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

Report on Modelling, Scenarios and Uncertainties for the PARADeS Project

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1 Introduction

This document is a detailed technical documentation of models assembled for the flood risk analysis of the PARADeS project. It is intended to deliver more information for modelling experts or decision makers with the need and interest to work with those models.

The presented work was carried out in the project "Participatory assessment of flood disaster prevention and development of an adapted coping system in Ghana - PARADeS". To build resilience to flood disaster risk, the PARADeS project aimed to strengthen Ghana's flood disaster risk management (FDRM) through an inclusive participatory approach. The PARADeS project is a research project included in the IKARIM framework which was funded by the German Ministry for Education and Research and executed from 2020 to 2023. The project consortium consists of German and Ghanaian Partners.

1.1 Project objectives

The overall objective of the PARADeS project is to contribute to Ghana's national flood disaster risk management (FDRM) strategy, thereby increasing its resilience to flooding disasters. The project comprises a combination of research, development, and institutional strengthening activities. It integrates diverse information and data sources and develops collaborative scenarios and sociotechnical tools to support coherent decision-making processes. A key aspect is investigating and modelling cascading risk effects regarding flood consequences, such as economic damage consequences for people and disruption of critical infrastructures. All processes and working steps were realised in a participatory manner, together with Ghanaian stakeholders. The end products strengthen institutional and citizen capacity through a series of activities on societal awareness and the training of specialists, decisions, and policymakers. Technologically, PARADeS has produced a set of information support tools to effectively disseminate vital information to citizens, researchers, and decision makers to alleviate the impact of flooding.

1.2 About the document

The models of this project were built to represent a wide range of aspects from flooding events. From the waterdrop to the consequences, models are used to support flood risk management by quantifying the flood hazard and its consequences, but also by highlighting the spatial extent of floods and their inherent consequences. The objective of this research project is not to create the best possible results, but to document and publish methodologies.

The documentation concentrates on the technical aspects of the models generated. This mostly includes the description of the model input, as well as the processing of the input data. The output of the models is accessible through the Flood Information System.

The documentation as well as the models are generated in collaboration with the University of Applied Science Magdeburg Stendal (Daniel.bachmann@h2.de) the University Bonn (Mariele.evers@uni-bonn.de) or Water Resources Commission Ghana (Maclumor@yahoo.com). If you wish to work with the presented models and have further questions, please approach the contacts above.

Figure 1-1: CC BY SA License logo.

1.3 Modelling software

1.3.1 ProMaIDes

Enhanced flood risk analysis and management should generally meet the following standards: performance on catchment scale, integration of analyses from precipitation to the consequences, and inclusion of different categories of consequences. All those aspects are to form a holistic approach.

The ProMaIDes modelling approach meets these standards. It is a modular-designed software package for flood risk analysis (Module RISK; Theory) and planning of measures. ProMaIDes includes three base analyses of flood risk, namely the hydrodynamic analysis (Module HYD; Theory & Application), the reliability analysis for flood protection line structures (Module FPL; Theory & Application), and the analysis of differentiated consequences (Module DAM; Theory & Application).

More information about the free ProMaIDes software can be found in publicly available documentation. Articles feature a range of different information, for example, a quick start guide, the technical framework and working procedure, file explanation for HYD and DAM or more background information on supportive software such as QGIS of the ProMaIDes software. Additional sources are presented in chapter 1.5.

The input and output of ProMaIDes is displayed and modified in the free QGIS software. For the simplification of this interaction a range of preprocessing and postprocessing plugins are available. The plugins as well as the whole software is publicly available and fully free.

The PROMAIDES software is used in the flood risk analysis of all case study areas using the HYD, DAM and RISK Module.

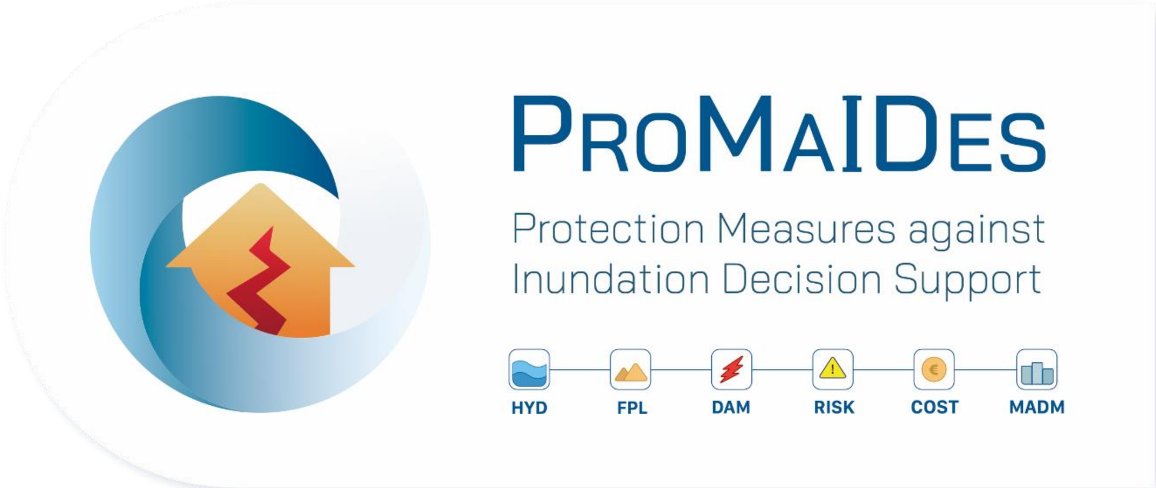

Figure 1-2: PROMAIDES logo including visual representation of the modules.

1.3.2 Soil and Water Assessment Tool (SWAT)

Soil and Water Assessment Tool (SWAT) is a widely used hydrologic model developed by the United States Department of Agriculture (USDA) to simulate and predict the hydrological processes within a watershed or river basin. It is a powerful tool for assessing the impact of land use, land management, and climate change on water resources. SWAT is a computer simulation model based on the water-balanced approach and has been widely applied in data-scare catchments. SWAT is a robust tool for hydrologic modeling but not a stand-alone tool. SWAT comes with a plugin, which uses ArcGIS and QGIS environment for layer integration and visualization of simulation results. In the case of the PARADeS project, the QSWAT plugin was used in the QGIS, as it is open-source software that can be downloaded and used for free. 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.

1.4 Area of investigation

In previous participations three case study areas have been highlighted that are being focussed on during the PARADeS activities:

- Odaw catchment in Accra
- Aboabo catchment, Kumasi
- White Volta catchment

Figure 2 below shows where the case study areas are placed and gives an overview of the modules of the PROMAIDES software that are used for each case study.

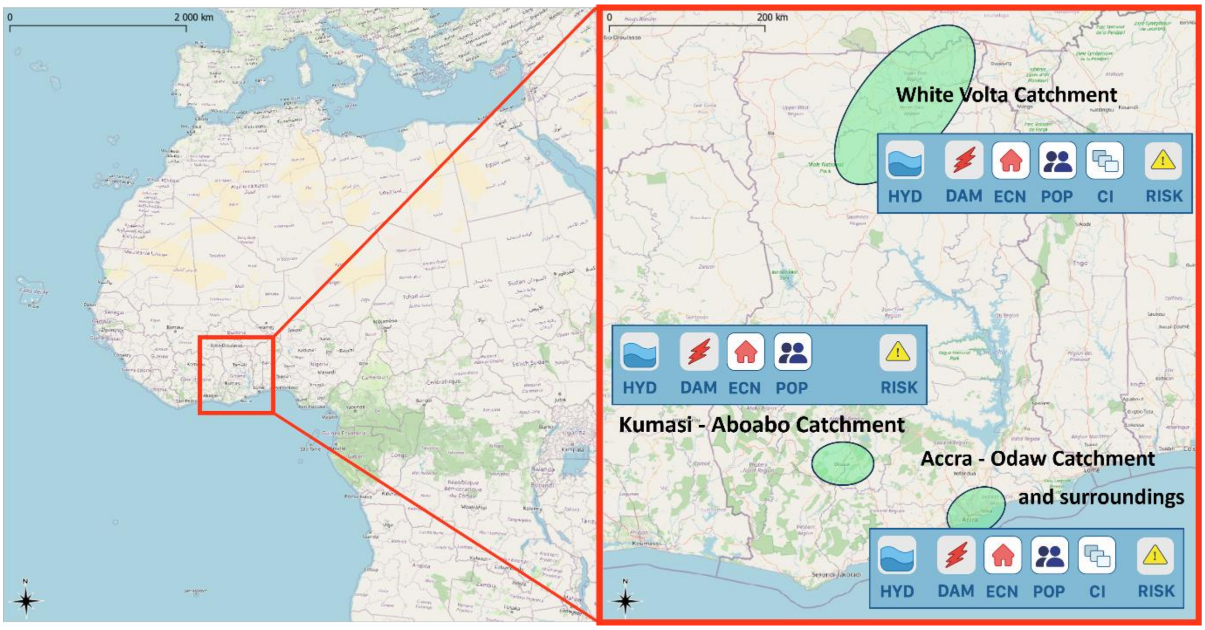

Figure 1-3: Case study areas of the PARADeS project; Three case study areas are investigated; The icons indicate which aspects were considered for each case study.

1.5 Supplementary documentation

PARADeS: Project webpage

Flood Information System (FIS): All model results are published on the flood information system which can be accessed publicly.

Set-up a Flood Information System: This documentation explains how to setup the FIS using PostgreSQL; PROMAIDES and with GeoSever and Openlayers.

PARADeS Handbook: The Handbook gives an overview of the work done in the PARADeS project overall and allows to derive more general conclusions and not only Ghana specific to the case study areas.

PROMAIDES documentation and download link: This extended documentation is a Wikipedia-like version that gives practical and theoretical background for the PROMAIDES software. Articles feature amongst others: General working procedures, technical framework or download links.

Open Education Resources Learning Material: Amongst other PARADeS findings a presentation gives a general introduction to the modelling with PROMAIDES.

2 Accra, Odaw and surrounding catchments

2.1 Hydrological analysis

For the hydrological analysis, river discharge data was not available for this research project, therefore, return periods were estimated, using historical daily annual maximum rainfall time series (1980 - 2020). The rainfall data for Accra Airports was obtained from the Ghana Meteorological Agency in Accra. The projected rainfall data for difference future climate scenarios (RCP 4.5 and 8.5) were included in the statistical analysis of future extreme rainfall events and flood risk in Accra (Table 1). Return periods were determined, using different statistical estimation methods such as Generalized Extreme value (GEV), Gumbel, Weibull, etc. The GEV produced higher estimations daily annual maximum extremes compared to the other approaches. Considering extreme events such as floods, the outcome of GEV is preferred for developing early warning systems and recommendations for flood risks adaption measures in the PARADeS project.

Table 1. Return periods for Accra for base case and future climate scenarios.

Return period	Base case	RCP4.5	RCP8.5
2	82	63	65
10	147	104	118
25	197	124	144
50	244	139	164
100	302	154	183
200	374	169	202
1000	609	204	246

2.2 Hydraulic model

The table at the end of this subsection Table 2 summarises the input of the hydraulic model of the Odaw and gives an overview of the aspects that complement the hydraulic model. In the following section this information is described in detail.

Spatial boundary

The spatial boundary for the case study area in Accra is outlined. Figure 3 above shows the placement of the bounding box in West Africa. In the detailed overview the catchment areas considered are shown. The main catchment of the Odaw is flanked from two smaller catchments on the West side mouthing into the sea: Lafa and Chemu-West. Two smaller catchments Odu-Klottey and Kpeshie are mouthing into sea from the east of Odaw.

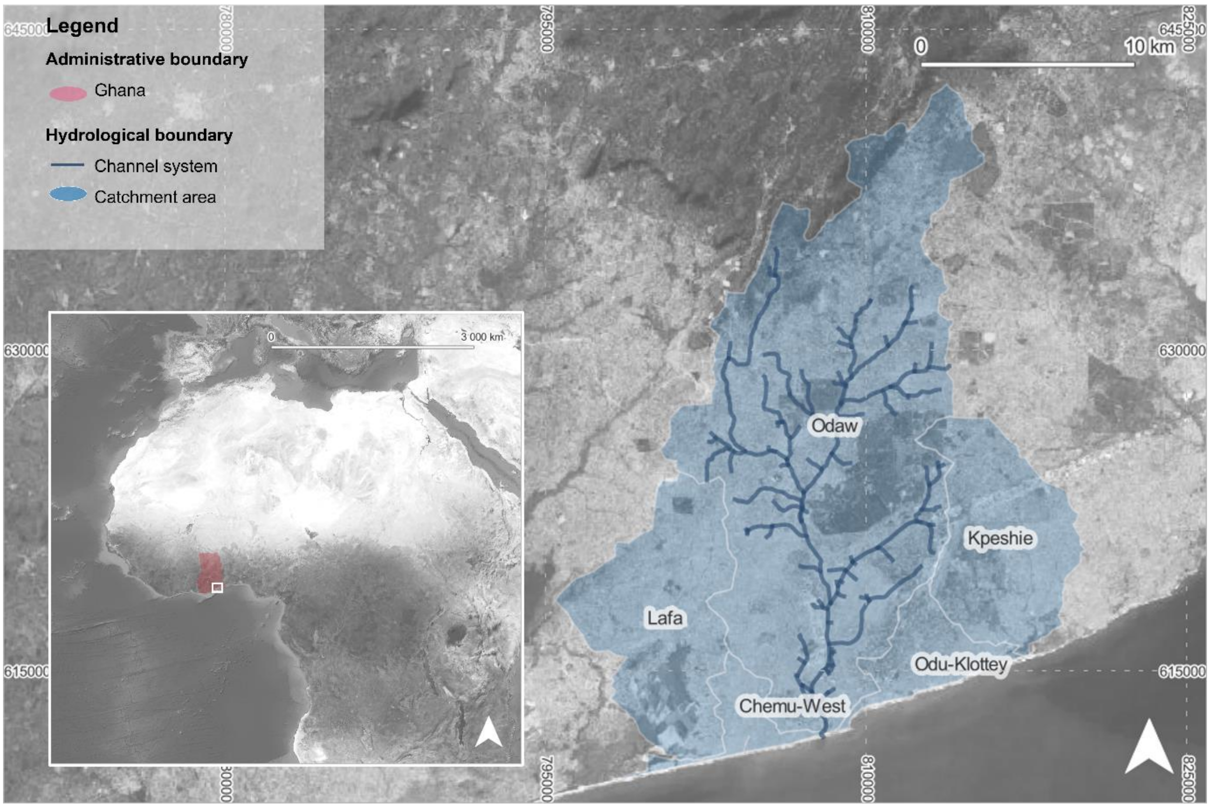

Figure 2-1: Area of interest for the Accra case study area.

