

# SIERRA LEONE

## COUNTRY REPORT



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





## Imprint



**Title:** GIS Hydropower Resource Mapping and Climate Change Scenarios for the ECOWAS Region, Country Report for Sierra Leone

**Publisher:** ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE), Praia, Cabo Verde. *All results and maps are published on the ECOWAS Observatory for Renewable Energy and Energy Efficiency - [www.ecowrex.org/smallhydro](http://www.ecowrex.org/smallhydro)*

**Contact:** [info@ecreee.org](mailto:info@ecreee.org)

March 2017

### Program Responsibility:

The ECOWAS Small-Scale Hydropower Program 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 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](http://www.ecowrex.org/smallhydro)

### Project Team:



#### Pöyry Energy GmbH, Vienna, Austria

Mr. Harald Kling (project management, team leader hydrology)

Mr. Martin Fuchs (team leader hydropower)

Mr. Philipp Stanzel (team leader climate change)

Ms. Maria Paulin

Mr. Bernhard Wipplinger

Mr. Stefan Wimmer

Ms. Elisabeth Freiberger

Mr. Christoph Libisch

Mr. Raimund Mollner

Mr. Rudolf Faber

Mr. Herbert Weilguni



#### ECOWAS Centre for Renewable Energy and Energy Efficiency, Praia, Cabo Verde

Mr. Mahama Kappiah, Executive Director

Mr. Hannes Bauer, Project Management, Lead hydropower Program

Mr. Daniel Paco, GIS Expert

#### The ECOWAS Small-Scale Hydropower Program is managed by:

ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE)

Mr. Hannes Bauer, ECREEE

Contact: [info@ecreee.org](mailto:info@ecreee.org)

### Project Funding



Austrian Development Cooperation – ADC

Spanish Ministry of External Affairs and Cooperation - AECID



## 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.

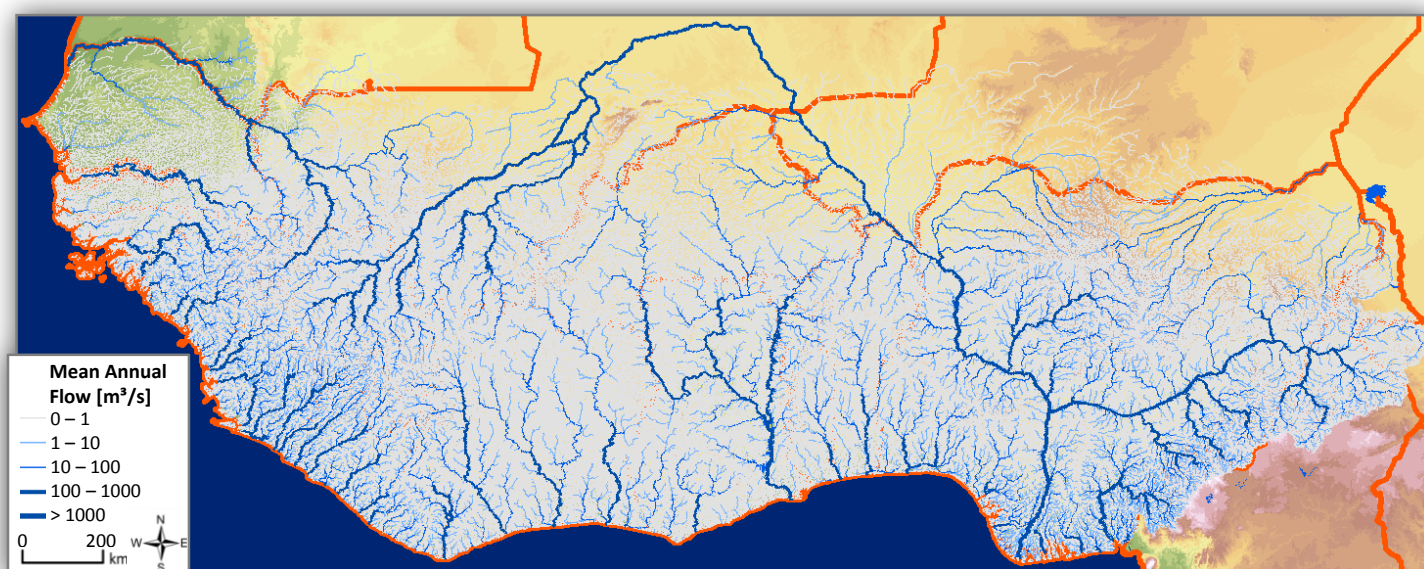
The ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE), founded in 2010 by ECOWAS, ADA, AECID and UNIDO, responded to these challenges and developed the ECOWAS Small-Scale Hydropower Program, which was approved by ECOWAS Energy Ministers in 2012. In the frame of this program ECREEE assigned 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 km<sup>2</sup>. 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](http://www.ecowrex.org)).

