Consultancy service for work package 2 – Enhancement of the Eastern Nile Flood Forecasting and Early Warning (EN-FFEWS) and Flood Risk Mapping

Flood Vulnerability and Flood Risk Assessment Report
(Deliverables 3.1 and 4.1)
Project No 11829050

17-JUN-2024

Prepared for Eastern Nile Technical Regional Office (ENTRO)

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Prepared for: Eastern Nile Technical Regional Office (ENTRO)
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Project No.:	11829050
Approved by:	Oluf Zeilund Jessen
Approval date:	17-06-2024
Revision:	Draft 0
Classification:	**Confidential:** This document is only accessible to the project team members and sharing it outside the project team is subject to the client's prior approval.
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List of abbreviations

ALOS	Advanced Land Observing Satellite
BAS	Baro Akobo-Sobat
BN	Blue Nile
DEM	Digital elevation model
EAD	Expected annual damage
EN	Eastern Nile
ENTRO	Eastern Nile Technical Regional Office
EU	European Union
FFEWS	Flood Forecasting and Early Warning System
FPEW	Flood Preparedness and Early Warning Project
FRM	Flood Risk Mitigation
GHSL	Global Human Settlement Layer
GIS	Geographic Information System
GPM	Global Precipitation Measurement
HD	Hydrodynamic
LT	Lake tana
TSA	Tekeze-Setit-Atbara
WP	Work package

1 Introduction

This report is a deliverable of ENTRO's project "Consultancy Service for Work Package 2 - Enhancement of the Eastern Nile Flood Forecasting and Early Warning (EN-FFEWS) and Flood Risk Mapping". The consultancy is one of three work packages as part of the Eastern Nile (EN) Flood Preparedness and Early Warning Project (FPEW):

- Work Package 1: Survey and Data Collection
- Work Package 2: Enhancement of the Eastern Nile Flood Forecasting and Early Warning System (EN-FFEWS) and Flood Risk Mapping – this consultancy.
- Work Package 3: Support in Establishing Flood Community Awareness and Preparedness – consultancy that builds on Work Packages 1 and 2.

This Work Package 2 also builds on results and outcomes from Work Package 1 from its following tasks:

- Collect Terrain Datasets of Flood Prone Areas.
- Compile Historical Hydro-Meteorological Datasets.
- Determine Key Characteristics of Flood Prone Communities.

The objective of this Work Package 2 is to contribute to the improvement of the Eastern Nile Flood Risk Mitigation (EN-FRM) Project as follows:

- An enhanced EN FFEWS, so that reliable flood forecasts and early warnings for the EN region become available to member countries.
- Flood maps with flood hazards and risks for key flood prone areas in the EN region, so that flood protection measures and flood response preparedness actions can be planned adequately.
- Enhanced forecasting capacity for better management of dam operation and water resources planning.

The scope of work under this Work Package 2 comprises five tasks for the riverine flood prone areas in the Eastern Nile basin:

- Task 1: Improve Performance of the EN-FFEWS
- Task 2: Flood Hazard Assessment and Flood Extent Mapping
- Task 3: Flood Vulnerability Assessment
- Task 4: Flood Risk Assessment
- Task 5: Flood Impact Assessment Capacity Building at Regional Level

This "Flood Vulnerability and Flood Risk Assessment Report" merges two deliverables of the project:

- Deliverable 3.1: Flood Vulnerability Assessment Report
- Deliverable 4.1: Flood Risk Assessment

It documents the results of "Task 3: Flood Vulnerability Assessment" and "Task 4: Flood Risk Assessment".

The comprehensive maps and detailed tables that contain flood exposure, flood damage and expected annual flood damage documenting the results for each flood hotspot are submitted as follows:

- Separate report volume that contains all maps with their respective tabular references

- Geospatial representations of the flood risk analysis results (as vectors and grids, with comprehensive attribute tables) in an object-relational database management system (deployed in the cloud and easily accessible through the internet)
- All geospatial representations are also submitted as files (as shape-files and grid-files, with attribute tables).

The Flood risks are assessed for 16 selected flood hotspots (see Figure 1-1):

1. Gambela (Baro-Akobo-Sobat Basin)
2. Itang (Baro-Akobo-Sobat Basin)
3. Pibor (Baro-Akobo-Sobat Basin)
4. Akobo (Baro-Akobo-Sobat Basin)
5. Nasir (Baro-Akobo-Sobat Basin)
6. Malakal (Baro-Akobo-Sobat Basin)
7. El Roseires (Blue Nile Basin)
8. Singa & Suki (Blue Nile Basin)
9. Wad Medani (Blue Nile Basin)
10. El Masudiya Khartoum (Blue Nile Basin)
11. Gumara (Lake Tana Basin)
12. Ribb (Lake Tana Basin)
13. Megech (Lake Tana Basin)
14. Dirma (Lake Tana Basin)
15. Humera (Tekeze-Setit-Atbara Basin)
16. Atbara (Tekeze-Setit-Atbara Basin)

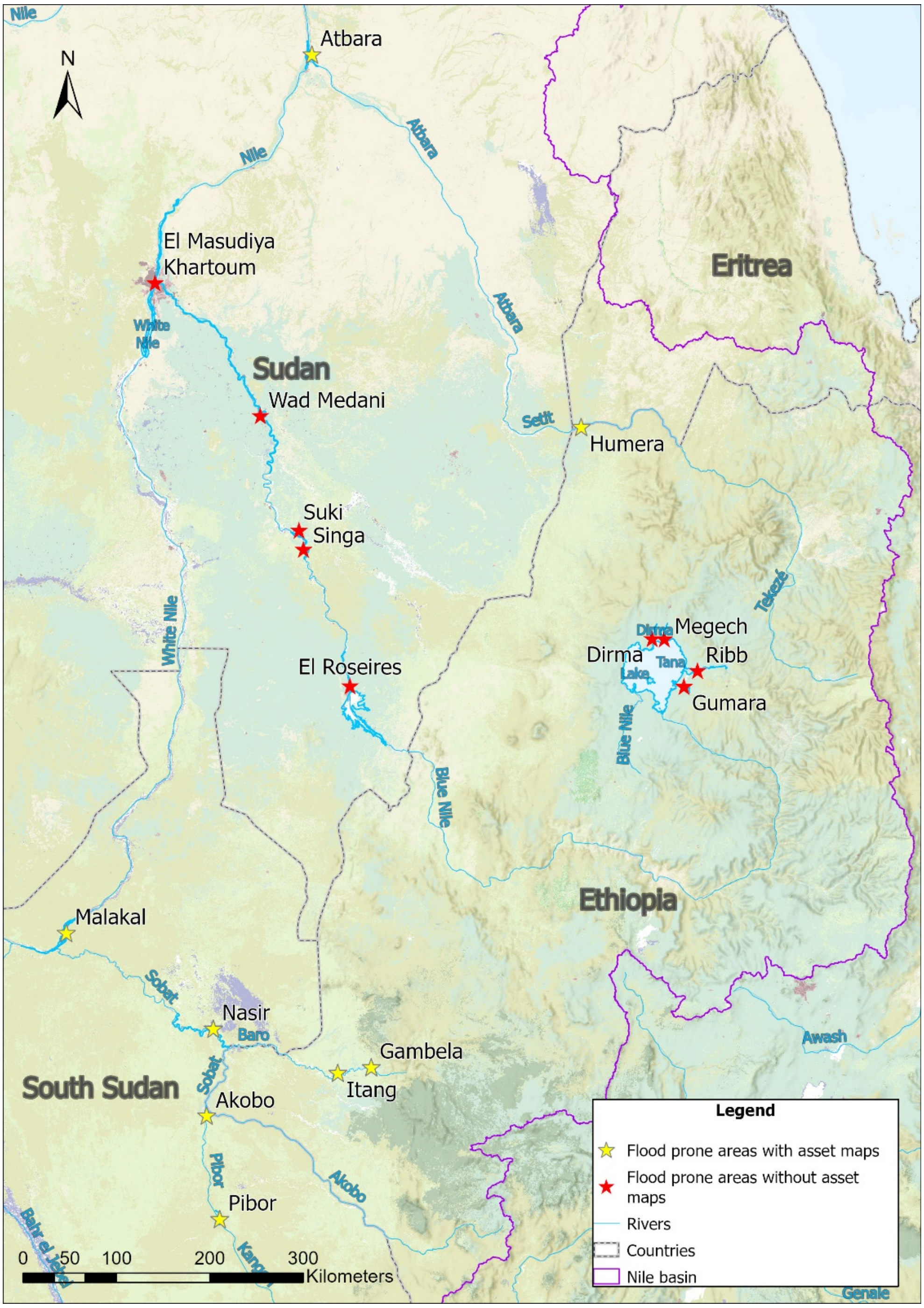

Figure 1-1 Flood risks are assessed for 16 selected flood hotspots.

The structure of this report is as follows:

- **Chapter 1** explains the context of the report (this chapter).
- **Chapter 2** documents the methodology of calculating flood exposure, flood vulnerability and flood risk.
- **Chapter 3** summarizes the results of the comprehensive calculations.
- **Chapter 4** gives a concise conclusion.

2 Methodology and Approach

Flood risk assessment encompasses assessments of flood hazard, flood exposure, flood vulnerability and flood risk. Their definitions are as follows:

1. Hazard is the probability or the likelihood of interaction between society and an extreme event that constitutes a threat. Flood hazards are expressed mathematically as the probability of occurrence of a flood event of a certain magnitude in a specific site. The magnitude of a hazard has an inverse relationship with the frequency of its occurrence (i.e., return period). The magnitude-frequency relationship is an inherent characteristic of a specific locality or region and therefore is driven empirically for a given place.
2. Exposure is the "interface" or presence of specific elements (people, infrastructure, property, etc.) and a hazardous flood event of a given magnitude. The nature of flood exposure is described in terms of water velocity, water level, and duration of the inundation.
3. Vulnerability is the inherent characteristics (biological, physical, or design factors) of elements that make them susceptible to damage or harm from a hazard. For example, a building may have certain characteristics (e.g. foundational materials, shape, or structural design) that make it vulnerable to floods.
4. Risk: Indicates the degree of potential losses that could result when a "vulnerable" element is "exposed" to a "hazard". Risk is often defined as a function of hazard, exposure, and vulnerability.