Data input

As an input for the hydraulic model the TanDEM-X elevation was used to make height references for a first version of river profiles and for the floodplains. The river profiles were then updated using the LIDAR DEM. The land cover dataset from CORINE was used to identify land cover types and the association with roughness coefficients. The boundary for the catchment areas and the main tributaries was taken from OpenStreetMaps.

Hydraulic boundaries

As hydraulic boundary condition spatially and timely uniform precipitation was taken from the hydrological analysis (cf. section **Fehler! Verweisquelle konnte nicht gefunden werden.**). The precipitation is used in the model in seven variations of the precipitation intensity representing seven return periods. As initial condition a water level corresponding to a medium discharge in the river was taken. The boundary at the mouths of the Odaw-river is the sea. Here, the water level from tidal water gauges was used as outflow boundary.

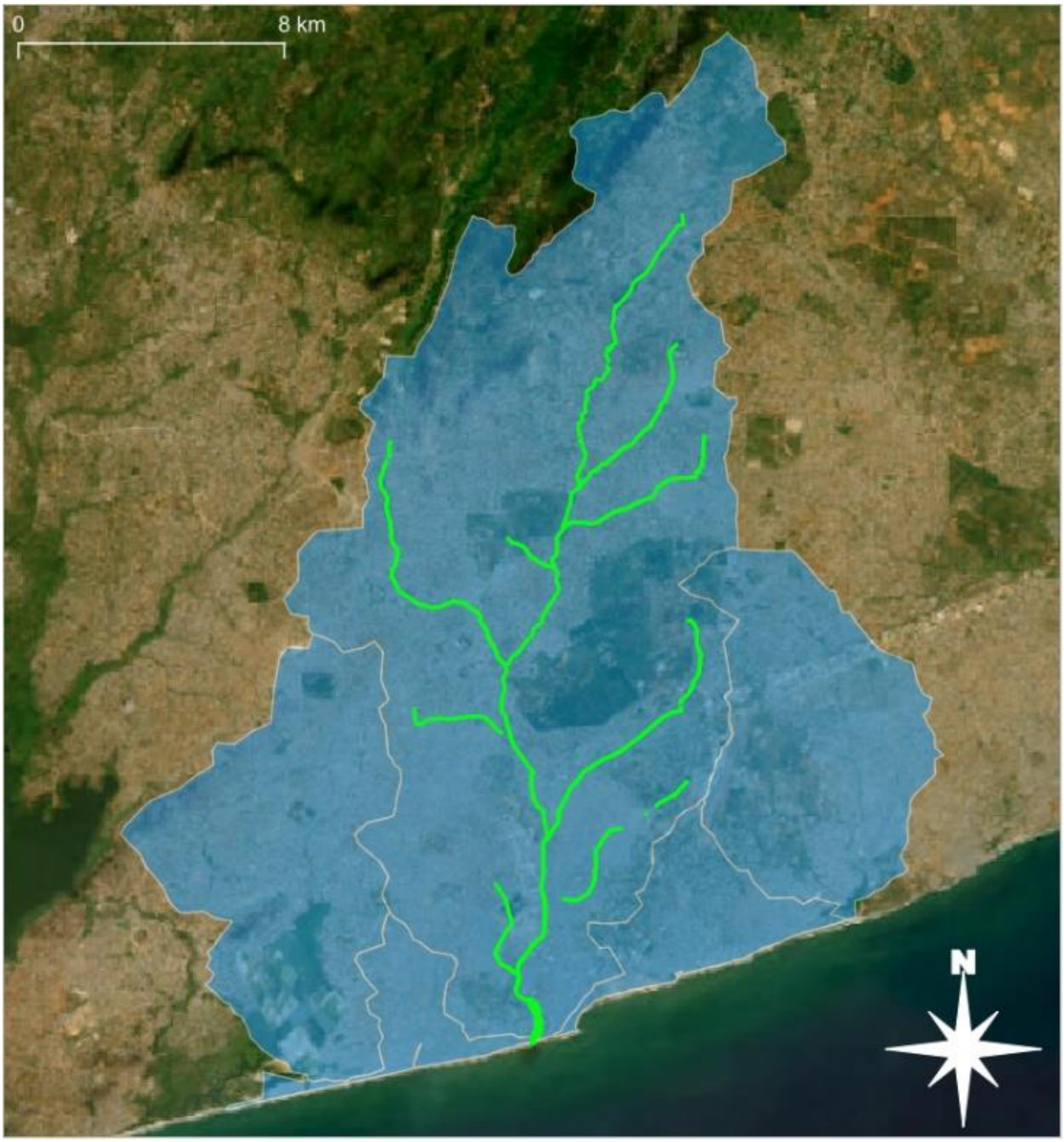

Figure 2-2: View of Accra and the considered catchments (blue); Overview of the river profiles (green) used for the 1D model of the Odaw and its tributaries.

1D Model – Processed Google Street View Imagery and digital elevation data

The 1D model consists of 2411 profiles with a varying width from 4 m – 60 m and a height reference after every meter. A range of profiles were generated using publicly accessible Google Street View imagery and a LIDAR dataset with a resolution of 1 m to increase the accuracy of the profiles. Figure 4 shows an overview of the placement of the 1D profiles along the Odaw and its tributaries.

Abosoe RS=3068.3

Facing upstream

Facing downstream

Figure 2-3: Example of using Google Street View imagery to validate profiles using LIDAR data. Green represents the profiles and red the riverbanks.

2D Model – Floodplains

The 2D model consists of one raster with 850 x 1030 cells with a 30 m x 30 m resolution by cell. For each cell the elevation was derived from TanDEM-X (DLR, 2023) and the material type per cell was derived from the land cover data CORINE (European Environment Agency (EEA), 2023).

Results

The figure below shows an example of how the spatial results of the model look alike for the water depth. Those can be accessed for all return periods on the FIS (cf. Chapter 1.5). Table below additionally summarises the previously briefly elaborated input parameters.

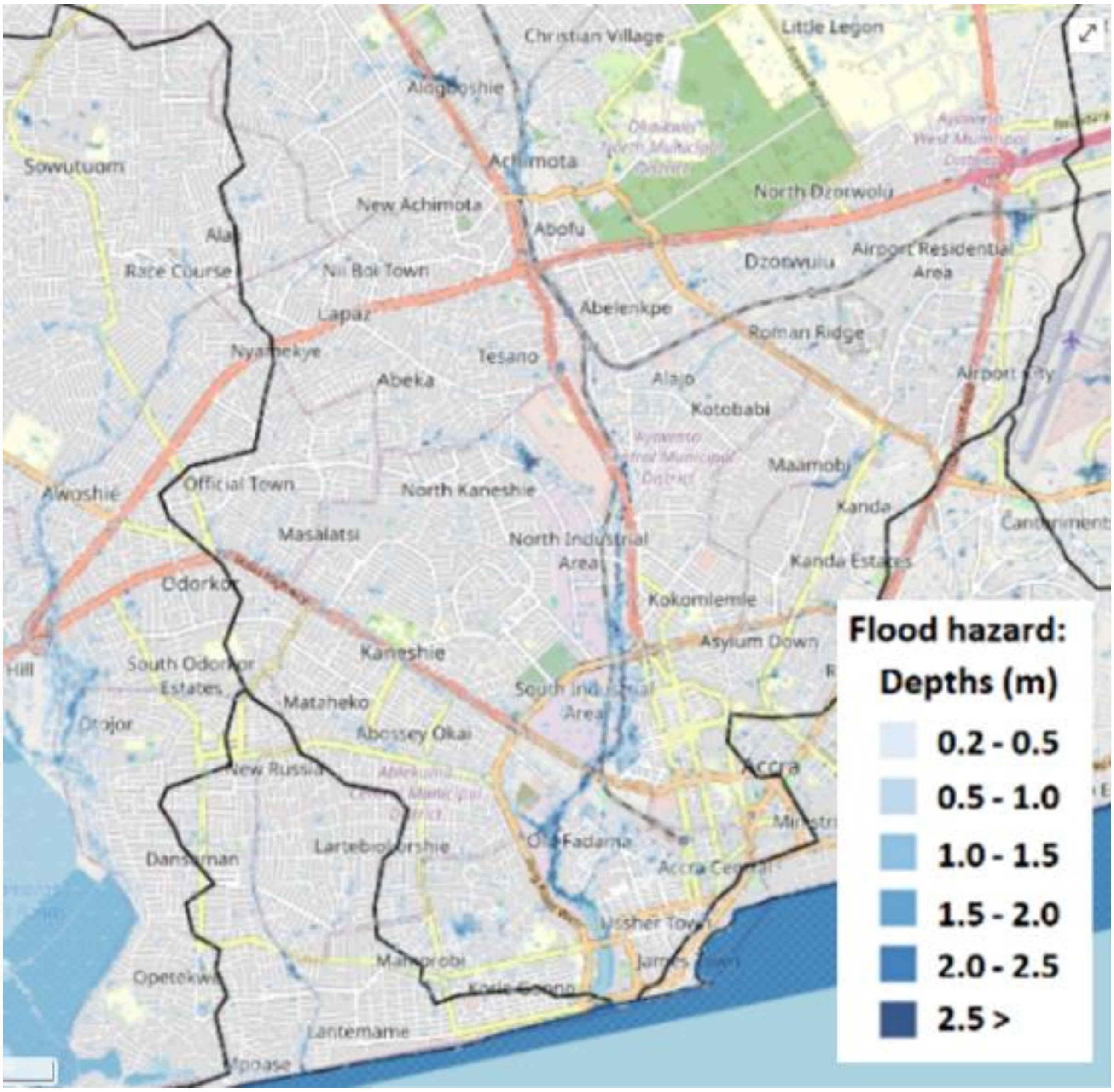

Figure 2-4: Flood depth results for the hydraulic model of the Odaw and its surrounding catchments

Table 2: Summary of model input for hydrodynamic model of the Odaw and surrounding catchments.

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 for the floodplain and LIDAR 1m for the cross-section 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)

2.3 Consequence Model

Based on the outcome of the hydrodynamic model, the consequences of flooding were derived as well based on models. The transfer of inundation maps and water depths to an impact makes it more tangible and allows decision makers to comprehend the flood hazard better. Table 3 shows a summary of the input parameters for all consequence models. In the sections below these are introduced briefly and the modelling actions are elaborated.

Table 3: Summary of model input for consequence models of the Odaw and surrounding catchments.

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

2.3.1 Population

Input

The consequences for population is derived using a range of datasets: 1. A high density population dataset from the Meta-Data for Good Team (*Facebook Data For Good*, 2023). The differentiation of when and how people are affected is taken from Jonkman (Jonkman, 2007) approach. The Jonkman approach not only derived the number of people affected but can also differentiate the type of consequence to people.

Preprocessing – Checking and removing exposure directly in the river channel

First step of the preprocessing was to check the quality of the population density dataset. Though already highly resolved the dataset showed that some cells of the population raster indicated population in the main river channel. Those datapoints were removed manually from the raster to ensure, that these are not considered in a state of normal discharge and therefore falsify the output

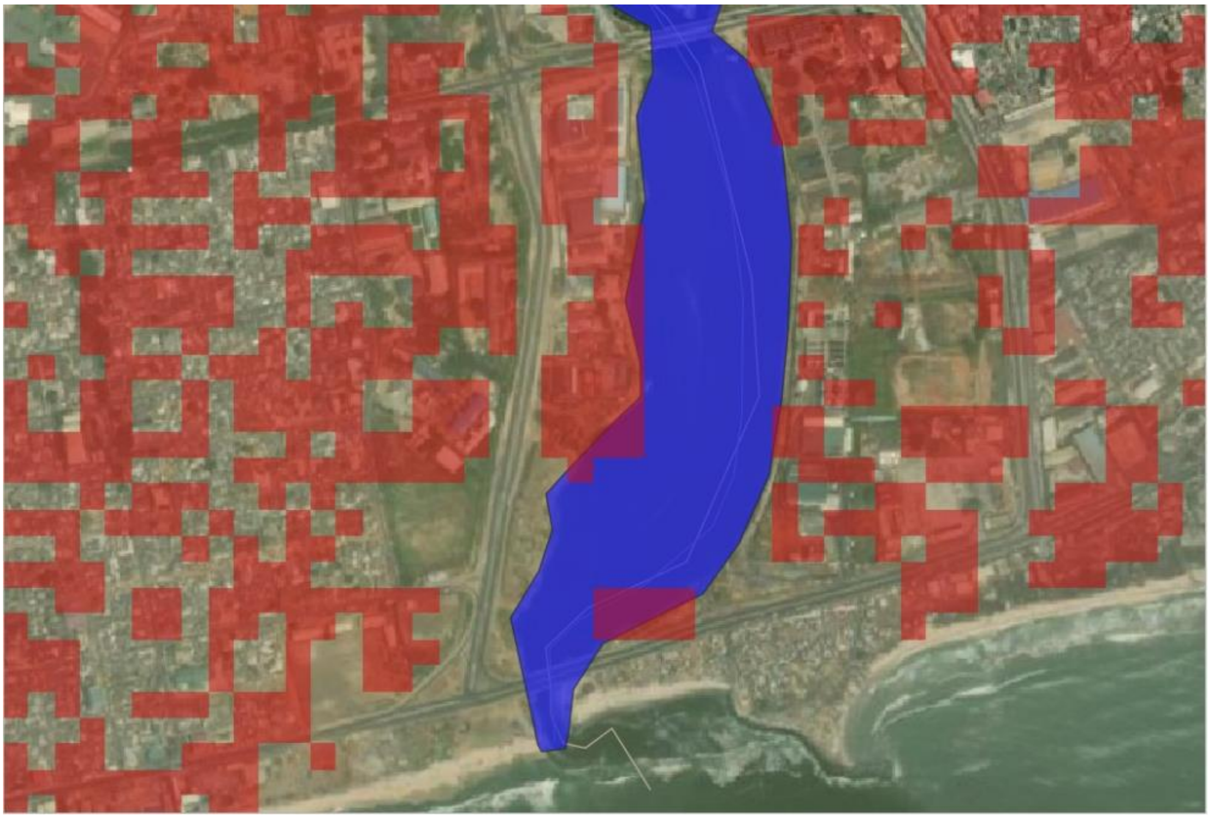

Figure 2-5: A satellite image of Odaw main channel mouthing into the sea superposed with the population density raster cells. Cells overlapping with the blue waterbody were cropped from the raster.

