CÔTE D'IVOIRE

COUNTRY REPORT

GIS Hydropower Resource Mapping and Climate Change Scenarios for the ECOWAS Region

ECOWAS Centre for Renewable Energy and Energy Efficiency
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AUSTRIAN DEVELOPMENT COOPERATION

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Program Responsibility:

The ECOWAS Small-Scale Hydropower Program was approved by ECOWAS Energy Ministers in 2012. In the frame of this program ECREEE assigned Poyry Energy GmbH in 2015 for implementation of a GIS Hydro Resource Mapping and Climate Change Scenarios in ECOWAS countries with Hydropower potentials. One deliverable of this project are 14 country reports summarizing the GIS Hydro Resource mapping and climate change scenarios. The overall methodology background information and lessons learnt of these Country Reports are described in the final report *"GIS Hydropower Resource Mapping and Climate Change Scenarios for the ECOWAS Region - Methodology & Lessons Learnt."*
www.ecowrex.org/smallhydro

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PREFACE

The 15 countries of the Economic Community of West African States (ECOWAS) face a constant shortage of energy supply, which has negative impacts on social and economic development, including also strongly the quality of life of the population. In mid 2016 the region has about 50 operational hydropower plants and about 40 sites are under construction or refurbishment. The potential for hydropower development – especially for small-scale plants – is assumed to be large, but exact data were missing in the past.

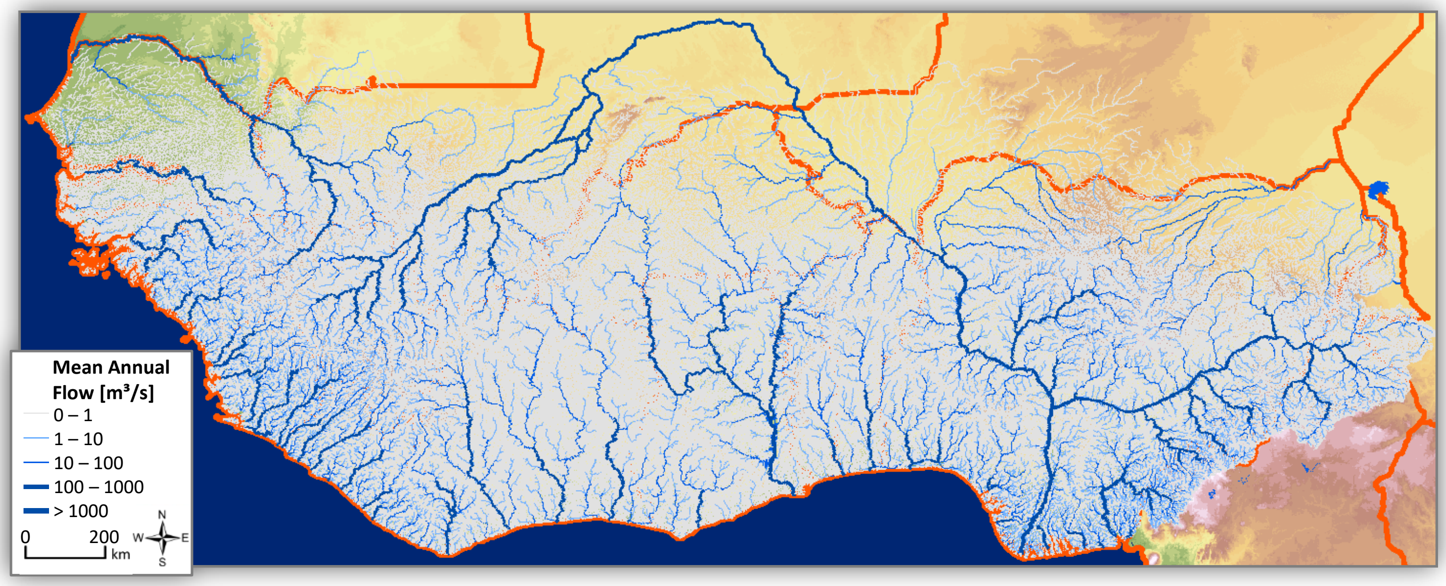
The ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE), founded in 2010 by ECOWAS, ADA, AECID and UNIDO, responded to these challenges and developed the ECOWAS Small-Scale Hydropower Program, which was approved by ECOWAS Energy Ministers in 2012. In the frame of this program ECREEE assigned Pöyry Energy GmbH in 2015 for implementation of a hydropower resource mapping by use of Geographic Information Systems (GIS) for 14 ECOWAS member countries (excluding Cabo Verde). The main deliverable of the project is a complete and comprehensive assessment of the hydro resources and computation of hydropower potentials as well as possible climate change impacts for West Africa. Main deliverables of the GIS mapping include:

- River network layer: GIS line layer showing the river network for about 500,000 river reaches (see river network map below) with attributes including river name (if available), theoretical hydropower potential, elevation at start and end of reach, mean annual discharge, mean monthly discharge, etc.
- Sub-catchment layer: GIS polygon layer showing about 1000 sub-catchments with a size of roughly 3000 km². This layer summarizes the data of all river reaches located within the sub-catchment.

Hydropower plants are investments with a lifetime of several decades. Therefore, possible impacts of climate change on future discharge were incorporated into the river network and sub-catchment GIS layers. The GIS layers are available in the ECREEE Observatory for Renewable Energy and Energy Efficiency (www.ecowrex.org).

This report summarizes the results of the GIS layers for Côte d'Ivoire and includes:

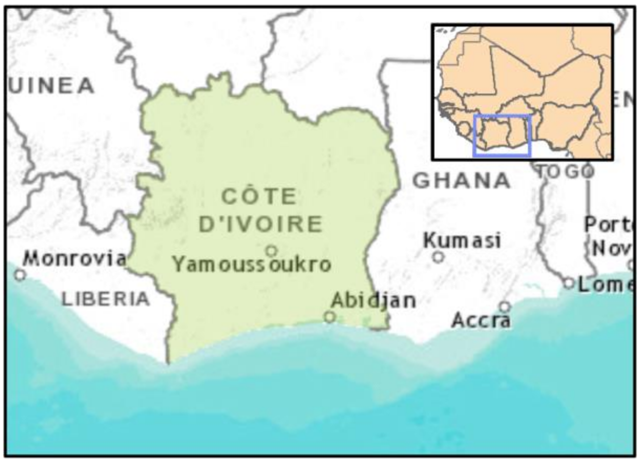
- General information
- Climate
- Hydrology
- Hydropower potential
- Climate change



GENERAL INFORMATION

Côte d'Ivoire has about 22 Mio inhabitants. The capital of Côte d'Ivoire is Yamoussoukro. The neighboring countries are Liberia and Guinea in the east, Mali and Burkina Faso in the north, as well as Ghana in the east (see map below).

Hydropower plays an important role for energy generation in Côte d'Ivoire. Currently there are 11 hydropower plants in Côte d'Ivoire, including small HPP, medium HPP as well as large HPP (see table below).



General Information for Côte d'Ivoire	
Inhabitants (2014)	22.2 Mio.
Area (2014)	332,460 km²
GDP per capita (2014)	1,546 USD
Electrification rate total/urban/rural (2014/2013)	26/45/3 %
Hydro installed capacity (2014)	604 MW
Electricity generation (2014)	8,166 GWh
Electricity generation from hydropower (2014)	1,901 GWh
Number of existing hydropower plants with installed capacity < 1 MW (2016)	11
Number of existing small hydropower plants with installed capacity 1-30 MW (2016)	3
Number of existing medium hydropower plants with installed capacity 30-100 MW (2016)	2
Number of existing large hydropower plants with installed capacity >100 MW (2016)	6

Source: ECOWAS Country Profiles (www.ecowrex.org)
Reference year given in brackets.

