PARADeS

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

Modelling Theory & Application

Photos by NADMO

www.parades.info

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Module objectives

1. Explaining the brief basics of the modelling theory
2. Enable audience to pick up the current modelling approach
3. Inform about the data sources input and assumptions of the presented models
4. Brainstorm about the development of measures and the usage of modelling techniques

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Structure of Module 2

Model Theory and Application

Module objectives

Modelling theory and literature sources

Examples: PARADeS models for Odaw, Aboabo & White Volta

Outlook

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Modelling Theory & Application

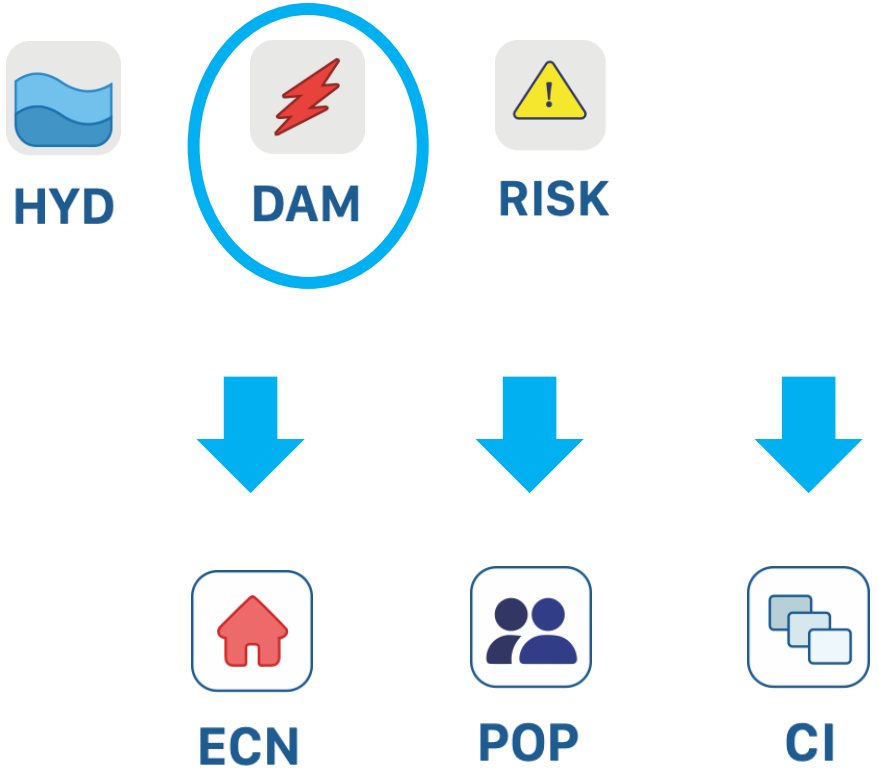
ProMaIDes Framework

PARADeS

ProMaIDes

Protection Measures against Inundation Decision Support

Free download and documentation:
www.promaides.h2.de



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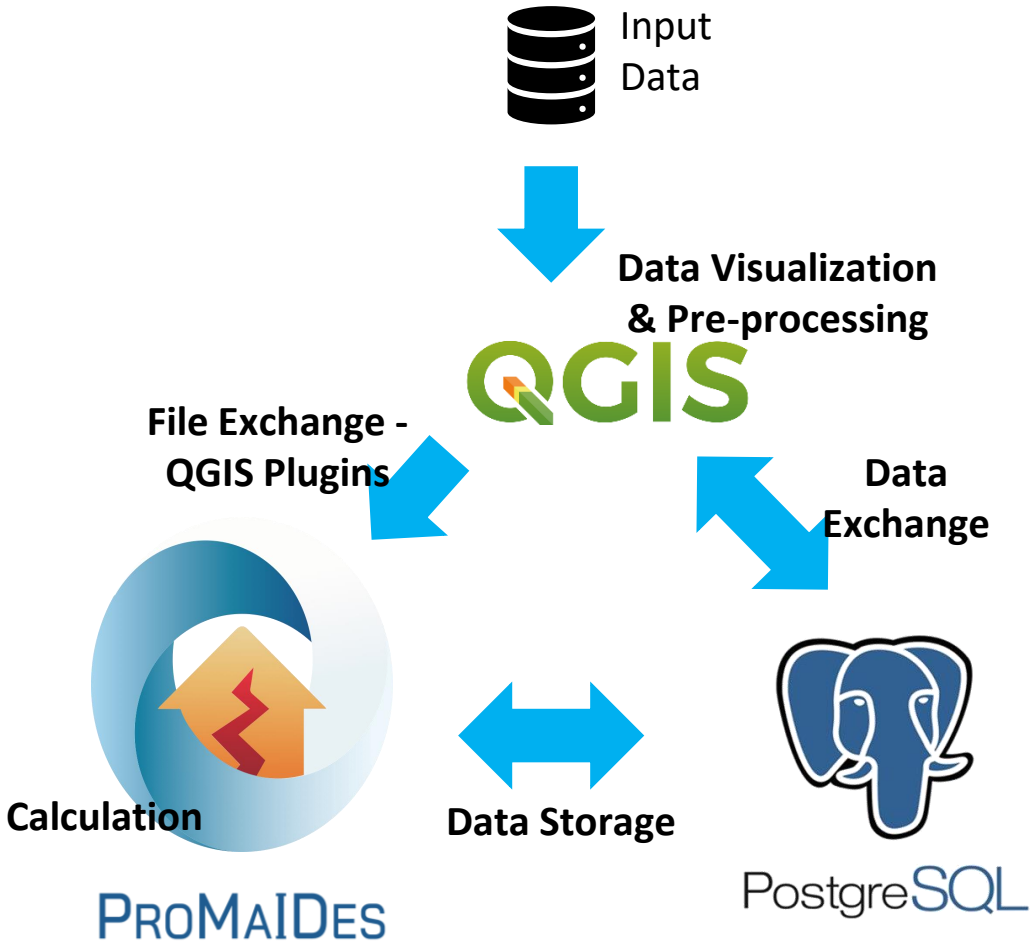
Modelling Theory & Application

ProMaIDes Architecture

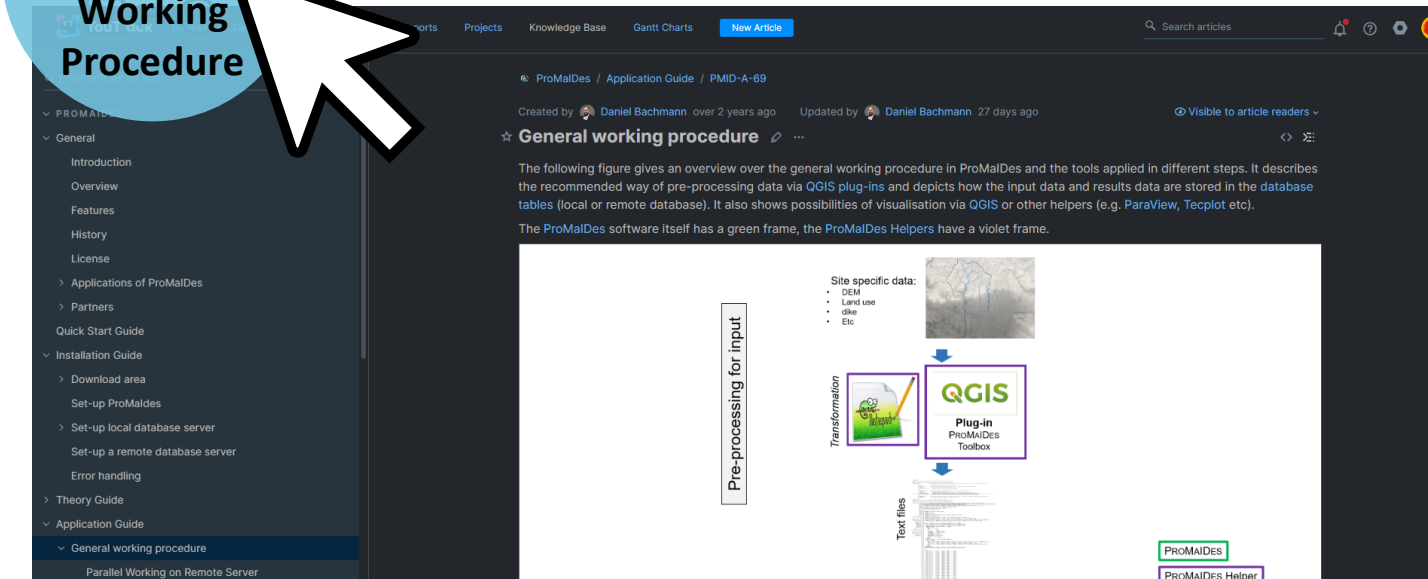


More information needed?

All items in circles are clickable and lead to a documentation page with further explanation.

Quick Start Guide

General Working Procedure



Modelling Theory & Application

HYD Hydraulic Modelling

Data & Preprocessing

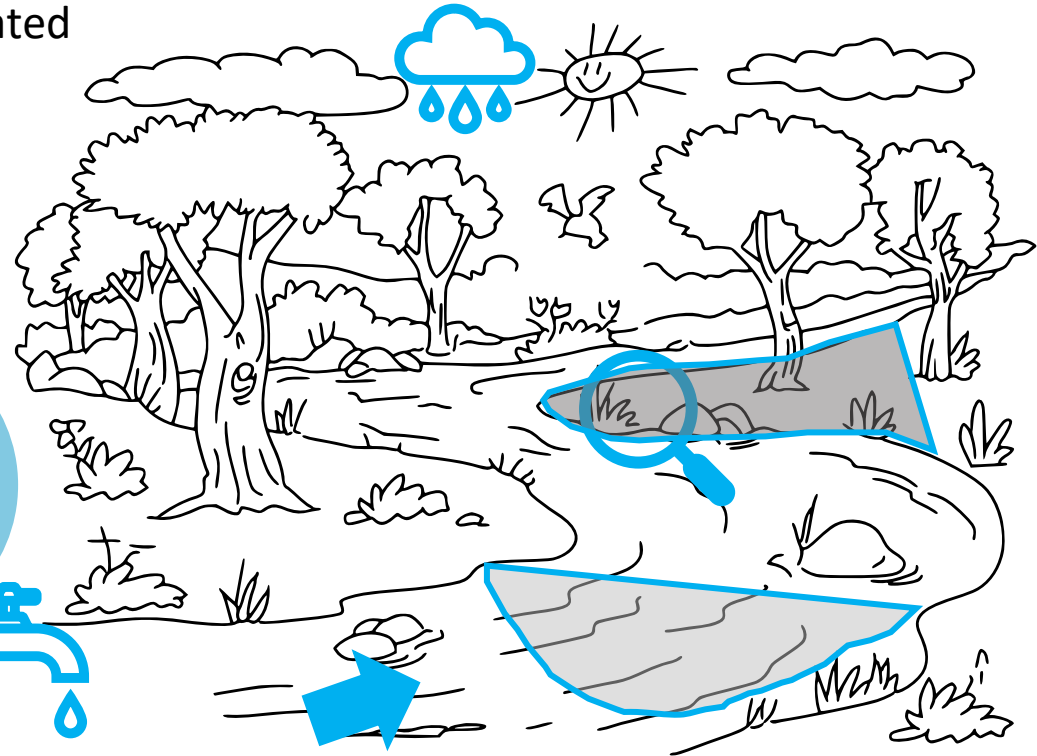
- Digital elevation model
- Surface roughness
- River main channel and tributaries
- Precipitation & discharge data including return periods
- Validation data

Model Input

- Calculation specifications (Cooking recipe)
- 1- dimensional Model Part – River profiles
- 2-dimensional Model Part - “Raster Files” for the inundated area
- Roughness files
- Boundary condition

Model Output

- Inundation maps
- Water depth and flow velocities



HYD Input Files

HYD Theory

HYD Application

HYD QGIS Plugins

Modelling Theory & Application

DAM Damage Modelling

ECN Economic Damages

Combination of land-use/ land-cover data and flood depth damage curves leads to direct economic damages

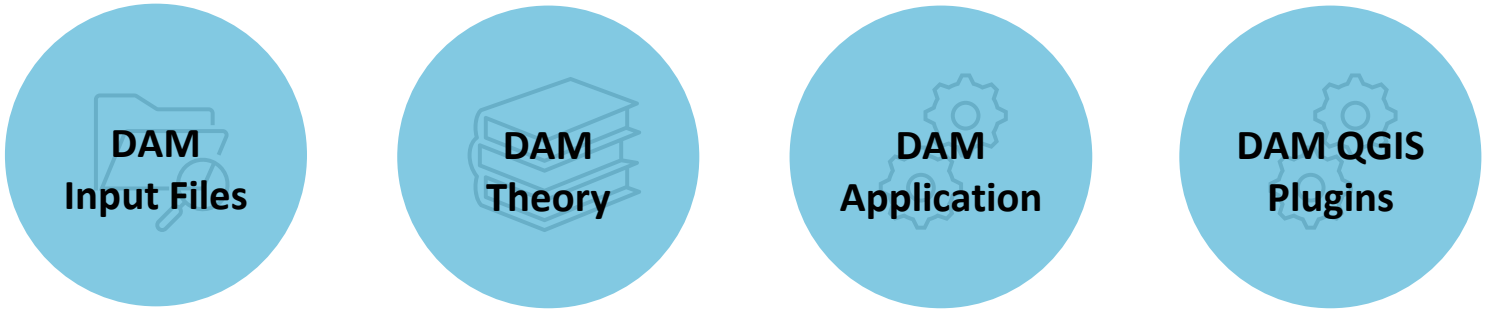
POP Population Affected & Endangered

Deriving all people with a contact to water

Concept of danger zones from Jonkmann derives number of Endangered People

CI Critical Infrastructure Service Disruptions

Considering the disruption of critical infrastructures and the potential cascading effects



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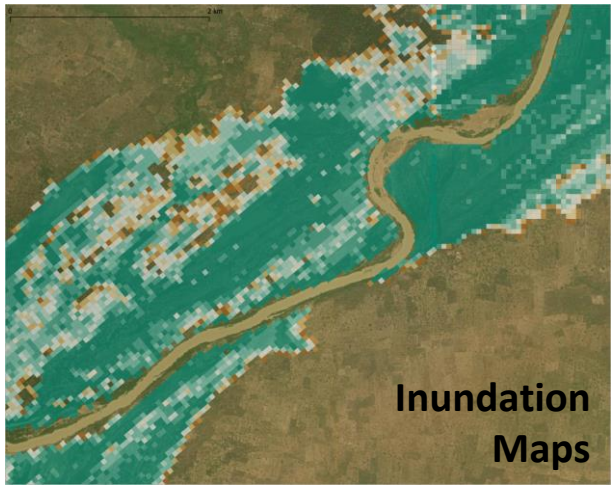
Modelling Theory & Application

DAM Economic Damage Modelling

PARADeS

Approach:

ECN



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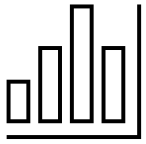

Flood-depth-damage-curves

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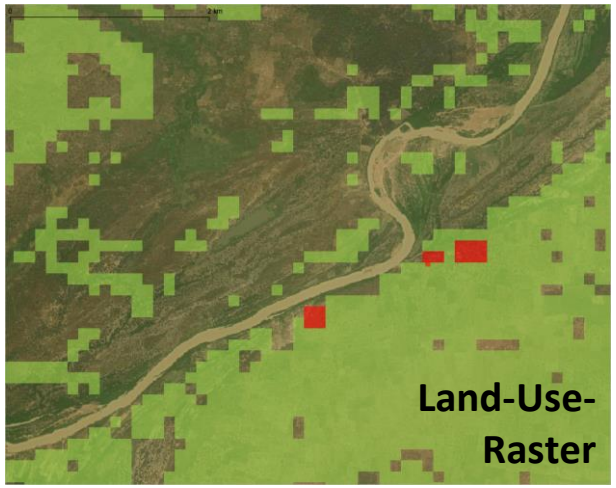

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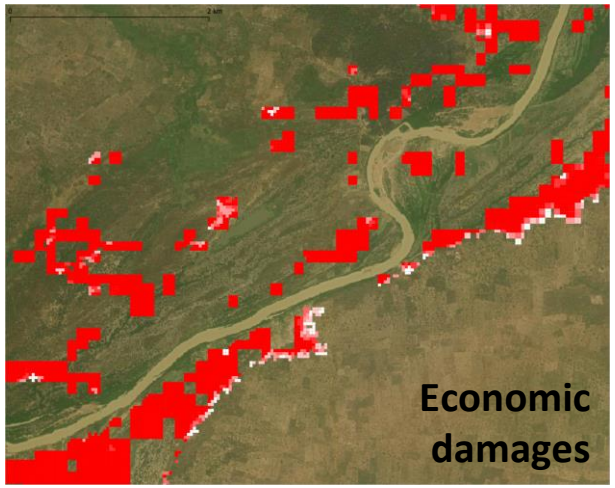

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Modelling Theory & Application

DAM

Economic Damage Modelling

ECN

Data & Preprocessing

- Land usage or coverage data
- Economic maximum value for usage or coverage type (a)
- Differentiation of mobile and immobile damages (b)
- Flood-depth-damage curves

Model Input

- “Raster Files” covering the area of inundation
- “Land Use Category File” combining (a) and (b)

Model Output

- Economic damage rasters (mobile, immobile, total)
- Absolute values of economic damages

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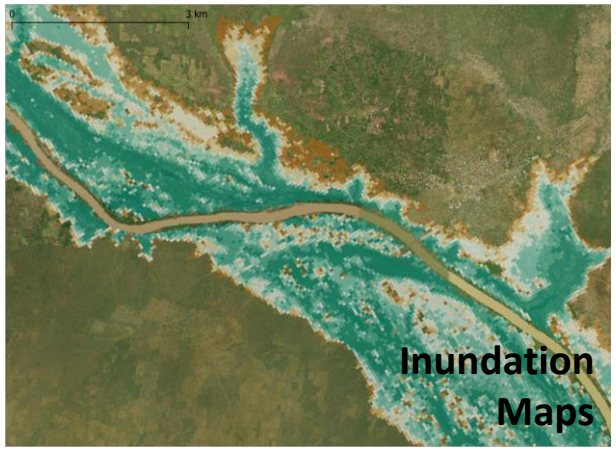
Modelling Theory & Application

DAM

Consequences for Population

POP

Approach:



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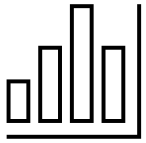

Flood-depth-damage-curves

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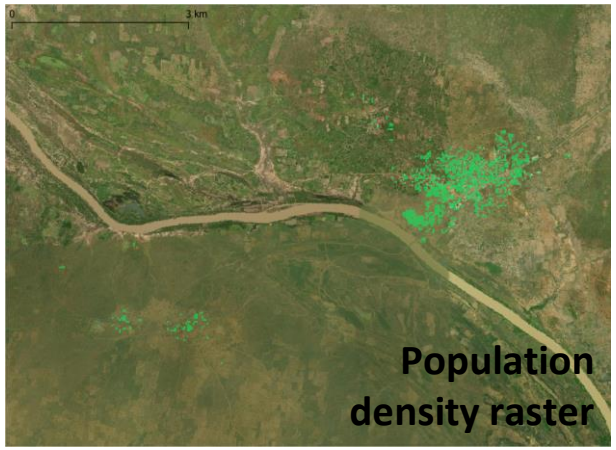

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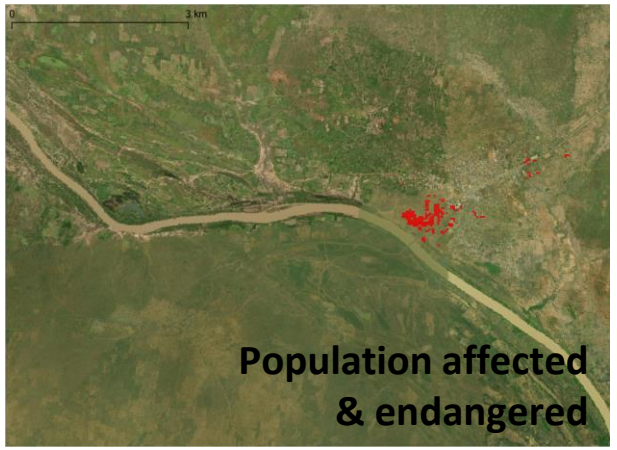

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Modelling Theory & Application

DAM

Consequences for Population

POP

QGIS

Data & Preprocessing

- Population density data
- Vulnerability categorisation for affected and endangered people

Model Input

- “Raster Files” covering the area of inundation
- “Vulnerability category file”

Model Output

- Rasters for population affected & endangered (Zone 1, 2, 3)
- Absolute numbers of people

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Modelling Theory & Application

DAM

Critical Infrastructure Disruption

CI

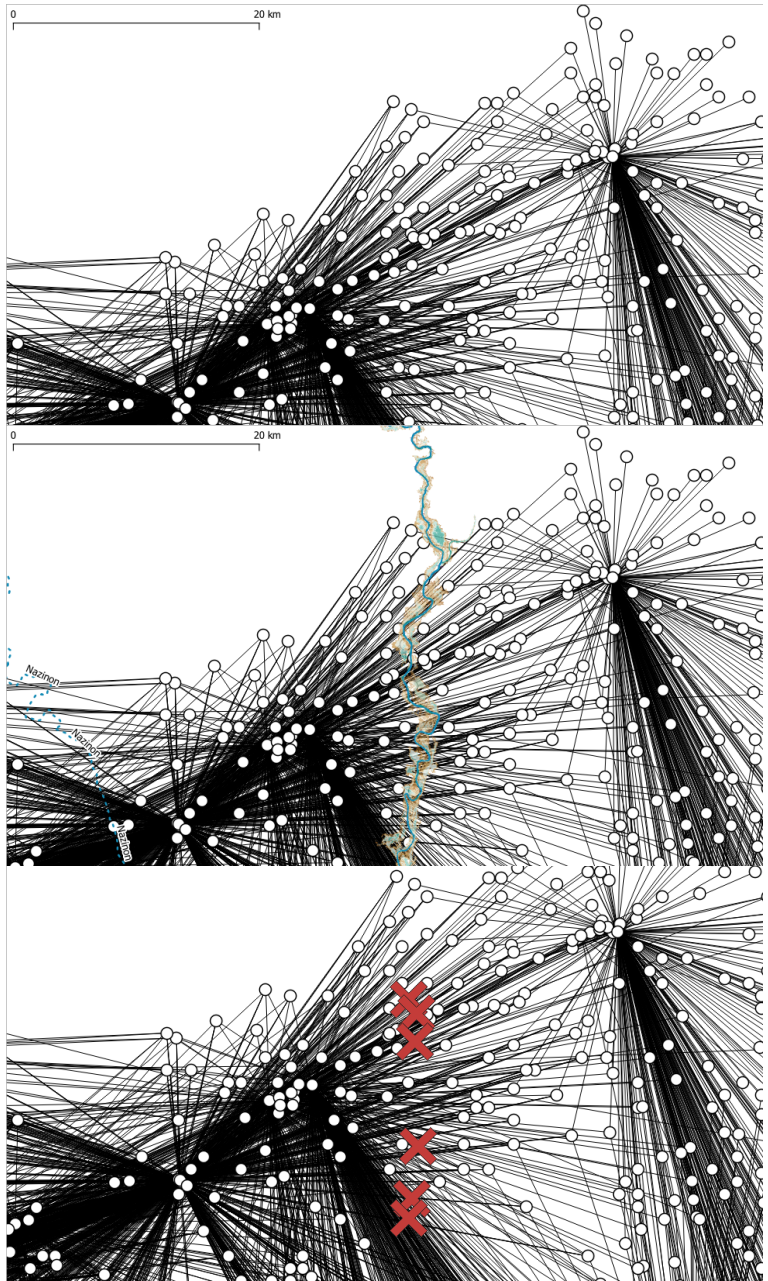
Approach:

Network represented by three types of CI - Elements

	CI – Element	Description	Example Sector: Electricity	Example Sector: Info Tec	Example Sector: Health Services
	Points	Punctual CI structures	Transformators, power plants	Transmitting towers	Hospitals, nursing home
	Connectors	Connections in between CI structures, services and users	physical, logical, geographical, cyber interdependency		
	Polygon	Coverage areas for CI services	Electricity costumers	mobile phone users	hospital catchment area, patients

CIN Theory

Publication CI & FRM



PARADeS

Point-, Polygon-, Connector-Elements are assembled to a network

+

Hydraulic model results

=

Disrupted critical infrastructures

Modelling Theory & Application

DAM

Critical Infrastructure Disruption

CI

Data & Preprocessing

- CI elements and attributes (e.g. locations, reconstruction time, water level thresholds)
- CI dependencies within and outside of sectors
- CI service users

QGIS

Model Input

- “CI Point Files”
- “CI Polygon Files”
- “CI Connector Files”

Model Output

- Quantification of cascading effects → Number of users disrupted
- Areas of service disruptions
- CI elements with high cascade potential and vulnerability

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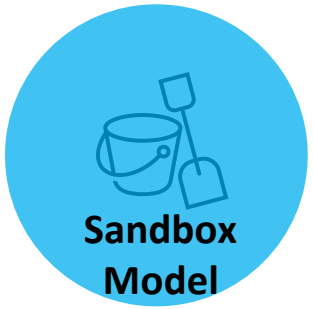
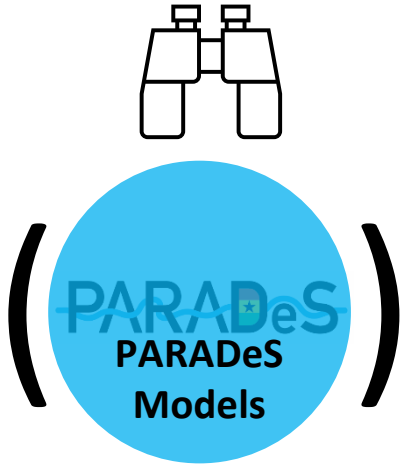
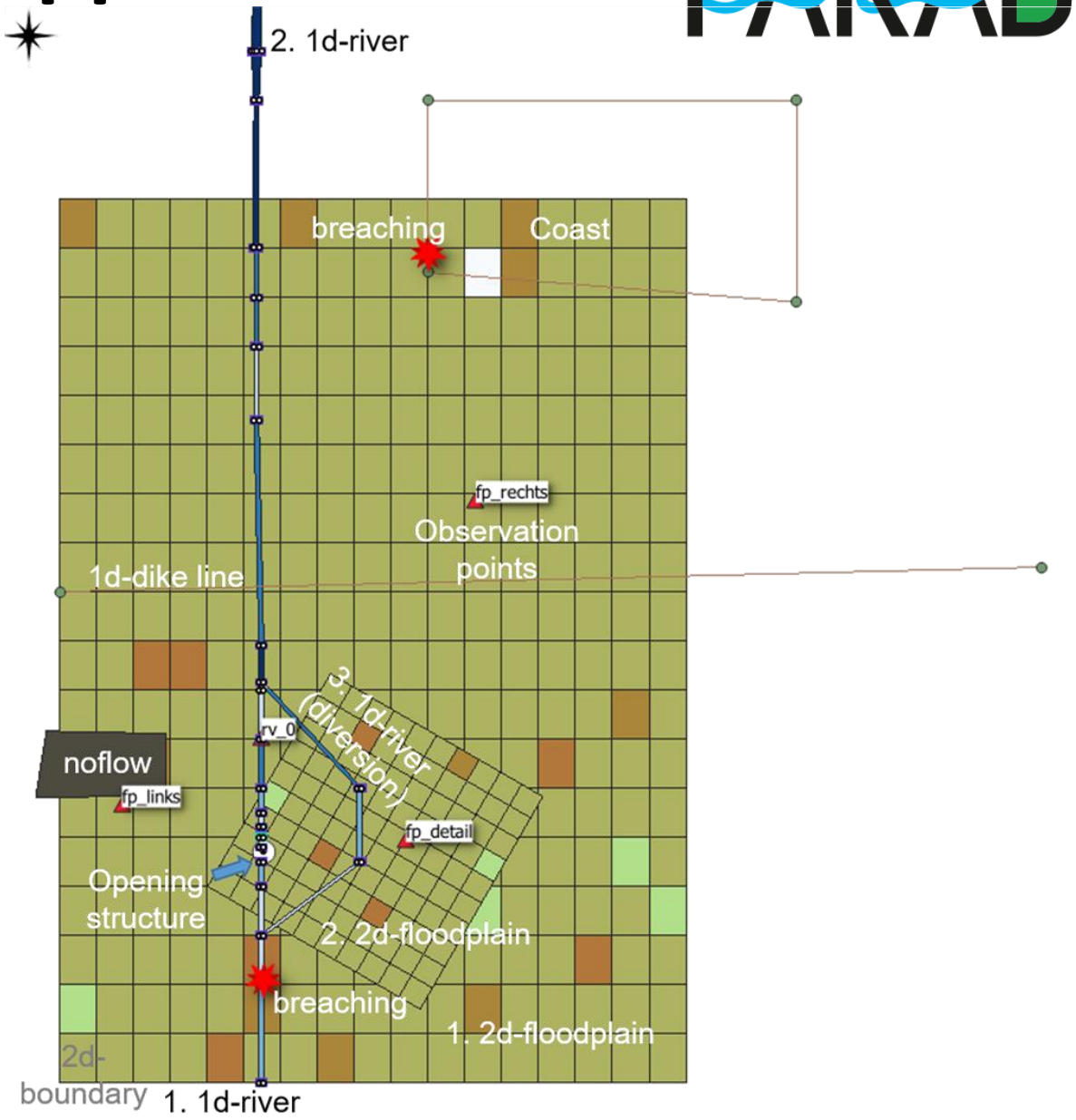
Modelling Theory & Application

Sandbox Model

- Simple model that encapsules all possible model variations on the smallest scale possible.
- Used for testing and learning purposes
- Example files for sandbox model as well as big scale models available







Structure of Module 2

Model Theory and Application

Module objectives

Modelling theory and literature sources

Examples: PARADeS models

Outlook

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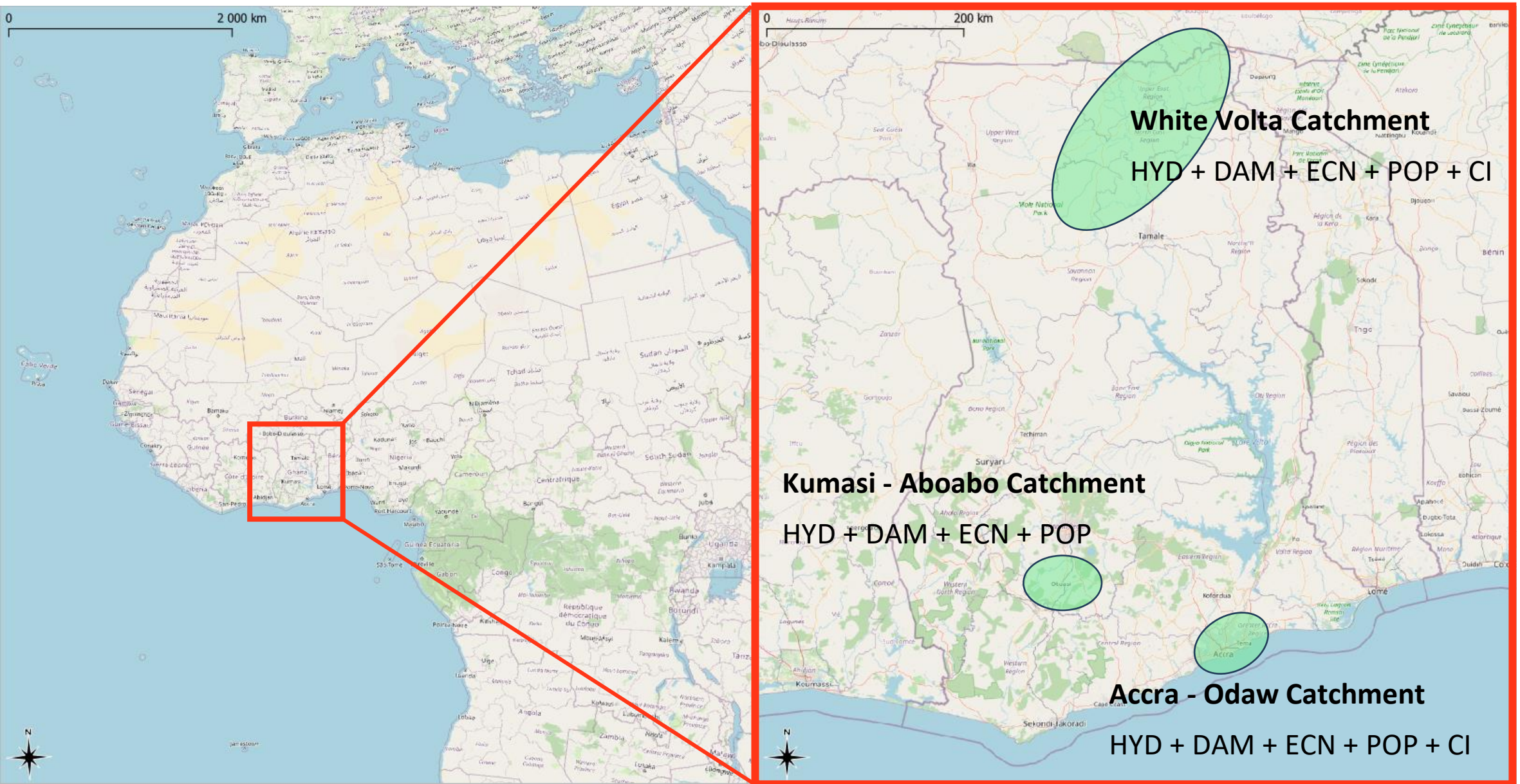
Examples - PARADeS Models



Structure of Module 2

Model Theory and Application

Module objectives

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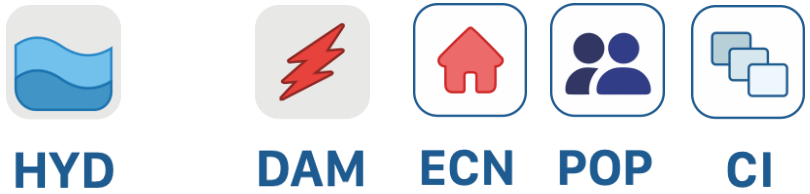
Examples: PARADeS models

White Volta:



Outlook

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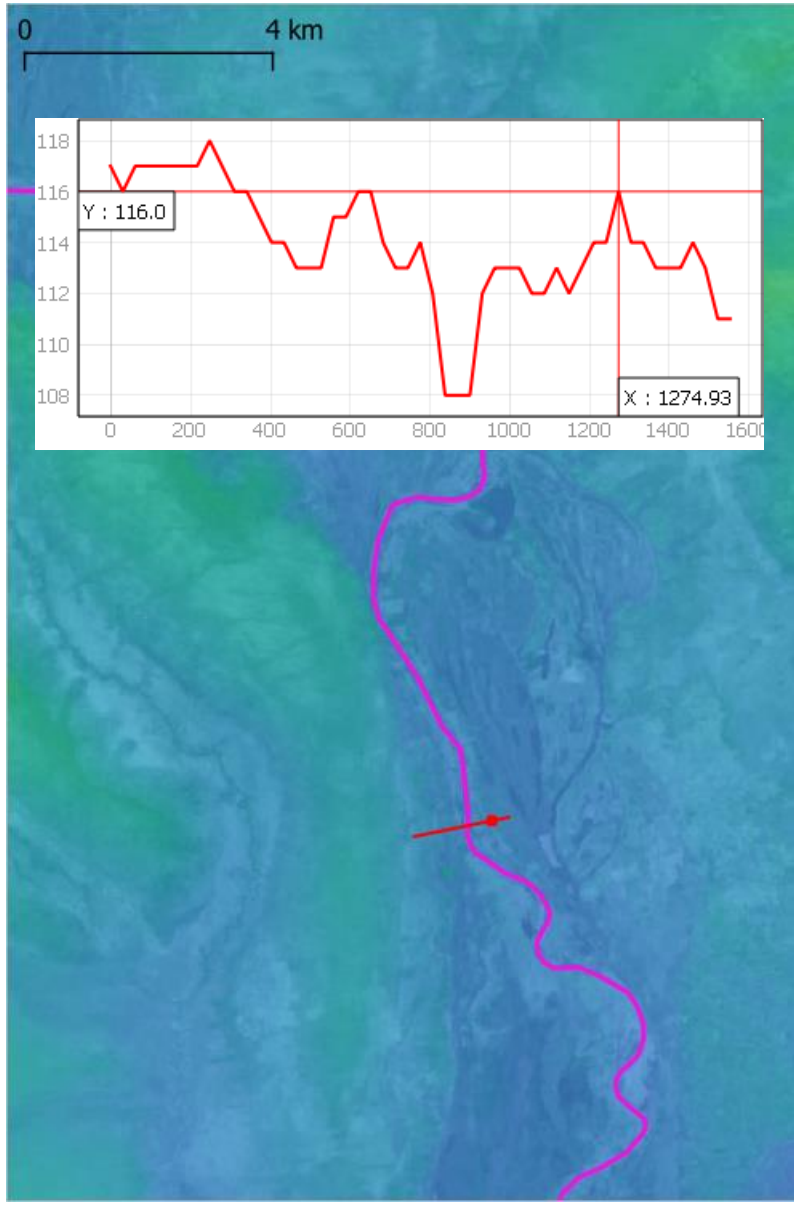
Examples - PARADeS Models

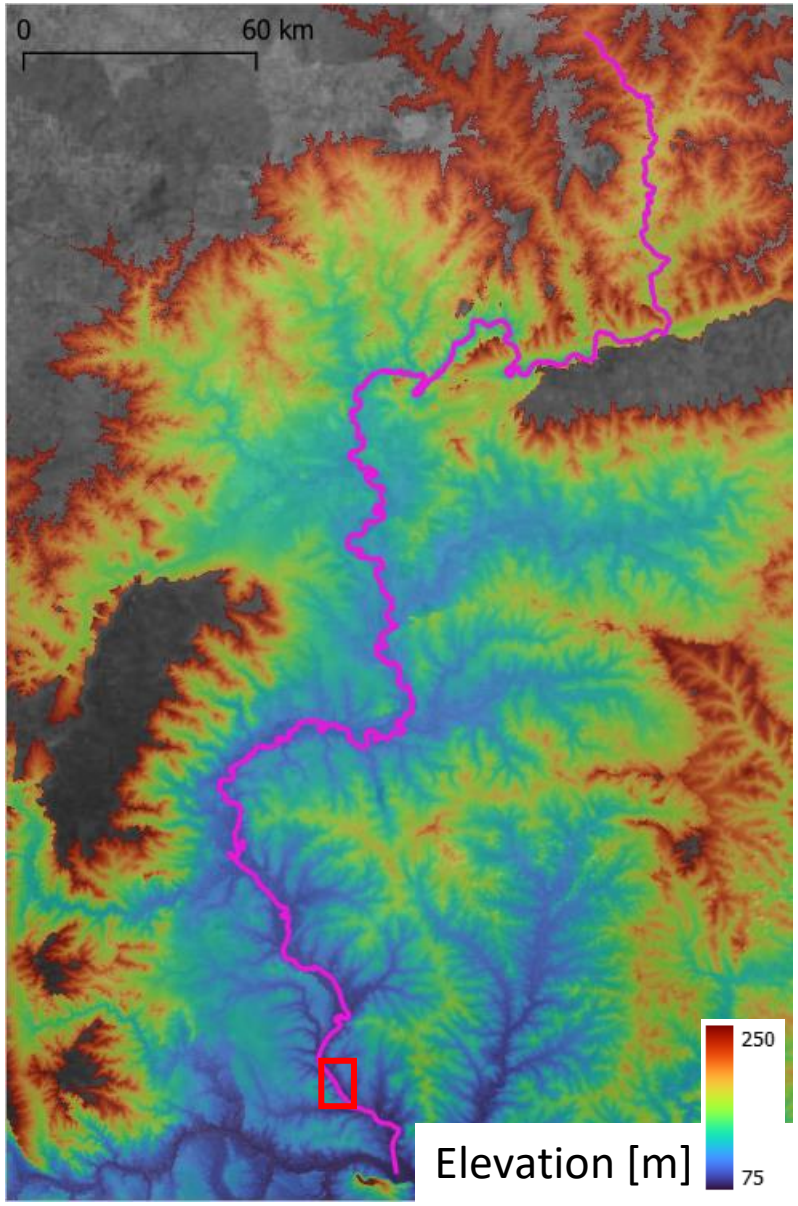
White Volta

HYD

Input and Data

- Digital elevation model (DEM): TandemX 30 m
- ~ 660km main river channel





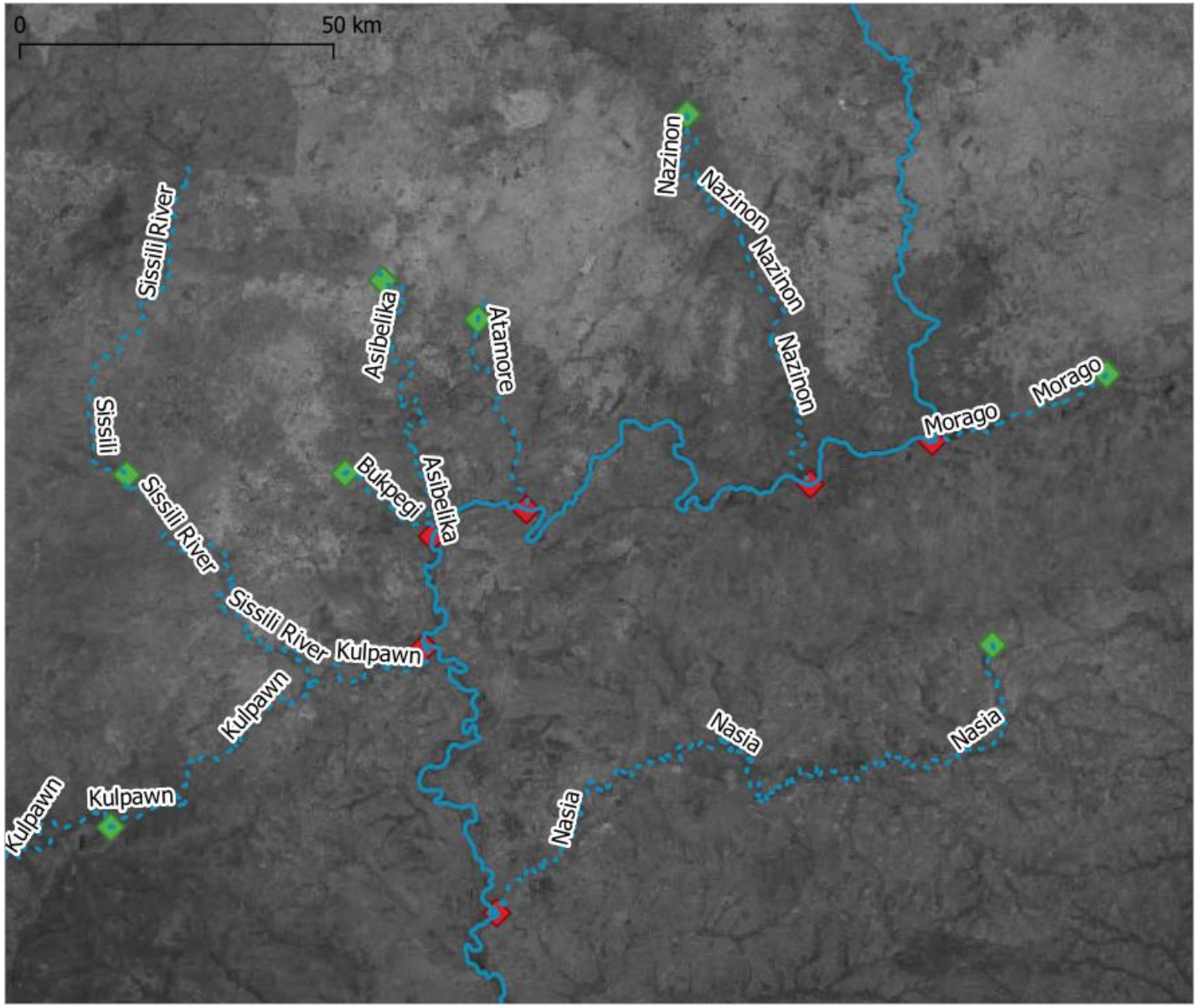
Examples - PARADeS Models

White Volta

HYD

Input and Data

- Digital elevation model (DEM): TandemX 30 m
- Discharges from hydrological model for Bagre Dam and 8 tributaries



Examples - PARADeS Models

White Volta

HYD

Input and Data

- Digital elevation model (DEM): TandemX 30 m
- Discharges from hydrological model for Bagre Dam and 8 tributaries

Uncertainties

- No validation
- 30 m resolution DEM affects resolution of profiles (100-400 m width)
- DEM's are static
- Temporal staggering of outflows
- Details about the dam operation of Bagre Dam remain unknown
- 15 years of discharge data → T50 furthest extrapolation

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Examples - PARADeS Models

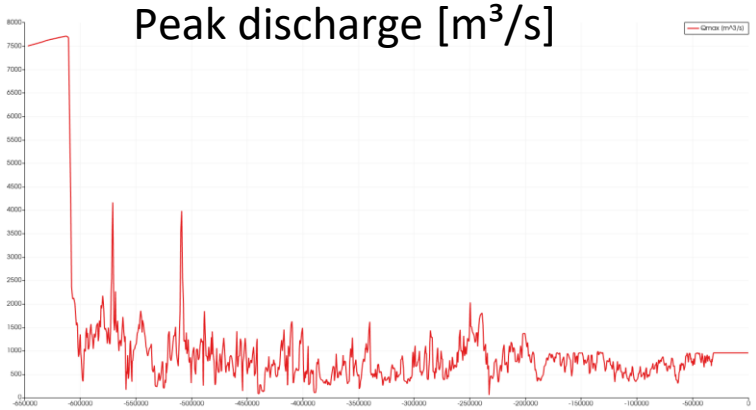
White Volta – Output: Results hydraulic models