(cf. Figure 7).

Results

The results for the consequence model for population does give a range of output: The number of people affected as well as the people endangered. Additionally, the spatial distribution of the consequences is an output which can be seen in the FIS for each return period (cf. Chapter 1.5).

2.3.2 Economic damages

Input

As an input for the model to derive economic damages land cover data was used (Sentinel-2 10-Meter Land Use/Land Cover) (Esri, 2023) and flood depth damage curves were derived from a report on flood-depth damage relations from the European Joint Research Centre. (Huizinga et al., 2017)

Flood depth damage curves & stock values

Table 3 as well as Figure 9 show the three different types of curves that have been used in this project. The three types feature a curve for damage to urban structures, agricultural areas and rural

Table 4: Flood-depth-damage relation used for the economic damage models in numbers.

Water depth [m]	Relative damage to urban areas [%]	Relative damage to built up area (rural) [%]	Relative damage to agricultural area [%]
0	0	0	0
0.5	0.04	0.22	0.24
1	0.09	0.38	0.47
1.5	0.44	0.53	0.74
2	0.79	0.64	0.92
3	0.98	0.82	1
4	1	0.9	1
5	1	0.96	1
6	1	1	1

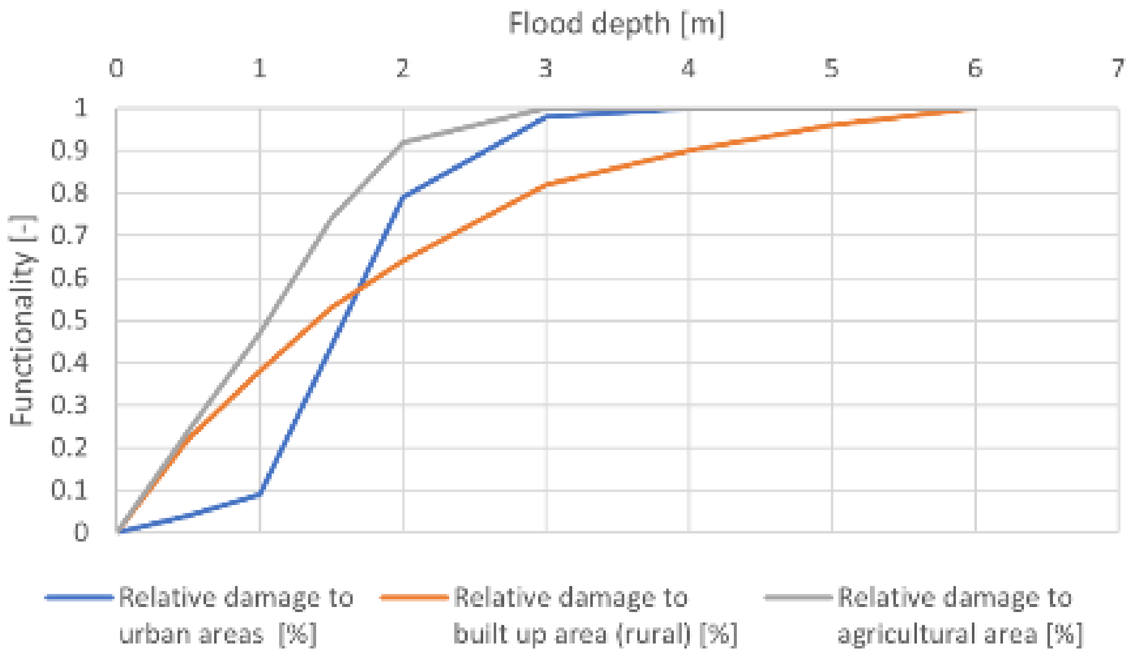

Figure 2-6: Flood-depth-damage relation used for the economic damage models in a graphical representation.

built-up areas. The stock values describe commercial, industrial, high-, medium-, low- and very low-income areas and have been taken from a previous collaboration of WRC and HKV and have been documented in the Table 2 at the beginning of chapter 2.3. Sources for these inputs is a thesis of Julius Kutscher at the Magdeburg-Stendal University of Applied Science (HS-M), the report from the collaboration of HKV and WRC, as well as the JRC report on flood depth damages.

Preprocessing – From land-cover to land-usage data

As indicated, land cover data was used as an input for the economic damage model. For the case study area in Accra though most of the land cover data is marked as built up. To better differentiate the areas which are impacted the land cover data was differentiated further towards a land usage data. The categories that were differentiated can be taken from the table at the beginning of chapter 2.3. These were set apart from each other by the typification of certain landmarks. This included the amount of greenery, the width or presence or roads or the number of levels of buildings. The method for that and the sampling of that was also taken from the previous collaboration of HKV and WRC (HKV Consultants, 2018). The findings from their input were updated with satellite imagery and street view imagery obtained in 2021 in collaboration with student assistant Nadja Kläring at HS-M.

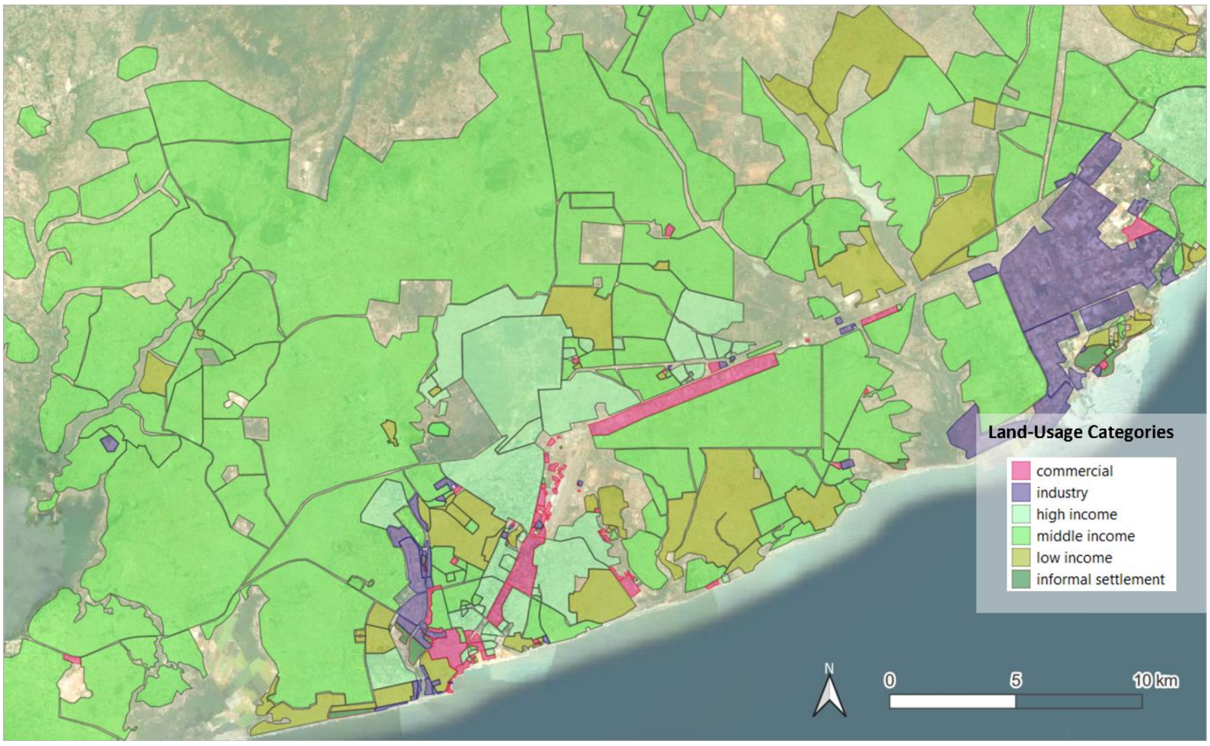

Figure 2-7: Land-usage data for the regional district of Greater Accra.

Preprocessing – Deleting data for 2D raster based on the 1D model

The land usage data introduced previously was rasterizes and used as an input for the damage rasters of the economic damage model. Though the input rasters had to be pre-processed. During the mapping of land usage data from land cover data, satellite, and street view imagery no attention was paid to the appearance of river bodies. The river bodies had to be excluded from the rasters. The figure below shows that river bodies overlapped in some areas with the land usage data (cf. Figure 10 left) and had to be cropped out to not consider damages during a normal discharge (cf. Figure 10 right). After that no damage is indicated for a normal flow and thus the results have one factor of uncertainty less.

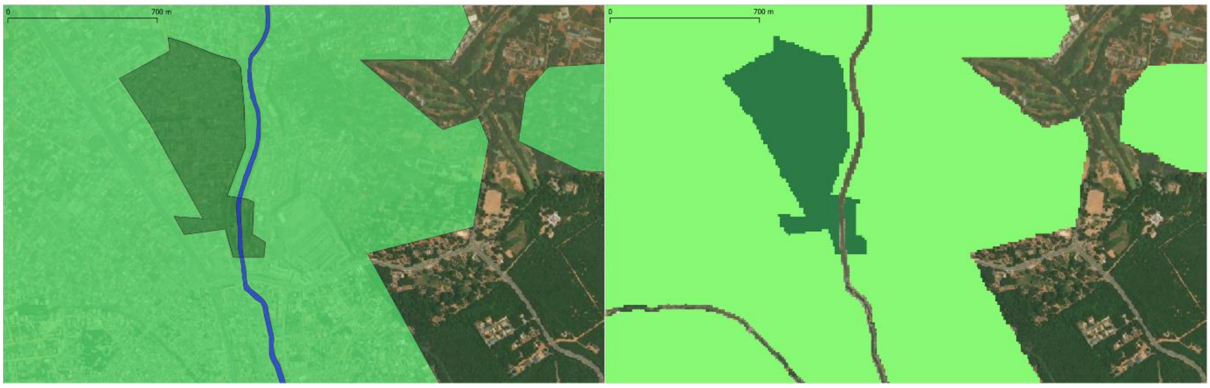

Figure 2-8: Land usage data before and after manual correction in the river bed.

Output – Numbers, spatial distribution, Usage-Type specific numbers

As an output of the economic damage model the damage per flood event for each return period is derived but also the spatial distribution which can be found on the FIS (cf. Chapter 2.3). Chapter 2.4 shows those number and the combination as risk for all consequence types.

2.3.3 Critical infrastructures

Method & Input

Critical infrastructure disruptions were derived by developing a new methodology to assess flood risk for critical infrastructure. In a publication this method as well as the case study of Accra is introduced in detail (Schotten & Bachmann, 2023). As an input, publicly available infrastructure data were used from OpenStreetMaps (OpenStreetMap contributors, 2017), it is stated in another publication that data availability and model quality are closely related and remain a challenge (Schotten et al., 2023). The first version of the input and model assembly was shown in a participatory workshop and anecdotally verified with a range of stakeholders. Figure 11 highlights the CI network that was

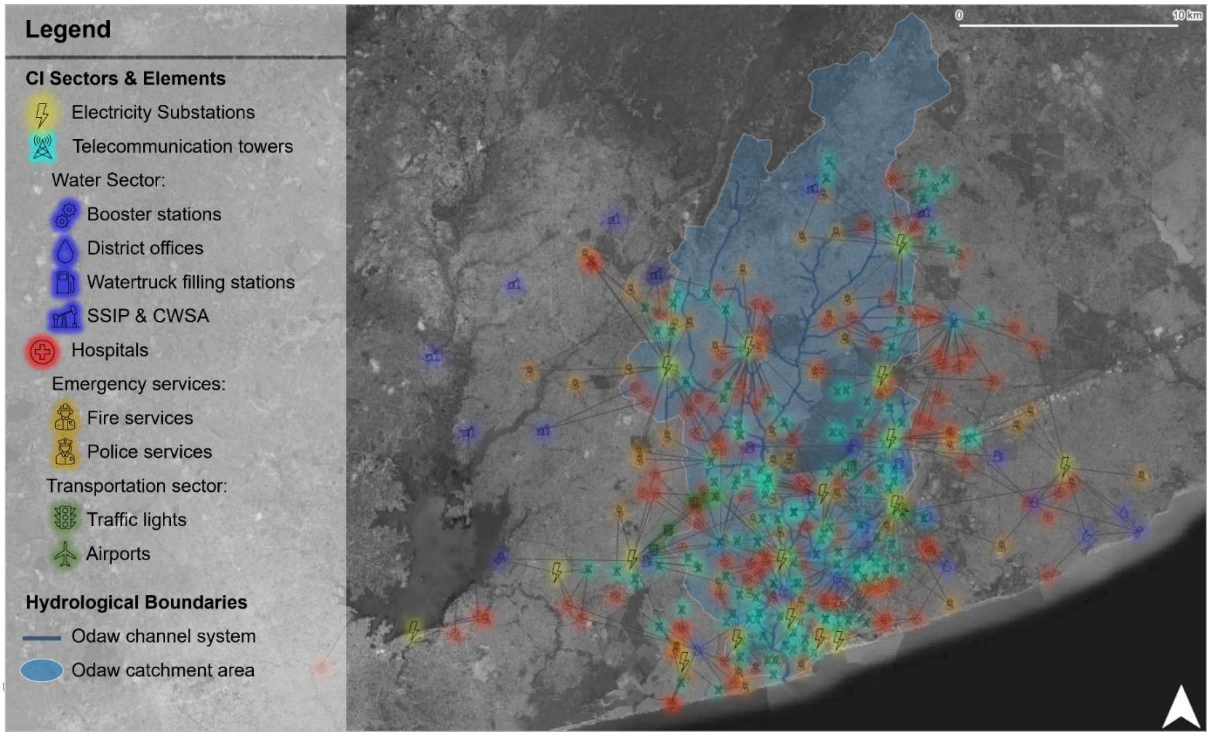

Figure 2-9: Case study area of Accra including point and connector elements of the CI network model.

assembled for the Accra case study.

Processing

The processing involved the attribution of characteristics for each network element. This preparation of input data is documented on a publicly available web page to be used by all users of the ProMaIDes software. The input from the included infrastructure networks is processed to point, polygon and connector elements (cf. Table 3).

The CI network metrics are derived by the ProMaIDes software after the processing input is uploaded. The network metrics feature information like the hub value, cascade potential value or cascade vulnerability value. More information on those metrics can be found here and in the previously mentioned publications.