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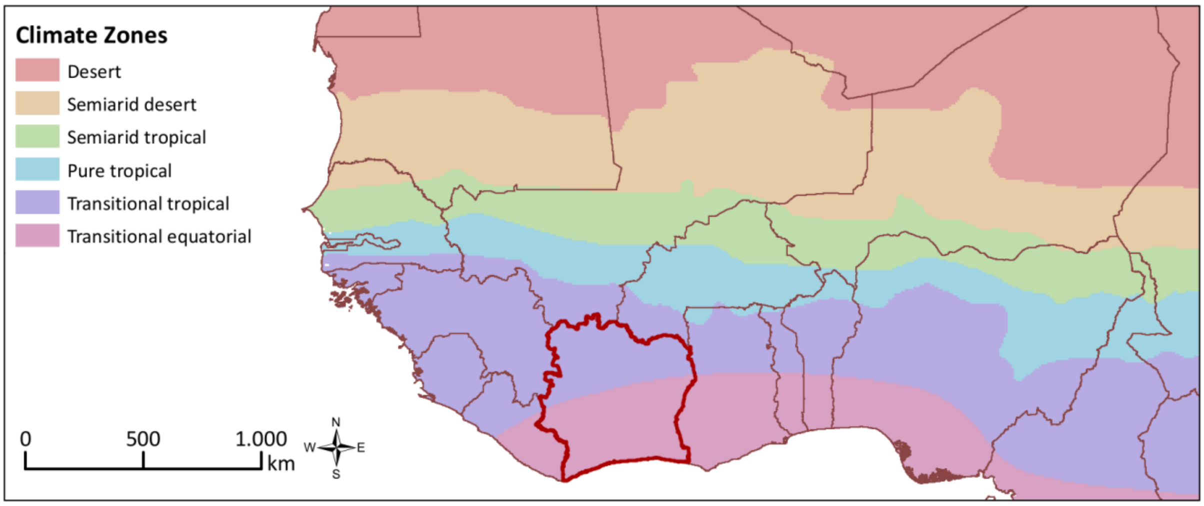
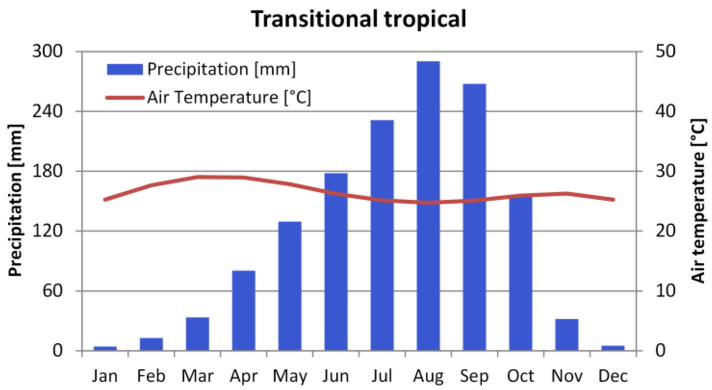
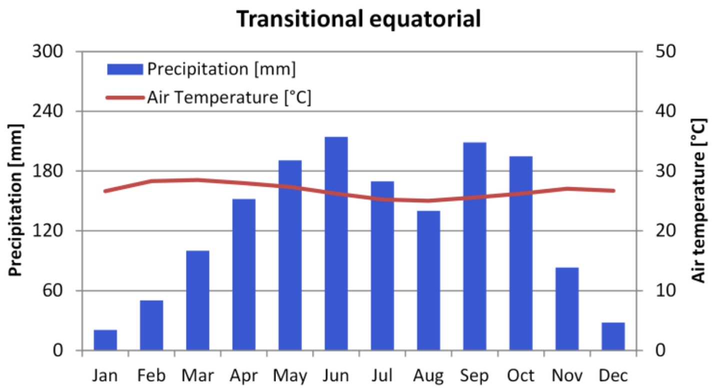
CLIMATE

The climate in West Africa can be grouped into six zones with distinctive seasonal rainfall patterns (L'Hôte et al., 1996). In Côte d'Ivoire the climate ranges from "Transitional equatorial" in the south to "Transitional tropical" in the north. The southern regions have two rainfall peaks in June and September, whereas in the north rainfall peaks in August. These differences are caused by the seasonal shifting of the Inter Tropical Convergence Zone (ITCZ) from south to north and back to the south. The diagrams below summarize the mean monthly rainfall and air temperature in these climate zones.





Precipitation data source: Tropical Rainfall Measuring Mission (NASA/JAXA), TRMM 3B42, mean 1998-2014
Air temperature data source: Climate Research Unit (University of East Anglia), CRU TS 3.22, mean 1998-2013



Precipitation data source: Tropical Rainfall Measuring Mission (NASA/JAXA), TRMM 3B42, mean 1998-2014
Air temperature data source: Climate Research Unit (University of East Anglia), CRU TS 3.22, mean 1998-2013

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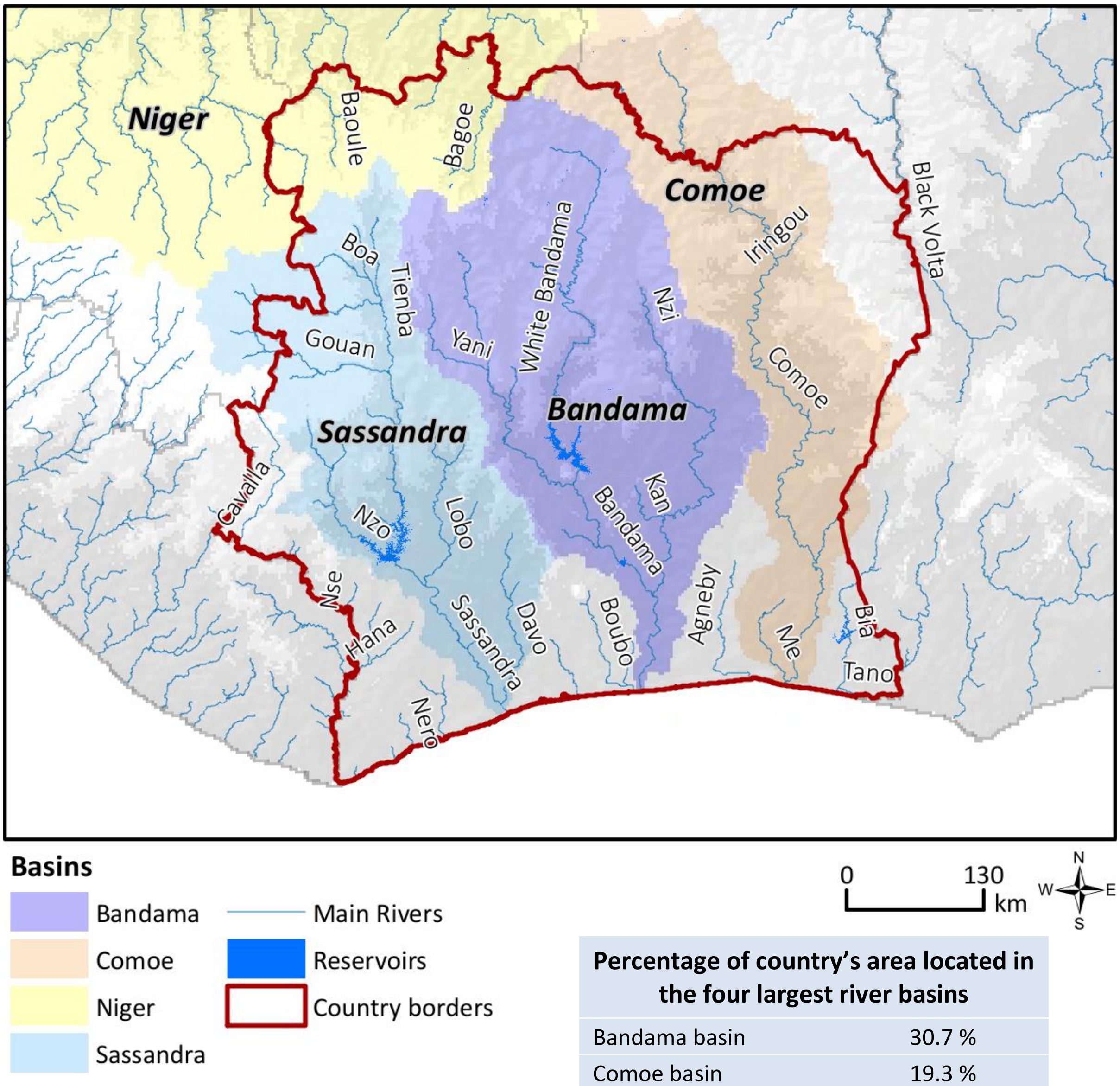
HYDROLOGY

The Sassandra, Bandama and Comoe rivers are the three largest rivers in Côte d’Ivoire. About 31 % of the country is located in the Bandama basin, 21 % in the Sassandra basin and 19 % in the Comoe basin. All of the three rivers discharge to the south into the Atlantic ocean. Rivers in the north-western parts of the country discharge to the north and are tributaries to the Niger River (see map and table below).