HYD

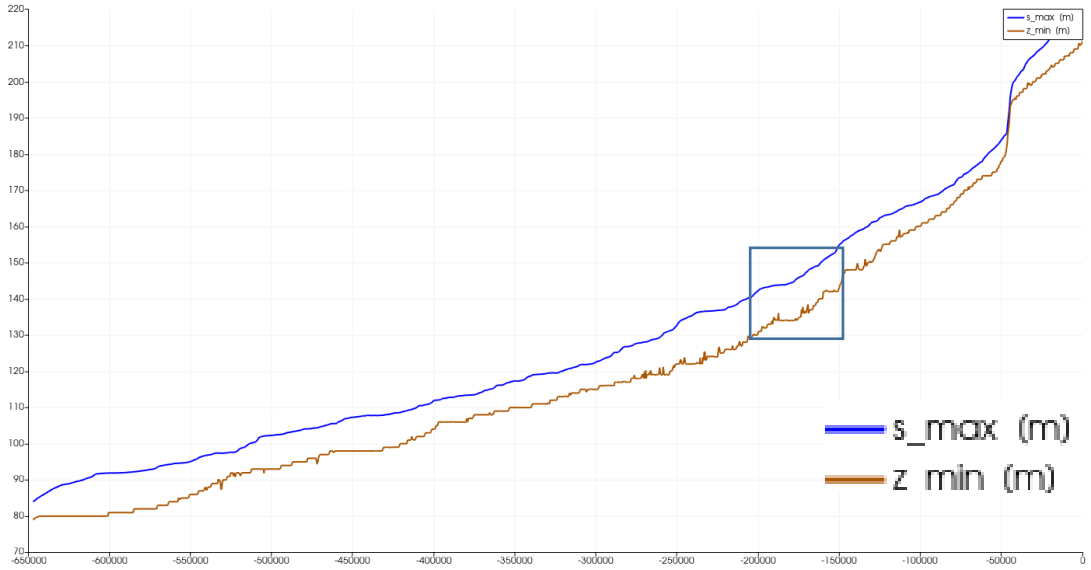
Output

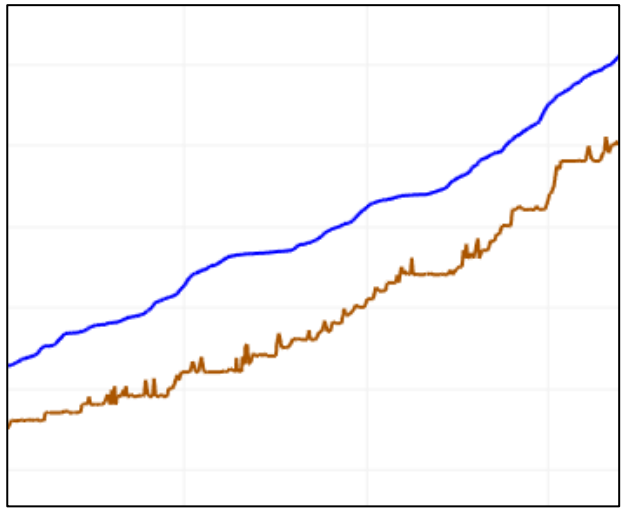
- *all Figures display a T50 return period

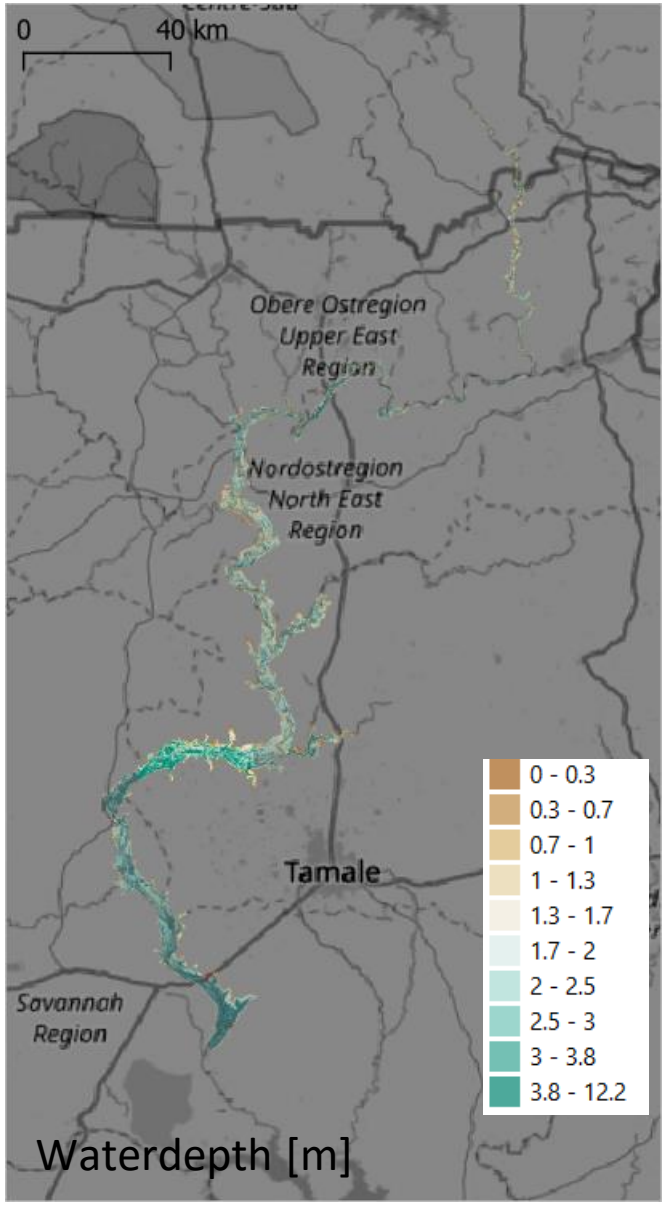
Peak discharge [m³/s]



Waterlevel (s_max) and groundlevel (z_min) of 1D model [m]





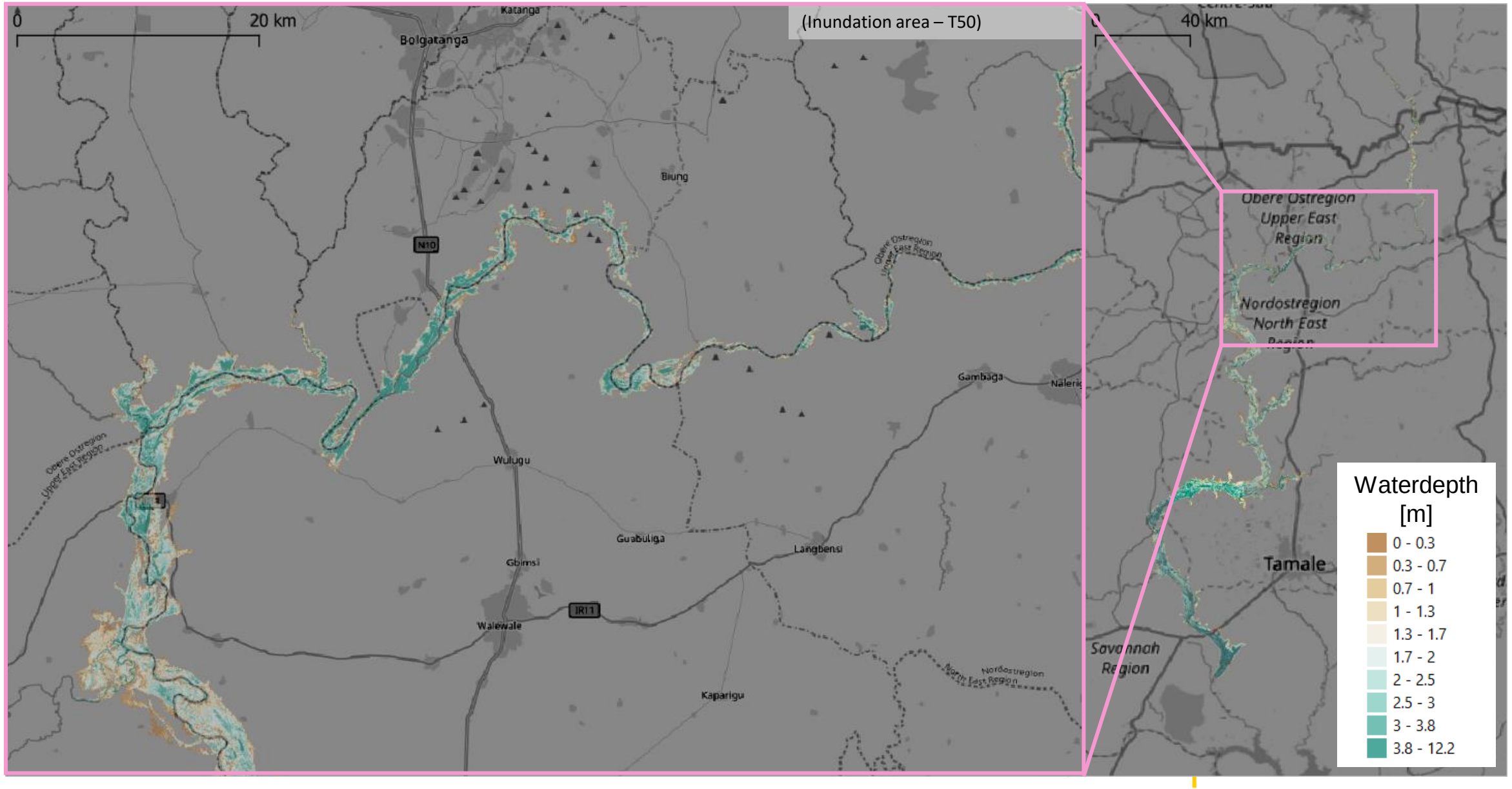


Waterdepth [m]

Examples - PARADeS Models

White Volta – Output: Results hydraulic models

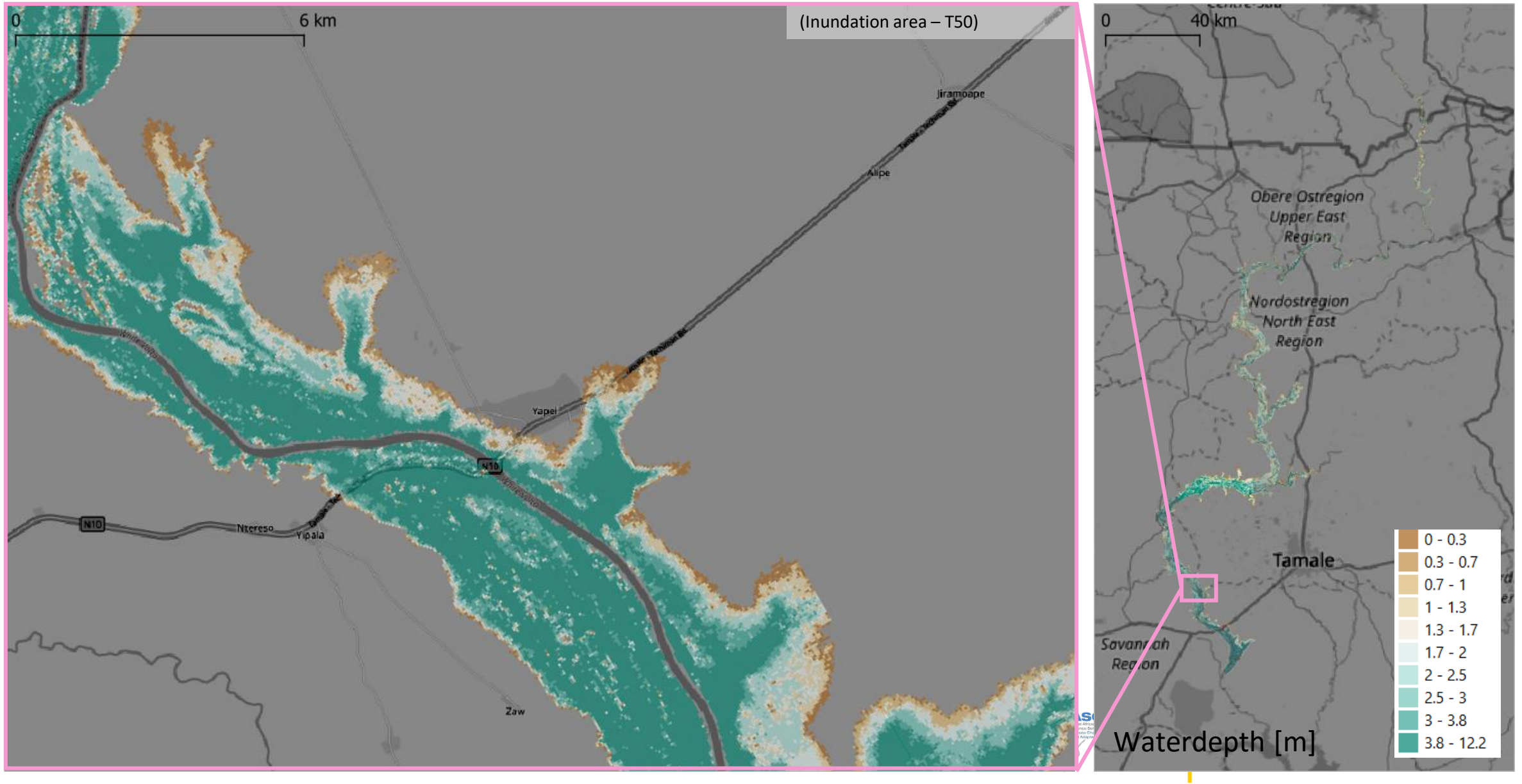
HYD



Examples - PARADeS Models

White Volta – Output: Results hydraulic models

HYD



Examples - PARADeS Models

White Volta

DAM

ECN

Input & Data

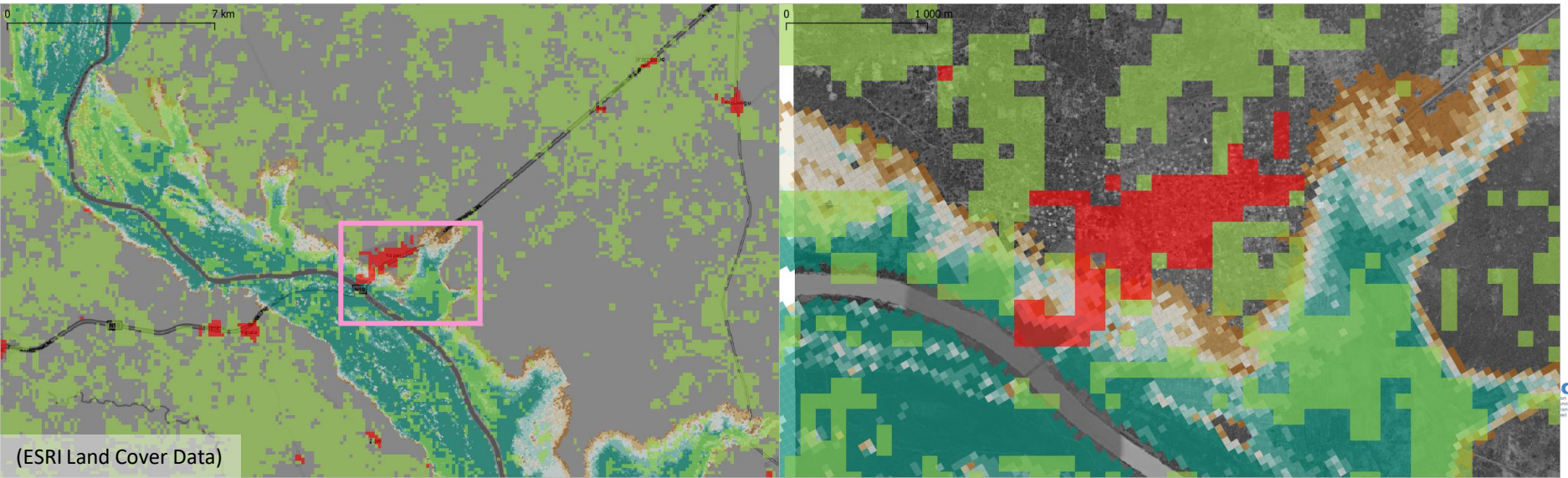
- Land Coverage Data: ESRI Satellite Data 30 m x 30 m
- Flood Depth Damage Curves & Absolute Damages

Uncertainties & Assumptions

- No validation of model results
- Absolute damage values from 2016
- Satellite Data from 2020

Output

- Economic damages: raster-based and absolute numbers
- In combination with hydrological return periods: Risk



(ESRI Land Cover Data)

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Examples - PARADeS Models

White Volta

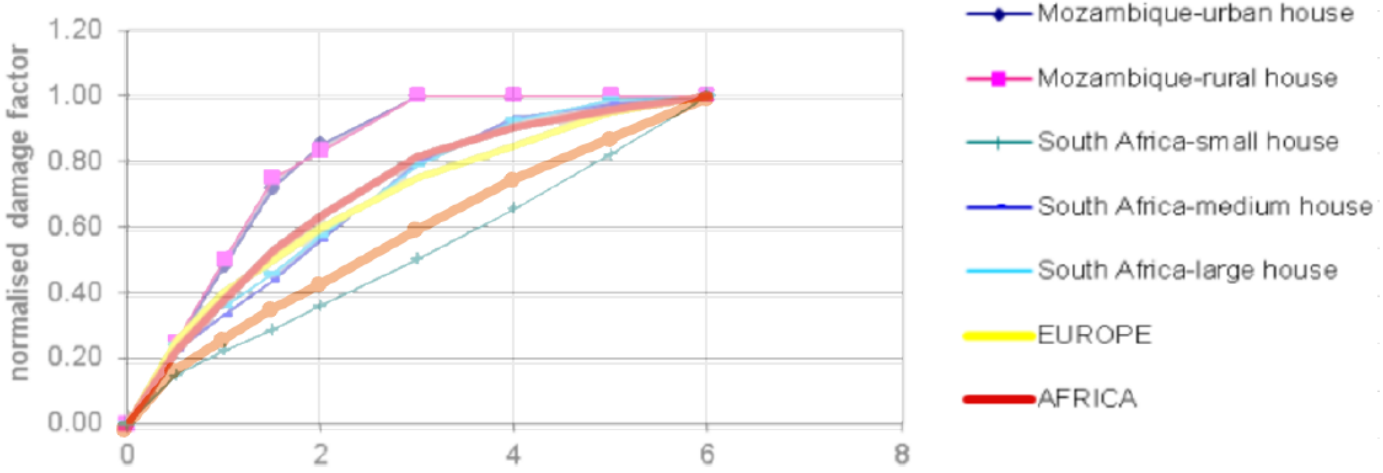
DAM

ECN

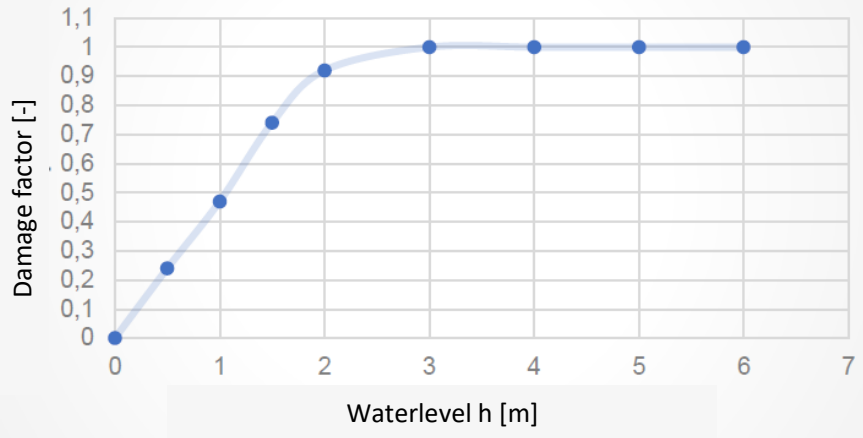
Flood Depth Damage Curves & Absolute Damages

- Urban (Build-up):
  Mobile - 96.25 USD/m²
  Immobile - 192.5 USD/m²
- Agricultural:
  Mobile - 0 USD/m²
  Immobile - 0.14 USD/m²

Flood Depth Damage Curve – Urban (Kutscher 2022)



Flood Depth Damage Curve – Agricultural (Kutscher 2022)

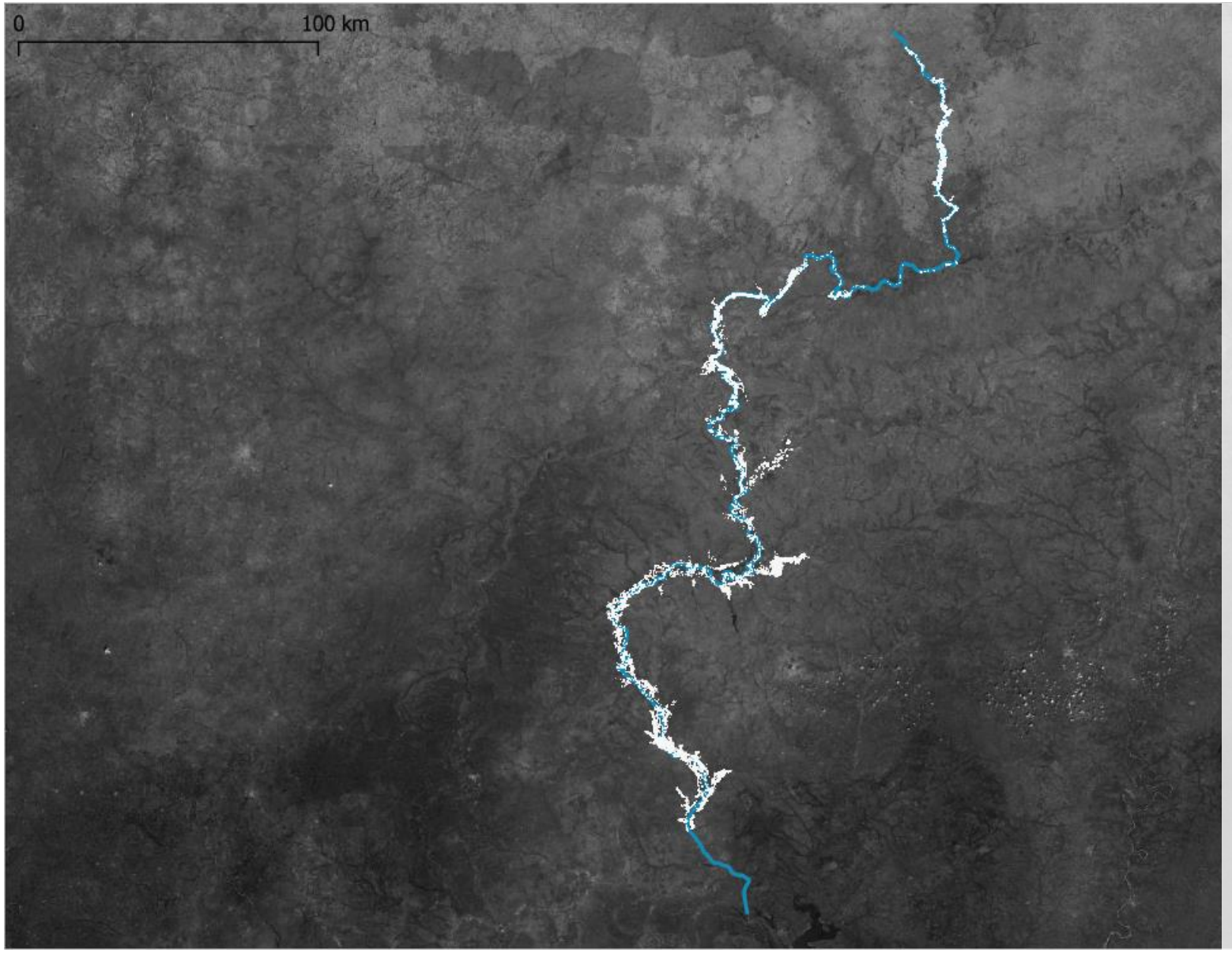


Examples - PARADeS Models

White Volta

DAM

ECN



Output

- Based on model output for a T50 event: Economic damages mainly on agricultural land
- ...