This report summarizes the results of the GIS layers for Sierra Leone and includes:

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



## GENERAL INFORMATION

Sierra Leone is one of the smaller countries in West Africa and has about 6 Mio inhabitants. The capital of Sierra Leone is Freetown. The neighboring countries are Guinea in the north and Liberia in the east (see map below).

Hydropower plays a considerable role for energy generation in Sierra Leone. Overall there are eight existing hydropower plants, most of them are small hydropower plants (see table below).

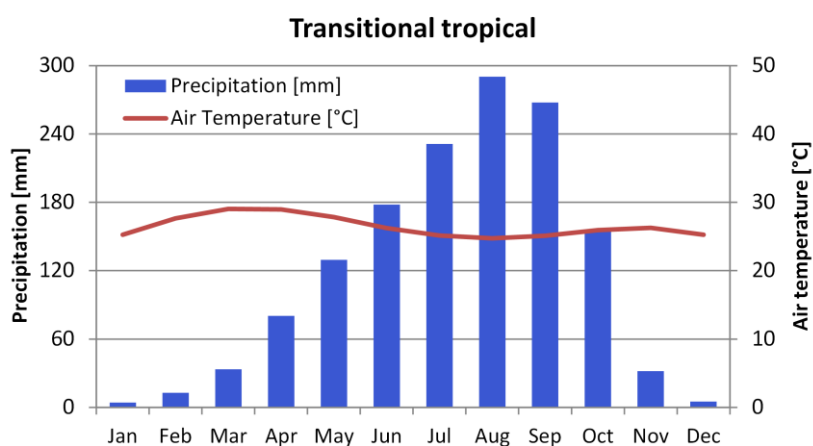
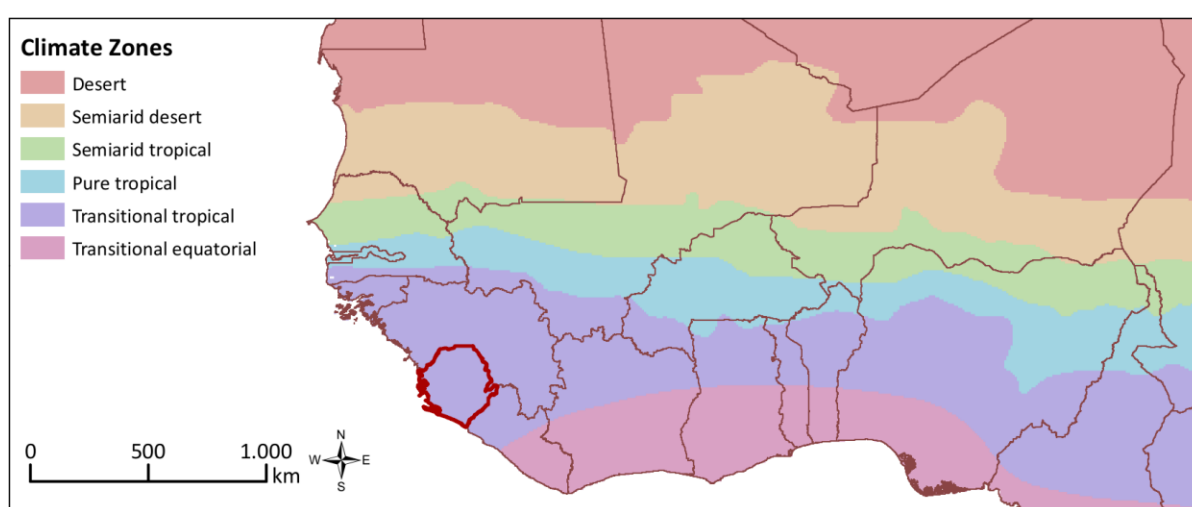


General Information for Sierra Leone	
Inhabitants (2014)	6.3 Mio.
Area (2014)	72,300 km <sup>2</sup>
GDP per capita (2014)	766 USD
Electrification rate total/urban/rural (2013)	13/4/16 %
Hydro installed capacity (2013)	56.3 MW
Electricity generation (2013)	325.2 GWh
Electricity generation from hydropower (2013)	147.9 GWh
Number of existing hydropower plants with installed capacity > 1 MW (2016)	8
Number of existing small hydropower plants with installed capacity 1-30 MW (2016)	6
Number of existing medium hydropower plants with installed capacity 30-100 MW (2016)	1
Number of existing large hydropower plants with installed capacity >100 MW (2016)	1