The figures on the following page illustrate the annual and seasonal variations in discharge for the Bandama, Sassandra and Comoe rivers.

All three rivers show strong variations in annual discharge over the last 60 years. Some extremely dry years occurred in the 1980s and early 1990s, whereas the period 1998-2014 represents moderately wet conditions in the historic context.

There is strong seasonality in discharge, with high flows in September and October. However, the lower stretches of the Bandama and Sassandra rivers are affected by reservoir operation with increased low flow during the dry season.



Percentage of country’s area located in the four largest river basins	
Bandama basin	30.7 %
Comoe basin	19.3 %
Niger basin	7.3 %
Sassandra basin	20.8 %

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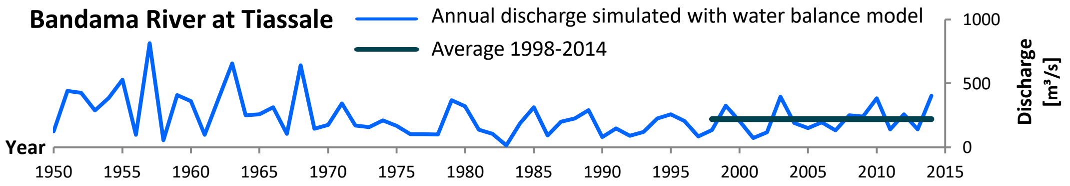
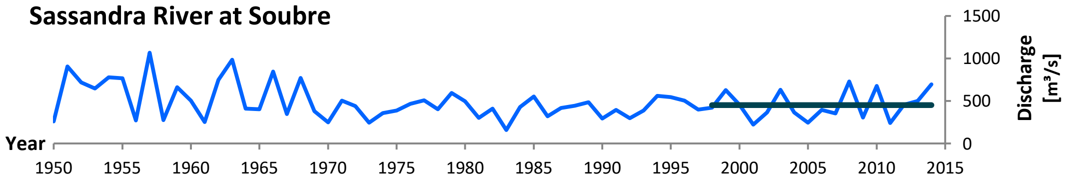
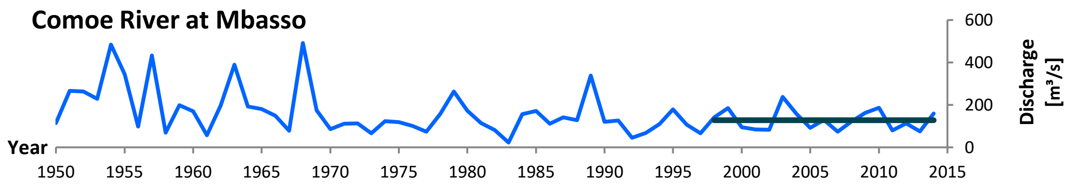
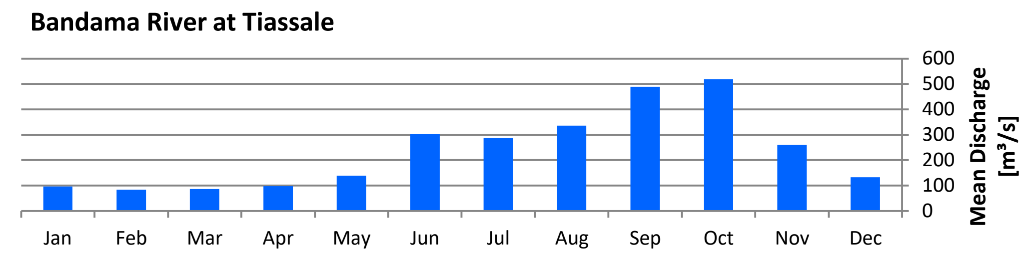
Historic Variation in Annual Discharge

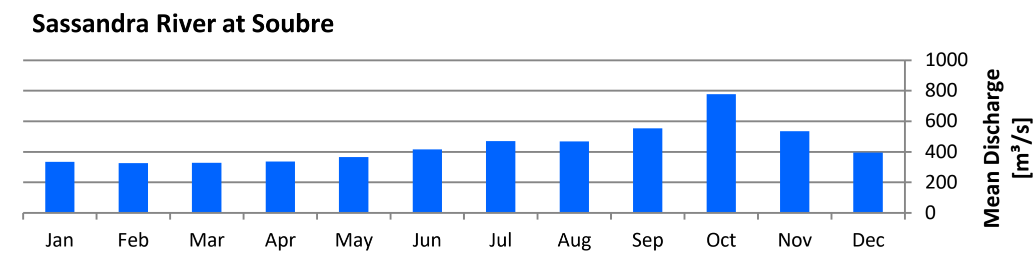


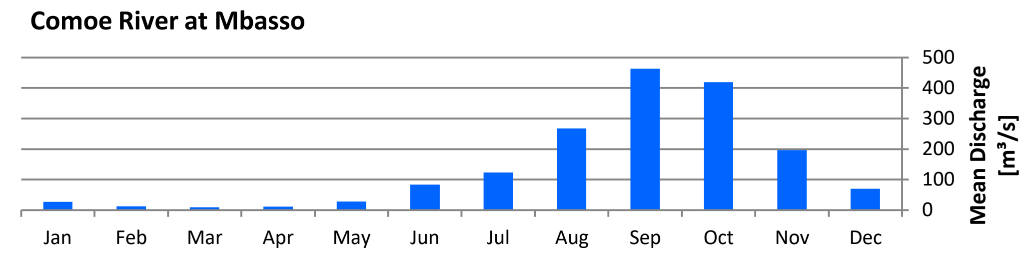




Seasonality in Discharge







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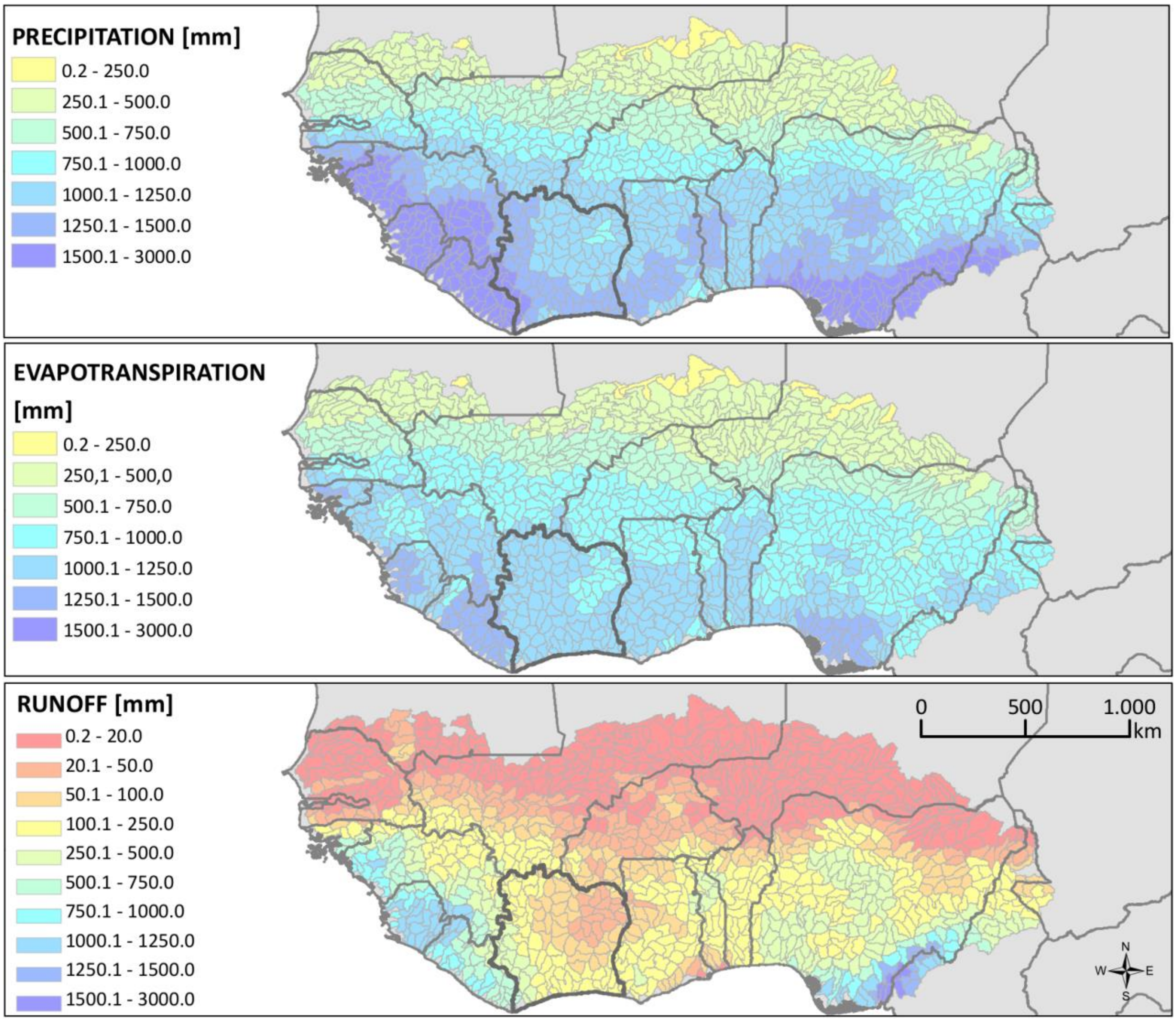
Annual Water Balance

