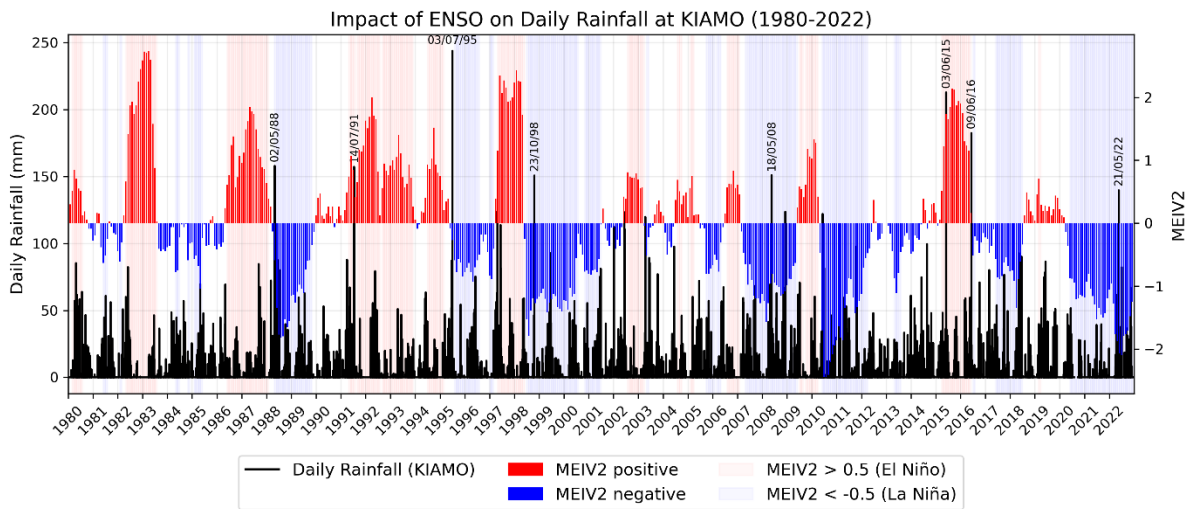


Figure 15: Time series analysis of ENSO indices and daily rainfall at Kotoka International Airport station (KIAMO) over the period 1980-2022, inclusive. The top 8 daily rainfall accumulations across the period are annotated.

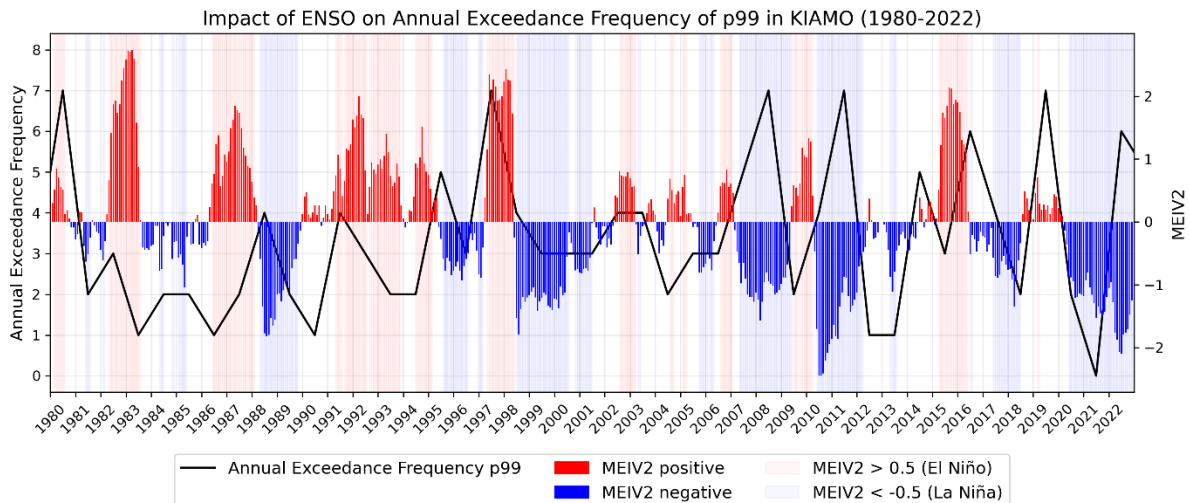


Figure 16: Time series analysis of ENSO indices and frequency of exceedance of the 99 percentile daily rainfall values at KIAMO over the period 1980-2022.

### 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 (Crédat, et al., 2024). 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 favoured in the positive (warm) phase of the AMO and in the negative phase of the IPO, and vice-versa (Crédat, et al., 2024).

### North Atlantic Oscillation (NAO)

The North Atlantic Oscillation (NAO) is characterised 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 (Met Office, 2015). In line with this, studies have shown that there is a relationship between the NAO and meteorological droughts in coastal Ghana (Addi, et al., 2021).

### Summary of large-scale drivers of rainfall variability

The analysis above reveals that, while large atmospheric circulations significantly affect rainfall in GAMA, their interactions with each other and local factors add complexity. Consequently, their influence on rainfall patterns in GAMA is neither systematic nor straightforward. Furthermore, it is observed that these large circulations, particularly those operating at longer temporal scales of the order of years to decades, are better predictors of longer-duration rainfall accumulations, such as annual or seasonal totals, whereas their impact on short-duration extremes is less clear, largely due to the significant role that local factors typically play in these events. In line with this, in the specific case of ENSO, which was analysed in greater detail, El Niño events are typically associated with below

annual average rainfall and the opposite is the case for La Niña events, albeit with some exceptions to note. However, no clearly discernible patterns were identified in terms of ENSO's impact on seasonal and, in particular, daily rainfall, including extremes. Therefore, the occurrence or prediction of El Niño or La Niña events, as well as long-range forecasts in general, are not anticipated to significantly influence the dynamics of parametric flooding insurance acquisition or pricing.

### 3.5. Climate trends

Understanding historical climate trends in the project area is crucial for informing the timeframe adopted in product design. Additionally, insights into future climate can highlight potential shifts in flood risk due to climate change. Below, an overview is first given of country-wide and regional current and future climate trends. This is followed by an analysis of observed trends across GAMA, based on GMet station records. A summary of the findings, with a focus on GAMA, is presented at the end.

#### 3.5.1. Country and regional overview

For context, the following provides an overview of Ghana's historical climate trends and future projections, primarily drawn from the World Bank and USAID's Ghana Climate Risk Country Profiles (World Bank, 2021; USAID, 2017), the World Bank's Climate Change Knowledge Portal<sup>22</sup>, and supplemented by local studies.

##### **Climate baseline trends for Ghana since 1960s include:**

- **Temperature:** mean annual temperature has increased by approximately 1°C, at an average rate of ~0.16°C per decade, with the increase accelerating from 1980s onwards (World Bank, 2024) (Figure 17). While overall rates of increase have been reportedly higher in the north (World Bank, 2021), the average country-wide warming rate is in line with values reported for Southern Ghana between 1980-2020 (Padi, Foli, Nyadjro, Owusu, & Wiafe, 2022) (Figure 17).
- **Hot days and nights:** the average number of very hot days (Tmax >35°C) and hot nights (Tmin >26°C) have increased by over 13% and 20% per year, respectively, with the most pronounced increase occurring between September and November (World Bank, 2021; USAID, 2017).
- **Precipitation:** while inter-annual and inter-decadal rainfall is highly variable, an overall reduction in cumulative rainfall of 2.4% per decade was observed (USAID, 2017). Generally, decadal rainfall decreased in the middle of the country, while more intense events have been noted in the northern and southern areas, suggesting heightened intensity and the potential for longer dry spells (Republic of Ghana, 2015).
- Increase in **sea surface temperature** (precise data unavailable) (USAID, 2017).
- **Sea level rise** of 63 millimetres in the past 30 years (USAID, 2017).
- **Average coastal erosion** of 1.13 metres per year (USAID, 2017).

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<sup>22</sup> <https://climateknowledgeportal.worldbank.org/country/ghana/climate-data-historical>

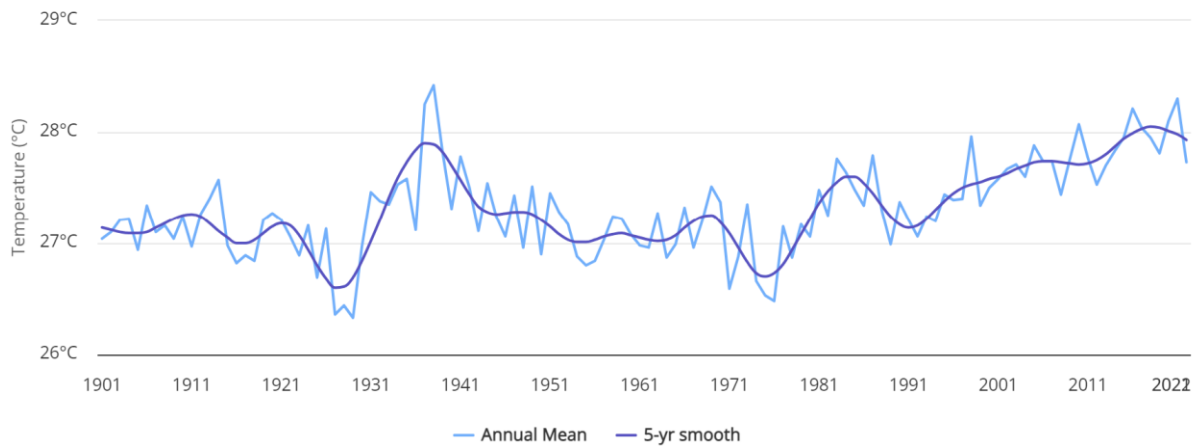


Figure 17: Observed annual average mean surface air temperature of Ghana for 1901-2022. Source: <https://climateknowledgeportal.worldbank.org/country/ghana/climate-data-historical>.

### Projected climate change for Ghana includes:

- **Temperature:** increase in mean temperatures of between 1-3°C by mid-century, and between 2.3°C to 5.3°C by end of the century (World Bank, 2021)<sup>23</sup> (Figure 18). Across the seasonal cycle, temperature increase will likely be most significant in July and August, with greatest increases in the north.
- **Hot days and nights:** increased frequency of hot days and nights of 18-59% by 2060 (USAID, 2017).
- **Precipitation:** at an aggregate national level and across all RCPs, overall, annual precipitation in Ghana is expected to largely remain the same by the end of the century (Figure 18). However, coastal zones are expected to receive higher rainfall than central and northern areas. Additionally, precipitation is expected to get more erratic and intense during the wet season, while lower precipitation levels are predicted in the dry season – with a larger decrease in the southern regions. As a results of these changes, 1 to 5-day rainfall maxima trends will likely increase in some areas but are expected to decrease in others (World Bank, 2021).
- Rise in **sea surface temperatures** by 2-4°C and **sea level rise** of 75-190 millimetres by 2100 (USAID, 2017).
- **Average coastal erosion** and shoreline loss of 0.38 metre per year (USAID, 2017).

<sup>23</sup> Based on CMIP5 (Coupled Inter-comparison Project No.5) data ensemble for different RCPs.

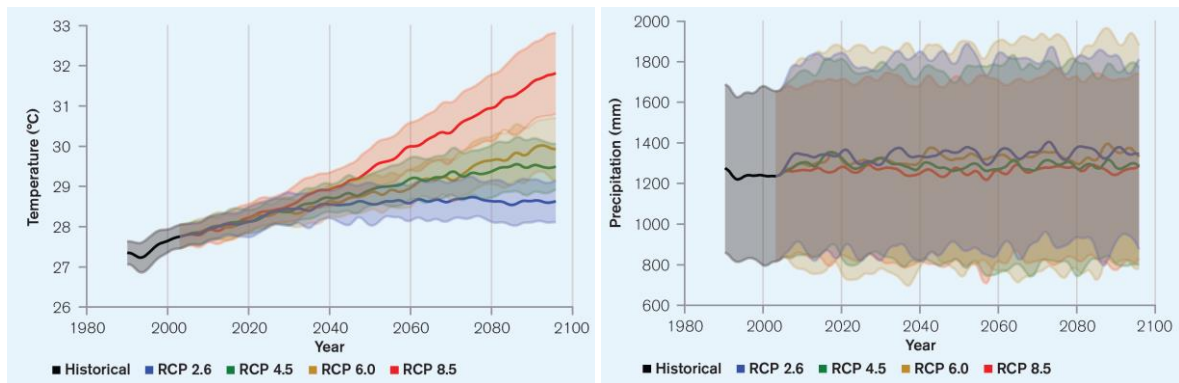


Figure 18: Historical and projected average temperature (left) and precipitation (right) for Ghana from 1986 to 2099 (Reference Period, 1986–2005). Source: (World Bank, 2021).

### 3.5.2. Current rainfall trends in GAMA

Current trends in annual, seasonal and daily precipitation across GAMA were investigated based on GMet records at KIAMO and Tema manual stations between 1960-2022. For context, the location of these two stations is shown in Figure 19, noting that KIAMO is located within the Accra district itself, close to the Odaw River (a key source of flood hazard) and to areas with high concentration of poor and vulnerable, whereas Tema is located 20 kilometres to the east of KIAMO, very close to the coastline and further from poor and vulnerable areas. While the stations are not too far, as will be seen, their rainfall patterns have non negligible differences and it was deemed appropriate to include them both in the analysis, to better understand rainfall trends across GAMA.

Table 2 displays annual rainfall statistics for the entire period of records (1960-2022) and across three 20-year epochs (1960-1979; 1980-1999; 2000-2022), thus facilitating the inter-comparison of temporal variations and identification of trends in rainfall patterns. This is supplemented by time series of annual rainfall, annual maxima and annual frequency of exceedance of set percentiles, presented in Figure 20. Lastly, the distribution of monthly rainfall totals and monthly average frequency of extreme exceedance across the full period of records and for the aforementioned 20-year epochs are shown in (Figure 21, Figure 22, Figure 23 and Figure 24) for the KIAMO and Tema stations, respectively.

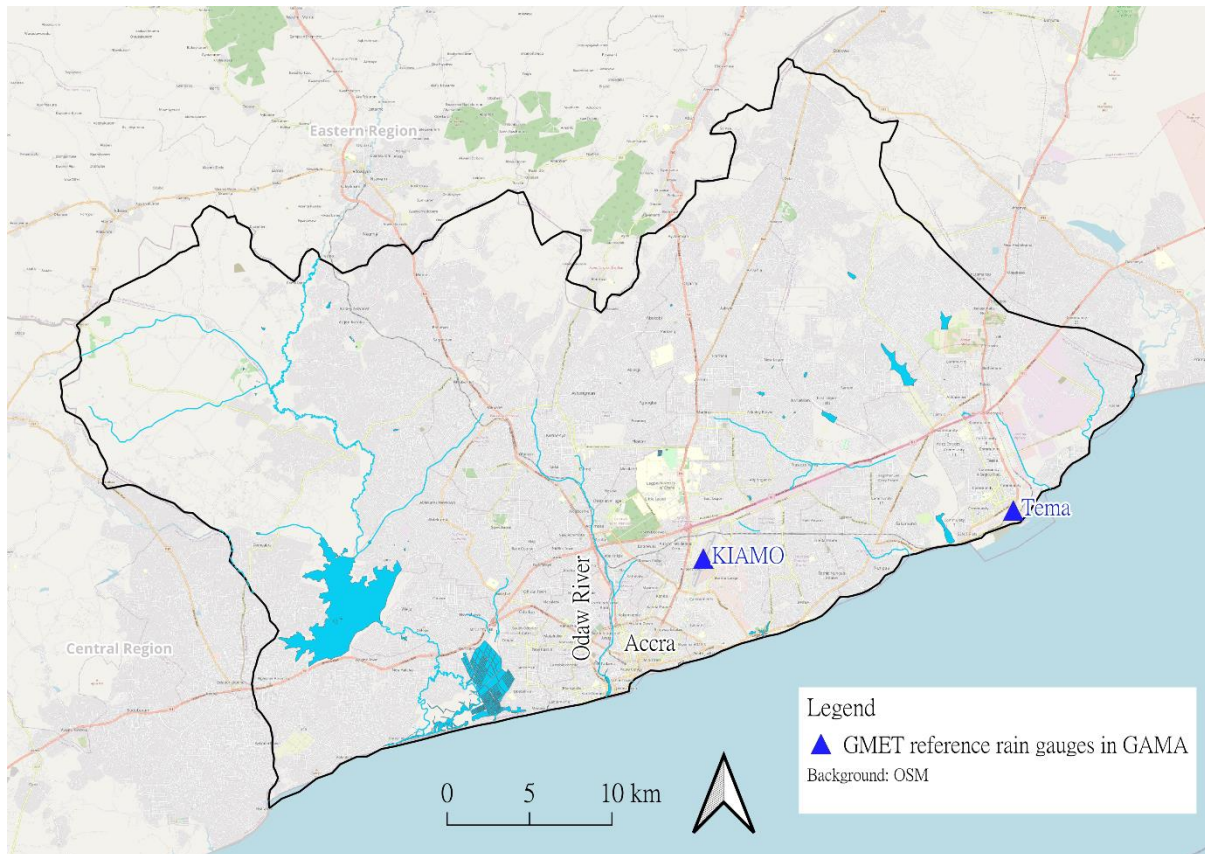


Figure 19: Location of GMet's KIAMO and Tema manual rain gauge stations within GAMA. For context, main rivers and Open Street background maps are included.

From this high-level analysis, the following observations and conclusions can be drawn:

- **Significant inter-annual and inter-decadal variability:** this analysis further underscores the significant inter-annual and inter-decadal variability in GAMA'S rainfall historic pattern, which complicates identification of trends and highlights the importance of utilising long time series in trend analysis. For instance, the intermediate epoch (1980-1999) was generally drier than both the preceding and following periods (Table 2). Analyses that only consider data post-1980 might erroneously suggest an increasing trend in annual rainfall, overlooking that the earlier epoch (1960-1979) exhibited comparable or even higher annual averages than the most recent 20-yr period.
- **Noticeable differences between stations across GAMA:** while inter-annual and inter-decadal behaviour is generally consistent between KIAMO and Tema stations, non-negligible

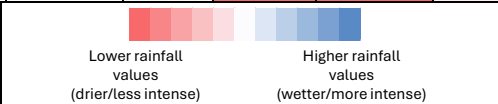

differences in rainfall patterns are visible between the two stations. KIAMO station generally records higher annual rainfall and daily extremes than Tema, and climate trends at the two stations show differences.

- **Annual rainfall trends** (Table 2 and Figure 20 (a)): amidst substantial inter-decadal fluctuations, annual average rainfall at KIAMO shows no notable changes, with comparable averages between the 1960-1979 and 2000-2022 periods. Similarly, no notable changes are visible in terms of average number of rainy days per year at KIAMO. For Tema, however, there appears to be a trend towards decreasing annual rainfall and rainy days per year, with average annual rainfall (AAR) over the most recent 20-yr period being 8% lower than that over the period 1960-1979 and AAR over the intermediate epoch 1980-1999 being even lower.
- **Magnitude and frequency of extremes** (Table 2 and Figure 20 (b) (c) (d)): the magnitude of relatively lower daily extremes<sup>24</sup> (defined here as the 99<sup>th</sup> percentile of daily rainfall with associated return periods of approximately 1.5 years) displays a decreasing tendency at both Tema and KIAMO (see p99 values across analysis epochs in Table 2). Higher extremes, including daily percentile 99.9 and annual maxima (Table 2 and Figure 20 (b)), exhibit a weak decreasing trend at Tema, whereas at KIAMO, there is a significant increase, indicating that larger extremes are becoming more severe. As regards frequency of significant heavy storms, hereby quantified based on the frequency of exceedance of long-term percentile values 99 and 99.9, the frequency of lower extremes shows a weak decreasing tendency at both stations, while the frequency of higher extremes (>p99.9) seems to be decreasing at Tema but significantly increasing at KIAMO. **In summary, available records suggest that lower extremes are decreasing in magnitude and frequency at both stations, whereas higher extremes are becoming more severe and frequent at KIAMO but are diminishing in both magnitude and frequency at Tema.** The observed increase at KIAMO may have significant implications in terms of flood risk, given the proximity of this station to the Odaw River and to areas with high concentrations of poor and vulnerable.
- **Changes in monthly and seasonal rainfall patterns** (Figure 21 and Figure 22): the main change to note in terms of monthly and seasonal rainfall patterns is the tendency towards wetter Mays and drier Junes, with a change in May particularly noticeable at KIAMO, and towards a wetter minor season – particularly during October. While Junes are getting drier, the frequency of high daily extremes (> long-term p99.9) during June remains similarly high over time, with average occurrence frequencies of 0.6 extreme events / month during the earliest and latest epochs analysed (Figure 23 and Figure 24). While extreme events remain infrequent during the drier months, occasional occurrences have been registered during the most recent epoch which were not observed before (see average frequency of high extremes across epochs during Oct-Jan). Additionally, rainfall over the drier months (Dec-Feb) appears to be getting more variable, as reflected by larger standard deviations, particularly at KIAMO.

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<sup>24</sup> In the context of excess rainfall and flooding insurance.

Table 2: Rainfall statistics across full period of records (1960-2022) and three 20-yr epochs (1960-1979, 1980-1999 and 2000-2022). Note: The final epoch extends three years to include latest records. This extension does not affect the comparability of the statistics, as they are based on averages or proportional analyses.

		Annual Average Rainfall [mm]	1D - p99 [mm]	1D - p99.9 [mm]	Average Annual 1D Maxima [mm]	Average number of rainy days per year	Average recurrence interval for exceedance of long-term percentile thresholds [years]	
							p99 (RP~1.5yr)	p99.9 (RP~5yr)
<i>KIAMO</i>								
Full period	[1960-2022]	777.30	45.00	97.61	92.48	51.24	0.28	2.62
~20yr epochs	[1960-1979]	802.77	47.12	94.41	86.90	51.90	0.24	4.00
	[1980-1999]	715.08	41.20	87.87	93.33	49.50	0.33	3.33
	[2000-2022]	809.27	45.11	111.94	96.60	52.17	0.27	1.77
<i>Tema</i>								
Full period	[1960-2022]	712.58	42.67	87.66	78.66	46.71	0.28	2.62
~20yr epochs	[1960-1979]	780.21	46.18	86.10	78.13	50.30	0.25	2.86
	[1980-1999]	642.03	39.96	88.83	81.54	43.75	0.32	2.00
	[2000-2022]	715.12	42.33	84.18	76.63	46.17	0.28	3.29
								

Note: Colour ramps applied across each individual column and station, therefore, colours are inter-comparable within a column/variable

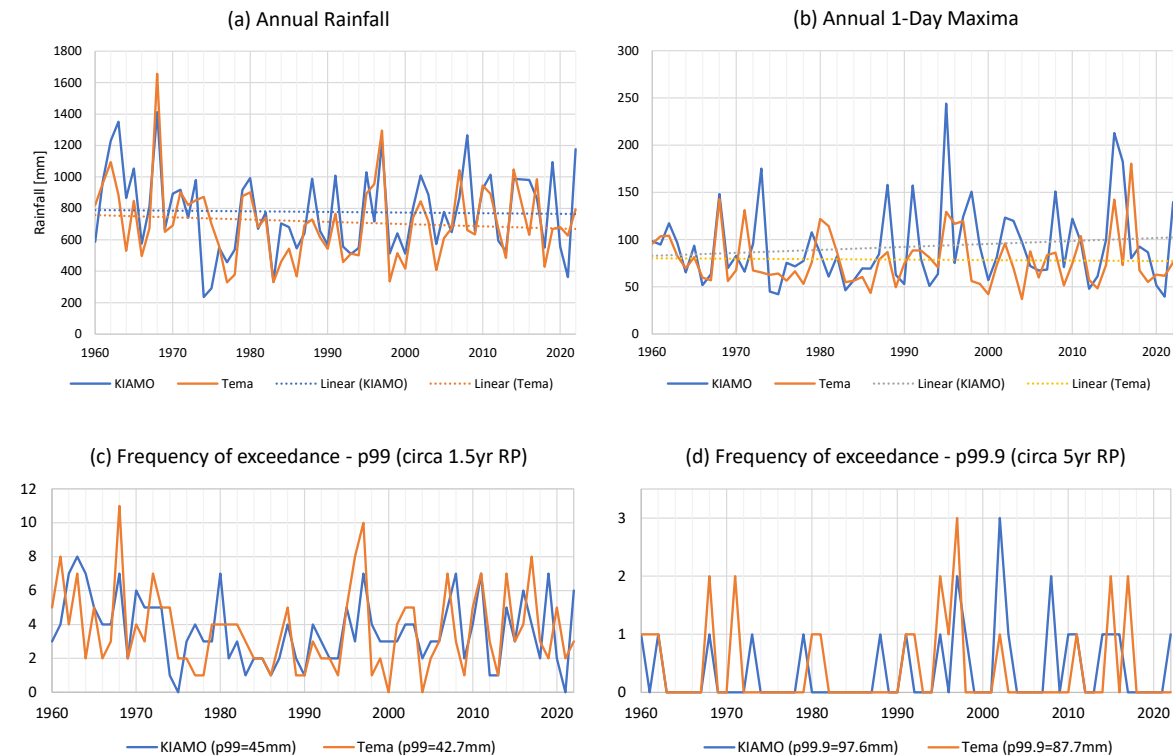


Figure 20: Time series of (a) annual rainfall, (b) annual daily maxima, and (c-d) annual frequency of exceedance of long-term percentiles 99 and 99.9, respectively, for KIAMO and Tema stations across the full period of records 1960-2022.

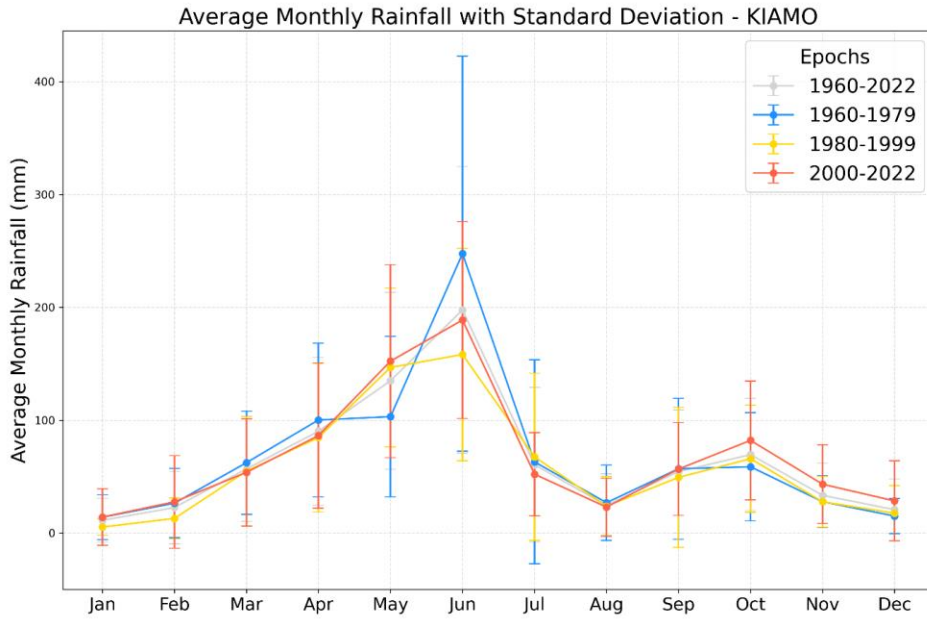


Figure 21: Monthly rainfall averages and standard deviation at KIAMO station across full period of records (1960-2022) and three 20-year sub-epochs: 1960-1979, 1980-1999, 2000-2022.

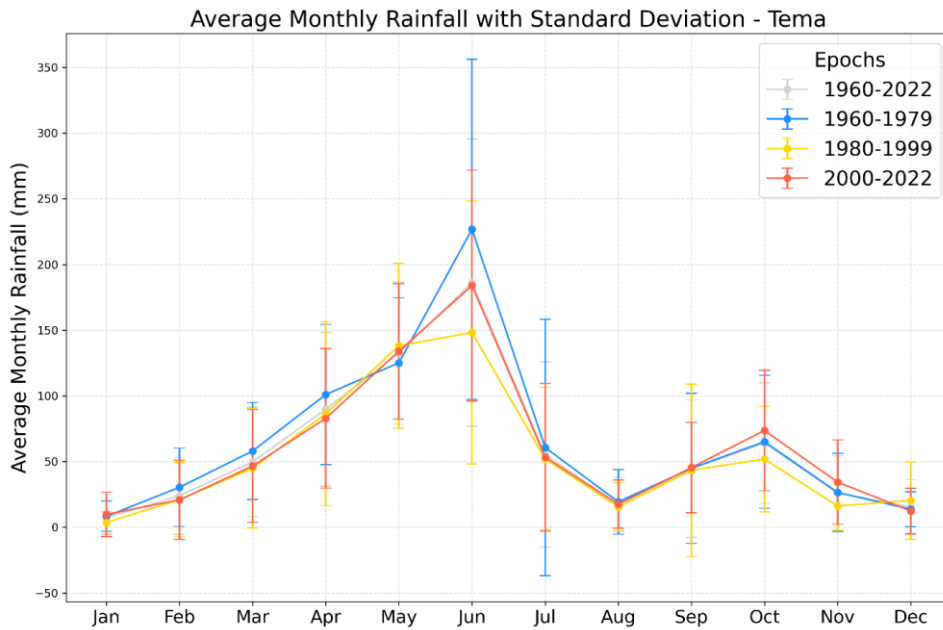


Figure 22: Monthly rainfall averages and standard deviation at Tema station across full period of records (1960-2022) and three 20-year sub-epochs: 1960-1979, 1980-1999, 2000-2022.

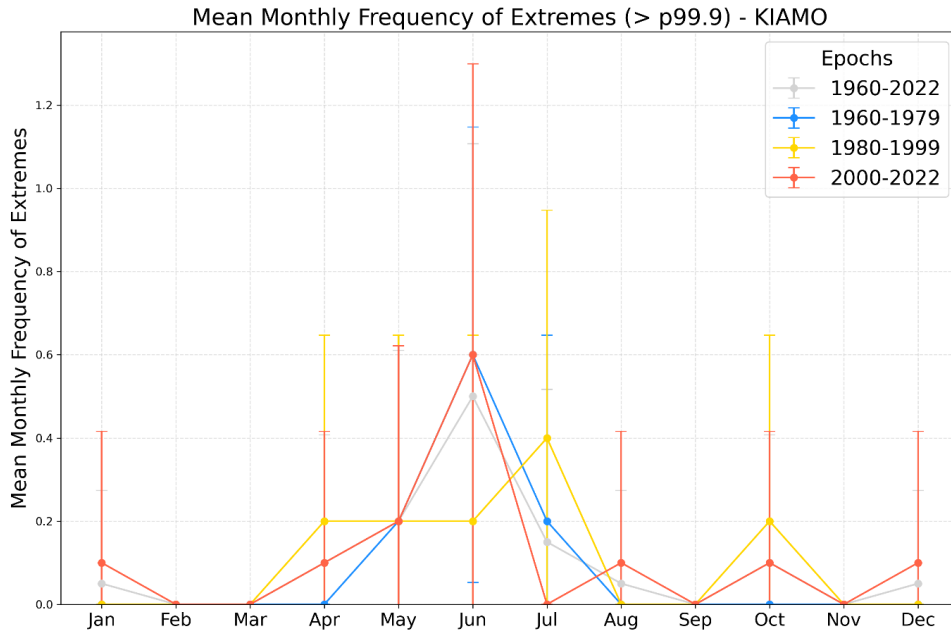


Figure 23: Mean monthly frequency of daily extremes (> long-term p99.9) at KIAMO station across full period of records (1960-2022) and three 20-year sub-epochs: 1960-1979, 1980-1999, 2000-2022.