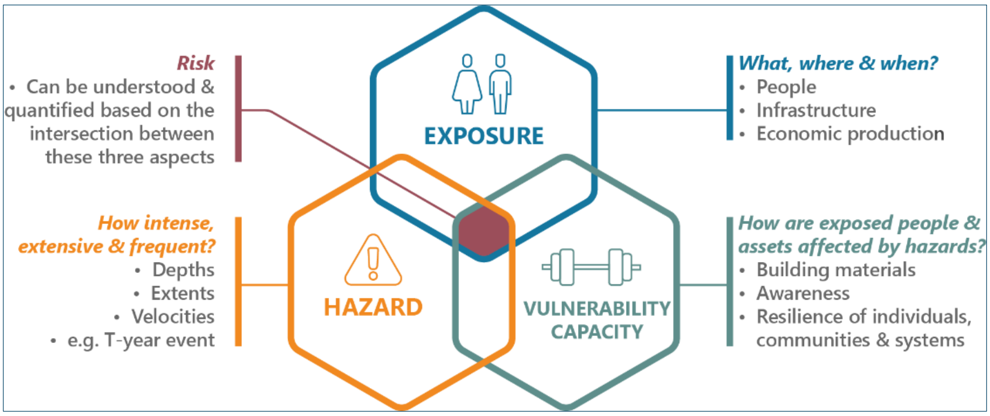

Figure 2-1 Framework for risk assessment, illustrating the relationship between hazard, exposure, vulnerability, and risk

Flood hazards are simulated based on floods for selected probabilities (return periods) – in this project the following return periods are assessed: 2-year, 5-year, 10-year, 50-year, 100-year, 200-year, and 500-year.

These flood events are assessed from rainfall-runoff modelling and statistical analyses.

For each return period flood inundation extents, based on hydrodynamic models (in this project: 2D-HD-models), are developed. These in turn are the foundation for (a) exposure assessment, (b) vulnerability assessment, and (c) risk assessment:

1. Exposure assessment involves identifying relevant elements (e.g. buildings, roads, utilities, people) in the flood hotspots and estimating the likelihood, level, duration, and extent of their exposure to a specific hazard.
2. Vulnerability assessment examines the ability of the physical, social, and natural elements to absorb the impact of a hazard of a given intensity while maintaining their functionality. This assessment is conducted by establishing empirical probability functions, referred to as vulnerability curves (in this project called "flood damage functions"). Vulnerability curves illustrate the relationship between the severity of a hazard and the amount of damage sustained by an element (in this project: flood damage as a function of water depth).
3. Risk is calculated as a function of hazards, exposure, and vulnerability. The flood risk in this project is the expected annual damage (EAD) which reflects the estimated statistical monetary flood damage that would occur in any given year.

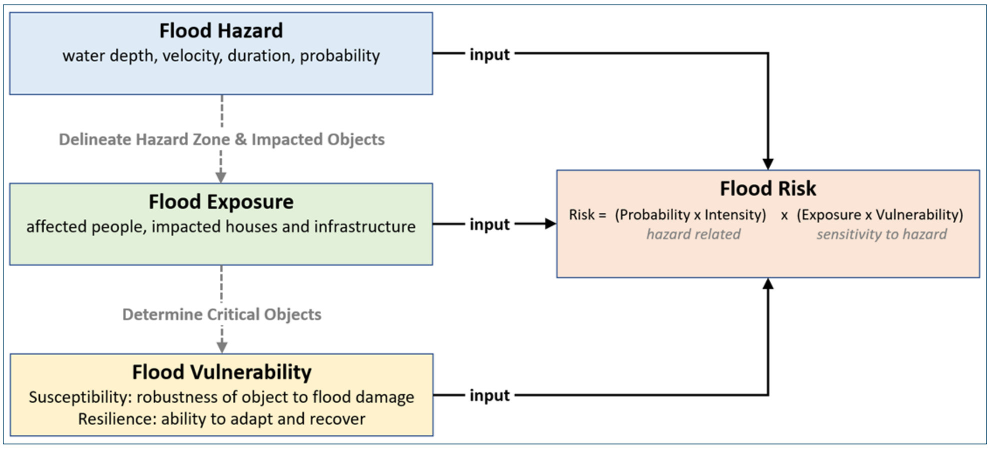

Figure 2-2 Simplified schematic for flood risk assessment

2.1 Flood Hazard Assessment and Flood Extent Mapping

Flood hazard assessment and flood extent mapping (with the flood hazard and extent maps) are documented in detail in the report "Deliverable 1.2: Report on the Enhanced and Improved EN-FFEWS". This chapter summarizes the concept and the key outcomes.

Flood extents are the main input for determining flood hazard at the selected flood locations. Flood extents have been calculated for selected return periods, of 2-year, 5-year, 10-year, 50-year, 100-year, 200-year, and 500-year.

Rainfall-runoff simulations were carried out with hydrological models using GPM as input rainfall. The obtained discharge timeseries at selected nodes/locations were statistically fitted to frequency distribution functions.

Then the obtained lateral inflows for selected return periods at selected river locations were used to simulate water surface profiles with 2D hydrodynamic models.

The water depths, as well as the water velocities were calculated using 2D models based on sets of finite element meshes which allow for a very precise representation of all characteristic parameters and features of the river channel, floodplains, as well as structures in the flood prone areas.

The 2D models are based on the DEMs available, such as the WP1 DEMs and ALOS (Advanced Land Observing Satellite: Japanese satellite mission product), the latter being used to add information where none was available from the WP1 datasets. The computational meshes are generated for each area considering the following principles:

- The 2D domain is extended enough to avoid any numerical instabilities induced by imposing various types of boundary conditions.
- The river geometry captures the transitions between river channel, banks, and floodplains.
- The river channel, as well as the area adjacent to it and the settlements' areas is described using a finer mesh which provides better resolution of results.
- The computational meshes are optimised for numerical stability and precision of results.

The results generated by the 2D models represent a continuous surface depicting various parameters, such as the water level, water depth, velocity with velocity components in x and y directions.

The 2D model results are processed in a GIS environment and the results are presented, for all return periods, as:

- Water depth raster with a 2 m resolution (in grid format)
- Water velocity raster a 2 m resolution (in grid format)
- Flood extent (in vector format)

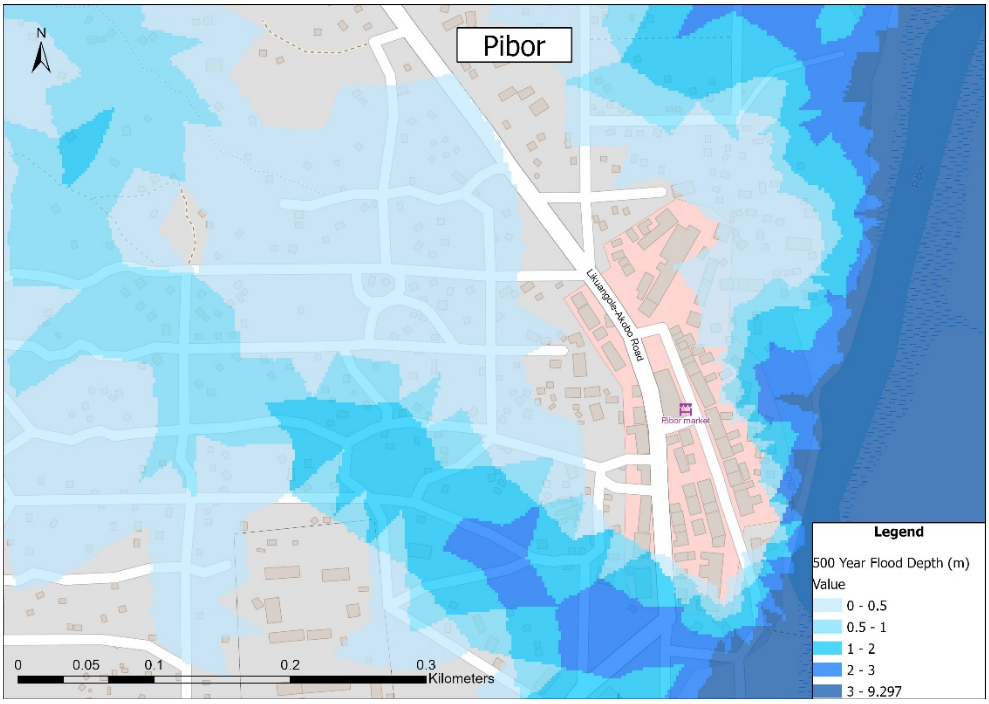

Figure 2-3 Example: map section with 2D-HD model simulation result representation as water depth grid for a selected return period

Figure 2-3 shows an example of the resolution of the water depth grid (2m x 2m) resulting from a 500-year flood in the centre of Pibor.

In total, for 16 hotspots and 7 return periods, there are in total (a) 112 water depth rasters, (b) 112 water velocity rasters, as well as (c) 112 flood extent polygons. These are the inputs for the analyses of flood exposures and flood vulnerabilities.

2.2 Flood Exposure and Vulnerability Assessment

The exposure assessment involved identifying relevant elements (e.g. buildings, streets, crops, vegetation, wetlands, water bodies, people).

For buildings, streets, crops, vegetation, wetlands, and water bodies, as documented in the inception report, Work Package 1 provided asset maps for selected flood hotspots (see also Figure 1-1).

For the other flood hotspots, for which asset maps from Work Package 1 were not available, alternative public domain sources have been used as follows:

- Google-Microsoft Open Buildings - combined by VIDA (see https://maps.worldbank.org/datasets/open_buildings): This dataset merges Google's V3 Open Buildings and Microsoft's latest Building Footprints. It reflects buildings worldwide as polygons with accurate georeference. But it does not categorize the buildings (e.g. how is the building used).
- The Global Human Settlement Layer (GHSL) project (see https://human-settlement.emergency.copernicus.eu/documents/GHSL_Data_Package_2023.pdf) is used as source for categorizing the buildings. It produces "new global spatial information, evidence-based analytics and knowledge describing the human presence on Earth". The added value of this source for this project is that this product categorizes buildings and land use.
- Overlaying these two products combines accurate building locations and sizes with adequate building categorization for the purpose of this project.
- Furthermore, transport infrastructure (e.g. streets, roads) is extracted from publicly available representations of OpenStreetMap – so called "OpenStreetMap-Shapefiles" (see https://download.geofabrik.de/africa.html).

