Lessons Learned from PARADeS Project for Flood Disaster Risk Planning and Management in Ghana

© J. Ntajal

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Preface

This document is intended for decision-makers, policymakers, and professionals responsible for flood risk management, particularly those involved in the implementation of flood risk management plans (FRMP) in Ghana. It aims to provide valuable insights and recommendations drawn from our experiences in Ghana. These lessons learned and suggestions can be beneficial in the development of Flood Disaster Risk Plans (FDRP) or Flood Risk Management Plans (FRMP), encompassing socio, technical, and governance components, as well as the models and tools developed in the context of Ghana's Flood Risk Management (FRM).

The contents published in this document is produced by the PARADeS project consortium funded by the German Federal Ministry of Education and Research (BMBF). The consortium is composed of partners who have already collaborated in other projects in the region and are active in dealing with FDRM at different institutional levels.

The German partner institutions are the University of Bonn (U-BN) research group Eco-hydrology and Water Resources Management, Department of Geography, Germany; University of Freiburg (U-FR) Faculty of Environment and Natural Resources, Chair of Forest and Environmental Policy, Germany; Flood Competence Center (HKC) Germany; and the University of Applied Sciences in Magdeburg (HS-M) Department of Water, Environment, Construction and Safety, Germany.

Key partner institutions from Ghana are the Water Resources Center (WRC), the National Disaster Management Organization (NADMO), and the Kwame Nkrumah University of Science and Technology (KNUST) - West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL). These organizations have contributed essential information, data, local expertise, and expert guidance throughout all research activities, making them invaluable partners in the project.

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About PARADeS Project

The PARADeS project focused on Ghana's national flood disaster risk reduction and management strategy by investigating existing flood risk and mechanisms for disaster management, governance-policy, human-water interaction, and development of possible future scenarios and feasible and sustainable measures.

Three case study areas with different types of flooding were identified and chosen in a participatory flood risk-based process. These are including the catchments Odaw in Accra (pluvial, fluvial and coastal floods), Aboabo in Kumasi (pluvial and fluvial floods), and the White Volta (fluvial floods).

The project used innovative socio-technical and participatory approaches and tools that combines research, development, and institutional strengthening activities. It integrated diverse information, local knowledge and data sources and was developed collaboratively with stakeholder scenarios and socio-technical tools in order to support coherent decision-making processes. A key aspect was analysing different scenarios of flood hazards, investigating and modelling cascading risk effects regarding critical infrastructure, and an assessment tool to identify flood risk at a household level, the FLOODLABEL Ghana. All processes and working steps are realized using interdisciplinary and participatory approaches together with Ghanaian stakeholders.

The end products are strengthening institutional and citizens' capacity through a series of activities on societal awareness and training of specialists, decision, and policymakers. Technologically, the project has produced a set of decision support tools (Flood Information Systems, FLOODLABEL Ghana, etc.) to effectively disseminate vital information to citizens, researchers, and decision makers to respond and mitigate the impact of flooding.

In pursuit of sustainable development in FDRM measures, we disseminated the outcomes and products, including technical tools, through reports and scientific publications. Additionally, we developed training materials tailored for students, experts, and decision-makers.

1. Introduction

This document targets decision and policy makers and professionals who are in charge of flood risk management and especially are working with flood risk management plans (FRMP) in order to reduce flood risk and enhance resilience against floods.

Within this document we compiled from our PARADeS project the lessons learned and recommendations based on our findings regarding Ghana's flood risk and its management. This may support the development of Flood Disaster Risk Plans (FDRP) or Flood Risk Management Plans (FRMP) and strategies in Ghana.

The PARADeS project aimed to contribute towards enhancing Ghana's national flood disaster risk reduction and management strategy by investigating key mechanisms, existing flood risk and disaster management, governance-policy, human-water interaction, development of scenarios, action plans and feasible and sustainable measures. In addition to examining national settings, a detailed investigation was conducted in three specific case study areas: the Odaw catchment in Accra, Aboabo in Kumasi, and the White Volta Catchment.

Worldwide since the past decade, the advancement of FRMPs envisaged to be more comprehensive, aiming to tackle various facets of flood management. This encompasses preventive measures, such as avoiding construction in flood-prone areas, protective measures to diminish the likelihood of floods in specific locations, and preparedness initiatives, including public awareness about flood risks and appropriate actions in the event of flooding (EC, 2007).

This is also reflected in the West African context, the Regional FRM Strategy and Action Plan 2020 – 2025 of the ECOWAS commission formulates the objective of a FRMP as follows "The flood risk management plan aims at reducing the negative effects of floods by taking into account local and national specificities and by integrating a regional vision at the transnational level too. Management plans should focus on prevention, protection and preparedness. Flood risk management plans should take into account the flood risk assessment; flood zone and flood risk maps; a description of the appropriate flood risk management objectives; a summary of the measures to achieve the appropriate flood risk management objectives, where they exist; a description of the cost-benefit analysis method, specified by the Member States concerned" (ECOWAS Commission 2020: 11).

Referring to the EU FRM Framework Directive, the following working steps and content, have to be considered for FRMPs:

1. Identification of water bodies at risk
2. Development of flood hazards maps with the scenarios (a) floods with a low probability, or extreme event scenarios; (b) floods with a medium probability (likely return period ≥ 100 years); (c) floods with a high probability, where appropriate. For each scenario the following elements shall be shown:

    (a) the flood extent;

(b) water depths or water level, as appropriate;

(c) where appropriate, the flow velocity or the relevant water flow.

3. Flood risk maps shall show the potential adverse consequences associated with flood scenarios referred to in paragraph and expressed in terms of the following:

   (a) the indicative number of inhabitants potentially affected;

   (b) type of economic activity of the area potentially affected;

   (c) installations as referred to in Annex I to Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control (1) which might cause accidental pollution in case of flooding and potentially affected protected areas identified in Annex IV (1) (i), (iii) and (v) to Directive 2000/60/EC;

   (d) other information which the Member State considers useful such as the indication of areas where floods with a high content of transported sediments and debris floods can occur and information on other significant sources of pollution

4. On the basis of the flood hazard maps, Member States shall establish flood risk management plans coordinated at the level of the river basin district, or unit of management.

In summary, FRMP shall address all aspects of FRM focusing on prevention, protection, preparedness, including flood forecasts and early warning systems and taking into account the characteristics of the particular river basin or sub-basin. FRMP may also include the promotion of sustainable land use practices, increase the quality of water bodies, improvement of water retention as well as the controlled flooding of certain areas in the case of a flood.

In the following sections, we illustrate the findings and lessons learned from the PARADeS project which can be useful for setting up a FRMP in Ghana. For structuring our recommendations, we referenced documents such as the EU Flood Risk Management Directive (EU FRM-FD) and the ECOWAS Regional Flood Risk Management Strategy and Action Plan. Additionally, our recommendations also drew inspiration from the following publications, which provide recommendations for establishing Flood Risk Management (FRM): "Handbook on good practices for flood mapping in Europe" (Eximap, 2007), "Current Practice in Flood Risk Management in the European Union" (EC, 2021), and "Cities and Flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century" (World Bank, 2011).

2. Flood Risk in Ghana

2.1. Flood Hazard and Risk

The dynamics of floods which are mainly induced by nature constantly change the hydro morphological structure. Often times this aggravate the impact of floods to the people and economy but this has also benefits for a multitude of biotopes. Regular flooding is a key factor for the preservation of the floodplain and its landscapes which are of high ecological value.

In hydrological terms, flooding is defined as a temporary discharge with a high-water flow at which a water level or discharge in a certain cross-section is above a (statistically) defined value. Floods are caused by high precipitation, i.e., rain or snowmelt or a combination of both. The amount of runoff depends largely on three factors: soil properties such as storage capacity and soil saturation, the amount of precipitation and the intensity of precipitation. Six types of floods are identified by “National Oceanic and Atmospheric Administration (NOAA)”, which are river flood (fluvial flood), coastal flood, storm surge, inland flooding, flash flood (pluvial flood) and debris flow. These floods can be characterised by the location, likelihood of occurrence, intensity or magnitude, duration and extent. While fluvial floods can affect large areas and therefore may affect many riparian people flash flood is most dangerous due to its sudden occurrence with some causes: as the result of intense storm rainfall over the catchment, from the failure of constructed dams, levee failure, glacial lake outbursts (Archer and Fowler, 2022).

Flood risk is the potential for loss of life, injury, or damage to assets within a system, society, or community over a specific period, assessed probabilistically by considering the likelihood of a flood event occurring and the resulting consequences, taking into account the interplay of hazard, exposure, vulnerability and, capacity (Own definition, drawing partly ; UNISDR, 2017)). To reduce the risks of the disaster significantly, the impacts of the disaster must be determined by figuring which factors are influenced on hazard itself, exposure and vulnerability through the application of models and frameworks.

There are various definitions or equations to describe the factors influencing flood risk.

A common definition published by IPCC (2013) is risk as a consequence of hazard, vulnerability and exposure (equation: $R = H \times V \times E$).

The hazard is normally defined by the probability of a certain flood event, expressed in terms of main hydrological figures or values. For example, a discharge with a return period of 100 occurs or is exceeded statistically once in 100 years (the so-called 100-year flood). The exceedance probability is 1%.

Floods are divided into "frequent events" (e.g., every 5, 10, 20 years), "average events" (every 100 years) and "rare events" (e.g., once every 200 or 500 years).

Both natural and anthropogenic factors influence the occurrence and extent of floods. Natural factors are primarily the characteristics of the area, such as topography, vegetation or the watercourse network. Anthropogenic factors such as land use (e.g. sealing of the landscape) and the development of watercourses (linear regulation, reduction of retention areas) can have an exacerbating effect on flood runoff and thus increase the flood risk.

It must be emphasised that extreme floods are possible at any time - regardless of human influences such as land use. The genesis of floods is complex and there are different hydrometeorological conditions and circumstances, that can cause extreme events.

Enormous economic and ecological damage only occurs when floodplains are used inappropriately, e.g., through the construction of settlements, industry or infrastructural facilities. As absolute flood protection is neither technically feasible nor economically viable, efforts are now focused on comprehensive management of the risks posed by flooding. The aim is to assess and visualize the flood risk and to reduce and avoid the consequences of flooding as far as possible. Such a comprehensive flood risk management comprises three areas:

1. flood and land management, such as the designation of legally established floodplains, buffer zones, flood polders, adapted land use in the catchment area
2. technical flood protection such as dykes, flood protection walls, retention basins, pumping stations, flood-adapted construction
3. behavioural precautions such as flood forecasts, early warning systems or insurance policies

Spatial planning, construction, organisational, awareness-raising and other instruments are available for implementing flood risk management measures, which must be coordinated between water management, urban and regional planning, nature conservation, agriculture and forestry and disaster control.

2.2 Hydro-meteorological conditions in Ghana

The climate of Ghana is influenced by its proximity to the equator. Ghana experiences a tropical climate with a mean annual temperature ranging between 24 ^{o}C and 36 ^{o}C and a mean relative humidity of 81% (Ampadu, 2021). Ghana experiences two distinct seasons, which are the wet and dry seasons. The southern coastal areas receive ample rainfall, while the northern part is more arid. The rainfall over the country decreases from south to north and eastwards, reaching an average of 800 mm in the extreme north-east and in the south-eastern coastal areas. The south-western part of the country and forest zone is the wettest (around Axim with an average annual rainfall of about 2,000 mm (Ampadu, 2021). The southern part of the country experiences a bimodal rainfall pattern, with a major rainy season from April to July and a minor rainy season from September to October, while the northern part experiences a uni-modal rainfall pattern from May to October, which peaks in August and September.

Climate change projection shows that the average annual temperature will increase over the entire West Africa Sub-region by 1.0˚C since 1960 with an average rate of 0.21˚C per decade. It is projected that the mean temperature will continue to increase from 2.5 ^{o}C by 2050 to 5.3 ^{o}C by the end of the century (Mcsweeney et al., 2023). These trends in temperature are similar across the West Africa sub-region, with similar projections for rainfall, leading to severe floods and droughts in most countries in West Africa (Awotwi et al., 2021).

Figure 1. Map of Ghana showing the topography and tourist attractions areas. (https://www.worldatlas.com/maps/ghana)

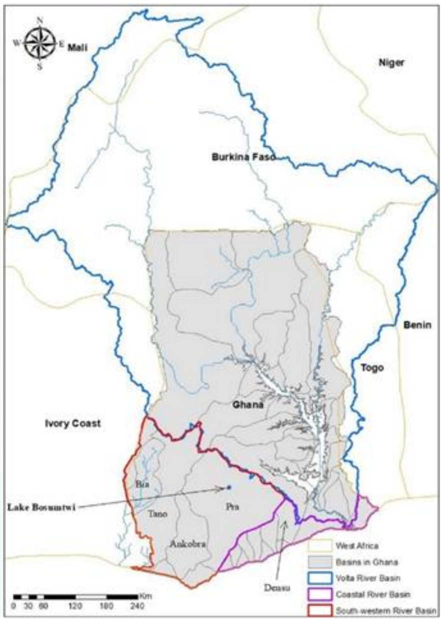

Figure 2. Major River systems in Ghana. (Agodzo et al., 2023)

2.3. Ghana's risk to flooding

Ghana is home to several major river systems generally classified as the Volta systems and the coastal river systems. The Volta River and its tributaries, including the Black Volta, White Volta, Oti, Lower Volta, and Lake Volta, flow through the country, providing essential freshwater resources and supporting irrigation, transportation, and hydropower generation (Obuobie, 2008). The Volta system has fertile flood plains and wetlands that largely support agriculture and aquaculture. Lake Volta is the largest man-made lake in the world by surface area and is formed by the Akosombo Dam on the Volta River. This reservoir serves as a critical water resource for the country, providing hydroelectric power, irrigation for agriculture, and fishing opportunities. The Volta River system occupies nearly 65 percent of Ghana's total land mass (Obuobie, 2008). The coastal river system occupying the southern coast is dotted with numerous smaller rivers, including the Pra (flowing through Kumasi), Ankobra, and Tano river systems. These rivers are vital for both agriculture and freshwater supply for coastal communities; however, they have been hugely polluted due to uncontrolled natural mineral mining such as gold. The Volta River system poses the highest risk of fluvial floods in Ghana, following some coastal river catchments such as the Pra, Densu, Odaw, etc., especially, in communities in Accra, Cape Coast, Takoradie, Kumasi, etc. Most communities in the Volta catchment face frequent and devastating flood events annually (Abass et al., 2023).

Ghana is one of the countries that are most prone to floods in West Africa (World Bank, 2011; Nansam-Aggrey, 2015). Its annual occurrence often leads to disasters that are mostly felt by the urban poor (Okyere et al., 2013). In 2017, the country's northern and southern parts experienced devastating floods that affected about 1 million people (IFRC, 2018). More recently, in 2018, floods caused by high-intensity rainfall combined with water releases from the Bagre Dam in Burkina Faso affected 100,000 people, with 34 deaths, and destroyed 196 km² of farmland (FLOODLIST 2018). Besides the annual occurrence of floods, Ghana has experienced several cascading disasters, which caused the disruption of Critical Infrastructure. For example, in 2015, the city of Accra was hit by severe rains which resulted in flooding in most parts. Critical Infrastructure such as roads, drainage systems and bridges were severely affected around the Odaw catchment areas. Also, in the same year a combined flood and fire disaster in Accra claimed the lives of 153 people and damaged properties worth millions of euros. NADMO further cited that there were also instances that telecommunication networks in Accra were disrupted during severe flooding.

In the PARADeS project we identified following gaps and challenges on Ghana's Flood Disaster Risk Management (FDRM) (Almoradie et. al. 2020):

1. the most critical regions are Accra, Kumasi, and the White Volta River basin
2. the most critical areas are with high population density, social hotspots and Critical Infrastructure, 3 FDRM are unsustainable and unintegrated, and it heavily relies on short-term projects and external funders,
3. there is a lack of human capacity and trained FDRM professionals
4. there is a lack of reliable data
5. communities need to be engaged more in the planning and provision of information and data
6. there is need for an effective Flood Early Warning System (FEWS) and communication mechanism to increase community coping capacity against floods
7. there are weaknesses in institutional collaborations and there are problems in policy implementation
8. the most important vulnerability criteria are the existence of FEWS, disaster relief agencies, areas with a high density of children and poverty rate
9. the interviewed communities in Accra and Kumasi claimed that flood disasters are caused mainly by human activities and interventions, and
10. in Northern Ghana, communities who are mostly farmers consider their farm to be a high flood risk zone as river overbank flow is very commonly caused by water spillage from the Bagré dam.