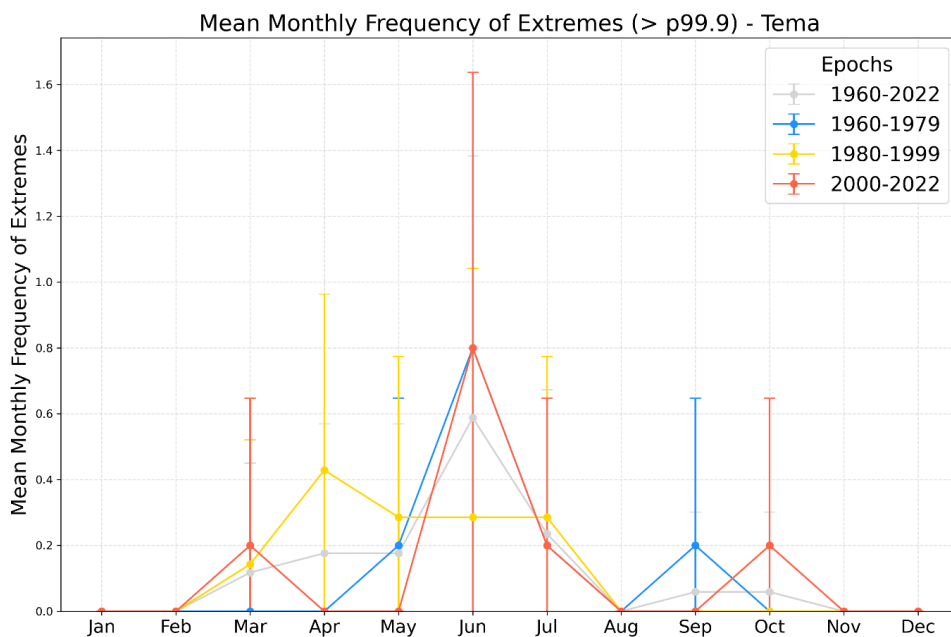


Figure 24: Mean monthly frequency of daily extremes (> long-term p99.9) at Tema station across full period of records (1960-2022) and three 20-year sub-epochs: 1960-1979, 1980-1999, 2000-2022.

### 3.5.3. Summary of climate trends

Global warming has led to approximately a 1°C temperature increase across Ghana, exacerbating rainfall volatility, contributing to a sea level rise of 63 millimetres, and causing an average coastal erosion rate of 1.13 metres per year — with these trends expected to continue. Regarding rainfall patterns, while no significant changes in annual rainfall have been detected or are predicted for Ghana and GAMA, notable shifts in seasonal rainfall and in the magnitude and frequency of short-duration

extremes have been observed. Specifically, GAMA has experienced a reduction in the magnitude and frequency of lower daily extremes (with return periods of 1-2 years), while higher extremes have become more severe and frequent across central GAMA, albeit less pronounced in outer GAMA. In terms of monthly shifts, May has become wetter, June drier, and the minor rainy season (September-November) has seen increased rainfall. Given the ongoing impact of global warming, with anticipated further increase in rainfall volatility and intensification of extremes, continuous monitoring and analysis of rainfall patterns in GAMA are essential, alongside monitoring of flooding exacerbating factors such as sea level rise. Special attention should be paid to the short-duration extremes that typically drive flooding in the capital. These insights could inform future parametric insurance product designs and updates.

### 3.6. Hydrology

GAMA's hydrology is influenced by both natural and man-made features. The area's topography, proximity to the ocean, and climatology, alongside human-driven factors such as water supply and drainage infrastructure, land-cover changes (particularly high degree of urbanisation), and waste management practices, play a critical role in shaping its hydrology.

GAMA's landscape gives rise to 14 major watersheds, with main rivers such as the Densu, Odaw and Sakumono draining into the Gulf of Guinea, often through estuarine lagoons like Korle, Sakumono, Kpeshie and Songor (see Figure 10 above). Additionally, GAMA is intersected by several smaller streams, artificial canals and dams, including the major Weija Dam on the Densu River, which serves as the main water supply for the area. This natural and man-made drainage network and its interactions with the Atlantic Ocean are crucial to understanding water flows and flooding in GAMA. Flood hazard in GAMA is examined in the next section.

## 4. Target Areas for Insurance Coverage

As previously indicated, the index-based flood insurance product under development aims to support post-emergency relief and recovery efforts, focusing on assisting the poor and vulnerable and accelerating the restoration of their economic activities after a flood event. With this in mind, and through consultation with local stakeholders, the focus is on low-income and informal residential areas, as well as key transport hubs and table-top markets, which are vital to the economic livelihood of the poor and vulnerable. Further details on the target areas and assets are provided below.

### 4.1. Identification of target residential areas

Low-income and informal residential areas were identified using a land use map developed by HKV (2018) through satellite imagery analysis and verification with stakeholders from Greater Accra's municipal assemblies (see Figure 25 (a) and Text Box 1. The reliability of HKV's map was confirmed against a vulnerability layer created by Swiss Re for this project, which incorporated open-source data on building counts, population<sup>25</sup> and informal settlements<sup>26</sup>. The comparison of these two layers is displayed in Figure 25, with detailed views at critical locations provided in Figure 26. There is a strong correlation between the informal and low-income areas identified by HKV and the high-vulnerability zones marked by Swiss Re, providing confidence in the analysis. The HKV map was further validated during a meeting with representatives from GAMA's municipal assemblies on July 11, 2023. At this meeting, some areas were reclassified and the initial decision to designate low-income areas and informal settlements as targets for the parametric products under design was reaffirmed. Due to further refinements with stakeholders HKV's mapping was chosen as the primary basis for definition of target areas in this project. Final target residential areas for the purpose of this insurance scheme are shown in Figure 27.

### 4.2. Further insights and validation of target residential areas using population data

The 2021 census data (Ghana Statistical Services, 2021) (Figure 7 and Figure 27) also supports the identified target areas, with high population density hotspots typically overlapping with the informal and low-income residential areas identified on HKV's map and the high-vulnerability zones on Swiss Re's layer. The census data was in fact utilised in product design, helping assign relative weights to target residential areas, as detailed in Section 6.4.6.

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<sup>25</sup> <https://hub.worldpop.org/>

<sup>26</sup> <https://unhabitat.org/>

Text Box 1: Residential area classes defined in HKV (2018).

- **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, coloured roofs.
- **High income:** Buildings in zones with considerable amount of trees and cars, coloured roofs, churches, hospitals, ministries, parliament, residential houses with larger surrounding space, fences, presence of civil and cultural infrastructure, fire departments.

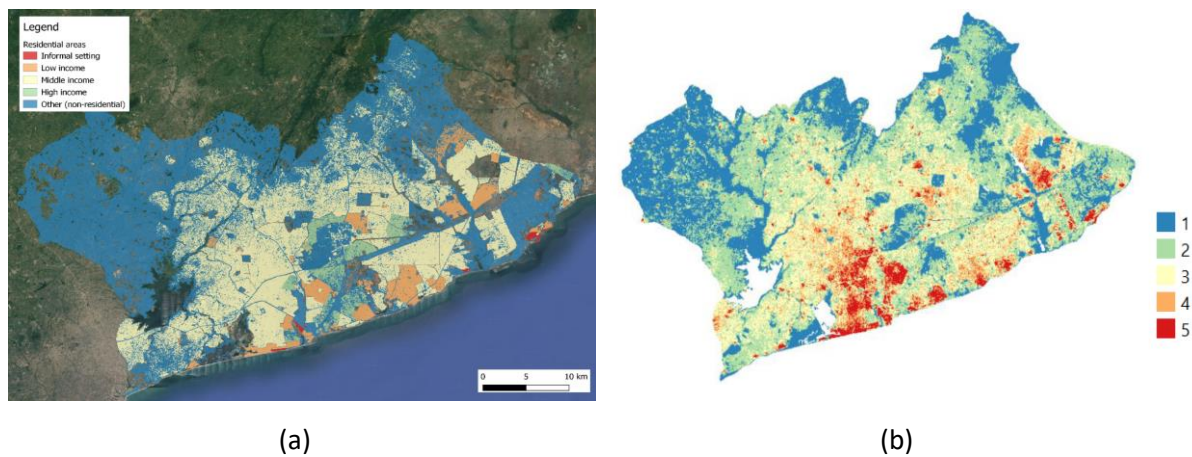


Figure 25: Layers informing selection of target areas for insurance cover. (a) HKV (2018) classification of residential areas into four income levels based on analysis of satellite imagery and validation with local stakeholders; (b) Swiss Re's relative vulnerability layer based on open population, building counts and mapping of informal settlements.

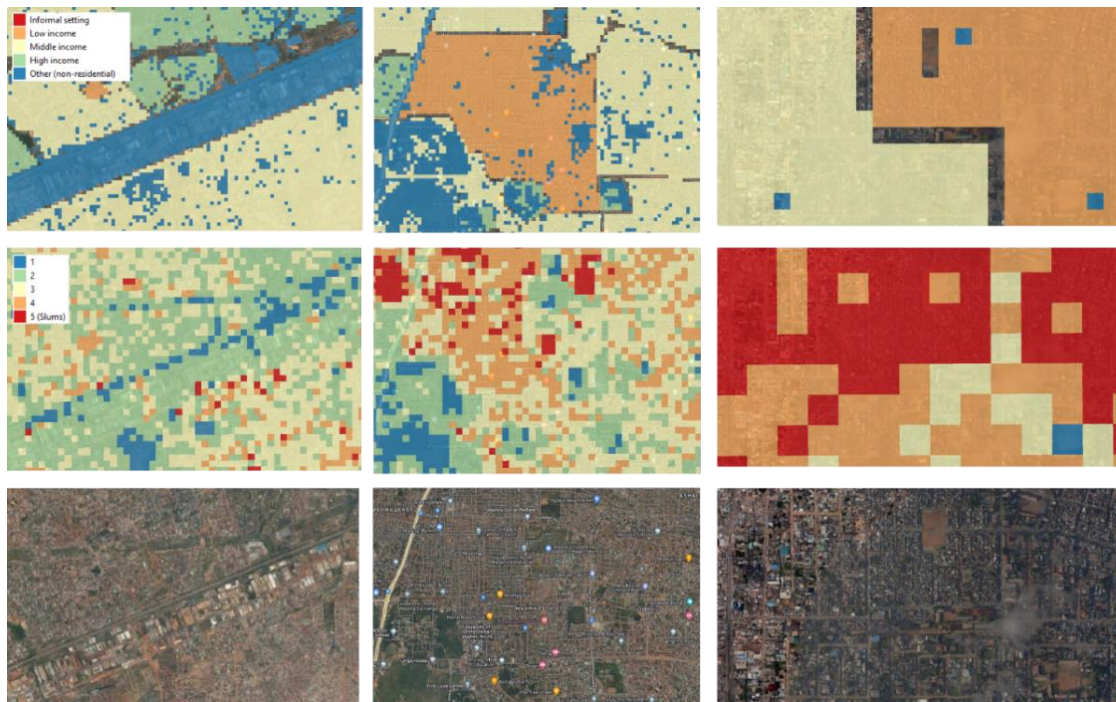


Figure 26: Zoom to details and inter-comparison of vulnerability maps for some areas in GAMA. Top: HKV (2018) maps; middle: Swiss Re maps; bottom: optical images from satellite for visual comparison.

### 4.3. Identification of target transport hubs and market areas

Important transport hubs and table-top markets, crucial for the reestablishment of economic activity among the poor and vulnerable, were identified and mapped in collaboration with representatives from GAMA's municipal assemblies during a meeting on July 11, 2023. These are shown in Figure 27 alongside final target residential areas.

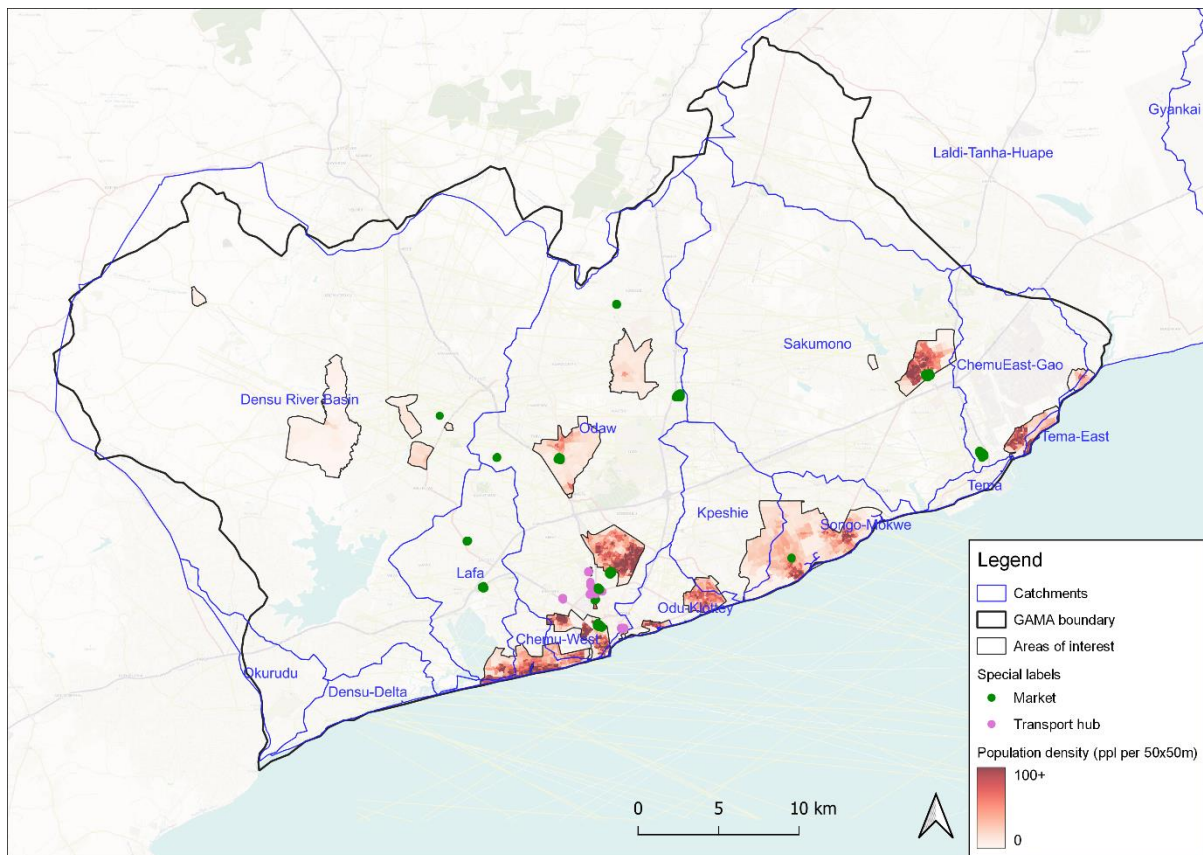


Figure 27: Areas and assets of interest for insurance product design, including informal settlements and low-income residential areas (grey), key transport hubs (pink) and markets (green).

## 5. Peril Characterisation: Flood Hazard & Risk in GAMA

In this section, flood hazard and risk in GAMA are characterised, and an analysis of historical flood events is made to further help understand and quantify flood hazard and risk. The information in this section and the historical datasets introduced here were instrumental to guide and enable validation of product design.

### 5.1. Flooding sources and hazard overview

Floods in GAMA are primarily caused by intense, short-duration rainfall during the main rainy season from March to July, peaking in June, and occasionally during the minor season (Sep-Nov), resulting in compound pluvial and fluvial flooding. Pluvial flooding, or flash flooding, involves rapid runoff generation and accumulation in low-lying areas, while fluvial flooding results from rivers like the Odaw and Sakumono and their tributaries overflowing. These floods are largely exacerbated by high and rapid runoff response due to extensive urban impervious surfaces, inadequate drainage systems, and obstructions in waterways, including siltation, solid waste accumulation, and the presence of buildings – particularly informal settlements that often occupy flood plains (Amoako & Frimpong Boamah, 2015). In particular, the Odaw River, flowing through the Accra district and into the Korle Lagoon<sup>27</sup>, is a significant source of flooding, with waste accumulation and siltation in the river, lagoon, and at the interception weir where they meet<sup>28</sup> often intensifying flooding severity. Additionally, the occasional coincidence of high sea levels with heavy rain can restrict river and drainage system discharge into the ocean, further exacerbating flooding.

Flood response times in GAMA are typically short, with modelled lag times between rainfall and flooding spanning just a few hours across most basins (HKV, 2017). The rapid onset of severe flooding following short-duration downpours has been corroborated by analysis of rainfall records and supported by anecdotal evidence from news and reports (Table 3).

Coastal flooding due to storm surges is rare and does not contribute significantly to flood risk in GAMA. Lastly, GAMA faces risks from man-made floods associated with dams, including occasional controlled and uncontrolled spills from the Weija dam on the Densu River, the main water supply for the area and which caused severe flooding as recently as October 2022, and smaller dams at risk of breaching due to poor construction and maintenance.

Figure 28 provides an initial overview of pluvial and fluvial flood hazard in GAMA. More information on flood models, including those adopted for product design, is provided in Section 6.4.2.

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<sup>27</sup> Korle Lagoon is a natural estuarine waterbody which has been subjected to man-made alterations and waste accumulation. In 2002, it was ranked among the world's most polluted water bodies (Owusu Boadi & Kuitunen, 2002), prompting restoration efforts.

<sup>28</sup> An interception weir exists at the intersection point between the Odaw River and the Korle Lagoon. From this weir, a by-pass previously existed to pump flows from the river directly into the ocean. The by-pass is no longer operational.

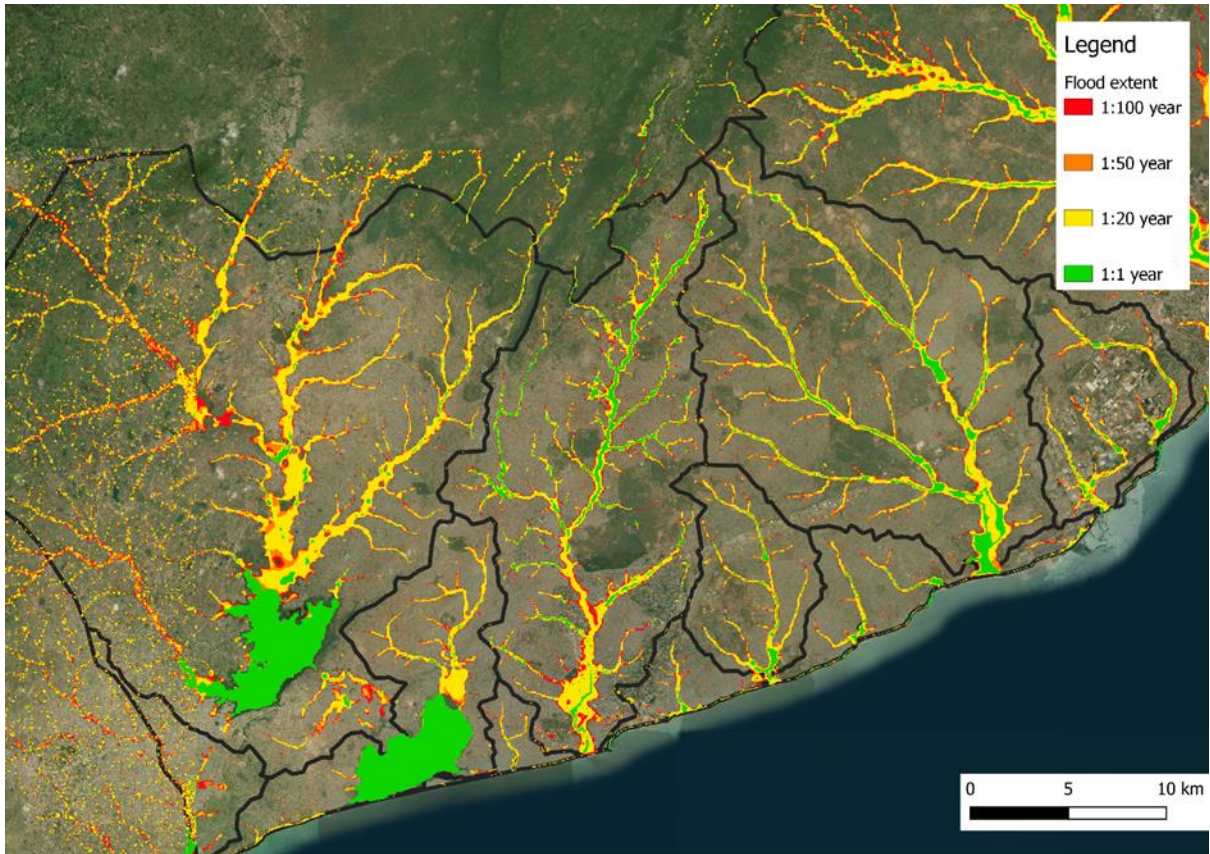


Figure 28: Overview of flood hazard in GAMA – Modelled flood extent for return periods 1:100 (red), 1:50 (orange), 1:20 (yellow) and yearly floods (green). The main river basins are outlined in black. Source: (HKV, 2018).

Table 3: Daily rainfall in Accra and anecdotal reports of severe flood events post-2000, demonstrating causality between short-duration intense rainfall and rapid onset of flooding.

Date	Max 24h rainfall @ GMET Accra Stations*	Excerpts from news articles and reports
27/06/2001	81	"Particularly affected by <b>yesterday's five hours of heavy rain that led to the flooding</b> were densely populated, low-income neighbourhoods... Rivers in the centre of the city broke their banks and roads had been either washed away or are completely under water." <sup>29</sup>
09-10/06/2002	139	"The city of Accra recorded 123.3 millimetres of rain during a <b>10-hour downpour between the night of Sunday 9th June and the morning of Monday 10th June 2002</b> , causing flooding in low-lying sections of the city." <sup>30</sup>
02/06/2007	66	"Two persons are reported dead at Kwashie-Bu in Accra <b>after a heavy downpour Saturday afternoon</b> ". <sup>31</sup>
19/06/2009	140	"The seven people (five males and two females) who lost their lives in last Friday's floods that occurred in the western part of Accra have been identified.... They all got drowned in and around Kaneshie <b>during the heavy downpour which lasted a little over two hours</b> ". <sup>32</sup>
25-26/10/2011	157	"On Wednesday, October 26, 2011, a <b>heavy downpour (approximately 100 millimetres of rain), which lasted for over four hours</b> , inundated most parts of the Greater Accra Region and some areas in the Volta and Eastern Regions" <sup>33</sup> "Reference was made to the floods that occurred in the late hours of 25th October 2011 to the early hours on the 26th of October 2011 in Accra. <b>The floods were argued to have been caused by five-hour duration of rainfall</b> with different depths recorded in the various rain gauge stations in the basins. <b>Its impact was described as unexpected</b> with hundreds of people rendered homeless, twelve people dead and property worth millions of cedi destroyed". <sup>34</sup>
05/06/2014	143	" <b>Torrential rain on Thursday 05 June 2014 left huge areas of the city flooded</b> in particular Kwame Nkrumah circle, Kaneshie First Light and the Central Business District. Roads are blocked and transport in some areas is virtually impossible." <sup>35</sup> " <b>The dawn to evening torrential rains in the capital Accra</b> has made majority of the roads in the capital inaccessible." <sup>36</sup>
03/06/2015	213	"Thirty-eight-year-old Gertrude Otobia Darko, was at home with her eight children and husband on the night of 3 June, <b>when her house began to flood after days of steady rainfall and then hours of heavy downpour across the city</b> ". <sup>37</sup> <b>Sub-daily records suggest core of storm between 5 p.m. - 12 a.m.</b>
09/06/2016	183	"Wide areas of Accra, Ghana, are under water after a period of heavy rain that began 09 June 2016. Residents of the city are fearing a repeat of last year's flood... Initial figures suggest that between 140 and 190 mm of rain fell in 24 hours between 09 and 10 June in some areas of Accra. <b>Most of the rain fell in a 3-to-6-hour period</b> , according to local media. Although this time of year marks the start of the rainy season, this is still a significant amount." <sup>38</sup>
23-24/05/2022	140	"For the second time in three days, residents of Accra were at the mercy of heavy floods after an overnight downpour submerged parts of the city and its environs... <b>The eight-hour rains lasted up to about 6 a.m. on May 24, 2022</b> , from the previous night, hitting hard at the flood-prone areas of the city, and leaving piles of garbage strewn across the roads and other open spaces." <sup>39</sup>

\*Maximum daily rainfall recorded at GMET stations KIAMO and Accra Academy within the Accra municipality. GMET 24-hour accumulations are measured from 9 AM to 9 AM the following day. Adjustments were made for the October 2011 and June 2014 events, as descriptions indicate that peak rainfall extended across the GMET daily cutoff.

<sup>29</sup> <https://edition.cnn.com/2001/WORLD/africa/06/28/ghana.floods/>

<sup>30</sup> <https://www.unocha.org/publications/report/ghana/ghana-floods-ocha-situation-report-no-1-1>

<sup>31</sup> <https://www.modernghana.com/news/137070/accra-counts-its-dead-after-heavy-rains.html>

<sup>32</sup> <https://www.modernghana.com/news/223856/rain-disaster-victims-identified.html>

<sup>33</sup> <https://reliefweb.int/report/ghana/report-october-26-2011-floods-3rd-update-311011>

<sup>34</sup> <https://tud.qucosa.de/api/qucosa%3A30395/attachment/ATT-1/>

<sup>35</sup> <https://floodlist.com/africa/accra-ghana-floods-june-2014>

<sup>36</sup> <https://www.modernghana.com/news/546944/accra-at-standstill-flood-waters-make-roads-inaccessible.html>

<sup>37</sup> <https://reliefweb.int/report/ghana/ghana-hard-hit-flooding-once-again>

<sup>38</sup> <https://floodlist.com/africa/ghana-accra-floods-june-2016>

<sup>39</sup> <https://www.graphic.com.gh/news/general-news/downpour-devastates-accra-again.html>

## 5.2. Flood exposure and risk overview

An overview of flood exposure and risk is presented in Figure 29, which intersects the target areas defined in Section 4 with the flood hazard information detailed in Section 5.1. As can be seen, the Odaw and Chemu West basins contain target areas within highly susceptible flood zones, leading to elevated exposure and risk. Other basins, such as Songo-Mokwe, also house significant portions of target areas, yet the associated flood hazard—and thus the exposure and risk—are comparatively lower.

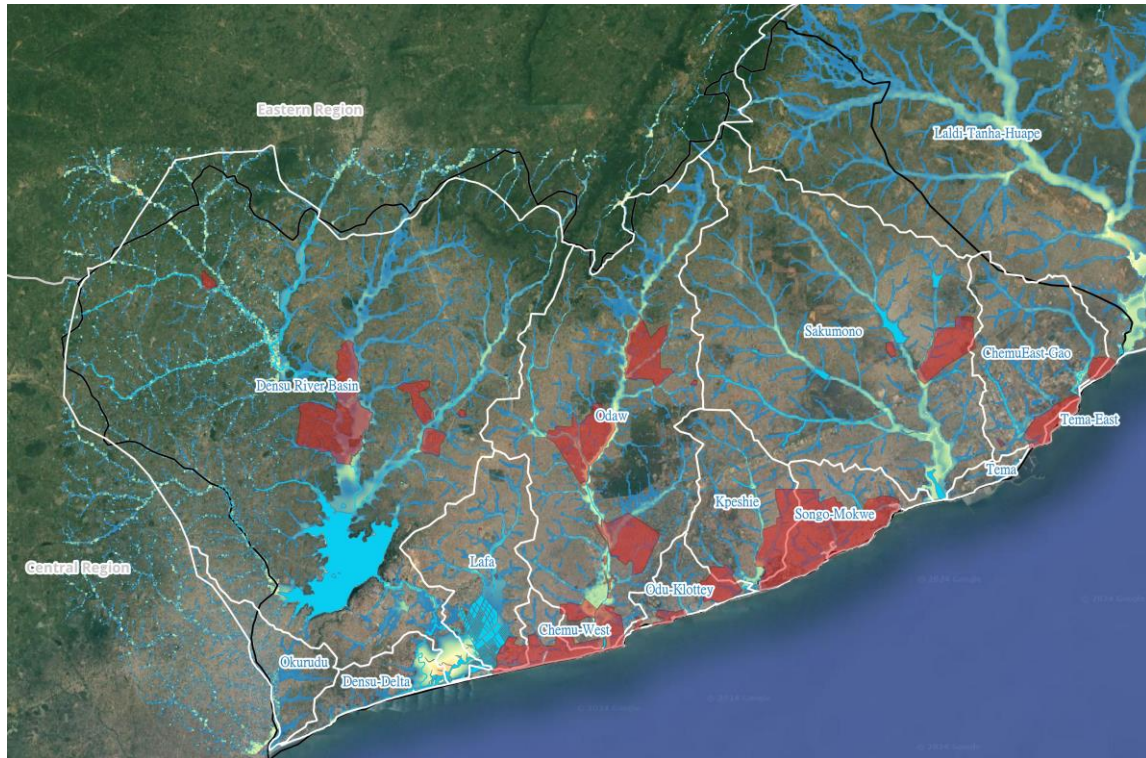


Figure 29: Intersection of target areas (red) with flood hazard maps (blue-orange colour scheme) to illustrate exposure and flood risk throughout GAMA.

## 5.3. Historical flood events

This subsection presents a timeline of historical flood events from 1955-2022, compiled from multiple sources, bringing together available information on associated rainfall and impacts. Afterwards, a summary of major flood events is presented, highlighting associated rainfall and reported losses. Following this, a detailed analysis of the 3<sup>rd</sup> of June 2015 flood event is provided, including a hydrodynamic model-based reconstruction using station rainfall data as input, and an investigation into event losses and Government response costs. Finally, considerations for determining the maximum insurance payout are discussed.

### 5.3.1. Historical flooding timeline

A timeline of historical flood events across GAMA was compiled specifically for this project to gain insights into flood frequency, drivers, and impacts, and to assess the flood predictability skill of various rainfall products. The following sections detail the data sources used, the compilation methodology,

and the event severity score assignment. This is followed by an overview of the final timeline, along with rainfall records and recurrence statistics. Copies of the historical flooding timeline and rainfall records can be found in Appendix 2.

## Data sources

The timeline draws upon a variety of sources, including reports, online portals, academic papers, information supplied by local agencies and a flood timeline based on news and social media posts commissioned from FloodTags specifically for this project. The main data sources are summarised in Table 4.

Table 4: Data sources consulted for the generation of the timeline of historical flood events in GAMA.