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

## CLIMATE

The climate in West Africa can be grouped into six zones with distinctive seasonal rainfall patterns (L'Hôte et al., 1996). Sierra Leone is located entirely in the “Transitional tropical” climate zone, which is characterized by high rainfall amounts between July and September, but also significant rainfall amounts in May, June and October. The seasonality in rainfall is controlled by the seasonal movement of the Inter Tropical Convergence Zone (ITCZ). Air temperature is highest in April before the start of the rainy season. After the rainy season in October there is a secondary peak in air temperature, whereas August, December and January are the coldest months of the year. The diagram below summarizes the mean monthly rainfall and air temperature in the Transitional tropical climate zone.

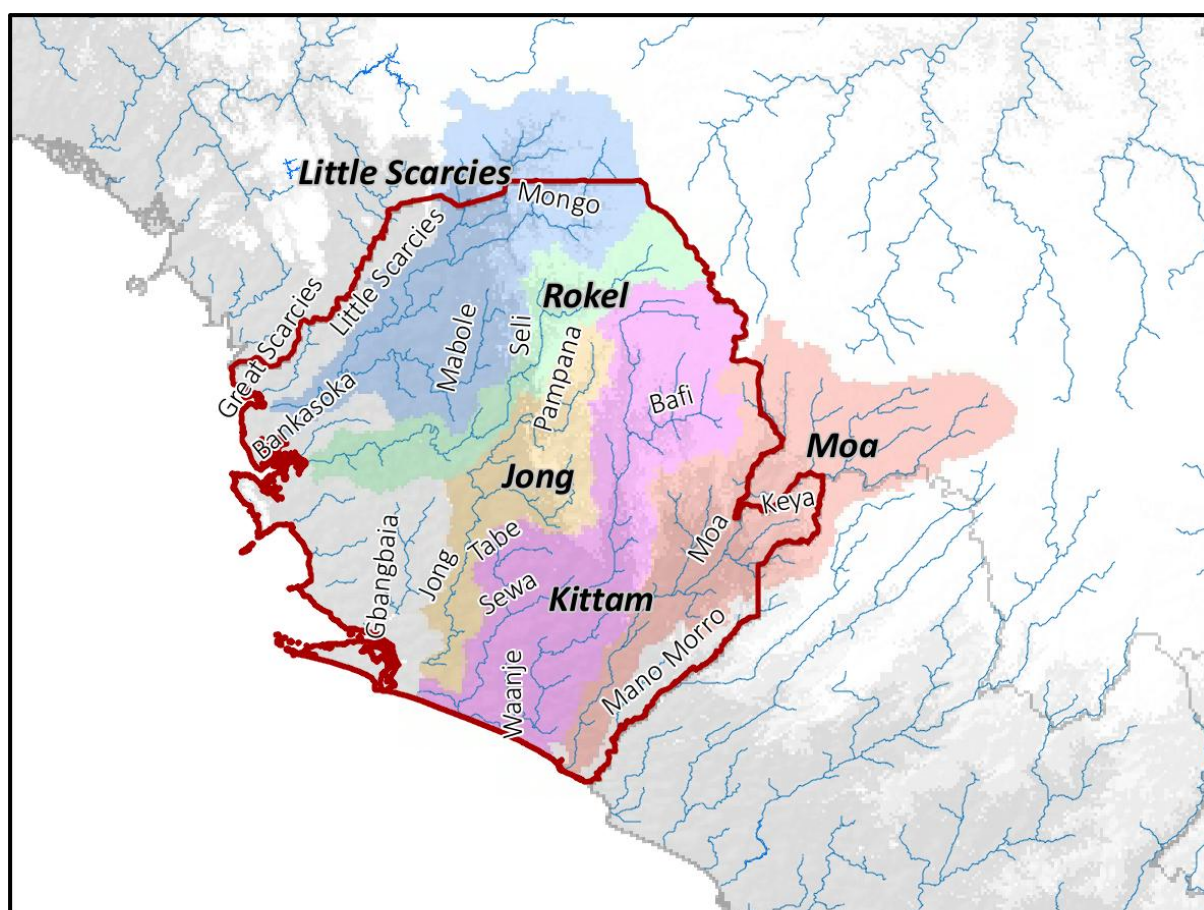


Precipitation data source: Tropical Rainfall Measuring Mission (NASA/JAXA), TRMM 3B42, mean 1998-2014  
Air temperature data source: Climate Research Unit (University of East Anglia), CRU TS 3.22, mean 1998-2013