Economic Damage USD/cell [Number of Cells]

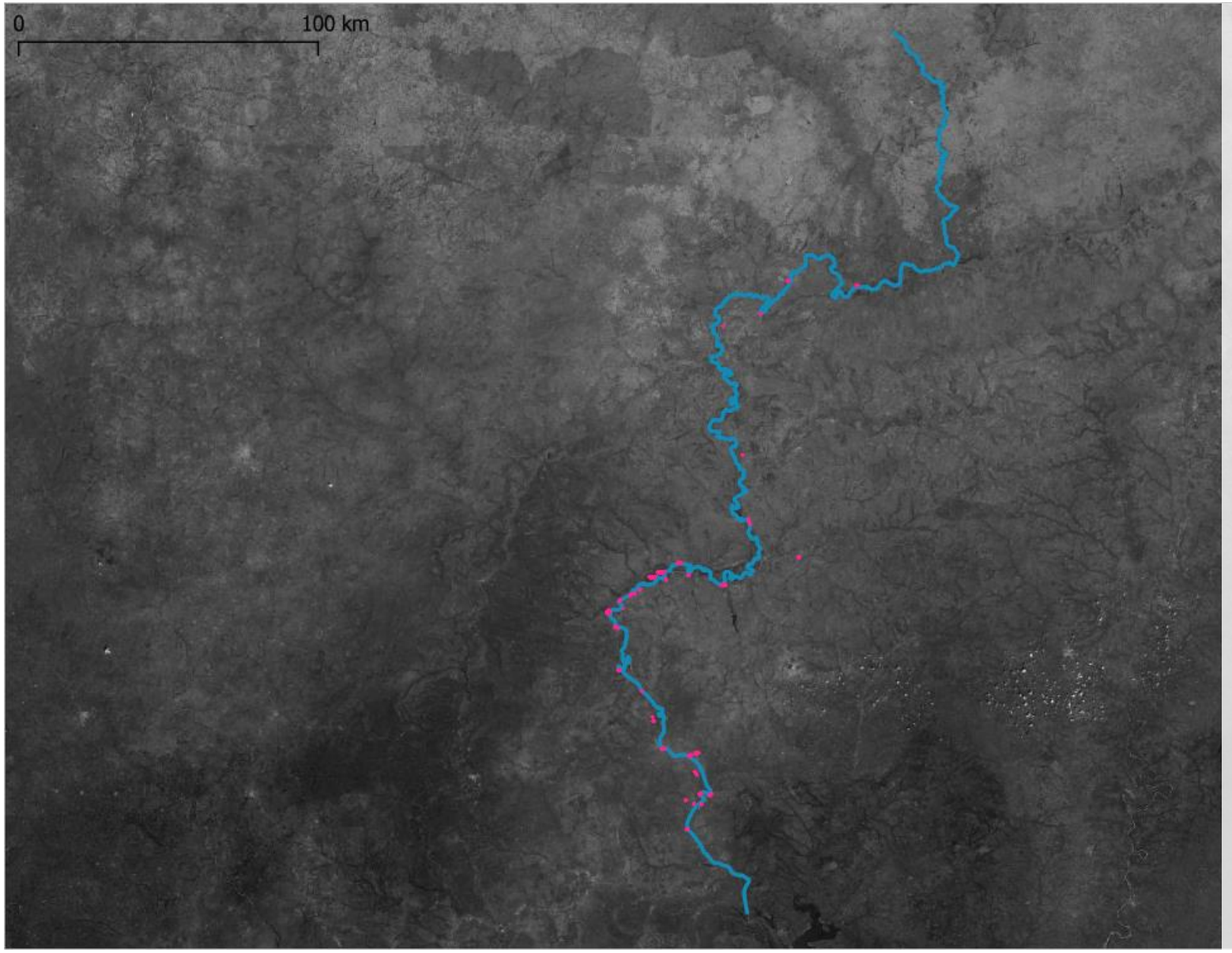
0 - 520 [1302468]
520 - 1040 [7462]
1040 - 1559 [700]
1559 - 2079 [586]
2079 - 2599 [948]

Examples - PARADeS Models

White Volta

DAM

ECN



Output

- Based on model output for a T50 event: Economic damages mainly on agricultural land
- → disabling of agriculturally affected cells results in a highlight of affected settlements

Economic Damage
USD/cell
[Number of Cells]

- ☐ 0 - 520 [1302468]
- ☑ 520 - 1040 [7462]
- ☑ 1040 - 1559 [700]
- ☑ 1559 - 2079 [586]
- ☑ 2079 - 2599 [948]

Examples - PARADeS Models

White Volta , Aboabo – Kumasi, Odaw - Accra

DAM

POP

Input & Data

- High resolution population density data – Meta - Data for Good
- Sensitivity Curves

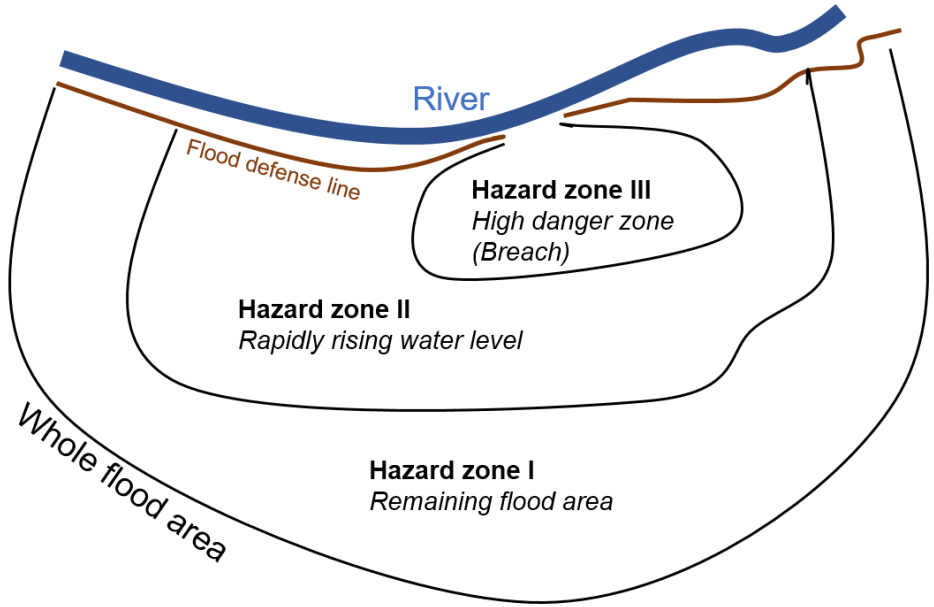
Uncertainties & Assumptions

- No validation of model results
- People are mobile and the numbers just estimates
- Satellite and census data from 2020
- No gender sensitivity

Output

- Population affected: raster-based and absolute numbers
- In combination with hydrological return periods: Risk

(Meta - Data for Good)



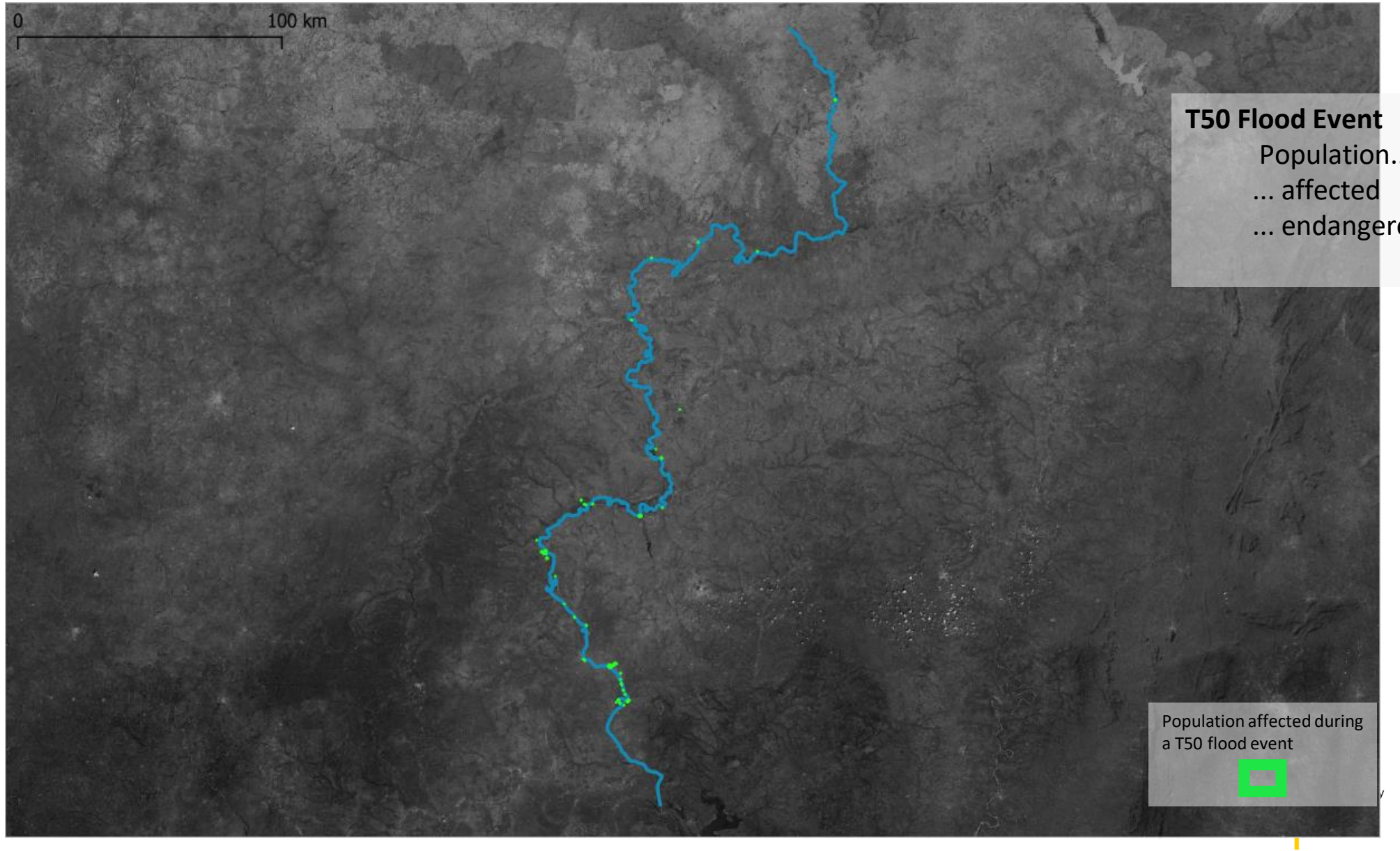
(Jonkmann, 2007)

Examples - PARADeS Models

White Volta

DAM

POP

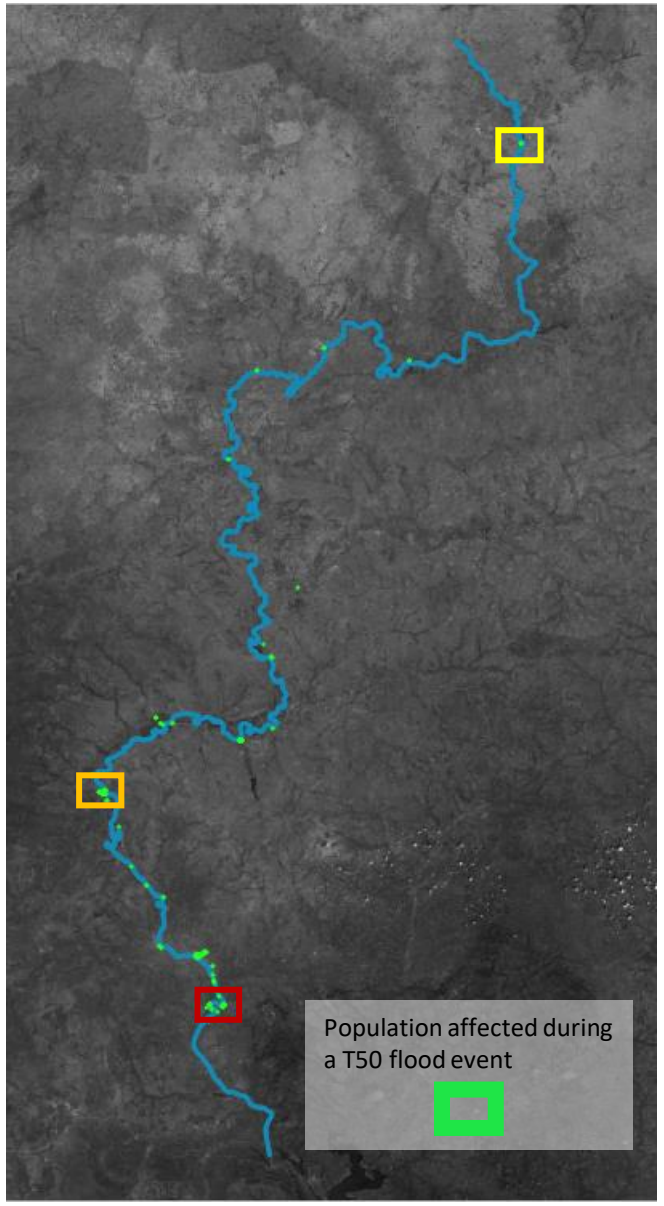


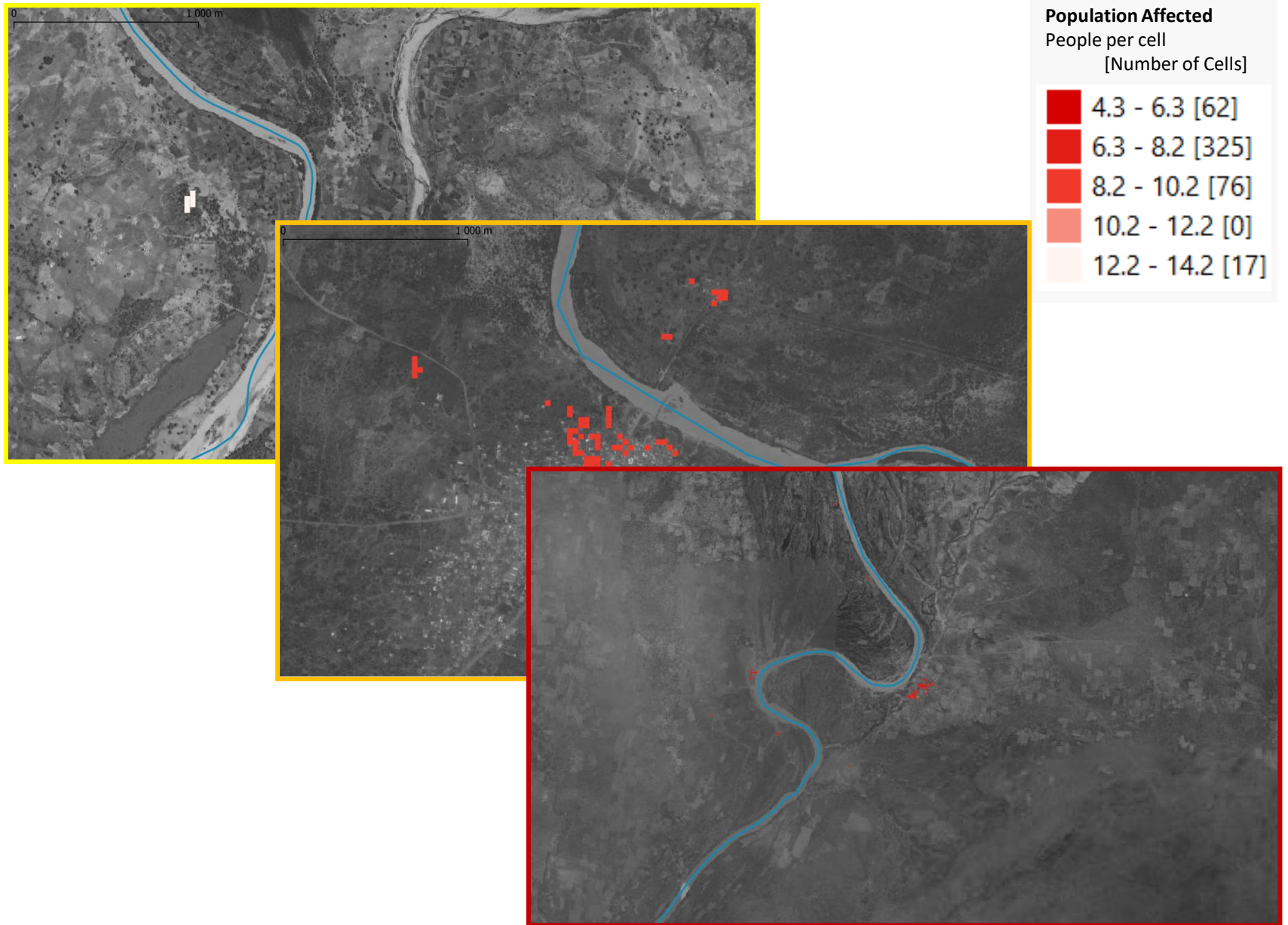
Examples - PARADeS Models

White Volta

DAM

POP



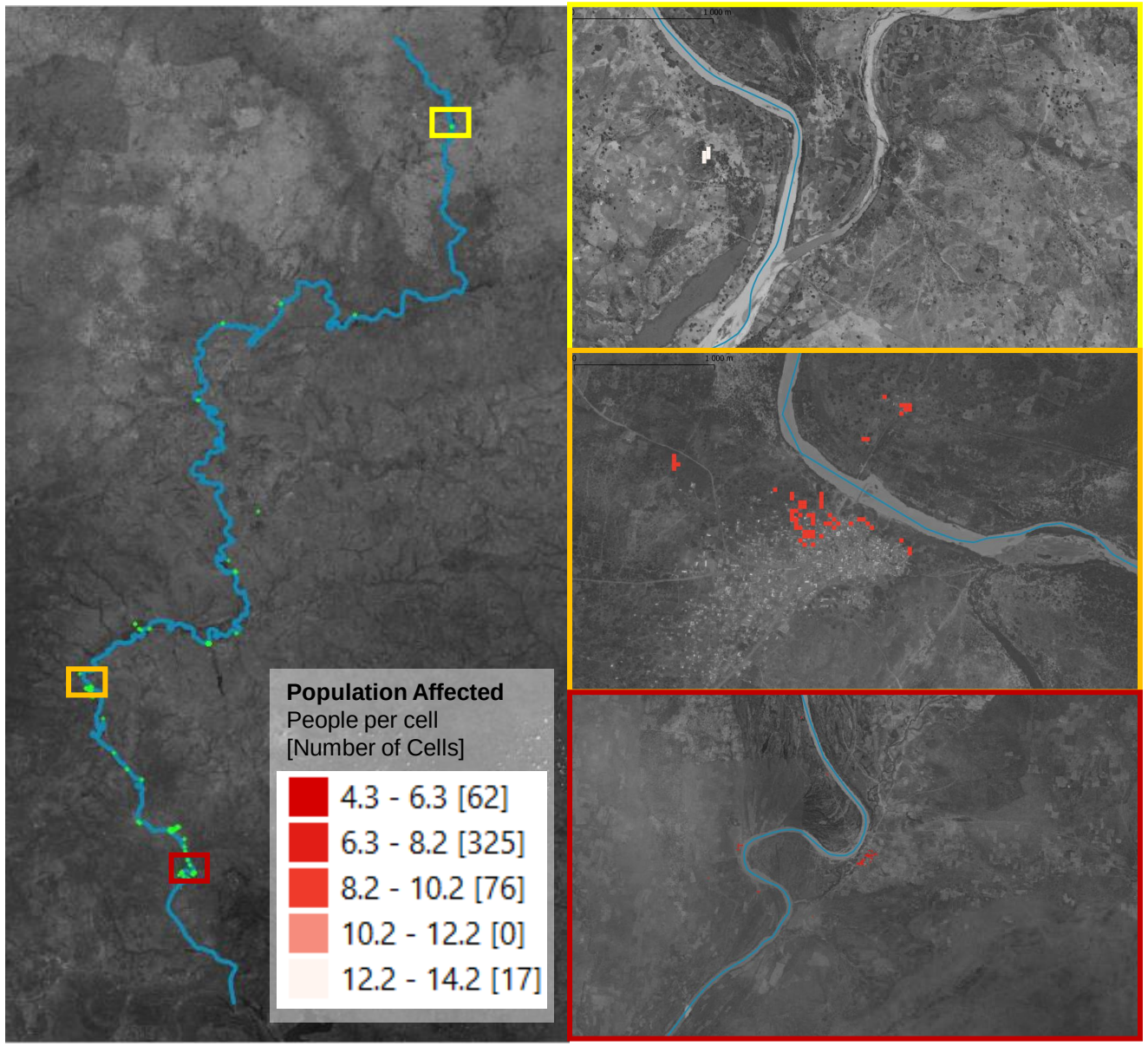


Examples - PARADeS Models

White Volta

DAM

POP



Examples - PARADeS Models

White Volta

DAM

CI

Input & Data

- Open Street Map Data
- Information about dependencies and CI characteristics – CI workshops
- Point elements 2989
  Polygon elements 2164
  Connector elements 26,676

Uncertainties & Assumptions

- No validation of model results
- Assumptions are made for the CI element attributes: Recovery time, water thresholds, CI users connected
- Dependencies are simplified

Output

- CI service disruption
- CI network metrics: Elements with a high cascade potential value
- In combination with hydrological return periods: Risk

(White Volta CIN Model)

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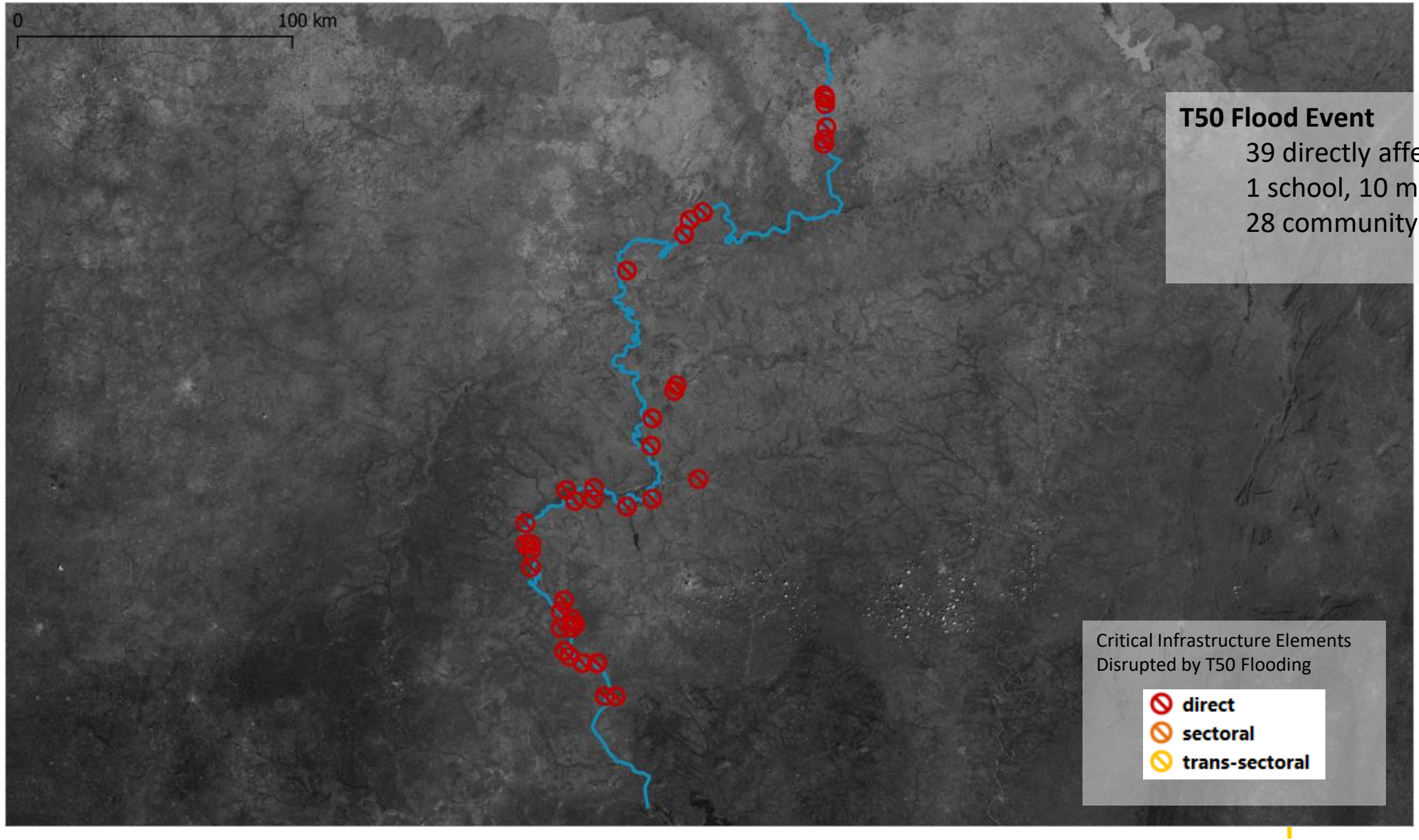
(Jonkmann, 2007)