Output

As an output of the presented model the disruption for every CI sector indicated are quantified. Additionally, the areas disrupted or to be more precise the polygon elements disrupted are highlighted. The findings have been published as well in a peer reviewed publication (Schotten & Bachmann, 2023). Figure 12 shows how the spatial extend of CI disruptions in two sectors derived from the model output (A) and (C) as well as the input to other sectors in (B) and (D).

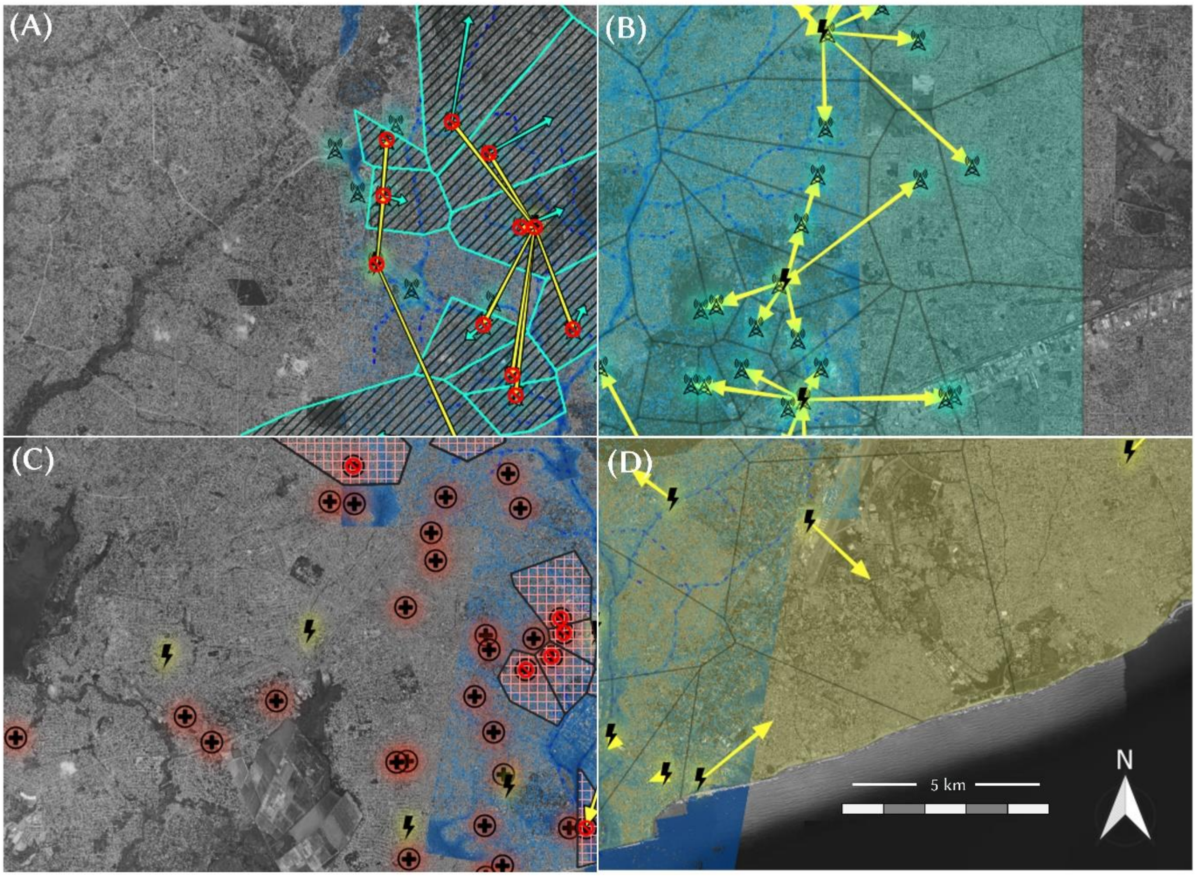

Figure 2-10: View of the Odaw catchment with four quadrants highlighting various aspects of the CI network model: (A) highlights the impacted ICT point elements, their associated disrupted polygons and the energy sector points. (B) shows the input for the ICT sector and the connection to energy points. (C) shows disrupted health sector elements and associated polygons. (D) shows the input point and polygon elements of the energy sector.

2.4 Current flood risk

Subsequently, the derived consequences were combined with the return periods from the hydrological model and the hydrodynamic model funnelling into the calculation of catchment-wide flood risk (Bachmann & Schüttrumpf, 2014). Table 5 below shows the derived risk for all consequence types introduced in the Accra catchment. The risk was derived only considering the return period for a 10, 100 and 1000-yearly event. The derived risk describes the current flood risk situation of the

Table 5: Flood risk for the case study area of Accra based on the model output.

	Annuality [a]	HQ10	HQ100	HQ1000	Risk *R* [... / a]
	Probability of reoccurence p_{hyd} [-]	0.145	0.0495	0.0055	
Classic flood consequences C	Economic damage [USD]	295.71 Mio.	465.83 Mio.	631.01 Mio.	**69.41 Mio.**
	Affected [people]	1.12 Mio.	1.3 Mio.	1.49 Mio.	**234 618**
	Vulnerable [people]	12 688	20 099	34 510	**3 024**
Population Time T_{Pop} per CI Sector	Energy [people x days]	2.23 Mio.	8.1 Mio.	9.53 Mio.	**776 546**
	Water [people x days]	1.61 Mio.	1.61 Mio.	2.43 Mio.	**326 465**
	Emergency services [people x days]	1.53 Mio.	13.16 Mio.	16.53 Mio.	**964 744**
	Information and communication technology [people x days]	2.03 Mio.	6.15 Mio.	7.47 Mio.	**640 264**
	Health Care [people x days]	3.15 Mio.	7.79 Mio.	11. Mio.	**903 260**
	CI risk sum [people x days]	10.56 Mio.	36.8 Mio.	46.95 Mio.	**3 611 279**

Odaw catchment. The numbers shown were obtained directly from the database of PROMAIDES.

2.5 Measures and climate change scenarios

This section provides a concise overview of the measures that have been calculated using the models previously introduced and released in the FIS. The conceptual basis of these measures as well as how they have been incorporated into the model is elaborated. The modelling methods inhere uncertainties, which needs to be considered when deriving decisions based on their outcome. Therefore, it is elaborated on the measures' objectives, the implementation into the model

Table 6: Overview of the effectiveness of flood measures in Accra for two flooding return periods.

Return period- T2

Measures	Flooded area in Odaw including west and east small basins (km²)		Population affected (No. of people)		Population endangered (No. of people)		Damage to economy-properties (USD 2016)	
	Area	Diff. w/ DN	No.	Diff. w/ DN	No.	Diff. w/ DN	No.	Diff. w/ DN
Do-nothing (DN)	115	-	637,254	-	621	-	194,596,000	
Rain water harvesting	109	-6	590,180	-47,074	511	-110	169,003,000	-25,593,000
Buffer zone 15m	115	0	634,210	-3,044	608	-14	196,418,000	1,822,000
House protection 0.5m	115	0	637,254	0	621	0	162,544,000	-32,052,000
House protection 1.0m	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated

Return period- T200

Measures	Flooded area in Odaw including west and east small basins (km²)		Population affected (No. of people)		Population endangered (No. of people)		Damage to economy-properties (USD 2016)	
	Area	Diff. w/ DN	No.	Diff. w/ DN	No.	Diff. w/ DN	No.	Diff. w/ DN
Do-nothing (DN)	174	-	1,109,440	-	4,128	-	606,367,000	
Rain water harvesting	172	-2	1,093,920	-15,520	3,961	-167	592,130,000	-14,237,000
Buffer zone 15m	174	0	1,102,810	-6,630	3,458	-670	582,132,000	-24,235,000
House protection 0.5m	174	0	1,109,440	0	4,128	0	561,397,000	-44,970,000
House protection 1.0m	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated	Not calculated

framework and their outcomes. Table 6 summarises the effect of the considered measures on the flood risk as well as hydraulic parameters.

Rainwater harvesting

Rainwater harvesting is a method of collecting and storing rainwater for various uses, such as irrigation, household chores, and even drinking in some cases. This process involves capturing rainwater that falls on rooftops, surfaces, and open areas, directing it through a network of gutters and pipes, and storing it in tanks or reservoirs for future use. By harnessing rainwater that would otherwise be lost as runoff, rainwater harvesting reduces the demand on conventional water sources and contributes to sustainable water management.

In terms of flood control, rainwater harvesting can have a positive effect. In urban areas with extensive concrete surfaces and limited green spaces, heavy rainfall can lead to rapid runoff and increased flooding due to inadequate drainage systems. Rainwater harvesting systems help to mitigate this issue by capturing a portion of the rainfall and diverting it into storage rather than allowing it to overwhelm drainage systems. This reduces the volume of water entering stormwater drains and can significantly decrease the risk of localized flooding. By managing rainfall at the source, rainwater harvesting contributes to better stormwater management, decreased strain on infrastructure, and improved flood control measures in urban environments.

In the analysis focused on Accra's situation, the evaluation of rainwater harvesting drew its foundation from the research carried out by Damman et al. (2017). This particular study involved surveying 11 households to probe the viability of rainwater harvesting as a water resource within the broader Greater Accra region. The computation of rainwater harvesting storage (*RWHS*) was accomplished by taking into account the storage average capacity identified among the surveyed households (*SAH*), determining the approximated total roof area (*TRA*) via building footprint data, and considering the proportion of usable roof area (*URA*), which was established at 85% based on this study (Damman et al., 2017). The calculation of RWHS was carried out in accordance with the following approach:

$$RWHS = SAH \ * \ (URA / \ Catchment\ area)$$

Where:

$$URA = TRA * 85\%$$

$$SAH \ = \ 85.71\ mm$$

$$TRA \ = \ 54\ 830\ 920.90\ m.^2$$

The rainfall scenario depth estimates were then subtracted using the calculated RWHS of 15.02 mm to simulate the storage effect on flooding.

Buffer zone for 15 m

Another measure which was highlighted by stakeholders is the buffer zone. The idea of the buffer zone is to define a proximity to a waterbody and remove and repress the construction of buildings in this corridor. For the case study of Accra, the corridor is defined to be 15 m to each side of the water body. The purpose of this measure is to prevent people being affected in proximity and economic damages of frequently affected lands.

Ongoing discussions assess the measure's effectiveness in preventing impacts and economic damages compared to the effort required to clear the 15 m buffer zone. Therefore, the consequence models were used to quantify this effect.

The measure was included in the models, by simply removing the damages and affected people from the model input of the land-usage data and the population density data.

House protection measures for 0.5 m and 1 m

Floods cause major damage when water enters buildings. Inadequately protected buildings are vulnerable to various types of water inundation. Several measures can be taken to reduce water inflow, and thus, damage. Efficiency and effectiveness are crucial when choosing an appropriate protection measure. However, the implementation of these 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.

Two scenarios where housing protection is considered for up to 0.5 m and 1 m water height. House protection measures till 0.5 m are relatively easy to implement at low budgets. House protection measures up to 1 m of water height need a different amount of extra effort depending on the measure.

For the quantification of the potential of house protection measures the economic damage model is used. The flood-depth-damage curves are modified to represent this protection by indicating that damage only occurs after surpassing 0.5 m or 1 m of water depth as shown in Figure 13. This

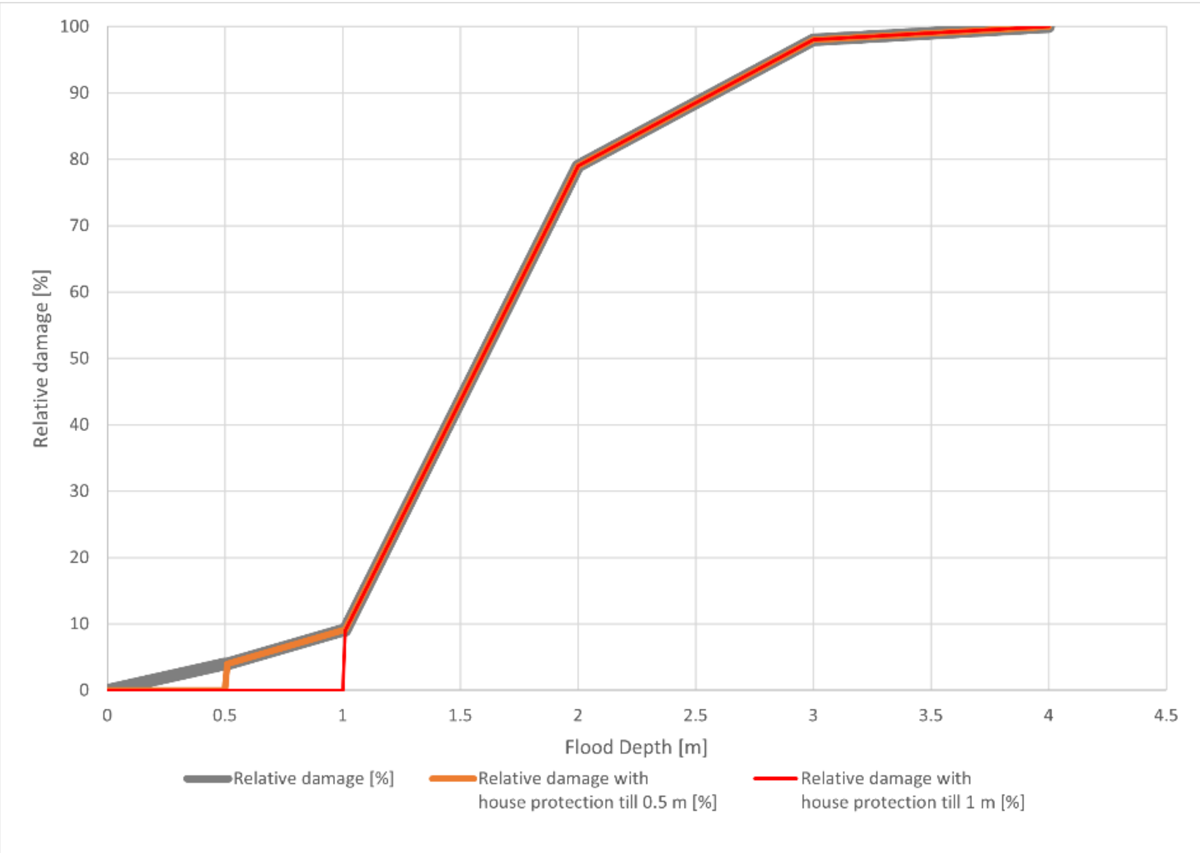

Figure 2-11: Flood-depth-damage curves used for the economic damage model (grey) and the modified curves which include house protection measures.

approach though assumes that all buildings and houses uniformly apply 0.5 m and 1 m of measures. Another assumption is that all protection measures are 100 % functional.