Data Source	Period Covered	Description
FloodTags flooding timeline	2004 to 2022	Based on database of news, tweets and other online sources. Includes number of tweets/articles, number of photos, number of affected, number of killed, max flood depth (when available), locations mentioned, links to articles and excerpts.
FloodList <sup>40</sup> search results for Accra	July 2014 to October 2022	Individual event descriptions, including how the event unfolded, areas affected, and impacts.
World Bank & GFDRR (2017) – Annex A: Overview of historic major floods in Accra <sup>41</sup>	1955 to 2015	Individual event descriptions with information on locations affected, general impacts, and, where available, lives lost.
UN OCHA ReliefWeb <sup>42</sup>	July 1995 to October 2019	Descriptions and relevant links about major floods anywhere in the country.
University of Colorado Global Active Archive of Large Flood Events <sup>43</sup>	1985 to Present (2022)	Archive of large flood events worldwide. Results available at country level with shapefile of estimated extent supplied. The shapefiles were used to identify events impacting GAMA. Includes main cause, estimated displaced, dead and indicative severity score.
NADMO: Disaster database for CREW project*	1987 to 2013	Includes monthly aggregates and occasional event-specific impact information.
NADMO: Annual disaster impact summaries*	2014 to 2018	Impact info aggregated per year for different types of disasters and regions, including GAR.
NADMO: GAR quarterly flood impact summaries*	2017 to 2022	Includes number affected, deaths, damages to houses/infrastructure/crops, with cost info sometimes provided.
Okyere et al (2013)	1955 to 2011	Contains tables of major floods in Accra, high-level analysis of flood occurrence vs. rainfall accumulations, and high-level information on affected people and costs. In turn, it cites the EM-DAT OFDA/CRED International Disaster Database as a key source.
Kusimi & Yeboah (2019)	2000 to 2015	Includes table of major Accra floods, impact, and cost info. Reportedly draws upon (Amoako & Frimpong Boamah, 2015).
History of flooding in Ghana timeline (supplied by Richard Kofi from Ghana Hydrological Authority)	1968 to 2015	Timeline of flooding in Ghana.

\*Event-specific impact information was difficult to infer from NADMO summaries. Therefore, this data was used for general insights on typical response costs rather than for event-specific details.

<sup>40</sup> <https://floodlist.com/>

<sup>41</sup> <https://documents1.worldbank.org/curated/en/949241495793834492/pdf/115296-REPLACEMENT-PUBLIC-Accra-v5-highres-nocutmarks.pdf>

<sup>42</sup> <https://reliefweb.int/report/indonesia/developing-parametric-insurance-weather-related-risks-indonesia>

<sup>43</sup> <https://floodobservatory.colorado.edu/Archives/>

## Standardisation and compilation methodology

A methodology was developed to standardise and compile information from various sources, resulting in a single continuous time series of flood events across GAMA covering the period 1955-2022.

Firstly, individual timelines from each data source were standardised, setting key fields: event ID, start and end dates, and impact metrics (e.g., number affected, deceased, damages), where available. Additional descriptive information was also recorded. These individual timelines were then merged into a single global time series, combining overlapping events and adopting the earliest start date and latest end date. Each event was assigned a global ID while keeping track of individual sources.

Manual checks included:

- Verification of closely timed events, which could in fact be the same event.
- Comparison against daily rainfall records in GAMA to refine dates and rule out false records, consideration of the number of sources, data quality, and geographic extent.
- Web searches and requesting FloodTags to check their media database for unreported events when high rainfall was recorded without a corresponding event, leading to the identification of several previously unrecorded events.

Additionally, for the most severe events, impact information from various sources was manually reviewed, and the most relevant impact metrics were consolidated for subsequent flood impact analysis.

## Assignment of qualitative severity index

A qualitative severity score ranging from 1 (low severity) to 3 (high severity) was assigned to each flood event based on an assessment of available impact information. The source reporting the event was also considered, with events in historical lists of major flood events in GAMA (e.g. Okyere et al (2013), World Bank & GFDRR (2017)) typically assigned at least a severity of 2. In the case of events identified by FloodTags, the number of tweets or news citing it was also considered. General considerations for severity score assignment is summarized in Table 5.

Table 5: General considerations for assignment of qualitative severity score.

Severity Index	Flood extent & depth	Number of deaths	Number of people affected	Example event descriptions
1	Relatively localised, < 1m flood depth	0	Dozens	"Two hours of heavy rain on Friday 31 January 2014 led to flash floods across the Ghana capital Accra. Although no casualties have been reported, property and buildings have been damaged and roads blocked" <sup>44</sup>
2	Medium – several neighbourhoods and considerable flood depth (typically > 1m)	1-10	Hundreds	"... streets in the Greater Accra Region under 1 metre of water, leaving cars submerged and buildings damaged. Many people trapped in their homes or vehicles. Two people have died and 4 are still missing." <sup>45</sup> "At least five people died after flash flooding in Accra late on Sunday 07 April 2019. Homes were damaged and scores of vehicles were trapped in the water" <sup>46</sup>
3	Widespread, deep and fast flood waters	>5	Thousands	"Vice President Alhaji Aliu Mahama has presented GHc 3.5 billion worth of relief items to 1,650 households living along the Lafa Basin in Accra that were affected by last week's floods."

<sup>44</sup> <https://floodlist.com/africa/ghana-accra-hit-flash-floods>

<sup>45</sup> <https://floodlist.com/africa/ghana-floods-accra-june-2018>

<sup>46</sup> <https://floodlist.com/africa/ghana-floods-accra-ho-kumasi-april-2019>

Severity Index	Flood extent & depth	Number of deaths	Number of people affected	Example event descriptions
				The flood claimed about six lives and destroyed property worth billions of cedis." <sup>47</sup> "For about 12 hours, many suburbs of Accra were submerged by flush floods, halting business activities and movement of people following incessant rains yesterday. The incident brought along devastation, with reports of 12 deaths including three people that were consumed by fire" <sup>48</sup>

### 5.3.2. Flooding timeline overview and associated rainfall

The compiled flooding timeline, along with maximum 1-day rainfall records from GMET's Accra rain gauges, is shown in Figure 30. While the timeline begins in 1955, rainfall records are only available from 1960 onwards, so the plot starts from 1960. The frequency and recurrence period of flood events of different severity levels across the full period and since 2000 are summarized in Table 8.

It is worth noting that the frequency of flood reporting has increased in recent decades, particularly from 2000 onwards, likely due to the advent of the internet and social media. Older records cover only very severe events, while more recent records include minor events in addition to severe ones.

Key insights from the timeline and associated rainfall records include:

- Extreme daily precipitation, particularly rainfall above 140 mm, shows a high correlation with severe flooding. Notably, the two largest 1-day rainfall depths on record correspond to two of the most severe flood events, namely the July 1995 and the notorious June 2015 floods. This underscores the critical role of intense precipitation in flooding across GAMA and highlights the potential for using rainfall depth as an index in a parametric product, discussed further in Section 6.
- The frequency of severity 3 events (which are believed to be consistently recorded across the analysis period) appears to have increased in recent decades. On average, severity 3 events occurred every 4.5 years across the full analysis period (1955-2022), compared to every 2.5 years in the last two decades. This can be partly attributed to an increase in severe daily rainfall (as evident from the plot above and discussed in Section 3.5) but is also likely due to exacerbating factors such as urbanization.

<sup>47</sup> <https://www.modernghana.com/news/137368/flood-victims-receive-35bn-relief-items.html>

<sup>48</sup> <https://www.peacefmonline.com/pages/local/social/201110/76258.php?page=2&storyid=100&>

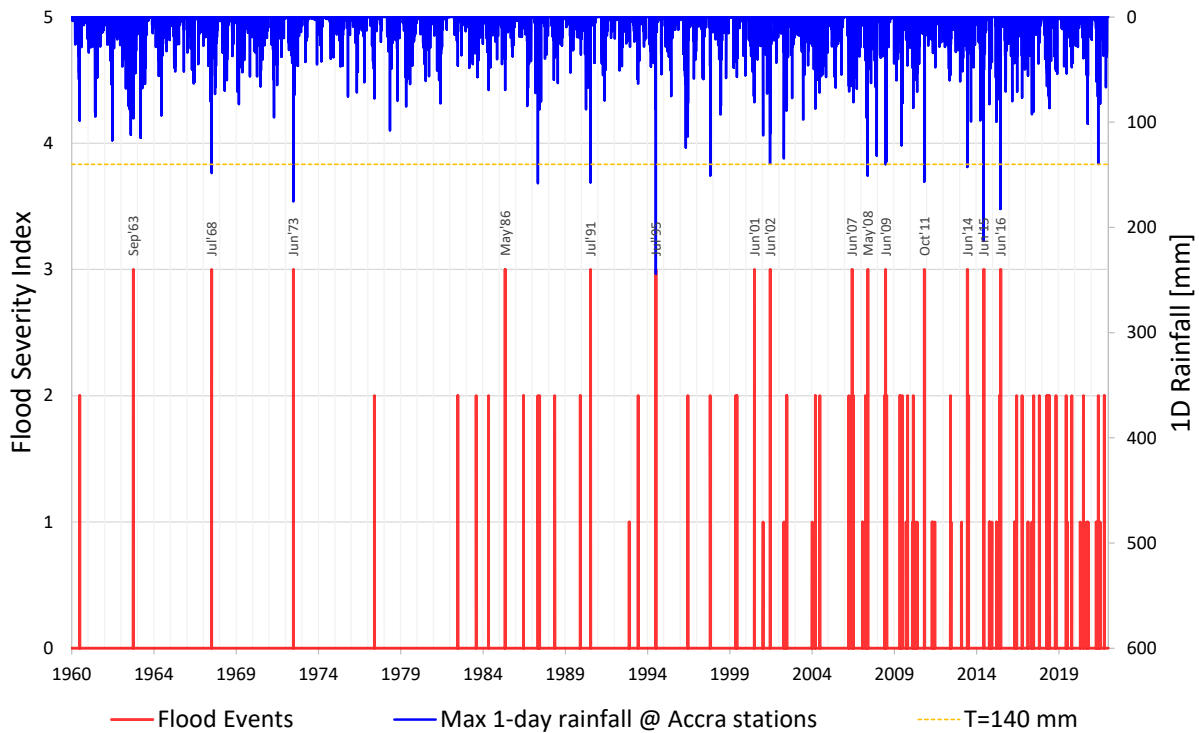


Figure 30: GAMA flooding timeline vs. maximum 1-day rainfall records across GMET Accra stations (KIAMO and Accra Academy).

Table 6: Count, annual frequency, and recurrence interval of flood events by severity level for (a) 1955-2022 and (b) 2000-2022.

(a) Flood event stats 1955-2022				(b) Flood event stats 2000-2022			
Severity	Count	Annual frequency	Recurrence interval (yr)	Severity	Count	Annual frequency	Recurrence interval (yr)
1	39	0.57	1.74	1	38	1.65	0.61
2	46	0.68	1.48	2	32	1.39	0.72
3	15	0.22	4.53	3	9	0.39	2.56

### 5.3.3. Overview of major flood events in recent history and associated losses

Table 8 lists all identified Severity 3 events since 2000, sorted by descending 1-day rainfall depth, along with available impact information. It also includes two Severity 2 events with significant rainfall accumulations, and for which cost estimates were available.

The well-documented June 2015 event (HKV, 2017; Kusimi & Yeboah, 2019; Amoako & Frimpong Boamah, 2015; World Bank & GFDRR, 2017) tops the list, with estimated total losses of 115 million for the Odaw basin (USD 382 million adjusted to 2023 values based on Ghana's inflation rates<sup>49</sup>). More information on costs associated to the June 2015 event, including response costs, is provided in the following section. For other events, information is both incomplete and inconsistent, with reported costs often lacking details on their coverage and the period they are valid for. Based on the available

<sup>49</sup> <https://data.worldbank.org/indicator/FP.CPI.TOTL.ZG?end=2022&locations=GH&start=2000>

data points and notwithstanding the uncertainty around the available estimates, average losses for high-severity events, adjusted to 2023 values, are around USD 100 million. For reference, annual flood damage across GAMA was estimated at USD 2 million by NADMO in 2008 (USD 16 million in 2023 value) and was expected to double in the following years (Karley, 2009), while HKV (2018) estimated annual average flood damage across the Odaw basin at USD 34 million (USD 79 million in 2023 value). This latter estimate aligns well with the average damage estimate for high-severity events derived from Table 8. Estimates focusing on relief costs are generally scarce. Karley et al. (2009) mention clean-up costs of about USD 0.5 million for the 2007 summer floods (USD 4.7 million in 2023 value), citing NADMO as the source. Details on response costs for the June 2015 event are provided in the following section.

Table 7: Most severe flood events since 2000 and associated flood losses\*.

Year	Start Date	Max severity (from source datasets)	Max 1-day rain across GMET GAMA stations [mm]	Max 10-day rain across GMET GAMA stations [mm]	No. Affected*	Casualties*	Estimated costs in USD million*	Estimated costs in USD million at 2023 values
2015	02/06/2015	3	212.8	334.9	53'000	159	115**	382
2016	09/06/2016	3	182.5	218.0	n/a	n/a	n/a	n/a
2011	25/10/2011	3	156.5	171.4	43'087-65'236	14	4.7	26.3
2008	18/05/2008	3	151.0	209.2	Not in	Not in	Not in	n/a
2014	05/06/2014	3	142.6	192.8	4'166	3	n/a	n/a
2009	19/06/2009	3	140.0	250.5	15'616	7	4.1	27.6
2002	09/06/2002	3	139.3	349.6	n/a	n/a	n/a	n/a
2001	27/06/2001	3	81.1	198.5	41'450-100'000	13	10.0	223.5
2007	01/06/2007	3	65.5	169.8	6'600-13'140	6	1.1	10.3
2003	09/06/2003	2	89.2	257.4	2'787	3	2.5	39.4
2005	12/03/2005	2	87.6	147.3	2'370	3	7.4	85.5

\*Damage estimates gathered from various sources; main sources include HKV (2018), Kusimi & Yeboah (2019), Amoako & Frimpong Boamah (2015). \*\*Total cost estimate by HKV for the Odaw basin, of which USD 91 million correspond to direct costs. For this event, the World Bank and the GFDRR (2017) report damages to housing, transport, water and sanitation of USD 55 million, and USD 105 million rebuilding costs.

#### 5.3.4. Detailed analysis of the June 2015 impacts and costs

The devastating Accra floods on 3<sup>rd</sup> June 2015 were reported amongst the ten deadliest worldwide that year. After days of severe rain, GAMA was hit by a six-hour downpour in the evening of 3<sup>rd</sup> June, which swamped the city, particularly the Odaw basin. The disaster affected approximately 53'000 people and claimed around 200 lives, of which 150 were due to a flood-related explosion at a filling station where people had taken cover from the rain and floods. Excerpts from FloodTags' georeferenced image analysis for this project illustrate the impact (Figure 31).

Total losses for this event were estimated at 115 million for the Odaw basin (USD 382 million adjusted to 2023 values based on Ghana's inflation rates<sup>50</sup>), of which USD 91 million (USD 303 million in 2023 value) correspond to direct costs (HKV, 2018). The World Bank and the GFDRR (2017) reported USD 55 million damages to housing, transport, water and sanitation, and rebuilding costs of USD 105

<sup>50</sup> <https://data.worldbank.org/indicator/FP.CPI.TOTL.ZG?end=2022&locations=GH&start=2000>

million (respectively USD 182 and 349 million in 2023 value). What is more, during this event GAMA's poorest households were disproportionately affected, as these are often located in informal settlements across flood-prone areas with inadequate drainage (World Bank & GFDRR, 2017; Erman, et al., 2018). Additionally, poor households' recovery periods were reportedly prolonged owing to the magnitude of losses in relation to income, income sources and lack of access to coping mechanisms (Erman, et al., 2018).



Figure 31: Images and map of visual reports for the June 2015 flood event from public sources (FloodTags Report, 2022).

The project team conducted detailed research of public information to estimate the cost of the government response to this major event. As shown in Table 9, the response costs are estimated at USD 5 million, including USD 2 million for emergency response through NADMO, USD 1.75 million in cash payouts, and USD 1.25 million in microloans. Adjusted to 2023 rates using a consumer-price index factor, this total would be approximately USD 6-7 million. According to a World Bank survey (Worldbank, 2018), only 10%-20% of affected individuals reported receiving support from the Government directly, or through NADMO.

Table 8: Estimation of costs related to Government response for the 2015 flood event.

Funding source*	Purpose	Amount
<b>Emergency relief</b>		
NADMO own means and cash + goods donated by companies, institutions and individuals	Food and non-food relief items	USD 2.1 million (estimate based on Red Cross report following flood relief provided in North Ghana)
Ministry of Health, Ghana	Provision of needed medical care to victims	Not quantified
<b>Subtotal</b>		<b>USD 2.1 million</b>
<b>Cash payouts</b>		
Ministry of Gender & Social Protection, Ghana	LEAP intervention programme	GHC 3.9 million = USD 1.0 million
MASLOC Disaster Support programme	June 3 <sup>rd</sup> Flood Victims Loans	GHC 4.84 million = USD 1.25 million
Ghana Government	Support for burial and funeral rites	GHC 960'000 = USD 246'000
Disbursement Committee on June 3 <sup>rd</sup> , 2015, 'Twin Disaster', Ghana Government	Support to victims	GHC 1.03 million = USD 250'000 million of which USD 200'000 million by Benin Government
<b>Subtotal</b>		<b>USD 2.75 million</b>
<b>TOTAL</b>		<b>Ca. USD 5 million</b>

\*Sources: National budgets, press articles, NADMO

### 5.3.5. Simulation of major historical events using hydrodynamic model

The 3<sup>rd</sup> of June 2015 flood in Accra was one of the most devastating floods in recent history. It was extensively assessed by various institutions and remains vividly remembered by Accra's population. Consequently, this flood event proved invaluable for calibrating the flood model. Both the hydrological and hydraulic parameters of HKV's model were calibrated based on data from the June 2015 event.

For calibration, the areal average rainfall depth from the 3<sup>rd</sup> June 2015 event was estimated using a weighted distance average of daily values from GMET stations in and around the Odaw catchment (Table 9). Notably, these stations are concentrated in the southern part of the catchment, introducing significant uncertainty in rainfall estimates for the entire GAMA. The areal precipitation was calculated to be 131 millimetres. Based on anecdotal information and EUMETSAT temporal rainfall profiles, this precipitation was assumed to have fallen over a six-hour period. The return period for the average rainfall across a 6h duration was estimated at approximately 10 years, with individual monitoring stations indicating return periods ranging from about 5 to nearly 60 years<sup>51</sup> (Table 9). Overall, the areal rainfall across GAMA on this day is estimated to have a return period between 10 and 20 years. Using the estimated accumulation and duration, a six-hour rainfall hyetograph was constructed following the alternating block method (Figure 32).

Table 9: Daily rainfall values for 3<sup>rd</sup> June 2015 collected from the June 3, 2015 Assessment Summary (Min Env, 2015).

Station	Precipitation on June 3, 2015 [mm]	Return Period* [yrs]	Station location map
Osu	90.3	4.7	
Archives	169.4	23.9	
St Mary's	154.2	17.5	
Accra Academy	169.4	23.9	
Wesley Grammar	96.6	5.4	
Weija	119.4	8.6	
Maamobi	89.8	4.7	
GMET (Legon)	148.3	15.5	
Airport	212	57.4	
<b>Weighted areal average rain</b>	<b>131</b>	<b>10.9</b>	

\*Return periods were estimated using GMet'S KIAMO's intensity-duration-frequency (IDF) curves and assuming a storm duration of 6h.

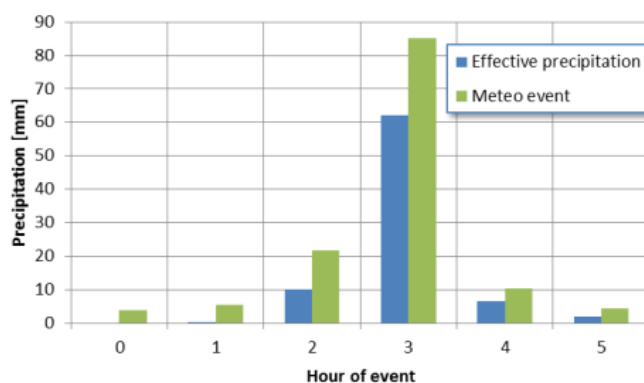


Figure 32: Constructed meteorological event for the 3<sup>rd</sup> June 2015 flood and resulting effective precipitation from the hydrological model.

<sup>51</sup> Return periods were estimated using Gmet'S KIAMO's intensity-duration-frequency (IDF) curves, which were validated by the project team

For the hydrological model parameters, boundaries were set based on a literature review. The hydrological and hydraulic models were then run jointly. Since measured discharges and water levels were not available for this or any recent flood events, calibration relied on photos, videos, field visits, and interviews from the 3<sup>rd</sup> of June 2015 floods. Model parameters were iteratively adjusted, within physical limits, to align model outcomes with available data. Given the uncertainty in areal rainfall estimates, model simulations were conducted for design storms of 10 and 25 years. The results for the 10-year design storm closely matched available observations, while the 25-year design storm produced a larger-than-observed flood extent (HKV, 2017). The results for the 10-year design storm, including simulated peak discharge at the Kwame Nkrumah Circle interchange in Accra, and flood extents and depths across the critically impacted Odaw basin (Figure 33), were considered plausible by Ghanaian flood experts.

It is worth noting that the flood extent resulting from the 2015 rainfall event was larger than it would be today. At that time, there was significant siltation and waste accumulation along the Odaw River, including at the interception weir between the river and the Korle Lagoon, and across the wider drainage system. Since then, regular dredging of the Odaw River and more frequent cleaning of waterways and drains have been conducted, leading to a tangible reduction – but not elimination – of flood hazard. HKV models allow for the simulation of different drainage conditions; this is further discussed in Section 6.

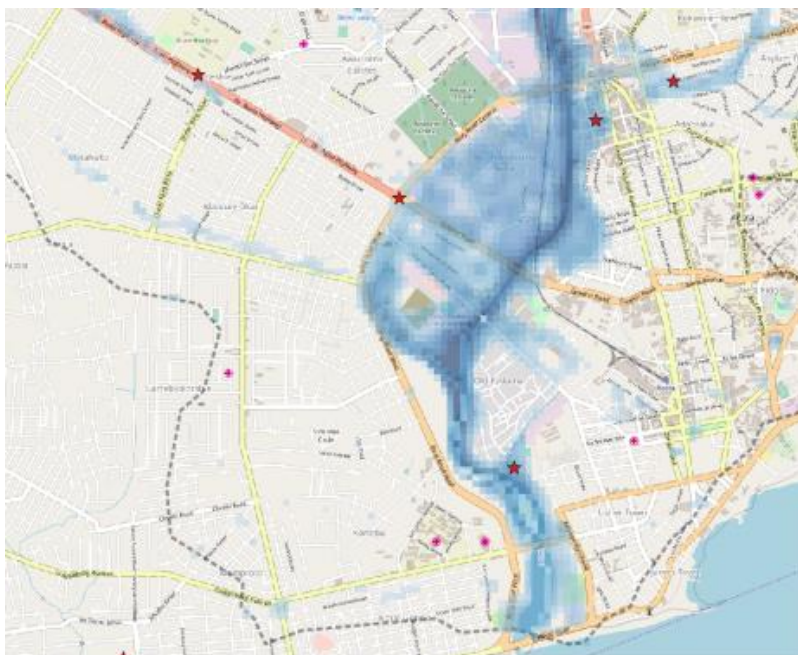


Figure 33: Simulated flood extent (blue area) for June 2015 and reported inundation locations (red stars) in the lower Odaw basin.

#### 5.4. Flood risk management in GAMA: challenges and mitigation

##### 5.4.1. Rapid urban growth and poor urban planning

GAMA has experienced drastic urbanization over the past years and is one of the fastest growing cities in Africa. GAMA's population has increased from 200'000 in 1958 (Ministry of Housing, 1958) to 4.99 million in 2021 (Ghana Statistical Services, 2021). Between 1985 and 2000, GAMA's extent

increased by 160% (ARUP, 2016), as shown in Figure 34. GAMA's fast growth underscores significant urban migration trends.

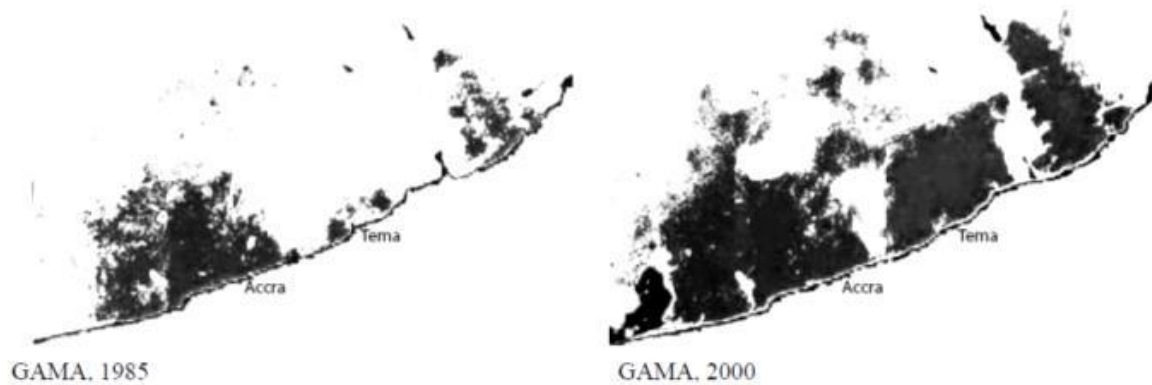


Figure 34: Urban growth in GAMA region. Source: World Bank, 2008; (HKV, 2017).

The rapid urbanization has led to a significant increase in impervious surfaces, as well as a higher concentration of people and assets susceptible to flooding. Furthermore, urban planning has struggled to keep pace with GAMA's rapid growth, resulting in:

- Poor development of drainage systems (Figure 35),
- Inadequate planning of building zones and infrastructure (HKV, 2017),
- Building in waterways and encroachment on waterbodies, increasing flood risk by obstructing water flows and expanding flood-prone residential areas, particularly informal settlements and low-income areas. Figure 36 shows a warning message by local authorities to stop construction works in a waterway. In practice, these warnings are not always enforced (HKV, 2020).



Figure 35: Examples of poorly constructed and maintained drainage systems in GAMA (Adentan). Source: (Annan, Adarkwah, Mattah, & Awuni, 2019).

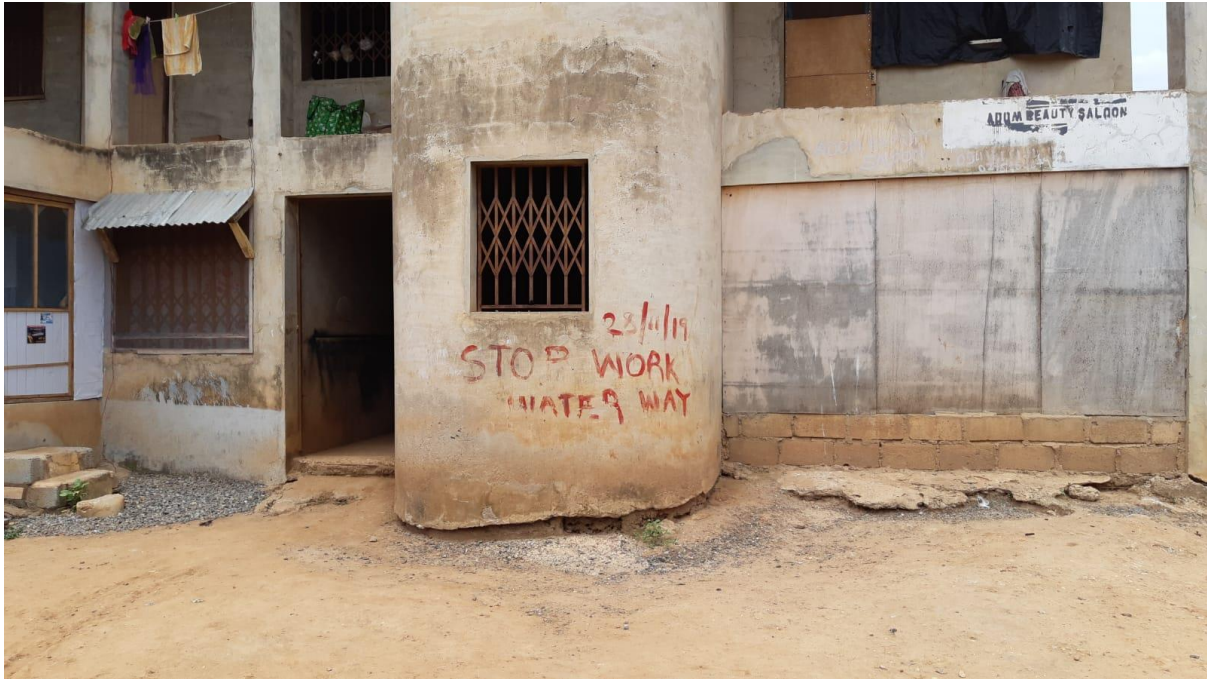


Figure 36: Example of warning message on construction in waterways. Source: (HKV, 2020).

#### 5.4.2. Poor waste management

Waste collection in GAMA is managed by the MMDA's through private companies, with coverage ranging from 35% to 91% across all districts. The inadequate coverage in some districts leads to accumulation of waste, especially in lower-income areas. Furthermore, some waste companies leave piles of waste uncollected from households or markets due to logistical constraints. Additionally, citizens who cannot afford the waste collection fees often resort to dumping solid waste into the drains. During rainfall, this waste flows into the drainage systems, where it accumulates and obstructs the flow of water (HKV, 2017). Waste accumulation as pictured in Figure 37 was, in fact, identified as a key exacerbating factor of the devastating flood in June 2015 (also see Section 5.3.5).



Figure 37: Examples of waste accumulated in drains. Source: Fotos by Dorien Lugt (HKV) (Left) and Durk Klopstra (HKV) (Right).

#### 5.4.3. Ongoing flood risk mitigation initiatives

Following the devastating floods in June 2015, the Greater Accra Resilient and Integrated Development Project (GARID) was initiated in 2017, backed by the World Bank. GARID aims to mitigate

flood risk in GAMA through a blend of structural and non-structural approaches, centred on three key areas: enhancing drainage infrastructure, improving solid waste management through better logistics and education, and implementing a flood early warning system. Furthermore, the project earmarks funds to support communities in flood-prone areas, including housing quality enhancements. To date, substantial progress has been made, and actions such as regular dredging of the Odaw River and removal of solid waste from crucial drainage points have already led to a noticeable decrease in the occurrence of severe flooding. Nonetheless, flooding remains a recurrent issue in GAMA, with the poorest households at the highest risk.

To enable the adequate design and effective operation of flood management strategies, the GARID project also incorporates significant data gathering and flood hazard quantification components. This includes generating a new high-resolution DTM, based on light detection and ranging (LiDAR) technology, and the ongoing installation of several automatic weather and flow monitoring stations across the area. Additionally, the envisioned installation of an X-band weather radar aims to further enhance rainfall monitoring and forecasting capabilities across GAMA.

## 6. Parametric Insurance Options

### 6.1. Introduction to parametric flood risk-transfer

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 GAMA

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 taken into account:

1. 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.
2. 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 teams' 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.

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. 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 8.2.1 basis risk).
- **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 (and data is usually only available for larger floods of catastrophic nature). For this solution 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 minimise basis risk further.

Table 10: 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.
		<b>Weather stations</b>	<b>Rainfall measurements on high temporal resolution at irregular points (where available).</b>	<b>Can have good historic data, but not guaranteed.</b>	<b>Low at station location, high the further away from the stations.</b>	<b>Some data free of charge, some commercially available.</b>
	River flow	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.
		<b>Remote sensing (radar)</b>	<b>Measurements of non-permanent water based on radar satellite technology. Various public and private sources, typically available globally. Results often enhanced with auxiliary data.</b>	<b>Can have good historic data, but high-resolution data is only recently available.</b>	<b>Low</b>	<b>Some data free of charge, high-resolution data is commercially available.</b>
		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 hazard 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 10, were considered. After extensive testing the project team determined that two are the most suitable for the purpose of the project (highlighted in Table 11). Despite their different characters, both trigger options were fully developed. Both also contributed to improving the general knowledge of the flood situation in GAMA, 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 either trigger option (Table 11).