These two datasets - (1) asset maps from WP1 and (2) the three public domain data sets - that mainly identify and describe buildings, infrastructure, and selected types of land use (e.g. agricultural use), have been harmonized to a coherent typology. For reporting purposes, the harmonized and aggregated typology is consolidated as follows:

- Agricultural Land
- Infrastructure
- Non-residential Building
- Open Space
- Residential Building
- Transport Infrastructure

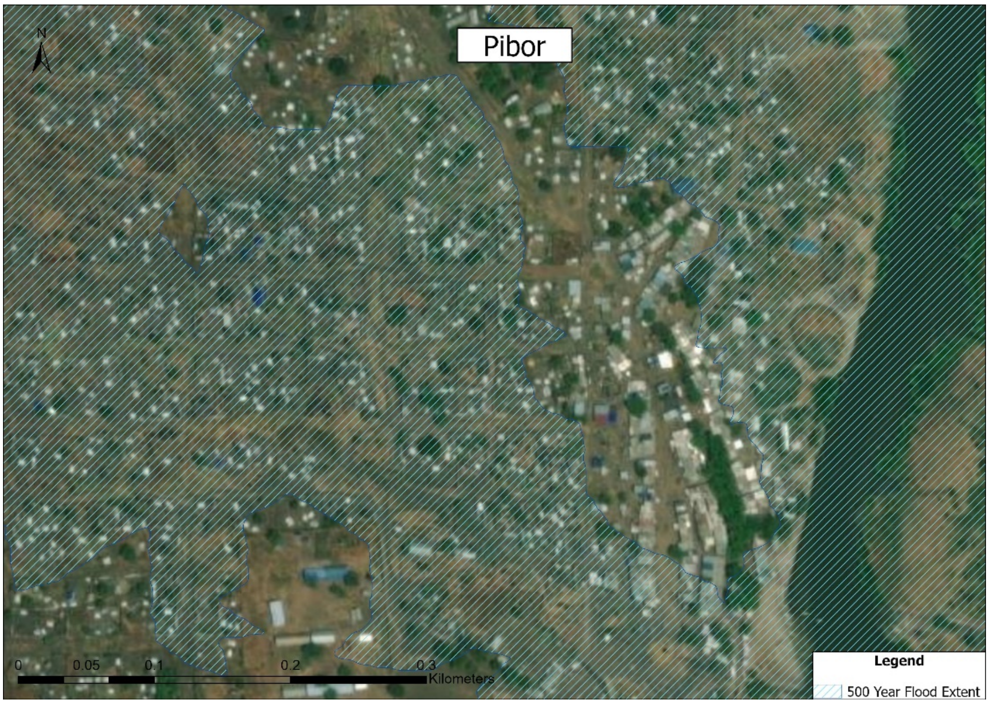

Figure 2-4 Example: satellite image representing land use/cover and buildings overlayed with selected simulated flood extent

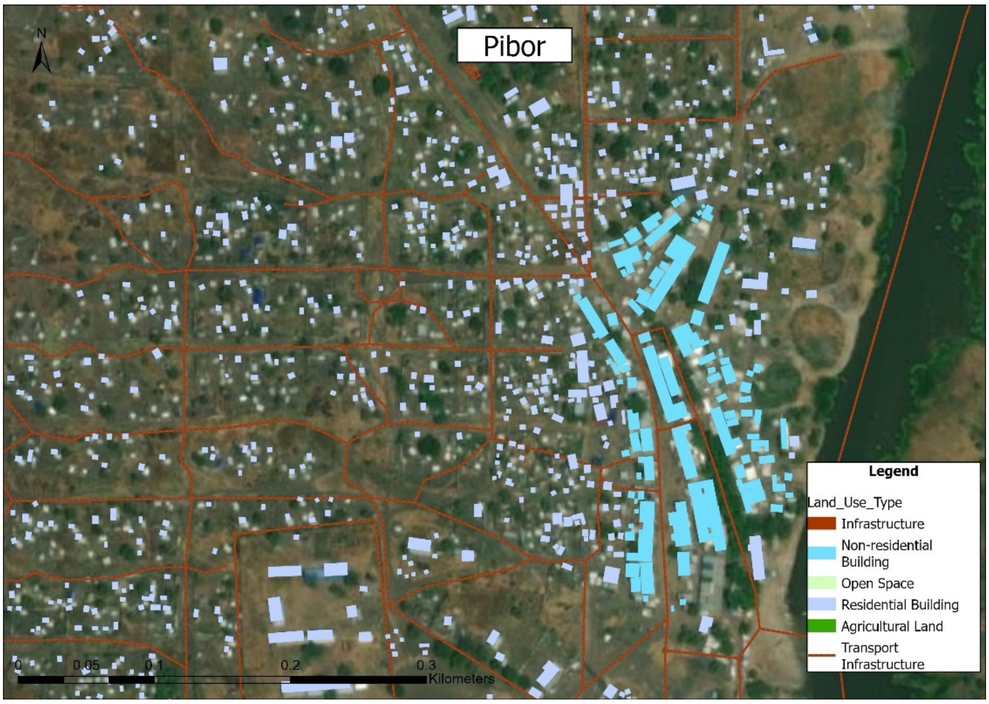

Figure 2-5 Example: map section with landuse/buildings categorized according to harmonized and aggregated typology overlayed with satellite image

Figure 2-5 shows an example of the buildings and infrastructure in the centre of Pibor. The land use categorization is aggregated according to the harmonized land use types. The map section shows the matching of the objects' locations and shapes with the respective entities in the satellite image.

2.2.1 Analyse Flood Exposures

As explained previously, all land use objects in the flood hotspots that are relevant to flood risk assessment are represented as geo-spatial vectors (geo-referenced polygons) and their typology is standardized for the purpose of flood risk assessment. For each return period, the respective flood extent polygons are intersected with the vector representations of the landuse/building objects.

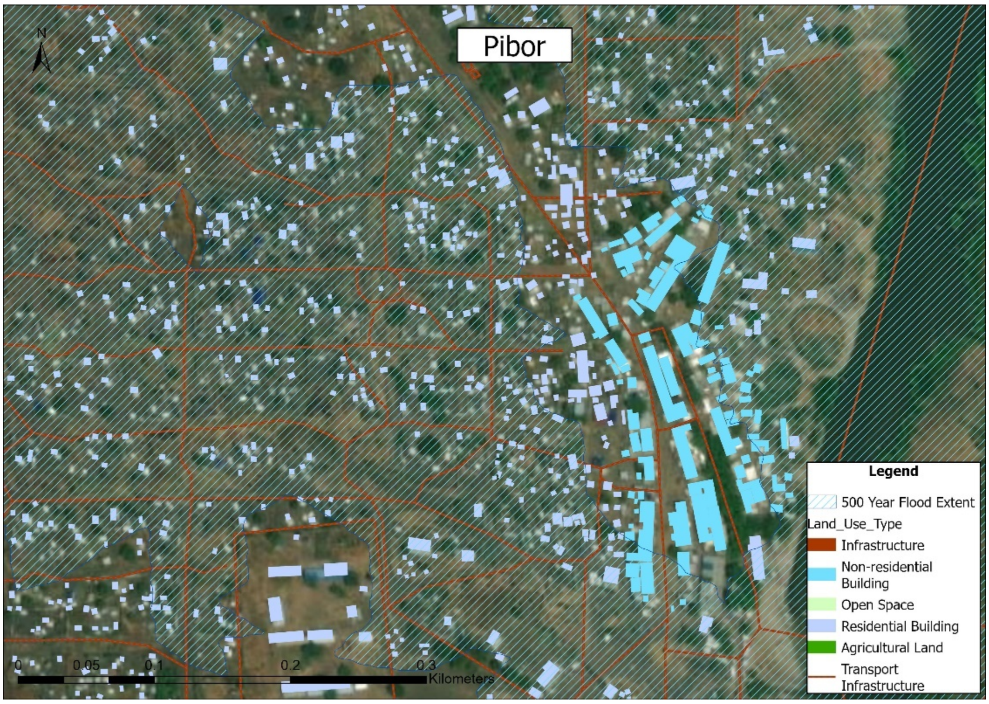

Figure 2-6 Example: map section with landuse/buildings overlayed with selected simulated flood extent

Figure 2-6 shows an example of the buildings and infrastructure in the centre of Pibor overlayed with a selected simulated flood extent with a return period of 500 years. The intersection calculation produces results as follows: (a) counts of affected buildings, (b) lengths of affected transport infrastructure, and (c) areas of affected agricultural land.

2.2.2 Analyse Flood Vulnerabilities

In this project, flood vulnerability refers to the conditions that make assets susceptible to the impacts of floods. It combines physical/environmental and socio-economic factors to assess overall vulnerability.

1. Flood vulnerability assessment is the process of evaluating the susceptibility of a community, infrastructure, or region to flooding. This assessment aims to identify the potential impacts, and damages that can result from flooding. Flood vulnerability assessment takes as a basis flood exposure analysis to overlay socio-economic factors, focusing in this project on physical vulnerability, reflected in damage curves (also referred to as damage functions or vulnerability functions), describing the relationship between the economic flood damage and water depth.
2. For the objects that are impacted by floods, vulnerability functions reflecting the flood vulnerability characteristics of the respective landuse/building category are developed. These describe the relationship

between the economic impact of a flood and the cause (flood water depth).

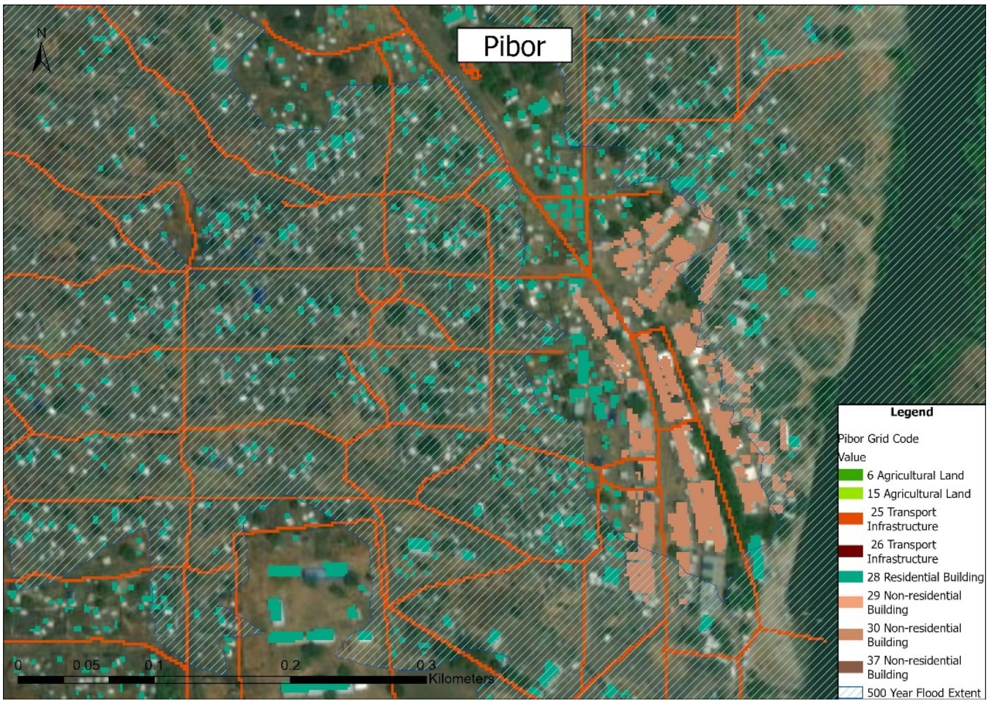

Figure 2-7 Example: map section with gridded representation of landuse/buildings overlayed with selected simulated flood extent.