The long-term mean annual water balance describes the partitioning of precipitation (rainfall) into actual evapotranspiration (transpiration by plants, evaporation from soil) and runoff, as over long time periods the change in storage (soil moisture, ground water) can be assumed to be negligible for the mean annual water balance.

The regional distribution of the water balance components in West Africa is strongly controlled by spatial variations in mean annual precipitation. An annual water balance model calibrated with observed discharge data of 400 gauges was used to determine mean annual actual evapotranspiration and runoff for the period 1998-2014, as shown in the maps below. In most parts of West Africa mean annual actual evapotranspiration is considerably larger than mean annual runoff.

This is also the case for the mean annual water balance in Côte d'Ivoire. In the south-western parts of the country about 75 % of rainfall is lost via evapotranspiration and only about 25 % of rainfall generates runoff. In the north-eastern parts of the country, where rainfall is lower, about 95 % of rainfall is lost via evapotranspiration and only about 5 % of rainfall generates runoff.

Mean annual discharge is computed by aggregating runoff along the river network, which together with channel slope determines the hydropower potential (see next section).



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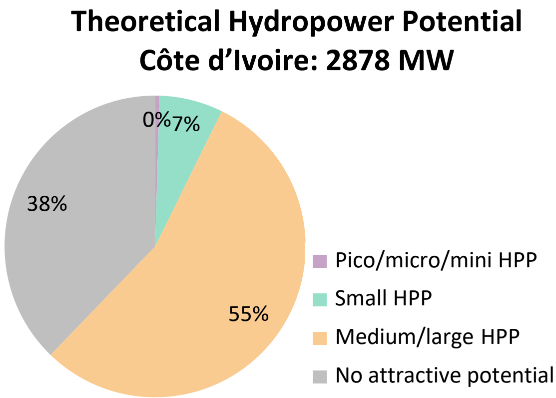
HYDROPOWER POTENTIAL

The theoretical hydropower potential of a river is defined as the amount of power that would be produced if the full head of the river was used and if 100 % of the mean annual discharge was turbinated (i.e. no spillway losses or environmental flow constraints). In this study overall plant efficiency (turbines, hydraulic losses) is assumed with 87 %.

The theoretical hydropower potential for Côte d'Ivoire is estimated to be 2878 MW (reference period 1998-2014), which is the total of all rivers in the country.

The following table and figures show how the total potential of the country is subdivided into theoretical potential for hydropower plants (HPP) of different plant size. A classification scheme based on mean annual discharge (m^3/s) and specific hydropower potential (MW/km) was applied to determine the preferred plant size for river reaches with a typical length of 1-10 km. Four classes were considered for the preferred plant size, including pico/micro/mini HPP (< 1 MW installed capacity), small HPP (1-30 MW installed capacity), medium/large HPP (> 30 MW installed capacity), and "No attractive potential" for river reaches with too low specific hydropower potential. For the latter in some cases it may still be worthwhile to utilize this potential in e.g. multi-purpose schemes. The technical potential was not assessed in this study.



Theoretical Hydropower Potential of Rivers in Côte d'Ivoire	
Pico/micro/mini HPP	14 MW
Small HPP	197 MW
Medium/large HPP	1580 MW
No attractive potential	1087 MW
Total of all rivers in country	2878 MW
Total of rivers with attractive theoretical potential for pico/micro/mini, small, or medium/large HPP	1791 MW

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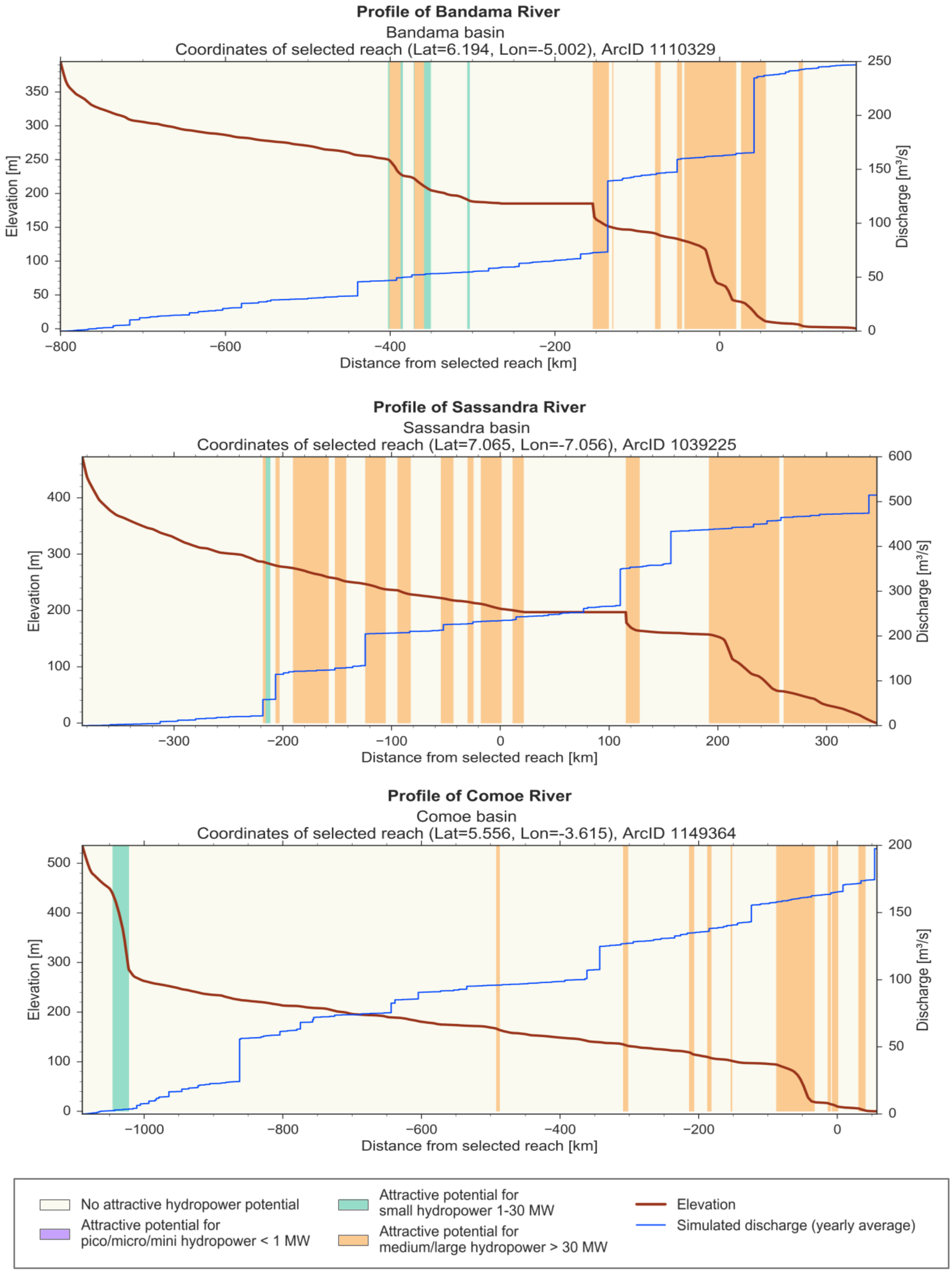
Longitudinal Profiles of Selected Rivers

The following graphs show longitudinal profiles of the Bandama, Sassandra and Comoe rivers, plotting elevation (red) and mean annual discharge (blue) from the source to the mouth of the river. Inflow from tributaries is clearly identifiable as sudden increase in river discharge. Reservoirs at the Bandama and Sassandra rivers are identifiable by horizontal elevation in the reservoir lake and sudden drop of elevation at the dam site. The background color indicates if a river reach has an attractive theoretical hydropower potential for pico/micro/mini HPP (< 1 MW installed capacity), small HPP (1-30 MW installed capacity), or medium/large HPP (> 30 MW installed capacity).