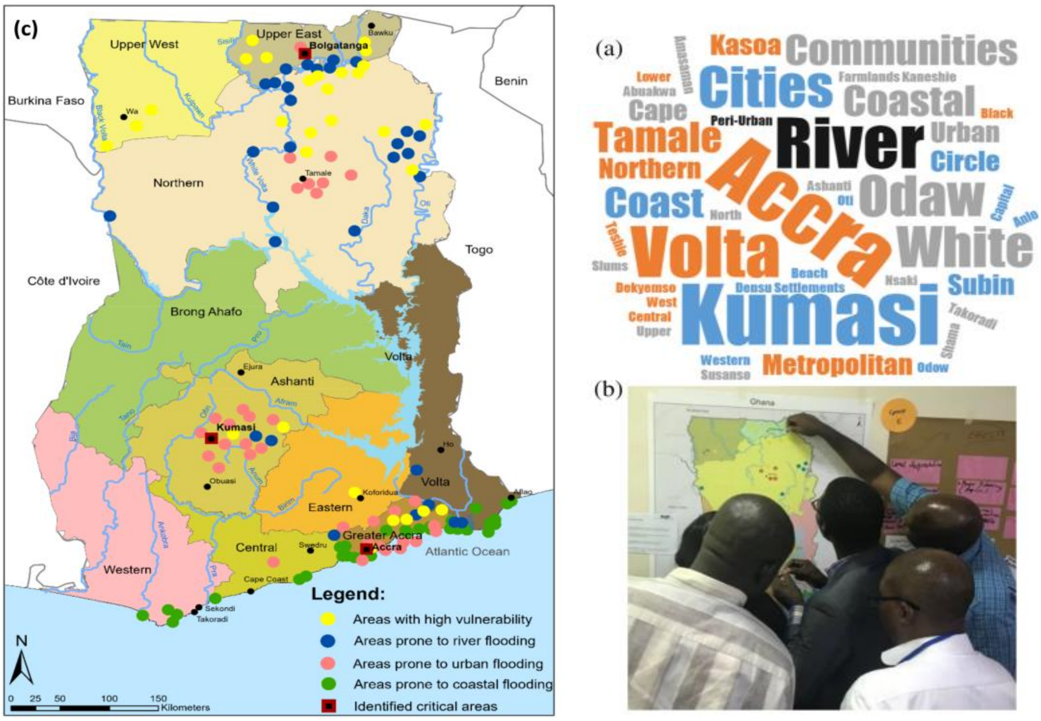

Figure 3. Flood hotspots identified by stakeholders during a workshop © PARADeS

During the initial phase of the PARADeS project, one of the objectives was to pinpoint the most vulnerable areas of flooding in Ghana (Almoradie et. al. 2020). The findings from both an online survey and a workshop revealed that Accra, Kumasi, the Volta river basin, and the White Volta river basin stand out as the regions of most susceptible to flooding in Ghana.

Accra's hotspots of flooding are mainly related to flash floods and poor drainage systems. In contrast, Kumasi hotspots are found around rivers and especially the encroachment into the natural wetland as the main type of flooding. Additionally, blocked drains due to improper waste management such as in Accra is observed as well. In Bolgatanga (Volta) region, a more rural dominated area, riverine flooding is also dominating in addition to flood risk caused by spillage of the Bagre dam in Burkina Faso. Relating these flooding patterns, the qualitative system models developed in each region shows that lives and livelihoods are affected in every region and that physical and mental health issues are also present. Same is true for infrastructure (transportation, communication, community services, education) (ibid).

The following describes in more detail the flooding situation and its adverse effects in the three cases:

Accra

In Accra, instances of riverine and urban flooding occur on an annual basis, with a particularly pronounced impact on informal settlements that frequently lack the necessary economic and physical resources to cope with these repercussions. This situation is exacerbated by limited government support, as noted by Abu and Codjoe (2018). Between 2001 and 2015, the risks associated with floods led to the unfortunate loss of approximately 250 residents and the displacement of 178,750 urban dwellers in Accra (Amoako and Inkoom, 2018). During the same period, over 75,000 livelihoods valued at more than 80 million US dollars were adversely affected (Amoako and Inkoom, 2018).

In the first stakeholder workshop, the flood hotspot mapping exercise revealed that the groups identified similar flood types and the underlying causes within the catchments in Accra. The stakeholder groups also identified overlapping areas of flood hotspots. The underlying causes of the floods at Weija Junction and the Ramsar sites were linked to spillage from the Weija dam and coastal floods. Similar trends of the flood types and the causes were observed in areas such as Latebiokorshie, Kaneshies, and Awudome, where flash floods, due to the siltation of the Kaneshie drains were common among the groups. Riverine and flash floods, due to siltation and drainage inefficiencies were generally identified in areas such as Dome, Alajo, Odawna, Nima, and Asylum-Down. While some neighborhoods were exposed to riverine and flash floods, communities around the Trade Fair Center, Burma Camp, Container-Joint, Dansoman Beach area, and Opetekwe were exposed to coastal floods. In sum, the participatory mapping exercise revealed that fluvial (riverine) floods and pluvial (flash) floods were prominent in the Odaw, Chemu, Lafa, Osu, and Kpeshie catchments. In addition, the coastal communities within the Kpeshie, Lafa, and Chemu catchments experienced coastal floods.

Kumasi

For the suburbs of Kumasi it is also plagued by recurrent riverine and urban floods. A significant flooding event occurred in June 2018, resulting from heavy rainfall, particularly affecting the eastern part of the city. This event resulted in five casualties, the evacuation of 293 people, and substantial damage to buildings and properties, as reported by FloodList in 2018. The situation in Kumasi is exacerbated by the inadequate drainage network and the haphazard positioning and construction of large portions of informal settlements (Campion and Venzke, 2013).

The flood hotspots mapping by the three stakeholder groups revealed some overlapping areas, where similar flood types were identified. For Example, along the Aboabo River in Dichemso, Oforikrom, and Patasi. The flood types identified were fluvial (riverine) and pluvial (flash, urban) floods. The most widespread flood type was fluvial, due to stream overflow. Siltation of the major drains as a result of the frequent disposal of solid waste into the streams was highlighted by all the groups. In addition, wetland encroachment was identified as an underlying contributing factor to flooding in the Aboabo River. The merging of the streams was found to contribute to flooding at the downstream areas including Sokoban Village. It was mentioned that the downstream, around Sokoban, and an extensive wetland is a potential hotspot due to urban expansion and human encroachment.

White Volta

In the Volta Delta, coastal flooding ranks as the most critical disaster. This region has witnessed the destruction of approximately 5,000 houses since the 1960s due to coastal erosion and flooding, resulting in the displacement of households, loss of livelihoods, and forced migration within and out of the Delta. The construction of the Akosombo dam, overharvesting of mangroves, and sand mining have been identified as major contributors to flooding problems in this area, as highlighted by Addo et al. (2018) and Codjoe et al. (2017). Riverine flooding, particularly during dam spillage amid heavy rains, has also been documented (Biney, 2010; Boateng, 2012). In the northern part of Ghana, areas along the White Volta and Black Volta rivers are regularly impacted by floods. Water spillages from the Bagre Dam are frequently cited as the primary cause of these flooding incidents (Bempah and Øyhus, 2017).

The participatory hotspots mapping exercise for the White Volta shows similar perceptions from the stakeholders about the flood extents, due to the overlapping of the areas identified, with similar underlying drivers or causes of the floods. Along the main White Volta River, the opening of the Bagre Dam in Burkina Faso was largely mentioned as a major cause of the floods in the downstream communities in Ghana. Localised floods due to the overflow of some tributaries such as Sisili, Kulpawn, Nasia, Vea, Yagaba, Kpasenkpe, and Atankwidi were mentioned. Flash floods were also identified in communities such as West Mamprusi, Savelugu, Kunbungu, and the North Gonja District. Most of the hotspot communities were largely identified as rural with agriculture as the main livelihood activity, which makes the households more vulnerable to the impacts of climate change, including flooding.

In the White Volta the degradation of farmland presents an additional threat. We can also see a cause pattern repeating in the different regions: inadequate structural measures, poor law enforcement and uncontrolled urban/rural planning. It became also clear that positive feedback loops (meaning reinforcing effects) affecting ecosystem health accelerate and aggravate flood risk. Even though the causes and impacts are very similar, the focus on adaptation measures especially when comparing the metropolitan areas with the more rural northern area is quite different. We found out that the focus lies on farming and adaptation of farming to conserve natural ecosystem function but also to adapt to the impacts of climate change. All have in common that non-structural measures are the most prominent measures which need implementation and enforcement and only with these, structural measures will gain full efficiency.

2.4. Models for flood risk assessment

Understanding the impact of floods requires an inter- and transdisciplinary approach supported with flood hazard maps. In this research project, flood hazard maps were generated through the use of a hydrodynamic model, allowing for the simulation of various return periods for extreme flood events. A hydrodynamic model is based on the movement of water (fluid) and the forces acting on it. It focuses on investigating the mechanisms driving flow by quantifying the key physical processes in water flow at various dimensions with the conservation of mass and momentum using shallow water equations. It often involved the application of the Mannings equation to estimate the roughness of the main channels and floodplains. The hydrodynamic model could focus on one or a combination of tidal dynamics, fluvial and pluvial floods in a given area based on the topography and the boundary conditions. The various dimensions of a flood hydrodynamic model include the 1D, 2D, and 3D, however, the time requirements for simulations and the cost involved in the implementation of model outputs are the underlying factors. The input data mainly consists of geometric data such as the bathymetry or cross-sections of the main channel, topography of floodplains and discharge, water level and/or rainfall data. In this study, the ProMaIDes 1D-2D hydrodynamic model was employed (https://promaides.h2.de/promaides/). It was utilized to simulate both fluvial and pluvial flooding for the Accra and Kumasi case studies. For the White Volta region, the model specifically focused on simulating fluvial flooding.

Furthermore, the hydrological model was established for the White Volta area using the Soil Water Assessment Tool (SWAT) modelling software, primarily due to the expansive geographical coverage of this region. Hydrological models are physically-distributed parametric models used to simulate the processes and exchanges of water within a catchment, or over the land surface on a continental scale. The hydrologic model provides coordinated guidance for water resource management, river runoff and flood forecasts, based on climate change scenarios and land use/land cover change (LULC) projections (Marshall, 2013). Numerous Hydrologic models exist and are adapted based on the anticipated purpose of the model and the spatial conditions of the catchment. In the PARADeS project, our hydrologic model focused on a catchment scale (i.e., the White Volta). The SWAT hydrologic model was adapted due to its suitability for large catchments. SWAT is a computer simulation model based on the water-balanced approach and has been widely applied in data-scare catchments. The SWAT model is integrated into GIS software (ArcGIS or QGIS) to optimize the visualization of model outputs. The input data broadly include DEM, drainage networks, soil data, climate data, LULC, etc. The simulated results can be calibrated, using SWAT-CUP software. However, the calibration process requires observed data (e.g., river discharge data at either daily, monthly or annual scale) for specific river/reservoir outlets, using relevant parameter ranges.

Climate change scenarios were also derived from climate models to get an idea of possible futures. These climate change scenarios were then used to simulate hazards for different return periods. Climate models are based on physical processes for simulating the transfer of energy and materials among the oceans, land, and the atmosphere, through the climate system. At a global scale, these models are also referred to as Global Circulation Models (GCMs). Climate models are probabilistic predictions, indicating areas with potential chances of experiencing higher or lower rainfall, temperature, etc.

The primary purpose of assembling hydrodynamic and hydrological models is to inform and guide decision-making and subsequent actions. It remains a challenge to effectively translate the specific outcomes of these models into comprehensible and comparable dimensions. Consequently, various flood consequences can be inferred from the hydrodynamic model. These modelling of consequences were also derived using the ProMaIDeS software framework. The range of consequences that are analysed include the affected and endangered population (POP) measured in number of people, economic consequences (ECN) in USD, and the consequences for the critical infrastructure disruption (CIN) quantified as disrupted people and days of disruption. A range of inputs is necessary to force the consequence models. The consequences for population rely on population-density data as well as water-depth/velocity-human interaction values. The critical infrastructure consequences are more complicated to assemble because they do not rely on spatial 2D datasets but rather on a network which includes CI components as well as their flood-interaction and service-related characteristics. However, it also needs an overview of the interdependencies within the CI components. A modelling method was newly developed for this research project (Schotten and Bachmann 2023a). For detailed information about the datasets used it is referred to the model documentation on the FIS.

The consequences are derived from the hydrodynamic model results and the return period from the hydrological models. Then, the derivation of risk as a decision-making unit is applied for all types of consequences *i*. The sum of the type-specific consequences C multiplied by the probability of occurrence p_{hyd} derived from the return period scenario k result in the risk of each consequence category R as follows:

$$R_i = \sum_{k=0}^{n} C_i \cdot p_{hyd,k} \qquad (1)$$

Next to the outcome of the absolute numbers for flood risk are spatial information on the areas that are impacted as well as the temporal resolution of this information. These results can thus be used for strategic flood risk management but also have the potential to supply useful information for operational flood risk management (Schotten and Bachmann 2023b).

The spatially-explicit products derived from these models are made available through the developed Ghana-Flood Information System (FIS).

2.5. Data for hydrodynamic, hydrological, climate and CI modelling

The hydrodynamic model relies on several inputs, including rainfall data (for Accra and Kumasi), discharge data (for the White Volta), a Digital Elevation Model (DEM), cross-sectional data, and land-use information used to estimate the Manning's friction coefficient. The DEM data was derived from DLR TanDEM-X, cross-sectional data was obtained through a combination of in-situ measurements and LIDAR data, while land-use data was sourced from the CORINE Land Use and Cover dataset spanning the years 2015 to 2019. (see also the data description in the FIS)

The SWAT hydrological model requires input data such as digital elevation model (DEM), climate data, including daily rainfall, maximum and minimum temperature (from 1970 to 2018), soil data, LULC (historical and future). The historical climate data for Accra, Kumasi and the White Volta were obtained from the Ghana Meteorological Agency. For the White Volta catchment, additional climate data were obtained from the Direction de la Météorologie Nationale in Burkina Faso. The Hargreaves method integrated into the SWAT tool was used to estimate potential evapotranspiration data, as the observed was not available in the catchment. Relatively consistent and reliable discharge data (from 1970 to 2010) from the Nawuni gauging station on the main White Volta River was obtained from the Ghana hydrological Authority for the model calibration and validation. The Bagre dam and the proposed Pwalugu multipurpose dam parameters were integrated into the model as additional input data.

Climate assessment and future climate change projections require observed daily rainfall and temperature (maximum and minimum) and future climate projections based on scenarios - Representative Concentration Pathways (RCP 4.5 and 8.5). Six best-performing climate models from the GCMs were selected and downscaled to our case study areas (Accra-Kumasi and the White Volta catchment).

Pre-processed and orthorectified Landsat satellite images were obtained from the US Geological Survey (Earth Explorer) and Copernicus Climate Change Service (Climate Data Store). LULC classification was performed, using supervised classification with maximum likelihood approach. The maximum likelihood approach works by creating a “training” sample by way of assigning each cell in the satellite image to a class that has similar spectral characteristics or reflectance. The historical LULC maps for 1995, 2005, 2015, and 2020 were created to detect changes in the LULC classes. These LULC data were used for future projections to obtain LULC maps for 2030, 2050, and 2070.

In the course of this project, the integration of critical infrastructures (CIs) played a pivotal role. The initial CI network modelling was enhanced by actively involving CI operators in the flood risk analysis process. Participatory workshops conducted in the White Volta and Odaw catchment areas have demonstrated that CI operators possess both the interest and expertise necessary for identifying flood risks and devising potential mitigation measures. Therefore, it is strongly recommended to continue engaging CI operators in future initiatives aimed at enhancing flood resilience.

Furthermore, it is advisable to tailor the selection of relevant CI operators to the specific area of investigation. For instance, in the case study conducted in the rural area of the White Volta, Highway Authorities played a crucial role, whereas electricity providers had a minor role. Conversely, in the Accra case study, the relevance of these two operators was reversed.