The results of the changes risk can be observed in the table summarising all measures for two return periods at the beginning of the chapter. What is not shown but still possible is the change of risk.

Climate Change RCP 4.5 and 8.5

The climate change scenarios derived from the hydrological analysis are used as well as an input for the flood risk modelling framework (cf. Chapter 3.1). The hydrological analysis derived additional precipitation rates, which are in general lower than the precipitation of the base case. Therefore, it can be expected that the flood risk is also decreasing. For more information the results can be viewed in the FIS as is highlighted in Figure 13 and in the previously introduced Table 6.

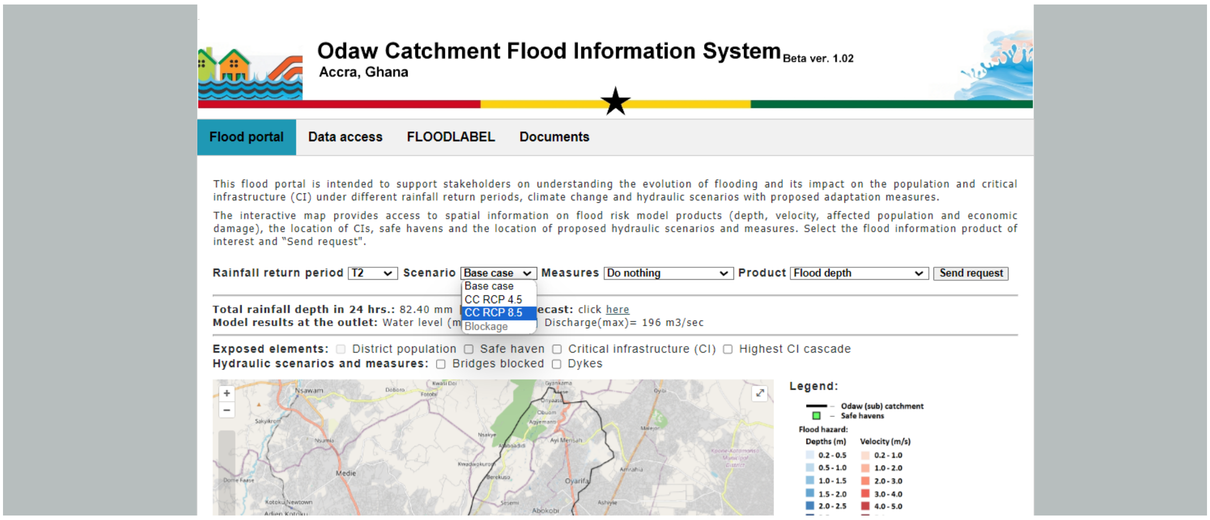

Figure 2-12: Screenshot of the [Flood Information System for Accra]() showing the Scenario option.

3 Kumasi, Aboabo catchment

3.1 Hydrological analysis

Similarly to the case of Accra, the hydrological analysis, river discharge data was not available for this research project, therefore, return periods were estimated, using daily annual maximum rainfall time series (1980 - 2020) for the Kumasi Airport. The rainfall data were obtained from the Ghana Meteorological Agency in Accra. The rainfall data for the future climate scenarios (RCP 4.5 and 8.5) used for the statistical analysis of future extreme rainfall events and flood risk in Accra and Kumasi (Table 8). Return periods were determined, using different statistical estimation methods such as Generalized Extreme value (GEV), Gumbel, Weibull, etc. The GEV produced higher estimations daily annual maximum extremes compared to the approaches. Considering extreme events such as floods, the outcome of GEV is used for developing recommendations for flood risks adaption measures in the PARADeS project.

Table 7. Return periods for Accra for base case and future climate scenarios

Base case	RCP4.5	RCP8.5
85	69	70
118	109	114
135	129	136
147	144	152
160	159	169
172	174	185
200	208	223

3.2 Hydraulic model

Table 8 as well as the content of the following section summarise the input of the hydraulic model of the Aboabo catchment and gives a quick accessible overview of the modelling aspects.

Spatial boundary

First, the spatial boundary for the case study area in Kumasi is outlined. Figure 15 shows the placement of the bounding box in Ghana. In the detailed overview the Aboabo catchment area

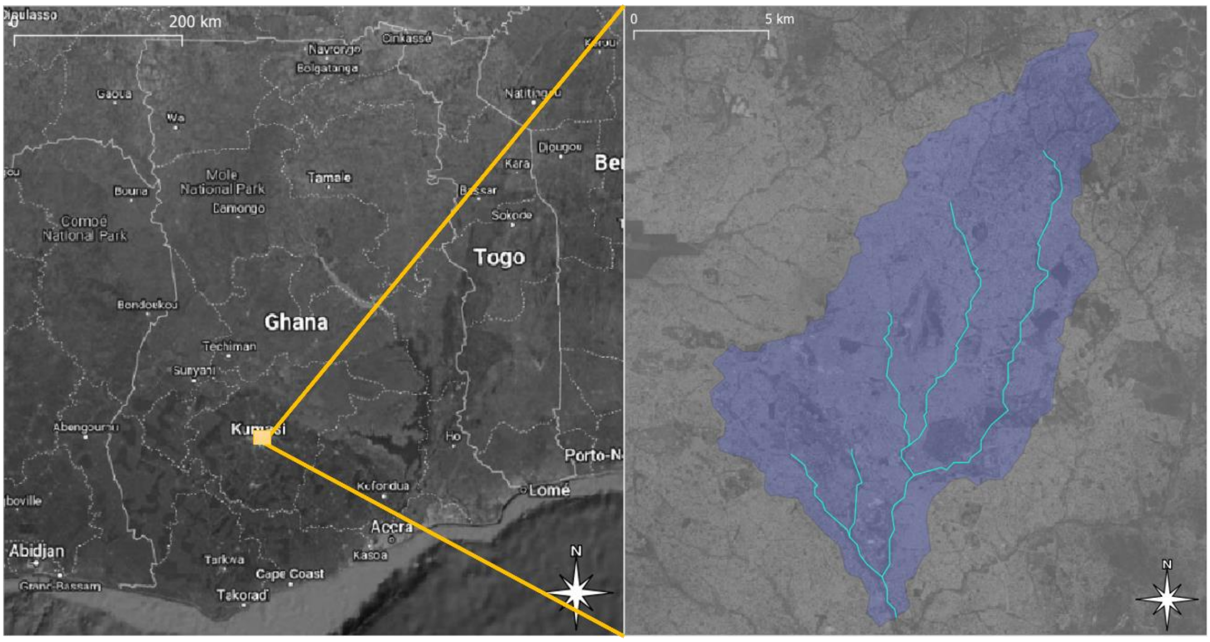

Figure 3-1: Case study area for Kumasi; Left: Placement in Ghana; Right: Aboabo catchment (blue) including main tributaries (bright blue).

included in this model is presented.

Data input

As an input for the hydraulic model the tanDEM-X elevation was used to make height references for profiles and floodplains. The land cover dataset from ArcGIS and Sentinel-2 was used to identify land cover types and the association with roughness coefficients. The boundary for the catchment areas and the main tributaries was taken from OpenStreetMaps.

Table 8: Summary of model input for hydrodynamic model of the Aboabo catchment.

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)

Hydraulic boundaries

As hydraulic boundary condition spatially uniform precipitation was taken from the hydrological analysis. The precipitation is used in the model in seven variations representing return periods. The 1D model was filled previously with a minimum water level. The Aboabo is mouthing into a water body with a higher grade near the Dompose area.

1D & 2D Model

The 1D model of the Aboabo and its 4 tributaries consists of 630 river profiles which were taken from the TanDEM-x 30m (cf. Figure 16). The profiles were then further corrected to have a representable conveyance specially for river section with less than 30 m width. The discharge-slope-area method was employed here. The 2D model consists of one raster which includes ~400 000 cells with a

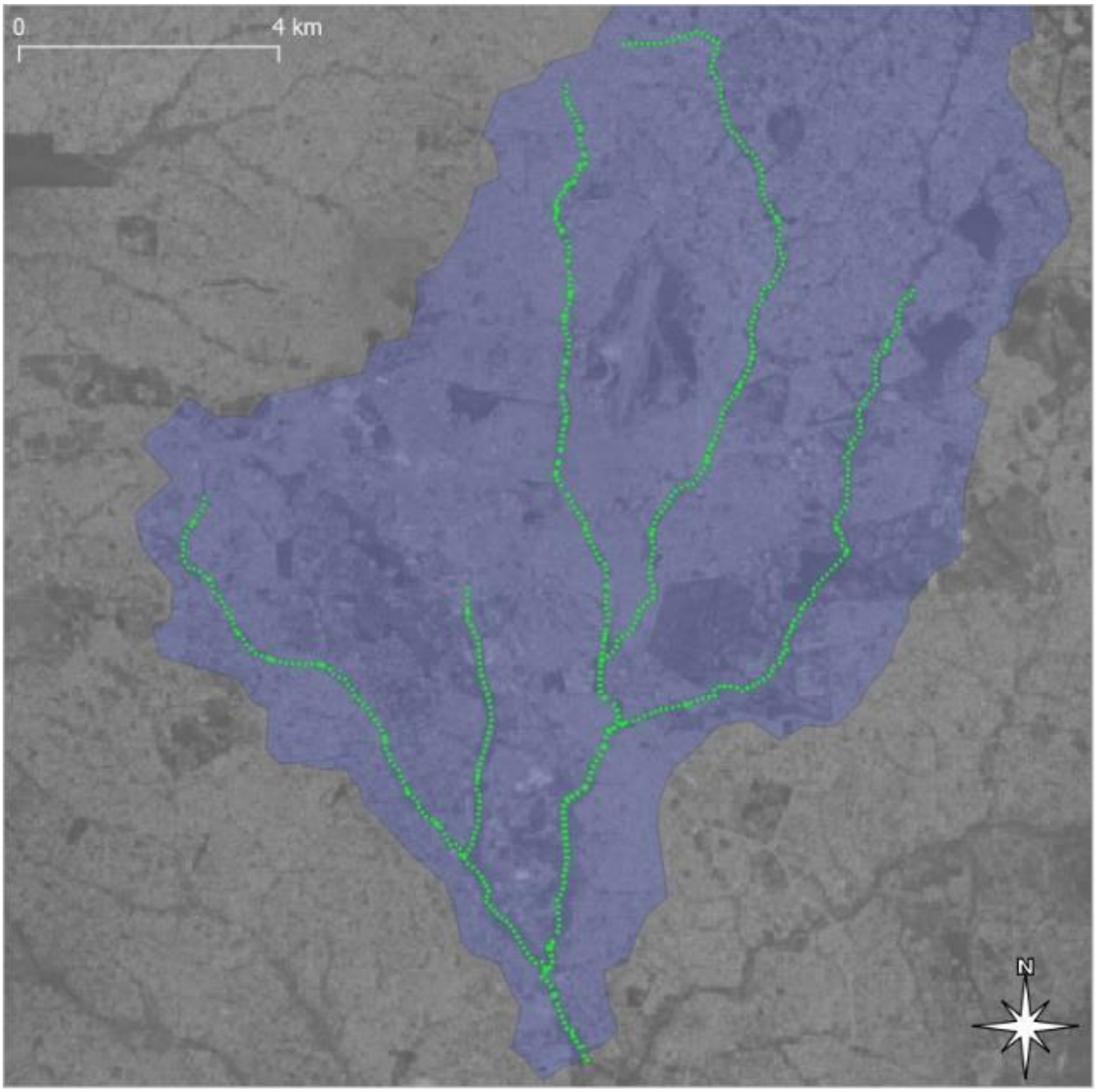

Figure 3-2: View of Kumasi and the considered catchment (blue); Overview of the profiles (green) used for the 1D model of the Aboabo and its tributaries.

resolution of 30 x 30 m and considers the entire Aboabo Catchment.

Output

The output as presented previously in chapter 2.2. can be observed in the FIS and includes spatial and time-step based information about the water depth and velocity for each return period.

3.3 Consequence model

Table 9 summarises the key aspects of the key facts of the consequence models which have been

Table 9: Summary of model input for consequence models of the Aboabo catchment.

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

compiled for the Aboabo catchment.

3.3.1 Population

The following aspects of “Input", “Preprocessing – Checking and removing exposure directly in the river channel” and “Results” are executed and elaborated equivalent to the actions for Accra. Therefore, it is pointed to chapter 2.3.1. for more information.

3.3.2 Economic

The following aspects of “Input“, “Preprocessing – Deleting data for 2D raster based on the 1D model”, “Preprocessing – From land-cover to land-usage data”, “Output – Numbers, spatial distribution, Usage-Type specific numbers" are executed and elaborated equivalent to the actions for Accra. Therefore, it is pointed to chapter 2.3.2. for more information.

3.4 Current flood risk

Based on the previously introduced modelling activities the flood risk for the Aboabo catchment can be derived as shown in Table 10.

Table 10: Current flood risk as derived by the flood risk model chain for fluvial and pluvial flooding in the Aboabo catchment.

Population [number of people]		Economic [USD]
Affected people	Endangered people	Immobile + Mobile
142 770	168	80 197 800

3.5 Measures and climate change scenarios

The measures and scenarios introduced for Accra are applied to Kumasi as well and therefore it is pointed to chapter 2.5 for more information. Table 11 shows the results for the Aboabo catchment.

Table 11: Overview of the effectiveness of flood measures in Kumasi and the Aboabo catchment for two flood return periods.

Return period- T2

Measures	Flooded area in Aboabo basin (km^2)		Population affected (No. of people)		Population endangered (No. of people)		Damage to economy-properties (USD 2016)	
	Area	Diff. w/ DN	No.	Diff. w/ DN	No.	Diff. w/ DN	No.	Diff. w/ DN
Do-nothing (DN)	22	-	136,172	-	153	-	73,664,700	-
Rain water harvesting	20	-2	125,727	-10,445	104	-49	60,483,200	-13,181,500
Buffer zone 15m	22	0	135,083	-1,089	152	-1	73,518,100	-146,600
House protection 0.5m	22	0	136,172	0	153	0	67,756,000	-5,908,700
House protection 1.0m	22	0	136,172	0	153	0	60,503,100	-13,161,600

Return period- T200

Measures	Flooded area in Aboabo basin (km^2)		Population affected (No. of people)		Population endangered (No. of people)		Damage to economy-properties (USD 2016)	
	Area	Diff. w/ DN	No.	Diff. w/ DN	No.	Diff. w/ DN	No.	Diff. w/ DN
Do-nothing (DN)	28	-	179,800	-	298	-	114,859,000	
Rain water harvesting	26.6	-1.4	173,383	-6,417	246	-52	109,161,000	-5,698,000
Buffer zone 15m	28	0	178,711	-1,089	297	-1	114,637,000	-222,000
House protection 0.5m	28	0	179,800	0	298	0	108,473,000	-6,386,000
House protection 1.0m	28	0	179,800	0	298	0	99,559,000	-15,300,000

4 White Volta catchment

4.1 Hydrological model

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.

