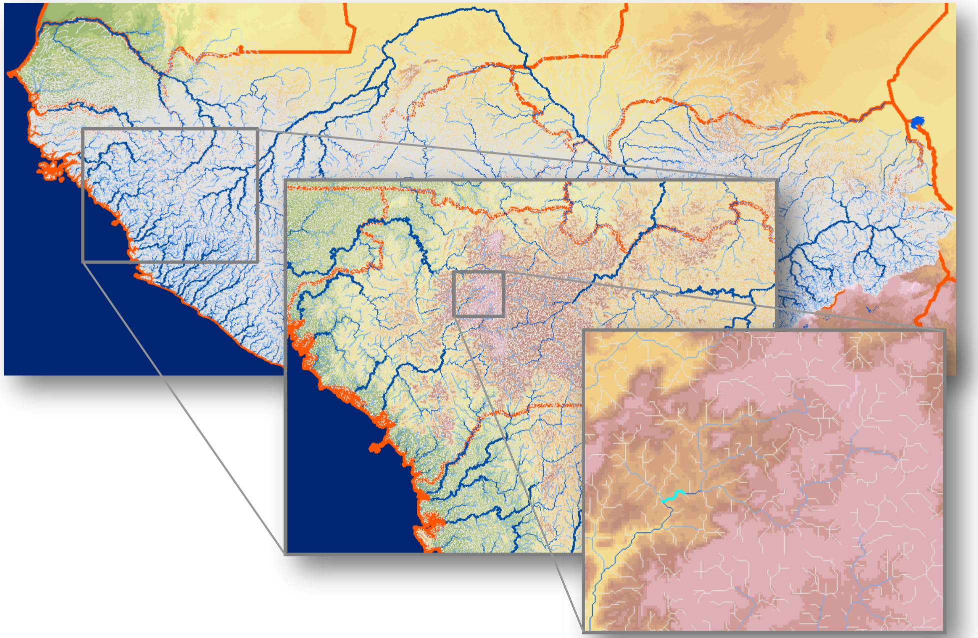
GIS Hydropower Resources Mapping for ECOWAS Region

Session 1: Introduction



Training, Dakar, Senegal, July 2016

Trainer: Harald Kling

Pöyry, Hydro Consulting, Hydropower, Austria

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Spanish Cooperation

Training program

Overview

- Day 1: General overview, group discussions
  - Overview about the study
    - General method
    - New layers for ECOWREX
  - Data challenges & Lessons learned
  - Flow estimation & Hydropower potential
  - Climate change projections

- Day 2: GIS layers, group work, practice examples
  - Hydropower classification:
    - Plant type
    - Plant size
  - Practice examples
    - Installed capacity & energy calculation
    - Water balance & climate change calculation

Introduction

Background & Objectives

- Background
  - Shortage of reliable energy supply is a critical topic in the 15 countries of ECOWAS.
  - The potential for future hydropower development is assumed to be large, but exact data are missing especially for small-scale hydropower development.
  - This study supports the energy initiatives of the "ECOWAS Centre for Renewable Energy and Energy Efficiency" (ECREEE).
- General project objectives
  - Assess the hydropower potential of all rivers in the ECOWAS region.
  - Prepare various data layers for integration into ECREEE's online platform ECOWREX, such that the study results are readily available to the general public.
  - Identify regions/rivers that are attractive for hydropower development to direct ECREEE's streamflow measurement initiatives.
  - This study focusses on hydropower potential for small-scale hydropower at small rivers, in addition to assessment for large rivers.

Hydropower potential

Definitions

- **Gross theoretical** hydropower potential

  Hydropower generation if all natural water flows would be utilized by 100% efficient turbines.

- **Theoretical** hydropower potential

  Rough consideration of energy losses due to turbine efficiency, hydraulic losses (penstock, etc.).

- **Technical** hydropower potential

  Also considering spillway losses due to limited design flow of turbines.

- **Economic** hydropower potential

  Also considering economic restrictions (investment costs, energy prices).

- **Exploitable** hydropower potential

  Also considering environmental and social restrictions (protected areas).

Hydropower theory

Theoretical hydropower potential of a river reach

Power [MW] = ***Flow*** [m³/s] * ***Height*** [m] * ***c***

Power	Theoretical hydropower potential [MW]
Flow	Mean annual discharge in reach [m^3/s]
Height	Elevation difference from start to end of river reach [m]
c	Constant, typically $c = 8.5/1000$

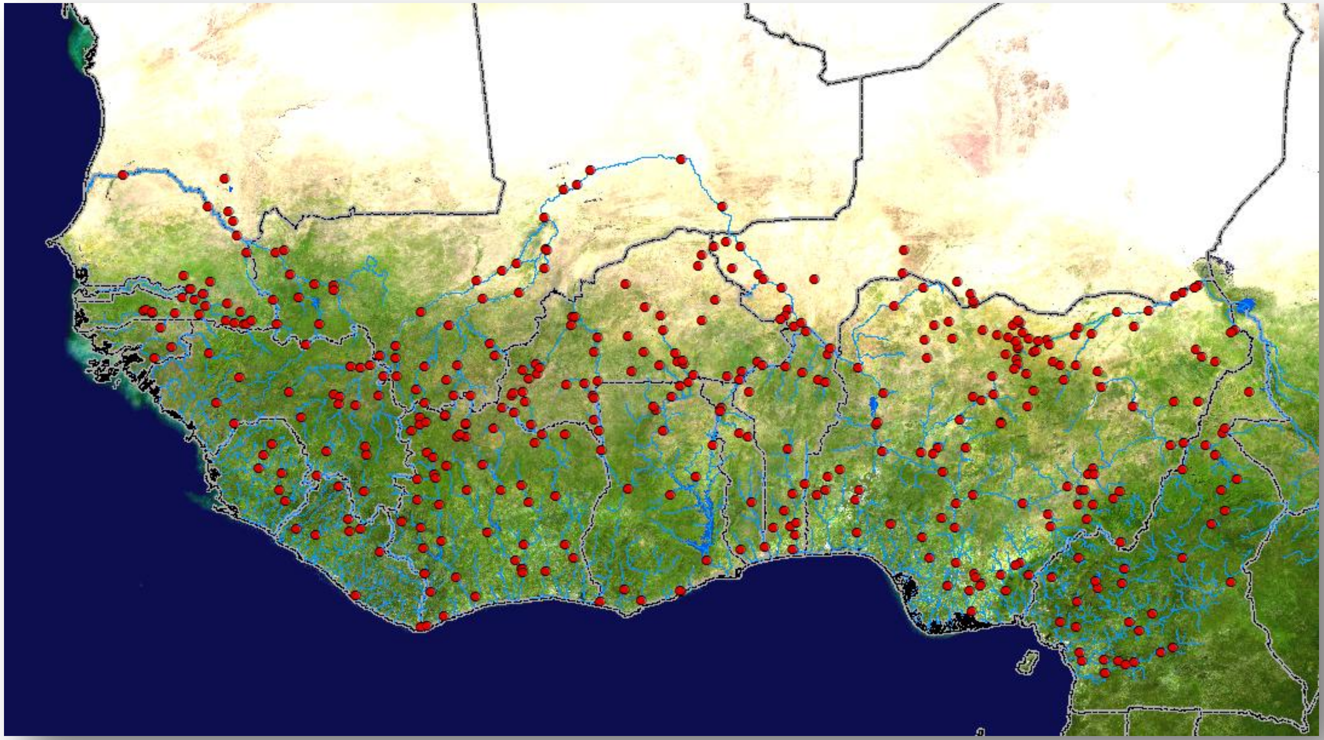
Hydropower theory

Aggregation of theoretical hydropower potential

- The theoretical hydropower potential is initially computed for each river reach.
- It gives the mean annual power (in MW) that could be produced in this river reach if a hydropower plant:
  - Utilizes the full head (elevation difference) in the reach
  - Turbinates the full river discharge (no spillway losses)
  - Turbine efficiency and hydraulic losses are already roughly considered
- Aggregation of theoretical hydropower potential:
  - River: Sum of theoretical hydropower potential of all reaches along the river
  - Basin: Sum of theoretical hydropower potential of main river and all tributaries in the basin
  - Country: Sum of theoretical hydropower potential of all basins in the country