Examples - PARADeS Models

White Volta

DAM

CI

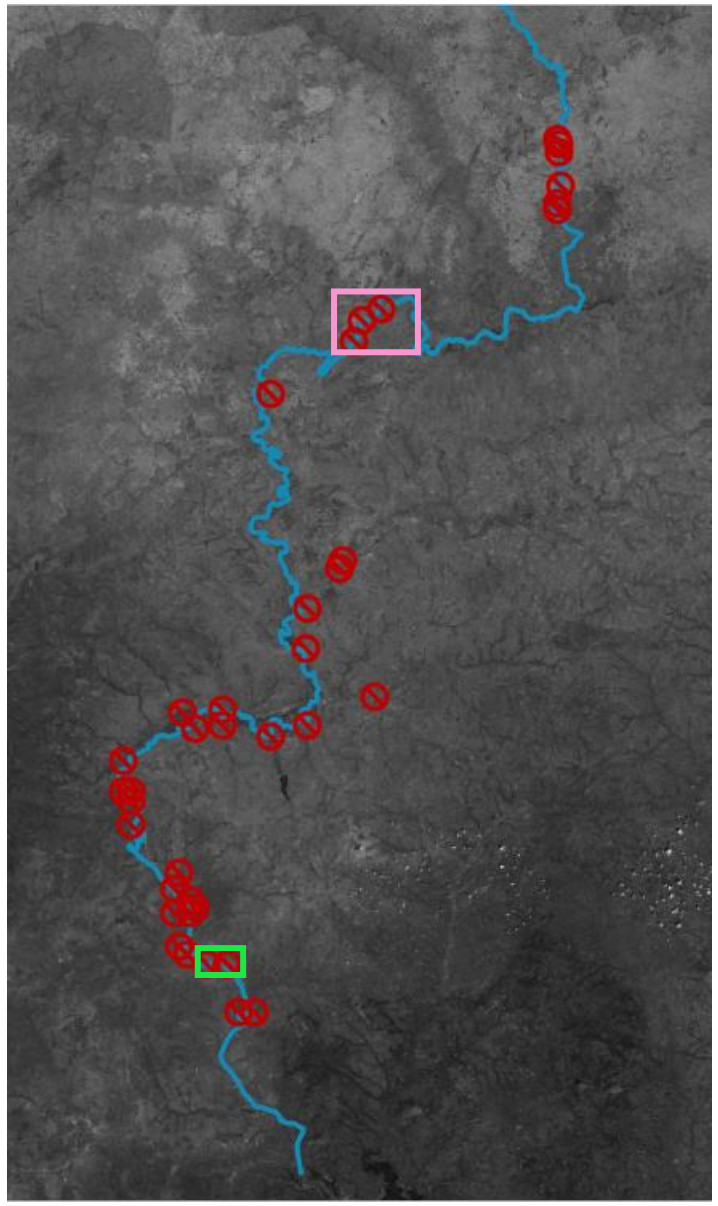


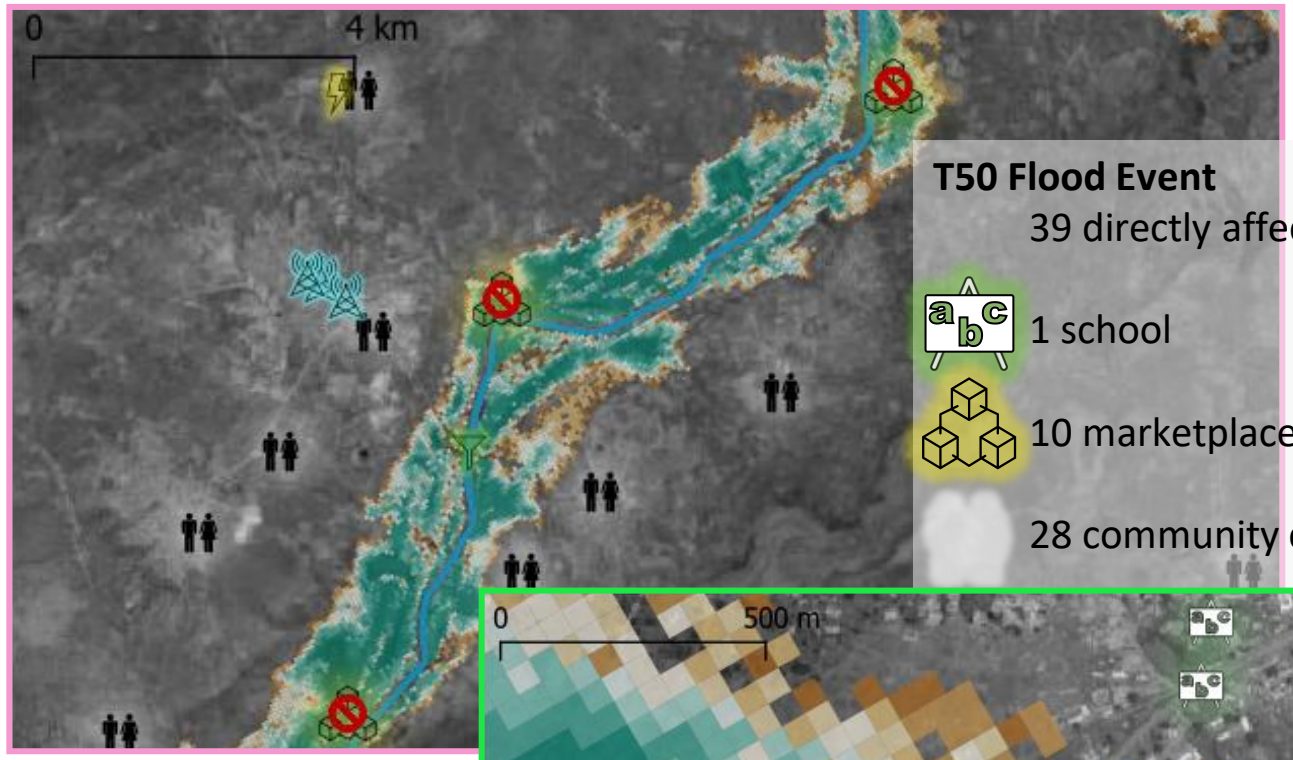
Examples - PARADeS Models

White Volta

DAM

CI





T50 Flood Event

39 directly affected:

1 school

10 marketplaces,

28 community cluster

Structure of Module 2

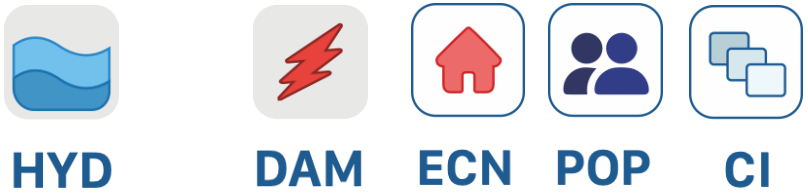
Model Theory and Application

Module objectives

Modelling theory and literature sources

Examples: PARADeS models

Kumasi - Aboabo:



Outlook

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Examples - PARADeS Models

Kumasi – Aboabo Catchment

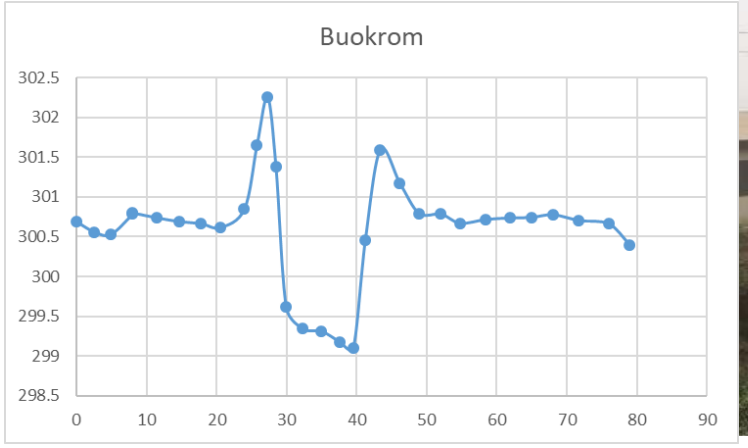
HYD

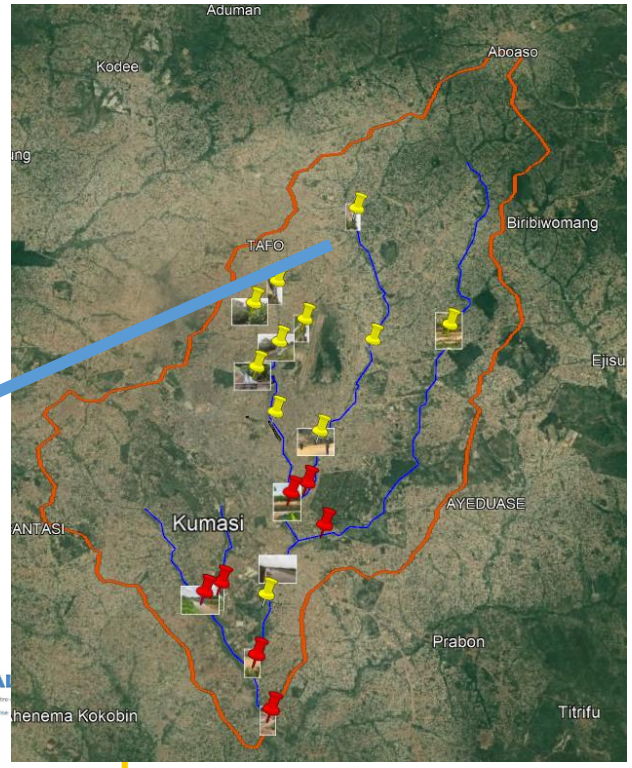
Input and Data

- Digital elevation model (DEM): TandemX 30 m
- Land-use: Copernicus GLS 30m (2018)
- Rainfall data from Kumasi airport: 1980-2021
- DEM derived cross-section manually corrected with measured cross-section: Aboabo main channel and 3 tributaries

Uncertainties

- Rainfall data is only available in 24hr sample → No flash floods captured
- No discharge and spatial data for validation
- Flood hotspot identification for plausibility does not capture all the areas affected.

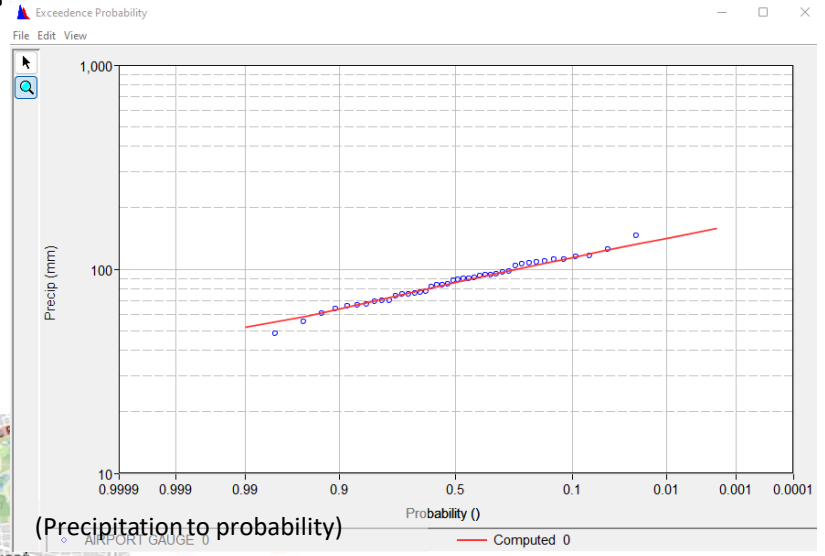




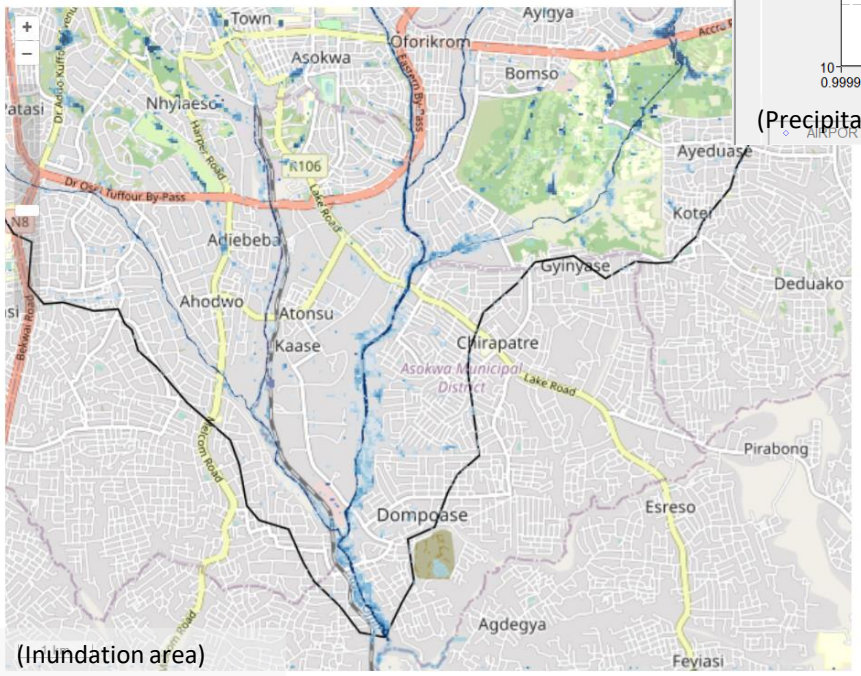
Examples - PARADeS Models

Kumasi - Aboabo Catchment

HYD



(Precipitation to probability)



(Inundation area)

1.0 - 1.5
1.5 - 2.0
2.0 - 2.5
2.5 >
2.0 - 3.0
3.0 - 4.0
4.0 - 5.0
5.0 >

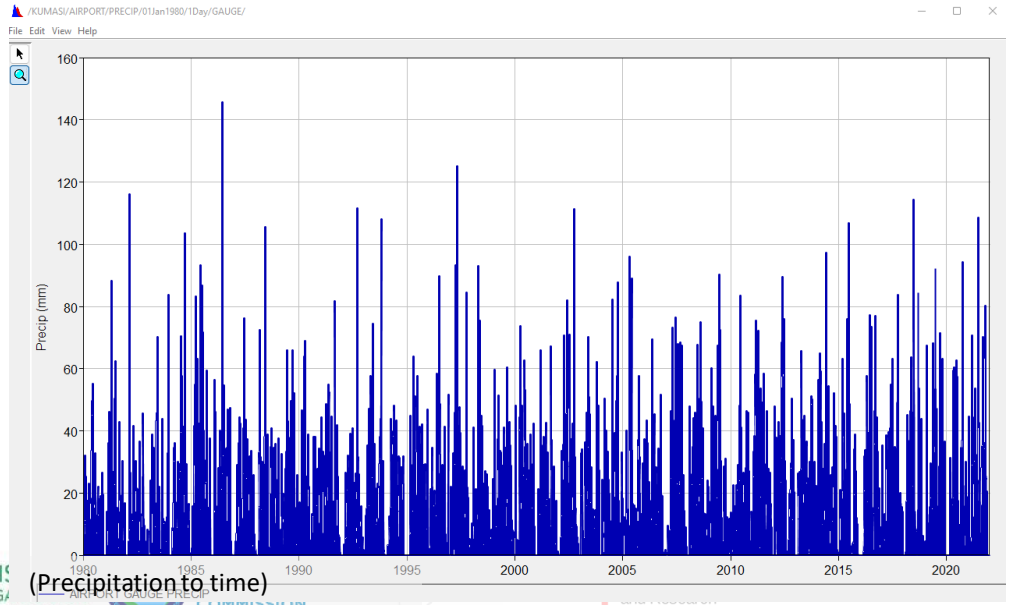
Population (people/cell):

Affected	Endangered
0 - 5	0 - 5
5 - 10	5 - 10
10 - 20	10 - 20
20 - 30	20 - 30
30 - 40	30 - 40
40 - 100	40 - 100

Economic damage (USD/cell yr. 2016):

Property

0 - 100
100 - 500
500 – 2,000
2,000 – 10,000
10,000 – 50,000
50,000 – 120,000



(Precipitation to time)

Output

- Depth and velocity of 2D Raster
- Peak discharge
- Inundation areas
- ...

Examples - PARADeS Models

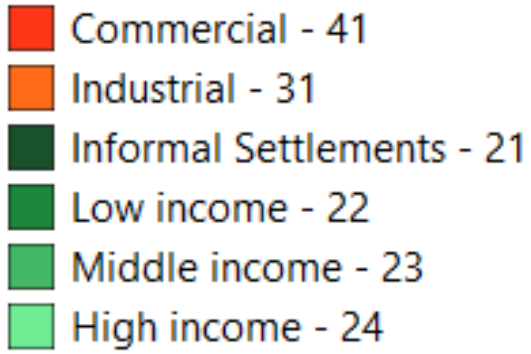
Kumasi - Aboabo Catchment

DAM

ECN

Input & Data

- Land Coverage Data: ESRI Satellite Data 25 m x 25 m
- Flood Depth Damage Curves & Absolute Damages
- Land-Use-Categorization:



Uncertainties & Assumptions

- No validation of model results
- Uncertainty from input data affects the model output – “A model’s quality is only as good as its input’s quality.”
- Absolute damage values from 2016
- Satellite Data from 2020
- House protection scenario’s assume an application of protection measures in all residential areas

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(Meta - Data for Good)

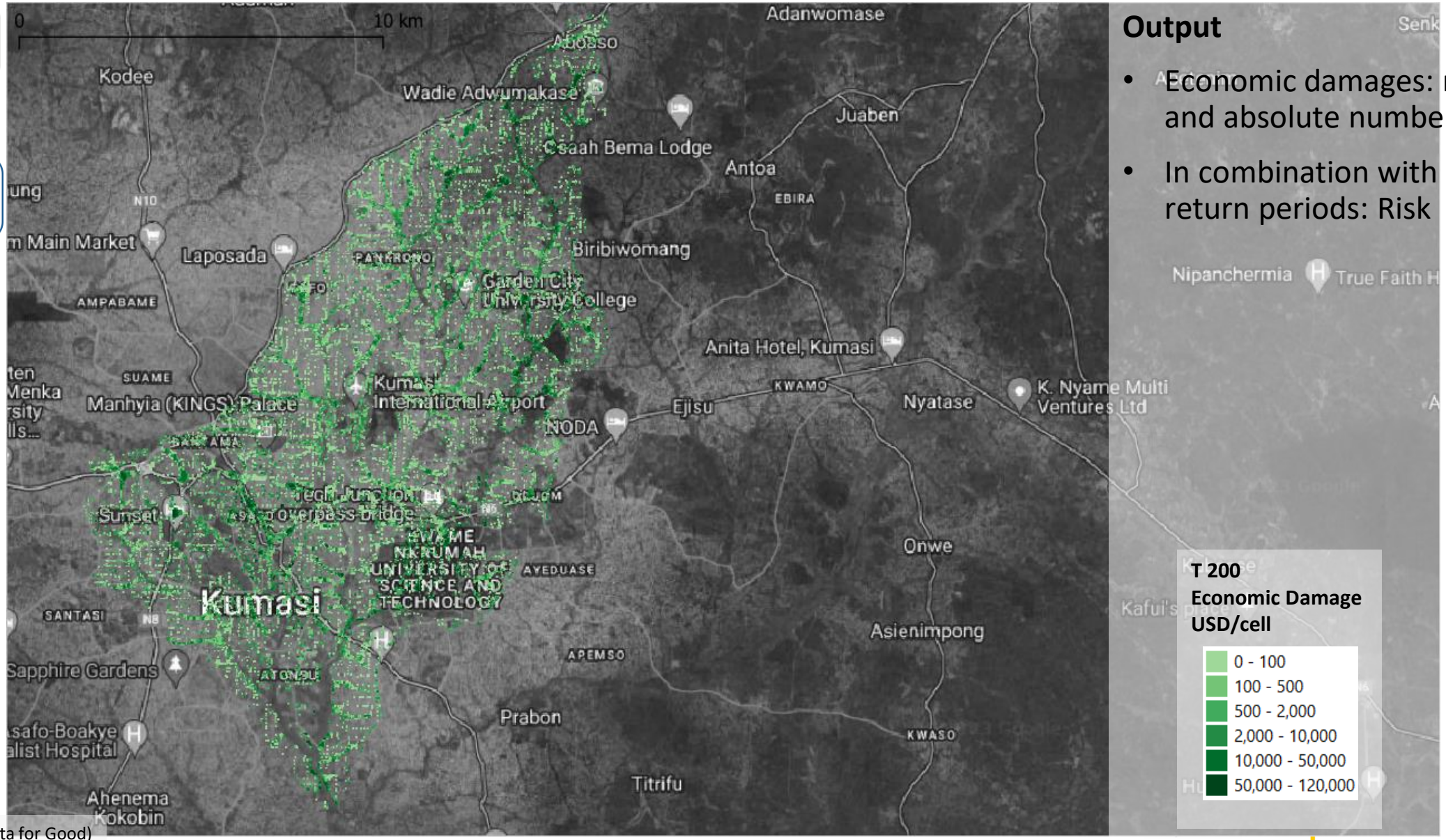
(Jonkmann, 2007)

Examples - PARADeS Models

Kumasi - Aboabo Catchment

DAM

ECN



Output

- Economic damages: raster-based and absolute numbers
- In combination with hydrological return periods: Risk

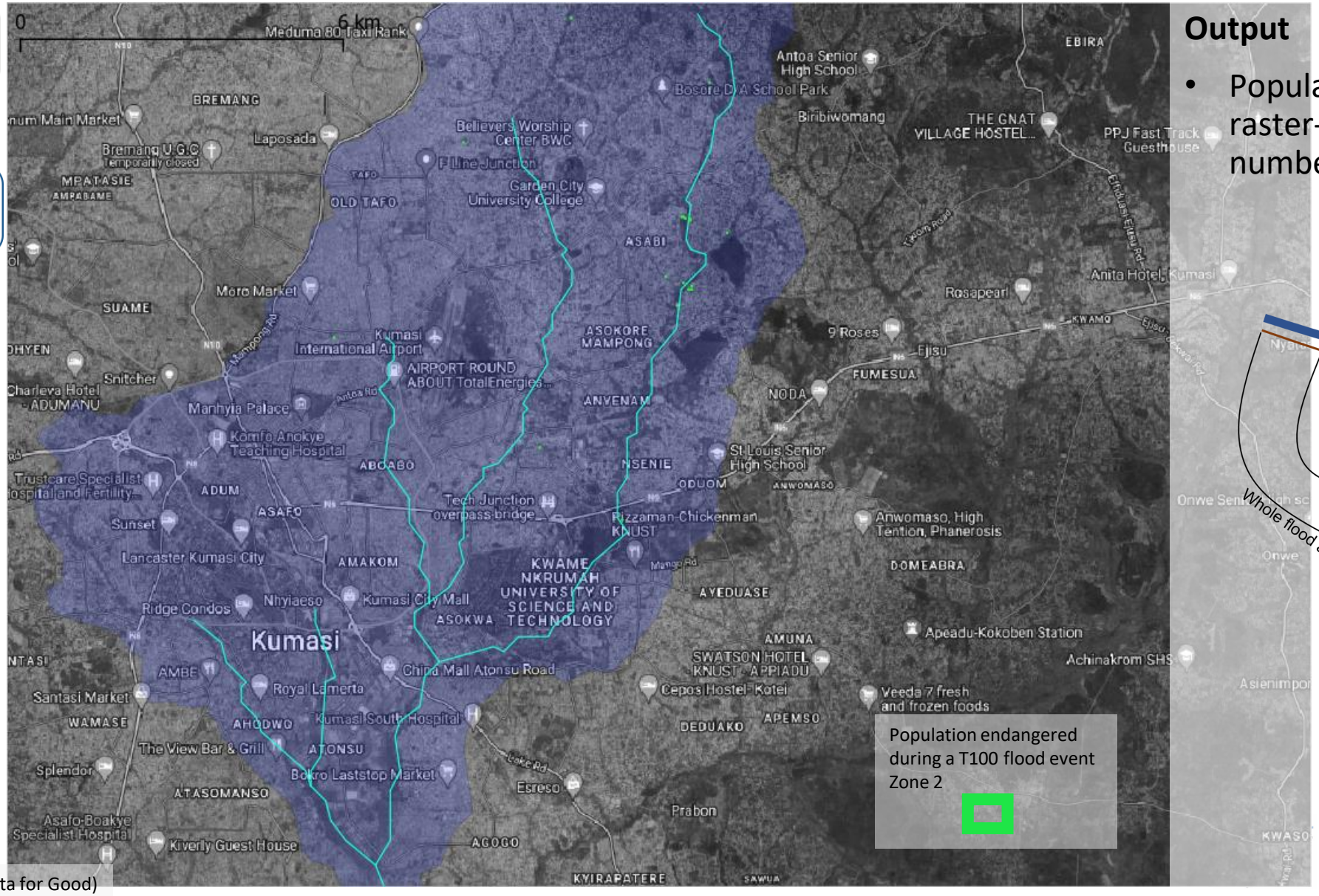
(Meta - Data for Good)