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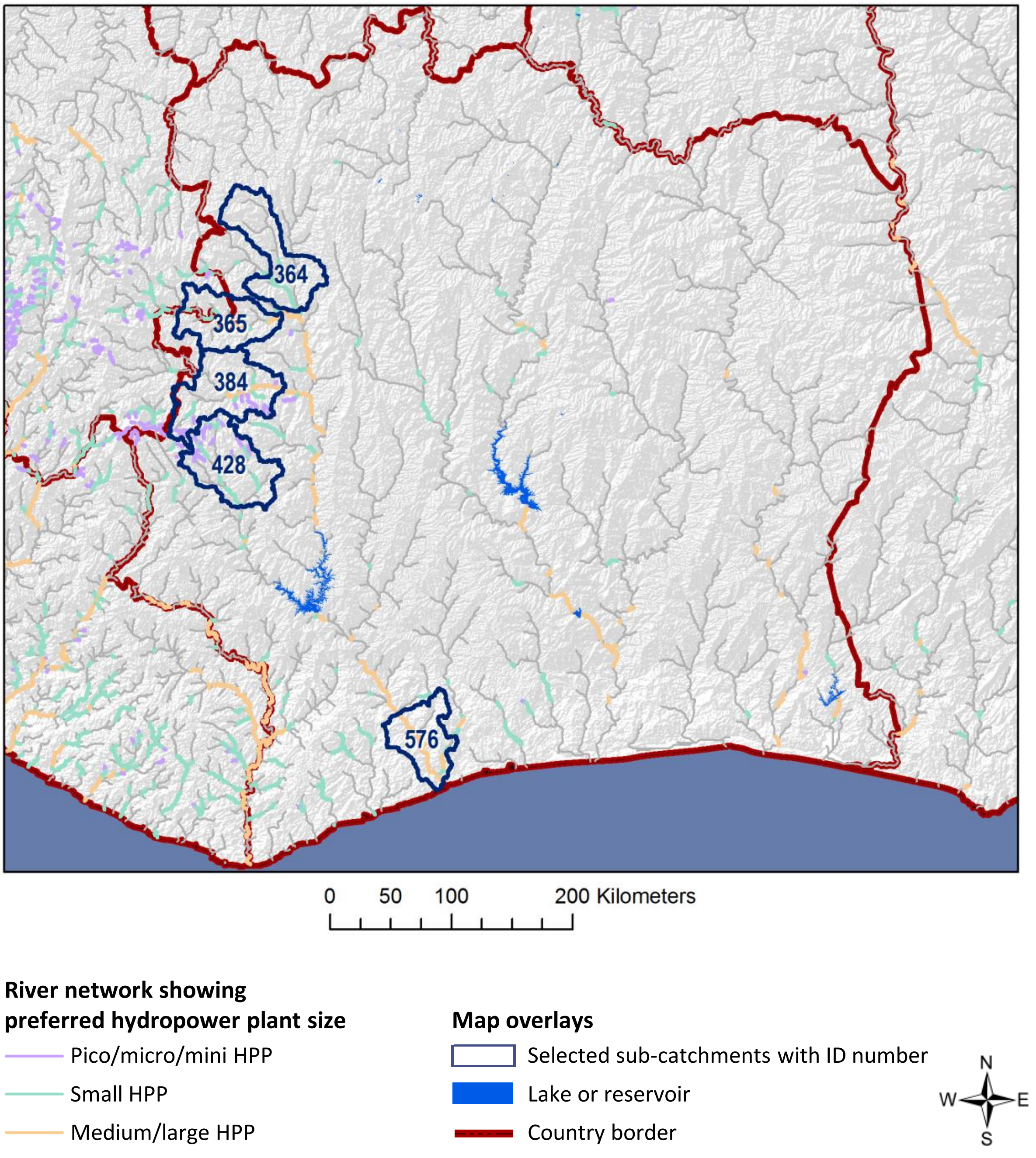
Hydropower Potential in Selected Sub-catchments

The following maps and tables give information about the theoretical hydropower potential of selected sub-catchments in Côte d'Ivoire. Sub-catchments with attractive theoretical hydropower potential are found in the west and south of Côte d'Ivoire.

The table data summarizes the total theoretical hydropower potential of all river reaches within the sub-catchment. River reaches were grouped according to preferred plant size for pico/micro/mini HPP (< 1 MW installed capacity), small HPP (1-30 MW installed capacity), or medium/large HPP (> 30 MW installed capacity). Similarly, the color code of the river network displayed in the maps indicates the preferred plant size. A grey color indicates no attractive potential for hydropower development.



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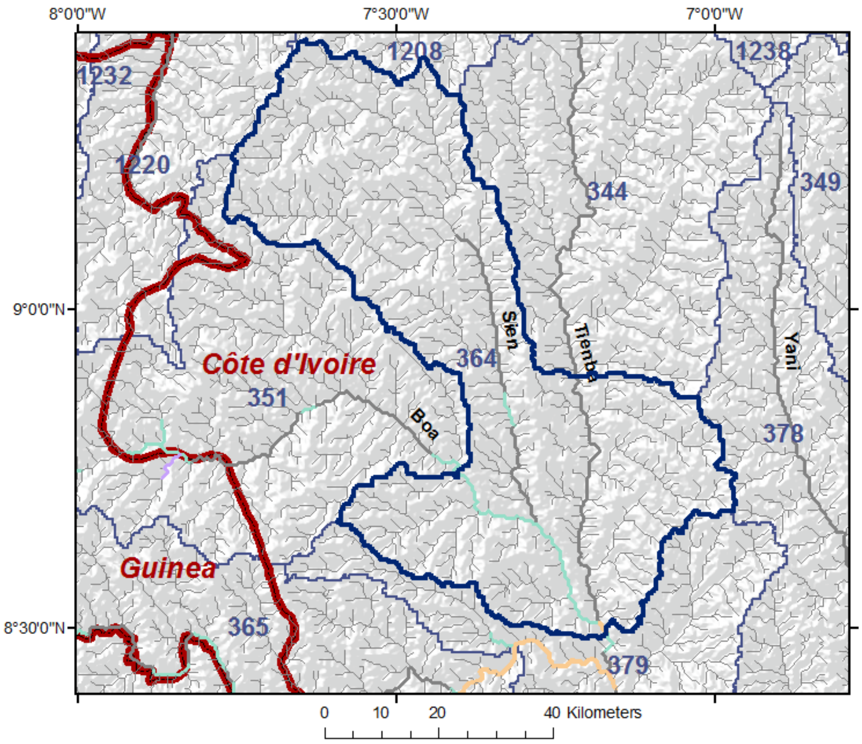
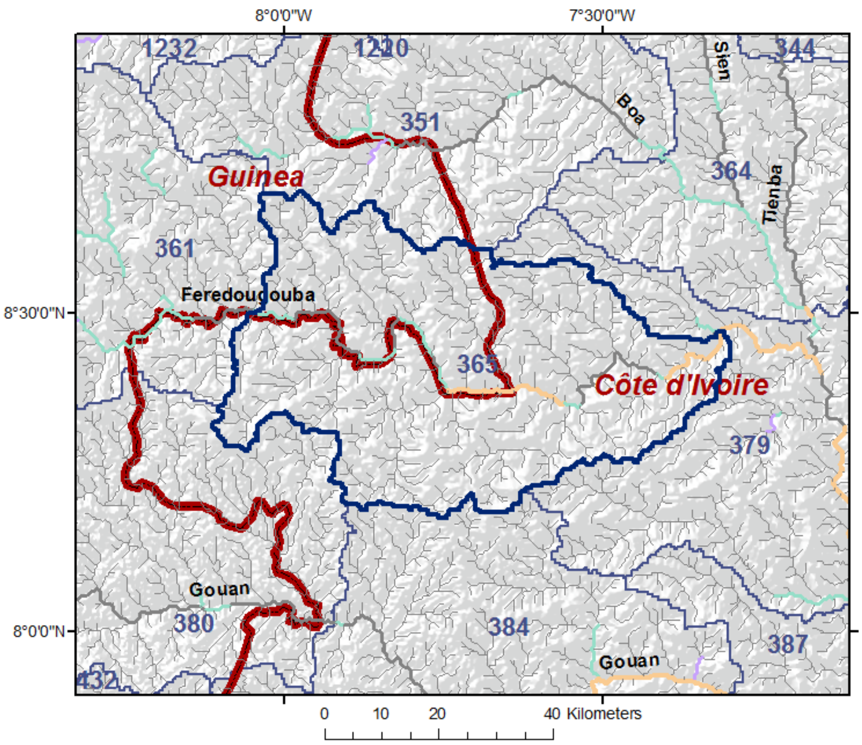