Discharge measurement in West Africa

410 discharge gauges available for this study

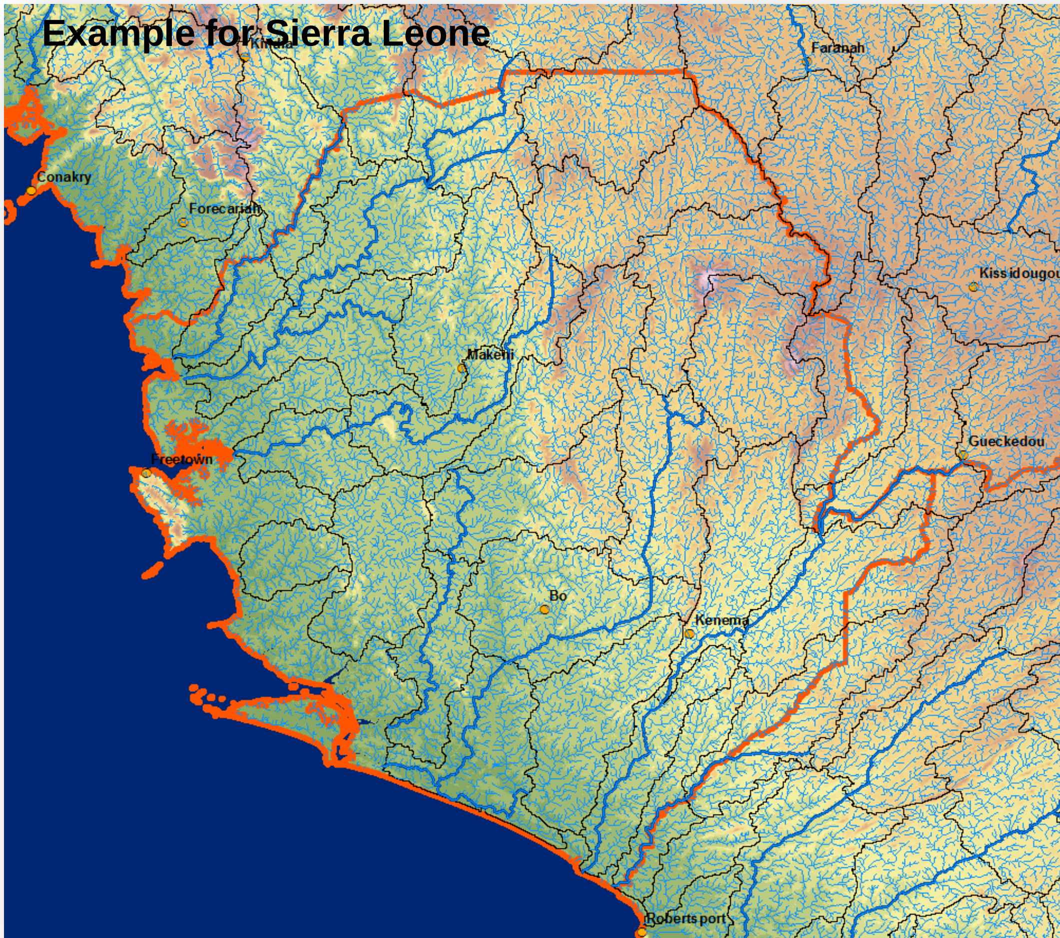


- Discharge (along with slope) determines the hydropower potential of a river.
- Gauges usually located at medium/large rivers.
- Hardly any gauges located at small rivers that are suitable for small-scale hydropower.
- Gauge data cover different observation periods.
- Regionalization of flow is required.

GIS mapping & water balance modelling

River network

GIS delineation of river reaches

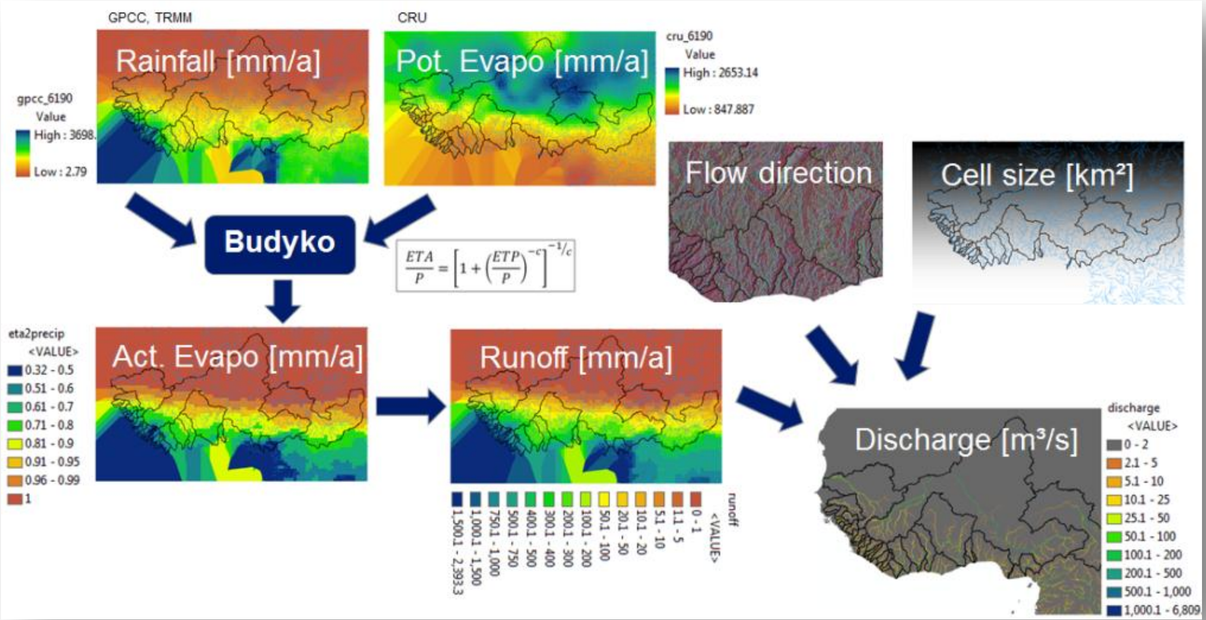


- Method:
  - Hydrosheds flow direction
  - GIS processing (> 2 km² threshold for reach delineation)
  - Eliminate reaches with no discharge (in arid regions)
- 500,000 river reaches in West Africa
- Delineate sub-catchments
  - 1060 sub-catchments
  - Inland: > 3000 km²
  - At coast: > 1000 km²
  - Manual adjustments at reservoirs
- Extract river elevation from DEM

Water balance modelling

Discharge estimation for 500,000 river reaches

- **Water balance model**
  - Spatially distributed
  - Routing along river network
  - Major losses:
    - Irrigation schemes
    - Floodplains



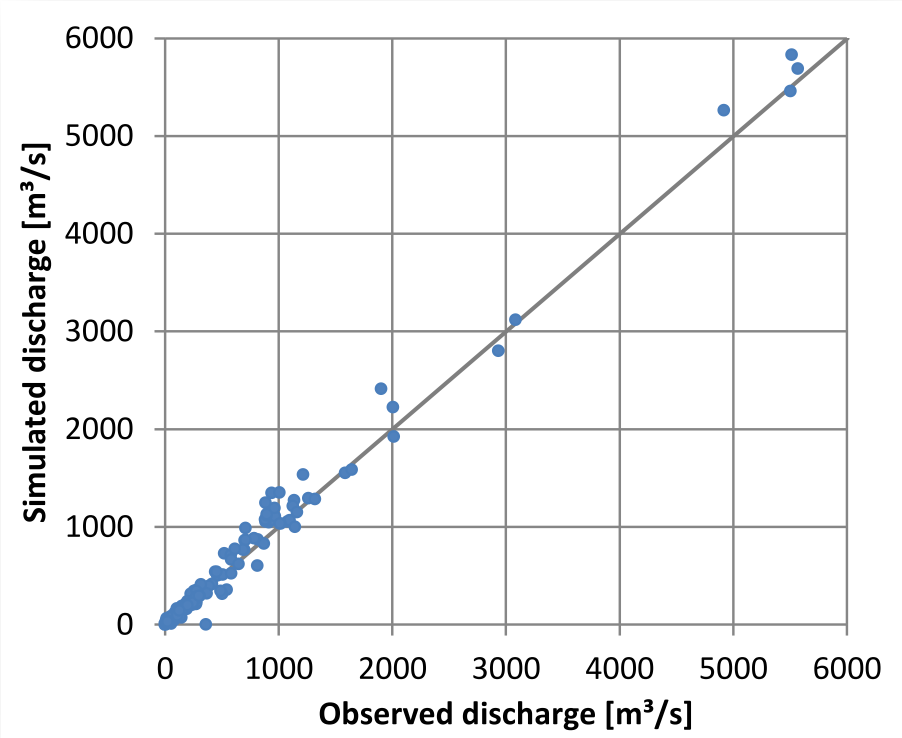
- **Inputs**
  - Rainfall
  - Potential evapotranspiration

- **Output**
  - Mean annual discharge for each reach

- **Calibration**
  - 410 gauges used for calibration / verification of results
  - Regional patterns of model parameters