Table 11: 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	2-day maximum rainfall (millimetres) for design; 24-hour rolling sum rainfall (millimetres) operationally	Maximum flood extent of equal or higher than 30 centimetres 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	Historic rainfall data (including extreme analysis) calibrated to actual loss events.	Trigger level assessment through flood hazard model, which was calibrated to historic loss events (e.g. June 2015 floods).
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 floods of flash flood nature. This means typically $\geq 12$ hours of non-permanent standing water, over affected areas of $\geq 300 \times 300$ meters and $\geq 30$ centimetres 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.

### 6.1.1. Trigger recommendation

The XSR trigger represents a simple but effective solution but is less suitable for urban areas due to elevated basis risk. Although less established, the FFP trigger utilizes the latest advancements in flood detection technology and is much more tailored to the stated project objectives of addressing an urban flood situation. The project team consequently recommends that the Government of Ghana pilots the novel and innovative FFP solution, while considering the XSR as backup in case there is no appetite to implement a more technical, novel and less tested solution.

The following sections explain basic elements of the parametric structure as well as all details of the XSR and the FFP trigger options.

## 6.2. Critical structuring items

The following section discusses some critical points that must be considered in any parametric insurance scheme, regardless of the trigger type. In this sense, the section applies to both the XSR and FFP options, elaborated below.

### 6.2.1. Basis risk

Definition of basis risk: *Insurance payout can deviate 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.

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

### 6.2.2. Parametric payout functions

In order to minimize basis risk (also see Section 6.2.1) so-called stepped parametric payout functions were applied. Stepped payout functions cover a wider range of event recurrence probabilities. They are typically attaching with first small payments for mid-size events, increasing payments up to the full limit for more impactful events of higher return periods. The number of steps and cover width should achieve two goals: (1) limit hit-or-miss situations and smooth out very sudden changes, while (2) avoiding overly complex and impractical patterns at the same time. Stepped parametric payout functions became industry practice, as they allow for seamless calibration to the insureds target risk profile at clear steps, while remaining easy to communicate and understand by all stakeholders.

During the structuring process all available rainfall data for XSR and flood hazard maps for FFP were used to determine the payout thresholds. It was decided to calibrate both the XSR and the FFP solution to clean and simple attachment conditions, to avoid overly complex payout patterns. Those predefined recurrence patterns (return period bands) reflect the Government's desired target risk profile very well.

In the following sections two payout options are presented for both the XSR and FFP solutions, referred to as BALANCED and CAT options. The BALANCED option first triggers for events with an approximate recurrence of 5 years (i.e., 5-years return period), with maximum payout reached for events of approximately 20-years return period. The CAT option has a first attachment for events at a return period of approximately 10 years, with its maximum payout reached for events of approximately 25-years return period. As illustrated in Table 12 and Figure 38, the BALANCED option

would trigger more frequently, whereas the CAT option, as the name suggests, would only trigger payouts under less frequent, more catastrophic events.

The attachment and full limit payout probabilities, also often referred to as the insured '*layer*', have a direct impact on the price. A BALANCED pattern, paying more frequently, will naturally be more expensive. The higher the *layer* sits, the more remote the probability of a full limit payment will be.

As with all other insurance solutions 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.

Table 12: Stepped payout functions for CAT and BALANCED options, showing event return period ranges<sup>52</sup> and corresponding payouts as a percentage of the maximum insured limit.

Return period range [years]	BALANCED option Payout relative to insured limit	CAT option Payout relative to insured limit
[5-10)	10%	0%
[10-15)	25%	10%
[15-20)	50%	25%
[20-25)	100%	50%
>= 25	100%	100%

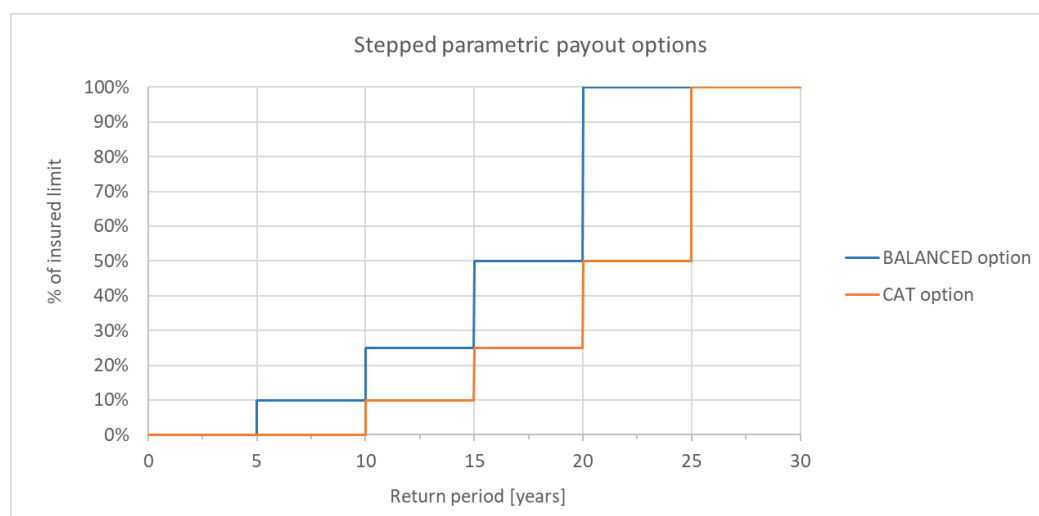


Figure 38: Graphical representation of stepped payout functions of the BALANCED and the CAT options from Table 12.

### 6.2.3. Determining payout limits

Below we provide some general reasons for determining the potential aggregate coverage limits that may make the most sense for the government. However, the final decision on the insurance limits must in any case be made by the Ghanaian government.

<sup>52</sup> For both XSR and FFP products, event return periods were estimated based on rainfall return periods derived from intensity-duration-frequency curves fitted to historical GMet records at KIAMO and Tema stations in GAMA.

## Historic losses

Section 5.3.3 provides an overview of past events and their estimated impact. In the last 25 years the 2015 disaster resulted in the largest single flood loss event of USD 55 to 115 million (USD 70 to 150 million at 2023 adjusted values). The average annual flood-related loss in the last 25 years amounted to around USD 5 million (USD 6.5 million at 2023 adjusted values).

## Government spending for emergency relief

Based on NADMO's annual reports, spending on '*Relief Items*' was approximately GHc 10 million to GHc 30 million per year (USD 3-6 million per year) in the years 2015, 2018, 2019 and 2021. This represents roughly 20% of NADMO's overall spending. No specific data was available for 2016, 2017 and 2020. Furthermore, we noted that the overall funding of NADMO by the Government has fluctuated noticeably in the last decade.

Only for the June 2015 disaster we could estimate the costs of the Government's response in direct relation to an individual flood event. In Section 5.3.4 we estimate this to amount to approximately USD 5 million (USD 6.5 million at 2023 adjusted values).

## Insurance premium support

ISF has indicated that the insurance solution proposed in this project would be in scope of the ISF's insurance premium support ('Pillar IV'). The two key terms and conditions of Pillar IV are:

- Total support of maximum EUR 2 million over 3 years;
- Relative premium support can be variable, but on average a maximum 75% of total premium volume over 3 years;

Given a hypothetical annual insurance premium rate of 14%, the exemplary insurance limit would then be EUR 9.5 million (approximately USD 10 million), based on the above considerations: ISF pays EUR 660'000, while the government would have to contribute approximately EUR 660'000, per year.

## Insurance limit recommendation

For an insurance scheme to be economically viable and to cover costs for every stakeholder involved, the project team roughly estimates that the total insured limit should be at least around USD 5 million. Smaller amounts are generally not economical due to the high costs of development, administration and placement. However, significantly larger sums over approximately USD 50 million could also pose a problem in the sense that the government cannot put the money to good use immediately after payment. These sums would also be far more than is necessary given the previous disaster aid. Furthermore, it may be difficult to find sufficient risk transfer capacity for such volume.

Based on historic losses, Government/NADMO budget spending and premium support considerations as presented above, the project team proposes to set the insurance limit for this parametric scheme to USD 10 million per year. This would entail the event limit, and the overall limit over a one-year term, the annual aggregate limit (AAL). While it certainly wouldn't cover all the economic losses following a major event like 2015, it would more than double the emergency funds the government had provided in the past through NADMO. The proposed limit has been briefly discussed with local stakeholders, including NADMO, NIC, GIA, and MoF, and has been initially deemed acceptable. The overall limit can also be adjusted to higher amounts in subsequent years based on the findings from

the program. For illustrative purposes we assume an insured occurrence (per event) and annual limit of USD 10 million in this report.

#### 6.2.4. Regulatory considerations

Ghana's Insurance Act, 2021 (Act 1061) recognizes an 'Index insurance contract' under section 210, pages 146 and 147 (NIC, 2021). Nevertheless, the project team proactively engaged with NIC during various meetings to present and consult regarding the proposed insurance solutions. [No-objection / endorsement by the NIC is yet to be received, pending feedback from the Ghana Insurers Association] for the products to be presented to the Ministry of Finance for a decision to implement.

### 6.3. Excess rainfall (XSR) parametric product

#### 6.3.1. Introduction and product overview

As indicated earlier, the excess rainfall (XSR) product falls under the 'indirect' or 'flood proxy' category (see Table 10). This approach is simple and well-established but entails higher basis risk compared to the flood footprint option, as the adopted data and index not only entail estimation uncertainty, but are, by definition, flood proxies, rather than direct observations of flooding on the ground.

After assessing multiple candidate flood hazard data sources and indices, including evaluating their flood predictability skill against the flooding timeline introduced in Section 5.3.1, a decision was made to use daily GMet station records from three stations across GAMA, two of them covering Central Accra, and another one in Tema, for parametric product design. Using this dataset and a 2-day (2D) index applied separately to Central Accra and Tema, and considering client needs and risk profiles, two product structure options were developed: a balanced option (BALANCED) and a catastrophe (CAT) option. Expected trigger frequencies and technical product rates for the two options were calculated based on historical rainfall data from 2000 to 2022. Considerations for operational index monitoring were also addressed, including the joint development with GMet of near real-time data access and processing protocols for data from automatic weather stations. It is worth noting that, while a 2D index was deemed more appropriate for design due to its ability to capture critical accumulations even when split across reporting calendar days, a 24-hour rolling sum index is recommended operationally to better reflect actual short-duration extreme events and for ease of communication.

The following subsections provide an overview of the main steps for product design: review of available flood hazard data sources, data source selection for product design and operation, index definition, product structuring and technical pricing, and considerations for operational deployment. Insights into product commercial rates, accounting for additional loadings, are provided in Section 7.

Copies of the historical rainfall and flooding time series used for XSR product design, along with final index time series, can be found in Appendix 2. A draft wording for the XSR product under the CAT option can be found in Appendix 4.

#### 6.3.2. Flood hazard data sources: overview and assessment

An overview of available flood hazard data sources considered for the design and/or operation of the 'flood-proxy' parametric insurance is provided in Table 13. This includes key product features, remarks about their potential application in the project, and potential shortcomings.

In general, the availability of non-rainfall datasets were limited. Except for the flooding timeline, which was instrumental for dataset evaluation, non-rainfall datasets were deemed insufficient or unsuitable for use in product design and operation. While modelled flows and flood extent have the potential to be used for parametric product development, this approach has been adopted as a fallback option under the flood footprint product.

Given these considerations and to maintain simplicity in the proxy product, the focus was shifted to rainfall datasets.

Table 13: Available flood hazard datasets. Note: main candidate datasets are highlighted in green.

Variable Observed or Simulated	Product Type	Product Name	Supplier	Space Res [deg]	Space Res [~km]	Temp Res	Temporal Coverage	Latency	Project Application	Additional Information & Comments
Rainfall	Satellite QPEs	CHIRPS	CHG UCSB	0.05	5.5	1 day	1981/01-Now	≥ 1 month	Dev	CHIRPS final similar to CHIRPS-p. Can be used jointly for design and operation. Widely used for parametric insurance worldwide. Quality drops after 1997 -> RG decrease
		CHIRPS-Prelim	CHG UCSB	0.05	5.5	1 day	2015/01-Now	3-5 days	Op	
		IMERG Early Run	NASA (GPM)	0.1	11	30 min	2000/06-Now	5-7 h	Dev&Op	-
		IMERG Late Run	NASA (GPM)	0.1	11	30 min	2000/06-Now	13 h	Dev&Op	Latency acceptable for operation. Reportedly superior ability as that of other sat products to capture high intensities (Mekonnen et al, 2023)
		IMERG Final Run	NASA (GPM)	0.1	11	30 min	2000/06-Now	3 months	Dev	Too long latency renders it unsuitable for operation
		CMORPH	NOAA	0.073	8	30 min	2002/12-Now	18 h	Dev&Op	IMERG's accuracy reportedly better.
		METEOSAT2 (MSG)	EUMETSAT	-	3	10 min	2002-Now	45 minutes	Dev&Op	IMERG's accuracy reportedly better.
		ARC2	EUMETSAT	0.1	11	1 day	1983/01	2 days	Dev&Op	IMERG's accuracy reportedly better.
	Climate re-analysis	ERA5-Land	ECMWF	0.1	11	1 h	1950/01-Now	5 days prelim	Dev&Op	Widely used for parametric insurance worldwide. May circumvent monitoring and estimation shortcomings of sat prod
	Ground stations	GMet main manual stations (3)	GMet	3 stations across GAMA		1 day	1960/01-Now	1 day	Dev	Good quality records at KIAMO and Tema. Patchy records @ Accra Academy
		GMet AWS at main stations (3)	GMet	3 stations across GAMA		1 min	Last year of records	Near RT	Op	Access subject to GMet arrangements. Under-recording tendency being investigated by GMet. More automatic stations will be installed in GARID project
		GMet additional manual stations (7)	GMet	7 stations across GAMA		1 day	2011/01-Now	1 day	Dev	Very patchy records, but useful to understand spatial variability and aid storm event reconstruction.

Variable Observed or Simulated	Product Type	Product Name	Supplier	Space Res [deg]	Space Res [~km]	Temp Res	Temporal Coverage	Latency	Project Application	Additional Information & Comments
		TAHMO AWS (15)	TAHMO	15 stations within and around GAMA		5 min	2016-Now	Near real-time	Dev&Op	Promising, yet high proportion of missing records and under estimation tendency
	Weather Radar	C-band radar	GMet	Presumed 1km		Presumed 5 min	UNK	Near real-time	Op	Reportedly not operational
Flows & Flood Hazard	River gauges	None currently operational	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Several flow gauges to be installed as part of GARID project
	Flood hazard maps	GloFAS flood depth maps for return periods 10-500yrs	JRC & ECMWF	30 arcs	1	n/a	n/a	n/a	Dev	Only covers major rivers and does not show any flood hazard across GAMA
	River discharge estimates	GloFAS daily flow estimates	JRC & ECMWF	0.05	5.5	1 day	1980/01-Now	3 days / 3 months	Dev&Op	Discarded due to GloFAS hazard maps not representing rivers across GAMA. Rejection further confirmed by poor extreme performance of ERA5, which is used as input for GloFAS generation
	Flood model	HKV - Odaw basin	GHA	-	12 m	-	n/a	n/a	Dev&Op	Discarded for use in proxy product. Instead used for FFP product development and fallback option
	Flood model	HKV - other GAMA basins	GHA	-	Based on spot heights	-	n/a	n/a	Dev&Op	
	Flood model	Ars Progetti - Odaw basin	ARS Progetti	-	Presumed 0.5 m	-	n/a	n/a	Dev&Op	Reportedly based on LiDAR DTM. Not available for project.
	Flood model	FiWA Aachen	FiWA Aachen	-	Presumed 12 m	-	n/a	n/a	Dev&Op	Reportedly based on world DEM and river cross sections. Not available for project

## Rainfall datasets - overview

Three main types of rainfall datasets are currently available across GAMA: ground station (rain gauge) records, quantitative precipitation estimates from satellites, and re-analysis datasets. Figure 39 illustrates the spatial distribution and coverage of some of the main available datasets.

It is worth noting that Accra has a C-band radar, but it is reportedly not functioning well, and data from it was unavailable for this project. The installation of an X-band radar is also planned as part of the ongoing GARID project. These radars could significantly improve rainfall monitoring and forecasting across GAMA, offering high spatial-temporal resolution, better coverage than current rain gauge networks, and improved accuracy over satellite products, particularly for short-duration convective events. Interested parties should keep track of data from these radars as they become available to take advantage of their potential benefits.

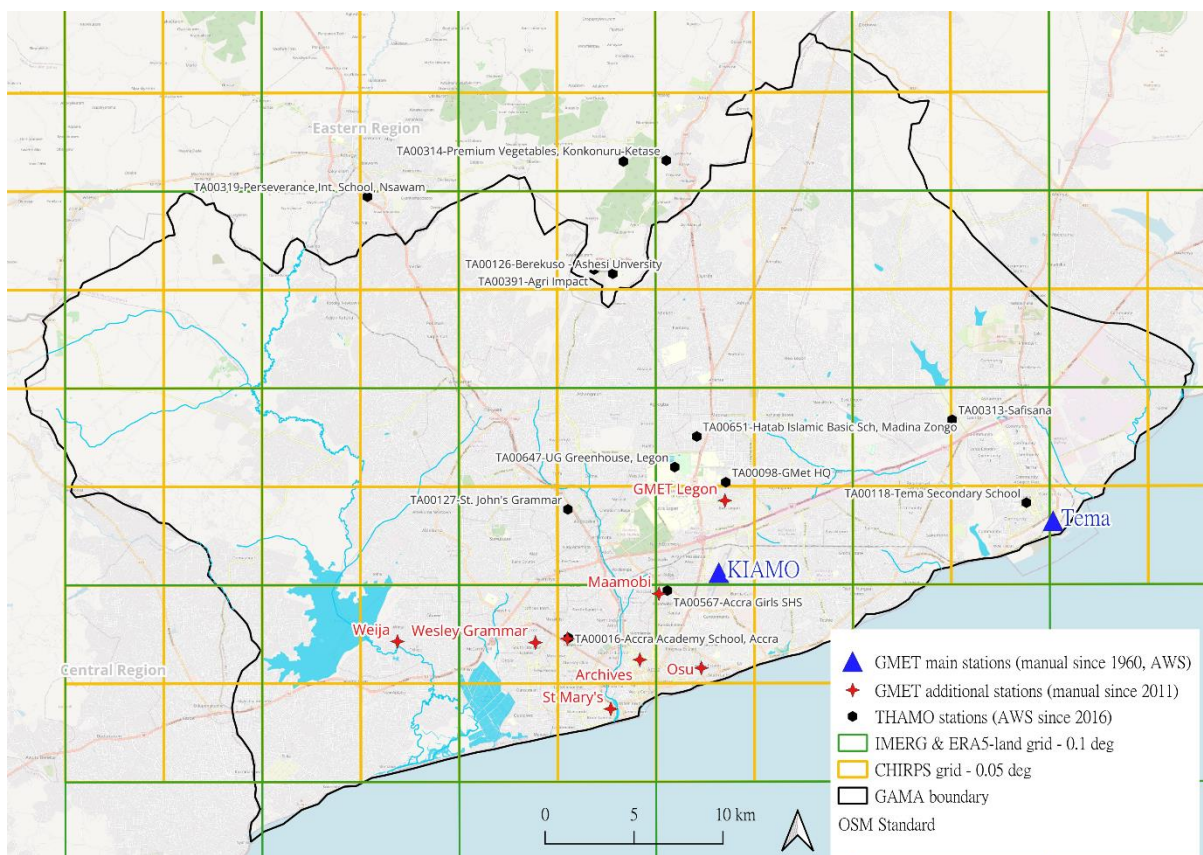


Figure 39: Spatial distribution and coverage of main rainfall data sources across GAMA.

## Ground rain gauges

There are two primary rain gauge networks in GAMA, respectively operated by the Ghana Meteorological Agency (GMet) and the Trans-African Hydro-Meteorological Observatory (TAHMO)<sup>53</sup>. Additionally, the GARID project is deploying a new set of automatic weather stations (AWS) to enhance GMet's existing network.

<sup>53</sup> <https://tahmo.org/>

GMet's network comprises

- **Two main stations, respectively located at Accra's Kotoka International Airport (KIAMO) and Tema (east of GAMA). Each station includes (1) a manual rain gauge with daily records dating back to 1960, and (2) an automatic weather station (AWS), installed around 2018, providing records at 1-minute resolution.** The specifications of the GMet gauges could not be confirmed, but they are assumed to be standard gauges with an 8-inch (203.2 millimetres) diameter (i.e. catch area of approximately 323 cm<sup>2</sup>).

Historical daily records from the two manual stations were purchased from GMet for the project and were found to be of reasonable quality, with limited gaps<sup>54</sup> and sensible estimates (Figure 40). Records from the KIAMO station, located centrally in Accra near high flood risk areas in the Odaw basin, were found to display high predictability skill for severity 3 flood events (see flooding timeline and initial rainfall predictability exploration in Section 5.3.2). While spatially correlated, rainfall patterns at Tema show marked differences compared to those at KIAMO (see Section 3.4) and their joint analysis also reveals high spatial variability in rainfall at the storm event level across GAMA. Due to its location in a lower flood risk area, Tema's records correlate less well with severity 3 flooding occurrences across GAMA. However, extreme rainfall at Tema could be linked to localized flooding in that part of GAMA. Overall, historical daily records from these two manual stations were deemed suitable as reference for evaluating other rainfall products and for designing the XSR product.

Continuous records from the co-located AWS at these two monitoring stations are not consistently available; instead, data is typically only retained for the most recent year, with older records being overwritten as new data is collected. Sample records from KIAMO's automatic gauge for one year were supplied by GMet to enable quality assessment through comparison against records from the manual gauge, considering that their near-real time availability may render them suitable for operational applications, including parametric insurance triggers. This evaluation revealed high temporal correlation between records from the co-located manual and automatic gauges, but records from the automatic gauge are systematically lower (on average 22 % lower) than records from the manual gauge. GMet is currently investigating this and aiming better align records from the two types of gauges, to enable their use for operational XSR product monitoring and triggering.

- **A third station at Accra Academy (in the Accra district, 9 kilometres west of KIAMO) was intermittently operated between 1963 and 2017, after which a TAHMO AWS was placed at the site.** The currently operational TAHMO AWS is currently referenced by GMet. Furthermore, the installation of a new manual gauge at this site is envisaged as part of the GARID project. Given its proximity to KIAMO and to high flood risk areas, where available, records from this third station proved useful to validate KIAMO records, to infill minor data gaps, and to improve our understanding of extreme rainfall and associated impacts across the critical Odaw basin.
- **Additionally, patchy daily records for seven more GMet manual gauges are available since 2011 until now.** These have helped reconstruct historical flood events such as the June 2015 (see Section 5.3.5) and provided insights into rainfall spatial variability across Accra -which can be particularly large during convective events- and into similarities and differences in the

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<sup>54</sup> The average proportion of missing records between 1960-2022 was 0.57 % for KIAMO and 1.57 % for Tema.

climatology at different monitoring locations, thus informing the selection of rain gauges for parametric product operation.

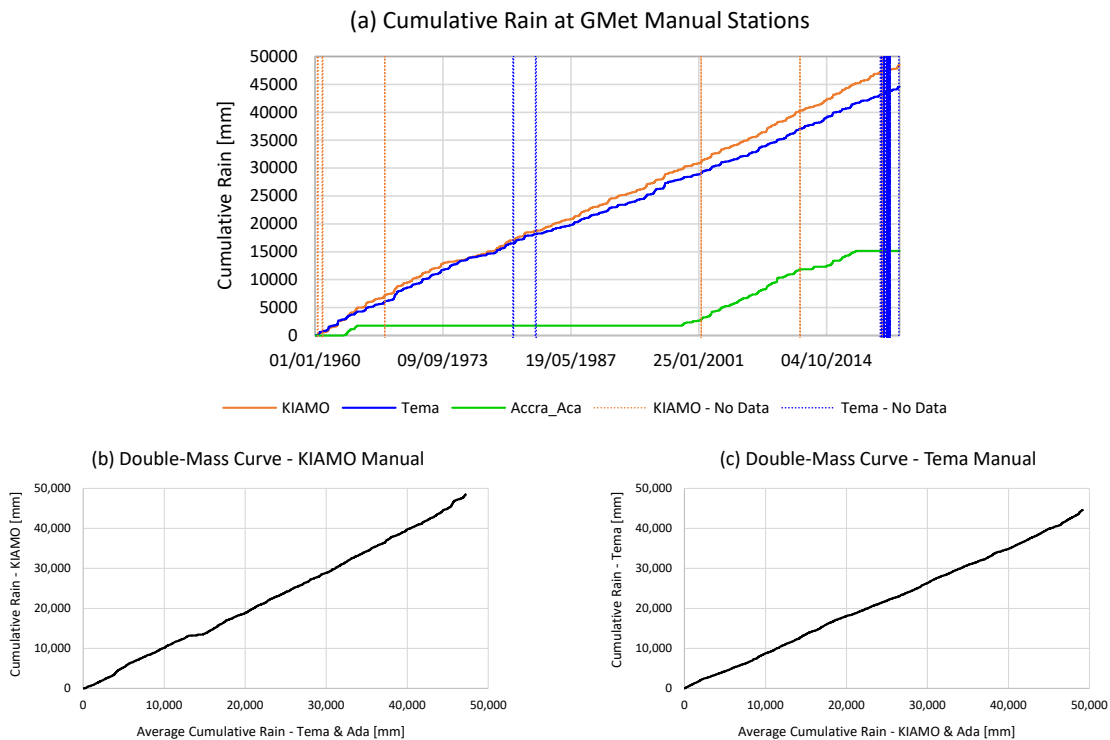


Figure 40: Quality assurance of records from GMet's main manual rain gauges. (a) Cumulative rainfall with vertical lines indicating missing data; (b) Double-mass curve for KIAMO gauge, using average measurements from Tema and Ada\* stations as reference; (c) Double-mass curve for Tema gauge, using average measurements from KIAMO and Ada\* stations as reference. Deviations from linearity in double-mass curves may indicate data quality issues.

The TAHMO network consists of 15 AWSs spread across and around GAMA, with additional stations beyond. This network has been operational since 2016, although installation dates vary per station. All monitoring sites use ATMOS41 all-in-one weather stations<sup>55</sup>. These are compact stations which measure several other weather parameters beyond rainfall. The ATMOS41 rain gauge has an unusually small catch area of 78 cm<sup>2</sup> (diameter of 10 centimetres) and measures rainfall by discretising the collected water into drop of a standard size, which are then counted. Data from TAHMO gauges are available via a dedicated web portal with API access also in place. TAHMO operates a subscription model, charging USD 10 per weather station per month (as of June 2023). A high-level analysis of TAHMO rainfall records revealed inconsistent data availability across stations, with significant gaps at many of them (Figure 41). Discussions with TAHMO officers suggest that a leading cause of this issue may be related to data logger battery life. A comparison of TAHMO rainfall records against co-located GMet manual stations indicated generally reasonable accuracy during periods of data availability, although TAHMO gauges tended to record slightly lower values than GMet ones (Figure 42). Overall, while TAHMO records are promising and can supplement hydrological analyses across GAMA, they were deemed unsuitable for product design due to their short and patchy length of records.

<sup>55</sup> <https://www.metergroup.com/en/meter-environment/products/atmos-41-weather-station>

\* The Ada station, located further east but within the region, aids in spatial consistency checks.

Additionally, they were deemed unsuitable for XSR trigger monitoring due to inconsistent reliability and the tendency to under-record.

	TA00016- Accra Academy	TA00042- CRIG, Tafo	TA00098- GMet HQ	TA00118- Tema Secondary School	TA00126- Berekuso - Ashesi University	TA00127-St. John's Grammar	TA00302- Ghana SHS	TA00313- Safisana	TA00314- Premium Vegetables	TA00319- Perseveranc e Int. School	TA00391- Agri Impact	TA00567- Accra Girls SHS	TA00647-UG Greenhouse (Legon)	TA00651- Hatab Islamic Basic Sch (Madina)	TA00691- Urban Jungle
2016	0%	100%	100%	100%	98%	98%	100%	100%	100%	100%	100%	100%	100%	100%	100%
2017	0%	0%	100%	32%	36%	45%	88%	91%	96%	95%	100%	100%	100%	100%	100%
2018	0%	0%	97%	0%	17%	0%	45%	0%	14%	0%	15%	79%	100%	100%	100%
2019	0%	75%	0%	0%	100%	0%	66%	33%	70%	92%	0%	1%	63%	67%	100%
2020	0%	64%	6%	0%	100%	17%	49%	0%	58%	0%	0%	0%	13%	0%	8%
2021	4%	1%	0%	1%	0%	0%	6%	1%	20%	1%	9%	0%	0%	0%	0%
2022	0%	1%	9%	2%	26%	8%	15%	4%	50%	2%	1%	10%	19%	2%	45%
2023	1%	0%	0%	3%	15%	8%	4%	1%	100%	6%	0%	3%	84%	1%	100%
all	1%	33%	43%	19%	53%	24%	51%	32%	60%	40%	31%	40%	57%	51%	66%

Figure 41: Proportion of missing records across TAHMO's GAMA stations.

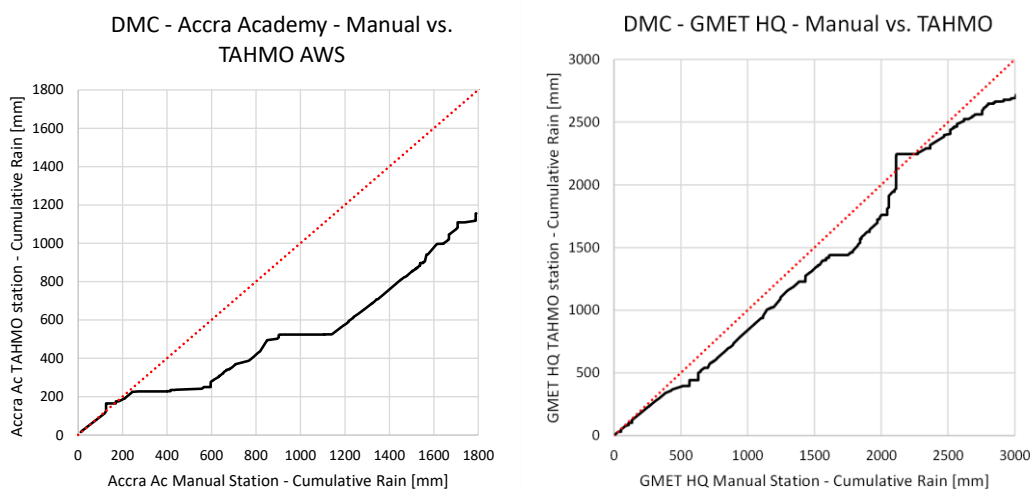


Figure 42: Comparison of cumulative rainfall records at test TAHMO stations against co-located GMet manual gauges. A 45-degree alignment indicates a perfect match, while slopes below 45 degrees suggest TAHMO gauges generally record less than GMet ones. Flat segments indicate missing data at TAHMO stations, and near-vertical segments may indicate either spurious data at TAHMO stations or missing records at GMet stations.