The steps for calculating flood vulnerability are the following:

1. Determine for the landuse-types flood-damage-functions that reflect the socio-economic damage-cause relationship. In the flood-damage-functions the maximum damage is normalized to 100%
2. Determine for the landuse-types the construction costs for buildings and transport infrastructure in USD/m2, and agricultural yield/production in USD/m2. These represent the respective statistical economic values.
3. Convert the landuse objects (buildings, transport infrastructure, agricultural land), that are represented as geospatial vector objects, to grids according to the resolution of the water depth grid that results from the 2D-HD-simulations.
4. Overlay water depth grids (results from the 2D-HD-simulations) with converted land use grids as input for flood damage calculations.

The flood damage functions applied in this project are derived from the results of the “Flood Risk Mapping Consultancy for Pilot Areas” in Ethiopia and Sudan carried out by ENTRO in 2010 and from similar studies conducted by DHI worldwide (e.g. “Damage, Loss and Risk Modelling Romania” - a methodology for a comprehensive flood damage and loss assessment and for flood risk maps – prepared for the 2nd cycle of the EU Flood Directive in 2021).

Figure 2-8 Example: flood vulnerability function for residential buildings

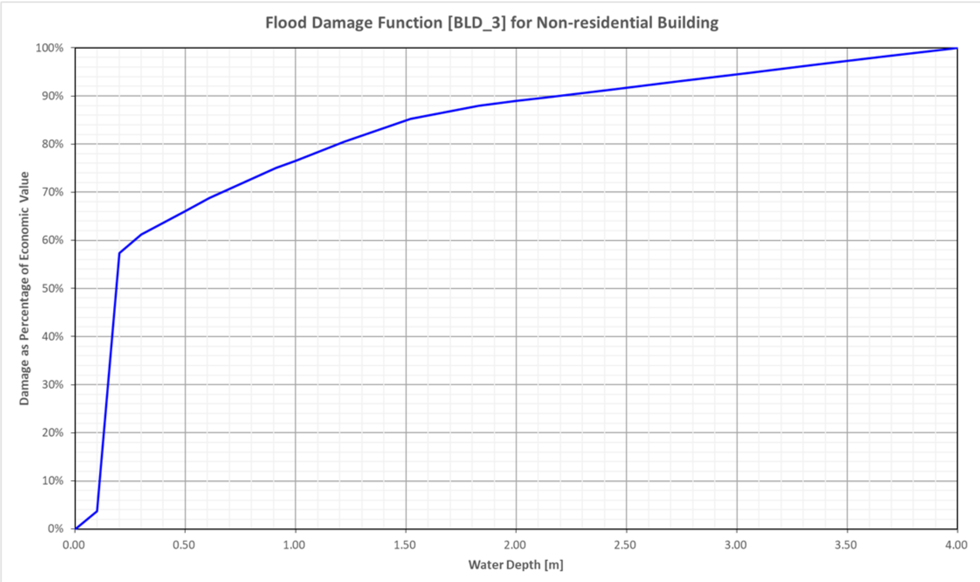

Figure 2-9 Example: flood vulnerability function for non-residential buildings

A simplified analysis to determine the construction cost estimates for buildings in Sudan. Ethiopia, and South Sudan by building category has been carried out, despite limited data availability. The following general benchmarks to assess the economic values are a result of research on the internet[1]:

Table 2-1 Construction cost estimates per square meter for building categories to represent economic maximal flood damage

Building Category	Sudan (USD/m²)	Ethiopia (USD/m²)	South Sudan (USD/m²)
Low-cost Residential	400	360	480
Mid-range Residential	650	585	780

[1] https://unhabitat.org/sites/default/files/2020/09/planning_urban_settlements_in_south_sudan.pdf; https://unhabitat.org/sites/default/files/download-manager-files/Supporting%20urban%20development%20in%20%20Sudan%20final.pdf

Building Category	Sudan (USD/m²)	Ethiopia (USD/m²)	South Sudan (USD/m²)
High-end Residential	1,000	900	1,200
Office Buildings	950	855	1,140
Retail Spaces	800	720	960
Basic Warehouses	550	495	660
Advanced Industrial Buildings	850	765	1,020
Schools	650	585	780
Hospitals	1,150	1,035	1,380

Similarly, for agricultural land, yields and costs for different agricultural land types have been used to assess flood vulnerability of agricultural land – main reference: https://www.nab.com.na/wp-content/uploads/2021/06/Peral-Millet-Market-Intelligence-Report-2021-Final-14062021.pdf - see details in Table 2-2.

Table 2-2 Yield and costs estimates for agricultural land to represent economic maximal flood damage

Crop/ Africa Major Crops typologies	Yield [kg per ha]	Cost [USD per kg]	Cost [USD/m²]
01. Rainfed-sc-sorghum	3,000	0.87	0.26
02. Rainfed-sc-millets/sorghums	1,000	5.00	0.50
03. Rainfed-sc-groundnut	1,000	1.50	0.15
04. Rainfed-sc-pigeonpea	700	0.70	0.05
05. Rainfed-sc-maize	2,000	0.40	0.08
06. Rainfed-dc-maize	2,000	0.40	0.08
07. Rainfed-sc-mixed	1,809	1.00	0.18
08. Rainfed-sc-tef	1,200	0.65	0.08
09. Rainfed-sc-rice	2,500	1.00	0.25
10. Rainfed-dc-rice	2,500	1.00	0.25
11. Irrigated-sc-rice	2,500	1.00	0.25
12. Rainfed-sc-wheat	1,500	0.40	0.06
13. Rainfed-sc-banana	12,000	0.40	0.48
14. Rainfed-sc-sugarcane	55,000	1.00	5.50
15. Irrigated-sc-sugarcane	90,000	1.00	9.00
16. Irri-dc-rice / irri-dc-mixed	8,000	1.00	0.80
17. Continous crop / plantation	1,809	1.00	0.18
18. Rangelands	0	0.00	0.00
19. Shrubs / grass / forest	0	0.00	0.00
20. Barren lands/ others	0	0.00	0.00
21. Settlements	0	0.00	0.00
22. Rainfed-SC_sorghum	3,000	0.87	0.26
23. Rainfed-SC-millet/sorghum-MS	3,000	0.87	0.26
24. Rainfed-SC-cotton/mixedcrops	600	1.50	0.09

Transport infrastructure costs, which are comparable internationally, have been derived from similar studies conducted by DHI worldwide (e.g. “Damage, Loss and Risk Modelling Romania” - a methodology for a comprehensive flood damage and loss assessment and for flood risk maps – prepared for the 2nd cycle of the EU Flood Directive in 2021) and adjusted with regional economic indicators – see details in Table 2-3.

Table 2-3 Cost estimates per square meter for transport infrastructure represent economic maximal flood damage

Transport Infrastructure	Cost [USD/m^2]
unclassified	3.50
unpaved	3.50
ground	3.50
mud	3.50
path	3.50
sand	3.50
cobblestone	250.00
paved	250.00
compacted	250.00
asphalt	250.00
railway	1,500.00

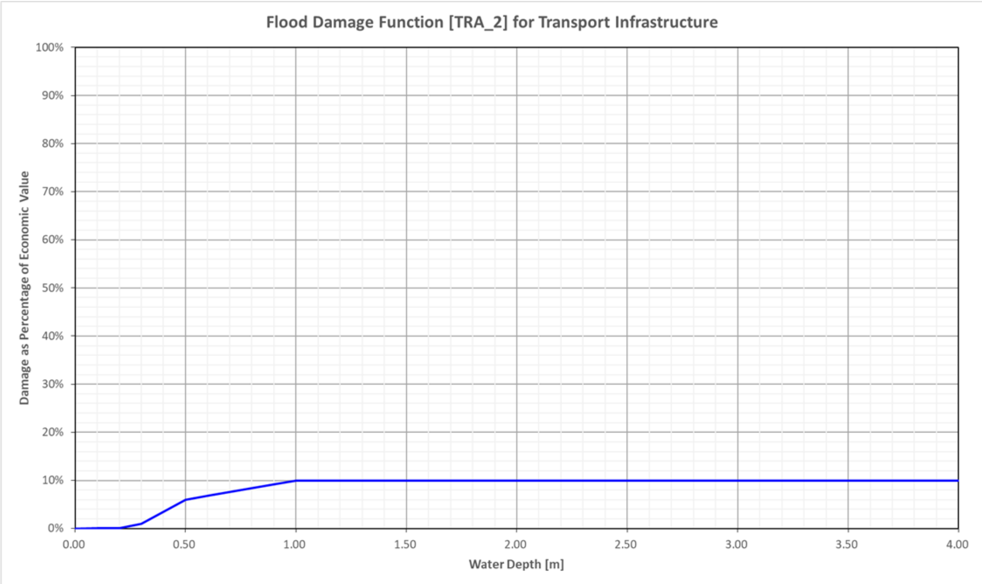

Figure 2-10 Example: flood damage function for transport infrastructure (maximum damage is 10% of economic value)

To reflect the socio-economic differences between Ethiopia, Sudan, and South Sudan, factors for multiplying the damages have been applied - using Sudan as reference: Ethiopia = 0.9, Sudan = 1.0, and South Sudan = 1.2. These ratios consider the slightly more stable economic environment and better infrastructure in Ethiopia compared to Sudan, and the challenging conditions and higher cost of materials and logistics in South Sudan.

2.3 Flood Risk Assessment

Flood risk assessment comprises the calculation of (1) flood damages for the return periods and the (2) the expected annual flood damage (EAD).

1. Flood damages are calculated by assigning the flood damage functions on the spatial distribution of land use (represented as grid) and overlaying this intermediate result with the water depth grid. The result, a damage

percentage per square meter, is then multiplied with the grid cell size (2m x 2m) and the economic value of the respective land use type.