Water balance modelling

Comparison of simulated vs. observed mean annual discharge at 410 gauges

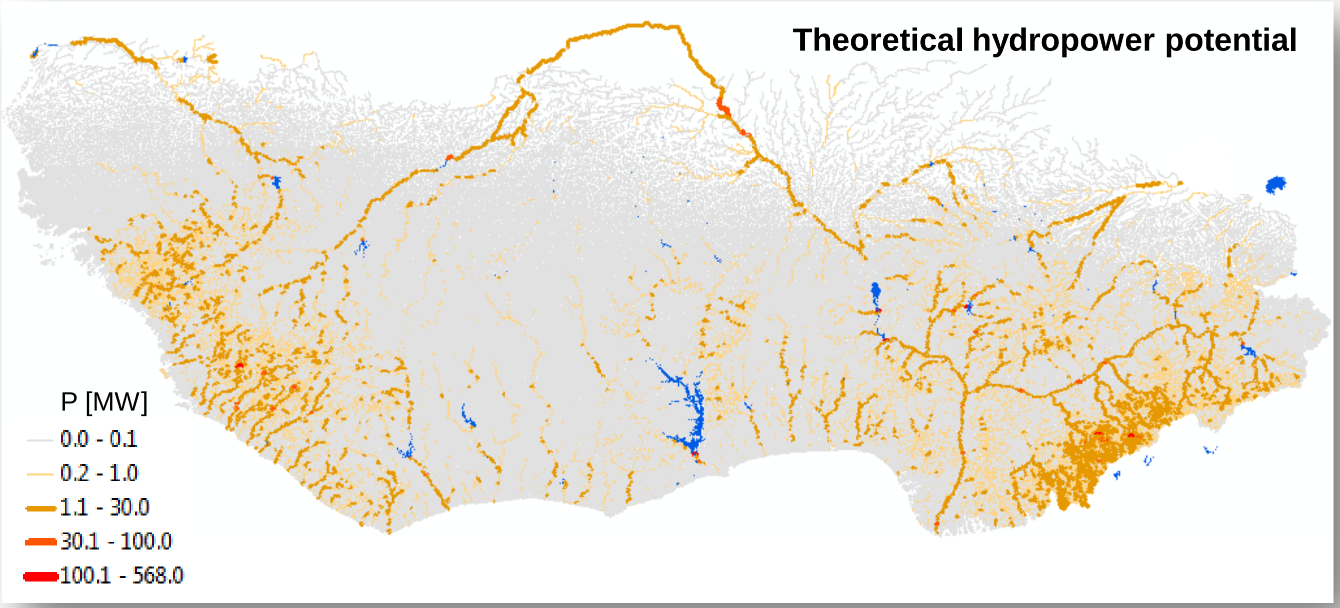


GPCC data, 1950-2010
401 gauges with available Qobs

Theoretical hydropower potential

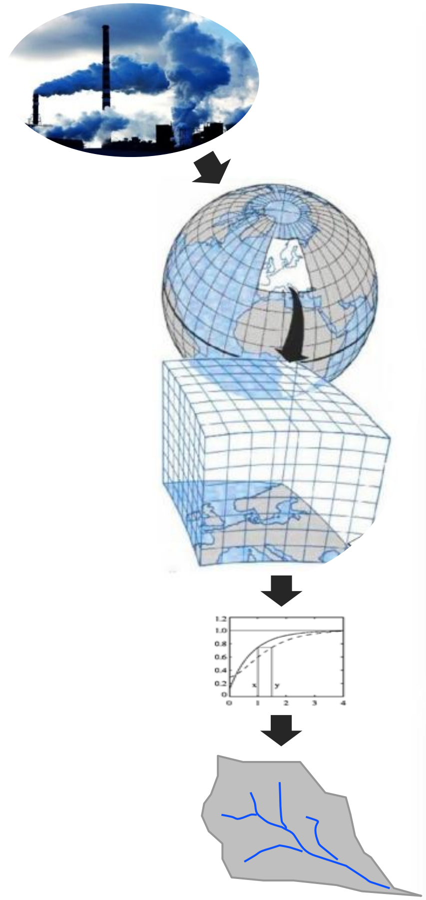
Computed for 500,000 river reaches

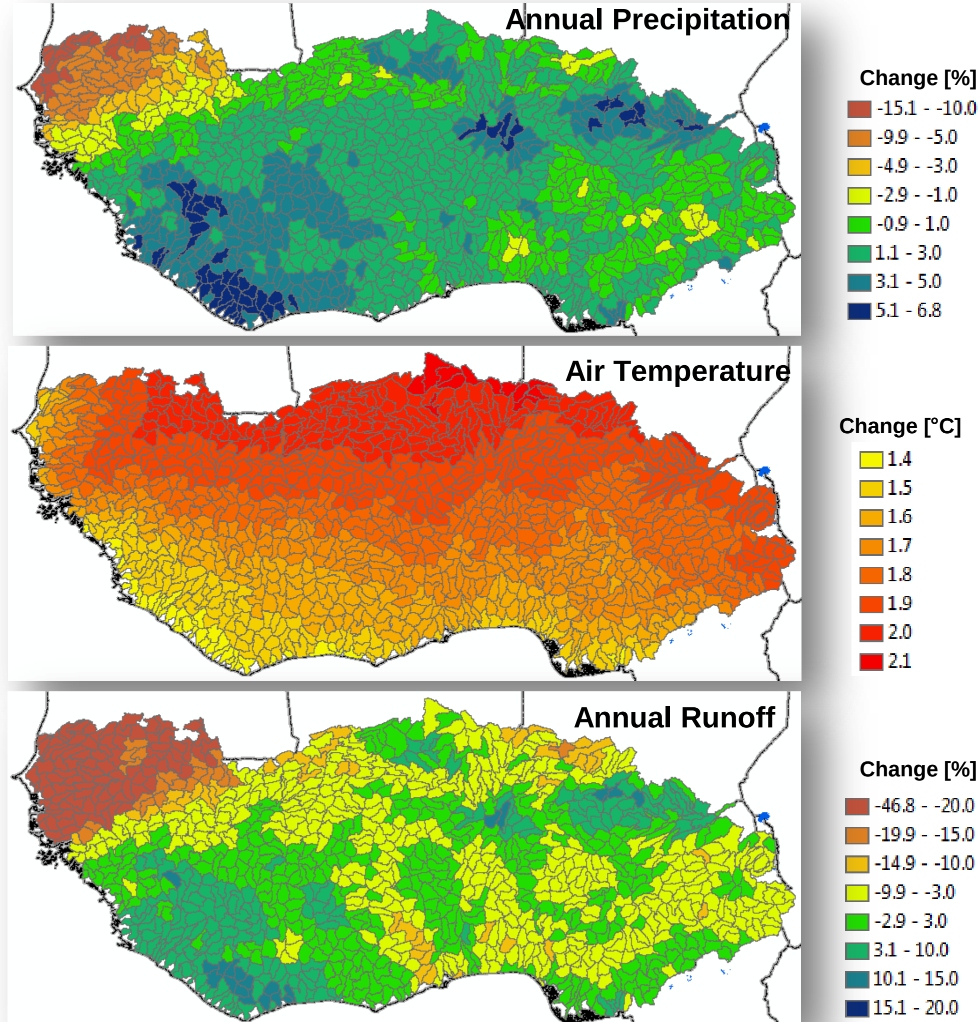
$$\textbf{\textit{Power}}\ [\text{MW}] = \textbf{\textit{Flow}}\ [\text{m}^3/\text{s}] * \textbf{\textit{Height}}\ [\text{m}] * \textbf{\textit{c}}$$



CORDEX Africa climate change analysis

2046-2065 vs. 1998-2014





Median projection out of 30 climate model runs.

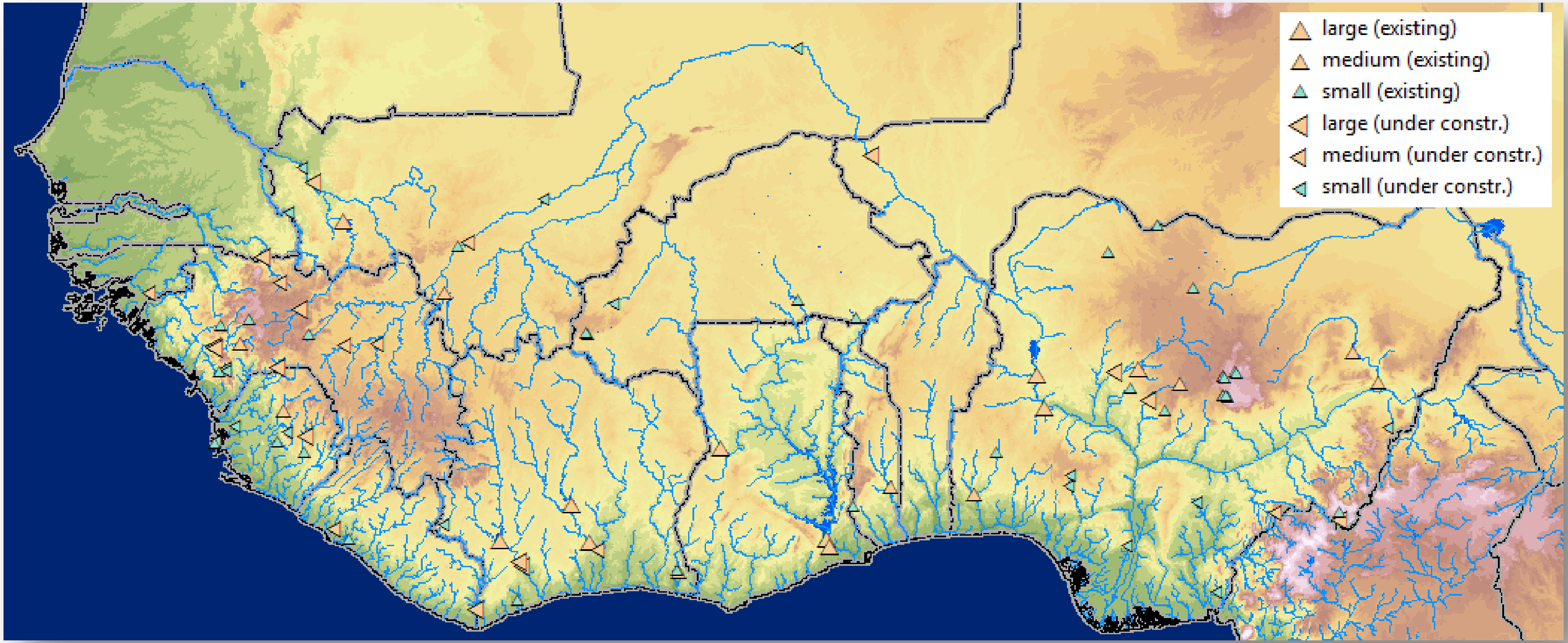
Results overview

New layers for ECOWREX system

- Existing hydropower plants layer
- Climatic zones layer
- River network layer
- Sub-areas layer (Sub-catchments)
- Country reports
- Climate change (incorporated into other layers)

New layer: Existing hydropower plants

GIS point shape file



- 91 HPPs:
  - 24 large HPPs (> 100 MW)
  - 17 medium HPPs (30-100 MW)
  - 50 small HPPs (< 30MW)

- ~20 attributes (installed capacity, start year, reservoir area, etc.)