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In general, we experienced with our transdisciplinary approach a great value in including stakeholders and experts in the data collection and data validation. Figure. 4 shows different working steps and methods we applied for the validation and ground truthing of data based or model result.

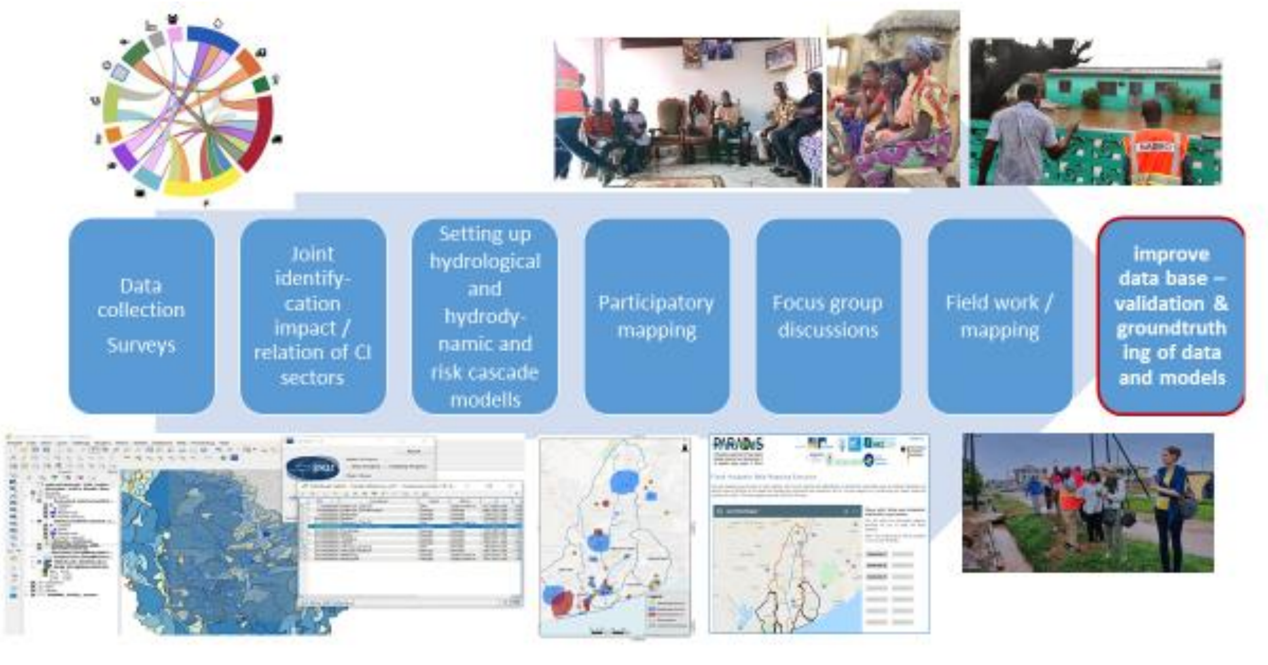


Figure 4. Working steps and participatory methods for the validation and ground truthing of data based and model results. © PARADeS

3. Model frameworks and simulation results

All models described in this chapter are based on the framework described in Chapter 2.3. Additionally, all models are documented more extensively in the model report of the PARADeS project. The report can be accessed through the Flood Information System (FIS) here. The spatial results can also be accessed through a web viewer in the FIS.

3.1. Hydrological model

SWAT is a robust tool for hydrologic modelling but not a stand-alone tool. SWAT comes with a plugin, which uses ArcGIS and QGIS environment for layer integration and visualisation of simulation results. The QSWAT plugin was used in the QGIS, as an open-source software. This allowed the establishment of the SWAT hydrological model for the White Volta River catchment, using input data mentioned section 2.5. Examples from the model simulation, calibration and validation of river runoff are presented in Figure 5 and 6. The calibration was performed using SWAT-CUP (SUFI2), a program that was developed to perform calibration, validation, conduct sensitivity analysis (parameters), and uncertainty analysis.

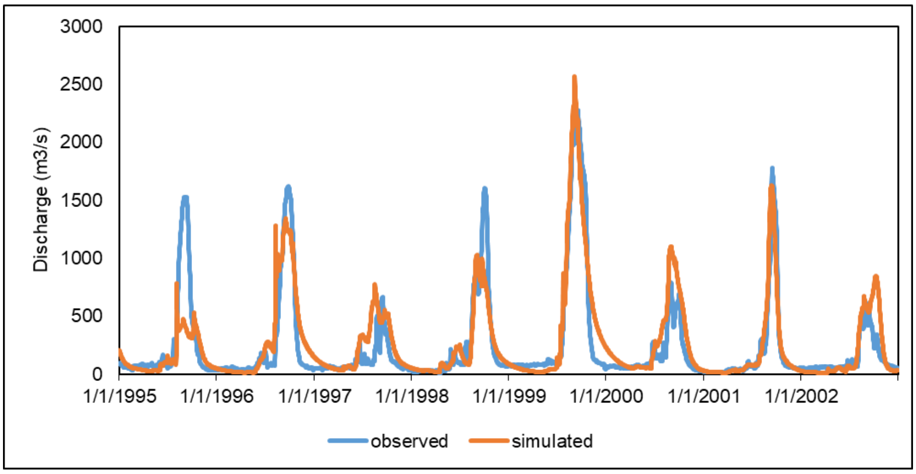


Figure 5. Calibrated runoff at Nawuni station: 1979-1990 © U-Bn

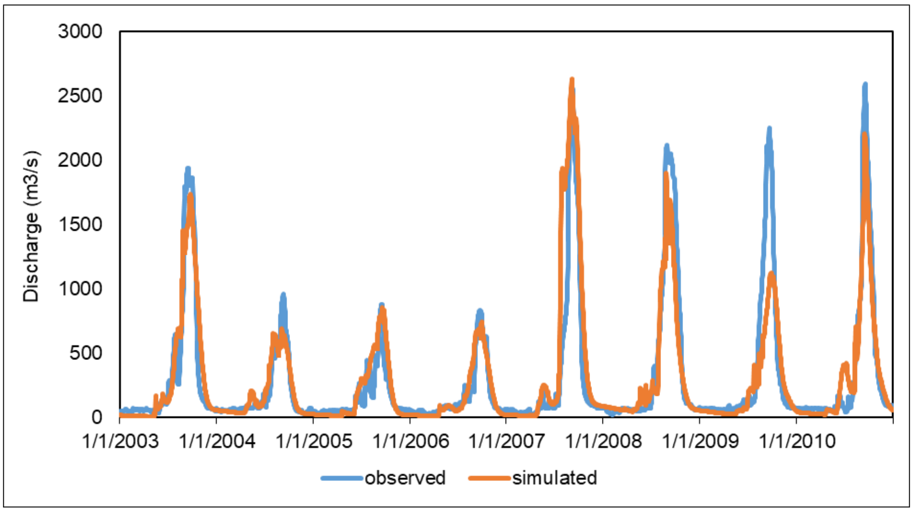


Figure 6. Validated runoff at Nawuni station: 2003 – 2010. © U-Bn

The SWAT model performance

It is important to evaluate the performance of models to identify their strengths and weaknesses, as well as the reliability of their outcomes. The SWAT model calibration and validation accuracy were evaluated, using the most used statistical efficacy methods such as the Nash-Sutcliffe Efficiency (NS), Coefficient of determination (R^2), and P-factor. The statistical evaluation of the SWAT model indicated a good performance as the efficacy values are above 0.5, ranging from 0.77 to 0.86 for both calibration and model validation, relative to a perfect model performance of 1.0 for NS and R^2. The SWAT model performance was relatively better in mimicking the hydrology of the catchment compared to previous studies within the White Volta catchment (Awotwi et al., 2015).

Lessons learned and challenges with the SWAT hydrological modelling

The SWAT software is a plugin that is integrated into QGIS or ArcGIS therefore, there are some associated challenges, regarding compatibility with the version of Microsoft Operating Systems, the version of the QGIS, and the SWAT plugin. These challenges, at times, make it difficult to create new SWAT input tables and run simulations. Further, it also makes it difficult to retrieve and visualise SWAT projects that were created with older versions of the software.

Building the SWAT model can be time-consuming, besides the requirements for high computing power. Adequate time and high computing power and resources should be provided for the modelling process.

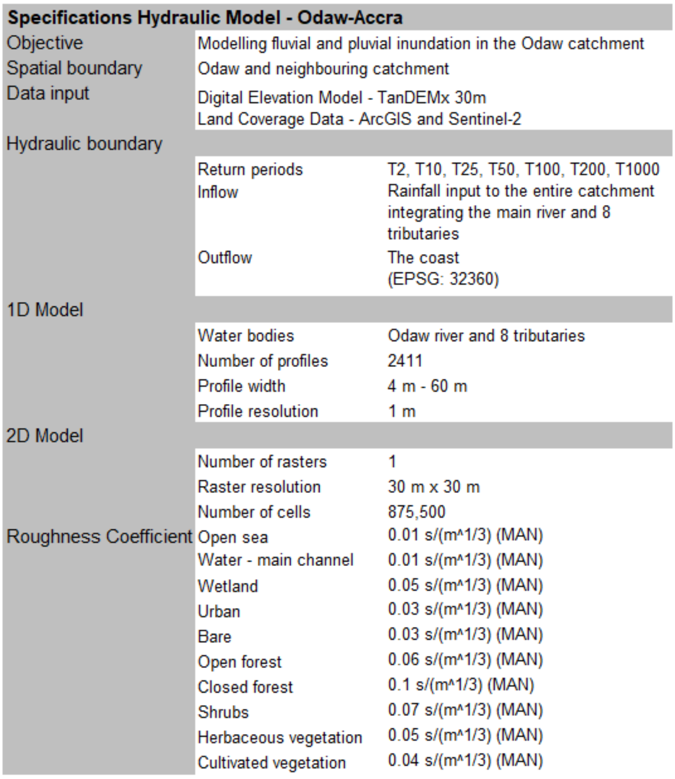
Additionally, care must be taken when preparing input data and SWAT input tables, as errors could lead to challenges in running model simulations and wrong model outputs.

3.2. Hydrodynamic model

Accra-Odaw

The Accra-Odaw hydraulic model was built to analyse the flooding for different return periods simulating fluvial and pluvial flooding. Table 1 summarises the input parameters of the Accra-Odaw model.

Table 1. Hydrodynamic model set-up Accra-Odaw ©U-BN



Specifications Hydraulic Model - Odaw-Accra		
Objective	Modelling fluvial and pluvial inundation in the Odaw catchment	
Spatial boundary	Odaw and neighbouring catchment	
Data input	Digital Elevation Model - TanDEMx 30m Land Coverage Data - ArcGIS and Sentinel-2	
Hydraulic boundary		
	Return periods	T2, T10, T25, T50, T100, T200, T1000
	Inflow	Rainfall input to the entire catchment integrating the main river and 8 tributaries
	Outflow	The coast (EPSG: 32360)
1D Model		
	Water bodies	Odaw river and 8 tributaries
	Number of profiles	2411
	Profile width	4 m - 60 m
	Profile resolution	1 m
2D Model		
	Number of rasters	1
	Raster resolution	30 m x 30 m
	Number of cells	875,500
Roughness Coefficient	Open sea	0.01 s/(m^1/3) (MAN)
	Water - main channel	0.01 s/(m^1/3) (MAN)
	Wetland	0.05 s/(m^1/3) (MAN)
	Urban	0.03 s/(m^1/3) (MAN)
	Bare	0.03 s/(m^1/3) (MAN)
	Open forest	0.06 s/(m^1/3) (MAN)
	Closed forest	0.1 s/(m^1/3) (MAN)
	Shrubs	0.07 s/(m^1/3) (MAN)
	Herbaceous vegetation	0.05 s/(m^1/3) (MAN)
	Cultivated vegetation	0.04 s/(m^1/3) (MAN)

The output of the hydraulic model gives information about flooded areas, the associated water depth and velocities for each return period. Figure 7 shows the 10-year return period inundation along the southern Accra-Odaw catchment.

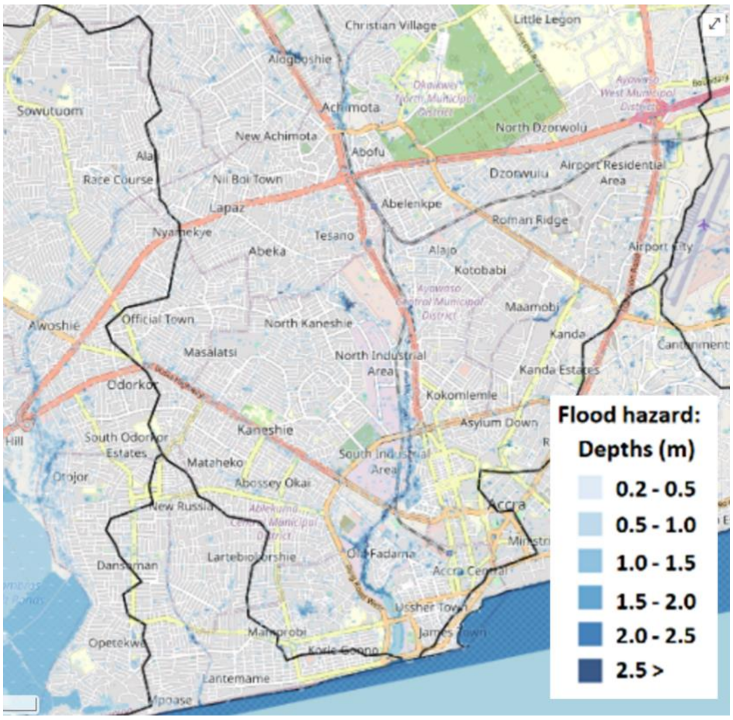
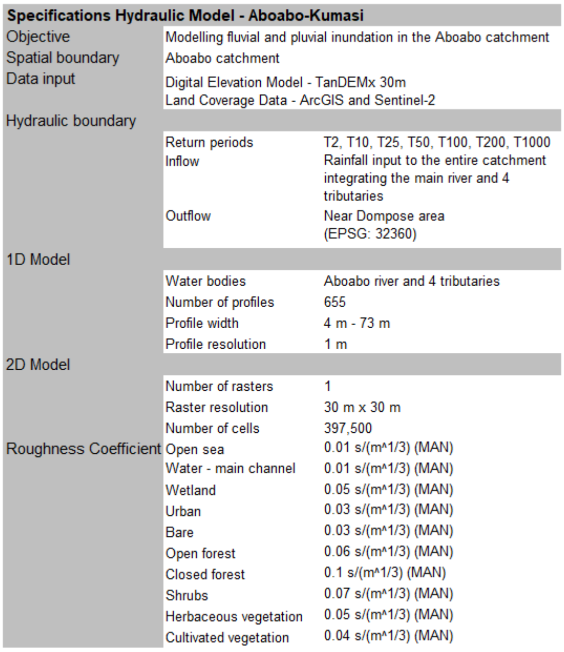


Figure 7. Flood hazard map southern Odaw-Accra (T10) ©U-BN

Kumasi-Aboabo

The Kumasi-Aboabo hydraulic model was built to analyse the flooding for different return periods simulating fluvial and pluvial flooding. Table 2 summarises the input parameters of the Kumasi-Aboabo model.

Table 2. Hydrodynamic model set-up Kumasi-Aboabo ©U-BN



Specifications Hydraulic Model - Aboabo-Kumasi		
Objective	Modelling fluvial and pluvial inundation in the Aboabo catchment	
Spatial boundary	Aboabo catchment	
Data input	Digital Elevation Model - TanDEMx 30m Land Coverage Data - ArcGIS and Sentinel-2	
Hydraulic boundary		
	Return periods	T2, T10, T25, T50, T100, T200, T1000
	Inflow	Rainfall input to the entire catchment integrating the main river and 4 tributaries
	Outflow	Near Dompose area (EPSG: 32360)
1D Model		
	Water bodies	Aboabo river and 4 tributaries
	Number of profiles	655
	Profile width	4 m - 73 m
	Profile resolution	1 m
2D Model		
	Number of rasters	1
	Raster resolution	30 m x 30 m
	Number of cells	397,500
Roughness Coefficient	Open sea	0.01 s/(m^1/3) (MAN)
	Water - main channel	0.01 s/(m^1/3) (MAN)
	Wetland	0.05 s/(m^1/3) (MAN)
	Urban	0.03 s/(m^1/3) (MAN)
	Bare	0.03 s/(m^1/3) (MAN)
	Open forest	0.06 s/(m^1/3) (MAN)
	Closed forest	0.1 s/(m^1/3) (MAN)
	Shrubs	0.07 s/(m^1/3) (MAN)
	Herbaceous vegetation	0.05 s/(m^1/3) (MAN)
	Cultivated vegetation	0.04 s/(m^1/3) (MAN)

The output of the hydraulic model gives information about flooded areas, the associated water depth and velocities for each return period. Figure 8. shows the 10-year return period inundation along the southern Accra-Odaw catchment.