Theoretical Hydropower Potential of Rivers in Sub-Catchment #364	
Pico/micro/mini HPP	0 MW
Small HPP	18.1 MW
Medium/large HPP	0 MW

This sub-catchment includes sections of the Boa, Sien and Tienba rivers in the north-west of Côte d'Ivoire, close to the border with Guinea. Most of the potential for small HPP in the sub-catchment is located at the Boa River. There is no potential for pico/micro/mini or medium/large HPP.



Theoretical Hydropower Potential of Rivers in Sub-Catchment #365	
Pico/micro/mini HPP	0 MW
Small HPP	11.4 MW
Medium/large HPP	46.6 MW

All of the hydropower potential in this sub-catchment is located at the Feredougouba River. The potential for small HPP is shared with Guinea, as this section of the river forms the international border, whereas the potential for medium/large HPP is mostly located in Côte d'Ivoire.

River network showing preferred hydropower plant size

- Pico/micro/mini HPP
- Small HPP
- Medium/large HPP
- No attractive potential

Map overlays

- Existing hydropower plant
- Lake or reservoir
- Sub-catchment boundary
- Country border

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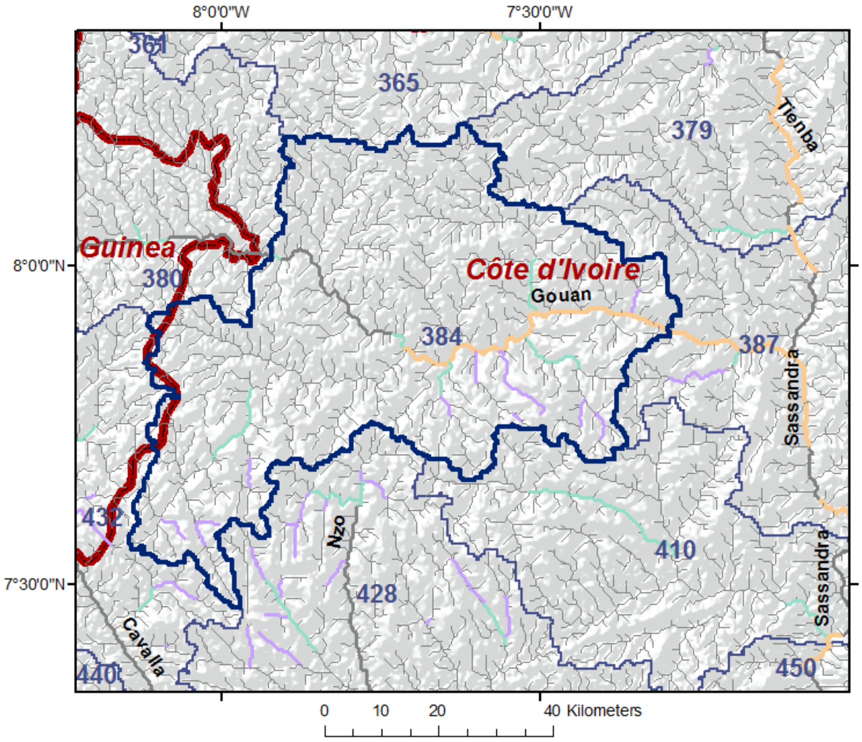
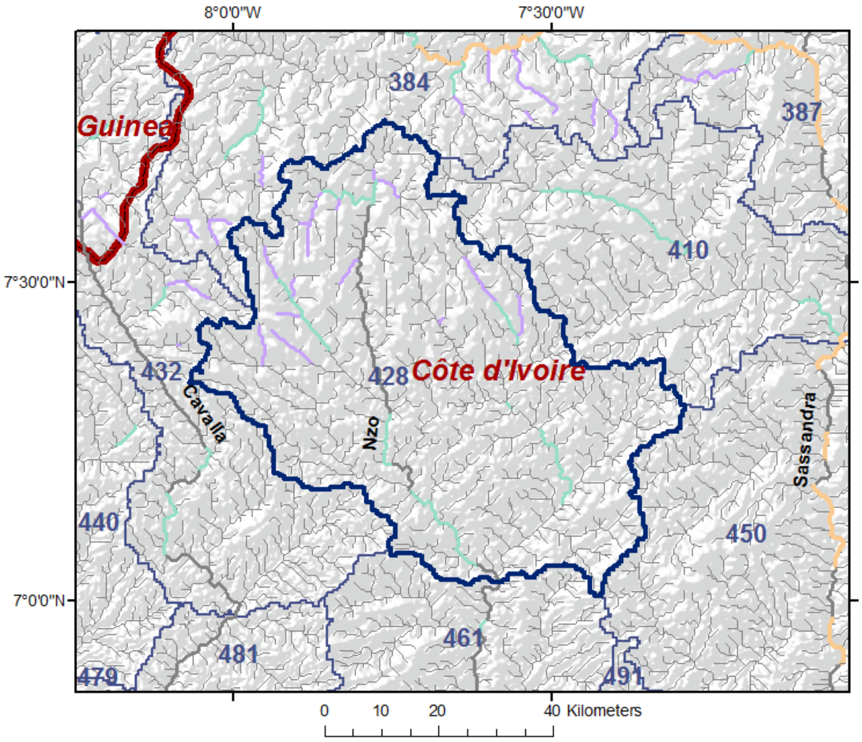


Theoretical Hydropower Potential of Rivers in Sub-Catchment #384	
Pico/micro/mini HPP	4.2 MW
Small HPP	7.6 MW
Medium/large HPP	73.3 MW

This is a sub-catchment of the Gouan River, which originates in Guinea in the east and flows to the Sassandra River in the west. The Gouan River has considerable potential for medium/large HPP, while some of the local tributaries have considerable potential for pico/micro/mini HPP.