- Data sources:

  ECOWREX, GranD, Aquastat, H&D, JICA, SHP News, World Small HPP Development Rep., Int. Water Power & Dam Yearbook, SE4ALL, online search, etc.

New layer: Existing hydropower plants

Attribute list for 91 HPPs

- Name: Name of HPP.
- Name_alt: Alternative name, if known.
- Country: Country of location of the HPP.
- ISO: Three letter country name acronym.
- Existing: Main status division (yes/no), further divided in the status attribute (see status attribute).
- Hpp_class: Capacity class according to the ECOWAS classification (small < 30MW, medium 30-100 MW, large > 100 MW).
- Status: Describes the status of the HPP in six categories: operational, under refurbishment, under construction (these three have the value Yes in the Existing attribute); identified, planned, proposed (these three have the value No in the Existing attribute).
- Lat: Latitude (decimal degrees North) of the location, snapped to river network.
- Lon: Longitude (decimal degrees East) of the location, snapped to river network.
- River: Name of the river where the HPP is located.
- River_alt: Alternative river name, if applicable.
- Year: Year of start of operation for existing HPPs. Estimated for HPPs under construction and under refurbishment.
- Dam_height: Height (m) of the main dam for existing HPPs.
- Cap_Instal: Installed capacity (MW) for operational HPPs and HPPs under refurbishment.
- Cap_Availa: Currently available capacity (MW) for operational HPPs.
- Cap_Planned: Planned capacity (MW) for HPPs under construction and under refurbishment.
- Volume: Reservoir volume (hm^3) for existing HPPs.
- Lake_area: Reservoir area (km^2) for existing HPPs.

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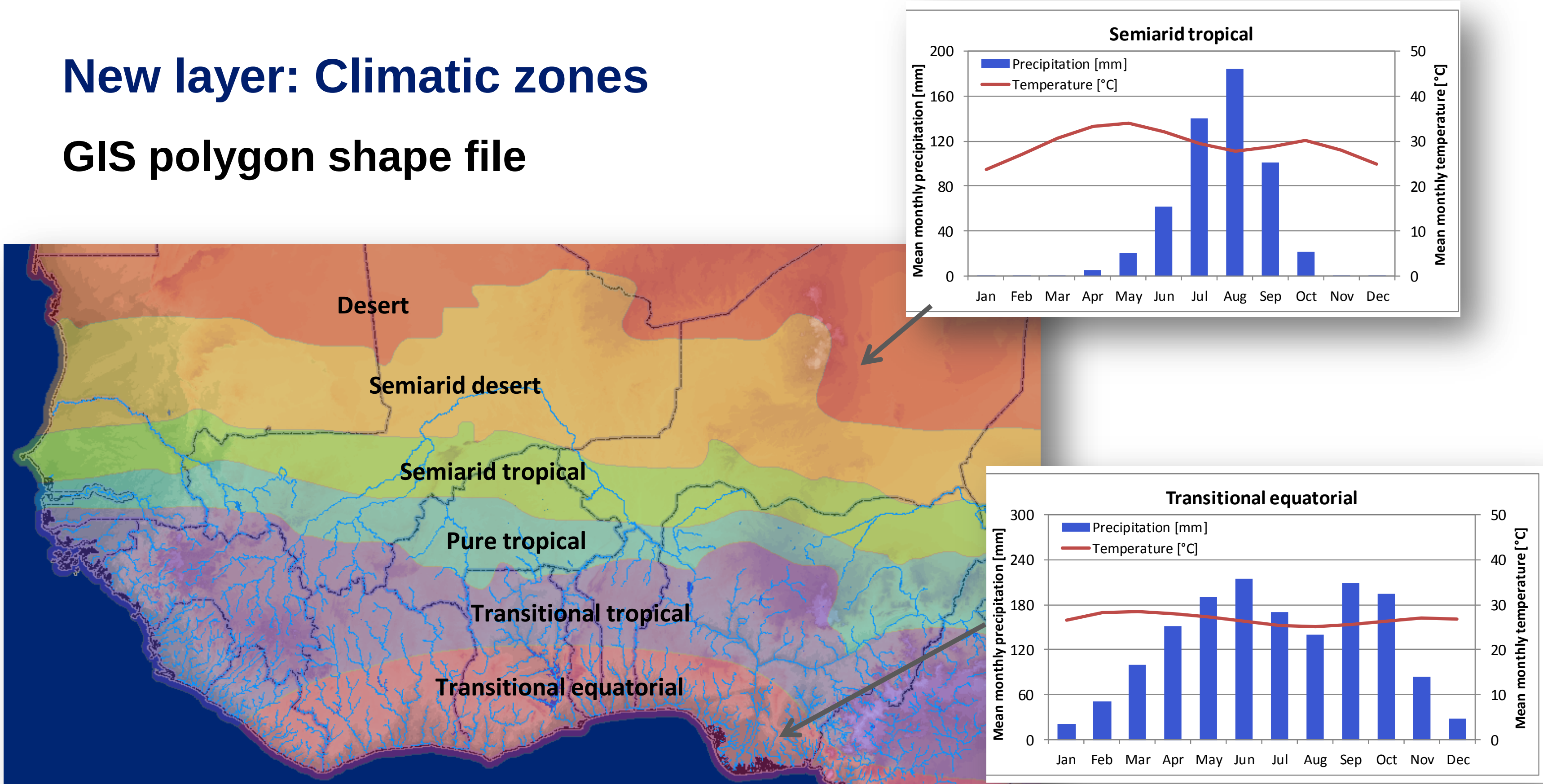
New layer: Climatic zones

GIS polygon shape file



- 6 climatic zones
- Classification
  - L'Hôte et al. (1996)
  - Based on rainfall characteristics
- GIS generalization & smoothing
- Data sources
  - Rainfall: TRMM 1998-2014
  - Air temperature: CRU 1998-2013
  - Potential evapotranspiration: CRU 1998-2013

New layer: Climatic zones

Attribute list for 6 climatic zones

- CLZ_ID: ID of climatic zone
- NAME_FR: Climatic zone denomination in French
- NAME_ENG: Climatic zone denomination in English
- PRECIP_Y: Mean annual precipitation (mm) in the period 1998-2014
- TEMP_Y: Mean annual air temperature (°C) in the period 1998-2014
- ETP_Y: Mean annual potential evapotranspiration (mm) in the period 1998-2014
- P_2035_P25: Change in future mean annual **precipitation** in % (**2026-2045** vs. 1998-2014) for the **lower quartile** projection of 30 RCMs
- P_2035_P50: Change in future mean annual **precipitation** in % (2026-2045 vs. 1998-2014) for the **median** projection of 30 RCMs
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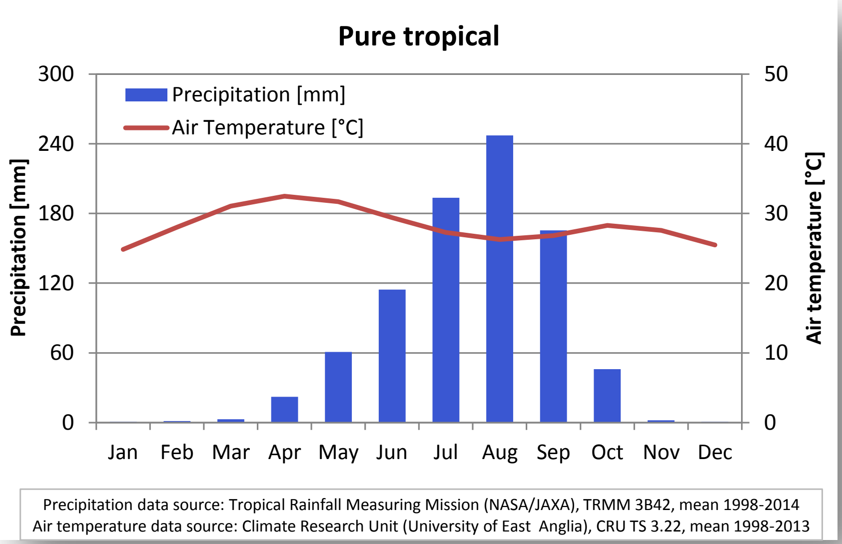
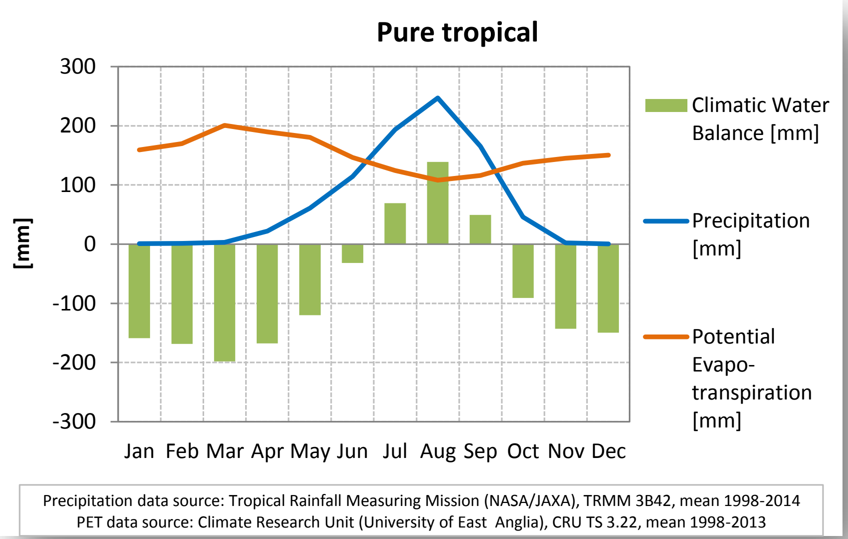
- T_2035_P25: Change in future mean annual **air temperature** in °C (2026-2045 vs. 1998-2014) for the lower quartile projection
- T_2035_P50: Change in future mean annual **air temperature** in °C (2026-2045 vs. 1998-2014) for the median projection
- T_2035_P75: Change in future mean annual **air temperature** in °C (2026-2045 vs. 1998-2014) for the upper quartile projection
- E_2035_P25: Change in future mean annual **potential evapotranspiration** in % (2026-2045 vs. 1998-2014) for the lower quartile simulation
- E_2035_P50: Change in future mean annual **potential evapotranspiration** in % (2026-2045 vs. 1998-2014) for the median simulation
- E_2035_P75: Change in future mean annual **potential evapotranspiration** in % (2026-2045 vs. 1998-2014) for the upper quartile simulation
- P_2055_P25: Change in future mean annual **precipitation** in % (**2046-2065** vs. 1998-2014) for the lower quartile projection of 30 RCMs
- etc.