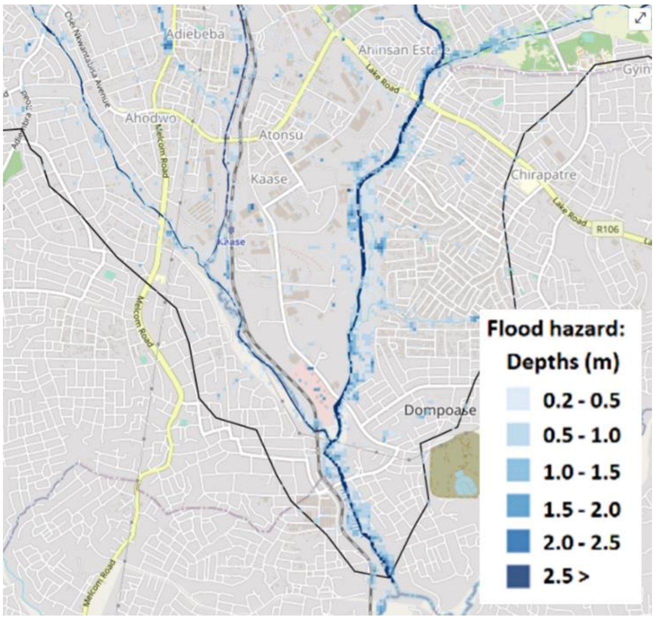
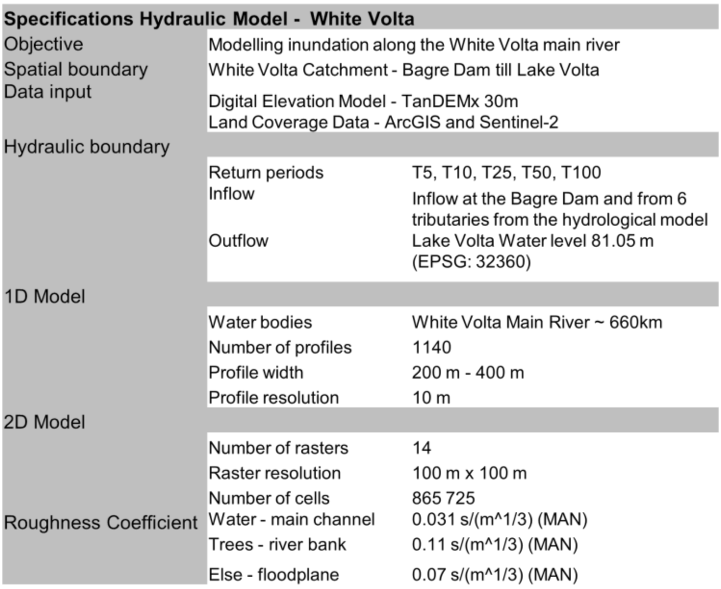


Figure 8. Flood hazard map southern Aboabo-Kumasi (T10) ©U-BN

White Volta

For the White Volta a hydraulic model was built to analyse the flooding for different return periods along the main river channel. Table 3 summarises the input parameters of the White Volta model.

Table 3. Hydrodynamic model set-up White Volta ©HS-M



Specifications Hydraulic Model - White Volta		
Objective	Modelling inundation along the White Volta main river	
Spatial boundary	White Volta Catchment - Bagre Dam till Lake Volta	
Data input	Digital Elevation Model - TanDEMx 30m Land Coverage Data - ArcGIS and Sentinel-2	
Hydraulic boundary		
	Return periods	T5, T10, T25, T50, T100
	Inflow	Inflow at the Bagre Dam and from 6 tributaries from the hydrological model
	Outflow	Lake Volta Water level 81.05 m (EPSG: 32360)
1D Model		
	Water bodies	White Volta Main River ~ 660km
	Number of profiles	1140
	Profile width	200 m - 400 m
	Profile resolution	10 m
2D Model		
	Number of rasters	14
	Raster resolution	100 m x 100 m
	Number of cells	865 725
Roughness Coefficient	Water - main channel	0.031 s/(m^1/3) (MAN)
	Trees - river bank	0.11 s/(m^1/3) (MAN)
	Else - floodplane	0.07 s/(m^1/3) (MAN)

The output of the hydraulic model gives information about flooded areas, the associated water depth and velocities for each return period. Figure 9 shows the inundation along the White Volta with a detailed view.

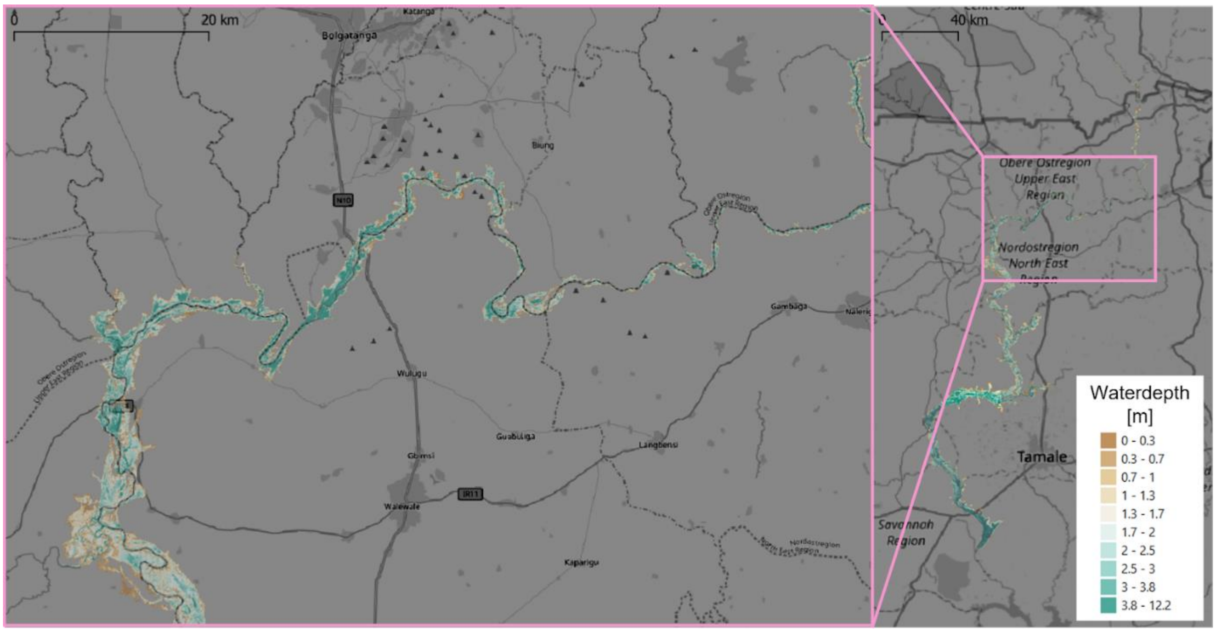


Figure 9. Inundation along the White Volta with a detailed view ©HS-M

3.3. Consequence

Using the consequence models to have some idea on the flood risk per year on the population and economy, the following summarizes the results of the simulation for the three areas of investigation.

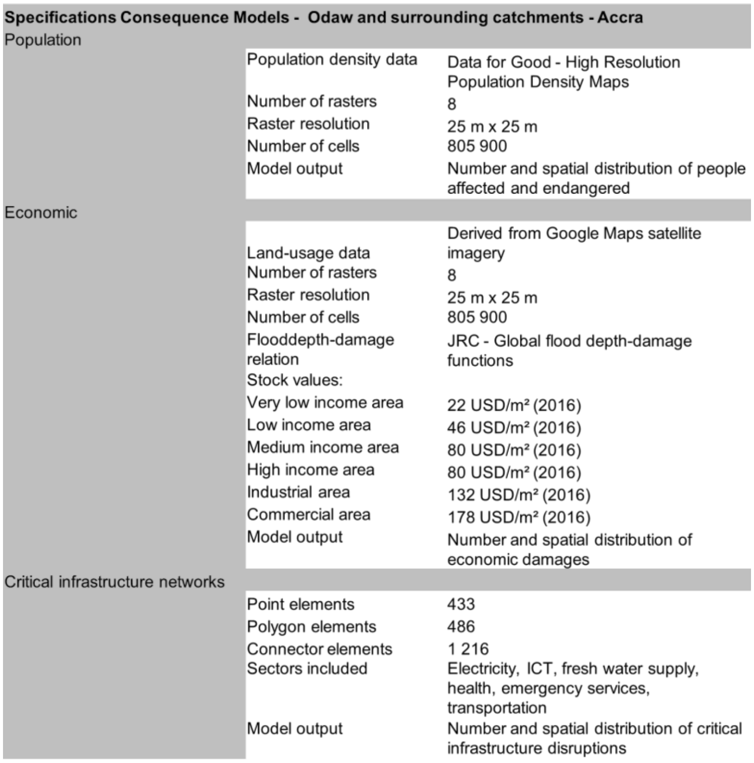
Table 4. Details of the consequence modelling for economy, population, and critical infrastructures for the three case areas ©HS-M

Case study area	Flood risk per year		
	Population [number of people]		Economic [USD]
	Affected people	Endangered people	Immobile + Mobile
White Volta	1024	68	892 355
Accra	695 570	881	235 459 000
Kumasi	142 770	168	80 197 800

Accra

For the area of investigation in Accra and the Odaw catchment as well as its surrounding catchments, consequence models were set up to consider economic damages, consequences to people and critical infrastructure networks. The specification for the model can be derived from Table 5.

Table 5. Consequence model set-up Accra-Odaw © HS-M

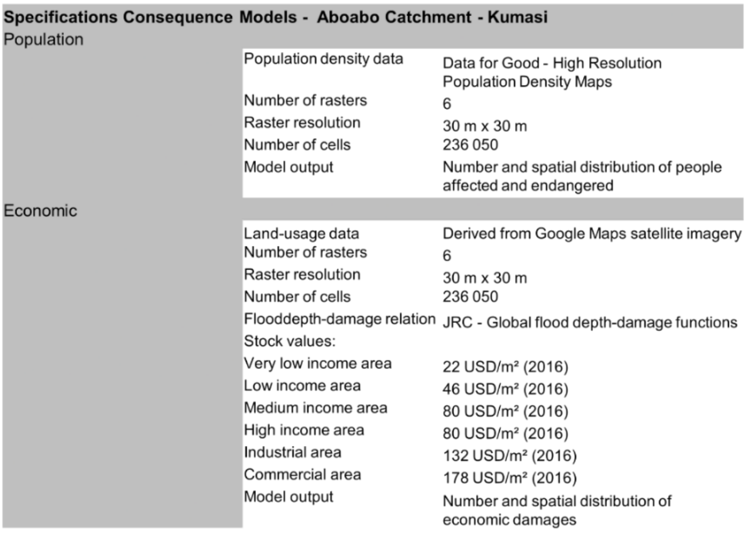


Specifications Consequence Models - Odaw and surrounding catchments - Accra		
Population		
	Population density data	Data for Good - High Resolution Population Density Maps
	Number of rasters	8
	Raster resolution	25 m x 25 m
	Number of cells	805 900
	Model output	Number and spatial distribution of people affected and endangered
Economic		
	Land-usage data	Derived from Google Maps satellite imagery
	Number of rasters	8
	Raster resolution	25 m x 25 m
	Number of cells	805 900
	Flooddepth-damage relation	JRC - Global flood depth-damage functions
	Stock values:	
	Very low income area	22 USD/m² (2016)
	Low income area	46 USD/m² (2016)
	Medium income area	80 USD/m² (2016)
	High income area	80 USD/m² (2016)
	Industrial area	132 USD/m² (2016)
	Commercial area	178 USD/m² (2016)
	Model output	Number and spatial distribution of economic damages
Critical infrastructure networks		
	Point elements	433
	Polygon elements	486
	Connector elements	1 216
	Sectors included	Electricity, ICT, fresh water supply, health, emergency services, transportation
	Model output	Number and spatial distribution of critical infrastructure disruptions

Kumasi-Aboabo

For the area of investigation in Kumasi and the Aboabo catchment, consequence models were set up to consider economic damages and consequences to people. The specification for the model can be derived from Table 6.

Table 6. Consequence model set-up Kumasi-Aboabo © HS-M

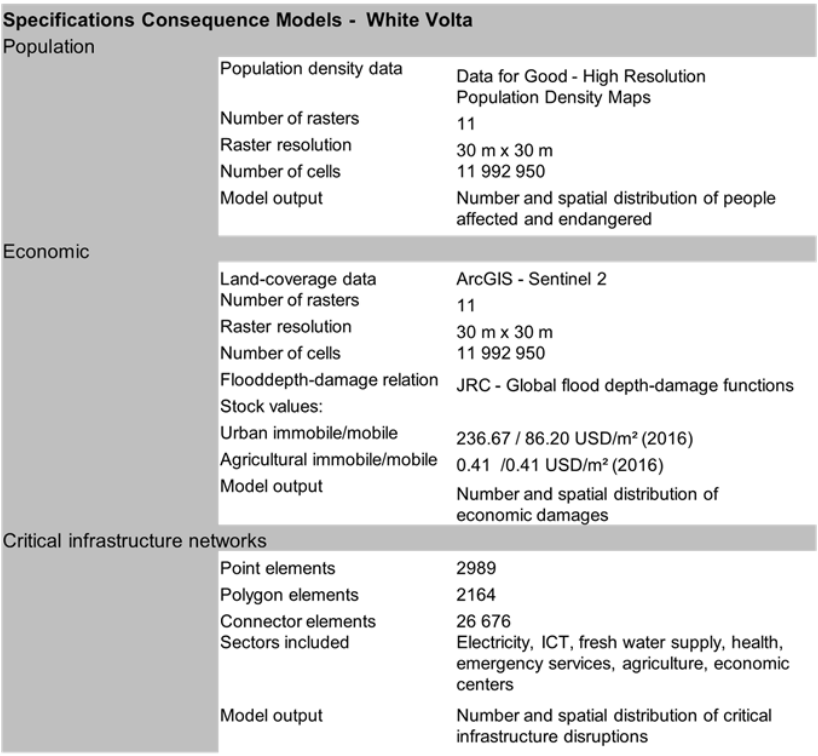


Specifications Consequence Models - Aboabo Catchment - Kumasi		
Population		
	Population density data	Data for Good - High Resolution Population Density Maps
	Number of rasters	6
	Raster resolution	30 m x 30 m
	Number of cells	236 050
	Model output	Number and spatial distribution of people affected and endangered
Economic		
	Land-usage data	Derived from Google Maps satellite imagery
	Number of rasters	6
	Raster resolution	30 m x 30 m
	Number of cells	236 050
	Flooddepth-damage relation	JRC - Global flood depth-damage functions
	Stock values:	
	Very low income area	22 USD/m² (2016)
	Low income area	46 USD/m² (2016)
	Medium income area	80 USD/m² (2016)
	High income area	80 USD/m² (2016)
	Industrial area	132 USD/m² (2016)
	Commercial area	178 USD/m² (2016)
	Model output	Number and spatial distribution of economic damages

White Volta

For the White Volta case study consequences from flooding have been modelled for population affected, economic damages, and critical infrastructure networks. Table 7 gives an overview of the input data model specifications and the output of the model. The Figure 10 below shows as an example the areas of affected population during a T50 event. Further on no visualisations of the model results are shown and it is pointed to the FIS or the modelling documentation for further input. The associated quantitative results from the consequence models show that the flood risk along the White Volta main channel is comparable to the low population density along the White Volta. It is recommended to also include the tributaries as an 1D model in the future and therefore enable the consideration of damages along the tributaries as well.