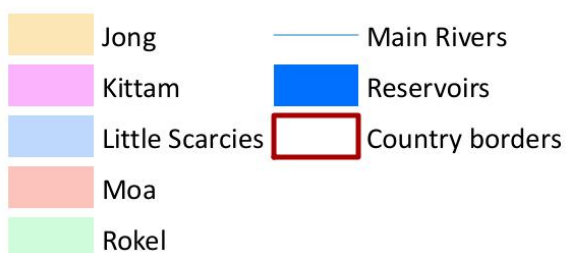
## HYDROLOGY

There are several large rivers in Sierra Leone that have their source in the border area between Sierra Leone and Guinea and flow from north-east to south-west discharging into the Atlantic Ocean. The main rivers include the Little Scarcies, Seli (also known as Rokel), Jong, Sewa (which together with the Waanje River drains the Kittam basin), Moa and Mano. About 27 % of the country is located in the Kittam basin and 18 % is located in the Little Scarcies basin. The basins of the Jong, Moa and Seli (Rokel) rivers each cover slightly more than 10 % of the country (see map and table below).

The figures on the following page illustrate the annual and seasonal variations in discharge for the Seli, Sewa and Moa Rivers. All three rivers show some variations in annual discharge over the last 60 years, but the variability is less pronounced than in other (drier) parts of West Africa. The period 1998-2014 represents typical flow characteristics when compared to previous decades. There is strong seasonality in discharge, with peak flow in September. The rivers are perennial (i.e. they flow year round), with low flow occurring between February and April.