### Satellite and re-analysis precipitation estimates

Based on a literature review and project team experience, main candidate satellite and re-analysis rainfall products were shortlisted for analysis (see remarks on different products in Table 13). These included CHIRPS, IMERG, and ERA5. While there was interest in testing the EUMETSAT rainfall product due to its high temporal resolution, data access proved difficult, and long-term records could not be sourced for use in the project.

A high-level assessment of the shortlisted satellite and re-analysis precipitation estimates against GMet station data and historical flooding records revealed poor skill in capturing the short-duration extreme rainfall that typically drives flooding in GAMA. The candidate satellite and re-analysis products significantly underestimate absolute high rainfall accumulations compared to rain gauge measurements (Figure 43 (a)). What is more, when rain gauges record extreme rainfall events relative to their historical records, the satellite and re-analysis datasets tend to reflect lower extremes relative to their own historical records (Figure 43 (b-d)). Notably, the rainfall associated with the infamous June 2015 event does not register as a significant extreme in the candidate datasets. In contrast, point

rain gauge records at KIAMO and Tema GMet stations identified return periods of approximately 30 and 20 years, respectively, for this event (Figure 43 (c and d)).

The identified shortcoming of candidate products in the estimation of short duration extremes can partly be attributed to the revisit frequency of the candidate satellite products, which is coarser than the typical duration of the intense convective storms driving flooding in Accra, and to the difficulties inherently associated with convection modelling (in the case of re-analysis products). Our findings align with the literature: a recent study by Mekonnen et al (2023), which tested 8 satellite and re-analysis products across Africa, including our candidate products, concluded that, on average, most rainfall products showed poor results at the daily timescale and that their overall accuracy is poor in detecting heavy, high-intensity rains. Of the tested products, they identified IMERG as having superior, yet still not great, performance for estimation of high-intensity rainfall.

The higher temporal resolution of EUMETSAT has the potential to improve on the identified shortcoming and initial evaluations with available EUMETSAT records reveal promising temporal rainfall profiles albeit with non-negligible biases. Future stakeholders could consider using EUMETSAT data, potentially alongside ground rain gauge records, to correct biases in satellite estimates while preserving the spatial-temporal patterns.

### 6.3.3. Data selection for product development

Based on the findings above, a decision was made to use ground station data from GMet's main monitoring stations at KIAMO and Tema, along with the complementary station at Accra Academy, for product development. Long-term daily records from the manual gauges, available from 1960 to the present, will be used for product design, while data from the co-located AWSs at these three locations will be used for trigger monitoring.

The limitations of using geographically sparse rain gauge records are acknowledged and will impact basis risk. However, despite their sparsity, records from the GMet stations, particularly those at KIAMO and Accra Academy, show high correlation with severe flooding occurrence. This strong predictability skill is reassuring and largely derives from the location of these gauges close to high-risk areas (where both flood hazard and vulnerability are high) in the Odaw basin.

Going forward, interested parties should monitor data from the new sensors being installed as part of the GARID project. These sensors have the potential to significantly enhance rainfall and flood hazard monitoring across GAMA, enabling better characterization of spatial-temporal patterns. The new installations include an X-band radar, 18 AWSs, and numerous river level and flow gauges. Data from these sensors can not only improve the design of a 'flood proxy' product but also enhance the calibration and forcing of flood models currently used for the design and fallback of the FFP solution.

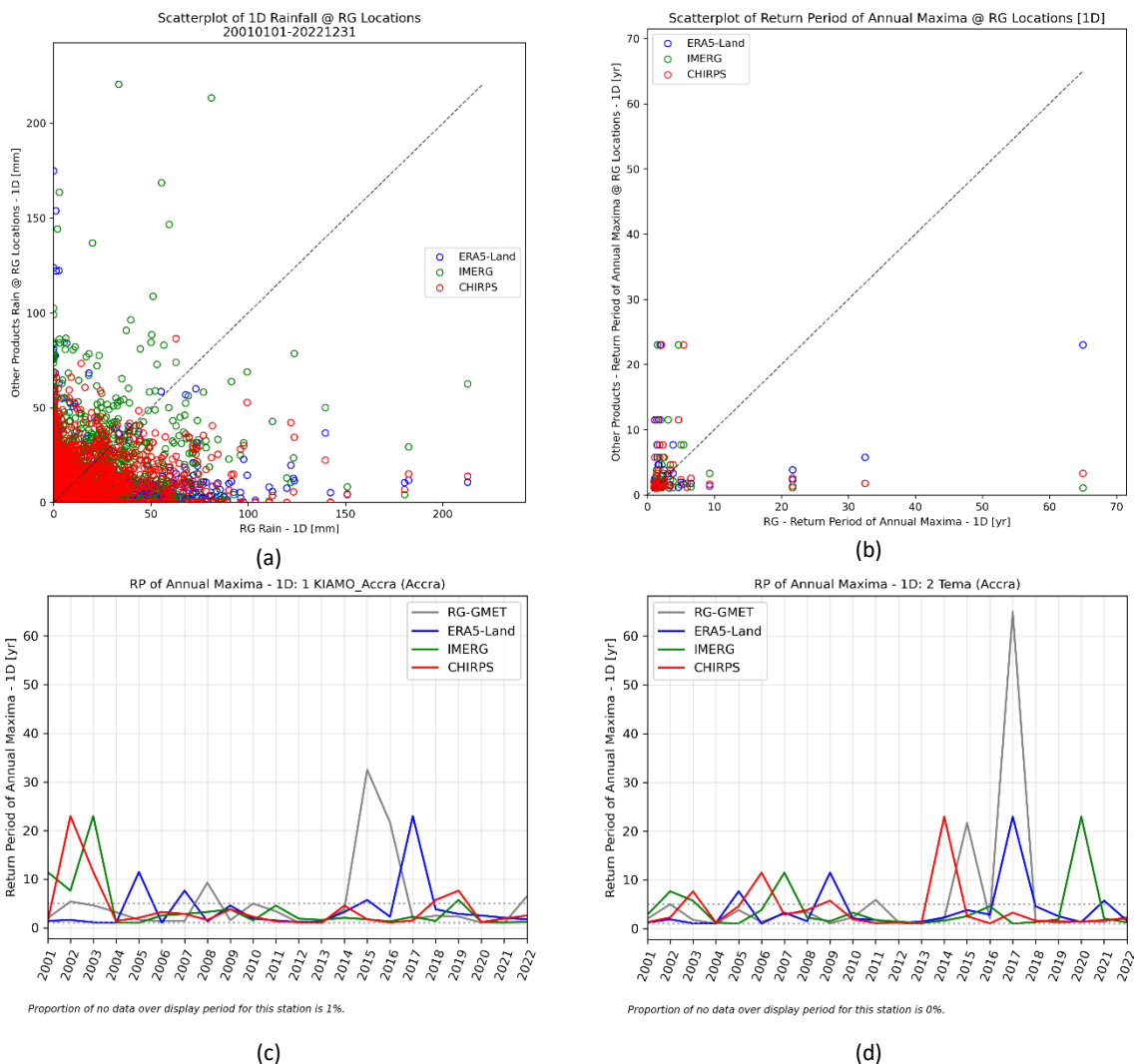


Figure 43: Evaluation of candidate satellite and re-analysis rainfall products against GMet rain gauge records. (a) Scatterplot comparing daily rainfall at GMet stations KIAMO and Tema with co-located daily estimates from candidate products. (b) Scatterplot comparing annual maxima at GMet stations with corresponding annual maxima from co-located candidate products. (c) Time series of annual maxima return periods at KIAMO station for rain gauge records and candidate products. Note: Return periods are computed relative to each dataset.

### 6.3.4. Index definition across coverage locations

Index definition involves creating a metric, based on the product design dataset(s), that best correlates with the flood events of interest. This process typically entails testing candidate metrics against historical flooding records to identify the most suitable one.

#### Candidate indices

Considering known flooding mechanisms and typically short catchment response times (see Section 5.1), as well as feedback from local stakeholders, some of whom perceived prolonged rainfall across multiple days as a potentially significant flood driver, the following candidate indices were defined based on the selected design dataset (i.e., GMet daily rainfall records from KIAMO and Tema stations, supplemented by records from Accra Academy):

- Rainfall accumulation across different durations (1D, 2D, 6D, 10D) at KIAMO.
- Maximum rainfall accumulation across different durations (1D, 2D, 6D, 10D) across central Accra stations (KIAMO and Accra Academy).
- Rainfall accumulation across different durations (1D, 2D, 6D, 10D) at Tema.
- Linear combination of 1D rain and 5D-10D antecedent rainfall at both central Accra stations and Tema.
- Return period-based indices simultaneously accounting for multiple rainfall durations (from 1D to 10D), both at central Accra and Tema stations.

It is worth noting that extreme rainfall accumulations were often found to be split across reported calendar days, even though they fell within a few continuous hours. This was confirmed through news reports, e.g., for the severity 3 events on 24-25/10/2011 and 05-06/06/2014. Additionally, as shown in Table 3, news reports indicate that flooding in GAMA is typically driven by short duration (sub-daily) intense rainfall. When evidence indicated that core rainfall accumulations were split across calendar days<sup>56</sup>, manual corrections were applied to 1D records to better reflect 24-hour accumulations by adopting the 2D accumulations for the identified dates. Tests were conducted on the original 1D records, the manually corrected 1D records (1Dc), and the other durations mentioned above.

**Spatial considerations:** Based on a separate investigation on the joint probability of extreme exceedance at central Accra (as captured by the KIAMO and Accra Academy stations) and Tema (on GAMA's eastern boundary), a decision was made to use separate indices for these locations, rather than adopting GAMA-wide areal averages, maxima values or multi-location conditional indices. While some larger scale rainfall systems resulted in significant rainfall at both locations, often each location was impacted separately by intense localized rainfall causing flooding in the surroundings. Additionally, differences in flood risk around each location meant that extreme rainfall in central Accra generally resulted in more severe flooding than at Tema. Consequently, separate indices and trigger levels will be set for each location.

### Index evaluation and selection

The candidate indices were evaluated using rainfall and flooding time series from 2000 to 2022. Only data from 2000 onwards was utilized to reflect recent rainfall patterns and drainage conditions, especially considering the rapid urbanization in GAMA.

Rainfall records were used to compute the candidate indices across the test period. The ability of these indices, with test trigger levels, to detect severity 3 flooding events was then assessed against the flooding timeline described in Section 5.3.1. The focus on severity 3 floods was a decision made in collaboration with local stakeholders, as these events are perceived to be the type where insurance payouts might be necessary, acknowledging that there are variations in severity within severity 3 events.

**Central Accra:** Figure 44 shows performance metrics, including hits, misses, and false alarms<sup>57</sup>, for candidate indices in central Accra based on the maximum rainfall accumulations of selected durations across the KIAMO and Accra Academy stations. Better overall predictability was achieved by taking the maximum accumulation across these two stations in central Accra rather than using KIAMO

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<sup>56</sup> Accounting for the fact that GMet daily records cover the period from 9 a.m. to 9 a.m.

<sup>57</sup> In the context of parametric insurance design, "hits" refer to instances where the index alongside a set threshold correctly predicts a flood event, "misses" are instances where the index fails to predict an actual flood event, and "false alarms" are instances where the index predicts a flood event that does not occur.

alone<sup>58</sup>. Results are shown for the best performing minimum threshold per index; that is, the minimum threshold that maximizes hits and minimizes false alarms. For some indices, results are shown for two thresholds, to illustrate threshold impact on event detection and false alarms.

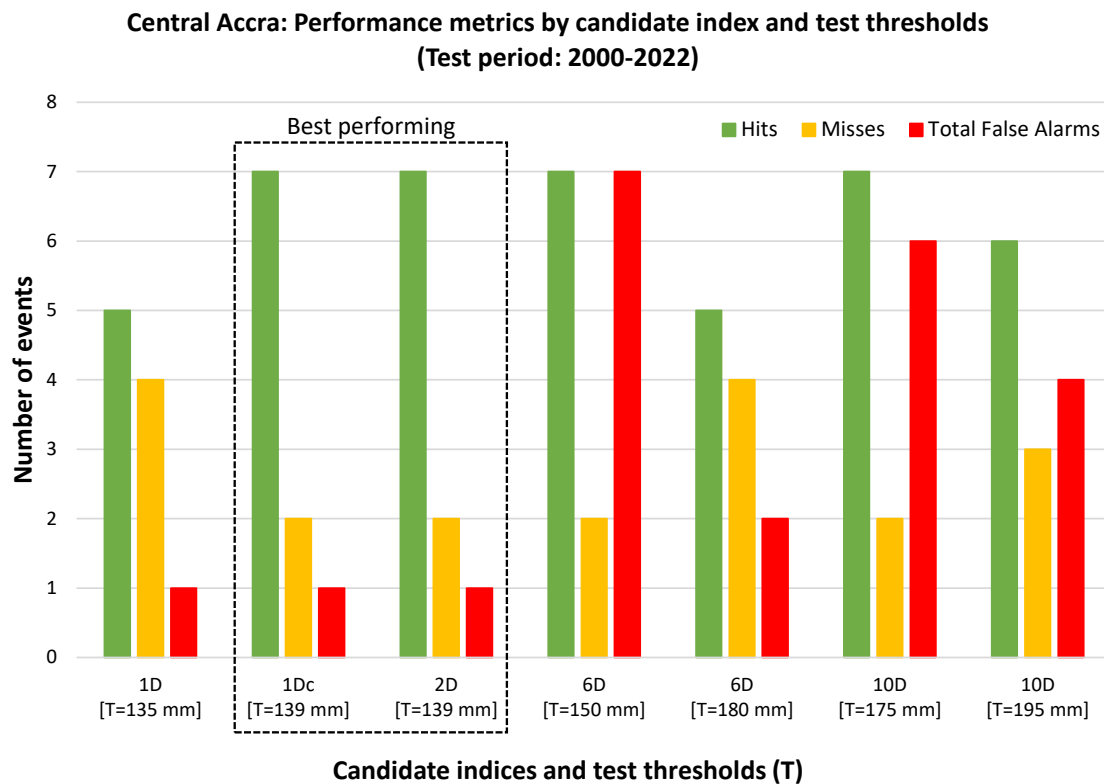


Figure 44: Performance evaluation of candidate indices and test thresholds (in millimetres) across central Accra. Candidate indices are based on maximum values across the KIAMO and Accra Academy stations.

As can be seen, the 1Dc (1D with calendar day correction) and 2D indices result in the greatest number of hits and the lowest number of false alarms, with the so-called false alarms at least corresponding to a severity 2 event. The 1D index (without calendar day correction) results in two fewer hits and consequently two more misses than the 1Dc and 2D indices, highlighting the impact of critical rainfall amounts being split across reporting calendar days. While the 10D index with T = 175 millimetres and the 6D index with T = 150 millimetres achieve the same number of hits as the 1Dc and 2D indices, they produce significantly more false alarms. Increasing the thresholds for the 10D and 6D indices reduces false alarms but also decreases the number of hits.

The linear combination of 1D rainfall and antecedent rainfall over the preceding 5 days (results not shown here) did not clearly and consistently improve performance compared to the 1Dc or 2D indices. The assignment of similar weights to antecedent conditions and 1D maxima allowed better differentiation of some severity 3 events (including the June 2015 event), meaning the index values for these events were significantly higher compared to other, less severe events. However, it also resulted in less clear differentiation for other severity 3 events, and hence more misses and false alarms. Assigning significantly larger weight to the 1D maxima and a lower weight to antecedent conditions (weights of 1.2 and 0.2, respectively) resulted in the best performance metrics, equal to

<sup>58</sup> The better performance of maximum values across the two stations, rather than relying solely on records from the main station (KIAMO), can be explained by two factors. First, the localized nature of storms often results in one gauge better capturing peak rainfall accumulations that correlate with severe flooding. Second, during severe rainfall events, one station may fail while the other records significant rainfall that matches flood reports.

those achieved with the 1Dc and 2D indices, while allowing a slightly better differentiation of some severity 3 events. However, in the interest of simplicity and considering only a very marginal improvement, a simpler index such is preferred.

Between the 1Dc and 2D indices, the 2D index is recommended for product design due to its greater simplicity and transparency. However, as previously mentioned, recorded 2-calendar day accumulations often occur within a few hours. Therefore, while using the 2D index for design purposes, an operational index based on a 24-hour rolling sum may be more appropriate for real-time monitoring and triggering, providing a balance between simplicity, accuracy, and ease of communication and understanding for all stakeholders.

The strong flooding predictability of the recommended 2D index is further validated by visual inspection of flooding time series versus maximum 2D rainfall accumulations across central Accra stations (Figure 45). Hits, misses, and false alarms, with a focus on severity 3 flood events, for a minimum 2D rainfall threshold of 139 millimetres are highlighted. This threshold maximizes hits and minimizes false alarms, triggering 8 times over the 2000-2022 test period, corresponding to a recurrence interval of approximately 1 event every 3 years. This interval roughly aligns with the theoretical 5-year return period for a 2D rainfall accumulation of 139 millimetres, estimated based upon reviewed IDF curves for KIAMO. Index performance -in terms of hit rate and false alarm ratio<sup>59</sup>- and trigger recurrence intervals for different 2D threshold levels are shown in Figure 46. As expected, lower thresholds result in higher hit rates and false alarm rates, while higher thresholds result in lower hit rates and false alarm rates, with the aforementioned threshold of 139 millimetres offering the best compromise between hit rate and false alarm ratio. The highest thresholds result in zero false alarms and only trigger a few times for the most severe events.

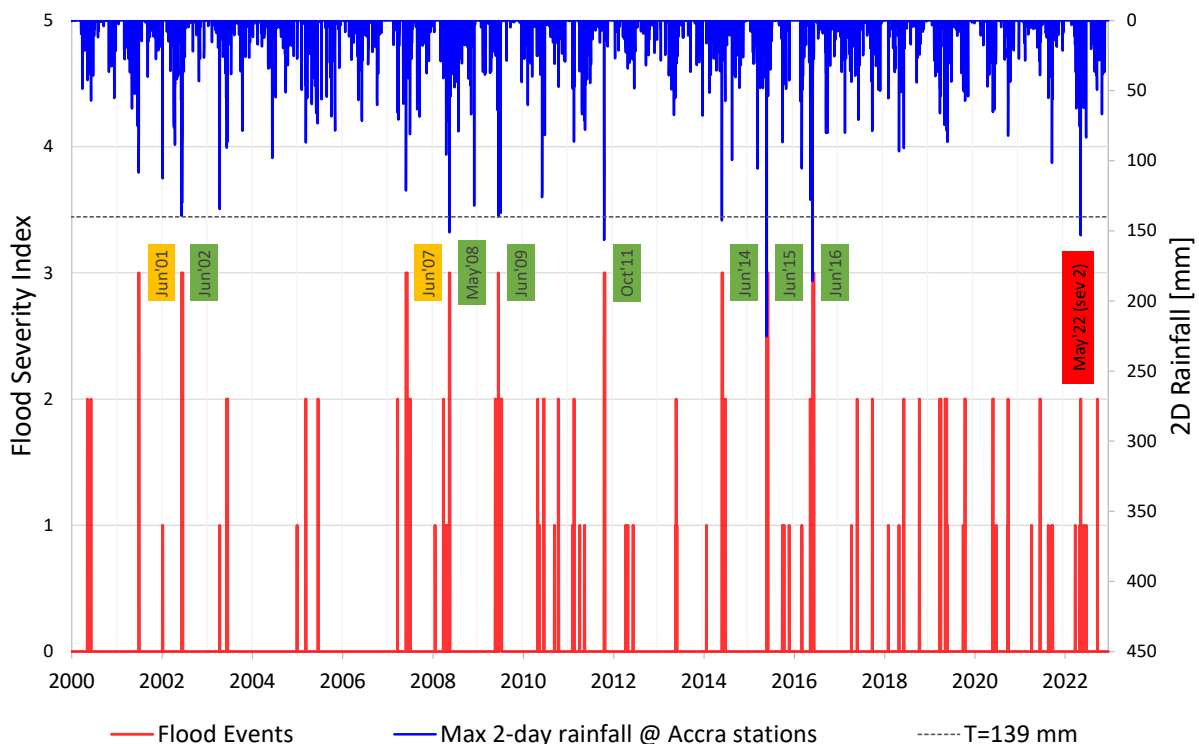
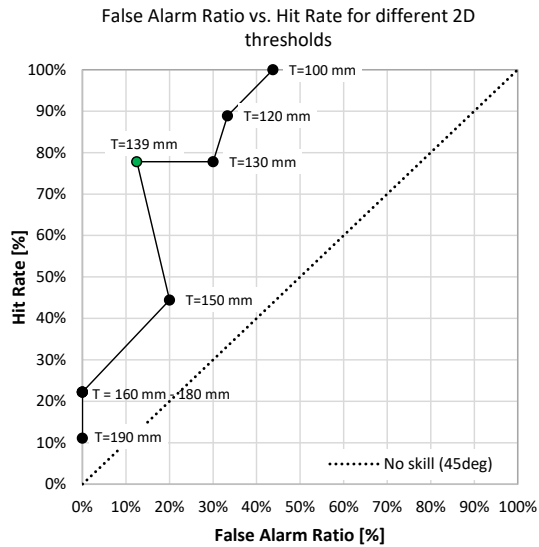


Figure 45: Time series of flood events by severity vs. maximum 2-day (2D) rainfall across central Accra stations (KIAMO and Accra Academy). Correctly identified severity 3 events (hits) are indicated in green, misses in yellow, and false alarms in red.

<sup>59</sup> Hit rate: The proportion of actual severe events correctly identified by the index; False alarm ratio: The proportion of predicted severe events that did not actually occur.



2D Threshold [mm]	Hits	Misses	False Alarms	Total Triggered Events 2000-2022	Trigger Recurrence Interval [years]
100	9	0	7	16	1.4
120	8	1	4	12	1.9
130	7	2	3	10	2.3
139	7	2	1	8	2.9
150	4	5	1	5	4.6
160	2	7	0	2	11.5
170	2	7	0	2	11.5
180	2	7	0	2	11.5
190	1	8	0	1	23.0

Figure 46: Index performance metrics (hit rate, false alarm ratio, and trigger recurrence intervals) for various 2D rainfall thresholds.

**Tema:** Proper index testing at Tema was more challenging due to fewer records and less information on flood events affecting that area of GAMA. However, similar to central Accra, 1D and 2D rainfall durations correlated well with severe events. Notably, a daily accumulation of 180 millimetres recorded at Tema station on 05/06/2017—the highest since records began in 1960—was conclusively matched to an event primarily affecting eastern GAMA. In contrast, only 13 millimetres of rain were recorded at central Accra stations on that day. Although this event was assigned a severity level 2, it was significant for the area, and a small payout would have been both helpful and justifiable.

More generally, 1D and 2D rainfall depths larger than 115 millimetres at Tema (corresponding to a return period of approximately 5 years) were consistently matched to severity 2 and 3 events mentioning Tema among the impacted locations. This confirms the suitability of adopting 1D or 2D rainfall accumulations as the index. For consistency with central Accra and considering the potential issue of rainfall amounts being split across reporting calendar days, it is recommended to adopt a 2D index for product design for this location, while considering a 24-hour rolling sum operationally.

### Conclusion – recommended index

**Coverage locations:** Firstly, considering the localized rainfall patterns and differences in extreme rainfall and flood risk across GAMA, it is recommended to use separate indices and trigger levels for two coverage locations, namely central Accra and Tema, where GMet rainfall records are available. For central Accra, indices that take the maximum rainfall accumulations across the KIAMO and Accra Academy stations showed better performance than using KIAMO records alone; therefore, indices based on maximum values across these two stations are recommended both for design and operation. In the case of Tema, product design and operation are limited to the single available monitoring location.

**Rainfall index:** Regarding actual indices, in line with known flooding mechanisms and catchment response times, 1D and 2D rainfall accumulations at central Accra and Tema appear to be reasonable indices for an XSR product and display better predictability of severe flooding than longer duration indices. While flooding-inducing storms are known to typically last only a few hours, critical rainfall accumulations are often split across reporting calendar days. Considering this, adopting a 2D index for

product design purposes is recommended over a 1D index to ensure total accumulations are captured, even if they occur across reporting calendar days. However, given that actual critical accumulations typically fall within a few hours, an operational index based on a 24-hour rolling sum may be more appropriate for real-time monitoring and triggering, providing a balance between simplicity, accuracy, and ease of communication and understanding for all stakeholders.

Regarding potential trigger levels, 2D rainfall accumulations with a return period of approximately 5 years at the two locations of interest—around 140 millimetres for central Accra and 115 millimetres for Tema—provided a reasonable prediction of local severe flood events while minimizing false alarms. These thresholds can serve as a starting point for XSR product structuring. The final trigger levels should be fine-tuned to balance client needs, such as the magnitude of events they wish to be insured for, trigger frequency, and overall product cost.

#### 6.3.5. Product structuring

Based on the identified rainfall index – 2-day rainfall for design and 24-hour rolling sum for operational purposes – for the two XSR coverage locations, central Accra and Tema, XSR products were structured for two risk profiles: BALANCED and CAT, as outlined in Section 6.2.2.

Initially, individual maximum event payout limits were set for each coverage location based on their relative flood risk. These limits were determined relative to the overall insured limit, which applies to the cumulative total of all event payouts during the policy period. With these location-specific limits established, stepped payout functions outlining threshold levels and associated payouts for each coverage location were developed for both the BALANCED and CAT options. Payouts for each trigger level and location are presented relative to the overall insured limit and in nominal USD, assuming a total insured limit of USD 10 million, as discussed in Section 6.2.3. Additionally, restrictions such as minimum event separation were implemented to ensure event independence, clarity, and fairness in product operation.

##### Event payout limits per coverage location

Event payout limits for each coverage location were set relative to the overall insured limit, considering the flood risk in each area. Central Accra, which includes the high-risk Odaw basin, was assigned a limit of 100% of the overall insured limit, while Tema was assigned a 10% limit. This aligns with the basin limits adopted for the FFP product (see Section 6.4.8 for more details), noting that the Tema rain gauge location is broadly representative of rainfall patterns across the Chemu East Gao and Sakumono basins, which were assigned relative limits of 5% and 15%, respectively, in the FFP solution.

Events are triggered independently at each coverage location. The associated payouts during the policy period are cumulative, but the total payouts are subject to an annual cap of 100% of the overall insured limit.

##### Stepped payout functions

Stepped payout functions, outlining threshold levels in terms of return period range, associated rainfall index thresholds, and payouts for each coverage location, accounting for the location payout limits, are shown in Table 14 (BALANCED option) and Table 15 (CAT option).

Rainfall index thresholds for each level and reference return period were identified using IDF curves for KIAMO and Tema GMet stations, fitted based on records from 1960 to 2022 as part of this project<sup>60</sup>. Final thresholds were rounded to the nearest 5 millimetres, ensuring a minimum of 10 millimetres difference between trigger levels.

As discussed in Section 6.3.4, a 2-day rainfall accumulation index was adopted for design to capture significant accumulations that may span across reporting calendar days. Operationally, a 24-hour rolling sum accumulation is recommended, maintaining the same 2-day thresholds specified in the tables below.

Table 14: XSR product - BALANCED option stepped payout function: trigger levels, associated rainfall thresholds and event payouts at Central Accra and Tema.

Return period	Probability per level	2-day rainfall trigger threshold [mm]		Event payout per level			
				[% relative to insured limit]		[USD]	
		Central Accra	Tema	Central Accra (location limit: 100% of insured limit)	Tema (location limit: 10% of insured limit)	Central Accra	Tema
5-10 years	10%	140	115	10.0%	1.0%	1 million	100'0000
10-15 years	3%	160	135	25.0%	2.5%	2.5 million	250'000
15-20 years	2%	180	150	50.0%	5.0%	5 million	500'000
>20 years	5%	200	160	100.0%	10.0%	10 million	1 million

Table 15: XSR product - CAT option stepped payout function: trigger levels, associated rainfall thresholds and event payouts at Central Accra and Tema.

Return period	Probability per level	2-day rainfall trigger threshold [mm]		Event payout per level			
				[% relative to insured limit]		[USD]	
		Central Accra	Tema	Central Accra (location limit: 100% of insured limit)	Tema (location limit: 10% of insured limit)	Central Accra	Tema
10-15 years	3%	160	135	10.0%	1.0%	1 million	100'0000
15-20 years	2%	180	150	25.0%	2.5%	2.5 million	250'000
20-25 years	1%	200	160	50.0%	5.0%	5 million	500'000
>25 years	4%	210	170	100.0%	10.0%	10 million	1 million

### Event separation criteria

In the identification of XSR events, a minimum separation criterion of 2 days is enforced to ensure event independence. Any 2-day rainfall accumulations exceeding the specified payout thresholds

<sup>60</sup> It is worth noting that, while IDF curves for KIAMO and Tema were received from GMet at project start and appeared reasonable, they were based on data up to around 2016 or 2017. This project included an extreme rainfall analysis to re-generate IDF curves using a GEV function and including data up to 2022. The new curves are similar to those from GMet, but slight differences are evident, especially for Tema. This is because the highest recorded daily rainfall occurred in 2018, after GMet generated their curves. Overall, the newly fitted IDF curves show lower return periods for the same rainfall amounts compared to the GMet curves.

must be at least 2 days apart to be considered separate events. If consecutive 2-day rainfall accumulations both exceed the payout thresholds, only the maximum value will be adopted, resulting in a single payout. If a 24-hour rolling sum is used operationally, a 24-hour minimum separation would be applicable.

#### 6.3.6. Payout calculation

As explained above, XSR events and payouts are triggered separately at each coverage location (i.e., Central Accra and Tema), with cumulative event payouts across all coverage locations during the policy period being subject to the overall insured limit. Therefore, individual event payouts at each coverage location must first be determined before calculating the actual claim amount, ensuring that cumulative payments over the policy period do not exceed the insured limit.

##### Event payout calculation

The process for calculating payouts under the XSR product for each coverage location is outlined below, building upon the rainfall datasets, XSR index and product structure defined above.

1. **Compute rainfall index time series for the coverage location of interest:**
  - a. Using input rainfall time series, compute rainfall index time series for each monitoring station associated with the coverage location of interest (i.e., KIAMO and Accra Academy stations for the Central Accra coverage location; Tema station for the Tema coverage location). For design purposes, 2-day rolling sum rainfall time series are to be computed based on historical daily records. Operationally, 24-hour rolling sum rainfall time series are to be computed based on 1-min records from automatic weather stations.
  - b. Produce an index time series for the coverage location of interest, based on the index time series for the associated monitoring stations:
    - i. For Central Accra, the index time series will take the maximum index value at each time step from the KIAMO and Accra Academy stations.
    - ii. For Tema, the index time series will be the index time series from the Tema Calculation Location.
2. **Identify trigger exceedances at coverage location:** Identify instances where the computed index exceeds the XSR trigger levels at the location of interest, as specified in the stepped payout functions (Table 14 and Table 15, respectively for BALANCED and CAT options).
3. **Apply event separation criterion and identify XSR event index:** Ensure a minimum separation criterion of 2 days between identified index exceedances to guarantee event independence. If consecutive 2-day accumulations exceed the payout thresholds, only the maximum value is adopted to avoid overlapping triggers. Operationally, a 24-hour separation period is applicable.
4. **Determine individual event payouts:** For each XSR event identified in Step 3, compare the identified maximum rainfall index against the specified trigger levels in the stepped payout functions. Determine the corresponding payout level and the applicable payout.

##### Claim and annual payout calculations

Operationally, individual XSR events and associated payouts are analysed as they occur. For each event, the insured must issue a claim where the claim payment amount is equal to the individual event payout (calculated as indicated above), subject to the insured limit for the period.