Theoretical Hydropower Potential of Rivers in Sub-Catchment #428	
Pico/micro/mini HPP	5.6 MW
Small HPP	18.5 MW
Medium/large HPP	0 MW

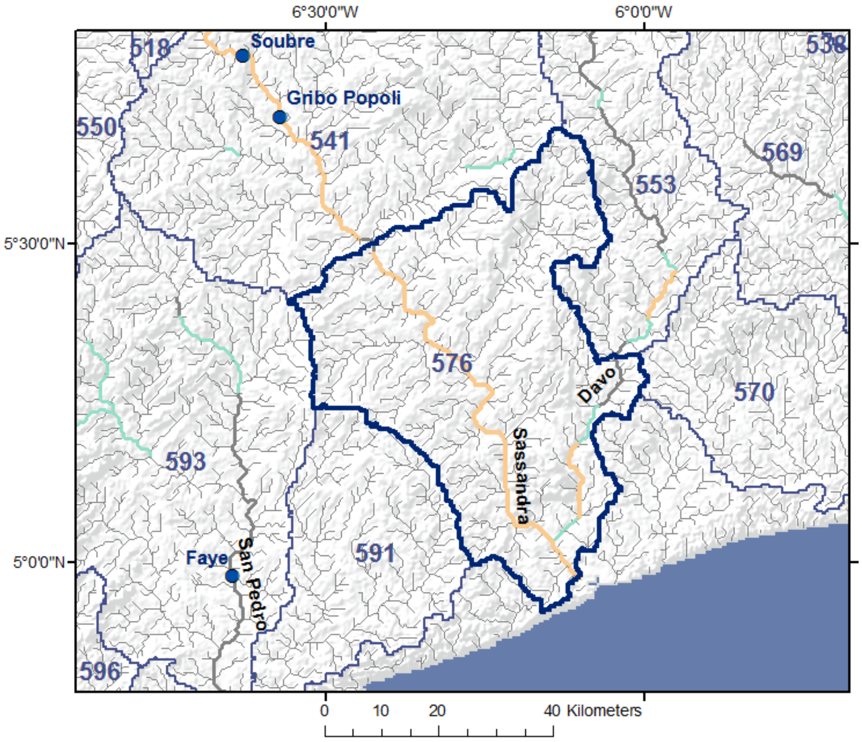
This sub-catchment forms the headwater region of the Nzo River. Several small tributaries have considerable potential for pico/micro/mini HPP. The Nzo River itself and other tributaries also show some potential for small HPP.

River network showing preferred hydropower plant size

- Pico/micro/mini HPP
- Small HPP
- Medium/large HPP
- No attractive potential

Map overlays

- Existing hydropower plant
- Lake or reservoir
- Sub-catchment boundary
- Country border



Theoretical Hydropower Potential of Rivers in Sub-Catchment #576	
Pico/micro/mini HPP	0 MW
Small HPP	6.8 MW
Medium/large HPP	246.3 MW

The section of the Sassandra River below the Soubre and Gribo Popoli hydropower plants shows further high potential for medium/large HPP. Also the Davo River has some potential for small HPP and medium/large HPP, but is adjacent to the Parc Naturel de Gaoulou.

River network showing preferred hydropower plant size

- Pico/micro/mini HPP
- Small HPP
- Medium/large HPP
- No attractive potential

Map overlays

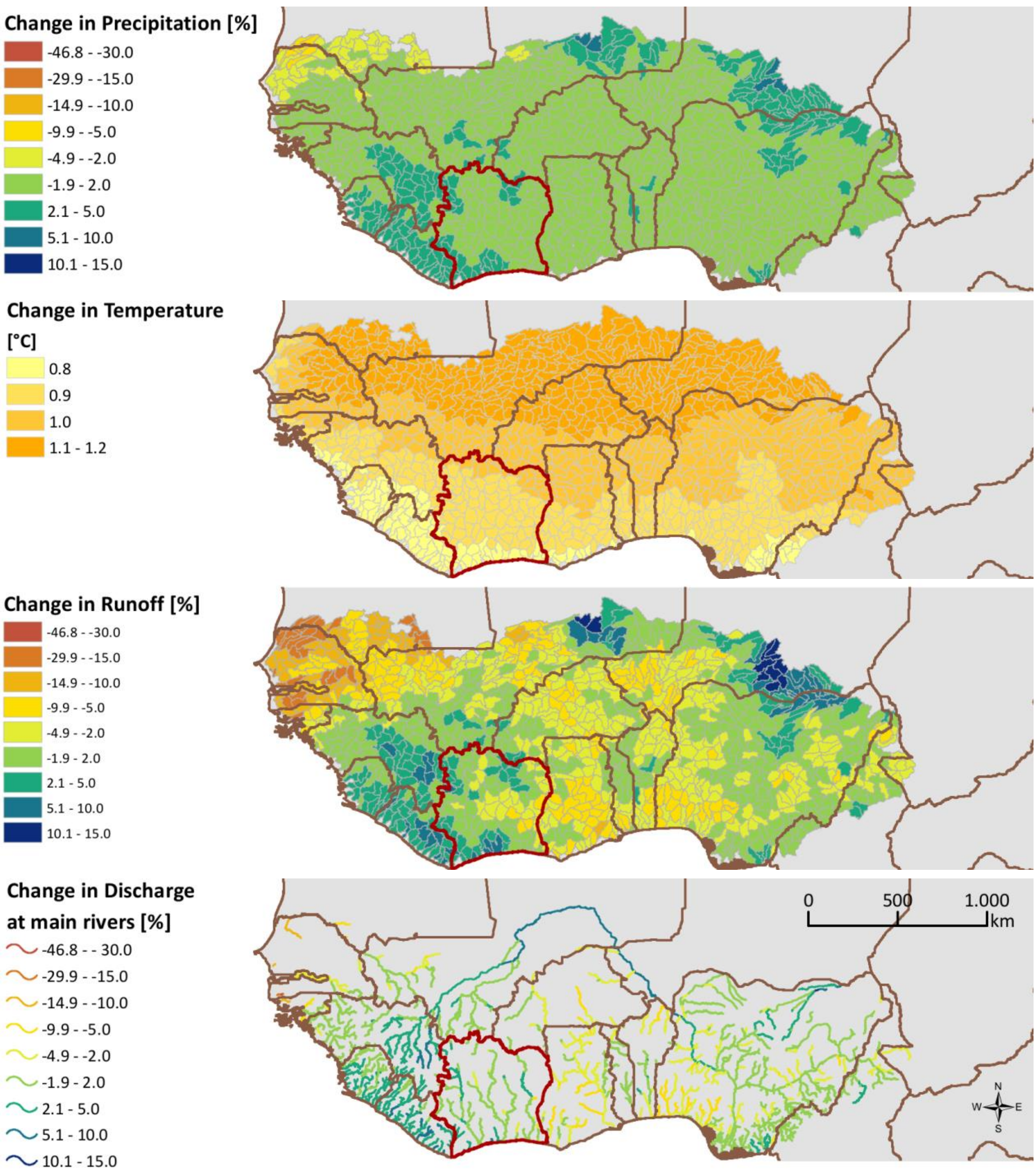
- Existing hydropower plant
- Lake or reservoir
- Sub-catchment boundary
- Country border

N W E S

CLIMATE CHANGE

Climate change may have considerable impact on future water resources and thus hydropower generation. The following figures show an assessment of climate change projections for West Africa based on 15 Regional Climate Models of the CORDEX-Africa ensemble. Two Representative Concentration Pathways (RCP4.5 and RCP8.5) were considered, thus yielding a total of 30 climate model runs. Future runoff was simulated by driving a water balance model with precipitation and temperature climate change signals with respect to the reference period 1998-2014.