Table 7. Consequence model set-up White Volta ©HS-M



Specifications Consequence Models - White Volta		
Population		
	Population density data	Data for Good - High Resolution Population Density Maps
	Number of rasters	11
	Raster resolution	30 m x 30 m
	Number of cells	11 992 950
	Model output	Number and spatial distribution of people affected and endangered
Economic		
	Land-coverage data	ArcGIS - Sentinel 2
	Number of rasters	11
	Raster resolution	30 m x 30 m
	Number of cells	11 992 950
	Flooddepth-damage relation	JRC - Global flood depth-damage functions
	Stock values:	
	Urban immobile/mobile	236.67 / 86.20 USD/m² (2016)
	Agricultural immobile/mobile	0.41 /0.41 USD/m² (2016)
	Model output	Number and spatial distribution of economic damages
Critical infrastructure networks		
	Point elements	2989
	Polygon elements	2164
	Connector elements	26 676
	Sectors included	Electricity, ICT, fresh water supply, health, emergency services, agriculture, economic centers
	Model output	Number and spatial distribution of critical infrastructure disruptions

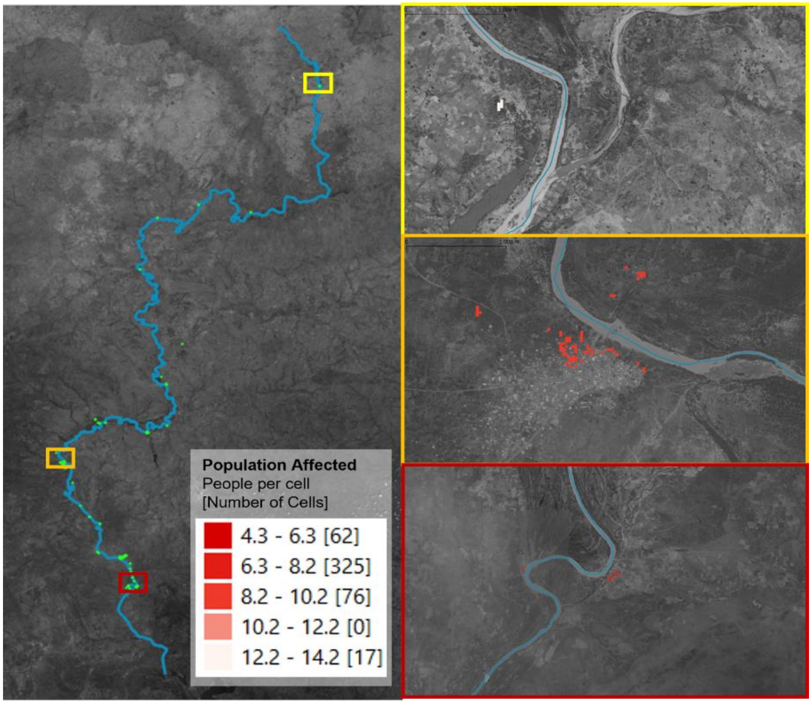


Figure 10. Consequence model- example of affected population in a section of the White Volta (T50) ©HS-M

3.4. Climate and Land Use Land Cover Change

While the major cities and low-lying areas experience flash floods, communities along the rivers and streams equally experience fluvial floods, particularly in the White Volta Catchment, and urban drains in Kumasi and Accra. To support efficient and adequate decision-making, Climate change modelling, land use and land cover change detection, and hydrological modelling are important steps to generate area-specific results and evidence-based information to support the development.

Trends in temperature and rainfall for Accra and Kumasi

Climate change assessment outcomes for both Accra and Kumasi show similarities in the annual trend in air surface temperature. Both RCP4.5 and RCP 8.5 indicated that the average annual air surface temperature is likely to increase between 2025 and 2096, however, RCP 8.5 shows a significant increase from 2061 to 2096.

The rainfall projections from both scenarios show a likely decrease steady in rainfall in Accra from 2025 to 2060. Thereafter, both scenarios show a steady increase in rainfall from 2067 to 2096. In Kumasi, a decrease in rainfall is projected from 2025 until 2060, under both scenarios. No significant change in rainfall was projected between 2061 and 2096, under the current levels of CO2 emissions for both scenarios in Kumasi.

Increase in temperature can have influences on rainfall and the frequency of floods in the region measures for flood risk management in Ghana.

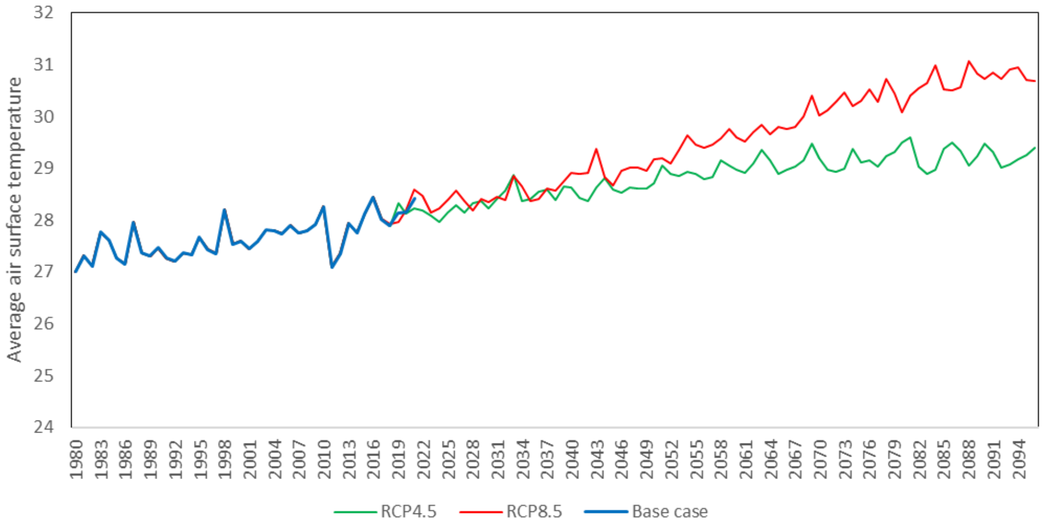


Figure 11.Trend in air surface temperature in Accra from 1980 to 2096. ©U-Bn

Return periods for Accra and Kumasi

The key results from the return periods generated from, using daily annual maximum rainfall for Accra and Kumasi are presented in Table 8. The results show the base case under climate change scenarios (RCP4.5 and RCP8.5).

In Accra, the returns periods show the expected amount of rainfall for the base case is higher than what was observed under the two climate change scenarios, however, the RCP 8.5 shows relatively higher rainfall return periods compared to the RCP 4.5 (Table 8). In the case of Kumasi, the RCP 8.5 projects higher return periods compared to the base case and the RCP 4.5 scenarios. However, rainfall projections under the RCP 4.5 are relatively lower than the base case scenario. This indicates that with levels of CO2 emissions under RCP 8.5 scenarios, flood mitigation measures, and early warning systems in Kumasi, must take into account the projected higher extreme high rainfall and likely flash and fluvial food events.

Table 8. Return periods of rainfall under climate change scenarios for Accra and Kumasi. © U-Bn

	Accra			Kumasi		
Return period	Base case	RCP4.5	RCP8.5	Base case	RCP4.5	RCP8.5
2	82	63	65	85	69	70
10	147	104	118	118	109	114
25	197	124	144	135	129	136
50	244	139	164	147	144	152
100	302	154	183	160	159	169
200	374	169	202	172	174	185
1000	609	204	246	200	208	223

Future temperature projections for the entire White Volta Catchment

The temperature within the White Volta catchment is generally high with no significant spatial disparity between stations. Therefore, it is quite representative to present an overview of the annual trends for the entire catchment (Figure 12). All the two climate scenarios project an increasing trend in air surface temperature; however, RCP8.5 projects higher temperatures, similar to projections for the entire West African.

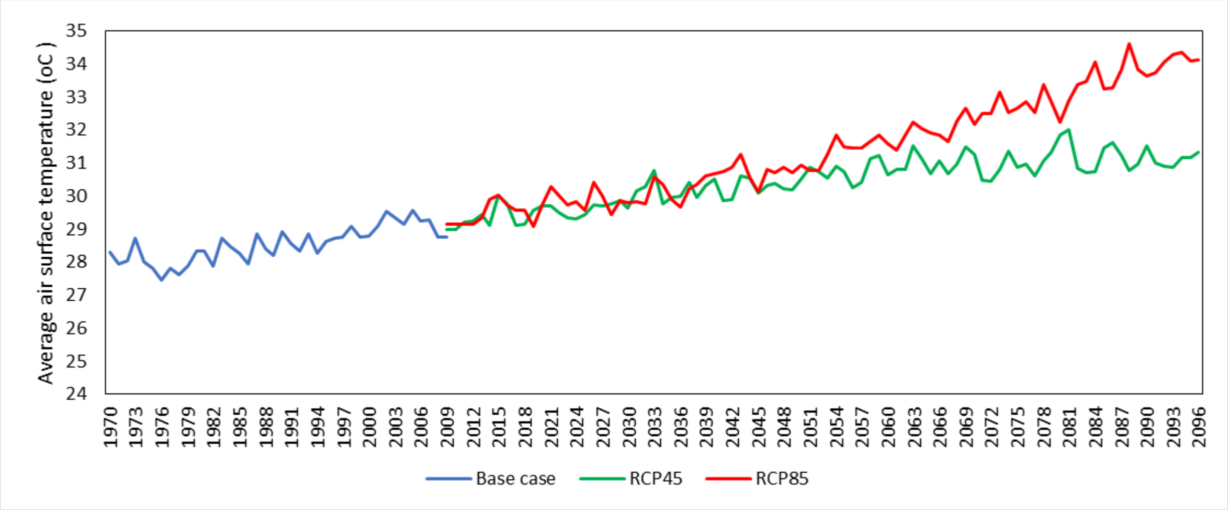


Figure 12. Average annual air surface temperature for the White Volta catchment under climate change scenarios. © U-Bn

Future rainfall projections for the entire White Volta Catchment

Future projections of rainfall for the entire White Volta catchment show decreasing trends under both RPC 4.5 and RCP 8.5 scenarios (Figure 13). The rainfall patterns indicate higher variabilities in annual peaks from 2025 to 2096. These do not necessarily indicate a likely reduction in flood hazards as other underlying drivers such as Bagre dam spillage and LULC change play crucial roles.

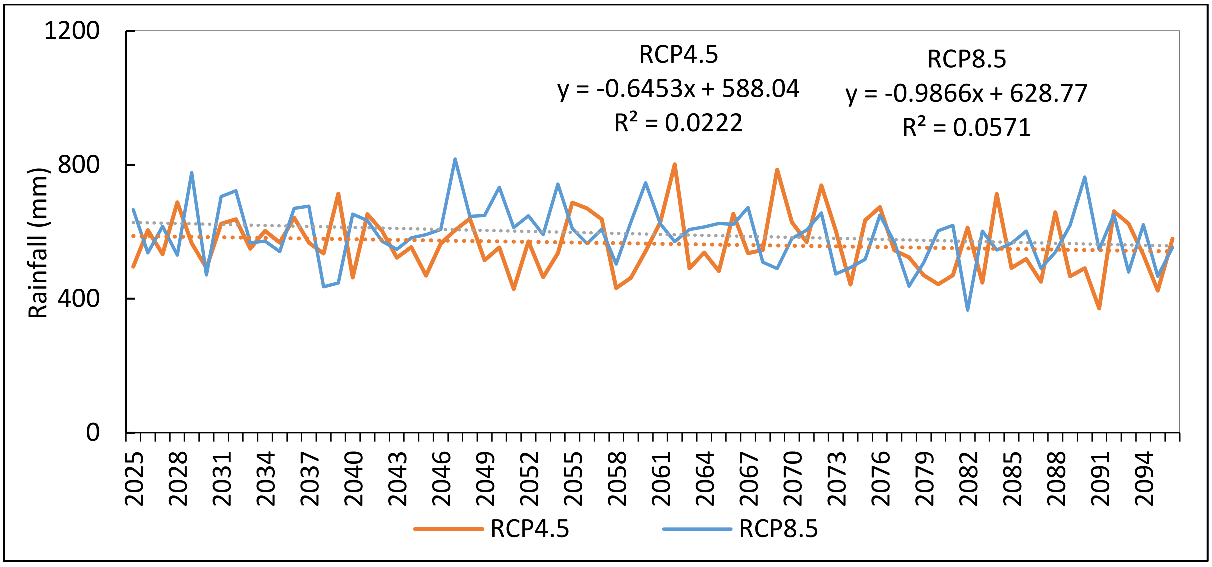


Figure 13. Trend in future annual rainfall based on climate change scenarios. © U-Bn

Recommendations for improved meteo-hydrological data collection and maintenance

- Investment and improvement in climate data collection and maintenance: availability and accessibility to high-quality data can improve model results and flood predictions. For the case of the PARADeS project, only daily rainfall and temperature data for two stations (Accra and Kumasi Airports stations) were accessible. The density of climate and weather stations within river catchments is crucial in modelling climate patterns.
- Improved data collection and maintenance for the White Volta catchment: Building a hydrologic model requires reliable time series data. As a general challenge in Ghana, availability and accessibility to hydrological data is a huge challenge in the White Volta catchment. Over 13 climate and hydrological stations exist in the White Volta Catchment, however, only a few of the stations are still functional with some amount of time series data. The density of the measuring stations is crucial for modelling as it determines the quality of the mode results and the accuracy of the spatial representation of the area under study. Some stations have data only for 10 years or less, which additionally contain missing values.

Key lessons based on the hydrological modelling

Climate change has impacts on current and future trends in temperature, evapotranspiration, rainfall, and water balance in the White Volta catchment. The modelling output indicates an increasing trend in average annual air surface temperature over the entire White Volta catchment for both climate change scenarios (RCP 4.5 and 8.5) from 2025 to 2096. Similar trends are true for both rainfall and river flow. The output of the hydrological model shows that runoff within the catchment will likely continue to decrease steadily in the future from 2025 to 2096 under both RCP 4.5 and 8.5, particularly in the case of RCP 8.5. However, high variabilities in rainfall and river flow are observed for the entire modelling period. These variabilities in rainfall and river flow, partly influenced by climate change and land use, will likely pose risks of frequent floods and droughts.

Additionally, the model results indicate that the construction of the proposed Pwalugu multipurpose dam in Ghana (downstream of the Bagre dam) will further contribute to lower water levels at the lower part of the White Volta catchment. This does not necessarily translate into low flood risk in the future, due to the interplay of multiple factors such as likely high extreme rainfall events, spillage of the dams, human encroachment into the buffer zone of the river networks, land cover change, as well as uncertainties in the model predictions.

Recommendations for flood risk mitigation based on hydrological model process

- To better prepare against flood disasters, it is recommended to implement and communicate early warning systems and continue to create flood risk awareness among flood-prone communities in the lower part of the catchment such as Karimigna, Sisili, Kulpawn, Nasia, Vea, Yagaba, Kpasenkpe, etc.
- Promote vegetation and forest land cover protection within the White Volta River catchment. Deforestation and vegetation removal around some sections of the river (for example, Karimigna, Nawuni, Pwalugu, etc.) do not contribute to only Greenhouse gas emissions and climate change but also increase surface water runoff and transportation of sediments into the river course. This contributes to sedimentation and siltation of the river course, leading to modifications in the river flow dynamics and possible flood events.
- It is strongly recommended to strengthened the existing collaborations between Ghana and Burkina Faso on the management of the Volta River Basin to facilitate data collection, maintenance, and public accessibility of climate, river discharge, and Bagre Dam management data. It is quite challenging to get access to discharge data for the inlet and outlet of the Bagre Dam in Burkina Faso. Accurate times series from the Bagre Dam management would support improve hydrological model and flood forecast.
- Policy formulations must recognize that while river flow and water levels are likely to decrease, drought risk will likely increase with its associated cascading impacts such as a decrease in food productivity, risk of food-water-borne diseases, poverty, which in turn can affect flood adaptation capacities of the communities within and their ability to build resilience.
- Strengthen buffer zones protection measures for the White Volta River through community engagement and forest protection incentives.

3.5. Uncertainties in the determination of flood hazard and planning of flood protection measures

Flood areas for hazard assessment and design of flood protection measures are generally determined with the help of modelling software. Examples are given here to illustrate the possibilities and limitations of the use of software.