New layer: Climatic zones

2 figures attached to each climatic zone





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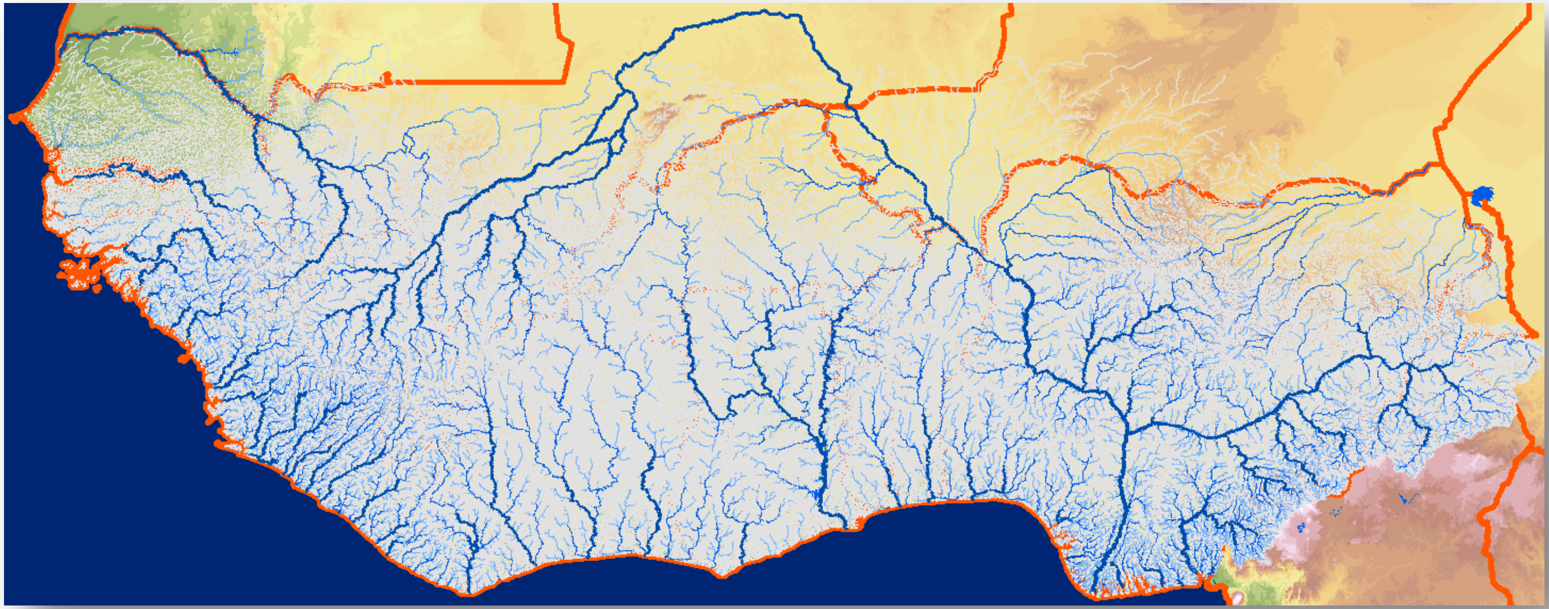
New layer: River network

GIS line shape file

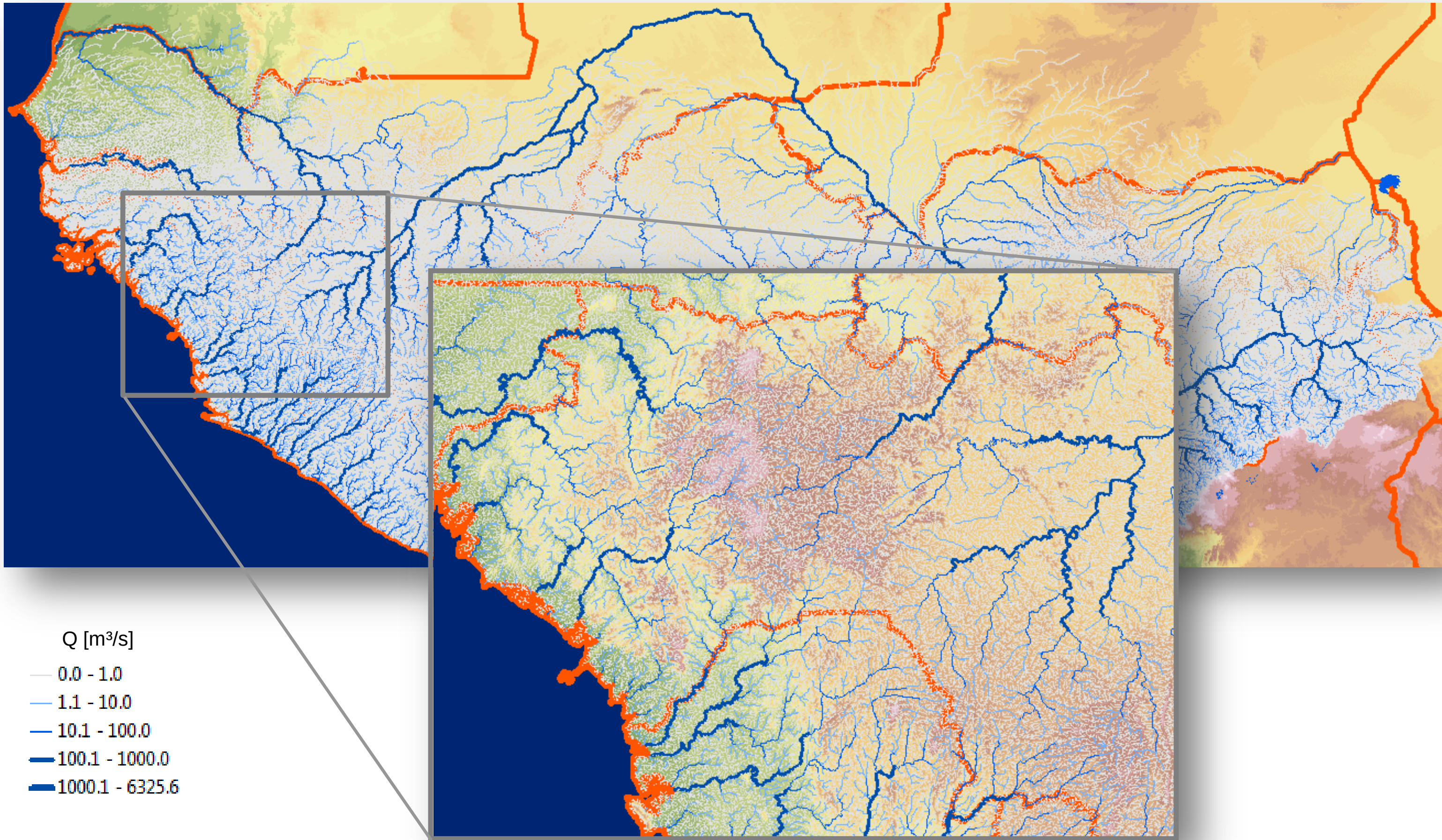


Q [m³/s]