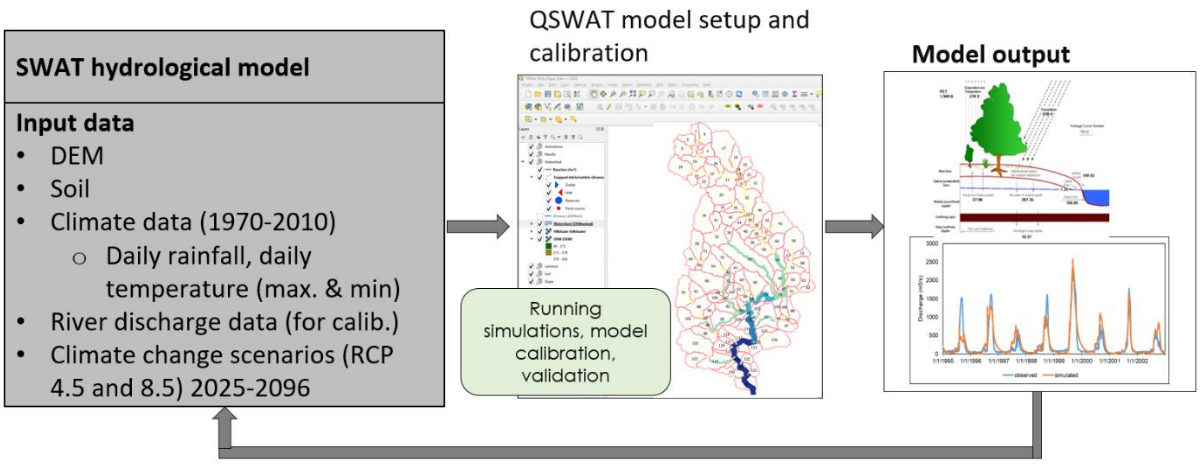

Figure 4-1: Hydrological model input data modelling processes for the White Volta catchment.

It is important to evaluate the performance of models by comparing observed and simulated runoff to identify their strengths and weaknesses, as well as the reliability of their outcomes (cf. Figure 18). 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 (R2), 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 R2 (cf. Table 12). 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).

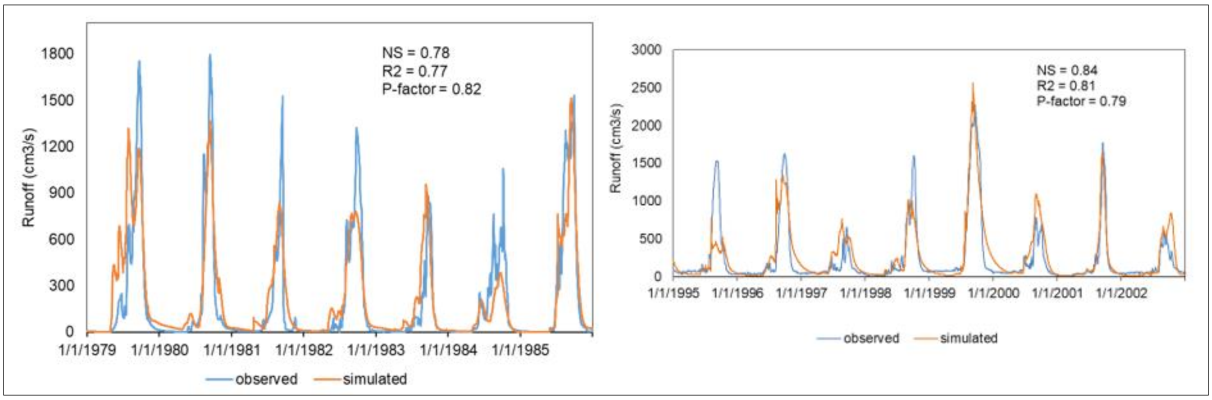

Figure 4-2: Performance for two locations in the White Volta catchment

Table 12. SWAT Model Performance

Models created	Calibration and validation periods	NS	R2	P-factor
Model 1	Calibration (1979 - 1985)	0.78	0.77	0.82
	Validation (1986 - 1990)	0.80	0.78	0.83
Model 2	Calibration (1995 - 2002)	0.84	0.81	0.79
	Validation (2003 - 2010)	0.82	0.82	0.86

Model output

The SWAT hydrological model was used to generate river and stream daily runoff data at specific sections of the main White Volta River and the tributaries. The river runoff data are also used as input for the Flood Information System (FIS). This helps to run simulations in FIS by selecting the desired return periods in combination with LULC, climate change scenarios (RCP4.5 and RCP8.5) and other important management measures to visualise flood extends and estimate damages to critical infrastructure in various communities.

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.

4.2 Hydraulic model

Table 14 as well as the subsections below summarises the input and processing of the hydraulic model of the White Volta and gives an overview of the aspects that complement the hydraulic model.

Spatial boundary

First of all, the spatial boundary for the case study area along the White Volta is outlined. The figure above shows the placement of the bounding box in West Africa. In the detailed overview the river body considered is shown. The White Volta is investigated from the Bagre Dam close to the Border from Burkina Faso down to the mouthing into the Lake Volta. For the presented model efforts fluvial flooding is considered along the main channel and therefore the catchment area is not outlined in

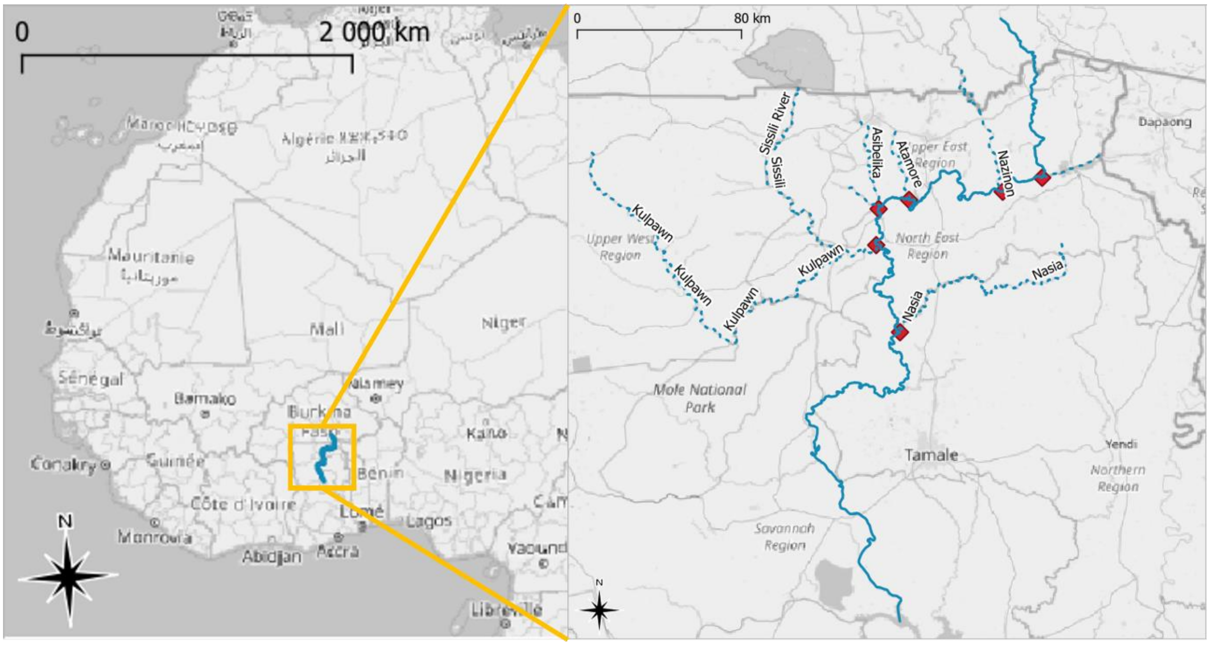

Figure 4-3: Area of investigation for the White Volta case study including the main channel of the White Volta (Blue), the tributaries (blue dashed) and the tributary input (red diamonds). Background: OpenStreetMaps.

Figure 19. For information about the catchment view Chapter 4.1.

Data input

As an input for the hydraulic model the tanDEM-X elevation was used to make height references for a first version of river profiles and for the floodplains. The land cover dataset from ArcGIS and Sentinel-2 was used to identify land cover types and the association with roughness coefficients. The main channel of the White Volta and the tributaries was taken from OpenStreetMaps.

Hydraulic boundaries

As hydraulic boundary condition discharge was taken from the hydrological analysis for the outflow of the Bagre Dam and the tributaries. The 1D model was filled previously with a minimum water level. The boundary water level at the river mouth of the White Volta was derived at Lake Volta from publicly available data of another publication (van de Giesen et al., 2001).

Table 13: Summary of model input for hydrodynamic model of the White Volta.

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)

1D Model – Processing elevation data in the main channel

The digital elevation model used for the generation of the 1D profiles showed unreasonably high peaks in the middle of the riverbed. This indicated that the data was falsified by inaccuracies during the data obtainment with satellite imageries due to the water surface. Figure 19 shows those peaks by visualising the lowest points of the riverbed along the main channel.

To fix this issue the main river channel was manually edited by burning in a corrected elevation. This was done by using a [DEM manipulation tool] that uses a few profiles along the main channel and

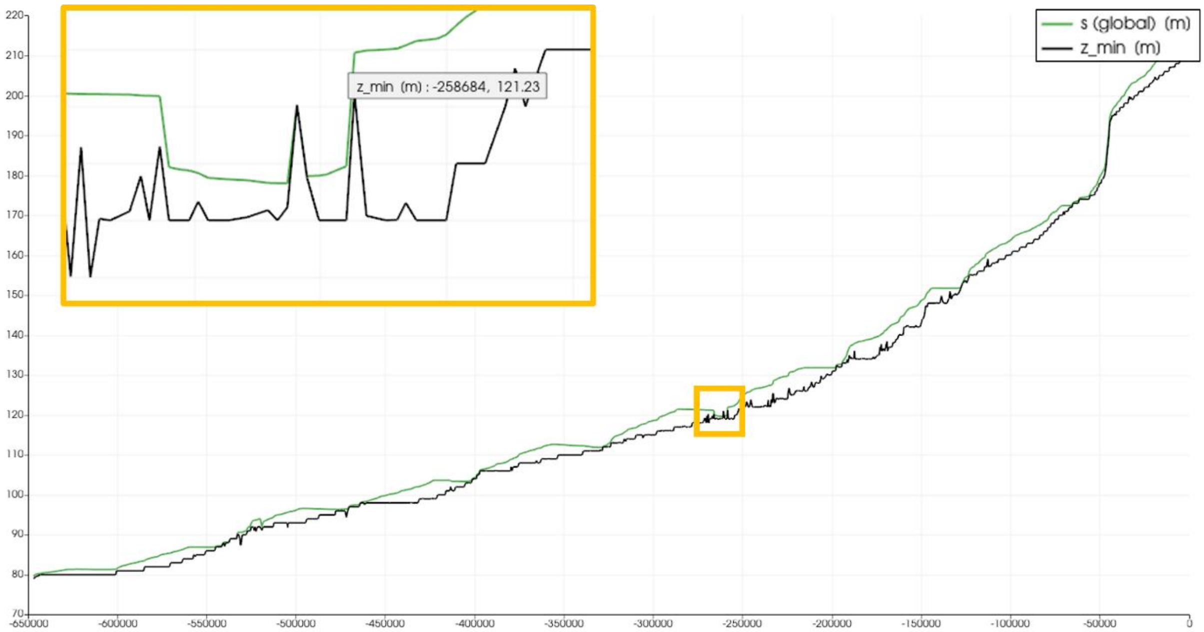

Figure 4-4: Minimum elevation z_min of the riverbed along the river channel of the White Volta based on tanDEM-X data and the maximum water level s.

interpolated the heights in between. These profiles were handpicked every 100 m along the channel and the elevation was checked for plausibility. After the application of the tool those peaks in the riverbed were smoothened and integrated in the whole DEM. This was then used to derive the 1140 profiles as well as the 2D rasters. Figure 21 shows the distribution and extend of the 2D rasters along the White Volta. Four small rasters have been added alongside the main axis to consider the inundated areas of tributaries as well.

Truncated version of White Volta considering the Pwalugu Dam

The hydrological model did additionally derive results on a discharge for a scenario where the planned Pwalugu Dam is being built (Volta River Authority, 2020). To consider this discharge as well in the hydraulic analysis a truncated version of the White Volta model has been built that starts at the outflow of the future Pwalugu Dam. This allows to consider the potential effect of the Pwalugu Dam regarding inundation. But since a dam structure only has an influence on the downstream area the model is truncated and thus only allows to derive findings downstream.