For the determination of flood areas and the planning of flood protection measures, a software family is required, which consists of a geo-information system and a group of simulation models, which are composed differently depending on the problem (e.g., Channel network models, rainfall-runoff models, steady-state and transient, one- to two-dimensional hydraulic models).

However, the quality of the input data and the calibration of the simulation models are crucial for the accuracy of the calculation results. By their very nature, the methods used are only approximations to the actual hydrological and hydraulic processes. In the following, the main issues that require special attention in order to ensure the best possible approximation of the simulation results to the natural processes are mentioned.

For the geospatial data used to build the model, the issues include

Geological and soil data:

- Are the generalization’s available in the map series sensitive to the design problem and model calibration? Can overly coarse assumptions in sub-basins lead to incorrect calibration parameters?

Survey data:

- Are aerial and terrestrial survey data compatible, is there a possibility of data optimisation?
- Is the watercourse geometry fully represented in the hydraulic model?
- Has the river geometry changed due to a flood event?
- What is the resolution of the digital terrain model?
- Is it possible to increase the validity of the digital terrain model by adding more structures, such as breaklines?

For the hydrological data used for model calibration, the questions are the following.

Precipitation measurement:

- How sensitive is the accuracy of the terrestrial, radar or satellite precipitation measurement to the results of the rainfall-runoff models?
- How sensitive is the extrapolation of terrestrial point measurements to the results of a rain runoff model?
- What is the accuracy of the measurement: local effects for terrestrial, artefacts for radar?

Runoff measurement:

- In fast-reacting catchments, it is rarely possible to capture the flood wave with a discharge measurement. Have enough flood events been measured?
- Hydraulic models are calibrated based on discharge measurements and, roughness is determined. However, the influence of roughness varies within the discharge spectrum. Calibration based on discharge measurements in the low and mid-water spectrum can result in incorrect roughness and therefore incorrect water level positions for flood discharges. How sensitive is the change in roughness for flood discharges?
- Water level/runoff relationships are needed to provide continuous discharge data from water level hydrographs for calibration of rain-runoff models:
- Are sufficient discharge measurements available over the full range of discharges, and is the part of the water level/runoff relationship not covered by discharge measurements well covered by hydraulic calculation results?

Suitable model approach

For the selection of a suitable model approach for the simulation of a flood area, the following possibilities have to be considered:

- Which runoff processes are in the foreground: is a rainfall-runoff model with a conceptual model approach sufficient or does a physically based hydrological area model need to be developed with more effort and what are the advantages of this?
- In the case of calibration or simulation with the hydrological area model, the questions are:
    - How are different runoff processes represented by the rainfall-runoff model?
    - Can the model represent small and extreme floods with the same quality?
    - If not, which parameter set is chosen to best simulate which condition, and how does this affect the simulation results?

Design flood

In determining a design flood, the questions are

- What is the length of the time series of the long-term simulation and how large are the events it contains?
- Are longer time series available for similar catchments and what are their characteristics?
- Are there any outliers in the simulated time series and how are they treated, what is the effect of the outlier definition on the result?
- Which distribution function is chosen for the extreme value statistics and how does this choice affect the dimensioning of the flood protection measure or the extent of the inundation area in the hazard maps?

To answer these questions, the planner has to make clear assumptions, where possible, and thus also limit the suitability of the software application for defined use cases. This leads to statements about which conditions or flow processes, which are the focus of the planning question, can be represented particularly well by a model.

In order to determine flood areas and plan flood protection measures, the user of the software has to take into account a large number of influencing factors. Many of the imponderables and uncertainties in the process can only be quantified with great effort. The use of software is essential for defining flood hazards and planning flood protection systems, as it can be used to simulate and represent complex hydrological and hydraulic processes. It is important how the user assesses, deals with and describes the uncertainties. This approach leads to decision support in the management of flood hazards and in the design and sizing of flood protection systems. It is the best tool we have for this purpose.

4. Increasing data availability with Citizens Science - Community Gauges

Citizen science gives the opportunity for science and society to benefit each other. Collaboration between researchers and citizens offers potential for innovation in science and can help to collect a greater volume of validation data. Community Gauges encourage citizens to take images of water levels and contribute to the data collection. As part of the PARADeS project, community gauges were installed in a citizen science pilot project in Accra.

For an overview on citizen science projects please see e.g. https://www.frontiersin.org/articles/10.3389/feart.2019.00044/full.

4.1 Citizen Science project in Accra

Water bodies in Accra and throughout Ghana are regularly examined to align the way of life and society with the characteristics of rivers, channels, or creeks. Gathering data and information is essential for observing, understanding, and comprehending these water bodies. However, a significant problem exists due to the absence of adequate measurements and data availability. The challenge lies in obtaining this data consistently for specific locations of interest and making it accessible to a broad network of users, including researchers and public authorities.

The Water Resources Commission, Flood Competence Center (HKC), and the University of Applied Sciences Magdeburg-Stendal have collaborated in an initiative to address this challenge within the context of the Ghanaian-German research project PARADeS. The initiative involves the implementation of Community Gauges, strategically placed at specific locations in Accra. These Community Gauges encourage communities and individuals to capture images, which are subsequently collected, managed, and shared as valuable information about water levels for anyone interested.

4.2 Pilot implementation of community gauges in Accra

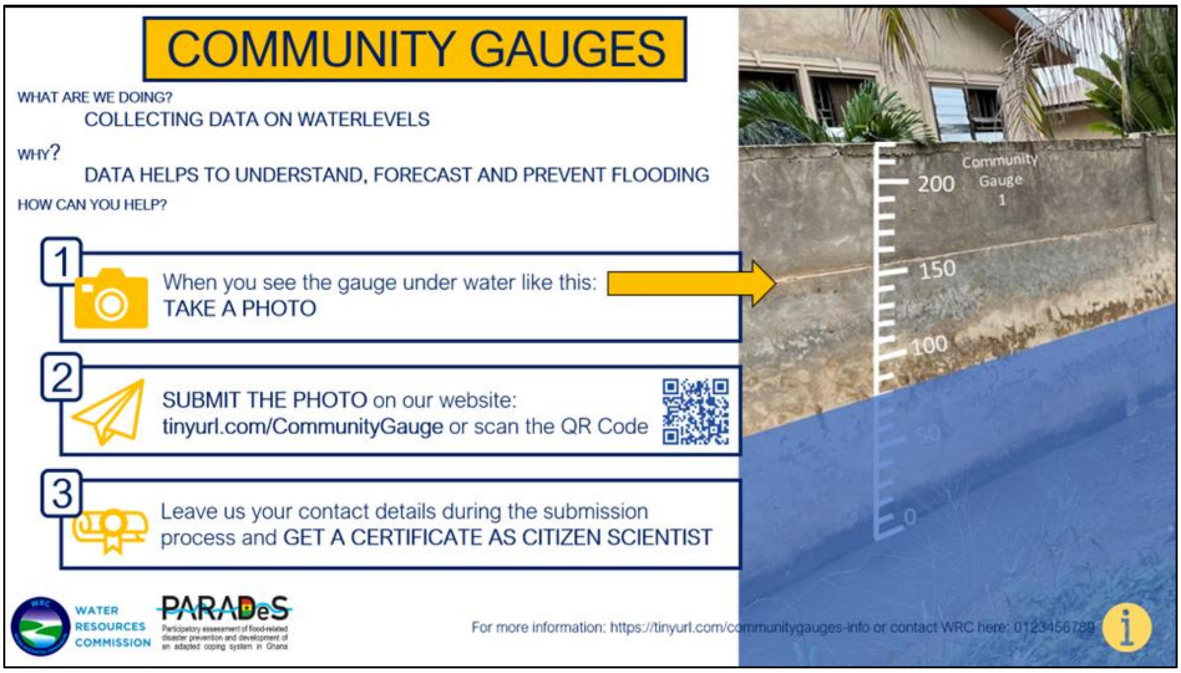
Figure 14. Scale placement for community gauge: Haatso right after installation. © WRC

Figure 15. Placement of posters near gauge scale ©WRC

The community gauges provide an accessible database of water levels, which is essential for project work. Citizens should use their mobile phones to take pictures of floods at specific, frequently affected locations, preferably every time an event occurs, from which the water levels can be easily read. The opportunity is to motivate citizens to participate in flood risk management. The challenge is to set up the necessary structure and convince the relevant communities to participate. A report has been compiled that explains the set-up of the community gauge that exists of a height scale near a water body as well as information material nearby to engage communities around (see Figure 14 and 15 above).

Advantages and challenges

The advantages for citizens are that they are encouraged to become proactive in relation to flooding. Problems in the flood risk situation can be highlighted. Connections are created between administrative organisations and citizens, enabling exchange and further information. For the institutions and researchers, the low-tech solution is low maintenance. They receive data and indications on the extent of flooding and water levels in flood hotspots. They get the opportunity to validate possible model results and indications of unknown problems (unexpectedly high water levels due to blockages). They also receive information on the development of water levels over time. The community gauges do not require large resources for initialisation. They involve communities and raise awareness of flood issues. A challenge for citizens is the investment required in terms of time, data volume and interest. For institutions and researchers, the accuracy of water level information is limited. They do not get a homogeneous temporal coverage of the data series. The functionality of the gauges has to be checked regularly. The success of community gauges depends on the willingness of communities and citizens.


COMMUNITY GAUGES

WHAT ARE WE DOING?
COLLECTING DATA ON WATERLEVELS

WHY?
DATA HELPS TO UNDERSTAND, FORECAST AND PREVENT FLOODING

HOW CAN YOU HELP?

1 When you see the gauge under water like this:
TAKE A PHOTO

2 SUBMIT THE PHOTO on our website:
tinyurl.com/CommunityGauge or scan the QR Code

3 Leave us your contact details during the submission process and GET A CERTIFICATE AS CITIZEN SCIENTIST

WATER RESOURCES COMMISSION

PARADeS
Participatory assessment of flood-related disaster prevention and development of an adapted coping system in Ghana

For more information: https://tinyurl.com/communitygauges-info or contact WRC here: 0123456789

Figure 16. Poster Community Gauges Accra, Ghana ©HKC & HS-M

Lessons Learned and Recommendations

Accuracy is important! The scale should end at a prominent part of the sub-structure, such as the top of a wall or the end of a pier, so that the scale can be measured or reconstructed later if necessary. The paint must be waterproof and adhere well to the substrate. It may be useful to test different colours. The poster should be installed at the same time as the scale. This will take advantage of any interest in the work. Interested residents could be instructed and the scale would be ready for use immediately. If the scale is put up much earlier than the poster, it may weather before people have had a chance to act. The reverse would also be disadvantageous. It is also advisable to choose a sustainable material for the poster. It is important to ensure that no greenery covers the explanatory material on the scale.

Several successful citizen science projects have already been carried out in the field of water, but with a different focus. The CrowdWater project (CH) created a platform to store geo-located photos from around the world. The Coast Snap (AUS) application uses mobile snapshots to monitor beaches. Other applications such as the Mobile Water Management application (NL & MY) use the potential of mobile phone images to measure water level. Scientific publications also focus on community mapping for urban flooding.

Conclusion

The habit of people to take and share pictures of unusual events was attempted to be used for low-cost water level data collection. However, the trial installation in Ghana revealed some challenges in terms of durability of the gauges and timing. However, as this approach is very cost effective and at the same time sensitises, informs and involves citizens, the principle of community gauges could be tested and developed in other countries. Suitable areas would be those that are relatively frequently affected, densely populated and adequately served by communication networks. It would also be helpful to have a local institution with a strong interest in the data. Further information and advice on the implementation of similar projects will be provided in a report.

5. Flood risk management

5.1. Stakeholders' perception on the implementation of adaptation measures

In Ghana, urban as well as rural areas are prone to flooding (Adegoke et al., 2019) and due to climate change, an increase in intensity and frequency of potential harmful precipitation events is expected with high confidence (Trisos et al., 2022). The challenges which the rural and urban residents face differ, while inadequate drainage system and pressure on land for building houses and business dominate in urban areas, it is the pressure on farmland, deforestation and erosion for the rural population (Höllermann et al., in prep.). Currently, rather reactive than preventive approaches dominate to reduce flood impact (Addo-Danso, 2017).

What different groups of stakeholders, such as residents, local government representatives, national disaster managers and hydro-meteorological experts to name but a few, choose as preferred adaptation measures in our interactive exercises highly depends on their human-flood interaction experience and affectedness. Insights from PARADeS experts and decision-maker workshops as well as focus group discussions of local affected communities in urban and rural settings could highlight commonalities and differences.

During the first workshop series, potential adaptation measures were gathered and deliberated upon with input from all stakeholders. Subsequently, the collected measures were ranked or selected according to the preference of implementation.

In the Accra Odaw catchment, after knowing the causes and problems of flooding, it became clear that adaptation measures need to address two different kinds of measures. On the one hand, there is a need for structural measures such a desiltation of drains and on the other hand, there is a need for soft measures to ensure that structural measures stay effective (Figure 17). Figure 17 ranks “Improvement of the drainage system and proper waste management ranks highest, followed by “Increase awareness and preparedness e.g., public engagement, stakeholder coordination” and “Increase capacity of disaster management institutions e.g., tools and equipment”.

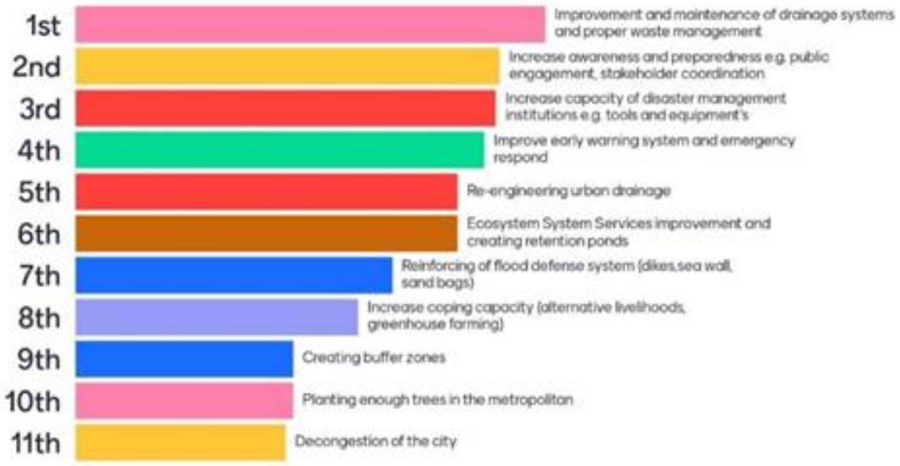


Figure 17. Ranking of adaptation measures that are most relevant for floods in Accra (Results of first workshop). ©U-Bn

The identified adaptation measures for Kumasi Aboabo catchment also include structural and non-structural measures (Figure 18). Looking at the top ranks, one can see that a combination of both kinds of measures is identified as essential. Almost all (13 out of 15) ranks the enforcement of by-laws at the assembly level, followed by technical measures ensuring quick and safe discharge of excess water. Buffer zones around the river and retention areas are also regarded as important measures. Hereby the buffer zones strongly relate to the identified cause of unplanned building in waterways as discussed above. To prevent losses of life and property also a combination of measures is highlighted by half of the participants which looks at early warning systems and flood defence structures.