- 0.0 - 1.0
- 1.1 - 10.0
- 10.1 - 100.0
- 100.1 - 1000.0
- 1000.1 - 6325.6

New layer: River network

GIS line shape file



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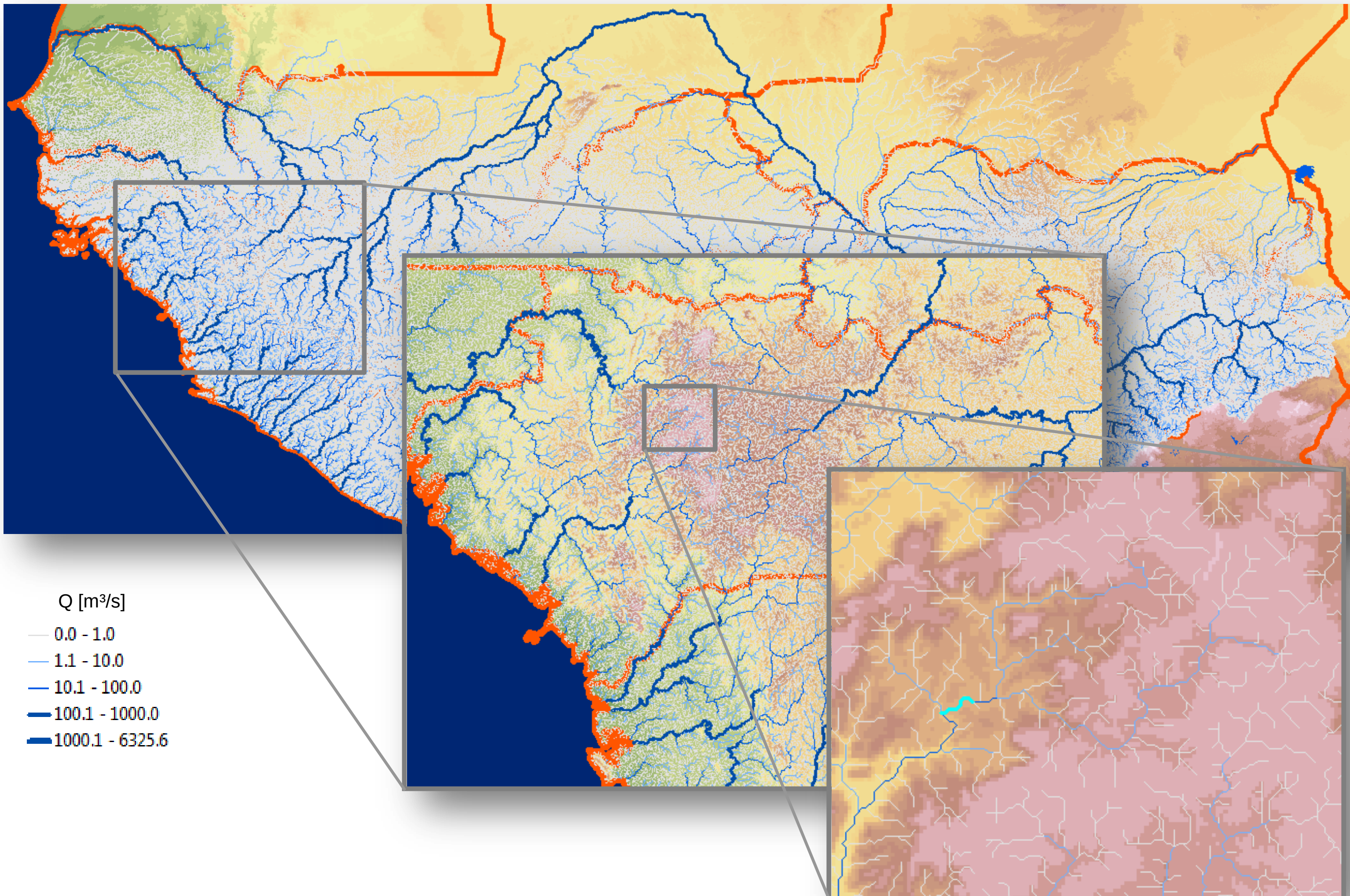
GIS line shape file



Field	Value
ARCID	622220
TOARCID	624320
FROMARCID	620958
NB	307
RIVER	Kakrima
RIVER_FREN	Kakirima
COUNTRY_1	GIN
COUNTRY_2	
AREA	988.46
LENGTH	4.82
EXRIVER	0
ELEV_US	497.5
ELEV_DS	446
ELEV_DIFF	51.5
SLOPE	0.01069
POWER	7.265
POWER_SPEC	1.508
Q_YEAR	16.60
Q_JAN	3.18
Q_FEB	2.83
Q_MAR	3.89
Q_APR	7.08
Q_MAY	17.69
Q_JUN	35.38
Q_JUL	46
Q_AUG	42.46
Q_SEP	21.23
Q_OCT	10.61
Q_NOV	5.31
Q_DEC	3.54
Q_2035_P25	-5.4
Q_2035_P50	-1.1
Q_2035_P75	4.2
Q_2055_P25	-8.8
Q_2055_P50	-0.2
Q_2055_P75	3.4
PLANT_SIZE	2
LAT	11.3104
LON	-12.6521

New layer: River network

Attribute list for 500,000 river reaches, part 1/2

- ARCID: ID number of reach
- TOARCID: ID number of next downstream reach
- FROMARCID: ID number of dominant upstream reach (largest inflow)
- LAT: Latitude (decimal degrees North) at end of reach
- LON: Longitude (decimal degrees East) at end of reach
- NB: ID number of sub-area
- RIVER: River name (English)
- RIVER_FREN: River name (French)
- COUNTRY_1: Country (ISO code)
- COUNTRY_2: Second country (ISO code) if reach forms international border
- AREA: Total upstream catchment area (km^2) of reach
- LENGTH: Length (km) of reach
- EXRIVER: Flag indicating external river originating from another sub-area (0: local river, 1: external river)
- ELEV_US: Elevation (m) at upstream end of reach
- ELEV_DS: Elevation (m) at downstream end of reach
- ELEV_DIFF: Elevation difference (m) in reach
- SLOPE: Slope (m/m) of reach
- POWER: Theoretical hydropower potential (MW) for the period 1998-2014
- POWER_SPEC: Specific hydropower potential (MW/km) for the period 1998-2014
- PLANT_SIZE: Preferred hydropower plant size (0: none, 1: <1MW, 2: 1-30MW, 3: >30MW installed capacity)
- ...

New layer: River network

Attribute list for 500,000 river reaches, part 2/2

- ...
- Q_YEAR: Mean annual discharge (m^3/s) simulated for the period 1998-2014
- Q_JAN: Mean monthly discharge (m^3/s) 1998-2014 in January
- Q_FEB: Mean monthly discharge (m^3/s) 1998-2014 in February
- Q_MAR: Mean monthly discharge (m^3/s) 1998-2014 in March
- Q_APR: Mean monthly discharge (m^3/s) 1998-2014 in April
- Q_MAY: Mean monthly discharge (m^3/s) 1998-2014 in May
- Q_JUN: Mean monthly discharge (m^3/s) 1998-2014 in June
- Q_JUL: Mean monthly discharge (m^3/s) 1998-2014 in July
- Q_AUG: Mean monthly discharge (m^3/s) 1998-2014 in August
- Q_SEP: Mean monthly discharge (m^3/s) 1998-2014 in September
- Q_OCT: Mean monthly discharge (m^3/s) 1998-2014 in October
- Q_NOV: Mean monthly discharge (m^3/s) 1998-2014 in November
- Q_DEC: Mean monthly discharge (m^3/s) 1998-2014 in December
- Q_2035_P25: Change in future mean annual **discharge** in % (**2026-2045** vs. 1998-2014) for the **lower quartile** simulation using 30 RCM runs
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- Q_2035_P75: Change in future mean annual **discharge** in % (**2026-2045** vs. 1998-2014) for the **upper quartile** simulation using 30 RCM runs
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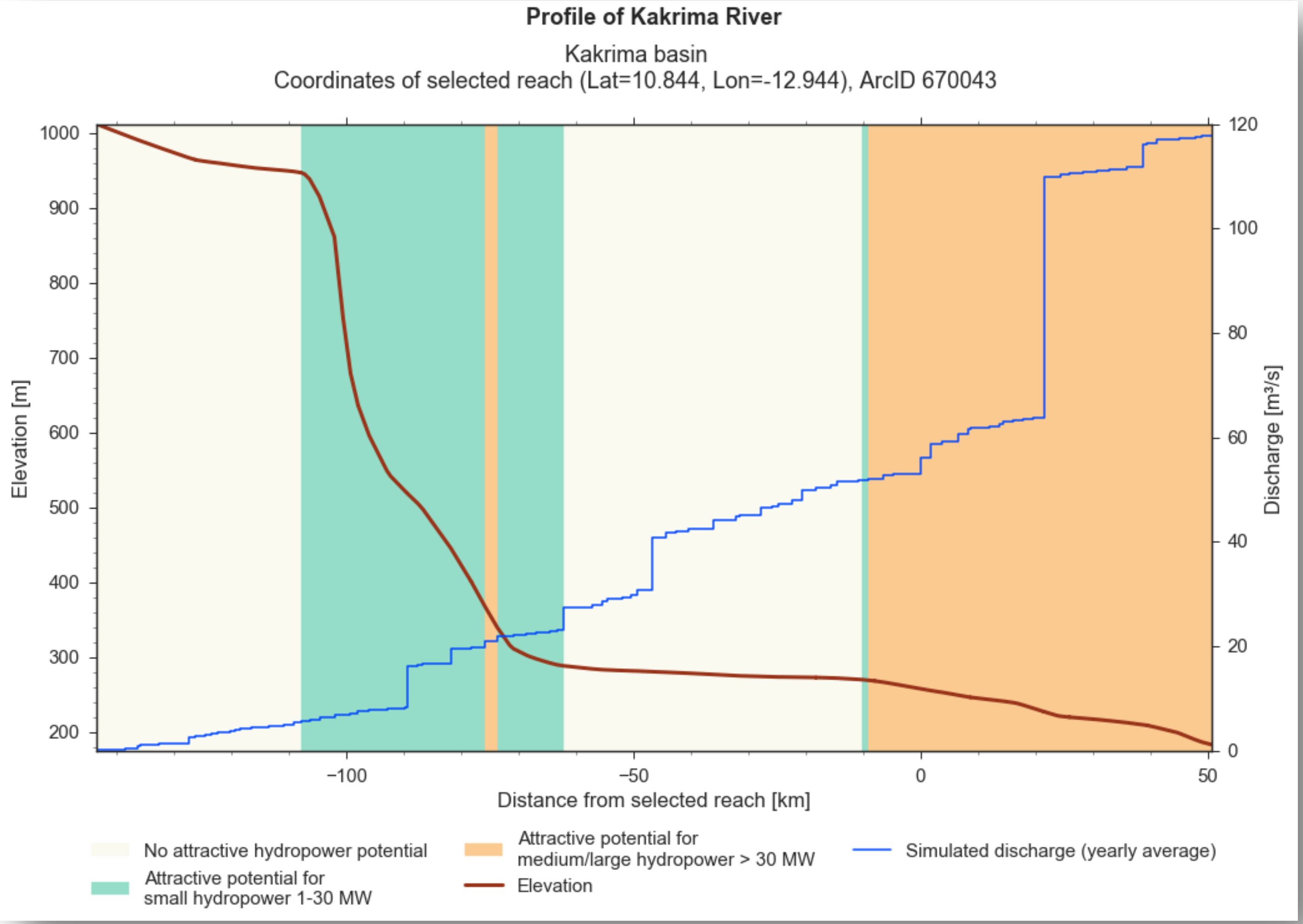
- Q_2055_P50: Change in future mean annual **discharge** in % (**2046-2065** vs. 1998-2014) for the median simulation using 30 RCM runs
- Q_2055_P75: Change in future mean annual **discharge** in % (**2046-2065** vs. 1998-2014) for the upper quartile simulation using 30 RCM runs