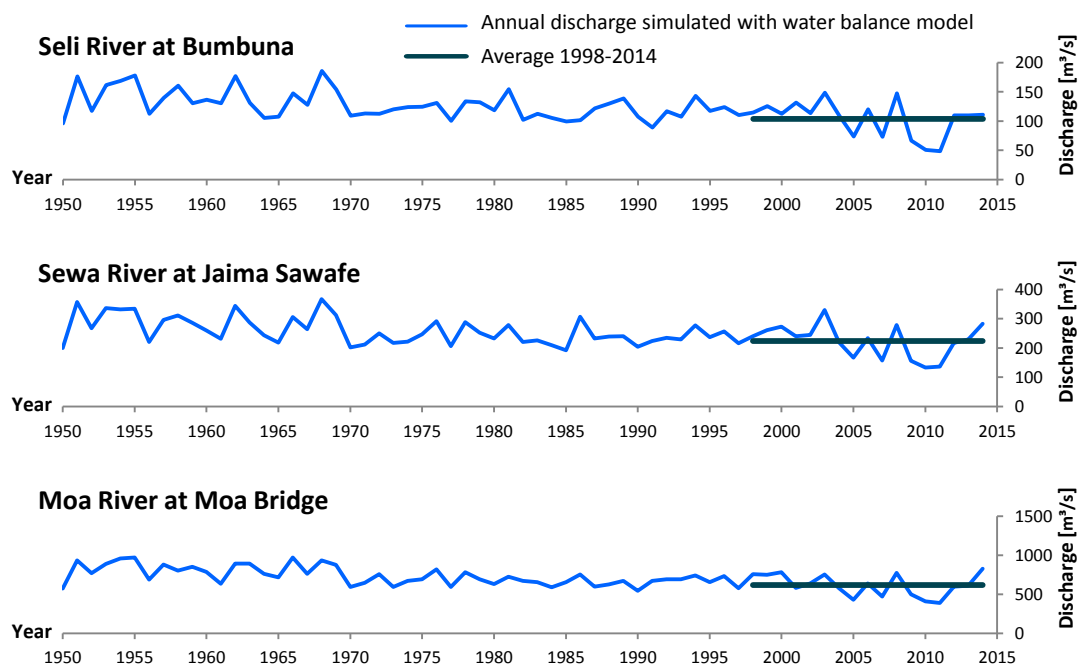
### Basins



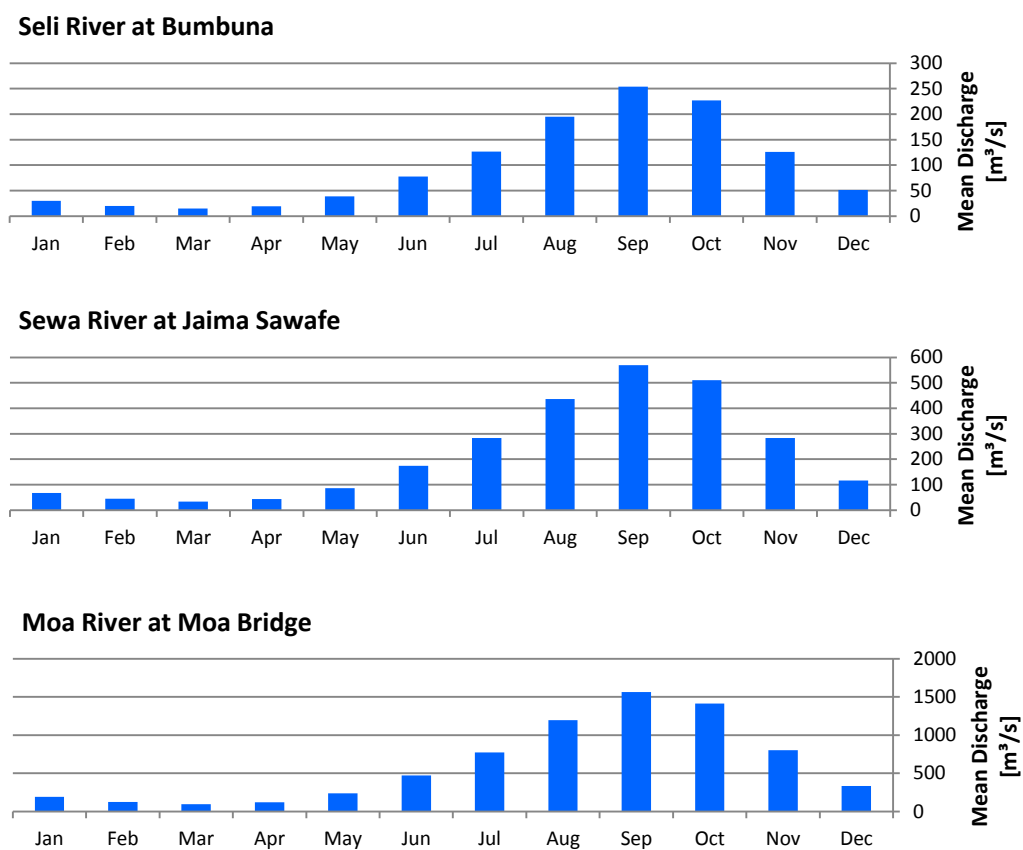
### Percentage of country's area located in the five largest river basins

Jong basin	10.8 %
Kittam basin	26.8 %
Little Scarcies basin	18.0 %
Moa basin	13.0 %
Rokel (Seli) basin	10.9 %