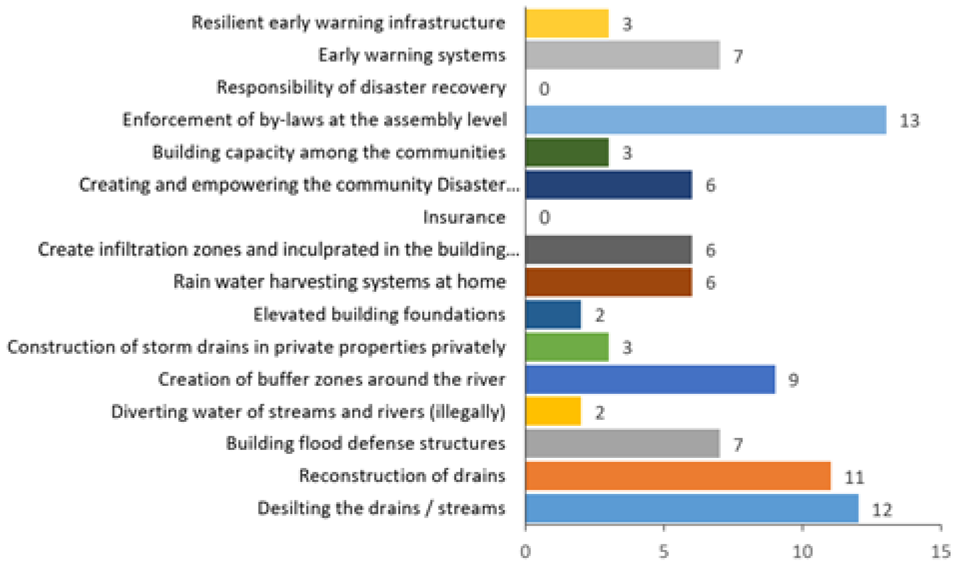


Figure 18. Ranking of adaptation measures that are most relevant for floods in Kumasi (Results of first workshop). ©U-Bn

In the White Volta, early warning system is the most appreciated adaptation measure (15 out of 18). This is followed by training of farmers regarding onset of rains and also regarding crop choices. In the middle field of potential adaptation measures we find a combination of structural and non-structural measures which combines urban planning and development with construction of discharge system. Even though the problem trees highlighted the natural drivers of flooding retention areas are not the first priority.

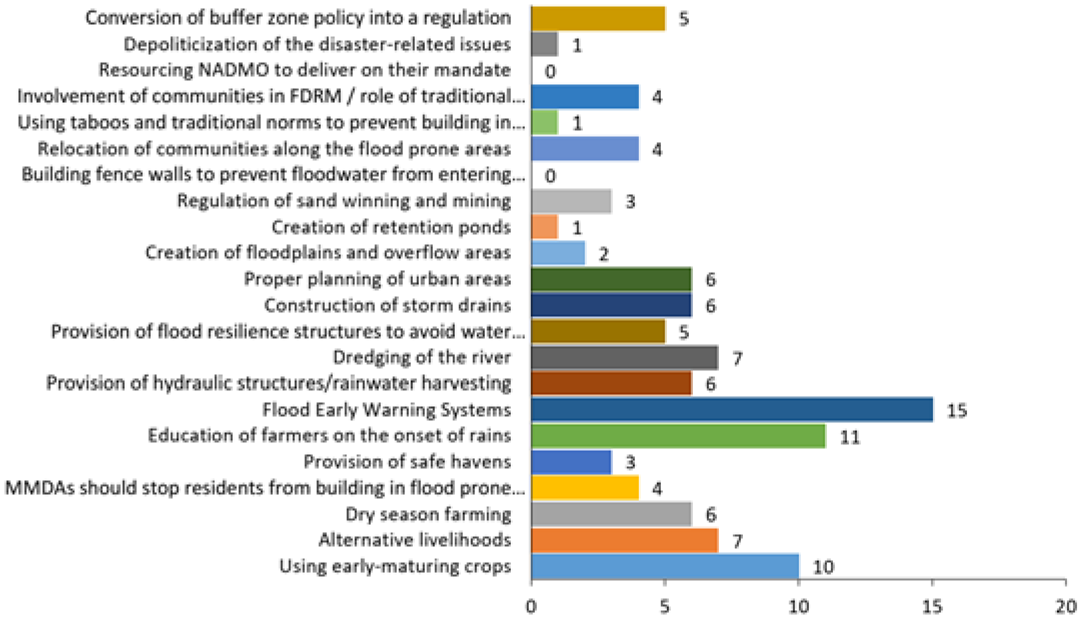


Figure 19. Ranking of adaptation measures that are most relevant for floods in White Volta (Results of first workshop). ©U-Bn

Various measures to reduce water levels during floods were also mentioned. In principle, the water level in a defined stretch of watercourse can be lowered by retention in the upper reaches. This can be done in the process of runoff formation or during translation in the watercourse. On the agricultural land, even a relatively small retention of a few millimetres of rainfall in the catchment can have a positive effect. Soils store water, reducing or preventing the rapid surface runoff that causes flooding. It is therefore important to make the best possible use of the water storage potential of soils for preventive flood protection. These measures are: direct seeding and conservation tillage, soil loosening, grassing of depth lines or edge and boundary structures. Retention measures in cities or on agricultural land play a role in runoff generation. Improve urban stormwater management: this includes measures such as stormwater retention, infiltration, green roofs, rain barrels and others that capture and use stormwater or allow it to soak into the ground instead of being discharged into storm drains or rivers. This can reduce the volume of runoff and the risk of flooding. To influence the shape of the flood wave, engineered retention basins or nature-based solutions could be implemented. One option is to build engineered retention structures, such as flood retention ponds. These structures can hold back water to reduce water levels. They can also act as reservoirs to ensure water supplies, for example for irrigation of agricultural land.

Restore floodplains. River floodplains are natural floodplains that can absorb and store water when the river overflows its banks. They also provide habitat for many plants and animals and improve water quality. These measures can be used individually or in combination, depending on local conditions and needs. However, they require good planning, coordination and funding to be successful.

While during the first workshop series in the metropolitan areas of Accra and Kumasi building infrastructure (hard) measures dominated (49% in Kumasi & 1st rank in Accra, see Figures 17-19), they had hardly any relevance during the second workshop where the participants applied a scenario exercise. It can be argued that the scenario perspective opened up the mind for more transformative measures, meaning that flood early warning systems (FEWS) and building structure are important for quick reaction, but only as an add-on, because those measure will not solve the flood risk problem in the long run. In contrast, measures such as land use planning, especially effective wetland management, and enforcement of laws and regulations in combination with efforts in improving education and awareness are promising to reduce flood impact in the long term (more details in Figure. 20).

For the rural experts and decision-makers, flood defence and water harvesting structures still play an important role since farming activities highly depend on water and water is thus not only regarded as a risk, but also as a resource. The scenario building exercise revealed that the participants independently developed a step-by-step transformative approach. In scenarios where awareness and attitude towards the environment were low, law and regulation as well as education and awareness are emphasized as priority measures. While in scenarios where an attentive attitude and behaviour towards the environment is already established, flood protection measures and event management are prioritized. This fits to the overall learning outcome of the first workshop series, where representatives from the national disaster management organization (NADMO) summarized, that only in a combination with soft measures, hard measures are effective.

Zooming-in to local affected communities revealed a slightly different and less future-oriented perspective, since the residents have to deal with the access water and have little possibilities to reduce their flood risk. The urban residents stress technical measures and demand governmental efforts to increase drainage infrastructure, its maintenance and flood defence measures. They also want to get involved in planning those measures to include their local experience. In the rural context, flooding was experienced as one of many other challenges and before effective flood reduction measures can be introduced, more general livelihood support is needed to increase adaptation capacity and resilience.

To avoid mal-adaptation, a shift from project-focused to transformative measures is needed. However, it still needs a mixture of long- and short-term measures to address the acute needs of affected citizens. This is a prerequisite to get them on board for participatory processes since the expectation between the affected residents and decision-makers do not (yet) align. In some parts this means, that efforts need to go beyond the water sector to create flood resilience. As the local case study in Northern Ghana highlights, livelihood support is needed first. Also, the urban case studies show, when reducing pressure on land and a reactivation of wetlands is envisaged, other livelihood options need to be strengthened. As it was concluded at the end of the second workshop series, it is important to “appreciate that flood risk management is an integrated task”.

	URBAN	RURAL
Experts & Decision-makers	- **Law enforcement = prosecution, sanctions, …** - Community engagement, awareness & **education** - Effective wetland management - Media debates/campaigns - Dedicated budget - Housing programs, strengthening rural livelihoods → **Soft measures**	- **Law enforcement = punishment, no building, …** - **Empowerment of locals**, traditional leaders - Reforestation, agroforestry, maintenance of wetlands - Water harvesting, flood defense structures, dams - Monitoring & early warning systems - Dedicated budget → **Soft & Hard measures**
Local affected communities	- Drainage infrastructure and maintenance of it - **Flood protection** - **Participation** (share experience, get heard) - Early warning dissemination improvement - No disaster relief → **Technical measures**	- Adapted cropping pattern, Agroforestry - **Recession cropping** - Early warning but "What to do?" - No disaster relief - Health care center → **Livelihood support**

Figure 20. Comparison of different perspectives on adaptation measure needs © PARADeS

In this research project, we have thoroughly examined the measures that can be incorporated into the model to assess their potential impact on reducing flood risk. These are rainwater harvesting, buffer zone and household protection for Accra and Kumasi, and dam and dykes for the White Volta. These measures were tested under different return periods (T2-T1000) and climate scenarios (RCP 4.5 and 8.5).

5.2 Flood protection measures for households - Recommendation for Accra Metropolitan Area

Flooding is a serious threat to urban and suburban areas, especially to homes, their owners, and therefore a major challenge for our society. The vulnerability of a community depends on people's adaptation and preparedness to flood risk. Providing information to homeowners about the expected flood risk and appropriate flood prevention measures for the building could prevent fatalities and damage. The communities’ resilience to these events will be increased if a sufficient number of citizens implement prevention measures. Flood risk assessment tools for housing can help authorities to obtain building-specific flood risk information to target the implementation of precautionary measures. For Ghana, the Flood Competence Center (HKC) in Germany has developed the FLOODLABEL tool to help homeowners protect themselves and move towards a flood resilient society.

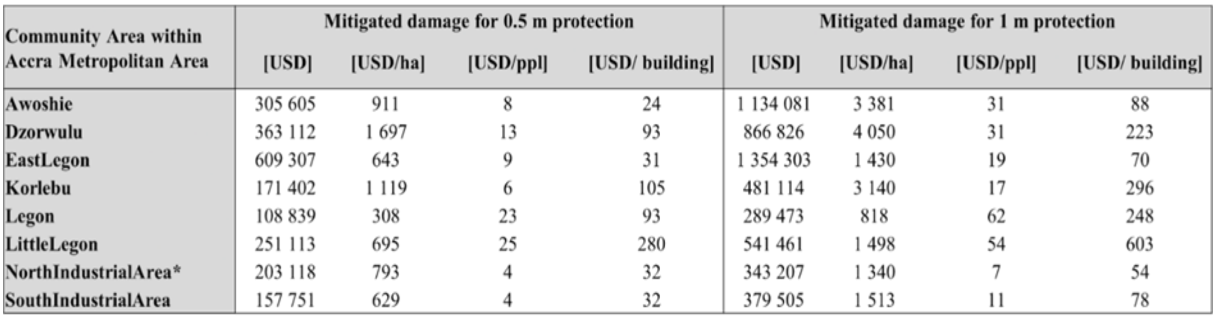
Floods cause major damage when water enters a building. In adequately protected buildings are vulnerable to many ways of water inundation. There are a number of measures that can be taken to reduce the water inflow and thus the damage (see FLOODLABEL Measure Booklet). When choosing the appropriate protection measure, its efficiency or effectiveness is crucial. The difficulty is that the implementation of measures is specific to each building. The FLOODLABEL tool makes it possible to assess buildings individually and implement appropriate measures. The effectiveness of the implementation of measures depends on the level of protection (e.g. 0.5 m or 1 m).

If an authority decides to use a tool such as the FLOODLABEL, the application should be planned in advance. At this point the question remains which areas to prioritise. Which communities are particularly affected and likely to benefit from flood protection measures? And which protection level is realistic to achieve? Modelling softwares can help to answer these questions by running detailed flood risk analysis. In the context of this work, the ProMaIDes software framework is used for flood risk analysis. ProMaIDes modules are used to derive flood maps, but also embeds modules to calculate the economic consequences as well as the population affected and endangered. On the Flood Information System (FIS) reports and data results are accessible with detailed information about all models input, output and uncertainties. The hydrodynamic model is based on a digital elevation model tandem-x and has a resolution of 30 m. Precipitation return periods (T2, HQ10, T25, T50, T100, T200, T1000) are derived from measured precipitation and used as an input for the determination of flood maps. After the derivation of the flood maps, land-use maps and flood depth damage curves are used to derive economic damages and the total risk. For the affected population, population density data is used to derive the number of people affected and endangered (see Chapter 3.2.).

Concentration on community areas in the Accra Metropolitan Area

To provide concrete steps for the implementation of the *FLOODLABEL*: Recommendations are derived from the model results. They highlight specific communities and suggest an appropriate water level of flood protection measures. The recommendations are based on flood risk modelling results for the Accra Metropolitan Area, Ghana and were summarised in the policy brief. As an example from the policy brief, Table 9 shows the potentially mitigated damage due to flood protection measures encouraged by the FLOODLABEL for 0.5 m and 1 m protection.

Table 9. Potential for mitigated damages for household flood protection measures derived from hydraulic and damage models of the Flood Information System Ghana



Community Area within Accra Metropolitan Area	Mitigated damage for 0.5 m protection				Mitigated damage for 1 m protection			
	[USD]	[USD/ha]	[USD/ppl]	[USD/ building]	[USD]	[USD/ha]	[USD/ppl]	[USD/ building]
Awoshie	305 605	911	8	24	1 134 081	3 381	31	88
Dzorwulu	363 112	1 697	13	93	866 826	4 050	31	223
EastLegon	609 307	643	9	31	1 354 303	1 430	19	70
Korlebu	171 402	1 119	6	105	481 114	3 140	17	296
Legon	108 839	308	23	93	289 473	818	62	248
LittleLegon	251 113	695	25	280	541 461	1 498	54	603
NorthIndustrialArea*	203 118	793	4	32	343 207	1 340	7	54
SouthIndustrialArea	157 751	629	4	32	379 505	1 513	11	78

Recommendation

Since many communities in the AMA district are affected by flooding it is important to prioritise the actions taking and define with which communities to start. The analysis showed how modelling results can be linked to the implementation of flood mitigation measures on household level in the communities using the FLOODLABEL. The following steps were suggested to take action for flood prevention household level:

1. Choosing the top 3 communities based on the potentially mitigated damages: Dzowrulu, Little Legon & Korlebu.
2. Plan the implementation of the FLOODLABEL in those communities: How many FLOODLABEL experts will have to be activated? Number of buildings gives an orientation (see policy brief).
3. Assess how long will this activity last?
4. Review the Flood Information System to prioritise the households in streets especially flood prone (see Chapter 3.1.).
5. Use the number for potentially saved USD/ building to recommend the amount of money that should be spent on protection measures for 0.5 m water level.
6. Hand out the FLOODLABEL in practice to increase resilience.
7. Evaluate whether measures have been successful after 3 years of time.

6. Collaborative development and implementation of FDRM strategies and plans

Flood risk management strategies and plans are not developed on the scratch or at the desk but in a cooperative and collaborative process of a broader range of stakeholders, experts and decision makers. Further, the implementation of FDRM strategies and plans is then realized within the multi-level regulatory setting from national to the local level, in a long-term collaborative effort and under the inclusion and participation of all relevant FDRM stakeholders.

6.1 Multi-level governance and regulation of FDRM in Ghana

FDRM is mainly in the responsibility of the government agency; National Disaster Management Organization (NADMO). Established in 1996, the organization is mandated to manage flood disasters and similar emergencies. Based on the National Disaster Management Plan (NDMP), NADMO coordinates all relevant civil authorities at the national, regional and district levels being thus a key actor steering over nine hundred zonal offices (see in Figure. 21 below) in a top-down approach. Further collaborative formats like the Hydromet committee (i.e., the department responsible for Hydrometeorological disasters) comprise a wide cross-sectoral participatory set-up of military officers, police, ambulance service etc. Further, in the formal set-up, disaster risk planning is performed by NADMO in consultation with agencies like the Hydrological Services Department (HSD), Water Resources Commission (WRC), and MMDAs (Metropolitan, Municipal, and District Assemblies). Yet, our analysis showed that next to emergency response which is covered also by the official mandate most activities of NADMO in the field of disaster prevention are rather informative, educative, or consultative in nature. At the same time, a tension exists when it comes to the implementation on the local level as here local communities as well as other stakeholders are needed for the implementation of FDRM strategies but often feel less consulted in the design of FDRM strategies that concern them directly.