At the design stage, events triggering within a calendar year (assumed policy period) are identified across all locations. Individual event payouts are computed for each event, and the annual total payouts are ultimately calculated as the sum of the individual payouts, capped at the insured limit for the period, when applicable.

Scenario description: Payout calculation for the June 2015 flood event – BALANCED option

**Original rainfall records:** Original daily rainfall records at GMet stations KIAMO, Accra Academy, and Tema for the period 24/05/2015 to 13/06/2015, encompassing the June 2015 flood event plus 10 days before and after the peak on 3<sup>rd</sup> June, are shown in columns 1 to 3 of Table 16.

**Index calculation:** Based on the original daily records, 2-day rolling sum rainfall accumulations are computed for each station (columns 4 to 6 in Table 16). Further, for each date, the maximum 2-day rainfall accumulation is extracted for each coverage location. That is, for central Accra, the maximum amongst KIAMO and Accra Academy is extracted (column 7). For Tema, index time series at Tema monitoring station are adopted (column 8). The resulting 2-day time series for Central Accra and Tema (cols 6 and 7 in Table 16) will be used for trigger assessment.

Table 16: Original daily rainfall records for GMet stations KIAMO, Accra Academy, and Tema from 24/05/2015 to 13/06/2015, and computed 2-day rolling sum rainfall accumulations. 2-day values exceeding XSR trigger thresholds at Central Accra and Tema are highlighted in pink.

Date	Original 1D rainfall records at monitoring stations [mm]			2D rolling sum at monitoring stations [mm]			2D rainfall index time series at coverage locations [mm]	
	KIAMO	Accra Academy	Tema	KIAMO	Accra Academy	Tema	Central Accra (Max of KIAMO and Accra Academy)	Tema
24/05/2015	0.0	10.1	0.0	0.0	10.1	0.0	10.1	0.0
25/05/2015	0.0	0.0	0.0	0.0	10.1	0.0	10.1	0.0
26/05/2015	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27/05/2015	36.3	0.0	11.1	36.3	0.0	11.1	36.3	11.1
28/05/2015	4.8	18.4	1.4	41.1	18.4	12.5	41.1	12.5
29/05/2015	0.0	0.0	0.0	4.8	18.4	1.4	18.4	1.4
30/05/2015	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31/05/2015	20.4	32.8	11.0	20.4	32.8	11.0	32.8	11.0
01/06/2015	35.2	37.2	142.3	55.6	70.0	153.3	70.0	153.3
02/06/2015	12.5	18.5	22.3	47.7	55.7	164.6	55.7	164.6
03/06/2015	212.8	169.4	91.4	225.3	187.9	113.7	225.3	113.7
04/06/2015	1.8	0.6	0.5	214.6	170.0	91.9	214.6	91.9
05/06/2015	11.1	7.2	4.7	12.9	7.8	5.2	12.9	5.2
06/06/2015	0.0	0.0	0.0	11.1	7.2	4.7	11.1	4.7
07/06/2015	1.0	0.3	3.6	1.0	0.3	3.6	1.0	3.6
08/06/2015	2.5	0.5	16.9	3.5	0.8	20.5	3.5	20.5
09/06/2015	4.8	2.2	14.2	7.3	2.7	31.1	7.3	31.1
10/06/2015	0.0	0.0	0.0	4.8	2.2	14.2	4.8	14.2
11/06/2015	1.7	0.0	0.7	1.7	0.0	0.7	1.7	0.7
12/06/2015	0.0	0.0	0.0	1.7	0.0	0.7	1.7	0.7
13/06/2015	18.5	0.9	36.7	18.5	0.9	36.7	18.5	36.7

**Event trigger assessment:** Based on the 2-day rainfall time series at Central Accra and Tema, instances are identified where XSR trigger levels (as specified in Table 14 for the balanced option) are exceeded. These instances are highlighted in pink in Table 16 and shown in Figure 47 (Central Accra) and Figure 48 (Tema), where 2-day rolling sum rainfall time series are plotted alongside XSR trigger thresholds for the BALANCED option. As shown, XSR thresholds are exceeded on two consecutive days for coverage location. Given the 2-day event separation criterion, only the maximum value of the consecutive days is adopted: 225.3 millimetres for Central Accra and 164.6 millimetres for Tema, both exceeding the highest XSR BALANCED thresholds. Thus, during the analysis period, two XSR events would have been triggered: one in Central Accra and one in Tema.

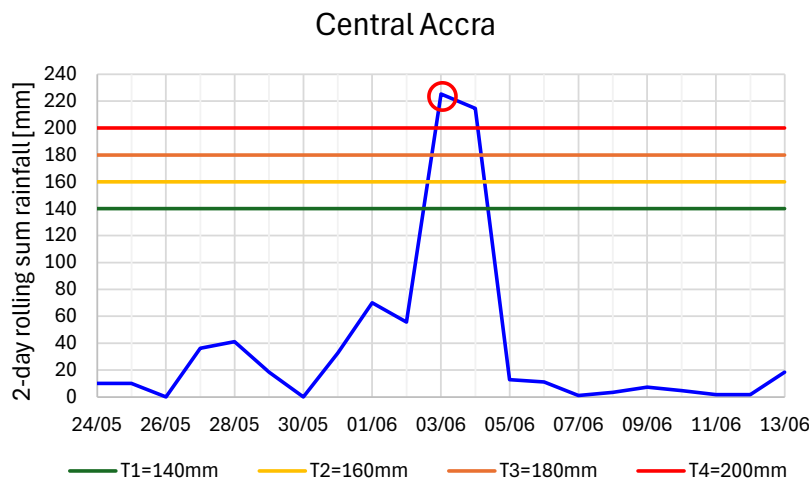


Figure 47: 2-day rolling sum rainfall time series for Central Accra (maximum value between KIAMO and Accra Academy stations) with XSR trigger thresholds under the Balanced option. The maximum 2-day rainfall value is circled.

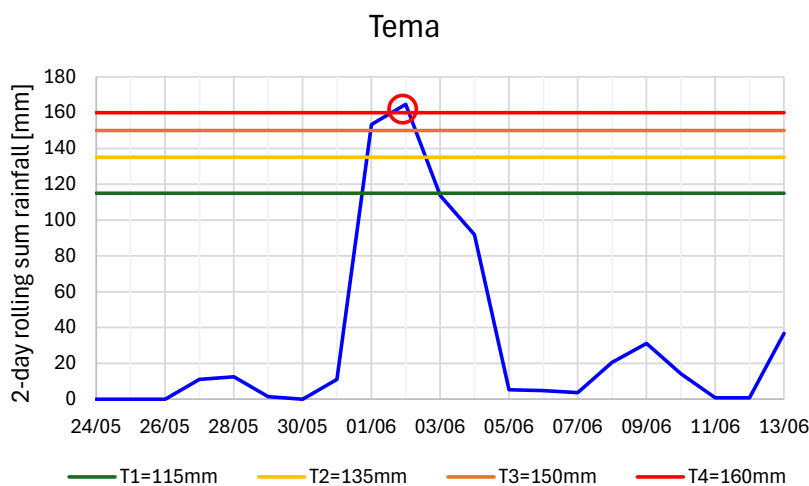


Figure 48: 2-day rolling sum rainfall time series for Tema with XSR trigger thresholds under the Balanced option. The maximum 2-day rainfall value is circled.

**Payout calculation:** According to the stepped payout functions under the BALANCED option (Table 14), the following payouts would be triggered:

**Central Accra:**

- The 2-day rainfall accumulation of 225.3 millimetres exceeds the highest trigger level of 200 millimetres.
- As per the payout function for Central Accra, this triggers a payout of 100% of the location's limit.
- Given that the location limit for Central Accra is 100% of the overall insured limit, the payout would be 100% of the insured limit.

**Tema:**

- The 2-day rainfall accumulation of 164.6 millimetres exceeds the highest trigger level of 160 mm.
- As per the payout function for Tema, this triggers a payout of 100% of the location's limit.
- Given that the location limit for Tema is 10% of the overall insured limit, the payout would be 10% of the insured limit.

**Joint Payout Calculation:**

- The combined payout from both locations totals 110% of the overall insured limit (100% from Central Accra + 10% from Tema).
- Due to the annual cap of 100% of the insured limit, the joint payout is capped at 100%.
- Assuming an overall insured limit of USD 10 million, the full amount would have been paid in June 2015, given the individual events triggered at Central Accra and Tema.

**Conclusion:** Had the XSR parametric product been in place during the June 2015 flood event, the extreme rainfall accumulations at both Central Accra and Tema would have triggered the maximum location payouts as per the defined thresholds for the BALANCED option. Despite the total (joint) payout being 110% of the insured limit, the annual cap would limit the final payout to 100% of the insured limit. Assuming an insured limit of USD 10 million, the payout would have been USD 10 million.

While the above example is based on the BALANCED option, the same final payout of 100% of the insured limit would have been triggered under the CAT option for this event. Under the CAT option, peak 2-day accumulations at Central Accra would trigger the maximum location payout (i.e., 100% of the insured limit), and peak 2-day accumulations at Tema would trigger step 3 of the payout function, with an associated payout of 50% of the location limit (10% of the insured limit), equating to 5% of the insured limit. Therefore, the joint payout for the two locations would be 105% of the insured limit, which, subject to the annual cap, results in a final payout of 100% of the insured limit.

### 6.3.7. Annual expected losses (AEL)

Annual expected losses (AEL) for the BALANCED and CAT options were computed based on product simulations from 2000 to 2022, utilising GMet station records over said period. These simulations accounted for triggered events at both coverage locations (Central Accra and Tema), applying an annual cap of 100% of the overall insured limit to joint or successive payouts, when applicable. The simulation results for both options, including simulated trigger frequencies per trigger level and location, associated payouts over the simulation period, and AEL, with AEL computed as the average of annual payouts over the 23-year design period, are presented in Table 16 (BALANCED option) and Table 17 (CAT option) below.

Table 17: XSR product - BALANCED option simulation results over period 2000-2022 and estimated AEL.

Return period	Number of events triggered per level		Total payout per level over design period	
	Central Accra	Tema	[% relative to insured limit]	[USD]
5-10 years	5	3	53%	5.3 million
10-15 years	0	1	3%	250'000
15-20 years	1	0	50%	5 million
>20 years	1	2	110%	11 million
<b>Total over design period</b>	<b>7</b>	<b>6</b>	<b>216%</b>	<b>21.6 million</b>
<b>Annual expected losses (AEL)</b> (computed as the average of total annual payouts over the 23-year design period)			<b>[% relative to insured limit]</b>	<b>[USD]</b>
			9.4%	940'000

Table 18: XSR product – CAT option simulation results over period 2000-2022 and estimated AEL.

Return period	Number of events triggered per level		Total payout per level over design period	
	Central Accra	Tema	[% relative to insured limit]	[USD]
10-15 years	0	1	1%	5.3 million
15-20 years	1	0	25%	250'000
20-25 years	0	1	5%	5 million
>25 years	1	1	105%	11 million
<b>Total over design period</b>	<b>2</b>	<b>3</b>	<b>136%</b>	<b>13.6 million</b>
<b>Annual expected losses (AEL)</b> (computed as the average of total annual payouts over the 23-year design period)			<b>[% relative to insured limit]</b>	<b>[USD]</b>
			5.9%	590'00

### 6.3.8. Real-time monitoring of the index

It is envisaged that data from GMet's automatic weather stations (AWSs) at KIAMO and Tema, and TAHMO's AWS at Accra Academy, will be used for trigger monitoring. Data will be accessible via API and a web portal, and index calculation (i.e., 24-hour rolling sum rainfall depth estimation) and checks against trigger levels will be performed by the calculation agent.

While GMet's AWSs are currently operational, infrastructure and processes need improvement to ensure consistent accuracy of the AWSs and alignment with the co-located manual stations used for product design. Additionally, streamlined, transparent, near real-time access to AWS records is essential for both local agencies and future product suppliers. The following actions have been identified and adopted by GMet to ensure reliable index monitoring:

- Review and, if necessary, rectify AWS siting and calibration to correct current systematic under-recording against co-located manual gauges.
- Develop actionable AWS maintenance protocols to ensure good quality records over time.

- Deploy an API-enabled database to improve both the handling of and access to AWS records, including the permanent collection of AWS records going forward, as the current setup only retains records for the past year.
- Develop a web portal for visualisation and querying of rainfall records from the AWSs.

The project team is in contact with GMet to coordinate the execution of these actions and assist with their implementation as needed. It is envisaged that future product providers will pay a subscription fee to GMet to cover setup and operational costs related to the near real-time supply of rain gauge records for trigger monitoring.

Regarding the TAHMO AWS at Accra Academy, records are already accessible in near real-time via TAHMO's web portal and API<sup>61</sup>. A subscription fee of USD 10 per station per month is required to access the data. If the XSR product option is chosen, it is recommended that future product suppliers establish direct contact with TAHMO to communicate the need for robust station maintenance at Accra Academy, including regular checks on battery levels to minimize periods of missing data.

#### 6.3.9. XSR fallback options

For this product, the fallback option involves using records from GMet manual rain gauges at KIAMO and Tema, and from the soon to be installed manual gauge at Accra Academy, which are co-located with the automatic gauges (AWSs) adopted for real-time index monitoring. The primary issue with using manual gauge records is their lack of near real-time availability and increased susceptibility to human error. However, these records are generally of high quality, and GMet ensures accurate readings, particularly at key stations like KIAMO, which are crucial for rainfall reporting in Ghana.

It is important to note that, since records from manual stations are typically available at daily resolution, when these are used, a 2-day rolling sum rainfall index should be adopted instead of the 24-hour rolling sum index which is applicable to 1-min records from AWSs.

### 6.4. Flood footprint (FFP) parametric product

#### 6.4.1. Introduction

Parametric flood coverage based on flood footprint data is generally considered a major advance over a precipitation index. Instead of an indirect and sometimes poorly correlated rainfall index, insurance payouts are determined based on the maximum extent of an actual flood (referred to as flood footprint). Reflection patterns from satellite-based Synthetic Aperture Radar (SAR) technology are used to detect non-permanent standing water. Flood footprints are composite images created from multiple passes by a constellation of specialized radar satellites around the peak of a flood. ICEYE operates the largest constellation of its kind and has established itself as a leading provider of flood footprints. In addition to satellite-based data, ICEYE also integrates auxiliary data for back tests and to further improve flood analysis (see Section 6.5).

Before concluding the insurance contract, the area of interest or the list of critical assets must be determined. Representative calculation points are defined, each with a set of coordinates and a value weighting. The occurrence of a flood event is measured at these calculation points. During the

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<sup>61</sup> <https://tahmo.org/>

insurance term, ICEYE acts as an independent reporter for the insurance contract and is tasked with monitoring and reporting on all significant flood events in the area of interest. When a flood is detected and the corresponding flood footprint is provided, a predefined parametric payout function is applied. The more weighted calculation points that are flooded (weighted based on their representation of poor and vulnerable households), the higher the insurance payout to the policyholder, the Government, up to an agreed limit per flood event and a limit for the entire insurance term. The main advantage of an FFP solution is a significant reduction in basis risk, i.e. the risk that payouts from the parametric product do not correspond to actual losses on site (see Section 6.2.1).

In general, parametric FFP solutions are most suitable for responding to catastrophic floods and are less suitable for spatially and temporarily smaller floods.

### Pricing methodology

Given there is limited historic data available from ICEYE's footprint database for Ghana, potential capacity providers must apply a so-called '*decoupled*' pricing approach to participate in the FFP solution. The prerequisite for underwriting an FFP solution is a state-of-the-art flood risk model. This means that the price is determined by use of flood models, while real-time monitoring of the parameter is carried out by the independent third-party data provider ICEYE. 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.

Copies of the flood hazard maps and target points adopted for FFP product design can be found in Appendix 3. A draft wording for the FFP product under the CAT option can be found in Appendix 4.

#### 6.4.2. Description of flood hazard models

Flood models used for this project were developed by HKV within the feasibility study for the World Bank that led to the Greater Accra Resilient and Integrated Development (GARID) project. The models are created to model pluvial and fluvial floods, coastal flooding is not included and of limited relevance for Accra. The models use rainfall as input and provide flood extent and depth as output. These outputs, which effectively quantify flood hazard, are used to determine insurance payout thresholds, and ultimately price the product. In this section the main characteristics of the models will be presented. For further details on model development, calibration, and available simulations, please refer to (HKV, 2018).

The adopted models comprise hydrological and hydraulic sub-models. The hydrological component was calculated from rainfall input and known hydrological parameters. For example, water resulting from pluvial events might not infiltrate the soil immediately, stays on the surface and accumulates in ponds or evaporates. The hydraulic component determines how water runoff flows through the drainage network, ultimately producing inundation maps. The model for the Odaw basin follows a 1D-2D setup, whereby flows along the (man-made) stormwater drainage network are simulated following a 1-dimensional (1D) approach, with main drains schematized based on cross sectional information, and flows on the surface are simulated with a 2-dimensional (2D) schematisation based on elevation data, with interactions between the 1D and 2D systems occurring at interfaces such as manholes and canal banks. Models for the other GAMA basins only include the surface drainage component, based on elevation data alone.

For the model of the Odaw basin, the WorldDEM Digital Terrain Model produced by Airbus was used. The accuracy of this terrain model is less than 4 metres, with a horizontal resolution of 12 x 12 metres (Figure 49).

For the other basins in GAMA, a combination is used of various terrain models. Contour lines provided by the Government of Ghana were available for some areas in the GAMA area. Exact accuracy is not known, but the interval between contour lines is 2 metres. For areas where no contour lines were available, a Digital Surface Model from Airbus was used named *Elevation20-SPOT*. This model has a horizontal resolution of 20 x 20 metres and a vertical error of less than 10 metres. Finally, for higher elevated areas in the basins other than Odaw, the SRTM Digital Elevation Model was used. This model has a horizontal resolution of 30 x 30 metres and a vertical accuracy of less than 14 metres.

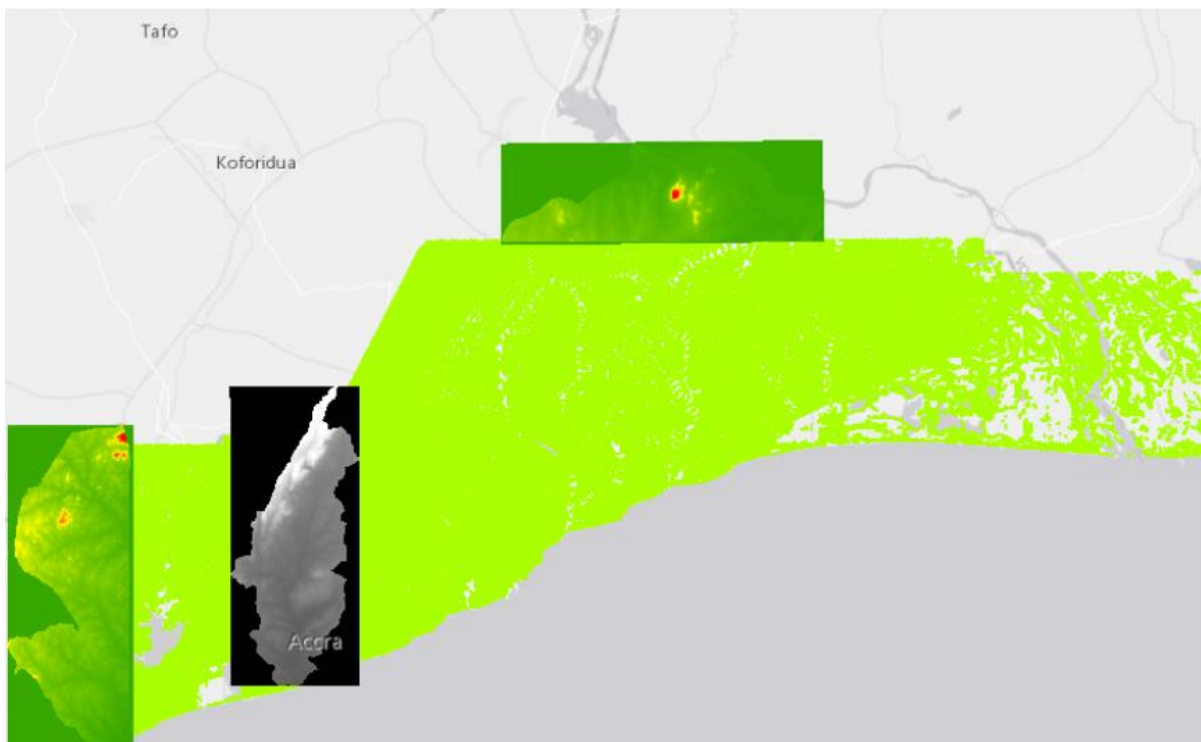


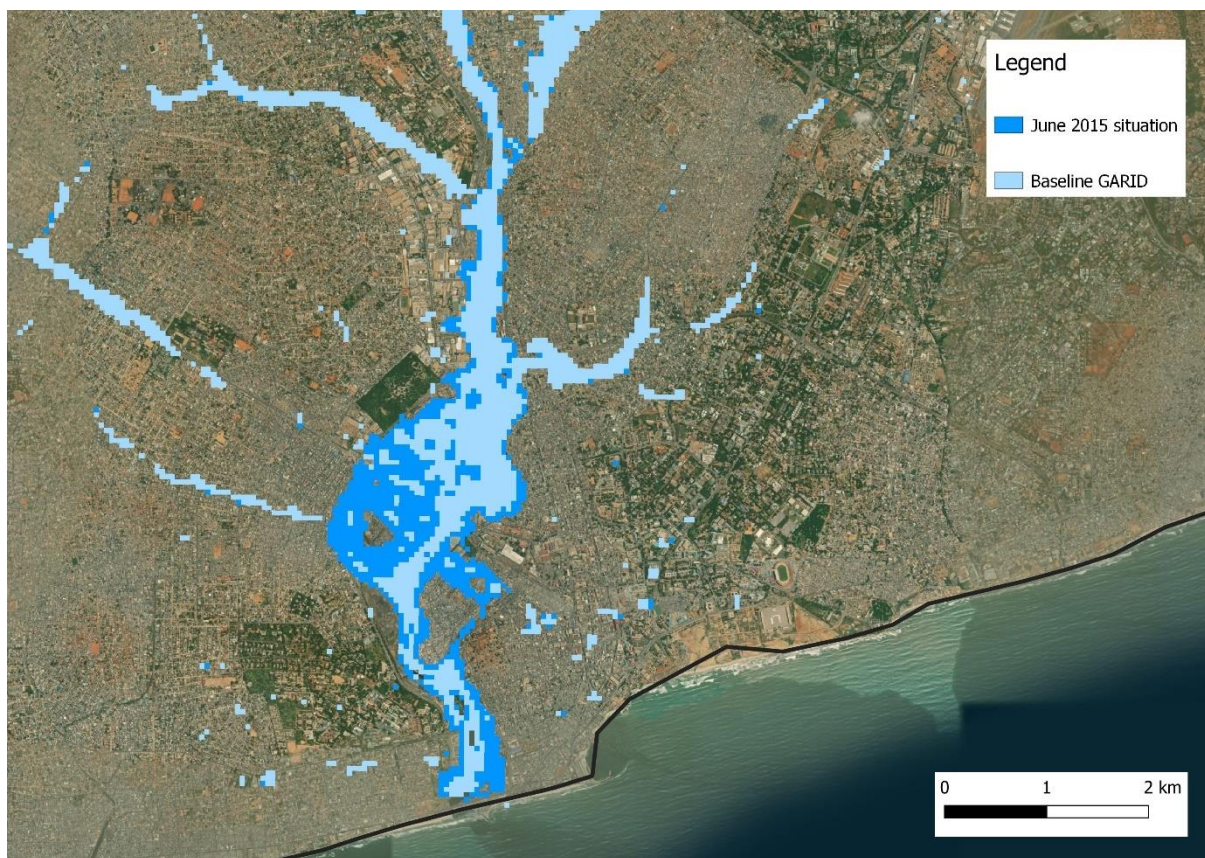
Figure 49: Elevation models used for flood modelling in the Odaw and other basins throughout GAMA. For the areas single-coloured bright green area, contour lines were available. The black and white image is the WorldDEM DTM for the Odaw basin. The multi-coloured areas are from Airbus Elevation20-SPOT. The SRTM Digital Elevation Model was also used in the multi-coloured areas for the higher elevated parts, but not indicated in the figure.

After collecting the necessary data, the hydrological and hydraulic models of the Odaw basin were built and validated in close collaboration with Ghanaian experts. As recent station observations of variables such as flow discharge, water levels and flood extent were unavailable, the model was calibrated and validated against flood extent and depth information from the 3<sup>rd</sup> of June 2015 event, including photos, videos and information collected via field interviews. The 2015 flood simulation results were discussed and ultimately approved by local experts, thus yielding a calibrated model.

There are three versions available for the Odaw model: (1) The first represents the situation as it occurred during the 3<sup>rd</sup> of June 2015 event. At the time of this significant flood, various drains were clogged due to solid waste. (2) A second model represents the baseline before implementation of the structural measures in the GARID project, in that baseline the drains are cleaned, but no additional

measures were implemented. Figure 50 shows the flood extent in the Odaw basin for both situations, showcasing a significant positive impact of clean drainages on the maximum flood extent. The GARID project aims to further reduce flood risk by implementing a series of structural measures. (3) The third model version thus represents the situation after these additional mitigation measures have been implemented. It is the ideal scenario. Please note, for basins other than Odaw these scenarios are not available, since drainages are not explicitly included in HKV's models.

Unfortunately, no structural measures have been implemented by GARID yet. Although drainages are now cleaned regularly at critical locations, such as at the Korle Lagoon inception weir, it cannot be assumed they are entirely clean throughout the rainy season. For the purpose of this project, we henceforward assume a situation that is between the June 2015 situation (1) and baseline (2).



*Figure 50: Flood extent at the lower Odaw basin for the June 2015 flood (dark blue) and the flood extent modelled for a situation in which the drains would have been clean (light blue). The difference shows the positive effect of clean drainages on the maximum flood extent.*

The models for other GAMA basins are based on the calibrated parameters from the Odaw model, taking specific basin characteristics like urban fraction and paved surfaces into account. No explicit calibration or verification was undertaken for the other basins. More details on the model approach, input data, calibration and validation processes can be found in (HKV, 2018).

### 6.4.3. Description of input data and model output

The models developed by (HKV, 2018) are used to determine the flood extents for given return periods. To generate these maps, simulations are run with design storms. These are rainfall events that are designed to estimate the inundation patterns for a given return period, using an alternating block method (HKV, 2018). Figure 32 further above shows the input rainfall to the hydrological model in green, this is a 6-hour event with every hour a different intensity. The event is selected such that the rainfall amount of the largest 1-hour sum within the event equals a 10-year return period for 1-hour duration, the rainfall amount of the largest 2-hour sum within the event equals a 10-year return period for 2-hour duration, and similarly for the largest 3-, 4- and 5-hourly sum as well as the entire 6-hour sum of the event. Events for return periods of 1, 2, 5, 10, 15, 20, 25, 50 and 100 years were created in a similar way. For the other basins, the same approach was used but then with events of 12-hour duration.

Rainfall statistics for point locations differ from rainfall statistics for an area. However, no accurate information on spatial variability is available. In line with common flood modelling approaches, rainfall is therefore assumed to be uniform over the basin area. To convert rainfall intensities from point statistics to the model domain, an area reduction factor (ARF) was used. The ARF is dependent on the size of the modelled domain, the larger the domain, the larger the reduction factor. More information can be found in (HKV, 2018).

The effective precipitation which will run-off and hence inserted in the hydrologic model is given in blue. The difference between rainfall and run-off into the drains comes from soil infiltration, vegetation interception or ponding on the surface.

The model output are inundation depths at each grid cell (at approximately 25 x 25 metres resolution) for every timestep in the simulation up to well after the peak of the event. These flood hazard maps for return periods of 1, 2, 5, 10, 15, 20, 25, 50 and 100 years are created showing the maximum flood extent during the event. The result of the flood modelling is shown visually for a few return period steps in Section 5.1 (Figure 29).

### 6.4.4. Flood return periods and correlation between basins

The above methodology results in maps that represent flood extents for each basin at a given return period, e.g. annual occurrence, 1 in 10 years, 1 in 50 years. The correlation between different basins depends on the spatial correlation in rainfall. That correlation determines how likely it is that two basins both face a 1 in 10 years rainfall event at the same time. This correlation is difficult to determine, we therefore explored two extremes:

1. The situation in which all basins are assumed to be **fully dependent**, this means that if one basin faces a 1 in 10 years flood, all basins do.
2. The situation in which all basins are assumed to be **fully independent**, this means that the probability of two basins facing a 1 in 10 years flood is the probability of one basin facing a 1 in 10 years flood times the probability of one basin facing a 1 in 10 years flood. That means that such a flood will happen much less often than once every 10 years in two basins at the same time.

Considering rainfall patterns across GAMA, particularly the high incidence of highly localised convective storms, the actual situation is likely closer to the fully independent scenario. Given that correlation assumptions can impact annual expected losses (AEL), both scenarios were further explored in Section 6.4.12.

#### 6.4.5. Target areas for parameter monitoring

The target areas and assets of interest for insurance product design and monitoring consist of informal settlements, low-income residential areas, key transport hubs and markets, which collectively represent the poor and vulnerable population of GAMA, as described in Section 4 and shown in Figure 27.

For the purposes of this insurance scheme, the flood risk for the aforementioned target areas must be calculated and flood monitoring must be tailored accordingly. The most suitable approach for this is to divide the area into pre-defined and equally spaced points that can be weighted as per their relevance.

#### 6.4.6. Creation of weighted points for areas of interest

To create the parametric flood footprint insurance scheme, a point layer was first created that covers all the target areas (see Section 4). Each point represents the centroid of a cell of a 50 x 50 metres raster. Working with local stakeholders, it was confirmed the 50 metres grid resolution is useful, on the one hand, to limit total amount of points for the flood hazard calculations and the post-event flood analysis, while on the other hand, to accurately represent the poor and vulnerable population and align with all other existing datasets.

During the development process it was verified and confirmed that all critical market areas and important transport terminals were covered by the point layer. It turned out that this was mostly the case, but some additional points were added to the point layer to account for exposure not yet captured. Finally, points that were within permanent water bodies were removed. The permanent water bodies were provided by ICEYE.

In the flood footprint solution, once the point is flooded more than 30 centimetres water depth, the grid cell is considered to be flooded. This is a binary approach at each centroid. No further refined payout condition is considered for water depths above 30 centimetres. Figure 51 shows an example of the grid points and a hypothetical flood footprint for the lower Odaw basin.