Examples - PARADeS Models

Kumasi - Aboabo Catchment

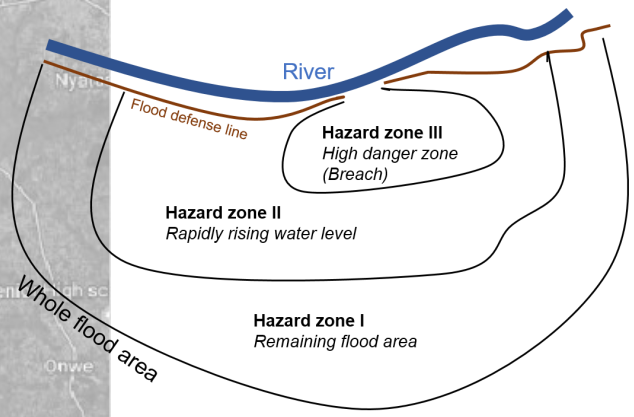
DAM

POP



Output

- Population endangered (Zone 2): raster-based and absolute numbers



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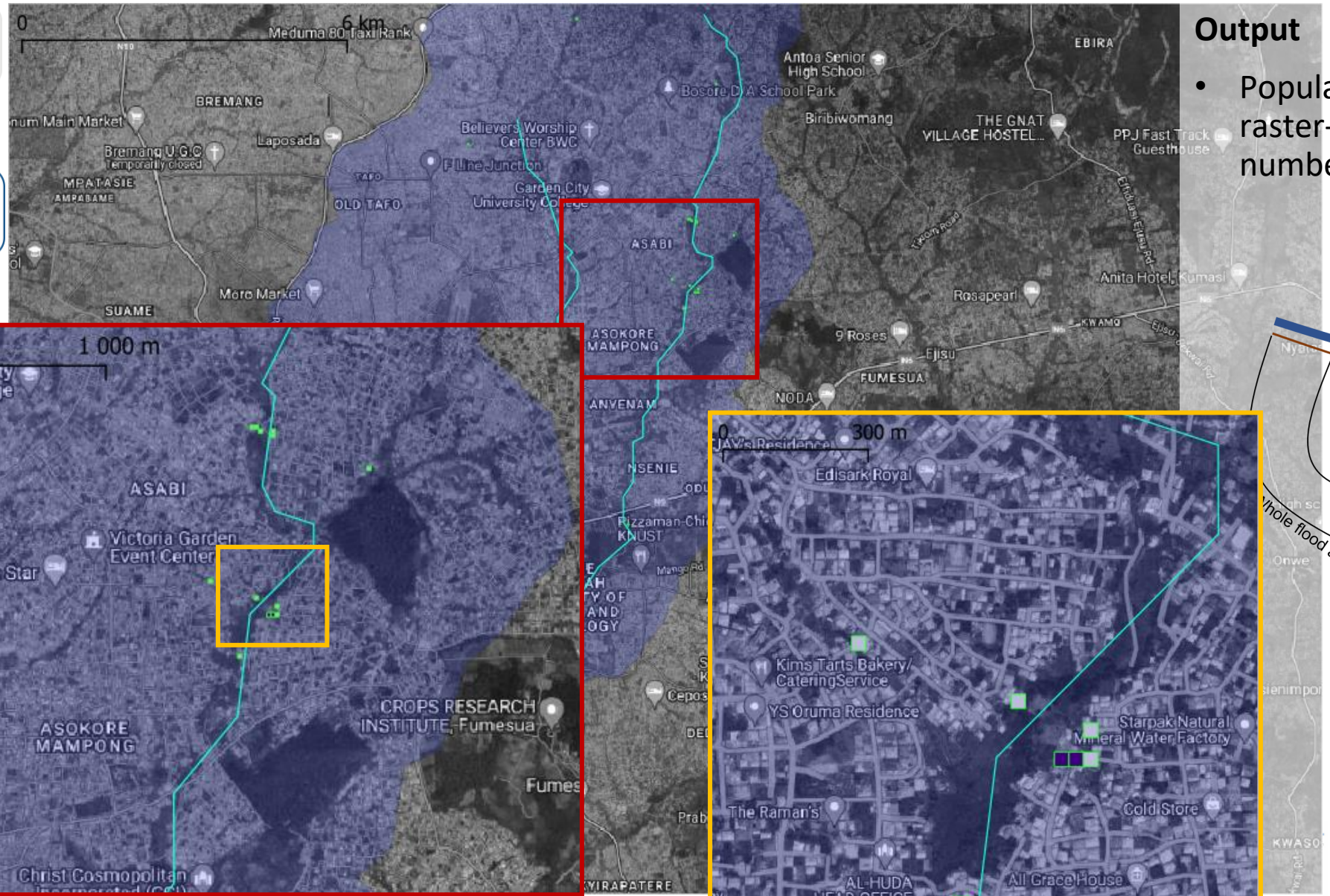
Examples - PARADeS Models

Kumasi - Aboabo Catchment

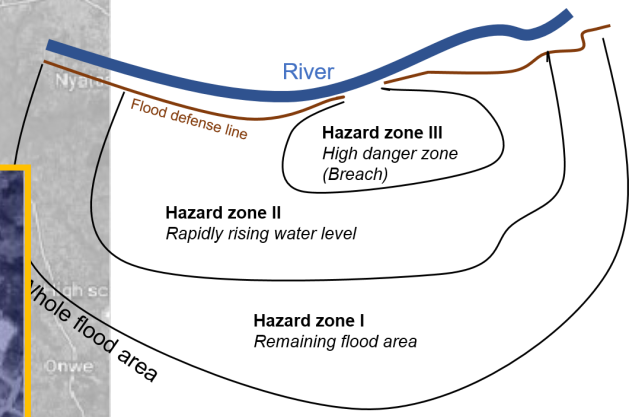
DAM

POP



Output

- Population endangered (Zone 2): raster-based and absolute numbers



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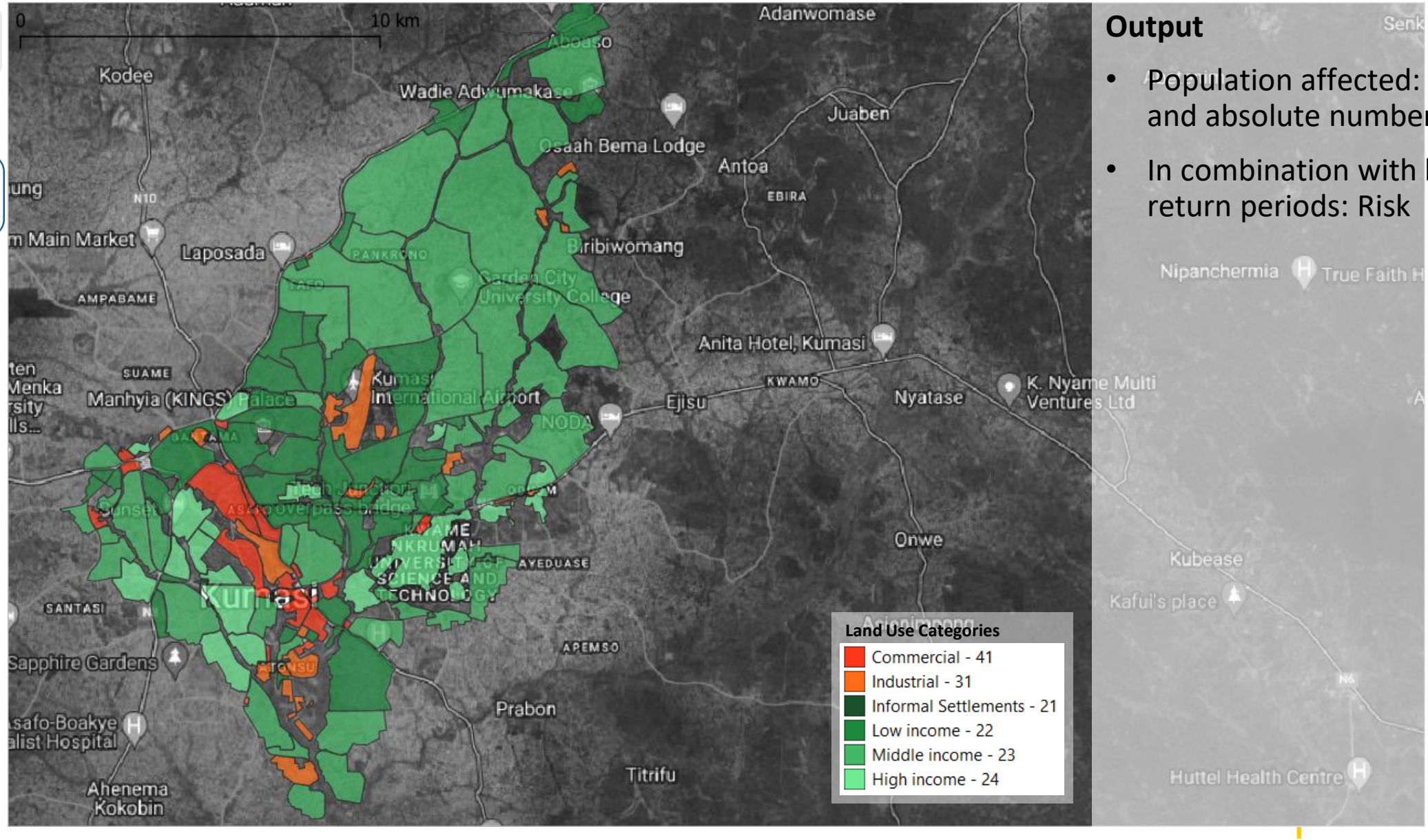
Examples - PARADeS Models

Kumasi - Aboabo Catchment

DAM

POP



Output

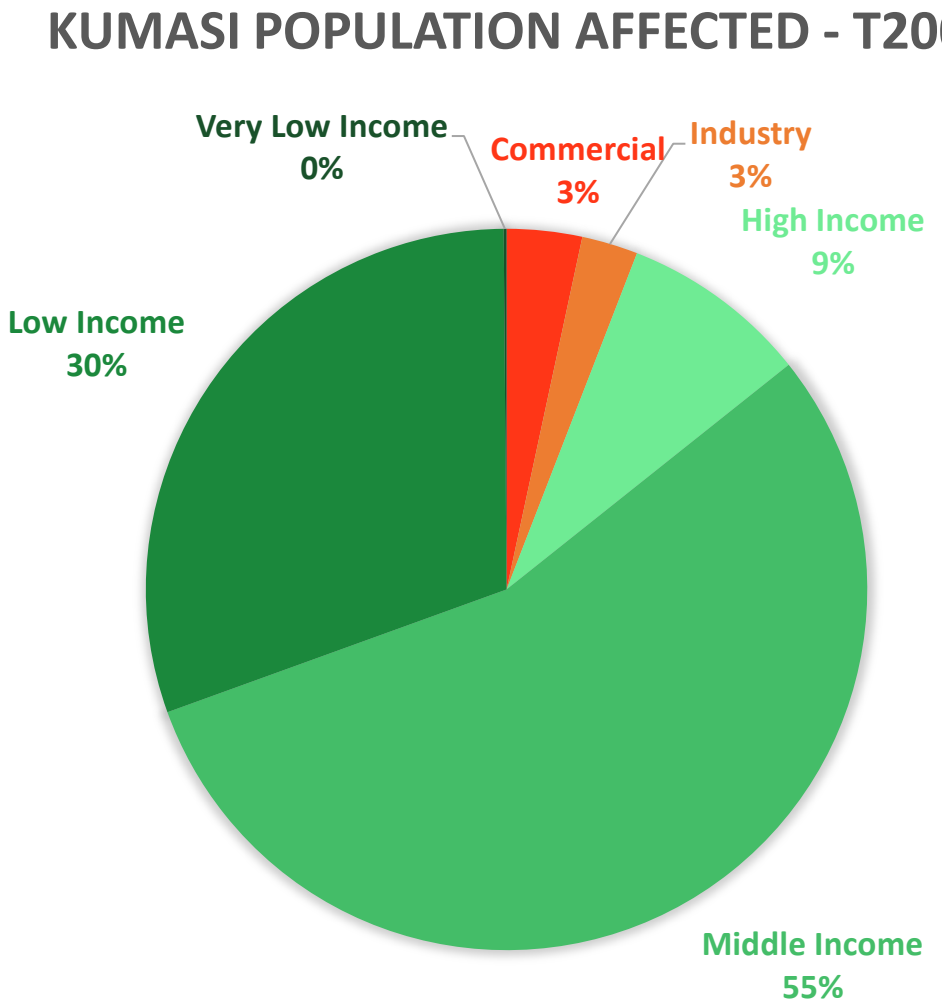
- Population affected: raster-based and absolute numbers
- In combination with hydrological return periods: Risk

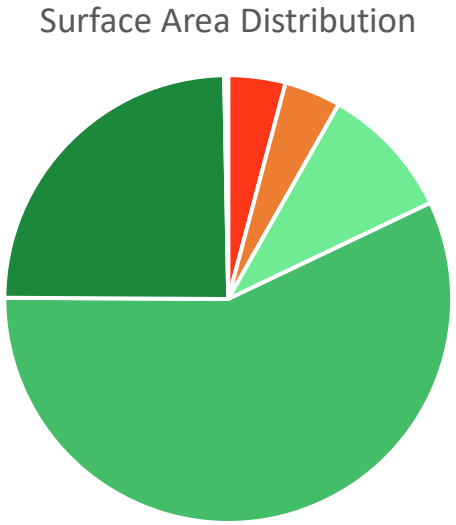
Examples - PARADeS Models

Kumasi - Aboabo Catchment

DAM

POP





Output

- Population affected: raster-based and absolute numbers
- The right pie chart describes the relative part of people affected in areas of the land-usage types

→ The comparison with the pie chart of surface area distribution shows that people in the “Low Income” areas are more affected by flooding than other areas.

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Structure of Module 2

Model Theory and Application

Module objectives

Modelling theory and literature sources

Examples: PARADeS models

Accra - Odaw:

Outlook

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Examples - PARADeS Models

Accra – Odaw Catchment and Surrounding

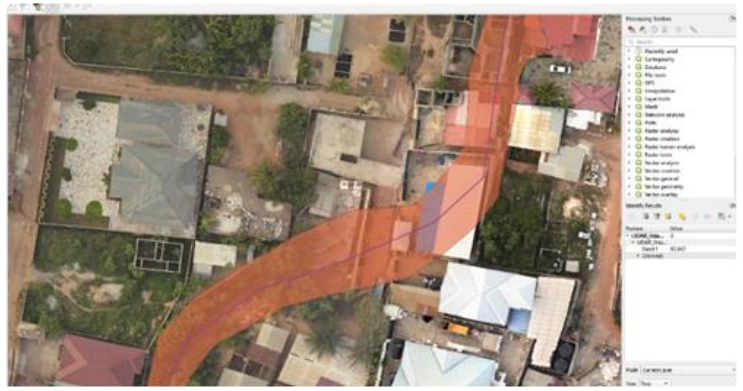
HYD

Input and Data

- Digital elevation model (DEM):
  - TandemX 30 m
  - LIDAR 1 m
- Land-use: Copernicus GLS 30m (2018)
- Sea level tides
- Rainfall data from Accra airport (1980 - 2018)
- Measured cross-section

Uncertainties

- Rainfall data is only available in 24hr sample. Estimates of flash floods in finer temporal resolution is not captured
- Very poor discharge data for validation
- No spatial data for validation.
- Flood hotspots identification through participatory mapping was used for plausibility checks, this however does not capture all the areas affected.

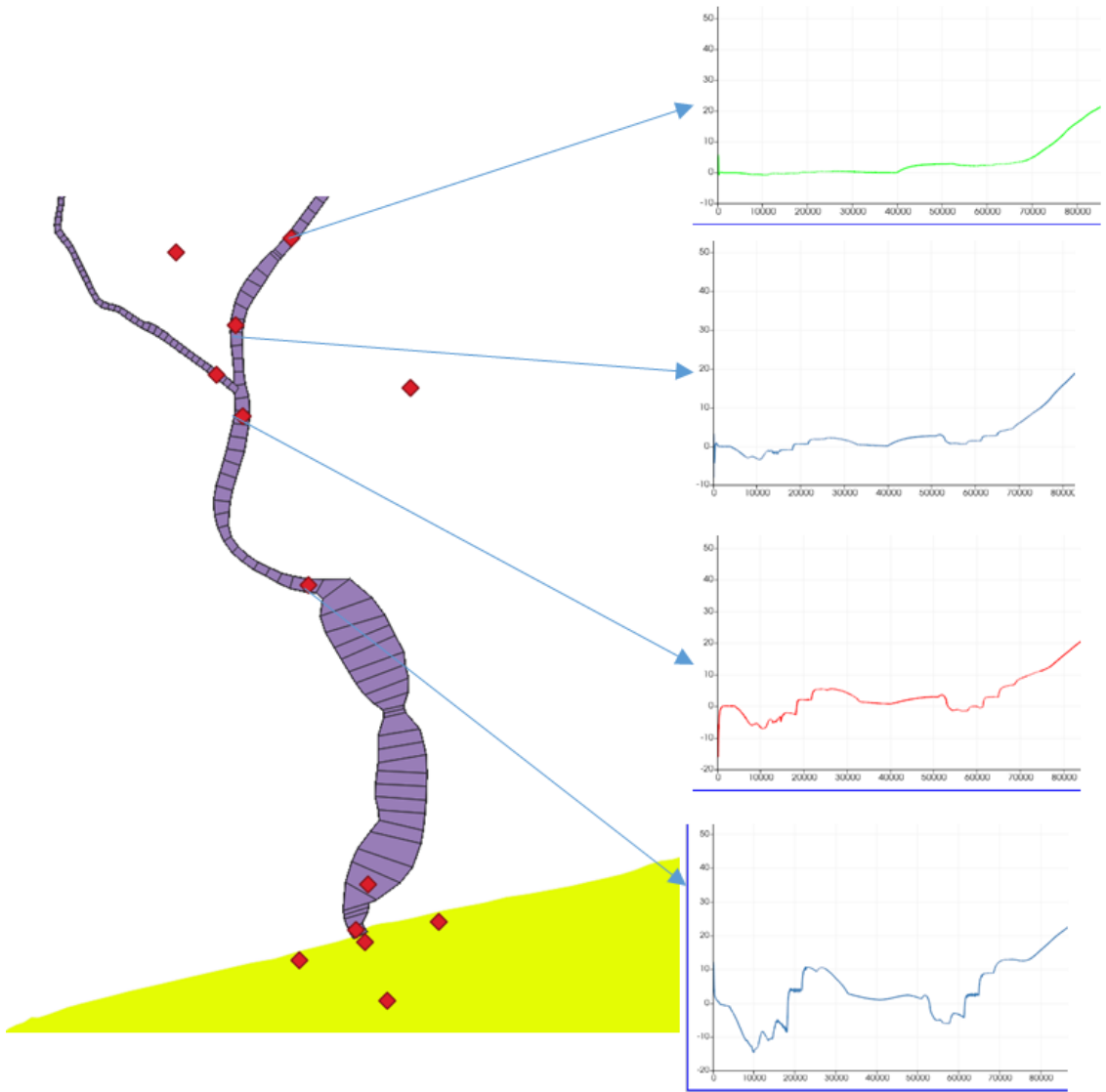


Examples - PARADeS Models

Accra – Odaw Catchment and Surrounding

HYD

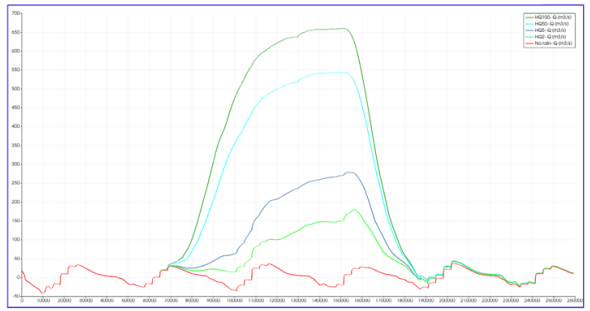
Tidal influence



Output

- Depth and velocity of 2D Raster
- Peak discharges
- Inundation areas
- ...