Projections for the Near Future 2026-2045



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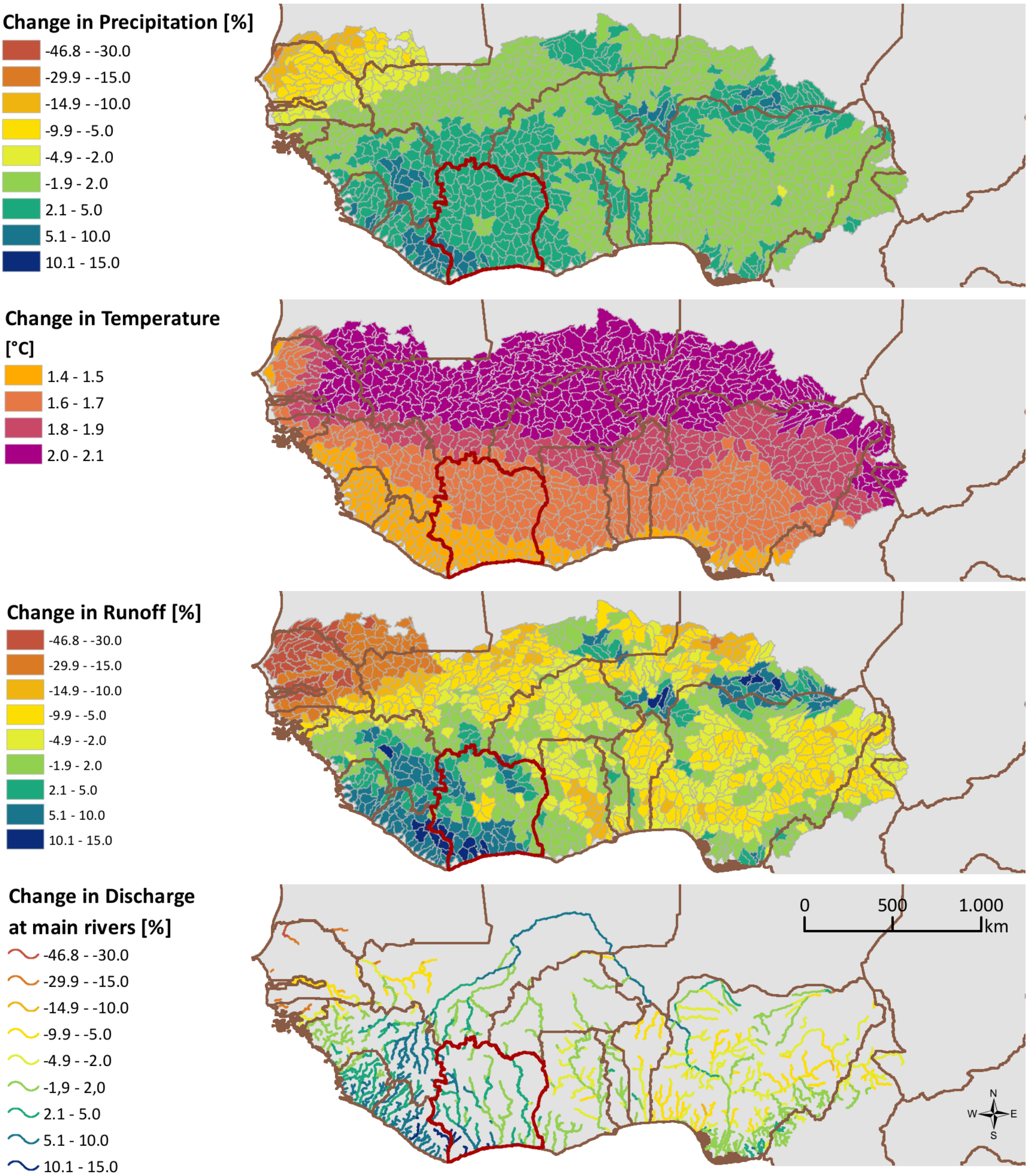
Projections for the Far Future 2046-2065

The maps below show the expected impact of climate change on future mean annual water resources. From the 30 climate model runs the median result was computed to generate the maps, which show change signals comparing the future periods 2026-2045 (previous page) and 2046-2065 (this page) vs. the reference period 1998-2014.

In large parts of West Africa increase or almost no change is projected for future precipitation. In Côte d'Ivoire precipitation is projected to increase. The combined effects of future precipitation and considerable warming (increase of evapotranspiration) were simulated with a water balance model to compute future runoff. In most parts of Côte d'Ivoire a slight increase is projected for future runoff (median of 30 model runs). The same applies to river discharge.



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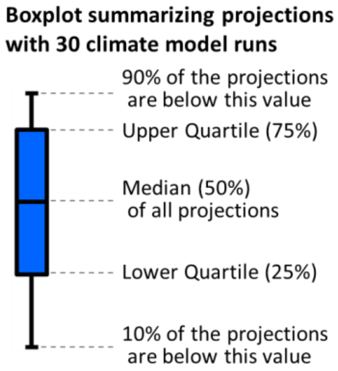
Projected Change in Discharge for Selected Gauges

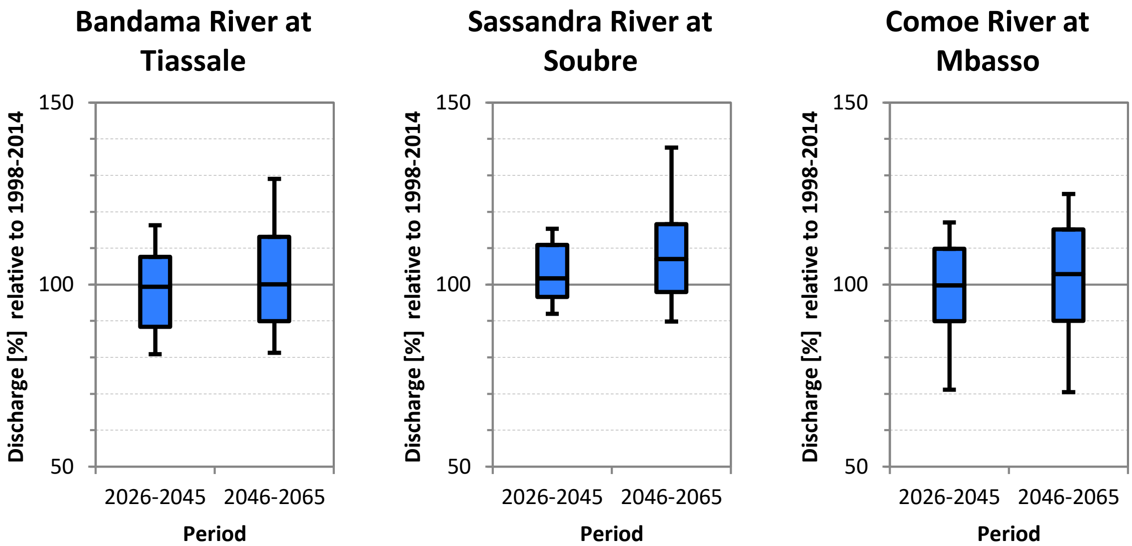
Future mean annual discharge was estimated with data from 30 different climate model runs. Boxplots are presented to summarize the spread in the simulation results (see explanation at right).

For rivers in Côte d'Ivoire the uncertainty in the climate model projections is rather high, as both increase and decrease is projected by different climate models for the same river.

For the Sassandra and Comoe rivers there is a tendency of climate models to project a slight increase in future discharge, whereas for the Bandama River an equal number of climate models project decrease and increase.

Overall the climate change impact assessment shows that given the projections with the most detailed climate models currently available (CORDEX-Africa) there is no clear signal for pronounced changes in future discharge. This means that climate change is not a 'worst-case' scenario for hydropower development in Côte d'Ivoire.





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This study was conducted by Pöyry Energy GmbH (Vienna, Austria) for the ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE, Praia, Cabo Verde). This is a contribution to the ECOWAS Small-Scale Hydro Power Program, which aims to develop the small-scale hydropower sector in West Africa and is funded by the Austrian Development Agency (ADA) and the Spanish Agency for International Development Cooperation (AECID).

Observed discharge data were used for hydrological model calibration and were obtained from the following sources: Global Runoff Data Centre (GRDC), Volta Basin Authority, Niger Basin Authority, Senegal & Gambia Basin Authorities (OMVS, OMVG), Liberia National Hydrological Service, Sierra Leone National Hydrological Service, Japan International Cooperation Agency (JICA).

Precipitation data 1998-2014 are based on Tropical Rainfall Measurement Mission (TRMM 3B42 v7). Additional precipitation data 1950-2010 for model calibration were obtained from the Global Precipitation Climatology Centre (GPCC). Air temperature and potential evapotranspiration data were obtained from the Climatic Research Unit (CRU, Univ. East Anglia), with additional data from the CLIMWAT database of FAO. River network and elevation data were derived from the Hydrosheds dataset (USGS). Climate model data were obtained from the Coordinated Regional Downscaling Experiment for Africa (CORDEX-Africa), which is a project of the World Climate Research Program.

The delineation of climate zones is based on: L`Hôte Y, Dubreuil P, Lerique J. 1996. *Carte des types de climats en Afrique Noire à l'ouest du Congo. Rappels, et extension aux régimes hydrologiques*. In: L'hydrologie tropicale: géoscience et outil pour le développement (Actes de la conférence de Paris, mai 1995). IAHS Publ. no. 238, p. 55-65

More information about the general methodology for the GIS hydropower resource mapping is available in: Kling H, Stanzel P, Fuchs M. 2016. *Regional assessment of the hydropower potential of rivers in West Africa*. Energy Procedia, Elsevier, Special Issue of ERE, 8 pp.

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