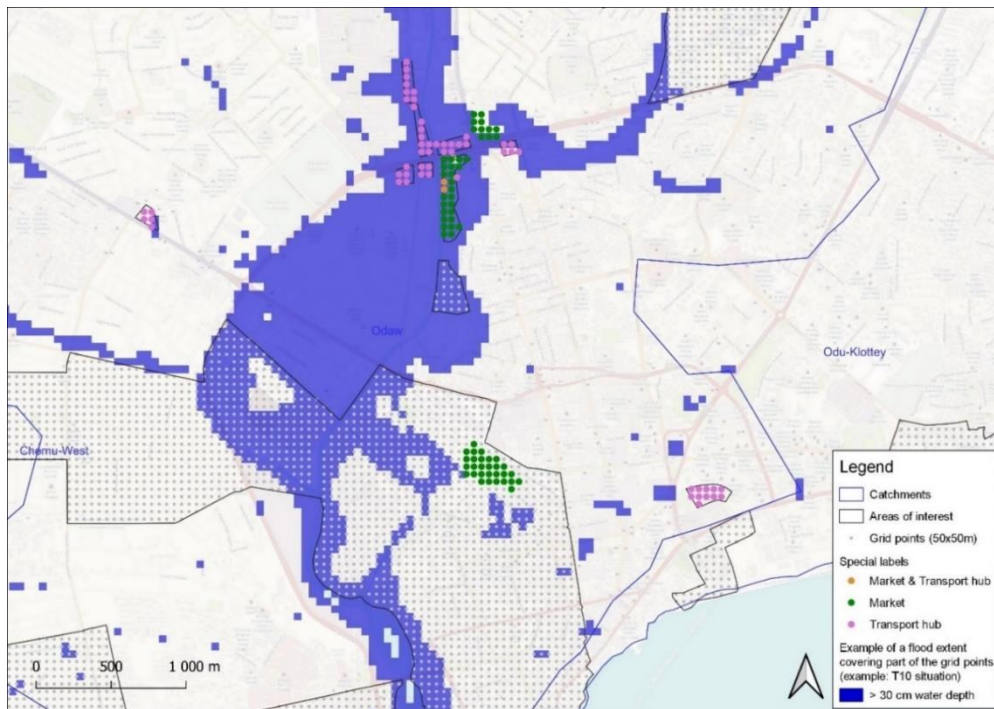


Figure 51: Map detail of target grid points within the GAMA area around Korle lagoon, lower Odaw basin, and a hypothetical flood footprint in blue (T10 situation). As per this scenario some points will be determined to be flooded and would count towards the parametric insurance payout calculations.

It was observed that the number of points in market areas or transport terminals are much smaller than the number of points in residential areas. However, discussions with local council representatives confirmed that flooding in markets or transport terminals has a far greater impact on the poor and vulnerable population. Therefore, the points were weighted higher to take the disproportionate impact of flooding into account.

The weights in residential areas correspond to the population density at that location (in number of people aggregated to the 50 x 50 metres grid cells). The weighting values range between 0 and 150. This value was based on the 99<sup>th</sup> percentile value for the population density in the points, which is 142, and then rounded to 150. The points in market areas or transport terminals were all given the maximum weight value of 150 to account for their importance relative to residential areas. The different basins comprise of different numbers of target points with different weights. Figure 52 shows the population density, market areas and transport hubs mapped on the point layer. From now on, the target insured points will be referred to as *weight points*.

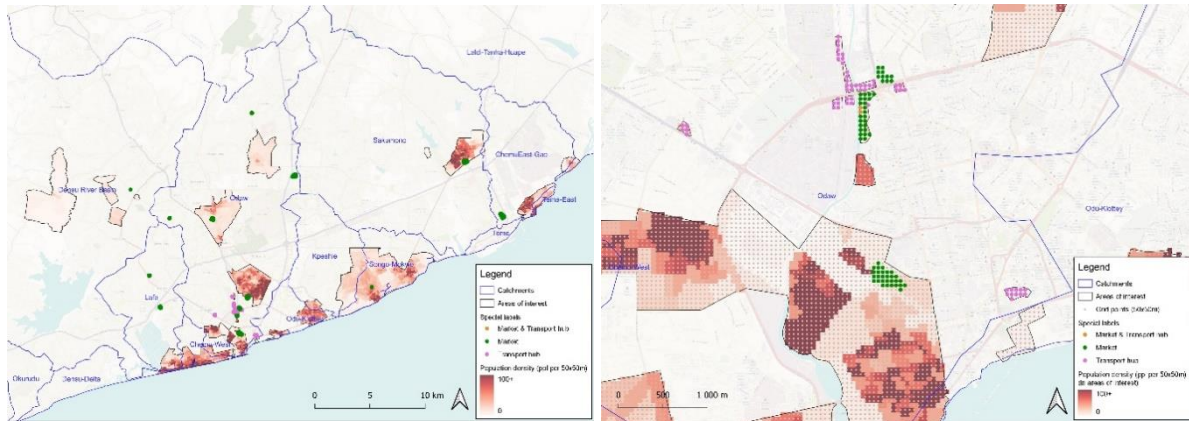


Figure 52: Point layer (centroids of 50 x 50 metres grid cells) with the aggregated number of people shown in the red color scheme. Points classified as markets marked in green, points classified as transport hubs marked in purple. GAMA overview on the left-hand side and detail of the lower Oduw basin on the right-hand side.

#### 6.4.7. Floodable weight points

To understand relative flood risk across basins, the concept of '*floodable*' points was introduced. These are defined as the number of *weight points* predicted to flood under a T100 (1 in 100 years) scenario for each basin, which ensures comparability between basins. It does not mean that other points cannot be flooded in each basin, but at probabilities of occurrence larger than a 1 in 100 years flood chances are relatively low.

The total number of '*floodable*' weight points per basin serves as a proxy for flood risk, as it combines vulnerability (number and weighting of target points) with hazard (likely floodable or not). This number serves to calibrate the payout thresholds per basin and their respective insured limits. Figure 53 illustrates the number of '*floodable*' weight points as share across all GAMA's basins at T20. Oduw faces by far the largest flood risk, which aligns with experience on the ground and findings from detailed flood analyses (HKV, 2017).

Sum of weights of the "floodable" points per basin (total 131.400)

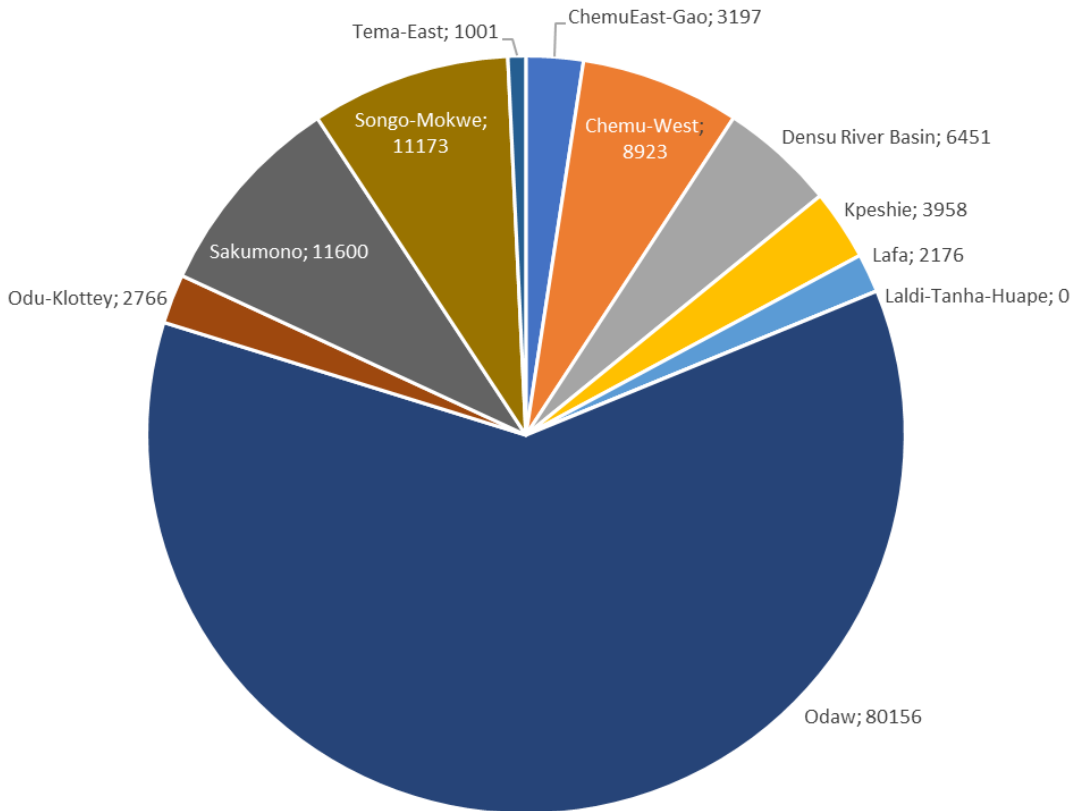


Figure 53: Sum of the floodable weight points per basin (at T20).

#### 6.4.8. Maximum payout limits per basin

Due to the increased flood risk of the Odaw basin and its overall importance, the maximum annual payout limit of USD 10 million has been allocated to Odaw as further explained in Section 0. Consequently, the Odaw basin served as reference for calibrating the maximum payout limits for all other basins. Since exposures in other basins are smaller, it seemed logical that the Government would not have the same financial needs for flood response. The other basin's payout limits were therefore defined as a percentage relative to the Odaw limit. It was decided to use clean and rounded fractions of the maximum USD 10 million for Odaw, essentially creating three basin groups I, II and III (Table 19).

The Laldi-Tanha-Huape and Tema East basins are excluded from the product due to them not facing significant pluvial or fluvial flood risk, either because flood hazard is low (Tema East) or because there are no target population or assets within the basin (Laldi-Tanha-Huape).

Table 19: Weighting of basins relative to Odaw to determine rounded maximum payout limits for three basin groups.

BASIN	Floodable weight-points (at 20 year RP level)	Flood risk relative to Odaw basin (%)	Rounded relative flood risk to Odaw (%)	Maximum payout limit (USD)	Basin Group
Odaw	80'156	100%	100%	10 million	I
Chemu East-Gao	3'197	4%	5%	0.5 million	III
Chemu -West	8'923	11%	15%	1.5 million	II
Densu River Basin	6'451	8%	5%	0.5 million	III
Kpeshie	3'958	5%	5%	0.5 million	III
Lafa	2'176	3%	5%	0.5 million	III
Osu-Klottey	2'766	3%	5%	0.5 million	III
Sakumono	11'600	14%	15%	1.5 million	II
Songo-Mokwe	11'173	14%	15%	1.5 million	II

This calibration step defines the maximum nominal payout limits for the three basin groups (I, II and III). As explained in Section 6.2.2 the payout functions, as state relative to the total insured limit (Table 12), can now be applied to maximum payout limits of all basins.

#### 6.4.9. Flooded weight point threshold levels

Unlike the XSR solution, which covers the entire GAMA area with a single and rather coarse index, the FFP option, due to the higher resolution of the point layer and flood footprint data, allows the creation of more refined parametric trigger thresholds (see Figure 52 and Section 6.56.4.6). This means that a much more precise adaptation to the vulnerable target population is achieved. Since different basins face different levels of flood risk, the individual trigger thresholds, outlined as payout fractions for each return period step in Section 6.2.2, can be transferred into the cumulative number of modelled weight points expected to flood for each basin. The following calibration step describes these individual trigger threshold calibrations.

For the purpose of this risk transfer scheme the relevant return period bands described in Section 6.2.2 range from an attachment level of 5 years to full limit payments at 25 years, depending on the option. HKV's flood hazard maps were used to determine the equivalent cumulative number of the *weight points* expected to flood, for each basin, and for each return period step. This calculation results in different threshold definitions for each basin, i.e. different number of *weight points* that must be flooded to trigger the respective payout step, as shown in Table 20. As soon as thresholds are reached the corresponding payment will be calculated and paid according to the previously defined basin groups' limits in Section 6.4.8 (Table 19).

Table 20: Threshold levels of the cumulative sum of weight points that need to be flooded, per return period step, per basin. Percentage values out of the total number stated brackets.

Return period (yrs)	Odaw	Chemu East-Gao	Chemu - West	Densu River Basin	Kpeshie	Lafa	Osu-Klottey	Sakumono	Songo-Mokwe
5	37'396 (8%)	2'181 (3%)	5'161 (4%)	3'856 (11%)	2'423 (4%)	717 (2%)	1'647 (2%)	8'394 (7%)	7'241 (4%)
10	56'277 (12%)	2'675 (4%)	6'490 (5%)	5'329 (15%)	3'244 (5%)	1'465 (3%)	2'286 (3%)	9'846 (8%)	8'992 (4%)
15	70'585 (16%)	2'746 (4%)	7'748 (7%)	5'932 (16%)	3'700 (6%)	1'710 (4%)	2'689 (3%)	10'721 (8%)	10'487 (5%)
20	80'156 (18%)	3'197 (5%)	8'923 (8%)	6'451 (18%)	3'958 (6%)	2'176 (5%)	2'766 (3%)	11'600 (9%)	11'173 (6%)
25	89'016 (20%)	3'565 (5%)	9'505 (8%)	6'815 (19%)	4'234 (6%)	2'435 (5%)	3'177 (4%)	12'123 (10%)	12'245 (6%)
<b>Total number of weight points</b>	452'917	68'306	118'143	36'279	65'702	47'444	81'721	127'140	203'028

Below graphs of Figure 54 show the proportion of the total number of *weight points* expected to flood at various return periods ranging from 1 to 100 years, relative to the total number of all *weight points* within each basin. Colours indicate the proportion of *weight points* corresponding to transport hubs (dark blue), table-top markets (light blue) and residential areas (grey). Figure 54 shows this analysis for the four most important and representative basins, namely Odaw, Densu, Chemu East Gao and Lafa.

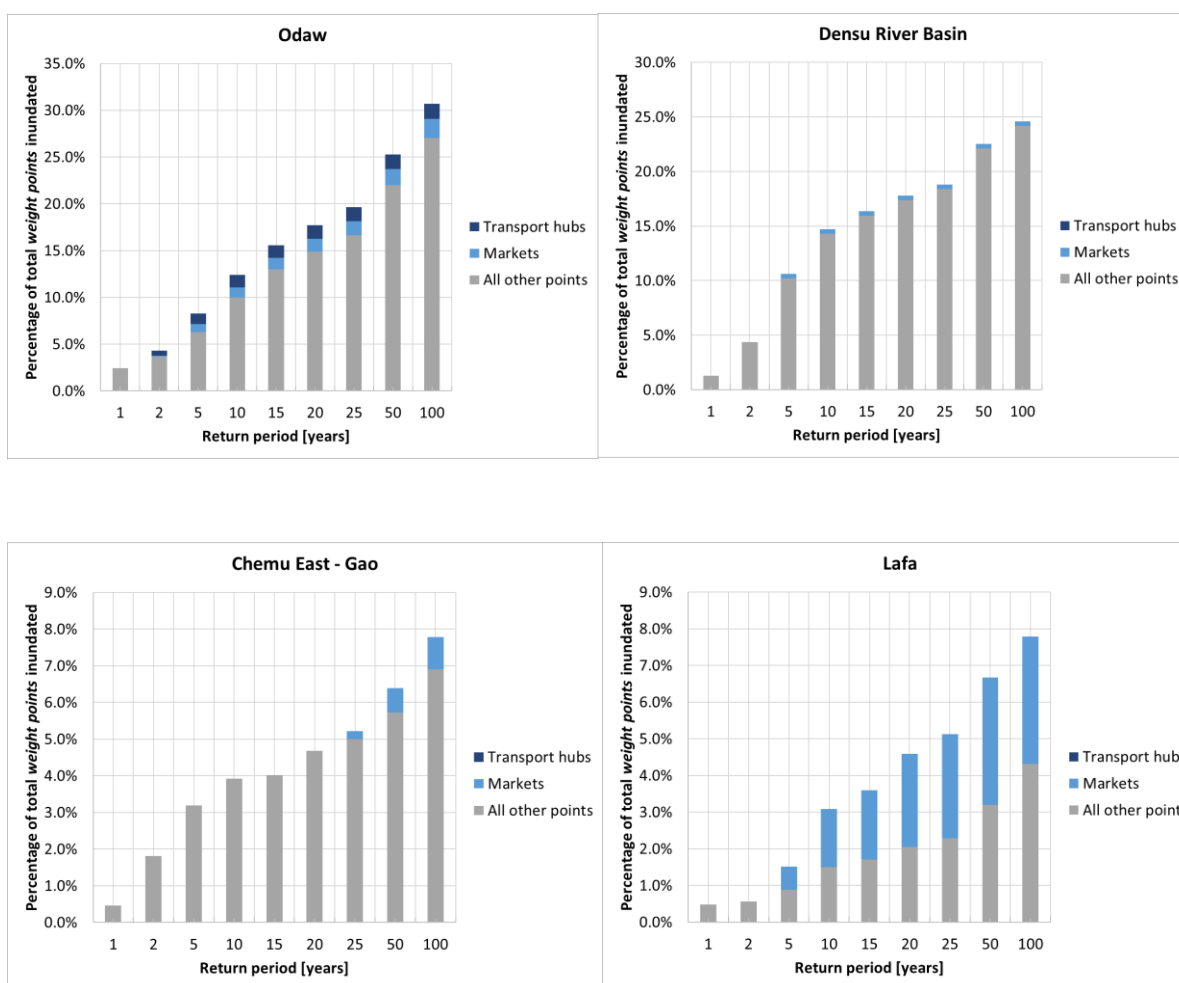


Figure 54: Graphs showing the percentage of flooded weight points, as per modelled return period bands, to total number of weight points for the basins Odaw, Densu, Chemu East – Gao and Lafa. The relative importance of table-top markets and transport terminals to residential areas are shown in light and dark blue, respectively.

#### 6.4.10. Payout calculation

In the operational system ICEYE's maximum extent flood footprint data will be used to determine the number of the flooded *weight points* within each basin shortly after each significant flood event. Any *weight point* at equal or higher than 30 centimetres of water will be considered to be flooded. If the sum of flooded *weight points* exceeds the individual pre-defined payout thresholds for any of the basins (Section 6.4.9) the insurance scheme will trigger.

The payout calculation procedure from this parametric FFP scheme essentially is a combination of (a) the payout function relating the return period of the flood to a percentage of the maximum payout (Table 12), (b) the scaled insurance limits for the three basin groups (Table 19) and (c) the individual *weight point* thresholds per basin per return period (Table 20). See following hypothetical payout calculation example:

*A flood is observed in the Osu-Klottey basin. After analysis of the maximum flood extent, provided by ICEYE, it is calculated that a total of 2'500 weight points were flooded. From Table 20 we find that this exceeds the threshold for the 10-years return period for this basin, but not the threshold for the 15-years return period. The Government has chosen the CAT coverage*

*option. From Table 12 we see that for a CAT coverage, at a return period of 10 years, 10% of the maximum payout will be triggered. In Table 19 we find that the maximum payout for the Osu-Klottey Basin is USD 0.5 million. This means that the payout for this event will be 10% of USD 0.5 million, which is USD 50'000.*

#### 6.4.11. Maximum annual payout (insurance policy limit)

Table 19 provides the maximum payout per basin and per flood event occurrence. Besides the individual occurrence limits the project team also recommends an annual maximum total payout limit across the entire policy. This would mean that if multiple flood events happen and/or multiple basins are hit by floods during the year, the payouts add up until they reach the cumulative annual aggregate policy limit, and in no case would there be a higher recovery under this scheme. Such an annual aggregate policy limit helps capacity providers to manage their exposure and sets clear expectations for the insured. It also limits the required budget.

Just like the maximum single event limit, the overall policy limit could also be set to USD 10 million. It would also be conceivable to set the limit twice as high, for example, in order to allow a maximum of two full limit payouts per insurance term. The following example assumes a USD 10 million policy limit:

*The Government has chosen the FFP scheme and the BALANCED payout option. A flood event in Sakumono in May is determined to have a return period of 15 years, resulting in a payout of 50% of the basin's maximum payout of USD 1.5 million. This results in a payout of USD 750'000. Later this year, the Odaw basin will be hit by a flood, which is determined to be a 20-year flood, which would theoretically result in a 100% payout of the basin's maximum payout (i.e. USD 10 million). However, the policy's maximum total annual payout is USD 10 million. With a USD 750'000 payout already made in May, the payout to the government for this second Odaw flood would now be capped at USD 9.25 million, bringing the total annual payout to the full policy limit of USD 10 million.*

#### 6.4.12. Annual expected losses (AEL)

The annual expected losses (AEL) for each basin individually and the resulting combined AEL for the entire scheme form the basis for determining the insurance price. To compute the AELs, the probability matrix of all possible payout combinations across all basins must be estimated for both the BALANCED option and the CAT option.

##### Basin correlation assumptions

The dependency between floods across GAMA'S basins is dictated by the spatial variability of rainfall, which was not accounted for in the original generation of flood hazard maps adopted for FFP product design (Section 6.4.4). As indicated in the model description section earlier, the available hazard maps were generated separately for each basin based on spatially uniform design storms, with the same design storm parameters adopted for all basins. To estimate correlation probabilities and, ultimately compute the AEL values, 20'000 Monte Carlo simulations were conducted for two dependency assumptions:

- Situation of **full dependency** between the basins: if a basin floods, then all basins flood with the same return period. The Monte Carlo samples a flood with a certain return period, which will then be assigned to all basins.
- Situation of **no dependency** between the basins: flooding occurs entirely independently throughout all basins. For each basin individually, the Monte Carlo samples a flood with a certain return period, without taking the sampled value for the other basins into account.

The AEL estimates for both assumptions provide upper and lower limits. In reality, the true dependency is somewhere between these two situations. Considering the high spatial variability of the area's typical rainfall patterns the actual AEL likely sits closer to a situation with no dependency than with full dependency, as already alluded to in Section 6.4.4. Potential capacity providers of this insurance system must develop their own understanding and arrive at their AEL (the technical rate) in the underwriting process.

### Annual expected loss range estimates

The AELs for full dependency and no dependency are presented in Table 21 for the BALANCED coverage option and in Table 22 for the CAT option. Calculating the BALANCED option results in higher annual expected loss rates, ranging from USD 0.9 million to USD 1.3 million, while the CAT option ranges from USD 0.6 million to USD 0.9 million.

Table 21: Annual exceedance probabilities for all return period payout steps for the BALANCED option, per basin group, and the overall AEL for this option highlighted in green.

Return period	Probability	Payout (USD) Group I basins <sup>62</sup>	Payout (USD) Group II basins <sup>63</sup>	Payout (USD) Group III basins <sup>64</sup>	Annual Expected Loss (USD) Full Dependency	Annual Expected Loss (USD) No Dependency
< 5 years	80%	-	-	-		
5-10 years	10%	1 million	150'000	50'000		
10-15 years	3%	2.5 million	375'000	125'000		
15-20 years	2%	5 million	750'000	250'000		
>20 years	5%	10 million	1.5 million	500'000		
<b>AEL (USD)</b>					<b>0.9 million</b>	<b>1.3 million</b>

<sup>62</sup> Group I: Odaw basin, with maximum basin payout USD 10 million

<sup>63</sup> Group II: Chemu -West, Sakumono, Songo-Mokwe, with maximum basin payout USD 1.5 million

<sup>64</sup> Group III: Chemu East-Gao, Densu River Basin, Kpeshie, Lafa, Odu-Klottey with maximum basin payout USD 500'000

Table 22: Annual exceedance probabilities for all return period payout steps for the CAT option, per basin group, and the overall AEL for this option highlighted in green.

Return period	Probability	Payout (USD) Group I basins	Payout (USD) Group II basins	Payout (USD) Group III basins	Annual Expected Loss (USD) Full Dependency	Annual Expected Loss (USD) No Dependency
< 10 years	90%	-	-	-		
10-15 years	3%	1 million	150'000	50'000		
15-20 years	2%	2.5 million	375'000	125'000		
20-25 years	1%	5 million	750'000	250'000		
> 25 years	4%	10 million	1.5 million	500'000		
<b>AEL (USD)</b>					<b>0.6 million</b>	<b>0.9 million</b>

## 6.5. Real-time monitoring of the index

### 6.5.1. Introduction to ICEYE Flood Solutions

ICEYE's Flood Solutions harnesses innovative, miniaturized synthetic aperture radar (SAR) technology, complemented by additional auxiliary data, to generate near real-time insights into natural catastrophes, beginning with floods (Figure 55). Leveraging the world's largest SAR constellation, ICEYE can monitor floods on a global scale, contingent upon weather conditions. SAR technology enables visibility through clouds, smoke, and darkness, rendering it ideally suited for monitoring catastrophic events such as widespread floods.

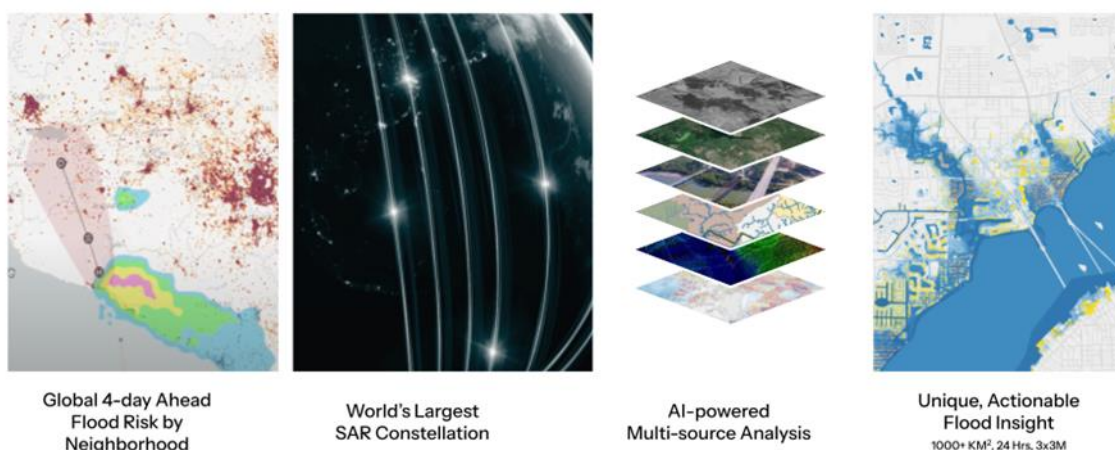


Figure 55: Basic pillars that make up the generation of ICEYE's flood footprints.

### 6.5.2. 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 analysing 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 56).

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).

## FLOOD INSIGHTS GENERATED THROUGH MULTI-SOURCE ANALYSIS FOR HIGHEST ACCURACY

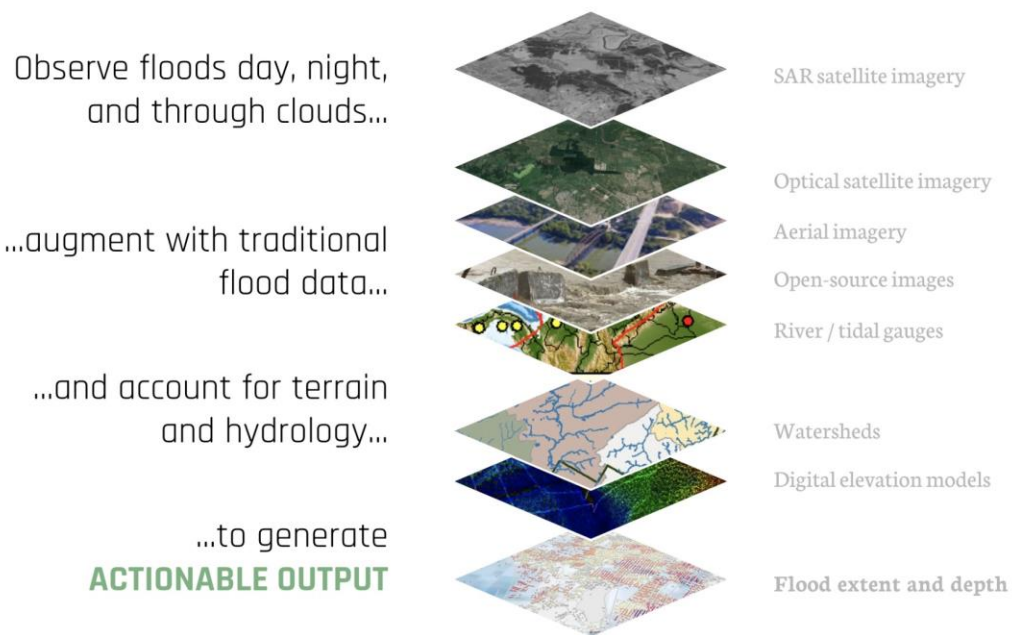


Figure 56: Further auxiliary data sources that augment the SAR imagery for the final maximum flood extent footprint.

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 centimetres 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 typically at 4-metre horizontal resolution (with discrete depth values at centimetres 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.

### 6.5.3. Timeline of different Flood Solution Deliverables

Currently, the ICEYE team activates a flood analysis when the designated flood threshold is met – which is determined on a combination of ICEYE acquired imagery and social media data collection. The status of activations and potential activations are shared with the end users.

If the analysis threshold is passed, ICEYE initiates an analysis and sends a notification to impacted customers in private and public sector, including MoF, NADMO and any other public stakeholders as

decided by the MoF. The notification includes an Observed Flood Report which provides an initial estimate of the impact of the event (including which towns have been impacted and where the flooding appears to be most severe), and an estimate for when data will be delivered.

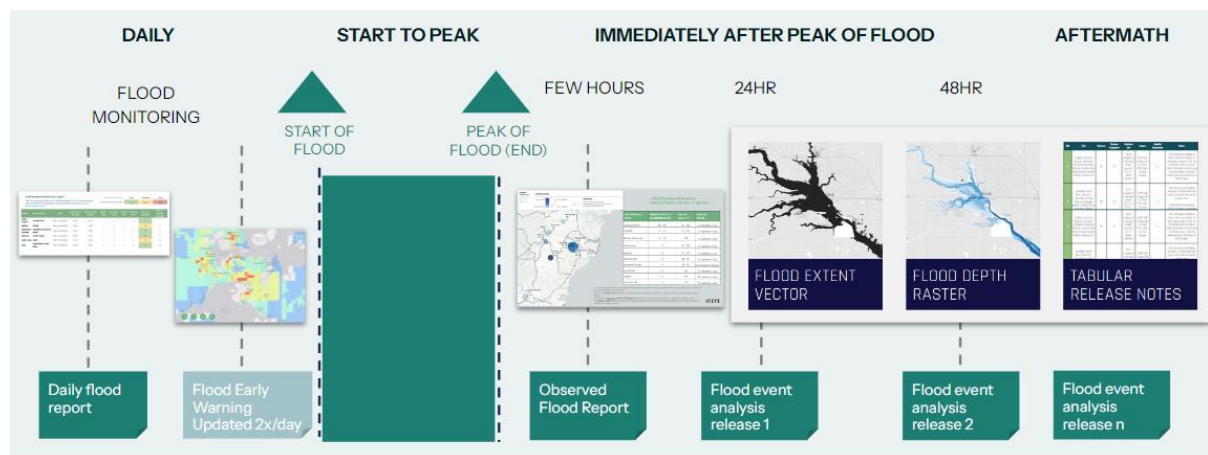


Figure 57: Timeline of different Flood Solution Deliverables.

For all events, ICEYE targets delivering the first release of data within 24 hours of activation (Figure 57 and Table 23). If the flood continues to evolve or more data becomes available, ICEYE produces a second release within the following 24 hours (i.e. 48 hours after initiating an analysis). Any subsequent releases depend on event size and duration – if the event is ongoing or additional data has become available, ICEYE will continue to produce additional data releases. In each release delivery notification, ICEYE includes whether the given release is the final release or if another release is expected. However, in most events of similar geography to the scope of this project, the final release is delivered within 5-7 days of the event peak (though there are examples of flash floods with only one release as the final release, and there are examples of larger tropical storms that triggered 8-10 releases).

Table 23: Details of different Flood Solution Deliverables.