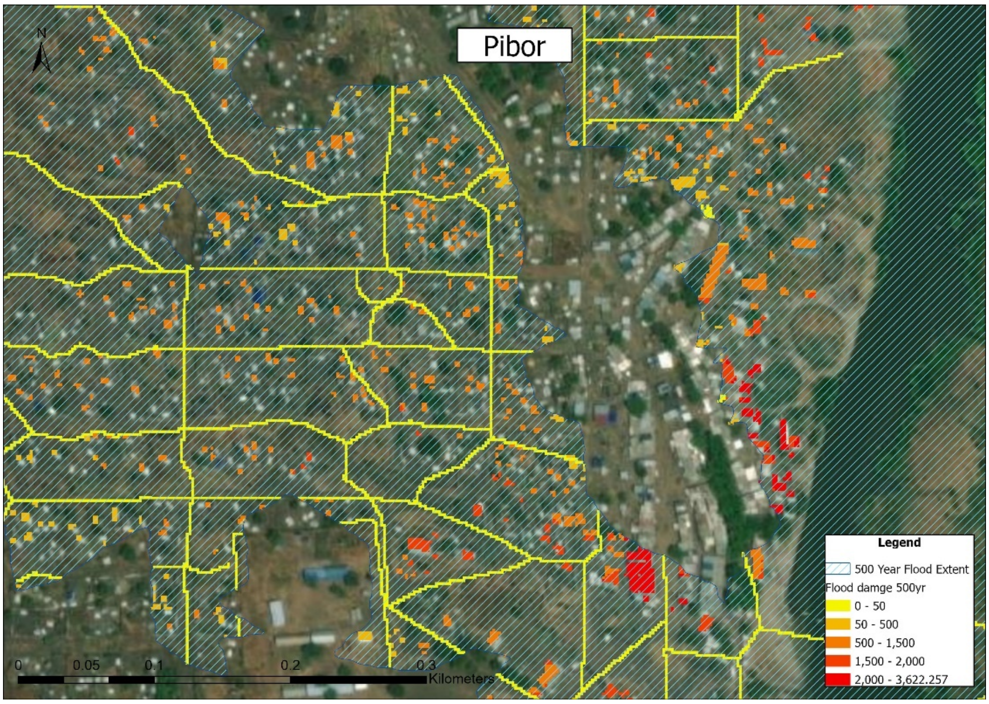

Figure 2-11 Example: map section with damages in USD for a 500-year return period flood overlayed with the simulated flood extent

Figure 2-11 shows an example the spatial distribution of flood damages in the centre of Pibor for a 500-year return period flood overlayed with the simulated flood extent. The flood damage calculations are made for each grid cell (2m x 2m) that has a flood water depth coming from the 2D-HD-simulation and has land use assigned to it (building, transport infrastructure or agriculture).

2. The expected annual damage (EAD) due to flooding is a metric that indicates the average yearly damage resulting from flood damages with different exceedance probabilities (reciprocal of return period). Rare flood events (e.g. 500-year return period) lead to high damages due to higher water depths and larger flood extents, and more frequent events (e.g. 2-years return period) rather lead to relatively lower damages. The EAD is the integral of the flood damage as a function of exceedance probability - summing the probability-weighted damages across the flood events. This formula is applied to each grid cell with flood damages assigned/calculated.

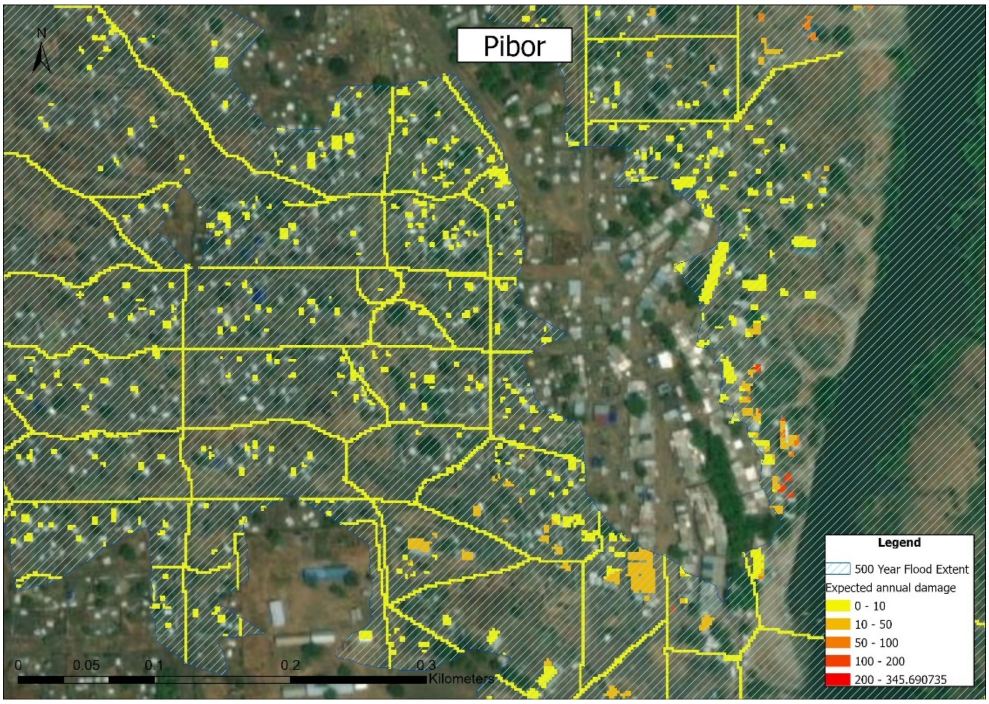

Figure 2-12 Example: map section with expected annual flood damages in USD/year overlayed with a simulated flood extent

Figure 2-12 shows an example the spatial distribution of the expected annual flood damages in the centre of Pibor overlayed with the simulated maximum flood extent. The EAD calculations are made for each grid cell (2m x 2m) that has a flood damage assigned to it. Objects which may have relatively high flood damages for a flood event with a high return period (e.g. 500-year) may have a relatively low EAD because they are not affected by flood with lower return periods.

All results - flood damages and expected annual flood damages - are documented in tables in chapter 3 and in maps that are submitted in a separate volume. The representation in maps is aggregated to a grid with lower resolution (250 m x 250 m) to make clear that the maps should rather highlight where the critical zones are in the flood hotspot (see Figure 2-13: example is Pibor). They should not mislead to identifying single objects (e.g. houses) and their calculated damages because the calculations are based on statistical analyses and simplified - but fit-for-purpose - land use categorizations.

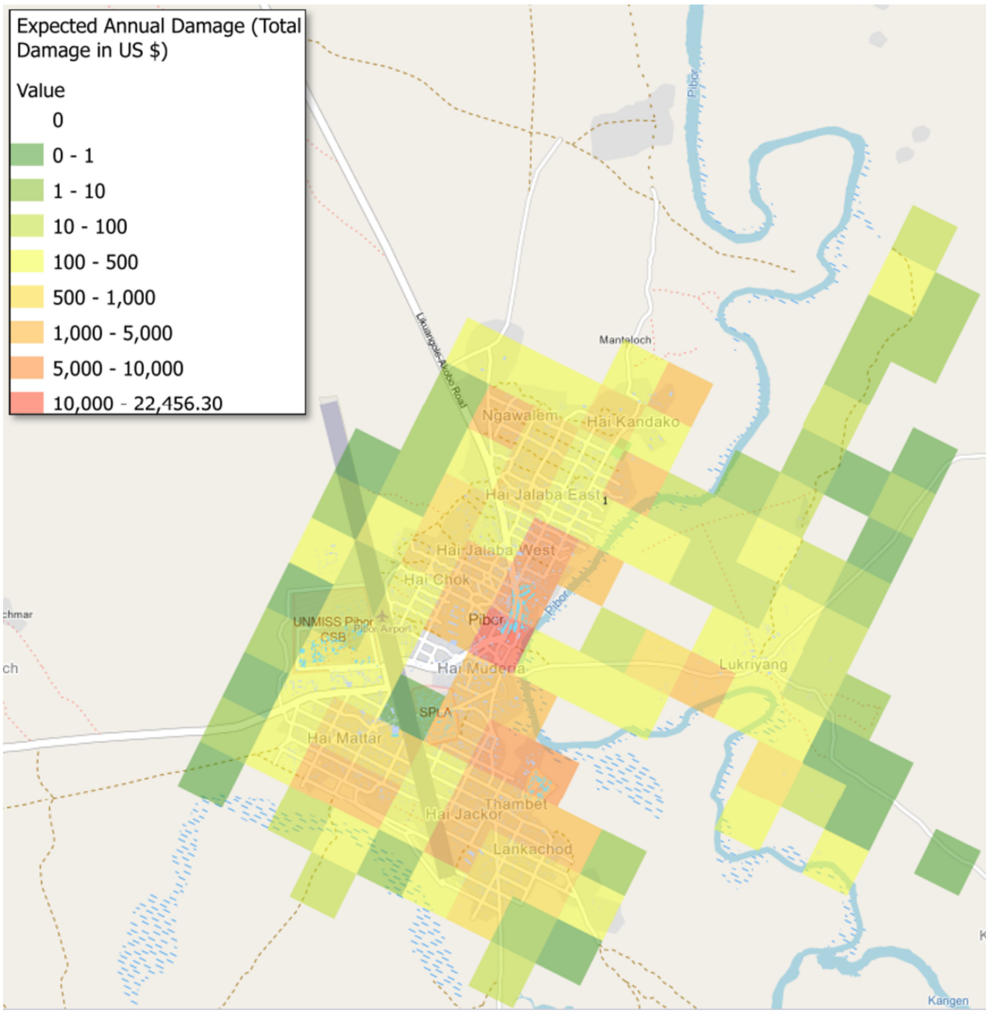

Figure 2-13 Example: map with expected annual flood damages with a resolution of 250 m x 250 m

2.4 Assessment of Directly Affected Residential Population

In addition to the assessment of tangible flood damages quantified as economic or monetary costs, intangible effects of floods are assessed. In this project, the assessment of intangible flood effects quantifies directly affected population in the flood hotspots.

The spatial distribution of people in the flood hotspots is assessed based on the public domain source "GHSL: Global population surfaces 1975-2030 (P2023A)" – see https://developers.google.com/earth-engine/datasets/catalog/JRC_GHSL_P2023A_GHS_POP: The GHS-POP R2023A dataset depicts the distribution of residential population, expressed as the number of people per cell – 100m x 100m. Residential population estimates between 1975 and 2020 in 5-year intervals and projections to 2025 and 2030 derived from CIESIN GPWv4.11 are disaggregated from census or administrative units to grid cells, informed by the distribution, volume and classification of built-up as mapped in the Global Human Settlement Layer (GHSL) global layer per corresponding epoch.