## Historic Variation in Annual Discharge



## Seasonality in Discharge





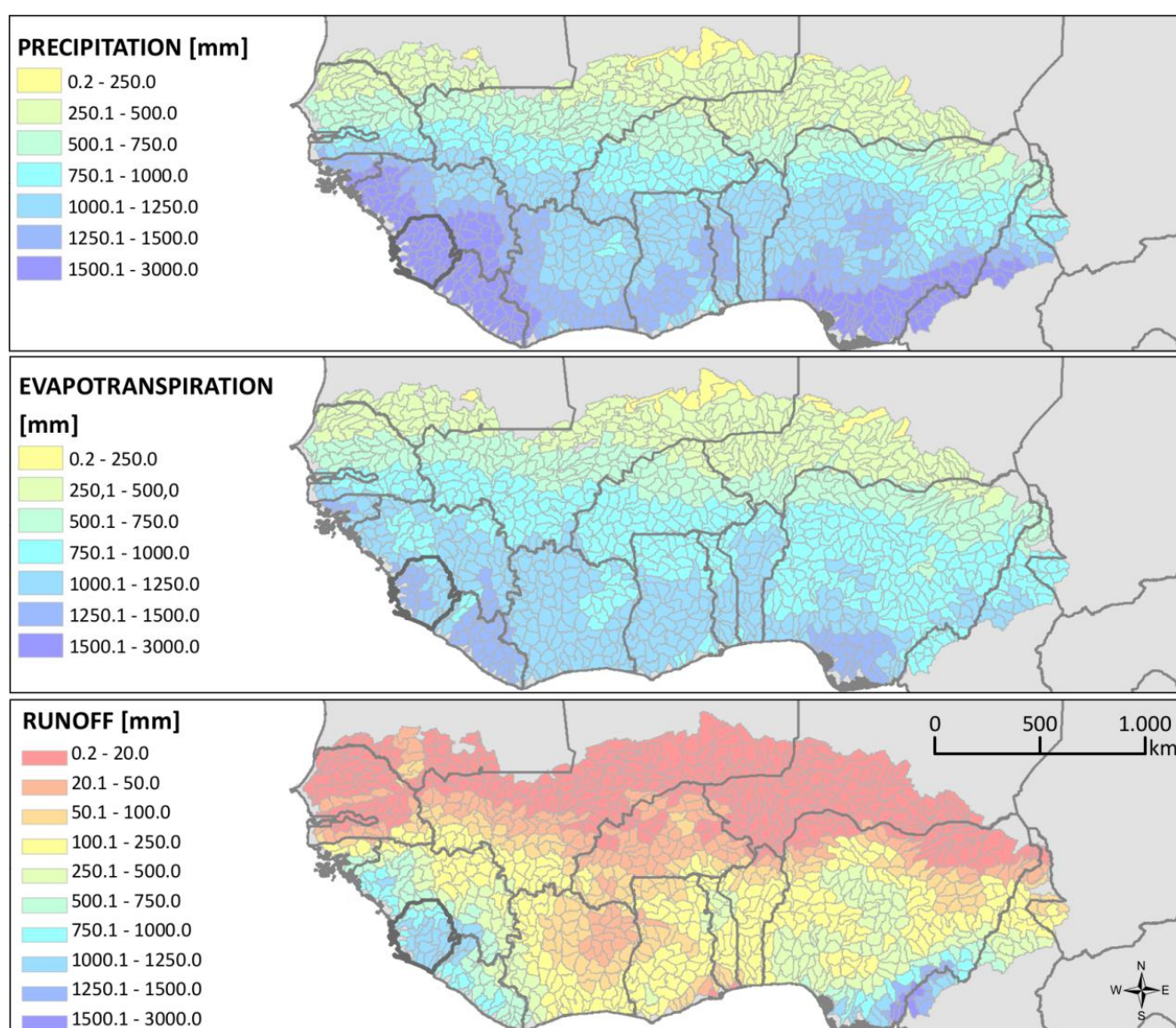
## Annual Water Balance

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.

In contrast, in the eastern, mountainous parts of Sierra Leone about half of the mean annual rainfall generates runoff and the other half is lost via evapotranspiration. In the western parts of the country still about 40 % of rainfall generate runoff, which is much higher than in most other West African countries.

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



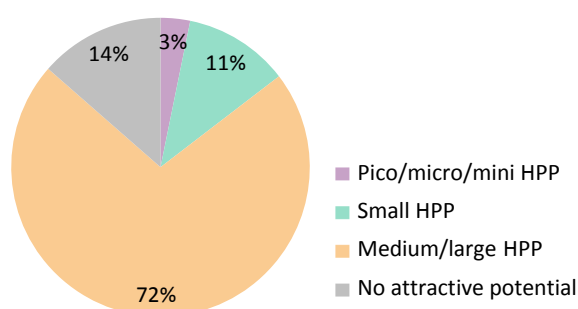
## HYDROPOWER POTENTIAL

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 Sierra Leone is estimated to be 4381 MW (reference period 1998-2014), which is the total of all rivers in the country.

The following table and figure 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<sup>3</sup>/s) and specific hydropower potential (MW/km) was applied to determine the preferred plant size for river reaches with a typical length of 1 to 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. The technical potential was not assessed in this study.