New layer: River network

Longitudinal river profiles for all reaches/rivers



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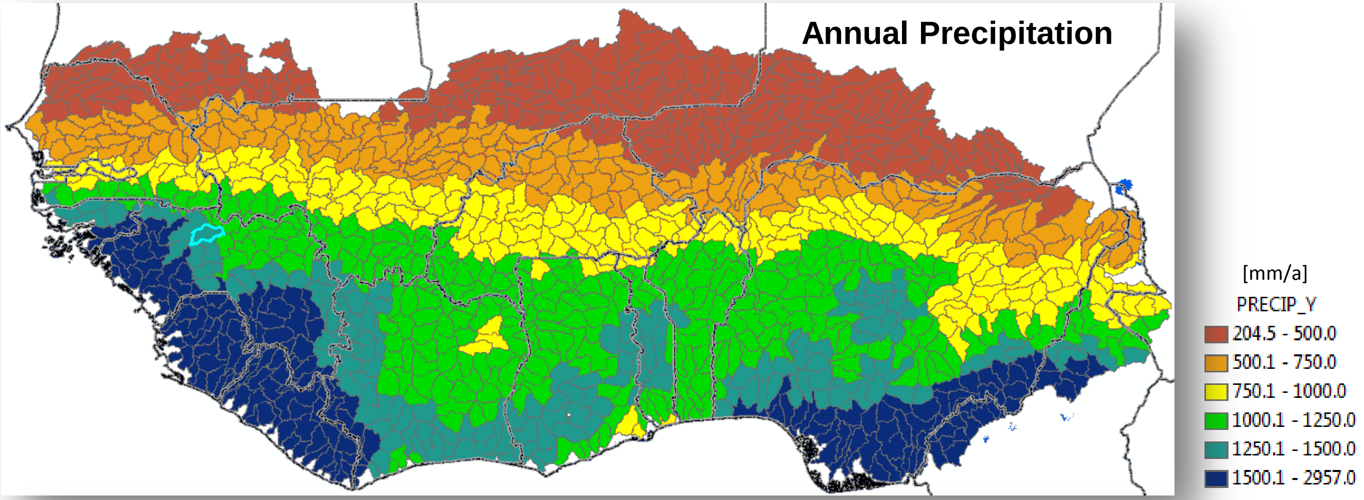
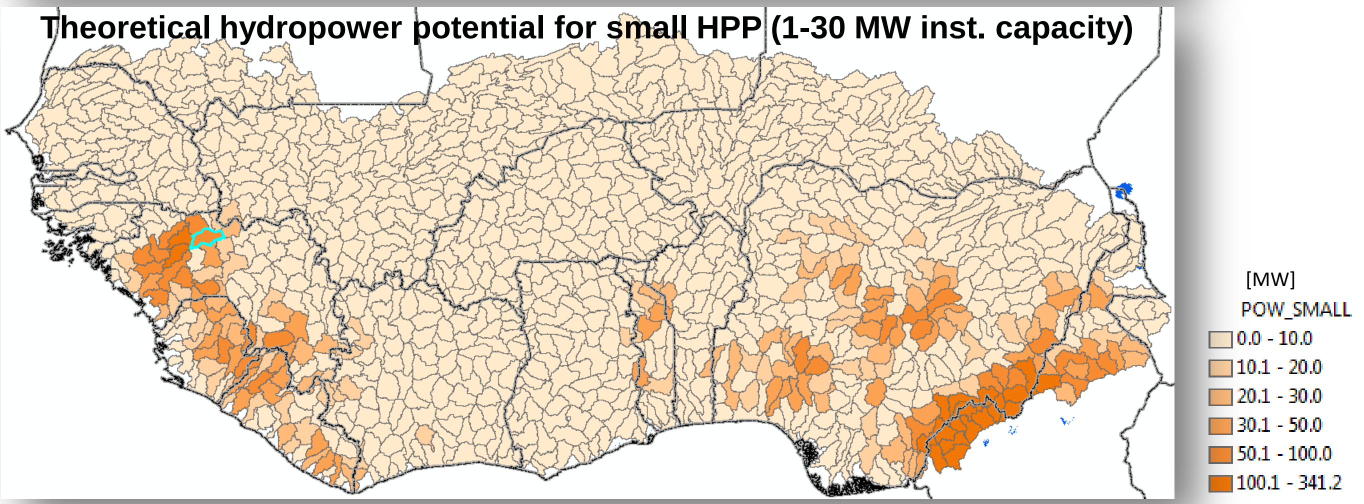
New layer: Sub-areas (sub-catchments)

GIS polygon shape file





Field	Value
NB	296
AREA	3626.9
PRECIP_Y	1334.6
ETA_Y	1041.9
RUNOFF_Y	292.7
TEMP_Y	25.9
P_2035_P25	-0.9
P_2035_P50	1.2
P_2035_P75	5.9
P_2055_P25	-0.4
P_2055_P50	2.9
P_2055_P75	7.4
E_2035_P25	0.4
E_2035_P50	2
E_2035_P75	4.1
E_2055_P25	1.4
E_2055_P50	3.5
E_2055_P75	5.9
R_2035_P25	-5.9
R_2035_P50	-0.9
R_2035_P75	12.4
R_2055_P25	-7.8
R_2055_P50	0.6
R_2055_P75	12.9
T_2035_P25	0.9
T_2035_P50	0.9
T_2035_P75	1.1
T_2055_P25	1.4
T_2055_P50	1.7
T_2055_P75	2
POWER	92.529
POW_MINI	8.224
POW_SMALL	65.795
POW_MEDIUM	0
ATT_MINI	1
ATT_SMALL	1
ATT_MEDIUM	0
PLANT_TYP1	0
PLANT_TYP2	0
PLANT_TYP3	0
PLANT_TYP4	0
MAC_MINI	
MAC_SMALL	
MAC_MEDIUM	
PT_2035_25	-5.865
PT_2035_50	-0.851
PT_2035_75	12.416
PT_2055_25	-7.766
PT_2055_50	0.659
PT_2055_75	12.867
PL_2035_25	-5.865
PL_2035_50	-0.851
PL_2035_75	12.416
PL_2055_25	-7.766
PL_2055_50	0.659
PL_2055_75	12.867

New layer: Sub-areas (sub-catchments)

Attribute list for 1060 sub-areas, part 1/3

- NB: ID number of sub-area
- AREA: local size (km²) of sub-area
- PRECIP_Y: Mean annual precipitation (mm) in the period 1998-2014
- ETA_Y: Mean annual actual evapotranspiration (mm) simulated for the period 1998-2014
- RUNOFF_Y: Mean annual runoff (mm) simulated for the period 1998-2014
- TEMP_Y: Mean annual air temperature (°C) in the period 1998-2014
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- P_2035_P50: Change in future mean annual **precipitation** in % (**2026-2045** vs. 1998-2014) for the **median projection** of 30 RCM runs
- P_2035_P75: Change in future mean annual **precipitation** in % (**2026-2045** vs. 1998-2014) for the **upper quartile** projection of 30 RCM runs
- E_2035_P25: Change in future mean annual **actual evapotranspiration** in % (2026-2045 vs. 1998-2014) for the lower quartile simulation
- E_2035_P50: Change in future mean annual **actual evapotranspiration** in % (2026-2045 vs. 1998-2014) for the median simulation
- E_2035_P75: Change in future mean annual **actual evapotranspiration** in % (2026-2045 vs. 1998-2014) for the upper quartile simulation
- R_2035_P25: Change in future mean annual **runoff** in % (2026-2045 vs. 1998-2014) for the lower quartile simulation using 30 RCM runs
- R_2035_P50: Change in future mean annual **runoff** in % (2026-2045 vs. 1998-2014) for the median simulation using 30 RCM runs
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- etc.
- ...