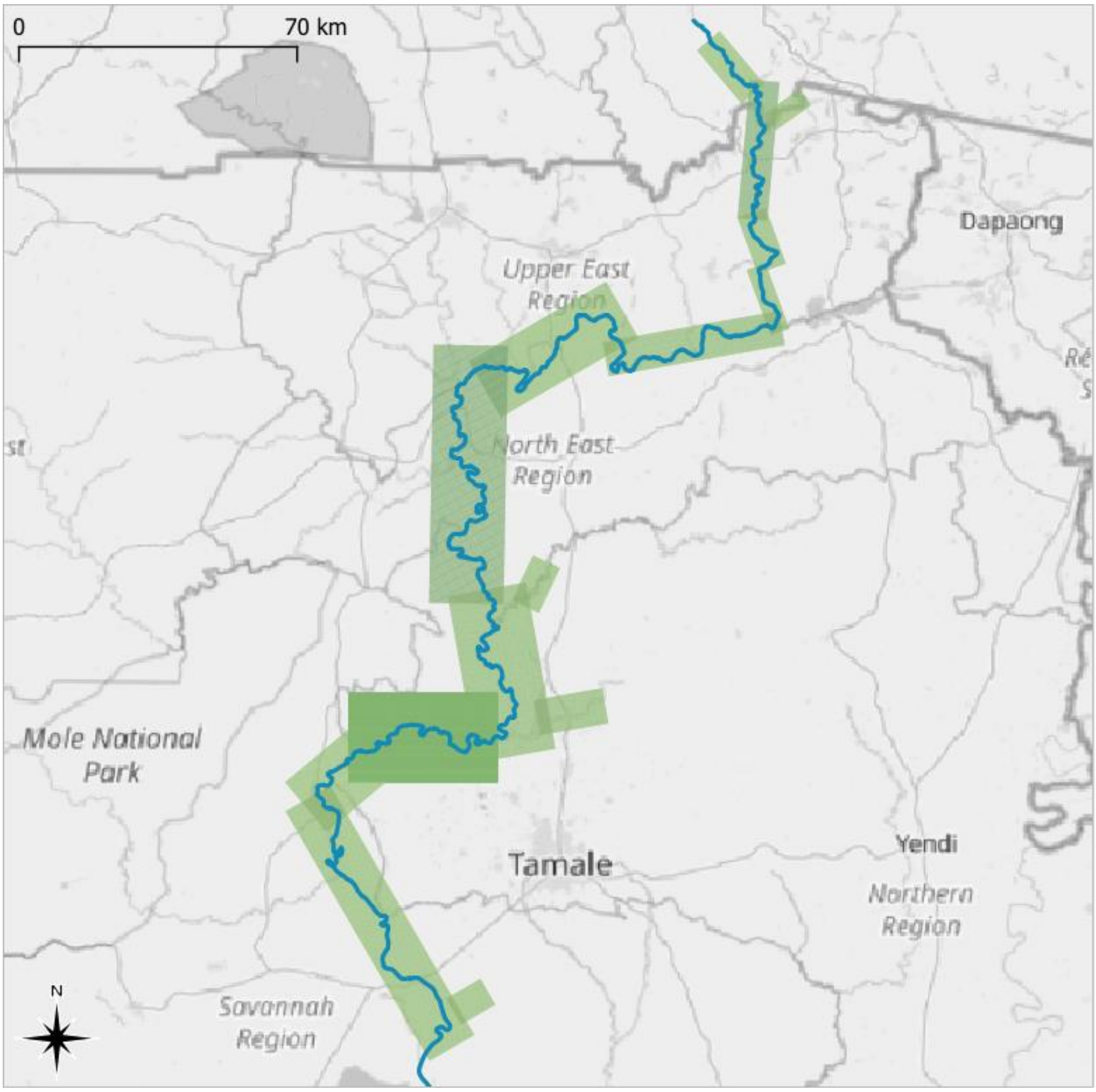

Figure 4-5: Overview of the 2D Floodplains (green) of the White Volta (blue) model.

4.3 Consequence model

4.3.1 Population

The following aspects of "Input", "Preprocessing – Deleting data for 2D raster based on the 1D model", "Output – Numbers, spatial distribution, Usage-Type specific numbers" are executed and elaborated equivalent to the actions for Accra. Therefore, it is pointed to chapter 2.3.2. for more information.

4.3.2 Economic damages

The following aspects of "Input", "Preprocessing – Deleting data for 2D raster based on the 1D model", "Output – Numbers, spatial distribution, Usage-Type specific numbers" are executed and elaborated equivalent to the actions for Accra. Therefore, it is pointed to chapter 2.3.2. for more information.

The point for "Preprocessing – From land-cover to land-usage data" is obsolete because land cover was used as an input for the economic damages due to the rural characteristics of the forelands.

4.3.3 Critical infrastructures

The critical infrastructure network model (CIN) which is assembled in the course of the PARADeS project is elaborated in this section. The description of the White Volta CIN is in more detail compared to the Accra CIN model because there is no publication published for the White Volta which could support the documentation.

Input

As an input for the CI network model OSM data was used and subsequently anecdotally verified and complemented through a participatory workshop. The users for the CI services were derived from high density population dataset from the **Meta-Data for Good Team.** The input data featured in total 2989 point elements, 2164 polygon elements and 26 676 connector elements. The following sectors were represented: power supply, telecommunication, fresh water, emergency services, health and public services, transportation (people), official and governmental, gas stations, industry and production, education.

Area of Investigation

The area of investigation for the CI model was extended over the catchment area to be able to represent potential cascading effects. For that a buffer zone was marked around the main channel of 50 km.

Processing

To derive the polygon elements for the end-user supplying CI point elements Voronoi polygons were created based on the previously introduced approach (cf. Chapter 2.3.3)

Output

The superposition of a T50 flood event showed that in total 39 CI elements were directly affected and included one school, ten marketplaces and 28 community cluster. No indirect effects could be derived from the model results. Figure 22 highlights where the affected locations are placed along the White Volta.

4.4 Current flood risk

Based on the previously introduced modelling activities the flood risk due to fluvial flooding along the main channel of the White Volta can be derived as shown in the Table 14.

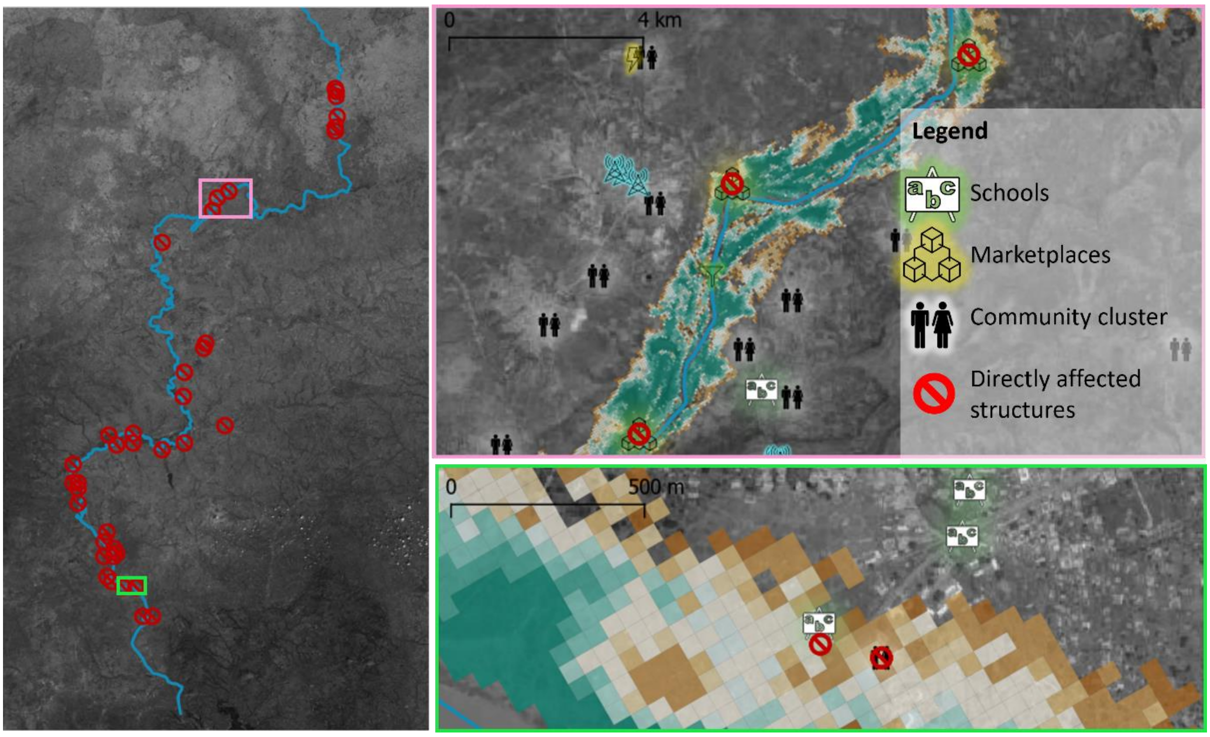

Figure 4-6: Critical infrastructure elements affected by a T50 flood event.

Table 14: Summary of the hydraulic parameters and flood consequences for each return period and the derived risk.

Current State

Return Periods	Flooded area in White Volta basin- Ghana Area (km²)		Population affected (No. of people)		Population endangered (No. of people)	
	Area	Diff. w/ T5	No.	Diff. w/ T5	No.	Diff. w/ T5
T5	1,137	-	2,191	-	151	-
T10	1,173	36	2,933	742	183	32
T25	1,221	84	3,267	1,076	216	66
T50	1,252	115	3,619	1,428	231	80
T100	1,278	141	3,816	1,625	259	108

Return Periods	Mobile damage to economy properties (USD 2016)		Immobile damage to economy properties (USD 2016)		Total damage to economy properties (USD 2016)	
	No	Diff. w/ T5	No.	Diff. w/ T5	No.	Diff. w/ T5
T5	763,000	-	1,345,550	-	2,108,550	-
T10	824,259	61,259	1,431,695	86,146	2,255,954	147,404
T25	908,607	145,607	1,621,532	275,982	2,530,138	421,589
T50	970,409	207,409	1,731,651	386,102	2,702,061	593,511
T100	1,031,944	268,944	1,835,042	489,492	2,866,987	758,437

4.5 Measures and scenario modelling

Pwalugu Dam

As indicated in chapter 4.2 a truncated version of the White Volta was generated which allows to derive inundation areas with and without the Pwalugu Dam structure.

Dike lines

A second set of measures which is tested using the model capabilities is the installation of flood protection dikes around three affected settlements along the White Volta main channel: Nawuni, Daboya and Yapei. Figure 23 shows where dikes were erected in the model in contrast to calculated inundation areas and the population density data cells. The list below shows the suggested dike heights for this measure model:

- Yapei - Dike height 94 m (EPSG 32360)
- Daboya - Dike height 103 m (EPSG 32360)
- Nawuni: Dike height 110 m (EPSG 32360)

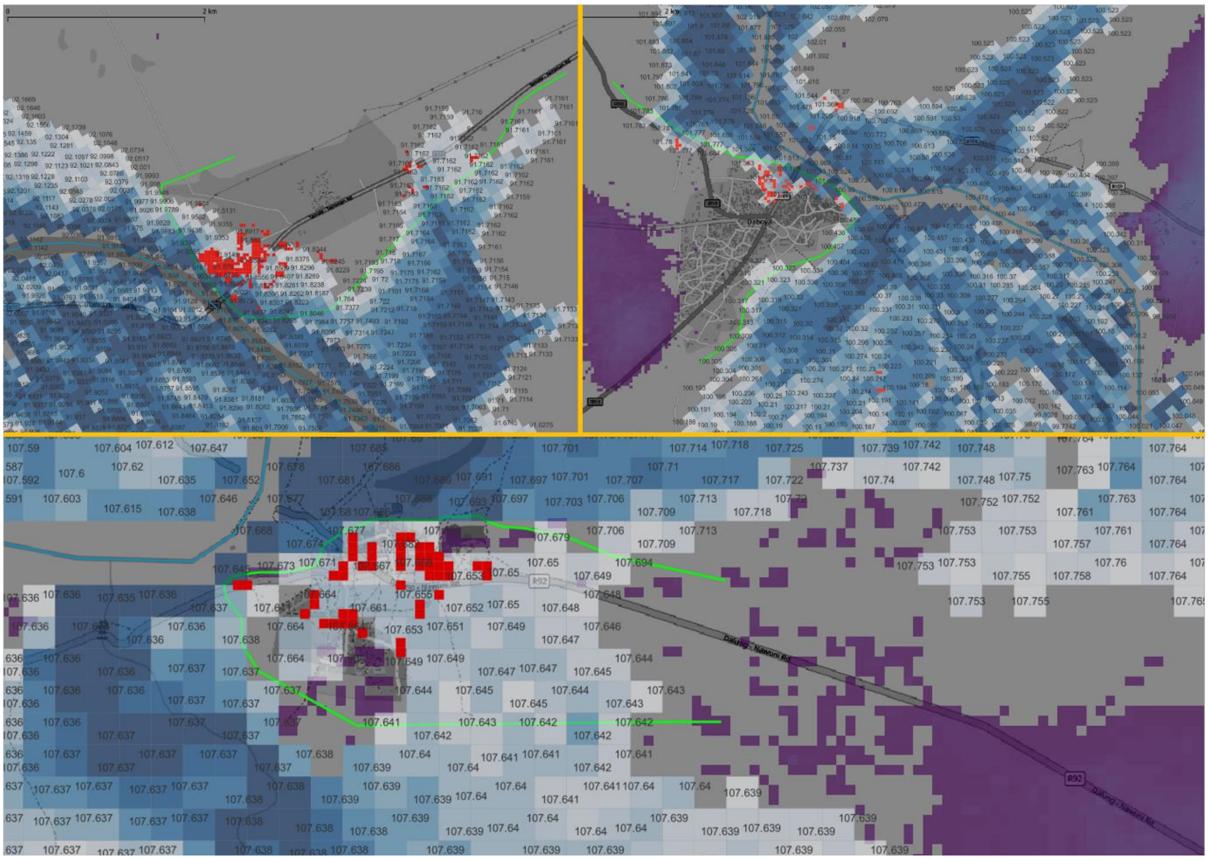

Figure 4-7: Dike protection measure for three settlements along the White Volta; Blues cells indicate the water level of an T100 flood event, red cells indicate cells of affected population and green lines the suggested dike lines; Left top: Yapei; Right top: Daboya; Bottom: Nawuni.

5 Uncertainties

Flood areas for hazard assessment and design of flood protection measures are generally determined with the help of 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 such as used in the ProMaIDes framework, 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 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 generalisations 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 fault lines?

For the hydrological data used for model calibration, the questions are:

Precipitation measurement

- How sensitive is the accuracy of the terrestrial, radar or satellite precipitation measurement to the results of the rain 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; 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?

Consequence models

The consequence models may only be as good as the input data and their resolution. Before deriving practical knowledge of these results, it is to prove whether the models allow for the influence the decision that is to be made. Something to consider involve:

- Are the presented model results validated with ground truth data? Are the numbers available to compare the affected population, economic damages or CI disruptions from historic flood events with the modelled equivalent.
- Does the resolution of the input data allow me to make a detailed assessment or household level or is it better to upscale the decisions to be made on a higher level?
- The presented CI network modelling approach is not representing linear structures such as roads or power lines and thus also cannot provide any insight on their service disruptions during flooding.

Model approach

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

- Which runoff processes are in the foreground: is a rain-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 rain-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?

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 must 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.

To determine flood areas and plan flood protection measures, the user of the software must 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.