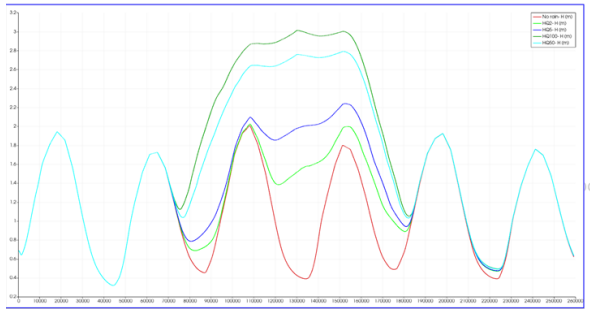
Discharge at outlet m^3/s



Line chart from lowest to highest:

-No rain
-HQ2
-HQ5
-HQ50
-HQ100

Water Level at outlet (m)



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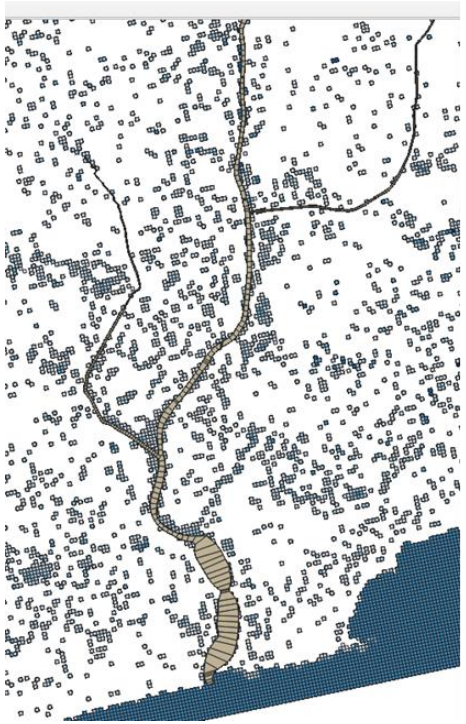
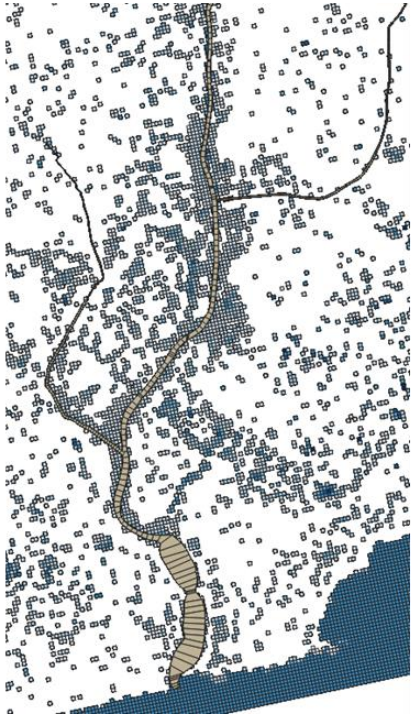
Examples - PARADeS Models

Accra – Odaw Catchment and Surrounding

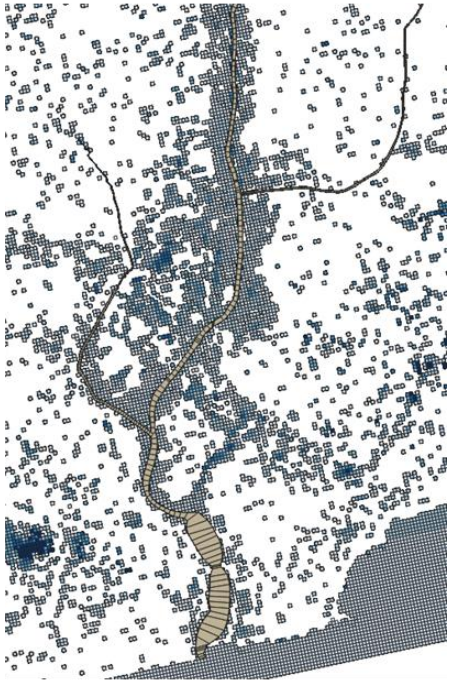
HQ2



HQ10



HQ50



Output

- Depth and velocity of 2D Raster
- Peak discharges
- Inundation areas
- ...for different return periods

HYD

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Examples - PARADeS Models

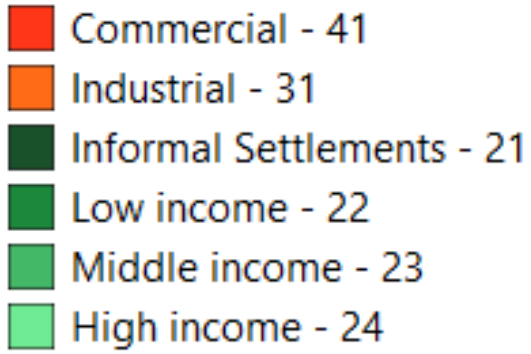
Accra - Odaw Catchment

DAM

ECN

Input & Data

- Land Coverage Data: ESRI Satellite Data 25 m x 25 m
- Flood Depth Damage Curves & Absolute Damages
- Land-Use-Categorization:



Uncertainties & Assumptions

- No validation of model results
- Uncertainty from input data affects the model output – “A model’s quality is only as good as its input’s quality.”
- Absolute damage values from 2016
- Satellite Data from 2020
- House protection scenario’s assume an application of protection measures in all residential areas

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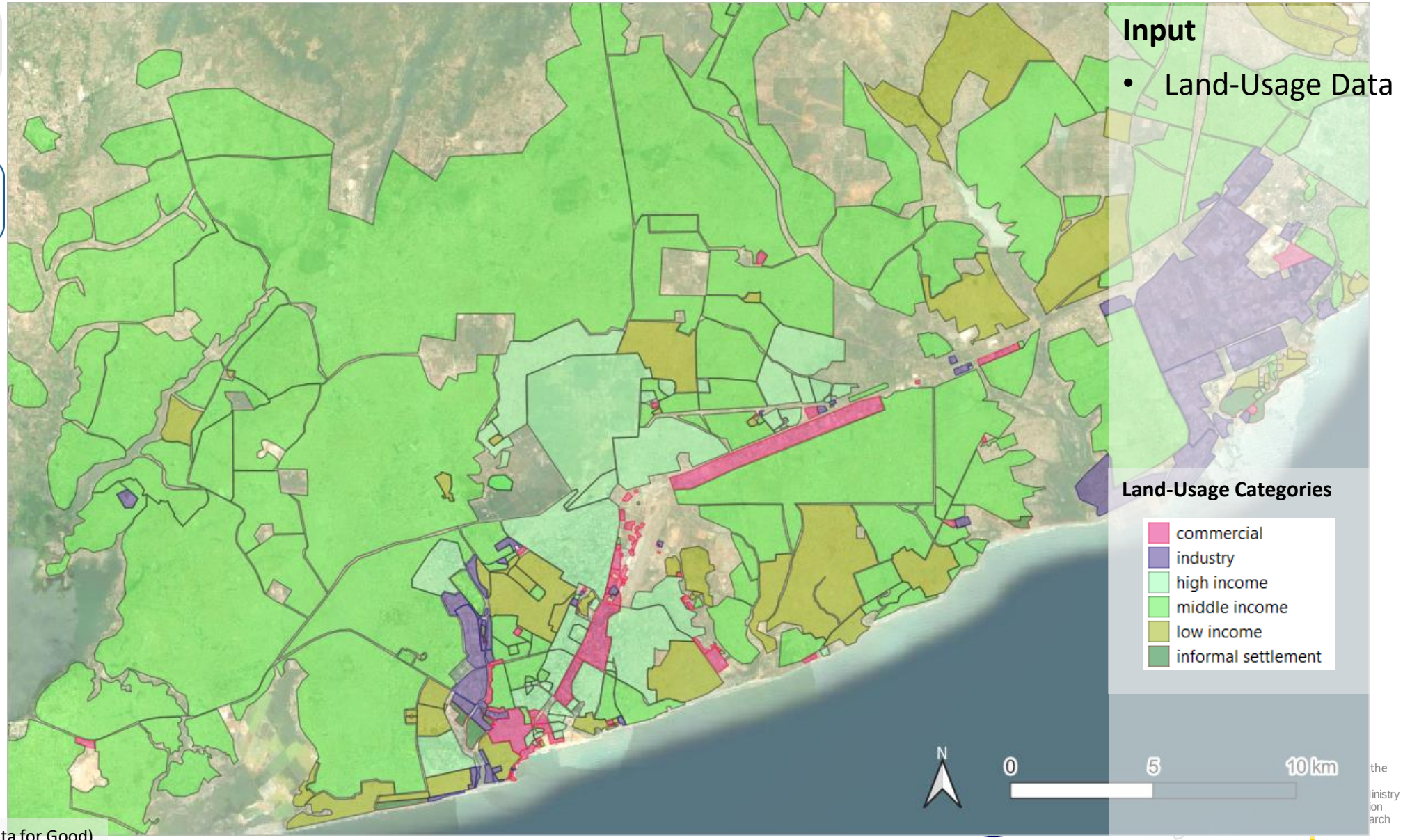
(Jonkmann, 2007)

Examples - PARADeS Models

Accra - Odaw Catchment

DAM

ECN

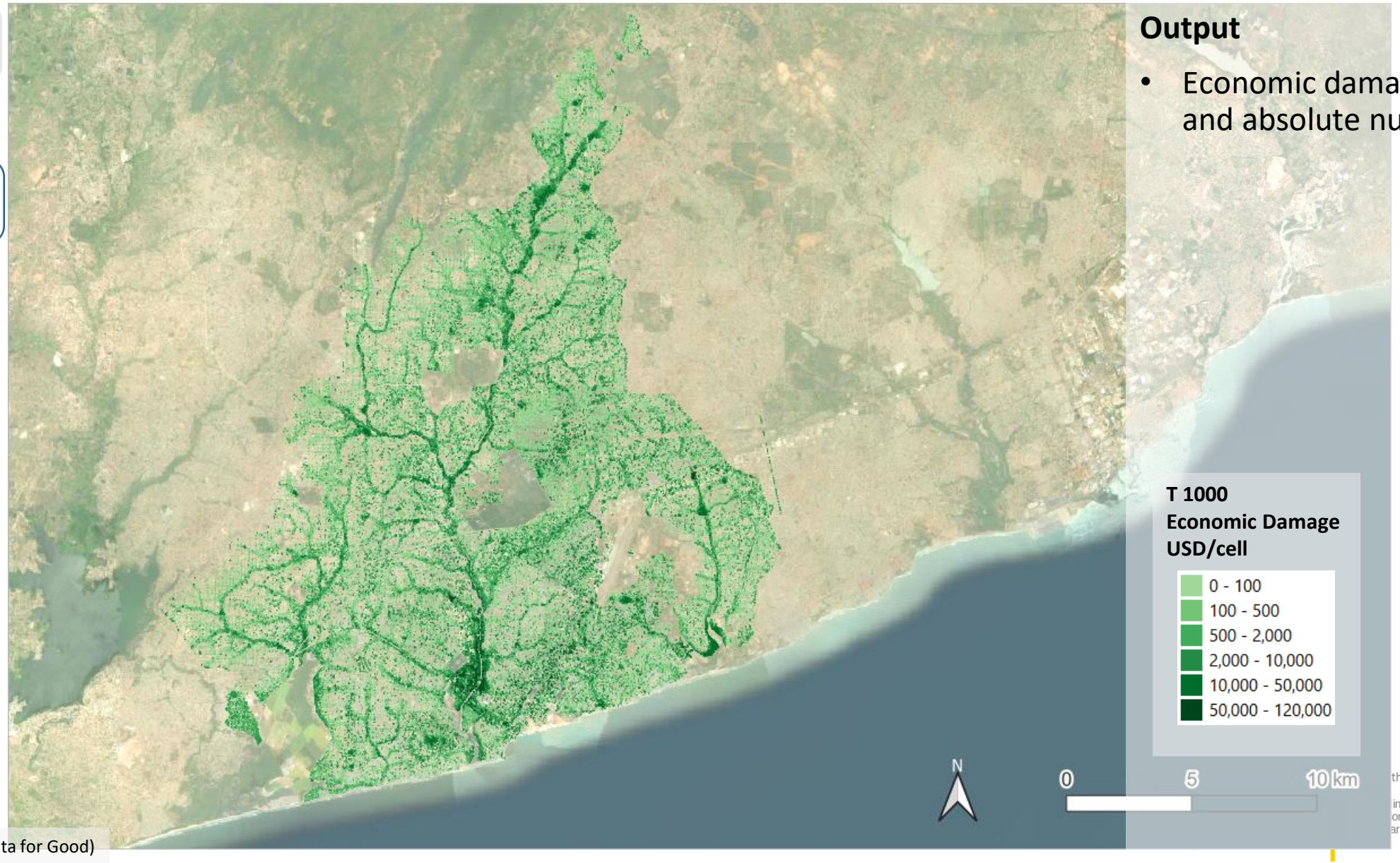


Examples - PARADeS Models

Accra - Odaw Catchment – ECN Results

DAM

ECN



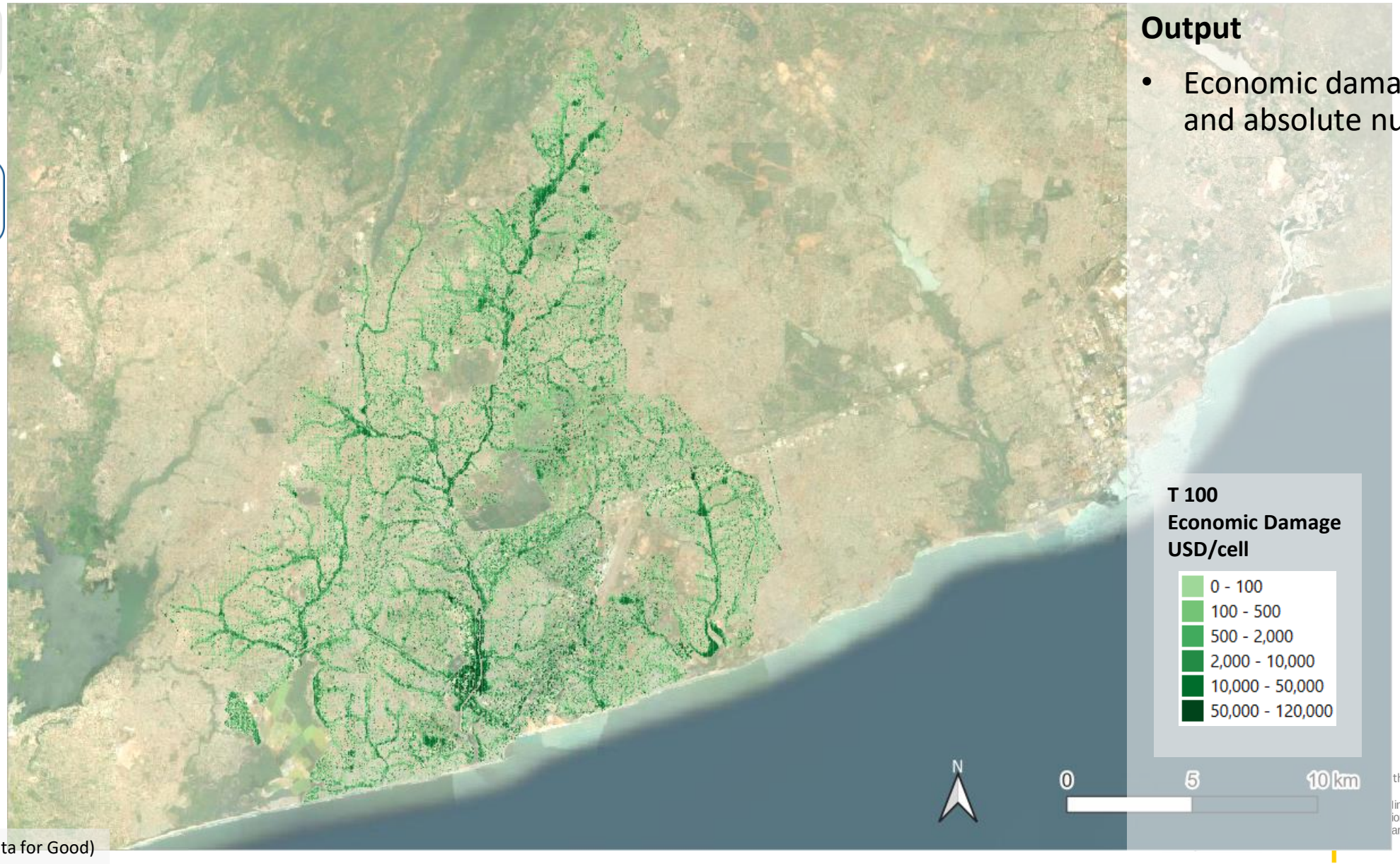
(Meta - Data for Good)

Examples - PARADeS Models

Accra - Odaw Catchment – ECN Results

DAM

ECN



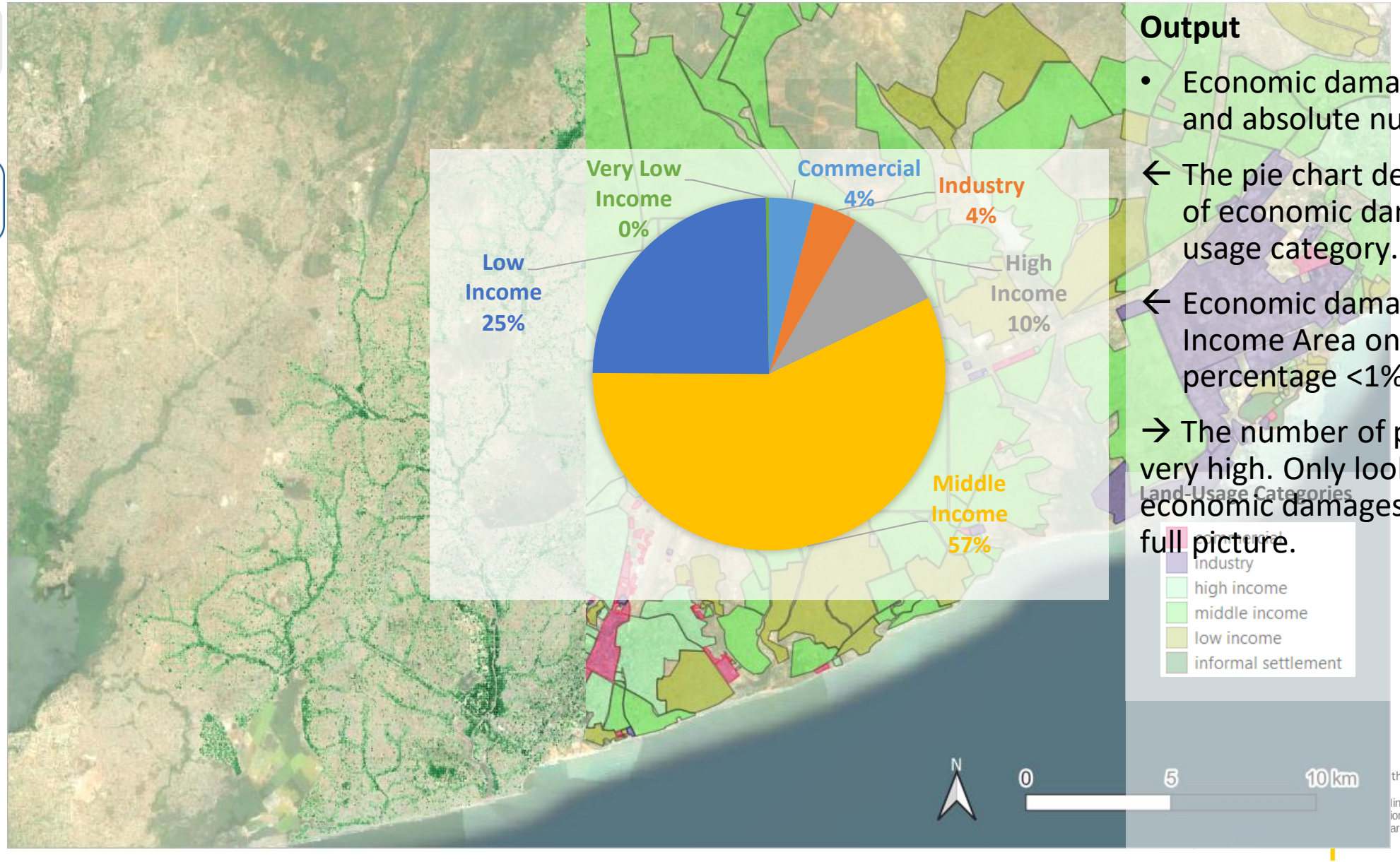
(Meta - Data for Good)

Examples - PARADeS Models

Accra - Odaw Catchment – ECN Results

DAM

ECN



Output

- Economic damages: raster-based and absolute numbers

← The pie chart derives the number of economic damages per land-usage category.

← Economic damages for Very-Low-Income Area only makes up a percentage <1%

→ The number of people though is very high. Only looking at the economic damages does not paint a full picture.

Examples - PARADeS Models

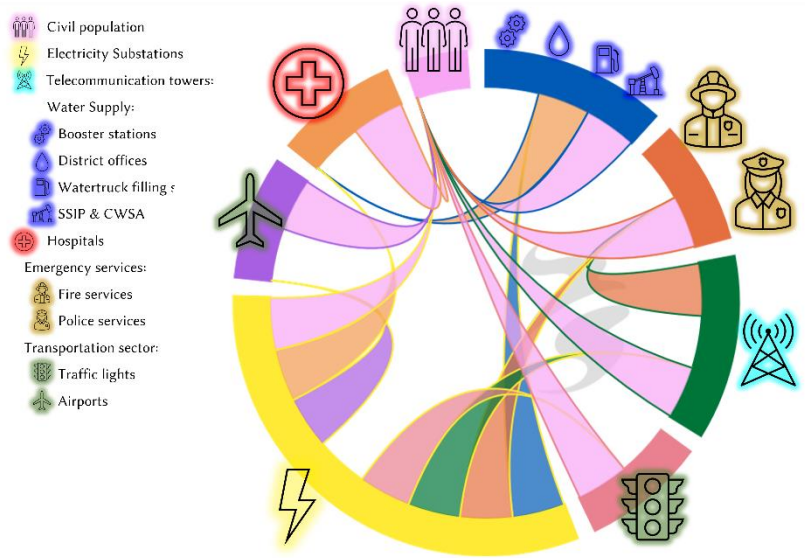
Accra - Odaw Catchment

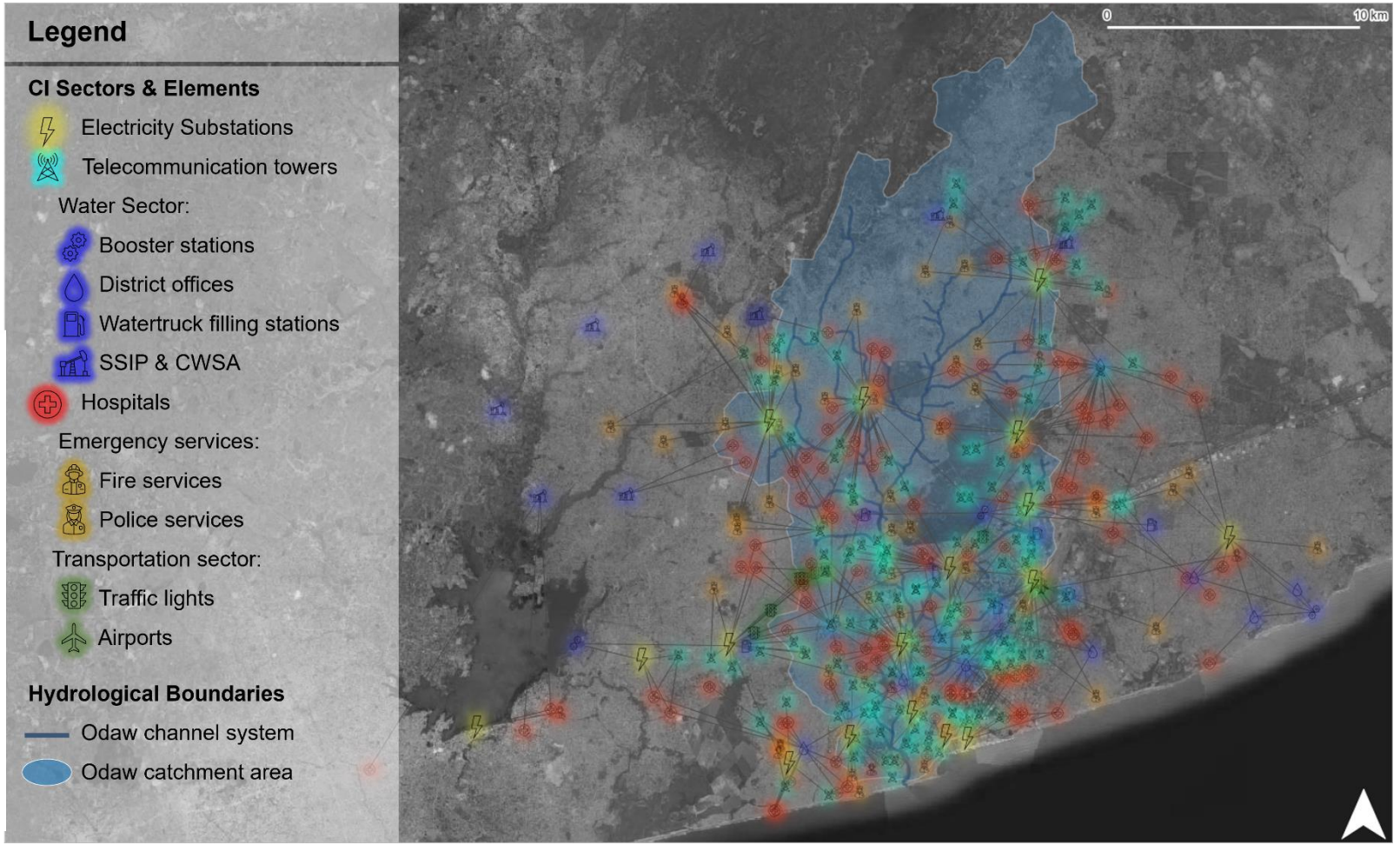
DAM

CI

Input & Data

- Open Street Map Data
- Information about dependencies and CI characteristics – CI workshops
- Point elements 433
  Polygon elements 486
- Connector elements 1216