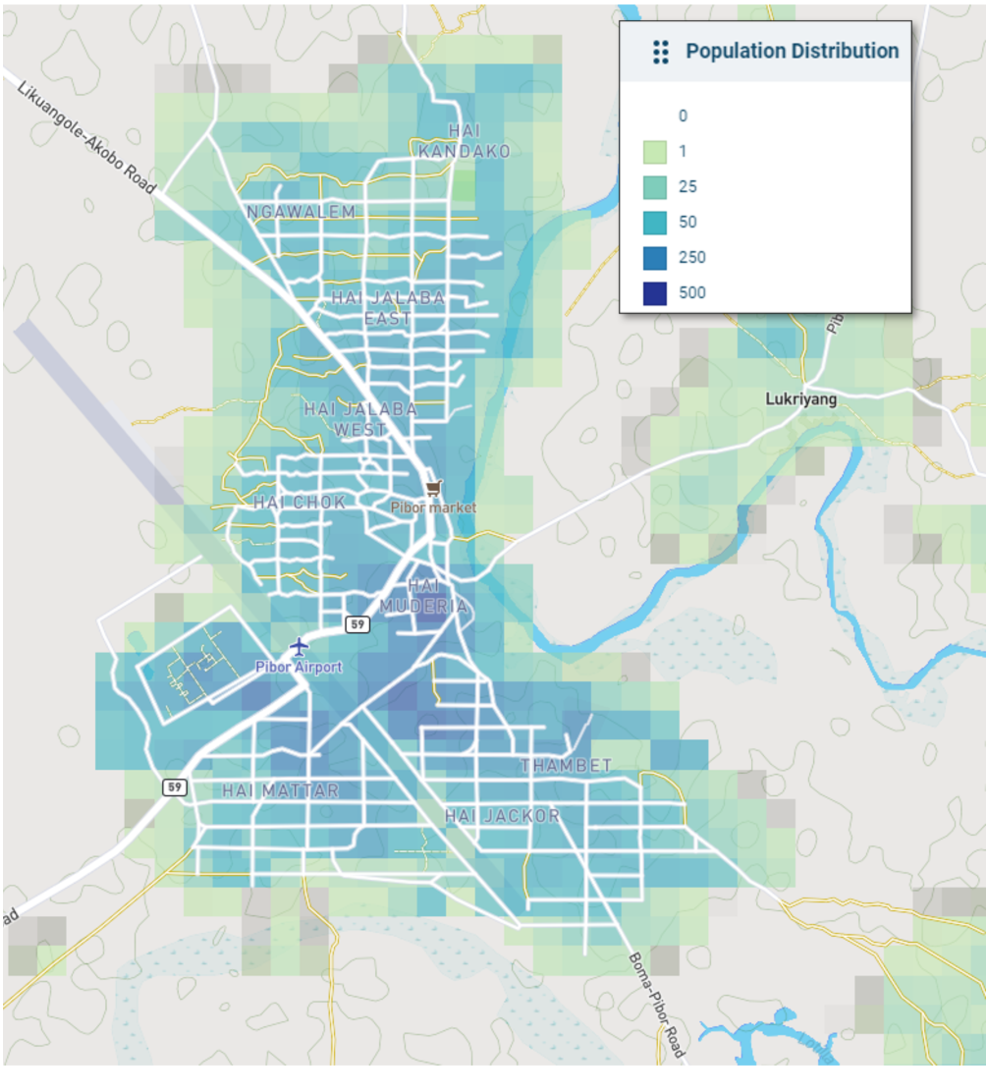

Figure 2-14 Example: map section with residential population in a selected flood hotspot – population count in 100 m x 100 m cells

Figure 2-14 shows an example of spatial distribution of residential population in Pibor. The grid resolution is 100 m x 100 m.

The assessment of directly affected residential population in the flood hotspots for each flood return period is calculated with standard GIS-functions as follows:

1. Reproject: Overlay the water depth grid of the flood (2 m x 2 m) with the residential population grid (100 m x 100 m).
2. Resample: For each water depth grid cell of the flood, determine the number of people affected, based on the average number of people per square meter for that cell (2 m x 2 m).
3. Sum the total number of affected residential population for all water depth grid cells: Result = directly affected residential population in the flood hotspots for the respective flood return period

3 Result Summaries

Comprehensive maps and detailed tables that contain flood exposure, flood damage and expected annual flood damage documenting the results for each flood hotspot are submitted separately as follows:

- Separate report volume that contains all maps with their respective tabular references
- Geospatial representations of the flood risk analysis results (shape-files and grids, with attribute tables) in an object-relational database management system (deployed in the cloud and easily accessible through the internet)

In this chapter the results of the flood risk analysis are summarized, and the summaries are documented in overview tables.

3.1 Flood Exposures

The flood exposures are documented as summaries of inundated areas for agricultural land, inundated lengths of transport infrastructure, and number of buildings.

Table 3-1 Inundated agricultural areas in hectares

Basin	Hotspot	Return Period						
		2	5	10	50	100	200	500
BAS	Gambela	15	17	18	19	21	22	23
BAS	Itang	114	126	129	131	132	134	135
BAS	Pibor	0	0	0	15	16	16	18
BAS	Akobo	0	0	0	0	1	6	9
BAS	Nasir	10,374	11,169	11,634	12,631	13,006	13,422	13,889
BAS	Malakal	54	55	55	56	56	57	57
BN	El Roseires	490	540	563	598	607	614	622
BN	Singa & Suki	4,375	5,530	6,021	6,322	6,378	6,421	6,466
BN	Wad Medani	4,422	5,854	6,376	6,895	7,028	7,127	7,227
BN	El Masudiya Khartoum	2,377	3,360	4,169	6,664	8,051	8,955	9,916
LT	Gumara	3,867	4,154	4,288	4,643	5,128	5,210	5,331
LT	Ribb	6,534	6,897	7,222	7,988	8,295	8,421	8,816
LT	Megech	2,689	3,010	3,554	3,959	4,156	4,309	4,656
LT	Dirma	1,928	2,140	2,271	2,522	2,616	2,636	2,660
TSA	Humera	2	3	5	6	7	8	10
TSA	Atbara	2,009	2,920	3,061	3,166	3,192	3,220	3,240

The inundated agricultural areas in Nasir and Ribb are rather high due to the flat topographies and the selected analysis extent. It is advised to analyse the inundated areas relative to the inundations for the 2-year return period – the respective differences to these reference values can indicate how sensitive the respective communities are to floods.

Table 3-2 Inundated transport infrastructure in kilometres

Basin	Hotspot	Return Period						
		2	5	10	50	100	200	500
BAS	Gambela	1	2	2	3	3	4	4
BAS	Itang	6	8	8	9	10	11	11
BAS	Pibor	0	0	1	6	12	24	51
BAS	Akobo	6	7	7	18	28	34	37
BAS	Nasir	6	7	7	8	8	8	8
BAS	Malakal	5	5	5	5	5	5	5
BN	El Roseires	10	14	16	19	20	21	21
BN	Singa & Suki	20	32	38	44	45	46	47
BN	Wad Medani	207	357	436	547	580	605	629

Basin	Hotspot	Return Period						
		2	5	10	50	100	200	500
BN	El Masudiya Khartoum	393	670	891	1,427	1,693	1,928	2,094
LT	Gumara	17	19	19	20	20	22	23
LT	Ribb	19	20	22	25	26	28	29
LT	Megech	17	19	24	25	26	28	33
LT	Dirma	3	4	4	5	5	5	5
TSA	Humera	0	0	0	2	3	3	4
TSA	Atbara	446	554	594	694	724	751	786

The following table shows the number of inundated buildings in the flood hotspots for the different flood return periods, distinguished, and categorised by building use type.

Table 3-3 Number of buildings affected in the inundated areas

Basin	Hotspot	Use Type	Return Period						
			2	5	10	50	100	200	500
BAS	Gambela	Infrastructure	1	1	1	2	3	3	3
BAS	Gambela	Non-residential Building	0	1	1	1	1	1	1
BAS	Gambela	Open Space	1	1	1	1	1	1	1
BAS	Gambela	Residential Building	12	69	108	216	262	323	417
BAS	Itang	Infrastructure	1	1	1	1	1	1	1
BAS	Itang	Non-residential Building	0	0	0	0	0	0	0
BAS	Itang	Open Space	0	0	0	0	0	0	0
BAS	Itang	Residential Building	30	36	44	50	54	58	58
BAS	Pibor	Infrastructure	0	0	0	0	0	0	0
BAS	Pibor	Non-residential Building	0	0	0	9	23	52	260
BAS	Pibor	Open Space	0	0	0	0	0	0	0
BAS	Pibor	Residential Building	0	3	5	80	301	824	2,546
BAS	Akobo	Infrastructure	0	0	0	0	0	0	0
BAS	Akobo	Non-residential Building	32	41	41	43	51	55	55
BAS	Akobo	Open Space	0	0	0	0	0	0	0
BAS	Akobo	Residential Building	125	133	134	148	188	279	357
BAS	Nasir	Infrastructure	0	0	0	0	0	0	0
BAS	Nasir	Non-residential Building	2	2	3	3	4	4	4
BAS	Nasir	Open Space	0	0	0	0	0	0	0
BAS	Nasir	Residential Building	266	340	357	394	403	433	465
BAS	Malakal	Infrastructure	8	8	8	8	8	8	8
BAS	Malakal	Non-residential Building	60	60	63	63	63	63	63
BAS	Malakal	Open Space	0	0	0	0	0	0	0
BAS	Malakal	Residential Building	570	572	578	583	583	583	587
BN	El Roseires	Infrastructure	0	0	0	0	0	0	0
BN	El Roseires	Non-residential Building	0	0	0	0	0	0	0