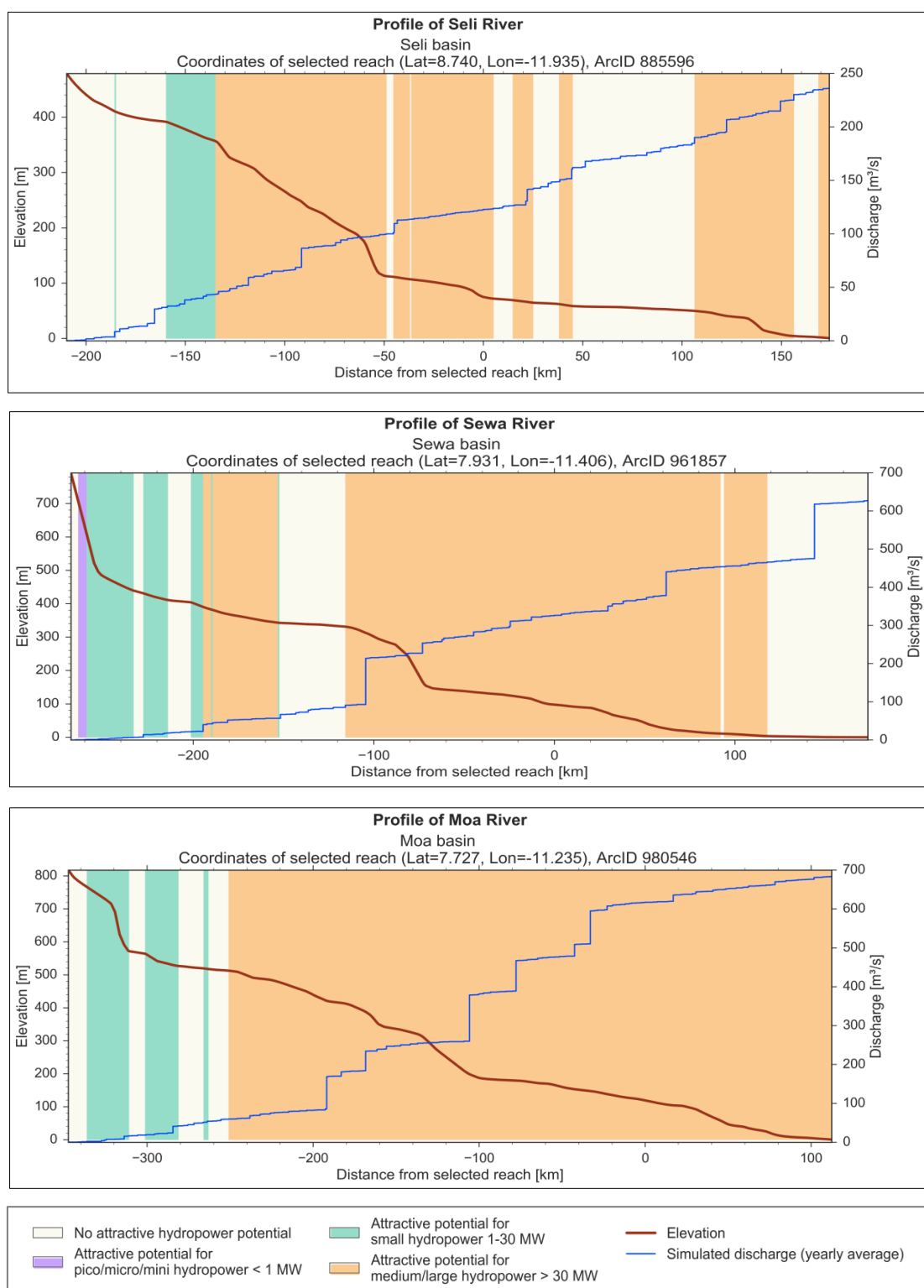
**Theoretical Hydropower Potential  
Sierra Leone: 4381 MW**



Theoretical Hydropower Potential of Rivers in Sierra Leone	
Pico/micro/mini HPP	140 MW
Small HPP	499 MW
Medium/large HPP	3148 MW
No attractive potential	594 MW
Total of all rivers in country	4381 MW
Total of rivers with attractive theoretical potential for pico/micro/mini, small, or medium/large HPP	3787 MW

## Longitudinal Profiles of Selected Rivers

The following graphs show longitudinal profiles of the Seli, Sewa and Moa 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. 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).