6 Data Transfer

This section supplies explanation on the data that is transferred for interested parties. Table 15, 16 and 17 make a connection from the key files of the ProMaIDes models and the catchment models and scenarios and measure calculations. It is recommended to check the documentation of the PROMAIDES ilm files to understand what is pointed out. Additionally, the .prm files indicate which calculations are made in one PROMAIDES project.

If there is an interest to gain access to the files feel free to contact the addresses highlighted in Chapter 1.2.

Table 15: Connection of data transfer files and the modelling efforts for the flood risk analysis and measure development for the Odaw catchment.

Scenario	PRM	Name/ .ilm	Repository	Description
Base case (BC)	parades accra.prm	Odaw Hydr 24hr BC HQ0002	[...]accra/data/HYD/Base Case/	Base case
	parades accra.prm	Odaw Hydr 24hr BC HQ0010	[...]accra/data/DAM/POP/	
	parades accra.prm	Odaw Hydr 24hr BC HQ0025	[...]accra/data/DAM/ECN/	
	parades accra.prm	Odaw Hydr 24hr BC HQ0050	[...]accra/data/DAM/CI/	
	parades accra.prm	Odaw Hydr 24hr BC HQ0100		
	parades accra.prm	Odaw Hydr 24hr BC HQ0200		
	parades accra.prm	Odaw Hydr 24hr BC HQ1000		
BC RWH	parades accra.prm	Odaw Hydr 24hr BC HQ0002 RWH B0	[...]accra/data/HYD/Base Case RWH/	Rain water harvesting
	parades accra.prm	Odaw Hydr 24hr BC HQ0010 RWH B0	[...]accra/data/DAM/POP/	
	parades_accra.prm	Odaw_Hydr_24hr_BC_HQ0025_RWH_B0	[...]accra/data/DAM/ECN/	
	parades_accra.prm	Odaw_Hydr_24hr_BC_HQ0050_RWH_B0	[...]accra/data/DAM/CI/	
	parades_accra.prm	Odaw_Hydr_24hr_BC_HQ0100_RWH_B0		
	parades_accra.prm	Odaw_Hydr_24hr_BC_HQ0200_RWH_B0		
	parades_accra.prm	Odaw_Hydr_24hr_BC_HQ1000_RWH_B0		
BC_BZ	parades_accra.prm	Odaw_Hydr_24hr_BC_HQ0002_BZ_B0	[...]accra/data/HYD/Base_Case/	25m Buffer zone around the main channel and 15m around the tributaries
	parades_accra.prm	Odaw_Hydr_24hr_BC_HQ0010_BZ_B0	[...]accra/data/DAM/POP/	
	parades_accra.prm	Odaw_Hydr_24hr_BC_HQ0025_BZ_B0	[...]accra/data/DAM/ECN/	
	parades_accra.prm	Odaw_Hydr_24hr_BC_HQ0050_BZ_B0	[...]accra/data/DAM/CI/	
	parades_accra.prm	Odaw_Hydr_24hr_BC_HQ0100_BZ_B0	[...]accra/data/ALT/DAM/Odaw_Hydr_24hr_BC_BZ_B0	
	parades accra.prm	Odaw Hydr 24hr BC HQ0200 BZ B0		
	parades accra.prm	Odaw Hydr 24hr BC HQ1000 BZ B0		
BC HPI	parades accra.prm	Odaw Hydr 24hr BC HQ0002 HP1 B0	[...]accra/data/HYD/Base Case/	The water depth damage curves are adjusted to allow damage only to happen after 0.5 m water depth
	parades accra.prm	Odaw Hydr 24hr BC HQ0010 HP1 B0	[...]accra/data/DAM/POP/	
	parades accra.prm	Odaw Hydr 24hr BC HQ0025 HP1 B0	[...]accra/data/DAM/ECN/	
	parades accra.prm	Odaw Hydr 24hr BC HQ0050 HP1 B0	[...]accra/data/DAM/CI/	
	parades accra.prm	Odaw Hydr 24hr BC HQ0100 HP1 B0	[...]accra/data/ALT/DAM/Odaw Hydr 24hr BC HP1 B0	
	parades accra.prm	Odaw Hydr 24hr BC HQ0200 HP1 B0		
	parades accra.prm	Odaw Hydr 24hr BC HQ1000 HP1 B0		
BC HPII	parades accra.prm	Odaw Hydr 24hr BC HQ0002 HP2 B0	[...]accra/data/HYD/Base Case/	The water depth damage curves are adjusted to allow damage only to happen after 1 m water depth
	parades_accra.prm	Odaw_Hydr_24hr_BC_HQ0010_HP2_B0	[...]accra/data/DAM/POP/	
	parades_accra.prm	Odaw_Hydr_24hr_BC_HQ0025_HP2_B0	[...]accra/data/DAM/ECN/	
	parades_accra.prm	Odaw_Hydr_24hr_BC_HQ0050_HP2_B0	[...]accra/data/DAM/CI/	
	parades_accra.prm	Odaw_Hydr_24hr_BC_HQ0100_HP2_B0	[...]accra/data/ALT/DAM/Odaw_Hydr_24hr_BC_HP2_B0	
	parades_accra.prm	Odaw_Hydr_24hr_BC_HQ0200_HP2_B0		
	parades_accra.prm	Odaw_Hydr_24hr_BC_HQ1000_HP2_B0		
CC1	parades_accra_CC1RCP45.p	Odaw_Hydr_24hr_CC1RCP45_HQ0002	[...]accra/data/HYD/CC_RCP_45/	
	parades_accra_CC1RCP45.p	Odaw_Hydr_24hr_CC1RCP45_HQ0010	[...]accra/data/DAM/POP/	
	parades_accra_CC1RCP45.p	Odaw_Hydr_24hr_CC1RCP45_HQ0025	[...]accra/data/DAM/ECN/	
	parades_accra_CC1RCP45.p	Odaw_Hydr_24hr_CC1RCP45_HQ0050	[...]accra/data/DAM/CI/	
	parades accra CC1RCP45.p	Odaw Hydr 24hr CC1RCP45 HQ0100		
	parades accra CC1RCP45.p	Odaw Hydr 24hr CC1RCP45 HQ0200		
	parades accra CC1RCP45.p	Odaw Hydr 24hr CC1RCP45 HQ1000		
CC2	parades accra CC1RCP85.p	Odaw Hydr 24hr CC2RCP85 HQ0002	[...]accra/data/HYD/CC RCP 85/	
	parades accra CC1RCP85.p	Odaw Hydr 24hr CC2RCP85 HQ0010	[...]accra/data/DAM/POP/	
	parades accra CC1RCP85.p	Odaw Hydr 24hr CC2RCP85 HQ0025	[...]accra/data/DAM/ECN/	
	parades accra CC1RCP85.p	Odaw Hydr 24hr CC2RCP85 HQ0050	[...]accra/data/DAM/CI/	
	parades accra CC1RCP85.p	Odaw Hydr 24hr CC2RCP85 HQ0100		
	parades accra CC1RCP85.p	Odaw Hydr 24hr CC2RCP85 HQ0200		
	parades accra CC1RCP85.p	Odaw Hydr 24hr CC2RCP85 HQ1000		

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Table 16: Connection of data transfer files and the modelling efforts for the flood risk analysis and measure development for the Aboabo catchment.

Scenario	PRM	Name/ .ilm	Repository	Description
Base case	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0002	[...]kumasi/data/HYD/Base_Case/	Done
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0010	[...]kumasi/data/DAM/POP/	
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0025	[...]kumasi/data/DAM/ECN/	
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0050		
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0100		
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0200		
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ1000		
BC_RWH	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0002	[...]kumasi/data/HYD/Base_Case_RWH/	
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0010	[...]kumasi/data/DAM/POP/	
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0025	[...]kumasi/data/DAM/ECN/	
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0050		
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0100		
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0200		
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ1000		
BC_BZ	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0002_BZ_B0	[...]kumasi/data/HYD/Base_Case/	15m Buffer zone around the main channel and the tributaries
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0010_BZ_B0	[...]kumasi/data/DAM/POP/	
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0025_BZ_B0	[...]kumasi/data/DAM/ECN/	
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0050_BZ_B0	[...]kumasi/data/ALT/DAM/Aboabo_Hydr_24hr_BC_BZ_B0	
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0100_BZ_B0		
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0200_BZ_B0		
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ1000_BZ_B0		
BC_HPI	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0002_HP1_B0	[...]kumasi/data/HYD/Base_Case/	The water depth damage curves are adjusted to allow damage only to happen after 0.5 m water depth
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0010_HPI_B0	[...]kumasi/data/DAM/POP/	
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0025_HPI_B0	[...]kumasi/data/DAM/ECN/	
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0050_HPI_B0	[...]kumasi/data/ALT/DAM/Aboabo_Hydr_24hr_BC_HP1_B0	
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0100_HPI_B0		
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0200_HPI_B0		
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ1000_HPI_B0		
BC_HPII	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0002_HPII_B0	[...]kumasi/data/HYD/Base_Case/	The water depth damage curves are adjusted to allow damage only to happen after 1 m water depth
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0010_HPII_B0	[...]kumasi/data/DAM/POP/	
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0025_HPII_B0	[...]kumasi/data/DAM/ECN/	
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0050_HPII_B0	[...]kumasi/data/ALT/DAM/Aboabo_Hydr_24hr_BC_HP2_B0	
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0100_HPII_B0		
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ0200_HPII_B0		
	kumasi_accra.prm	Aboabo_Hydr_24hr_BC_HQ1000_HPII_B0		
CC1	parades_kumasi_CC1RCP45.pr	Aboabo_Hydr_24hr_CC1RCP45_HQ0002	[...]kumasi/data/HYD/CC_RCP_45/	
	parades_kumasi_CC1RCP45.pr	Aboabo_Hydr_24hr_CC1RCP45_HQ0010	[...]kumasi/data/DAM/POP/	
	parades_kumasi_CC1RCP45.pr	Aboabo_Hydr_24hr_CC1RCP45_HQ0025	[...]kumasi/data/DAM/ECN/	
	parades_kumasi_CC1RCP45.pr	Aboabo_Hydr_24hr_CC1RCP45_HQ0050		
	parades_kumasi_CC1RCP45.pr	Aboabo_Hydr_24hr_CC1RCP45_HQ0100		
	parades_kumasi_CC1RCP45.pr	Aboabo_Hydr_24hr_CC1RCP45_HQ0200		
	parades_kumasi_CC1RCP45.pr	Aboabo_Hydr_24hr_CC1RCP45_HQ1000		
CC2	parades_kumasi_CC1RCP85.pr	Aboabo_Hydr_24hr_CC2RCP85_HQ0002	[...]kumasi/data/HYD/CC_RCP_85/	
	parades_kumasi_CC1RCP85.pr	Aboabo_Hydr_24hr_CC2RCP85_HQ0010	[...]kumasi/data/DAM/POP/	
	parades_kumasi_CC1RCP85.pr	Aboabo_Hydr_24hr_CC2RCP85_HQ0025	[...]kumasi/data/DAM/ECN/	
	parades_kumasi_CC1RCP85.pr	Aboabo_Hydr_24hr_CC2RCP85_HQ0050		
	parades_kumasi_CC1RCP85.pr	Aboabo_Hydr_24hr_CC2RCP85_HQ0100		
	parades_kumasi_CC1RCP85.pr	Aboabo_Hydr_24hr_CC2RCP85_HQ0200		
	parades_kumasi_CC1RCP85.pr	Aboabo_Hydr_24hr_CC2RCP85_HQ1000		

Table 17: Connection of data transfer files and the modelling efforts for the flood risk analysis and measure development for the White Volta catchment

Scenario	PRM	Name .ilm	Repository	
Base case (BC)	parades_wv.prm	WV_Hydr_24hr_BC_HQ0005	[...]kumasi/data/HYD/Base_Case/	From Bagre Dam till Lake Volta
	parades_wv.prm	WV_Hydr_24hr_BC_HQ0010	[...]kumasi/data/DAM/POP/	
	parades_wv.prm	WV_Hydr_24hr_BC_HQ0025	[...]kumasi/data/DAM/ECN/	
	parades_wv.prm	WV_Hydr_24hr_BC_HQ0050	[...]kumasi/data/DAM/CI/	
	parades_wv.prm	WV_Hydr_24hr_BC_HQ0100		
Dikeline	parades_wv.prm	WV_Hydr_24hr_BC_HQ0005_DL	[...]kumasi/data/HYD/Base_Case/	Including dike protection lines
	parades_wv.prm	WV_Hydr_24hr_BC_HQ0010_DL	[...]kumasi/data/DAM/POP/	
	parades_wv.prm	WV_Hydr_24hr_BC_HQ0025_DL	[...]kumasi/data/DAM/ECN/	
	parades_wv.prm	WV_Hydr_24hr_BC_HQ0050_DL	[...]kumasi/data/DAM/CI/	
	parades_wv.prm	WV_Hydr_24hr_BC_HQ0100_DL	[...]kumasi/data/ALT/Dikelines/	
Base case pwalugu (BCp)	parades_wv_pwalugu.prm	WVp_Hydr_24hr_BC_HQ0005	[...]kumasi/data/HYD/Base_Case_Pwalugu/	From PwaluguDam till Lake Volta
	parades_wv_pwalugu.prm	WVp_Hydr_24hr_BC_HQ0010	[...]kumasi/data/DAM/POP/	
	parades_wv_pwalugu.prm	WVp_Hydr_24hr_BC_HQ0025	[...]kumasi/data/DAM/ECN/	
	parades_wv_pwalugu.prm	WVp_Hydr_24hr_BC_HQ0050	[...]kumasi/data/DAM/CI/	
	parades_wv_pwalugu.prm	WVp_Hydr_24hr_BC_HQ0100		
Pwalugu Dam	parades_wv_pwalugu.prm	WVp_Hydr_24hr_BC_HQ0005_PD	[...]kumasi/data/HYD/Base_Case_Pwalugu/	Under consideration of different dichsarge regime with PwaluguDam built
	parades_wv_pwalugu.prm	WVp_Hydr_24hr_BC_HQ0010_PD	[...]kumasi/data/DAM/POP/	
	parades_wv_pwalugu.prm	WVp_Hydr_24hr_BC_HQ0025_PD	[...]kumasi/data/DAM/ECN/	
	parades_wv_pwalugu.prm	WVp_Hydr_24hr_BC_HQ0050_PD	[...]kumasi/data/DAM/CI/	
	parades_wv_pwalugu.prm	WVp_Hydr_24hr_BC_HQ0100_PD		

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