Basin	Hotspot	Use Type	Return Period						
			2	5	10	50	100	200	500
BN	El Roseires	Open Space	0	0	0	0	0	0	0
BN	El Roseires	Residential Building	1,000	1,424	1,662	1,910	1,999	2,035	2,135
BN	Singa & Suki	Infrastructure	0	0	0	0	0	0	0
BN	Singa & Suki	Non-residential Building	0	0	1	1	1	1	1
BN	Singa & Suki	Open Space	0	0	0	0	0	0	0
BN	Singa & Suki	Residential Building	3,217	7,579	10,355	14,133	15,197	16,151	16,987
BN	Wad Medani	Infrastructure	0	0	0	0	0	0	0
BN	Wad Medani	Non-residential Building	0	0	0	0	0	0	0
BN	Wad Medani	Open Space	0	0	0	0	0	0	0
BN	Wad Medani	Residential Building	20,301	40,631	52,115	69,334	74,400	78,669	82,581
BN	El Masudiya Khartoum	Infrastructure	0	0	0	0	0	0	0
BN	El Masudiya Khartoum	Non-residential Building	14	23	70	112	120	133	136
BN	El Masudiya Khartoum	Open Space	0	0	0	0	0	0	0
BN	El Masudiya Khartoum	Residential Building	32,824	62,038	83,158	128,382	147,628	165,063	181,122
LT	Gumara	Infrastructure	0	0	0	0	0	0	0
LT	Gumara	Non-residential Building	0	0	0	0	0	0	0
LT	Gumara	Open Space	0	0	0	0	0	0	0
LT	Gumara	Residential Building	4,555	4,874	5,076	5,344	5,666	5,723	5,821
LT	Ribb	Infrastructure	0	0	0	0	0	0	0
LT	Ribb	Non-residential Building	0	0	0	0	0	0	0
LT	Ribb	Open Space	0	0	0	0	0	0	0
LT	Ribb	Residential Building	4,006	4,224	4,334	4,957	5,289	5,328	5,392
LT	Megech	Infrastructure	0	0	0	0	0	0	0
LT	Megech	Non-residential Building	0	0	0	0	0	0	0
LT	Megech	Open Space	0	0	0	0	0	0	0
LT	Megech	Residential Building	1,392	1,494	1,767	1,889	1,999	2,108	2,383
LT	Dirma	Infrastructure	0	0	0	0	0	0	0
LT	Dirma	Non-residential Building	0	0	0	0	0	0	0
LT	Dirma	Open Space	0	0	0	0	0	0	0
LT	Dirma	Residential Building	911	1,028	1,139	1,240	1,292	1,302	1,319
TSA	Humera	Infrastructure	0	0	0	0	0	0	0
TSA	Humera	Non-residential Building	0	0	0	0	0	0	0
TSA	Humera	Open Space	0	0	0	0	0	0	0

Basin	Hotspot	Use Type	Return Period						
			2	5	10	50	100	200	500
TSA	Humera	Residential Building	6	16	40	181	304	406	545
TSA	Atbara	Infrastructure	0	0	0	0	0	0	0
TSA	Atbara	Non-residential Building	17	18	18	18	18	18	18
TSA	Atbara	Open Space	0	0	0	0	0	0	0
TSA	Atbara	Residential Building	41,092	47,685	51,742	64,115	68,227	72,272	77,777

This overview shows that most affected buildings in the hotspots are "Residential Buildings", which reflects the respective local socio-economic structures of the communities. Furthermore, the communities in the Baro-Akobo-Sobat basin seem to have adapted their land use to flooding (examples are Gambela and Pibor) – see ratio of affected houses for 2-year and higher return periods (e.g. 500-year). This can also be seen in the respective flood hazard maps (submitted in a separate document).

3.2 Flood Damages and Expected Annual Flood Damages

Applying the flood vulnerability analysis results – the flood damage functions – on the flood exposure leads to economic/monetary flood damages for the flood hotspots for the seven flood return periods. The flood damages reflect the direct potential economic losses resulting from flood events with the respective return periods. Based on the calculated flood damages expected annual damages (EAD) are calculated. The expected annual flood damages reflect the average annual direct economic losses due to flooding.

3.2.1 Flood Damages

Flood damages of agricultural areas are calculated for spatial extents of the respective flood hotspots that go beyond the extents of the respective settlements (e.g. Nasir). Therefore, the calculated direct agricultural damages – as losses related to crops – are normalized per hectare. Table 3-4 shows normalized flood damages on agricultural areas [USD/ha] in the flood hotspots for the different flood return periods.

Table 3-4 Flood damages on agricultural areas [USD/ha] in the flood hotspots

Basin	Hotspot	Return Period						
		2	5	10	50	100	200	500
BAS	Gambela	58,719	59,018	58,914	57,982	57,687	57,290	57,109
BAS	Itang	35,184	34,953	34,511	34,039	33,792	33,286	33,022
BAS	Pibor				106,847	107,779	107,779	95,101
BAS	Akobo	1,861	1,861	1,861	1,763	1,783	1,751	1,827
BAS	Nasir	82,820	83,485	83,702	83,346	83,061	83,053	82,451
BAS	Malakal	60,369	60,303	60,129	59,993	59,911	60,002	59,977
BN	El Roseires	2,236	2,263	2,271	2,278	2,282	2,286	2,288
BN	Singa & Suki	16,742	15,459	14,706	14,306	14,236	14,182	14,140
BN	Wad Medani	3,258	2,806	2,658	2,520	2,490	2,490	2,441
BN	El Masudiya Khartoum	1,230	1,077	949	657	572	527	510
LT	Gumara	854	853	854	850	869	867	864
LT	Ribb	834	834	832	845	849	848	846

Basin	Hotspot	Return Period						
		2	5	10	50	100	200	500
LT	Megech	811	1,101	1,132	1,211	1,221	1,203	1,168
LT	Dirma	981	1,377	1,492	1,598	1,635	1,630	1,623
TSA	Humera	2,357	2,349	2,312	2,349	2,345	2,326	2,342
TSA	Atbara	225	197	192	187	185	184	183

Similarly, flood damages of transport infrastructure are calculated for spatial extents of the respective flood hotspots that go beyond the extents of the respective settlements (e.g. Nasir, Singa & Suki). Therefore, the calculated direct flood damages on transport infrastructure – roads – are normalized per kilometre. Table 3-5 shows normalized flood damages on transport infrastructure [USD/km] in the flood hotspots for the different flood return periods.

Table 3-5 Flood damages of transport infrastructure [USD/km] in the flood hotspots

Basin	Hotspot	Return Period						
		2	5	10	50	100	200	500
BAS	Gambela	1,546	2,880	3,232	4,032	4,028	4,088	4,302
BAS	Itang	1,365	1,470	1,576	1,884	1,949	1,989	2,150
BAS	Pibor	3,341	2,445	3,723	3,961	3,875	3,637	3,929
BAS	Akobo	13,837	17,804	19,744	11,381	9,820	10,012	11,358
BAS	Nasir	1,351	1,449	1,534	1,752	1,859	1,962	2,109
BAS	Malakal	7,855	8,373	8,544	8,809	8,891	8,911	8,930
BN	El Roseires	33,431	44,947	64,140	82,338	86,168	93,037	99,703
BN	Singa & Suki	77,503	81,097	87,285	97,947	103,290	105,812	105,961
BN	Wad Medani	46,856	54,637	59,040	67,386	70,040	72,156	74,986
BN	El Masudiya Khartoum	43,078	46,583	46,038	45,088	44,003	44,190	45,239
LT	Gumara	9,565	9,711	9,799	10,017	9,975	9,548	9,200
LT	Ribb	4,635	4,845	4,655	4,450	4,464	4,351	4,306
LT	Megech	4,508	4,510	5,787	6,073	6,502	6,765	8,018
LT	Dirma	1,261	1,167	1,209	1,240	1,261	1,270	1,256
TSA	Humera	11,123	8,124	6,139	7,930	7,891	8,143	7,689
TSA	Atbara	4,230	6,260	6,937	7,364	7,500	7,701	7,879

The direct economic flood damages reflect property damages - damage to buildings, and infrastructure excluding transport infrastructure (e.g. utilities). Table 3-6 shows flood damages on buildings [Thousand USD] in the flood hotspots for the different flood return periods. The damages are distinguished by different building use types (1) Infrastructure, (2) Non-residential Building, (3) Open Space, and (4) Residential Building.

As explained for the flood exposures of buildings, reference to the damages of the 2-year return period can be seen as guidance for interpreting the flood resilience and vulnerability of the respective communities in the flood hotspots.

Table 3-6 Flood damages of buildings [Thousand USD] in the flood hotspots

Basin	Hotspot	Use Type	Return Period						
			2	5	10	50	100	200	500
BAS	Gambela	Infrastructure	2	34	41	131	146	159	170
BAS	Gambela	Non-residential Building		672	1,248	2,719	3,308	4,048	5,434
BAS	Gambela	Open Space	556	1,128	1,269	1,419	1,449	1,457	1,460
BAS	Gambela	Residential Building	68	973	1,495	3,298	4,317	5,491	7,053
BAS	Itang	Infrastructure	4	10	13	18	19	20	22
BAS	Itang	Residential Building	361	464	561	720	766	818	887
BAS	Pibor	Non-residential Building				64	388	770	2,009
BAS	Pibor	Residential Building		5	30	434	1,649	4,643	13,491
BAS	Akobo	Non-residential Building	1,372	1,990	2,220	2,358	2,610	2,862	3,058
BAS	Akobo	Residential Building	2,594	3,810	4,312	4,718	5,234	6,380	7,890
BAS	Nasir	Non-residential Building	39	46	58	83	191	1,121	1,173
BAS	Nasir	Residential Building	922	1,177	1,324	1,617	1,725	1,897	2,215
BAS	Malakal	Infrastructure	136	151	155	159	161	163	165
BAS	Malakal	Non-residential Building	4,377	4,646	4,791	5,172	5,243	5,309	5,388

Basin	Hotspot	Use Type	Return Period						
			2	5	10	50	100	200	500
BAS	Malakal	Residential Building	11,854	12,527	12,821	13,328	13,506	13,655	13,834
BN	El Roseires	Residential Building	10,975	16,096	18,578	22,156	23,228	24,110	24,978
BN	Singa & Suki	Non-residential Building			37	63	71	78	84
BN	Singa & Suki	Residential Building	19,742	52,191	73,279	104,787	113,051	119,645	126,735
BN	Wad Medani	Residential Building	264,723	509,230	654,418	899,448	973,724	1,039,800	1,100,352
BN	El Masudiya Khartoum	Non-residential Building	2,957	3,658	6,202	20,046	25,736	31,625	35,512
BN	El Masudiya Khartoum	Residential Building	659,044	1,070,429	1,377,730	2,288,258	2,680,068	3,091,114	3,380,971
LT	Gumara	Residential Building	53,156	59,015	62,436	68,730	71,726	73,072	74,963
LT	Ribb	Residential Building	35,523	40,044	42,340	48,694	51,120	51,807	52,849
LT	Megech	Residential Building	7,614	8,333	10,204	11,318	12,134	13,061	15,717
LT	Dirma	Residential Building	3,743	4,273	4,657	5,172	5,345	5,436	5,600
TSA	Humera	Residential Building	24	66	171	1,428	2,907	4,933	8,144
TSA	Atbara	Non-residential Building	409	820	1,046	1,330	1,387	1,429	1,470
TSA	Atbara	Residential Building	636,310	857,092	964,203	1,207,298	1,310,885	1,420,697	1,581,090

Table 3-7 summarizes the flood damages on buildings shown in Table 3-6: Summary of flood damages of buildings [Thousand USD] in the flood hotspots (regardless of building use type).