New layer: Sub-areas (sub-catchments)

Attribute list for 1060 sub-areas, part 2/3

- ...
- POWER: Theoretical hydropower potential (MW) for the period 1998-2014 (total of all river reaches located in the sub-area)
- POW_MINI: Theoretical hydropower potential (MW) for pico/micro/mini hydropower plants (< 1 MW installed capacity) for the period 1998-2014
- POW_SMALL: Theoretical hydropower potential (MW) for small hydropower plants (1-30 MW installed capacity) for the period 1998-2014
- POW_MEDIUM: Theoretical hydropower potential (MW) for medium/large hydropower plants (>30 MW installed capacity)
- ATT_MINI: Region with theoretical hydropower potential that is attractive (0: no, 1: yes) for pico/micro/mini hydropower plants (< 1 MW installed capacity)
- ATT_SMALL: Region with theoretical hydropower potential that is attractive (0: no, 1: yes) for small hydropower plants (1-30 MW installed capacity)
- ATT_MEDIUM: Region with theoretical hydropower potential that is attractive (0: no, 1: yes) for medium/large hydropower plants (> 30 MW installed capacity)
- PLANT_TYP1: Region suitable (0: no, 1: yes) for hydropower plant type 1 (run-of-river without diversion)
- PLANT_TYP2: Region suitable (0: no, 1: yes) for hydropower plant type 2 (run-of-river with diversion)
- PLANT_TYP3: Region suitable (0: no, 1: yes) for hydropower plant type 3 (storage without diversion)
- PLANT_TYP4: Region suitable (0: no, 1: yes) for hydropower plant type 4 (storage with diversion)
- MAC_MINI: Preferred machine type for pico/micro/mini hydropower plants (< 1 MW installed capacity)
- MAC_SMALL: Preferred machine type for small hydropower plants (1-30 MW installed capacity)
- MAC_MEDIUM: Preferred machine type for medium/large hydropower plants (> 30 MW installed capacity)
- ...

New layer: Sub-areas (sub-catchments)

Attribute list for 1060 sub-areas, part 3/3

- ...
- PT_2035_25: Change in future **hydropower potential** in % (**2026-2045** vs. 1998-2014) for the **lower quartile** simulation using 30 RCM runs
- PT_2035_50: Change in future **hydropower potential** in % (2026-2045 vs. 1998-2014) for the **median** simulation using 30 RCM runs
- PT_2035_75: Change in future **hydropower potential** in % (2026-2045 vs. 1998-2014) for the **upper** quartile simulation using 30 RCM runs
- PL_2035_25: Change in future **hydropower potential** in % (2026-2045 vs. 1998-2014) of **local rivers** (originating from the same sub-area) for the lower quartile simulation using 30 RCMs
- PL_2035_50: Change in future **hydropower potential** in % (2026-2045 vs. 1998-2014) of **local rivers** (originating from the same sub-area) for the median simulation using 30 RCMs
- PL_2035_75: Change in future **hydropower potential** in % (2026-2045 vs. 1998-2014) of **local rivers** (originating from the same sub-area) for the upper quartile simulation using 30 RCMs
- PT_2055_25: Change in future **hydropower potential** in % (**2046-2065** vs. 1998-2014) for the lower quartile simulation using 30 RCM runs
- etc.

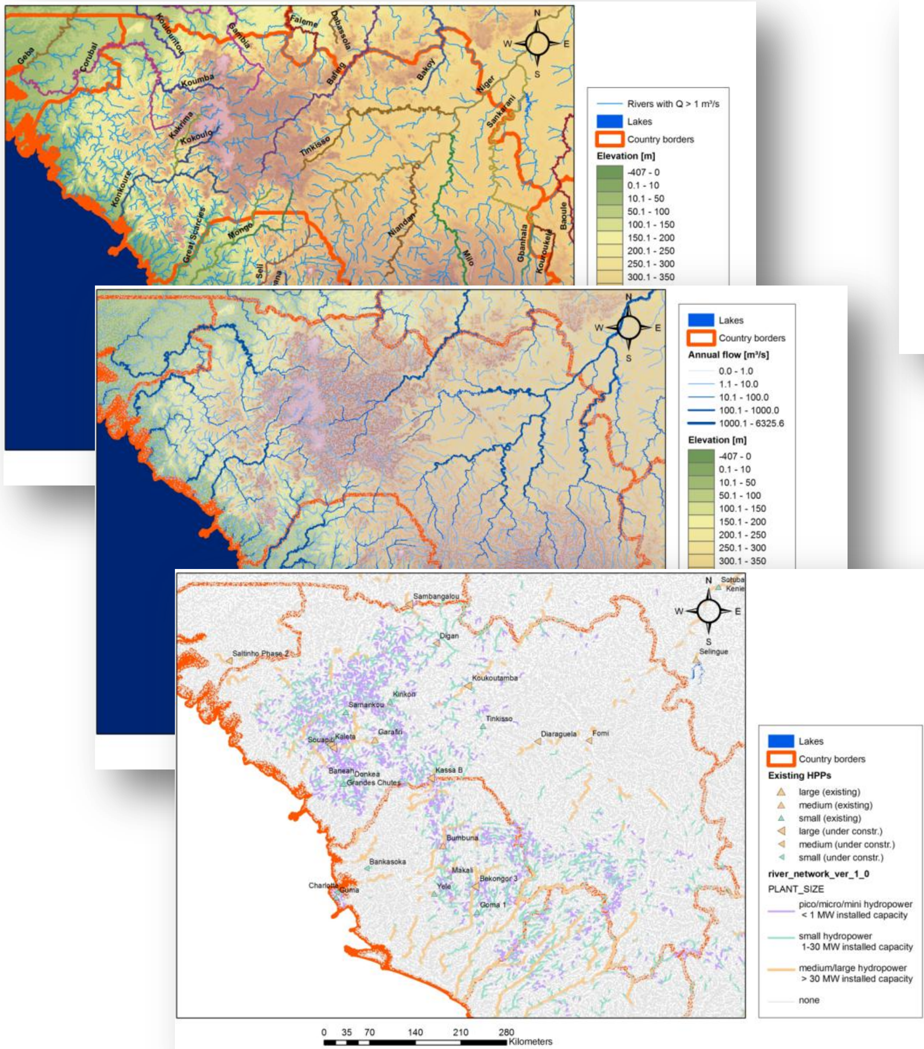
Results overview

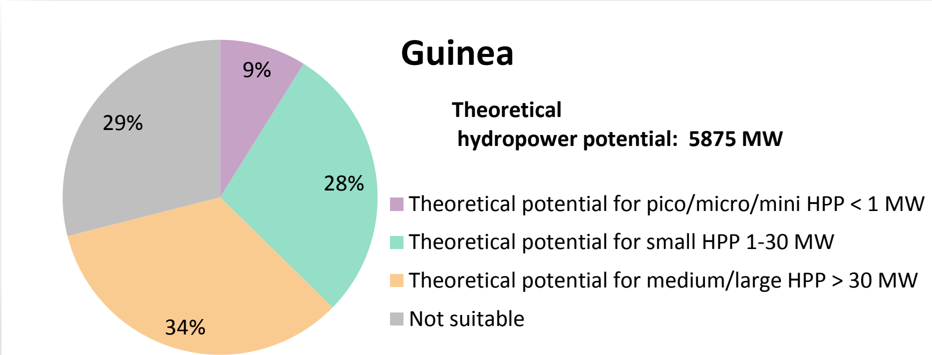
New layers for ECOWREX system

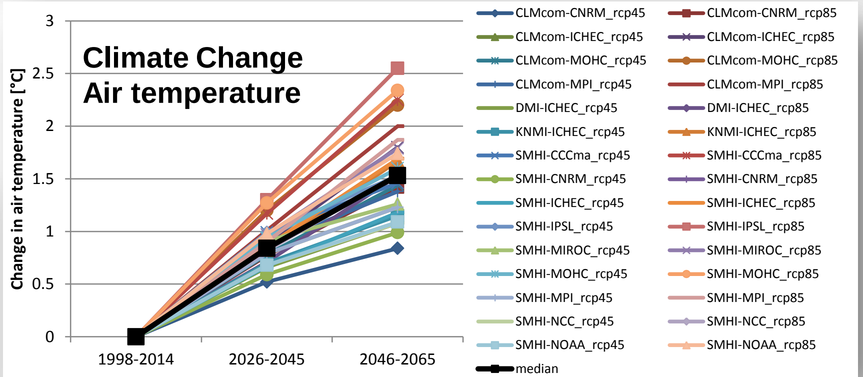
- ✓ Existing hydropower plants layer
- ✓ Climatic zones layer
- ✓ River network layer
- ✓ Sub-areas layer (sub-catchments)
- → Country reports
- Climate change (incorporated into other layers)

New layer: Country reports

14 text documents with maps, tables and figures







Results overview

New layers for ECOWREX system

- ✓ Existing hydropower plants layer
- ✓ Climatic zones layer
- ✓ River network layer
- ✓ Sub-areas layer (sub-catchments)
- (✓) Country reports (under preparation)
- ✓ Climate change (incorporated into other layers)

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