Output	Scope	Release timing	Delivery method
Daily Flood Events Report	Produced globally for all events ICEYE is monitoring or analyzing	Daily (weekdays only)	Sent to customers via email
Observed Flood Report	Produced for each flood event ICEYE analyzes	Within 12 hours of initiating a flood analysis	Sent to customers via email
Analysis release 1		Generally, within 24 hours of initiating a flood analysis	Sent to customers via their selected data delivery option
Analysis release 2	24 hours after the first release	of secure cloud transfer (eg AWS S3 or Azure Blob), partner platform, Esri image/feature service	
Analysis release n	Ongoing releases as additional flood observations are collected or as the flood is evolving		

#### 6.5.4. Flood types and ICEYE flood footprint data

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 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 analyse 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.

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

#### 6.5.5. May 2022 Accra Flooding Case Study

##### Event Description

Heavy rainfall with totals of up to 150 millimetres hit the West African coast between 21-26 May 2022 as a result of a flare-up activity from the ITCZ (Intertropical Convergence Zone) which flows eastward across central Africa. This caused flash floods in different parts of Accra from 22-25 May 2022.

##### Flood Data Inputs

- ICEYE SAR imagery: image acquisition on May 25 at 9:24 UTC (Figure 58);
- Sentinel-2 data shows some open area flooding on May 23;
- 72 geolocated observational data points showing evidence of flood; and
- High resolution 0.5 metre DEM;

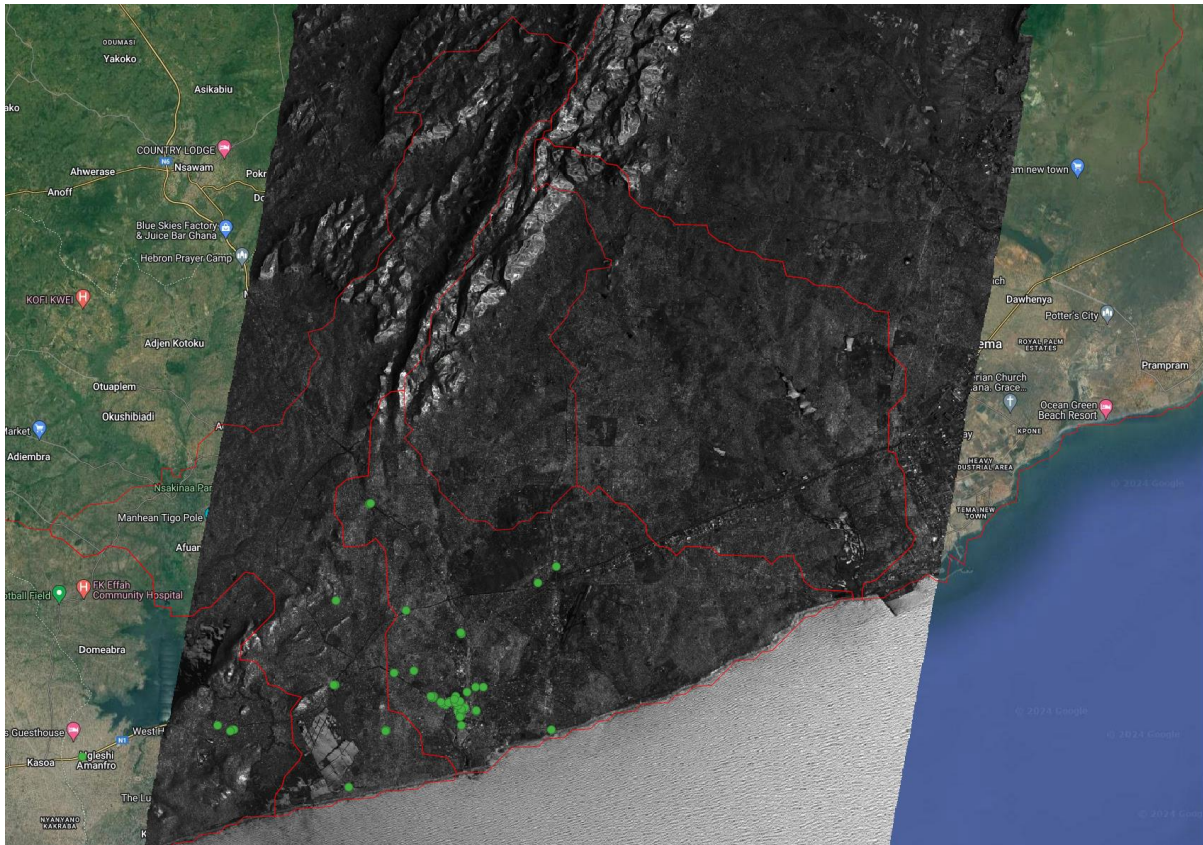


Figure 58: ICEYE's original data inputs for flood analysis of the May 2022 Accra floods.

## Statistics

Total flooded area observed by ICEYE: 32 km<sup>2</sup> (Figure 59).

It is important to note, the 21-26 May 2022 flood event was monitored before Ghana was officially onboarded for the purpose of this project and going forward. Only one SAR image was captured by chance. Future floods will now be monitored consistently (24/7) and flood footprint results will likely come out at a higher accuracy and resolution.

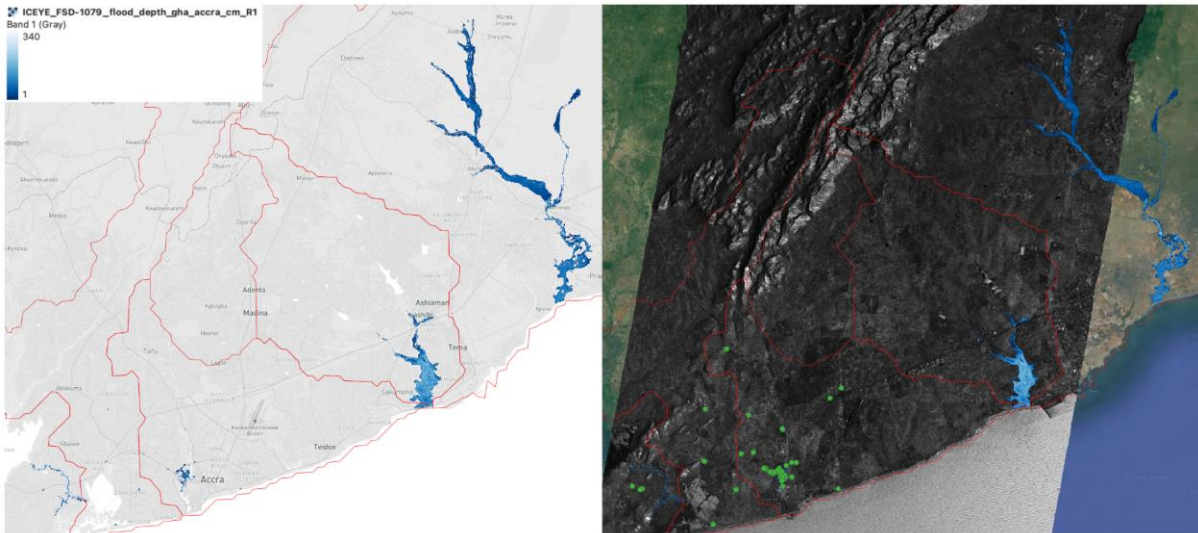


Figure 59: ICEYE's Flood Footprint output of the May 2022 Accra Floods. Blue colour scheme shows water depth of the maximum flood extent.

#### 6.5.6. ICEYE Flood Insights Validation

The images in Figure 60 show comparisons of the ICEYE Flood Insights data with visual confirmations of flooding from the same event – 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.

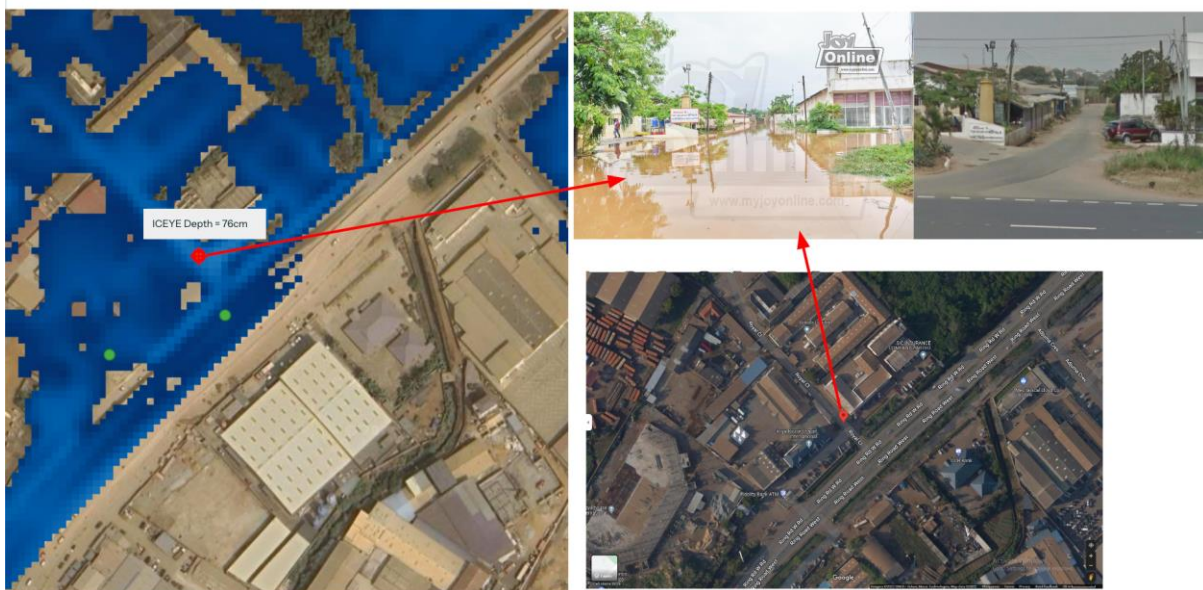


Figure 60: Details of ICEYE's Flood Output of the May 2022 Accra Floods. Blue colour scheme shows details of the maximum flood extent in left image. Marked location coordinates are 5.563386, -0.227861, determined at water depth of 76 centimetres. Right top images show the location's street with and without floods. Bottom right satellite image for reference. Source: ICEYE.

#### 6.5.7. Costs for monitoring services

The 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 itself, which would be a 'first', ICEYE will also make its data available to all Ghanaian authorities involved in direct disaster relief after floods. This is an extra service that is delivered exclusively with the FFP solution. 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.

Quoted pricing for ICEYE's data service for the FFP insurance scheme ranges from a total annual fee of [REDACTED] For the example of a 12% RoL and USD 10 million insured limit, the Government should factor in a total service fee of anywhere between approximately [REDACTED] of the total premium).

This fee varies depending on the risk profile the Government chooses 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 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.

#### 6.5.8. Garbage Monitoring with ICEYE SAR imagery

The accumulation of garbage in certain areas of Accra is a known problem – and one that is likely to worsen flooding during heavy rain events due to blockage of drainages. ICEYE's satellites with their radar technology can see the ground unhindered by cloud cover or darkness. The consistent monitoring of landscape changes is a central use case. Therefore, as a side project, driven by discussions with project participants, ICEYE sought to see whether it could detect changes in waste accumulation, i.e. the cleanliness of key drainage (Figure 61). This waste monitoring can then be used as part of an incentive program for Government actors in future transactions. This means that capacity providers could offer premium discounts for a garbage-free situation throughout the rainy season due to the significantly lower risk of flooding.

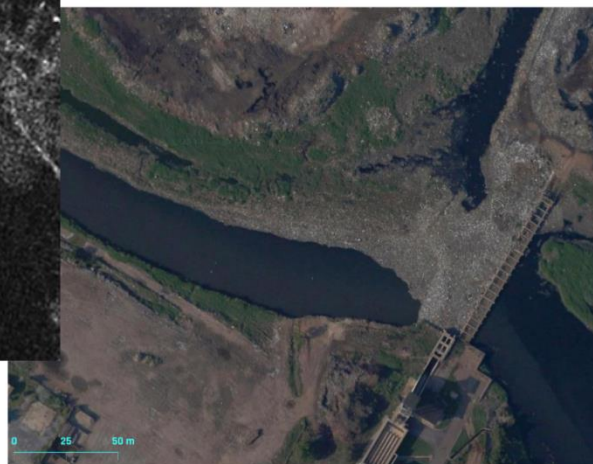


Figure 61: ICEYE imagery showing Garbage clogging in the Odaw river at the Korle Lagoon interceptor weir on the 20<sup>th</sup> (upper) and the 27<sup>th</sup> (lower) of April 2023. Top and lower left-hand are SAR images, lower right-hand is an optical image for comparison.

While more research needs to be completed, it does appear that ICEYE's satellites could identify garbage patches within the main river basins – and thus, some volumetric calculation of garbage in these areas (or, more accurately, the amount of garbage clean-up) could be used in a local incentive program.

## 6.6. 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. Specialized third-party modelling agencies can create modelled flood footprints using rainfall inputs and hydrological considerations. 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. Fallback reporting agencies that could be considered for the Ghanaian territory include HKV, Fathom and JBA.

## 7. Illustrative Pricing

*Disclaimer: this chapter contains only non-binding indications developed from general market experience with parametric insurance schemes elsewhere. The final price of the proposed parametric flood insurance scheme is subject to final terms and conditions, the risk transfer environment at time of placement, as well as fully established primary insurance and reinsurance wordings.*

Just like in any other insurance contract, the price of the proposed parametric XSR or FFP coverage will contain a risk transfer margin, often referred to as loading. This section provides a general overview of the loading that would be charged by capacity providers if the scheme were to be placed through the local and international re-/insurance market. The loading must be added to the annual expected loss rate (AEL), the pure *technical rate*, presented in the sections above. Loadings will first be determined individually by each capacity provider and later summarized into a uniform average rate applicable to the insured. The combined nominal amount, AEL plus loading, forms the final annual price for the parametric insurance scheme (the premium).

### Elements that make up insurance loadings

The loading contains several elements, such as:

- **Cost of capacity** that suppliers have to accommodate: variable as per target risk profile, i.e. depending on attachment and full limit exceedance frequency and AEL;
- Internal and external **operational expenses** of suppliers;
- **Reporting fees** for the provision of monitoring services to accurately determine flood events (e.g. ICEYE in case of FFP coverage, see Section 6.5, no extra costs expected for the XSR coverage);
- Potential **calculation and event reporting fees**;
- Potential **legal fees**;
- **Profit margin** of suppliers; and
- Further **frictional costs** (Table 24) include, amongst others:
  - Fronting commissions;
  - Premium and re-insurance tax;
  - Brokerage – in the event that brokers are involved in the placement.

Indicative costs for items attributed to frictional costs are presented in Table 24 as a proportion of the premium, based on proportional business across five comparative African markets. It is important to note that the item '*commissions*' will likely be benign, or not applicable at all, to the proposed novel sovereign risk transfer scheme. However, the fronting cedent must decide on this.

*Table 24: Estimates of frictional costs based on proportional business across five African markets. Rates are stated as an additional loading to be added on top of the technical rate and other loadings.*

Frictional cost item	Kenya	Uganda	South Africa	Ghana	Senegal
Commission (approx.)	23.00%	23.00%	31.00%	23.00%	31.00%
Premium Tax	1.00%	1.50%	-	-	-
Reinsurance Tax (on net)	5.00%	10.00%	-	1.73%	-
RI Brokerage	2.50%	2.50%	2.50%	2.50%	2.50%
<b>Total (approx.)</b>	<b>31.50%</b>	<b>37.00%</b>	<b>33.50%</b>	<b>27.23%</b>	<b>33.50%</b>

### Price range

Despite the novelty of the FFP product and requirement for high quality flood hazard models, which may be challenging for some capacity providers, the FFP solution promises lower basis risk in contrast to the XSR solution. Lower uncertainty is therefore expected to tighten the technical rate in favour of the FFP solution.

However, loadings must be applied to both solutions. The loading can be expressed in form of a multiple, which makes communication easier. This multiple is a number larger than one that is ultimately multiplied with the AEL to result in the so-called *rate on-line* (RoL), or nominally, the insurance premium.

In any case the project team assumes that the local and global insurance industry prices the insurance scheme at affordable rates. For this scheme and under current market conditions, the project team expects a multiple for either the XSR and FFP solution in the range of 1.5 to 2.0. This is highly speculative and subject to final terms and conditions.

## 8. Conclusions, Limitations and Outlook

### 8.1. Recommendation to the Government

The objective of this project was to design an insurance solution to help poor and vulnerable people in Accra recover and re-establish economic activity quickly after a severe flood.

After consideration of all data, information and requirements, the project team is convinced that parametric insurance is feasible. Consequently, both the excess rainfall (XSR) and the flood footprint (FFP) parametric schemes were fully developed. Given the higher resolution and the fact that it is better tailored to locations with poor and vulnerable people, the project team believes that the basis risk for the FFP is lower, and it is best suited to achieving the Government's goal. Due to the novelty of this technology and other side benefits, it would also reflect positively on Ghana's image as a front runner in the fight against climate risks. In case the Government or the insurance market does not feel comfortable implementing the more novel FFP technology, they can fall back to the excess rainfall solution.

Based on historical and budgetary considerations, the project team proposes to set the maximum payout from this insurance scheme at USD 10 million. To achieve cost efficiency and optimal return on investment, the project team suggests focusing on less frequent but more catastrophic events. A parametric trigger ideally starts with smaller payout amounts for 1 in 10 years events and pays the full USD 10 million limit for 1 in 20 years events. Taking all circumstances into account, the total price for such recommended insurance coverage is likely to be around USD 1'500'000 annually, of which the state would have to finance around USD 700'000 itself in the first three years. Final terms and conditions will have to be considered.

In parallel to the technical product development, UNDP and NADMO lead the creation of a contingency plan and consulted over 35 stakeholders. In the plan it is determined that funds from an insurance payout can be best employed by food relief assistance, restoration of livelihood support for affected small businesses, emergency shelter and non-food relief items, logistics services, environmental sanitation and hygiene promotion, support for restoration of teaching and learning and restoration of critical infrastructure. In case of a payout, insurers will distribute the funds to the MoF, who will forward them to NADMO's account. NADMO then determines how funds are best employed as per the contingency plan, using its internal accounting control system. Distribution of funds is audited later.

After successful implementation of the scheme, the parametric structure, the insurance limits, the contingency plan, etc. can all be modified and further enhanced in the next years.

### 8.2. Limitations

#### 8.2.1. Basis risk considerations

The payout of a parametric insurance is pre-defined based on the exceedance probabilities of naturally occurring parameters, as explained in Section 6.2.1. With parametric solutions, there is always some discrepancy between the payout and the actual financial losses in a flood disaster. However, the FFP solution stands out positively. Floods are directly observed in certain areas that are attributed to the

poor and vulnerable population. It is therefore avoided to use precipitation as a proxy indicator for flood. 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.

A remaining source of basis risk for FFP solutions arises from low quality flood hazard models and their consistency with respect to the monitoring technology. On the trigger side there is a risk of intermittent or erroneous satellite observation. ICEYE must ensure it steers 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.

### 8.2.2. Data availability and quality

For XSR product development, records from only two main GMet monitoring stations, plus a supplementary third station, were found suitable for product design and operation. Records from seven other GMet manual stations and 15 TAHMO stations across GAMA were too short and patchy for use in product design or operation. While the gauges adopted for product development show good predictability of severe flood events across GAMA, their sparsity is a limitation that will impact basis risk, particularly given the typically high spatial rainfall variability across GAMA. Going forward, interested parties should monitor improvements in the GMet and TAHMO networks, keep an eye on data from new sensors being installed as part of the GARID project, as well as on new satellite-based and re-analysis rainfall datasets which could improve rainfall and flood hazard characterisation across GAMA.

In the case of the FFP product, it is important to point out that data from ICEYE is only available for larger and more catastrophic flood extents, not for shorter flash floods. This means data will only be made available for floods of typically  $\geq 12$  hours of non-permanent standing water, over affected areas of  $\geq 300 \times 300$  meters and  $\geq 30$  centimetres of flood depth. No ICEYE flood footprint can be expected for smaller floods of flash flood nature.

Another point to mention for FFP is the alignment of the hazard view and the trigger: discrepancies between the modelled maximum flood extents and the operational data set can be further reduced through upgrades on both sides. New insights and high-resolution data will help with flood modelling; A growing constellation and increasingly frequent monitoring of even smaller events by ICEYE will further improve the trigger side.

For historical loss estimates, the project team relied on third-party data sources rather than direct Government data sources. Furthermore, only the June 2015 event was analysed in detail. Improvements of the historic database are conceivable and would help to refine parametric trigger thresholds.

### 8.2.3. Public opinion and political risk

Given the characteristics of GAMA's flood risk and the goals of the Government, the project team believes the proposed '*catastrophic*' (CAT) payout function is most fit for purpose. However, under such structure significant time may pass without any payout from the scheme. Experience has shown that public and political perception might become negative over time ("*premium is waste of money*").

Although this insurance scheme should pay out once every ~10 years over the long term, depending on the desired risk profile, it is not as guaranteed as a reserve fund. Less tangible, but not to be forgotten even if no payout has yet been made, insurance contributes to economic confidence and reduces the volatility of budget planning. For example, in 2022, the Turkish Catastrophe Insurance Pool (TCIP) announced that it had paid out USD 84 million since its inception 21 years ago. But after the devastating Kahramanmaraş earthquake in 2023, it announced in 2024 that it had paid out USD 1'140 million (MiddleEastInsuranceReview, 2022&2024). This makes the sense of such an insurance scheme very clear.

### 8.3. Potential next steps

#### 8.3.1. Road map 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 suggests the following steps:

- 1) Endorsed by NADMO and NIC, the Ghanaian MoF can decide to implement the insurance solution.
- 2) In an introductory meeting in April 2024, the MoF's procurement team indicated that after MoF's official decision to proceed they can drive the procurement process. The procurement team would also determine if support from a consultant/broker is deemed necessary. UNDP's IRFF has offered to support MoF during this process.
- 3) Depending on the chosen procurement path, the MoF might decide to initiate a tender.
- 4) Once the local fronting insurer and the re-/insurance panel has been selected, the cover can be bound and incept.

It is important to consider that there will be national elections in December 2024 which may change the stakeholder landscape on the Government's side.

#### 8.3.2. Insurance panel

An insurance panel to this scheme will require at least one local insurer in Ghana at possession of a primary insurance license. From an alignment of interest, it is desirable that this fronting insurer retains at least 1% of the risk. It will issue the insurance policy to the MoF and secure sufficient capacity. Given that natural catastrophe risk, particularly parametric insurance for urban flooding, are relatively novel to the Ghanaian insurance market, it is likely that most of the insurance capacity will be provided by larger reinsurers such as Allianz Re, Swiss Re or their peers. The majority of the capacity is therefore expected to be provided by international reinsurers. From a regulatory perspective, NIC wishes that other local insurers are also invited to consider their participation as a *'follower'* on the panel, with smaller shares.

#### 8.3.3. Further enhancement of the products

The reliability of an XSR solution could be significantly enhanced by improving and expanding the rainfall monitoring network across GAMA (Section 6.3.2). Regular maintenance of existing stations and the deployment of backup gauges would increase data quality and reliability. Expanding the network

with new stations and other rainfall sensors would enable better characterization of rainfall spatial-temporal patterns, thus reducing basis risk and improving flood modelling, benefiting both the XSR and FFP products. Interested parties should monitor improvements in the GMet and TAHMO networks and pay attention to data from new sensors being installed as part of the GARID project. These include an X-band radar, 18 automatic weather stations (AWSs), and numerous river level and flow gauges. Additionally, the potential use of EUMETSAT rainfall estimates, ideally in combination with ground stations, should continue to be explored. Interested parties should also keep an eye on new satellite-based and re-analysis products that could enhance rainfall and flood hazard characterization in GAMA.

The ongoing GARID project will further improve drainage, which should reduce flood risk throughout the GAMA area. So, after significant improvements in the near future, flood hazard maps should be updated based on GARID's LiDAR DTM data and incorporating improvements in the drainage system.

Future potential incorporation of flow gauges into ICEYE's flood footprint generation process would improve event reconstruction.

Since waste clogging significantly increases the risk of flooding, the project team also took this into account in the FFP insurance solutions. One idea is to use ICEYE's radar satellite technology to detect reflection patterns that provide insight into the amount of waste accumulation (or lack thereof) in the major rivers and drains that flow through GAMA (Section 6.5). Depending on whether these rivers are litter-free at some point in the year before the rainy season, a premium discount could be considered. Insurers would be exposed to less risk and share the benefits with the Government, representing a win-win and an overall improvement in resilience. However, such an incentive mechanism would require careful design and consideration. For example, if waste is deposited right next to riverbeds and drains, rising water levels after heavy rains would immediately wash it back into the waterways.

#### 8.4. Lessons learned

As the two-year project aimed at developing a parametric flood insurance solution in Ghana concludes, several key lessons have emerged. These lessons, drawn from both general project management and the technical development process, offer valuable insights for future projects.

##### Strong local collaboration and introducing a local project manager

The appointment of a local project manager was instrumental in aligning the project team with government stakeholders, ensuring that cultural nuances and local context were fully understood and integrated into the project. This role facilitated smooth data exchange, fostered trust among stakeholders, and effectively addressed challenges related to data sharing, project administration, and stakeholder engagement.

##### Early stakeholder onboarding and continuous engagement

Engaging regulatory authorities and national insurance associations from the outset proved invaluable, particularly as the technical product design reached its draft stage. Early and continuous involvement ensured alignment with regulatory frameworks and helped address potential challenges before they escalated.

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. The in-person kick-off workshop in Accra was a catalyst, but it took an additional six months of close collaboration for the project team and local stakeholders to align on a common goal and project scope. In addition, all important local partners should be regularly informed about the latest status of the project.

#### Communication, feedback and capacity building

Clear and transparent communication regarding the role of insurance in catastrophe risk management and financial planning was vital. Emphasizing and regularly repeating that insurance reduces volatility and creates stability, despite its costs, helped manage stakeholder expectations. Frequent roundtable discussions with local stakeholders provided a platform for sharing progress, gathering feedback, and addressing concerns. This open communication helped in aligning expectations and building a shared understanding of the project's goals and benefits.

Building local capacity through training programs for government officials and other stakeholders ensured that the technical knowledge required to sustain and further develop the insurance solution remains within the country.

#### Planning for political shifts and securing government champions

Political changes, such as elections, can cause delays and disruptions. In the case of Ghana, there has been a change of the finance minister and elections came up at the end of the project. Anticipating these shifts and securing active participation from key government "champions" were crucial in navigating political complexities and maintaining continuous project support. These champions must have decision-making authority, facilitate data sharing from other institutions, navigate political complexities, and be deeply invested in representing the project's goals at a high level.

#### Early discussions on implementation and premium financing

Initiating early discussions with the government on implementation decision criteria and premium funding is crucial for aligning expectations and securing the necessary financial commitments. These early dialogues helped clarify the project's financial and operational aspects, ensuring a smoother transition from design to implementation.

#### Alignment of the product solution with the contingency plan

As the product needs to be closely aligned to the purpose of the insurance payout, there is a critical dependency on the contingency plan. This alignment ensured that the insurance payouts are used effectively to mitigate flood risks and support affected communities. Clarifying the critical elements of the contingency plan early is essential for ensuring alignment with the insurance product.

#### Overcoming data challenges and enhancing data infrastructure

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, potentially during the grant application phase, is vital for determining the project's timeline and success potential.

Local Government institutions sometimes questioned whether the project team should pay for data sharing. This should not be the case. The project is supported by the ISF and (partially in-kind) by the industry, and the beneficiary is the Government of Ghana. More and better data means less

uncertainty and therefore a smaller risk margin for which the Government would 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.

#### Streamlining project administration and budget flexibility

The project's administration, including time and budget management, benefited from being simplified and centralized from the start. Allowing flexibility in budget allocation was beneficial, enabling the project team to adapt to unforeseen challenges and avoid significant delays.

## 9. Acknowledgements

We extend our sincere gratitude to everyone who contributed to the completion of this project over the last two years. This achievement would not have been possible without the dedication and support of many individuals.

Firstly, we express our deepest appreciation to the Government of Ghana and its institutions. In particular, we thank the Ministry of Finance, National Disaster Management Organization, Ghana Hydrological Agency, Ghana Meteorological Agency, National Insurance Commission, and Ghana Insurance Association for their trust and guidance.

A special thanks goes to Foster Gyamfi, Principal Economics Officer at the Ministry of Finance, and Charlotte Norman, Director for Climate Change Adaptation and Disaster Risk Reduction at NADMO, whose leadership and guidance were instrumental in bringing this project to completion.

Productive collaboration with Government stakeholders could never have been established without the introductions and continuous facilitation by the United Nations Development Programme, in particular Amina Sammo and Linet Odera.

The first-time development of an insurance solution like this is costly and risky. It is unlikely it would have materialized without the approach of the Tripartite Agreement between UNDP, the Insurance Development Forum and BMZ, which separated the product development from a potential risk transfer. We commend the InsuResilience Solutions Fund for providing 50% funding through grant from the IDF and its partners (in this case Allianz, Swiss Re and HKV) for providing 50% of the funding in kind.

Special thanks are due to Annette Detken and Olga Mursajew, Annette from the Frankfurt School of Finance & Management, whose critical insights, constructive critiques and feedback during the project execution significantly enhanced the quality of the project.

We are immensely grateful to the technical team that helped to design the parametric product and contributed to this report, including Lukas Sunderman (Swiss Re), Bastian Manz and Lovemore Forichi (Allianz), Dorien Lugt and her team (HKV), Susana Ochoa Rodrigues (RainPlusPlus), Lawrence Gynaye and Michael Bennett (ICEYE) as well as Petra Izeboud (FloodTags). Their tireless work in data collection, analysis, and interpretation combined with their expertise and attention to detail, have been invaluable.

We also wish to acknowledge the project management provided by Akua Acheampomaa Asante (Allianz Ghana), Franziska Wasserhess, Nico Ahn, Louis Gaudin (Allianz SE) and Yussel de Kraa (Swiss Re) whose organizational skills ensured the smooth coordination of this project, and their editing guaranteed the delivery of this report.

To all who have contributed, directly or indirectly, your efforts and support are deeply appreciated.

We hope this insurance solution will be implemented so that, when an extreme flooding disaster occurs in GAMA, significant funds will be made available to support a swift recovery, particularly for the economically less resilient group of society.

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## 11. Appendices

Please note that two versions of the appendices have been prepared, bundled in zip folders:

- **C5.23 ISF IDF Ghana\_ReportAppendices\_All\_Data.zip:** Includes all report appendices, as detailed below, featuring proprietary rain gauge records from GMet and flood hazard maps from the GHA. This version is intended exclusively for local Ghanaian agencies.
- **C5.23 ISF IDF Ghana\_ReportAppendices\_NoProprietaryData.zip:** Similar to the above, but excludes long-term records from GMet stations and flood hazard maps. These proprietary data sets require permission from GMet and GHA for access. This version is intended for wider dissemination.

### 11.1. Appendix 1: Geographic Boundaries

Folder name: C5.23 ISF IDF Ghana\_Appendix 1\_GeographicBoundaries

### 11.2. Appendix 2: Rainfall & flooding time series used for XSR product design

Folder name: C5.23 ISF IDF Ghana\_Appendix 2\_Rain&FloodingTimeSeries\_XSR\_DesignData

### 11.3. Appendix 3: Target weight points and flood hazard maps used for FFP design

Folder name:

C5.23 ISF IDF Ghana\_Appendix 3\_TargetWeightPoints&FloodHazardMaps\_FFP\_DesignData

### 11.4. Appendix 4: XSR & FFP wording templates

Folder name: C5.23 ISF IDF Ghana\_Appendix 4\_XSR&FFP\_Product\_Wordings