Table 3-7 Summary of flood damages of buildings [Thousand USD] in the flood hotspots

Basin	Hotspot	Return Period						
		2	5	10	50	100	200	500
BAS	Gambela	626	2,807	4,053	7,567	9,220	11,155	14,117
BAS	Itang	365	474	574	738	785	838	909
BAS	Pibor	0	5	30	498	2,037	5,413	15,500
BAS	Akobo	3,966	5,800	6,532	7,076	7,844	9,242	10,948
BAS	Nasir	961	1,223	1,382	1,700	1,916	3,018	3,388
BAS	Malakal	16,367	17,324	17,767	18,659	18,910	19,127	19,387
BN	El Roseires	10,975	16,096	18,578	22,156	23,228	24,110	24,978
BN	Singa & Suki	19,742	52,191	73,316	104,850	113,122	119,723	126,819
BN	Wad Medani	264,723	509,230	654,418	899,448	973,724	1,039,800	1,100,352
BN	El Masudiya Khartoum	662,001	1,074,087	1,383,932	2,308,304	2,705,804	3,122,739	3,416,483
LT	Gumara	53,156	59,015	62,436	68,730	71,726	73,072	74,963
LT	Ribb	35,523	40,044	42,340	48,694	51,120	51,807	52,849
LT	Megech	7,614	8,333	10,204	11,318	12,134	13,061	15,717
LT	Dirma	3,743	4,273	4,657	5,172	5,345	5,436	5,600
TSA	Humera	24	66	171	1,428	2,907	4,933	8,144
TSA	Atbara	636,719	857,912	965,249	1,208,628	1,312,272	1,422,126	1,582,560

3.2.2 Expected Annual Flood Damages

Based on the normalized flood damages for agricultural areas expected annual flood damages are calculated. Table 3-8 shows the normalized expected annual flood damages on agricultural areas [USD/ha/year] in the flood hotspots.

Table 3-8 Expected annual flood damages on agricultural areas [USD/ha/year] in the flood hotspots

Basin	Hotspot	USD/ha/year
BAS	Gambela	9,496
BAS	Itang	6,500
BAS	Pibor	5,246
BAS	Akobo	7
BAS	Nasir	14,106
BAS	Malakal	11,578
BN	El Roseires	411
BN	Singa & Suki	2,706
BN	Wad Medani	455
BN	El Masudiya Khartoum	80
LT	Gumara	139
LT	Ribb	139
LT	Megech	174
LT	Dirma	259
TSA	Humera	216
TSA	Atbara	36

Similarly, expected annual flood damages of transport infrastructure are calculated based on the normalized flood damages for transport infrastructure. Table 3-9 shows the normalized expected annual flood damages on transport infrastructure [USD/km/year] in the flood hotspots.

Table 3-9 Expected annual flood damages of transport infrastructure [USD/km/year] in the flood hotspots

Basin	Hotspot	USD/km/year
BAS	Gambela	366
BAS	Itang	256
BAS	Pibor	50
BAS	Akobo	423
BAS	Nasir	277
BAS	Malakal	1,634
BN	El Roseires	10,346
BN	Singa & Suki	14,522
BN	Wad Medani	8,460
BN	El Masudiya Khartoum	4,388
LT	Gumara	1,630
LT	Ribb	707
LT	Megech	780
LT	Dirma	207
TSA	Humera	310
TSA	Atbara	1,079

Expected annual flood damages of buildings distinguished by different building use types (1) Infrastructure, (2) Non-residential Building, (3) Open Space, and (4) Residential Building, as well as the total are calculated. Table 3-10 summarizes this result.

Table 3-10 Expected annual flood damages of buildings [Thousand USD/year] in the flood hotspots

Basin	Hotspot	Total	Land Use Type			
			Infrastructure	Non-residential Building	Open Space	Residential Building
BAS	Gambela	981	13	317	253	397
BAS	Itang	119	3			117
BAS	Pibor	86		12		74
BAS	Akobo	654		221		434
BAS	Nasir	294		19		275
BAS	Malakal	3,552	31	965		2,557
BN	El Roseires	3,782				3,782
BN	Singa & Suki	15,444		7		15,437
BN	Wad Medani	133,788				133,788
BN	El Masudiya Khartoum	320,041		2,016		318,025
LT	Gumara	12,606				12,606
LT	Ribb	8,674				8,674
LT	Megech	2,011				2,011
LT	Dirma	936				936
TSA	Humera	137				137
TSA	Atbara	202,061		213		201,847

The following outlier is noticeable: In Gambela, high flood damages on “infrastructure”, “non-residential buildings” and “open space” are concentrated on few objects. The reason for this is the following: (1) the flood affected infrastructure is the bridge over the Baro River, (2) the flood affected non-residential building is the stadium, and (3) the flood affected open space is the bus-station.

3.3 Directly Affected Residential Population

The directly affected residential population by floods in the flood hotspots is documented as number of people.

Table 3-11 Directly affected residential population in the inundated areas

Basin	Hotspot	Return Period						
		2	5	10	50	100	200	500
BAS	Gambela	712	1,266	1,601	2,303	2,564	2,905	3,342
BAS	Itang	874	964	1,066	1,159	1,263	1,347	1,428
BAS	Pibor	144	249	382	2,693	6,763	15,542	38,686
BAS	Akobo	1,058	1,252	1,266	1,836	2,875	4,036	4,883
BAS	Nasir	37,143	49,865	57,736	75,215	81,045	87,517	93,200
BAS	Malakal	2,579	2,601	2,641	2,693	2,695	2,698	2,711
BN	El Roseires	1,915	2,903	3,528	4,136	4,360	4,463	4,752
BN	Singa & Suki	5,529	12,478	16,824	22,078	23,477	24,789	25,990
BN	Wad Medani	28,251	60,401	80,079	111,182	120,956	128,578	135,671
BN	El Masudiya Khartoum	34,841	74,994	106,453	194,901	236,471	281,644	311,449
LT	Gumara	14,764	15,971	16,767	17,982	18,967	19,123	19,550
LT	Ribb	23,104	24,410	25,023	27,128	27,887	28,189	28,778
LT	Megech	5,854	6,176	7,300	7,802	8,190	8,569	9,687
LT	Dirma	3,063	3,477	3,755	4,012	4,096	4,132	4,215
TSA	Humera	52	84	141	365	553	743	993
TSA	Atbara	79,438	90,921	97,239	117,124	123,508	130,616	139,673

3.4 Analysis and Interpretation Summary

Jointly analysing the results, shows the following on the flood risks in the flood hotspots:

1. A significant part of the flood risk in the flood hotspots is on residential buildings. The few exceptions are plausible. The outlier in Gambela – one “infrastructure” object, one “open space” object, three “infrastructure” objects – reflects that the bridge over the Baro River, the stadium, and the bus-station are affected by floods.
2. Flood damages of agricultural land and transport infrastructure are documented per hectare and kilometre respectively. This is important not to distort the damage proportions. Both normalized flood damage costs are plausible.
3. Directly affected population vis-à-vis exposed residential buildings reflects to some extent population density in the flood affected areas. The ratio of affected population and exposed residential buildings is high in Nasir, medium in Itang and Pibor, and it declines in Gambela with increasing return period (in simple words: more people live near the river than further away from the river).
4. The flood exposure of buildings for the different flood return periods compared with the number of buildings exposed for a 2-year return flood event shows the following:
    a. In wide flood plains people “live with and in the floods” (in Itang, Akobo, Nasir, and Malakal, and to a higher extent in all hotspots in the Tana basin).
    b. In larger communities/settlements (on Blue Nile and in Atbara City at the confluence of Atbara and the Nile) buildings are built further away from flood plains of lower return periods - as far the topography allows (and possibly constrained by urban development pressures).
    c. The flood effects of lower return period floods in Pibor and Humera are rather low. One can assume that settlement patterns are adapted to experiences with floods – having at the same time few constraints related to topography and urban development pressures.

4 Conclusion

This report shows the flood risks of 16 selected flood hotspots in the river basins (1) Baro-Akobo-Sobat, (2) Blue Nile, (3) Lake Tana, and (4) Tekeze-Setit-Atbara. The flood risks are assessed for the following flood hotspots:

1. Gambela (Baro-Akobo-Sobat Basin)
2. Itang (Baro-Akobo-Sobat Basin)
3. Pibor (Baro-Akobo-Sobat Basin)
4. Akobo (Baro-Akobo-Sobat Basin)
5. Nasir (Baro-Akobo-Sobat Basin)
6. Malakal (Baro-Akobo-Sobat Basin)
7. El Roseires (Blue Nile Basin)
8. Singa & Suki (Blue Nile Basin)

9. Wad Medani (Blue Nile Basin)
10. El Masudiya Khartoum (Blue Nile Basin)
11. Gumara (Lake Tana Basin)
12. Ribb (Lake Tana Basin)
13. Megech (Lake Tana Basin)
14. Dirma (Lake Tana Basin)
15. Humera (Tekeze-Setit-Atbara Basin)
16. Atbara (Tekeze-Setit-Atbara Basin)

The flood risks were calculated on the following basis:

1. Comprehensive **2D hydrodynamic** model simulations for 7 flood return periods, which in turn were calculated based on **hydrological and statistical** analyses.
2. Flood **exposure analysis** based on compilation of land uses in the flood hotspots: The compilation of the land uses is partly based on inputs from a separate consultancy: Work Package 1 (Survey and Data Collection). Gaps in this context have been filled with public domain data on land use and building inventories. The flood exposure analysis shows what type of asset/building would be affected by floods with different return periods to what extent and where.
3. Flood **damage analysis** based on statistical **flood vulnerability functions** with project specific adjustments and **economic valuations** of assets in the region based on publicly available country **statistics**: The flood damage analysis localizes and quantifies damages of the different types of assets/buildings that would result from floods with different return periods.
4. **Flood risk** is represented as **expected annual flood damage** (EAD). This indicator considers that infrequent flood events (e.g. 500-year return period) lead to high damages and frequent events (e.g. 2-year return period) rather lead to relatively lower damages. On this basis, it represents an average annual damage. The EAD analysis also distinguishes between different land use types and shows the spatial distribution of flood risk for each flood hotspot.

The flood risk analysis for the 16 selected flood hotpots shows that residential houses are mostly affected by floods. This, to some extent, reflects the respective local socio-economic structures of the communities. The geospatial analyses also show that valuable assets are mainly located in areas that are rarely flooded (located at higher elevations). This is essentially the case for flood hotspots in the Baro-Akobo-Sobat basin - there seems to be an inherent flood awareness in the respective communities.