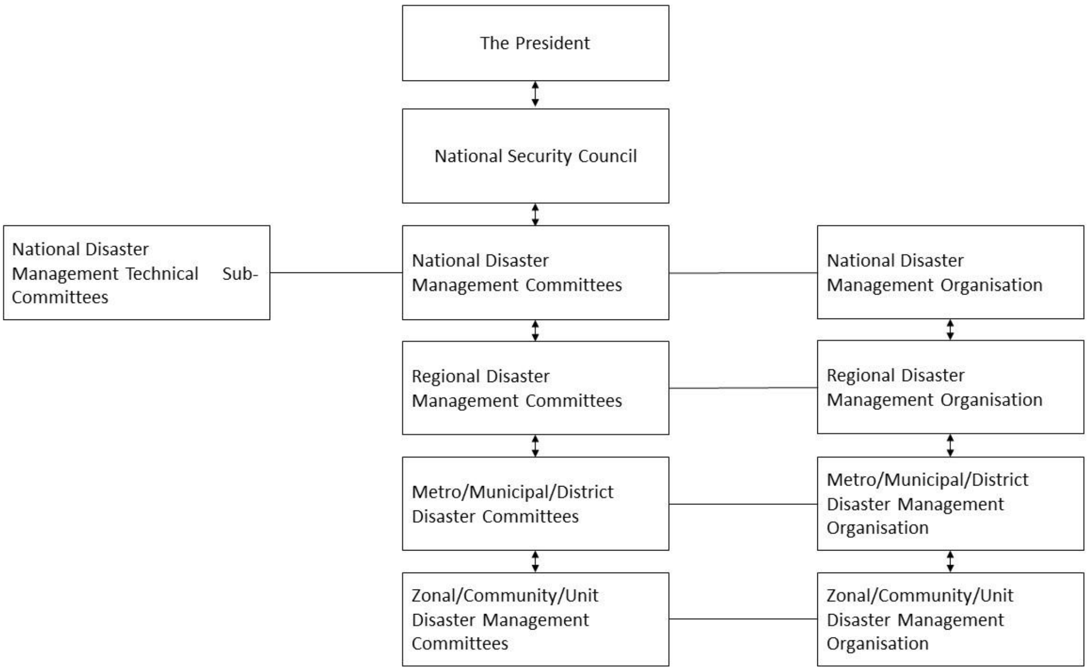


Figure 21. Structure of Flood Disaster Risk Management in Ghana. Each committee at different governance levels consist of state agencies such as Ghana Police Service. (NDMP, 2010)

6.2 Collaborative Governance

Over the last two decades, collaborative governance has developed as a new mode of governance in FDRM that brings multiple stakeholders together in collective forums with public agencies to engage in decision making and implementation. Specifically, in FDRM, policy and decision-makers and disaster risk managers are facing multiple challenges. Effective governance is key to FDRM that often situated in an environment characterized by a high degree of uncertainty and complexity. Collaborative governance is proposed as a key mechanism to implement the United Nation's Disaster Risk Reduction programme (UNDRR), as set out in the Sendai Framework for Disaster Risk Reduction (SFDRR) (UNISDR, 2015: 10). Collaborative governance is considered highly suitable for accomplishing the priority actions outlined in the SFDRR, aligning with essential resilience characteristics such as diversity, heterogeneity, self-organization, as well as fostering innovation and learning (Ansell and Gash, 2008).The shift towards collaborative governance in FDRM builds on previous initiatives towards decentralisation and participation in disaster response strategies and in many cases, collaborative governance is complementing the so-called top-down and managerial modes of policy making and implementation (Ansell and Gash, 2008: 543). Collaborative governance can be broadly defined as „the processes and structures of public policy decision-making and management that engage people across the boundaries of public agencies, levels of government, and/or the public, private and civic spheres to carry out a public purpose that could not otherwise be accomplished (Emerson and Nabatchi, 2012).

Within the realm of disaster management, which traditionally concentrated on government agencies, there is an increasing acknowledgment of the benefits and needs for collaborative governance. Functions and tasks that have been carried out exclusively by public institutions in the past are distributed across a wide range of actors.

In flood risk management, timely and effective governance is crucial to save lives and contain damage. It requires concerted action on various levels, across sectors, and including various stakeholders. However, with this task, challenges arise. Often, flooding responses face similar governing challenges, including e.g., difficulties with coordination among departments, sectors and administrative levels or lack of financial and personnel resources. Collaborative governance can help to establish connections among various government levels and therefore lead to more efficient policies. Next to cohesive action among governmental and non-governmental actors operating in different regions and at different administrative levels, collaborative governance can help recognize multiple sources and types of knowledge, facilitate learning processes and increase resilience in complex hazard situations.

6.3 Stakeholder identification and consultation

The term stakeholder comprises individuals as well as organized groups and institutions, including both public agencies and non-state stakeholders (Ansell & Gash 2008). Stakeholders in FDRM typically involve state actors (e.g., ministries, state agencies and authorities as well as Metropolitan/Municipal assemblies) and non-state actors (e.g., civil society organizations, local communities, international organizations, NGOs, private and business actors, research/academia and media).

When identifying stakeholders for a collaborative or participatory development of FDRM strategies or plans, the following dimensions should be considered:

- The vertical levels of scales on which the strategy or plan should address or should be implemented at, e.g., the local municipal level, the district level, the region or the national level.
- The horizontal level of policy sectors that are affected or need to be included for developing or implementing the strategy or plan. For FDRM, this is of course the policy sector of disaster management, but beyond that, the environmental and water sector, the land use and spatial planning sector as well as the forestry and agricultural sector need to be included. Further, the health sector, energy sector and social welfare sector might be impacted. Within each sector specific state and non-state actors are to be involved.

Initiating collaborative approaches require a thorough identification of who holds what specific stake along both the vertical and horizontal dimensions. Stakeholder analysis is considered instrumental in FDRM policy decision making, intervention or implementation processes. Stakeholder analysis is in fact prerequisite for successful consultation. Where specific project facilitators or Disaster Managers like NADMO already have a thorough knowledge of the focal phenomenon, participation in the stakeholder analysis may not be necessary. However, in situations where there are blurred lines especially characterized by the complex institutional context within which flood disasters occur (Ziga-Abortta and Kruse, 2023), there is the need to consider stakeholder analysis typologies such as suggested by Reed et al. (2009), see in Figure 22. Admittedly, for facilitations of policy implementation by practitioners and disaster managers, stakeholder analysis does not necessarily have to be as rigorous as researchers employ in participatory projects due to time or resources. Commonly employed alternatives are often the interest–influence matrices.

In conclusion, we assert that stakeholder analysis as a means to develop strategies and processes that enhance the representation and engagement of stakeholders in the field of FDRM. Although, it is acknowledged that the aforementioned statement might be an oversimplification, it is nonetheless crucial to underscore the reciprocal influence that exists between stakeholder analysis methodologies, as well as the interplay between the analysis of stakeholders and the broader contextual factors. In the PARADES project, an examination of stakeholder interactions was conducted through the application of Social Network Analysis. This analysis served to distinguish and classify several groups of stakeholders, who were categorized based on their collective perspectives regarding problem descriptions and desired solutions (Ziga-Abortta, 2023). Worthy of note is that stakeholders differ in perspectives, interests, capacities and resources as well as knowledge and ideas about FDRM. The stakeholder involvement processes should be designed to account for these diverse and often diverging perspectives (Fliervoet et al., 2013). Different forms of knowledge (e.g., practical, scientific, management-based, etc.) are acknowledged and that through active and skilled facilitation innovations, perspectives, resources and experiences can be harnessed to identify and discuss solutions and new ideas. In this way, participation helps to improve empowerment, equity, trust and mutual learning in diverse stakeholder settings (Reed, 2008).

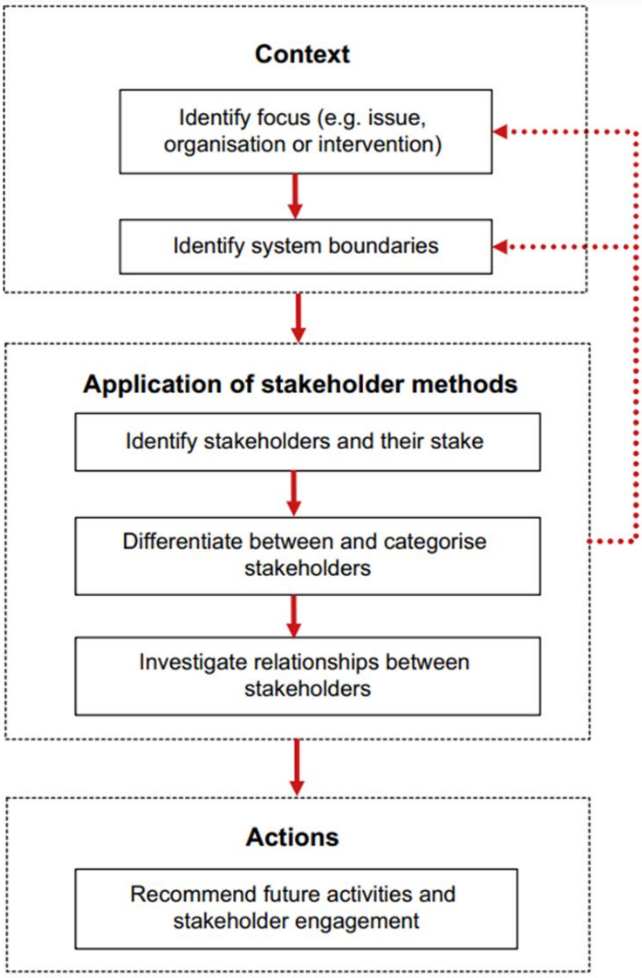


Figure 22. Key methodological steps necessary for stakeholder analysis (Reed et al., 2009)

6.4 Lessons Learned: Empowerment, accountability and inclusiveness helps build trust in FDRM institutions

Summing up, our research suggests to consider the following lessons learned when developing FDRM strategies and plans:

- Coordinating meaningful community involvement and active participation of traditional authorities through facilitating community campaigns. These campaigns should aim to raise awareness about flood risks and bolster preparedness efforts. This is both empowering local communities but also leading to a perception of self-efficacy if the voices of the population are actually taken up in official FDRM strategy development.
- Building a robust framework of accountability and by strengthening accountability mechanisms through rigorous measures to enforce FDRM regulations. Fostering greater transparency in the allocation of resources and the execution of FDRM projects is also crucial. This transparency not only safeguards against misuse but also nurtures public trust, crucial for successful disaster management.

- Fostering inclusivity and nurturing collaboration across various stakeholders aims to address biases and disparities in resource distribution within FDRM processes. Collaboration among government agencies, civil society organizations, and local communities aims to improve effective coordination and synergy among these entities are vital for successful FDRM efforts.

7. Summary of lessons learned

Flood risk in Ghana is a central and increasing challenge. Thus, appropriate and adapted Flood Disaster Risk Management (FDRM) is of immanent relevance. The purpose of risk management is to reduce the impact of events through modification of the hazard, exposure and/or vulnerability. FDRM instruments such as flood risk management plans entail a set of measures to reduce flood risk. Flood risk and vulnerability are context specific, and local and regional conditions have to be considered. Against this background, we compiled lessons learned from the PARADeS project for Flood Disaster Risk Planning and Management in Ghana in order to support the development of FDRM plans and policies and their implementation.

For effective FDRM, it is first important to identify the areas with significant risk. In the PARADeS project we identified hot spots of risk by modelling flood hazards using hydrological and hydrodynamic models, and by simulation of cascading risk with a focus on critical infrastructure and potential consequences with regard to damage and the affected population. We included additional expert knowledge in order to improve the data base and validity of the model results, for example by the application of web-based participatory mapping during workshops with stakeholders, and involved critical infrastructure operators during our analyses, which was a valuable contribution.

The hydrodynamic model that was developed in PARADeS relies on several inputs, including rainfall data (for Accra and Kumasi), discharge data (for the White Volta), a Digital Elevation Model (DEM), cross-sectional data, and land use information used to estimate the Mannings n friction coefficient. The DEM data was derived from DLR TanDEM-X, cross-sectional data was obtained through a combination of in-situ measurements and LIDAR (Light detection and ranging) data, while land use data was sourced from the CORINE Land Use and Cove. We developed hazard and risk scenarios for the urban areas in Accra and Kumasi with return periods of 2, 10, 25, 50, 100, 200, 1,000 years and for the rural area of the White Volta with 5, 10, 25, 50, 100 years.

The model results showed a high level of agreement with the regional expert knowledge as well as with observed data during recent flood events, thus proving the suitability of our models.

Normally, flood hazard and flood risk maps are published in different maps which can be retrieved from the website of one authority. We decided in PARADeS to combine the information on hazard, risk, scenarios or effects of adaptation measures in one tool, the

Flood Information System (FIS). Due to the implemented features, each user can simulate and learn about different scenarios and cause-effect relationships.

This data and information enable the development of Flood Risk Management Plans based on a deterministic approach where strategies and measures are defined to meet a certain security level, mostly for a 100-year flood. However, it is also possible to follow a risk-based approach with the provided results, where strategies and measures are defined and prioritized for high-risk areas.

We invested considerable time and resources on the acquisition and validation of data to generate a good data base for the flood modelling. However, by their very nature, the methods used are only approximations to the actual hydrological and hydraulic processes, and results still contain un-certainties. There are certain rules which should be followed to reduce this uncertainty, such as the selection of a suitable model or ensuring that sufficient discharge measurements are available. In this report, we compiled a checklist to reduce the uncertainty of flood model results.

To improve the data base, a citizen science pilot project was set up beside the Odaw river in Accra for the collection of water level/discharge data by community gauges. This pilot has shown high potential not only for data availability but also for awareness raising in the respective communities. However, we also learnt that certain aspects such as timing or coordination of different sub-activities are crucial and should be taken into account to make citizen science projects a success.

In order to increase preparedness and adaptation on a local and household scale we developed an assessment tool which is tailored to the conditions in Ghana, the FLOODLABEL GHANA. This tool helps to identify individual risk and personal adaptation and risk-reduction measures. Based on the model results, specific communities at risk in the Accra Metropolitan Area (AMA) are identified and a set of measures are suggested, for example, for a level of 0.5 m and 1 m protection of a house. Since many communities in the AMA district are affected by flooding it is important to prioritise the actions and define with which communities to start. The analysis showed how the FLOODLABEL can be used to link modelling results to the implementation of flood mitigation measures on a house-hold level in the communities.

In the PARADeS project we experienced the added value of a transdisciplinary approach, for example to increase the data validity, to gain knowledge on human-flood-dynamics through participatory scenario development or to identify suitable adaptation measures. This approach was also appreciated by the participants, as the evaluation results illustrate.

Initiating collaborative approaches requires a thorough identification of who holds what specific stake along both the vertical and horizontal dimensions. The vertical scales represent the level that the strategy or plan should address or at which it should be implemented at, i.e. the local municipal, district, regional or national level. The horizontal level shows the policy sectors that are affected or need to be included for developing or implementing the strategy or plan.

Based on this generic structure, the PARADeS project added to the identification of stakeholders and the analysis of their interactions through the application of Social Network Analysis (SNA). This helps to understand how stakeholders differ in perspectives, interests, capacities and resources as well as knowledge and ideas about FDRM. Therefore, stakeholder involvement processes should be designed to account for these diverse and often diverging perspectives.

In this way, they can set the basis for collaborative governance, where Disaster Risk Management is not only developed and implemented through government agencies, but also actively including stakeholders from non-governmental and civil society organisations, private companies, and the local population. Collaborative governance is regarded as a key mechanism to improve Flood Disaster Risk planning and management as it helps to coordinate meaningful community involvement that both helps to improve FDRM and create risk awareness and self-efficacy; it facilitates the building of a robust framework of accountability and transparency that helps to build public trust; and it fosters inclusivity and collaboration across various stakeholders, also aiming to improve just resource distribution within FDRM processes.

We can conclude that the PARADeS transdisciplinary approach supports a pro-active FDRM to reduce flood vulnerability. With the participatory and collaborative approach, we could especially support the following crucial aspects:

1. Validation & ground truthing of data and models by input of local and expert knowledge
2. Overcome mismatch between knowledge and action and increase the potential for sustainable implementation of research results
3. Joint knowledge production and mutual and social learning, and
4. Generating ownership and increase the chance of sustainable implementation by the respective authorities and multipliers

We hope that we contribute with this document valuable input to support FDRM in Ghana in order to reduce flood risk and enhance resilience against floods.

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