Examples - PARADeS Models

Accra - Odaw Catchment

DAM

CI

Input & Data

- Open Street Map Data
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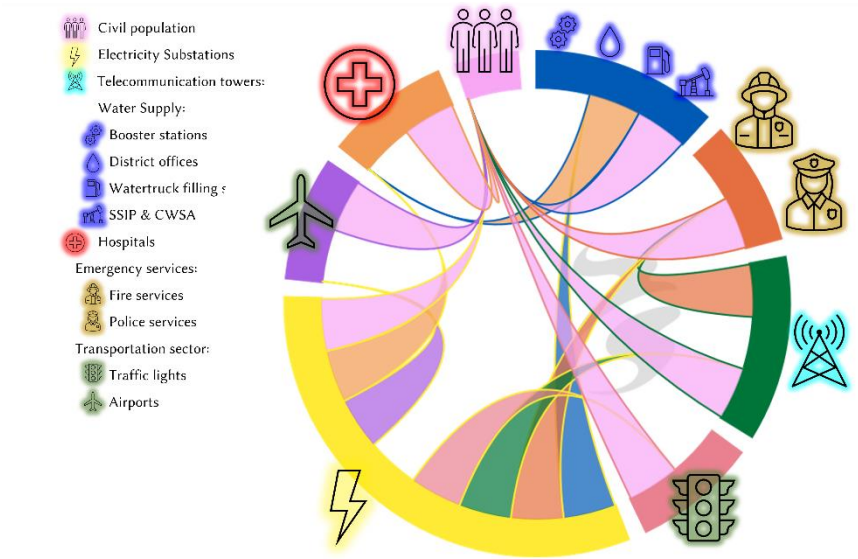
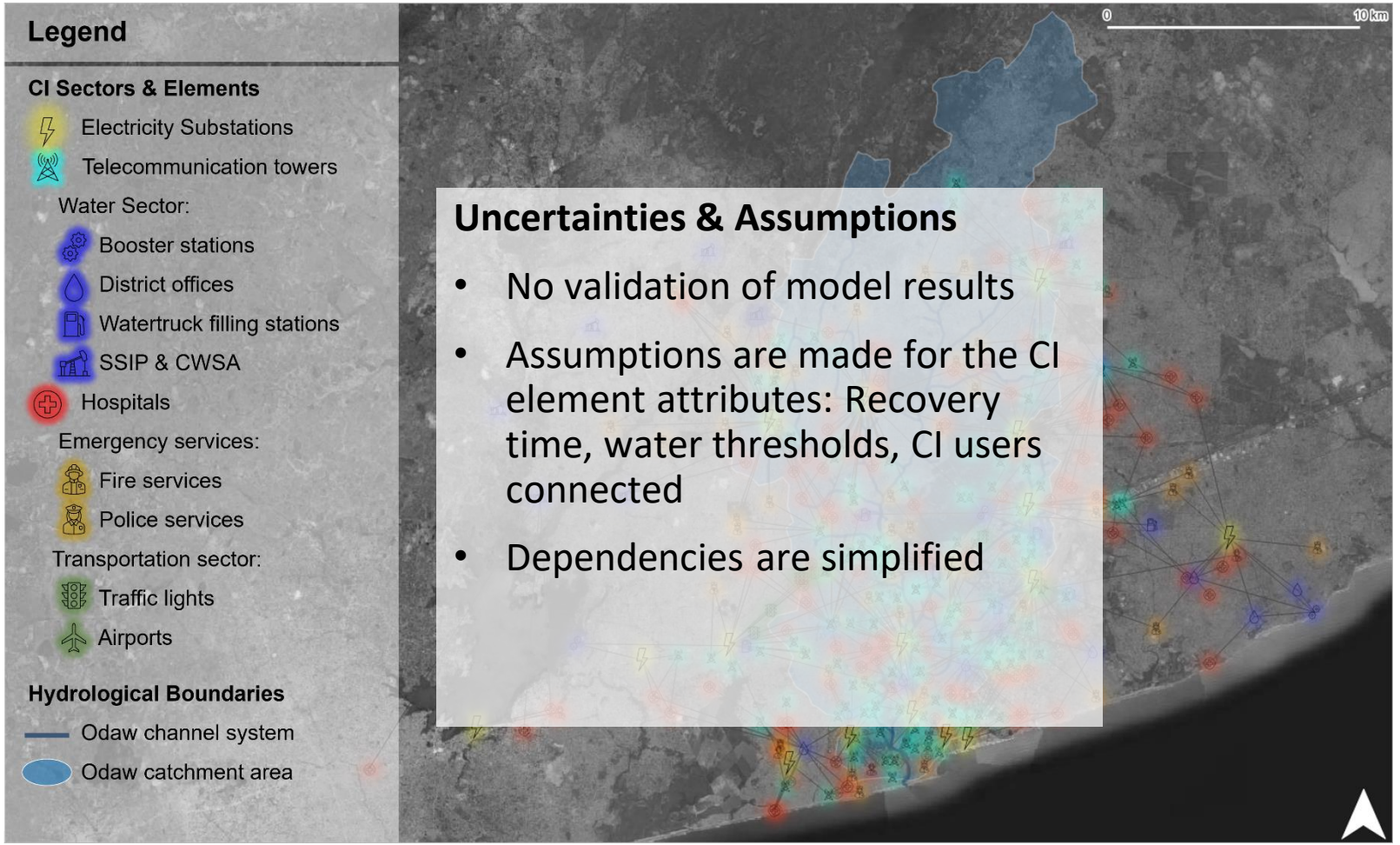
  Polygon elements 486
- Connector elements 1216





Uncertainties & Assumptions

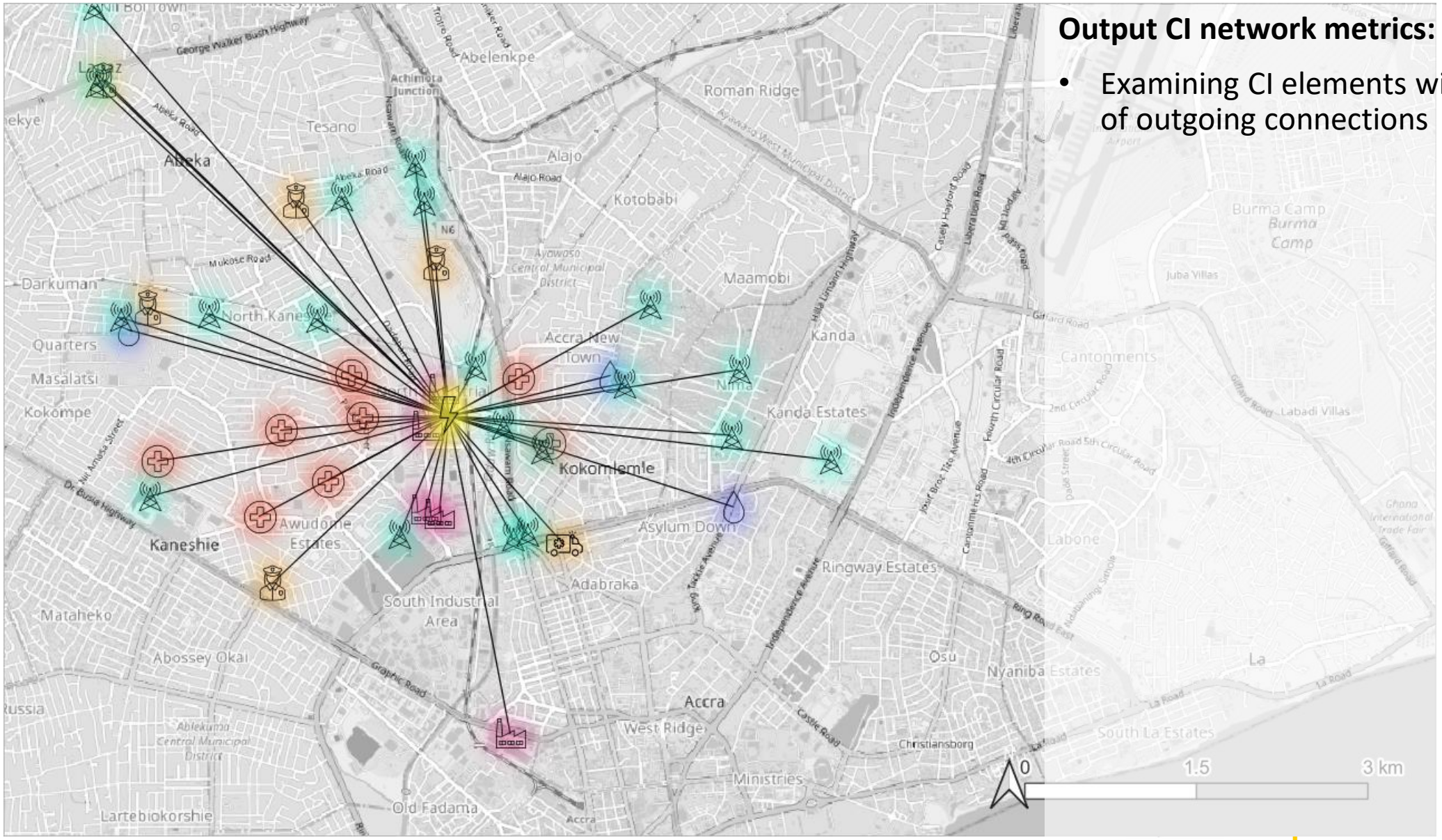
- No validation of model results
- Assumptions are made for the CI element attributes: Recovery time, water thresholds, CI users connected
- Dependencies are simplified

Examples - PARADeS Models

Accra - Odaw Catchment

DAM

CI



Output CI network metrics:

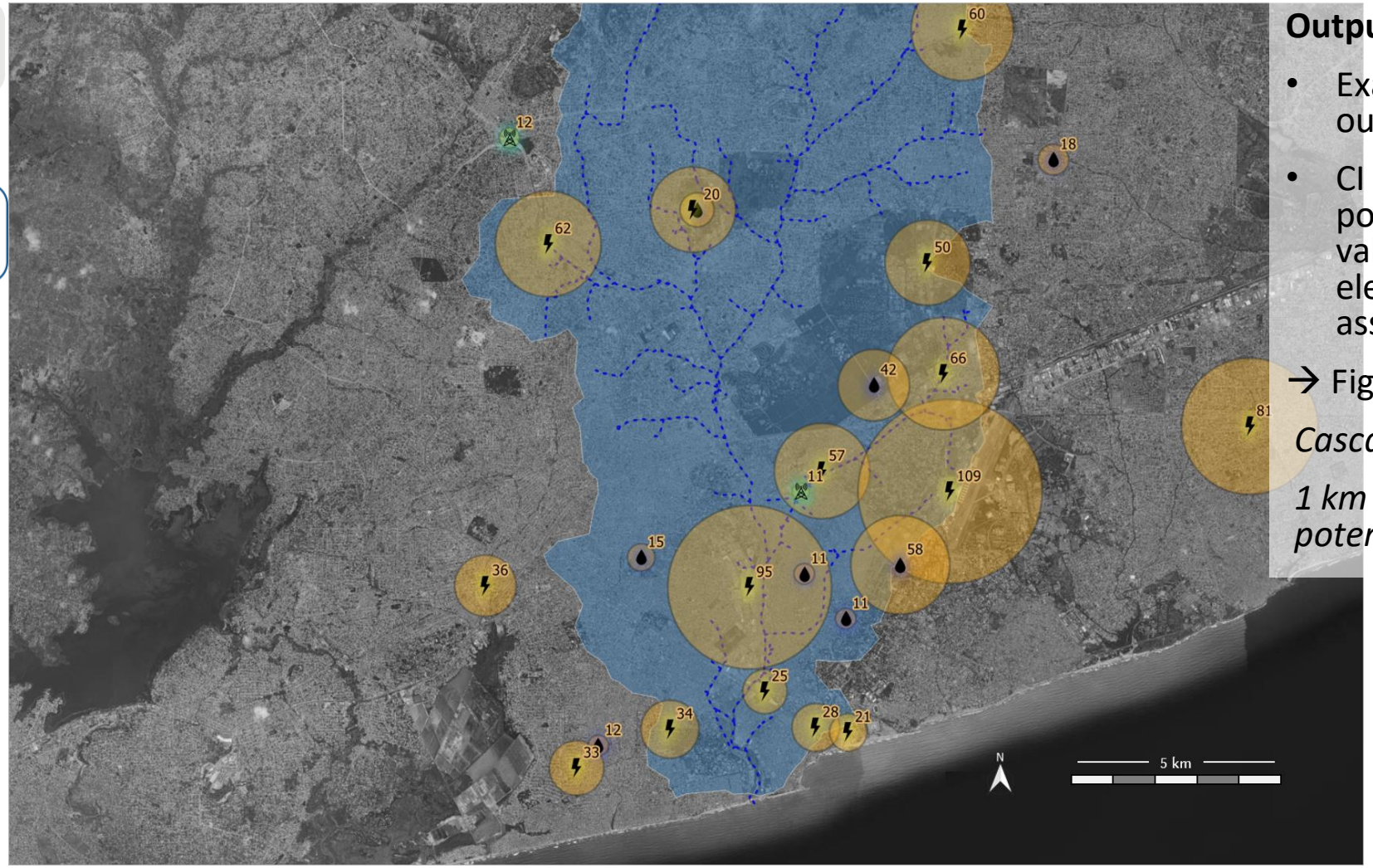
- Examining CI elements with a lot of outgoing connections

Examples - PARADeS Models

Accra - Odaw Catchment

DAM

CI



Output CI network metrics:

- Examining CI elements with a lot of outgoing connections
- CI elements with a high cascade potential value: Cascade potential value describe the number of elements disrupted when the associated element is disrupted.

→ Figure shows:

Cascade potential values P > 10

1 km radius equals a cascade potential value P = 50.

CIN Network Properties

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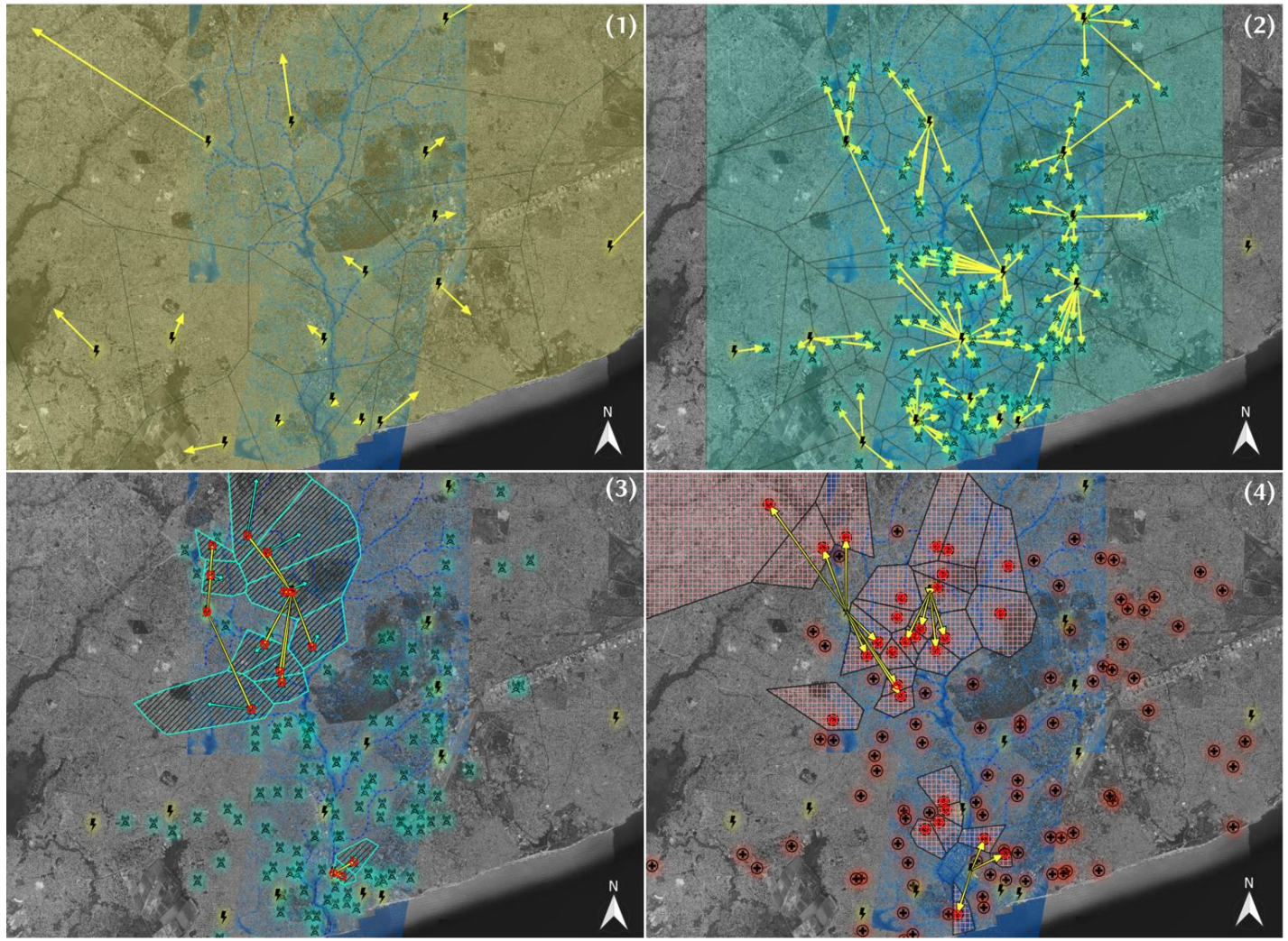
Examples - PARADeS Models

Accra - Odaw Catchment – CI Results

DAM

CI



Output

- CI network metrics:
- CI elements with a lot of outgoing connections
- CI elements with a high cascade potential value
- Number of disrupted CI users per sector and flood event

CIN Theory

Publication CI & FRM

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Structure of Module 2

Model Theory and Application

Module objectives

Modelling theory and literature sources

PARADeS models for Odaw, Aboabo & White Volta

Outlook

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Outlook

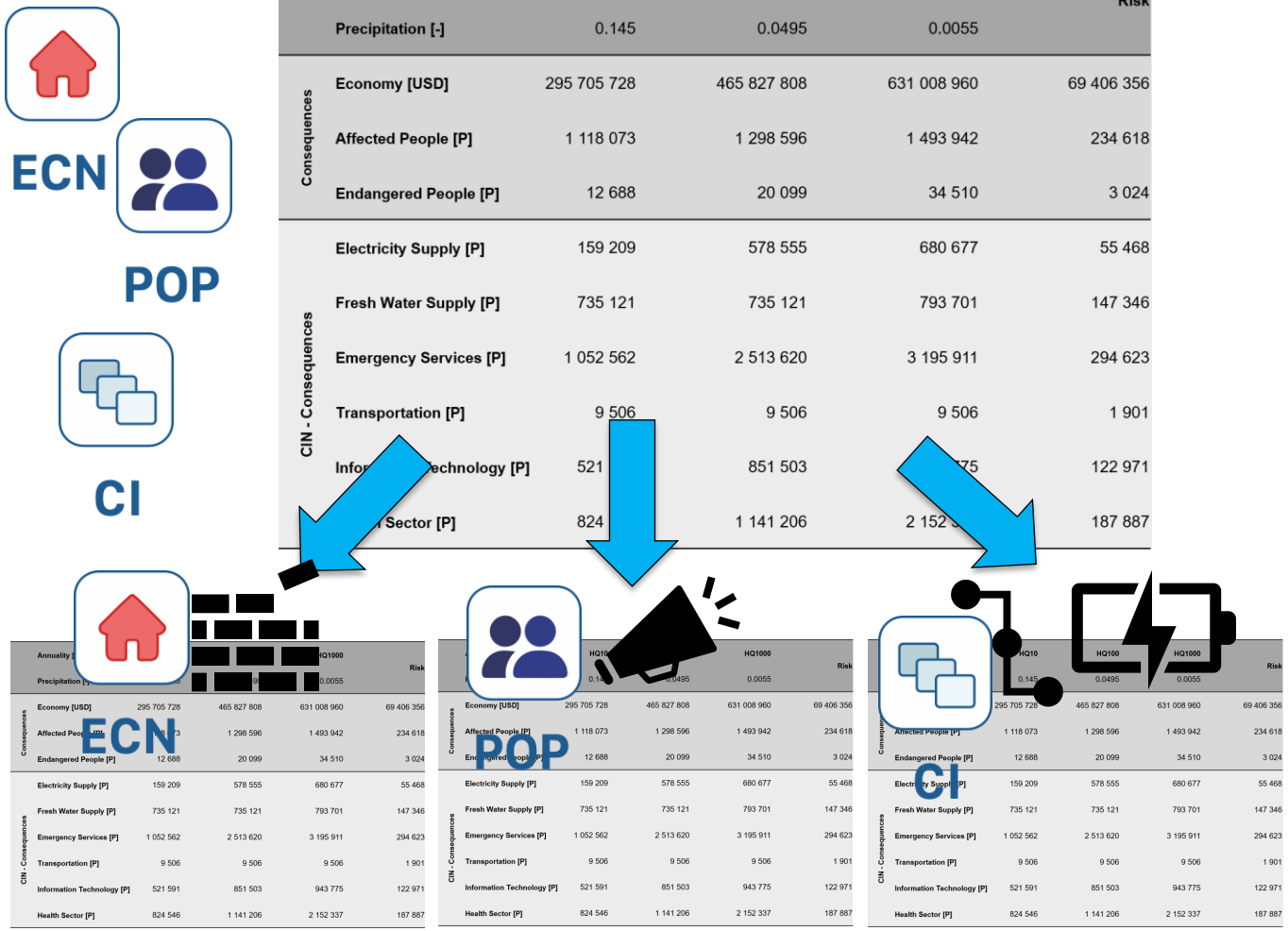
What to do with the model?

1. The different models help to describe the **current situation** of a system and can be combined to an overall risk.

2. Changing the model will resemble **potential future scenarios**.

3. **Comparison** of flood consequences.

4. This supports the **identification** of the optimal solution.



	Annuality [a]	HQ10	HQ100	HQ1000	Risk
	Precipitation [-]	0.145	0.0495	0.0055	
Consequences	Economy [USD]	295 705 728	465 827 808	631 008 960	69 406 356
	Affected People [P]	1 118 073	1 298 596	1 493 942	234 618
	Endangered People [P]	12 688	20 099	34 510	3 024
CIN - Consequences	Electricity Supply [P]	159 209	578 555	680 677	55 468
	Fresh Water Supply [P]	735 121	735 121	793 701	147 346
	Emergency Services [P]	1 052 562	2 513 620	3 195 911	294 623
	Transportation [P]	9 506	9 506	9 506	1 901
	Information Technology [P]	521	851 503	[illegible]	122 971
	Health Sector [P]	824	1 141 206	2 152 [illegible]	187 887

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Questions?

https://promaides.h2.de

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Prof.-Dr.-Ing. Daniel Bachmann

Daniel.Bachmann@h2.de

Publications

Schotten, R.; Bachmann, D., Methodology of a Critical Infrastructure Network Modelling Module for Flood Risk Assessments Including a Case Study in Accra, Ghana. *J. Flood Risk Manag.* **2023**, 16, 3. https://doi.org/10.1111/jfr3.12913

Bachmann, D.; Schüttrumpf H., Integrating the reliability of flood protection structures into catchment-based flood risk analysis, *Hydrologie und Wasserbewirtschaftung*, vol. 58, pp. 168–177, Jun. **2014**, https://doi.org/10.5675/HyWa_2014,3_1

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PARADeS

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

NATIONAL DISASTER MANAGEMENT ORGANISATION

WATER RESOURCES COMMISSION

WASCAL

UNIVERSITÄT BONN GEOGRAPHIE

Hochschule Magdeburg • Stendal

universität freiburg

Flood Competence Center HKC Hochwasser Kompetenz Centrum e.V.

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Citation reference

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Dipl.-Hydrologe Georg Johann
Flood Competence Center

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