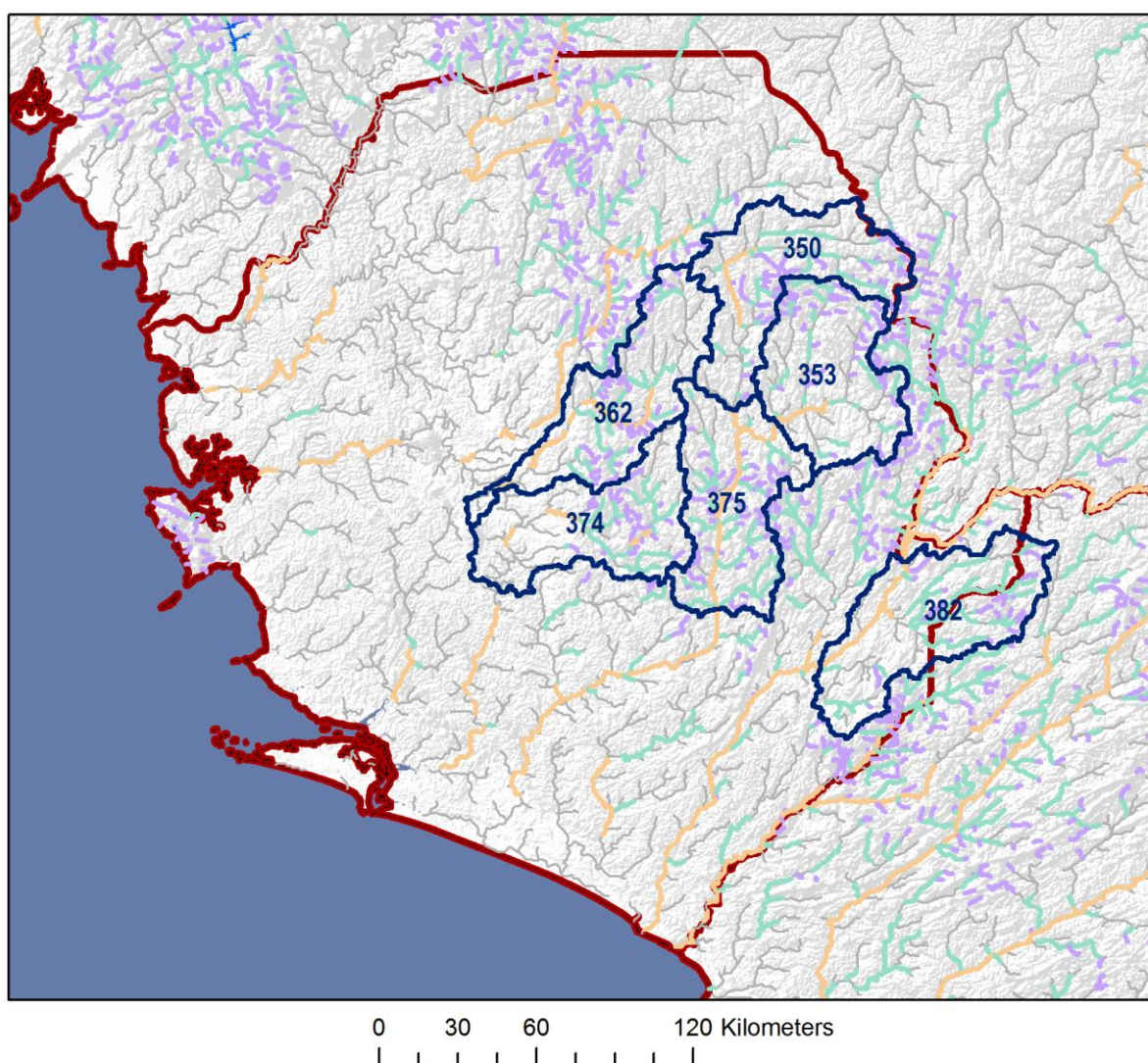




## Hydropower Potential in Selected Sub-catchments

The following maps and tables give information about the theoretical hydropower potential of selected sub-catchments in Sierra Leone. Sub-catchments were selected from the mountainous eastern part of Sierra Leone.

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.



### River network showing preferred hydropower plant size

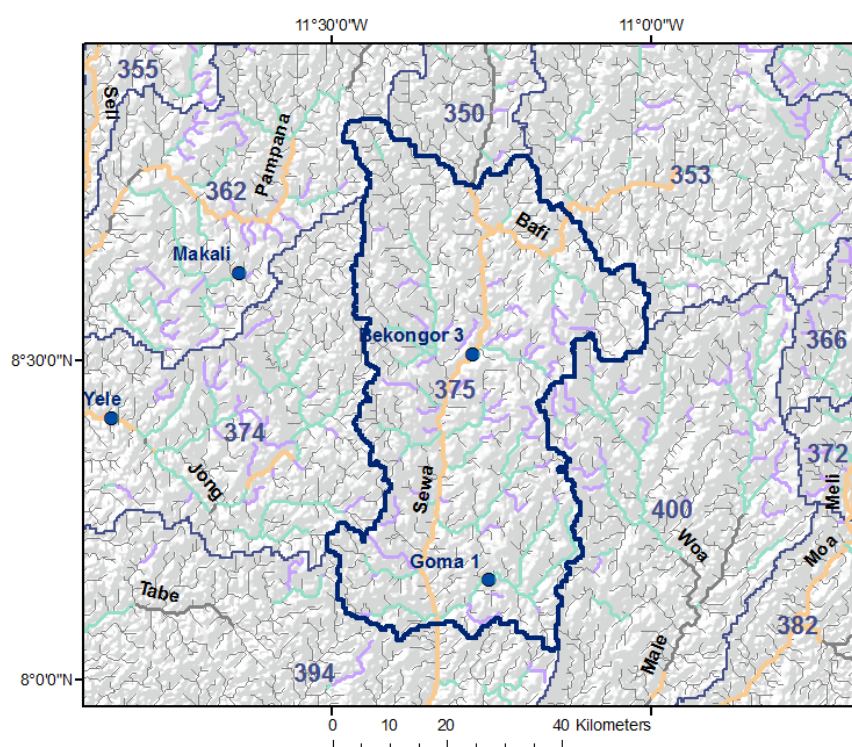
- Pico/micro/mini HPP
- Small HPP
- Medium/large HPP

### Map overlays

- Selected sub-catchments with ID number
- Lake or reservoir
- Country border



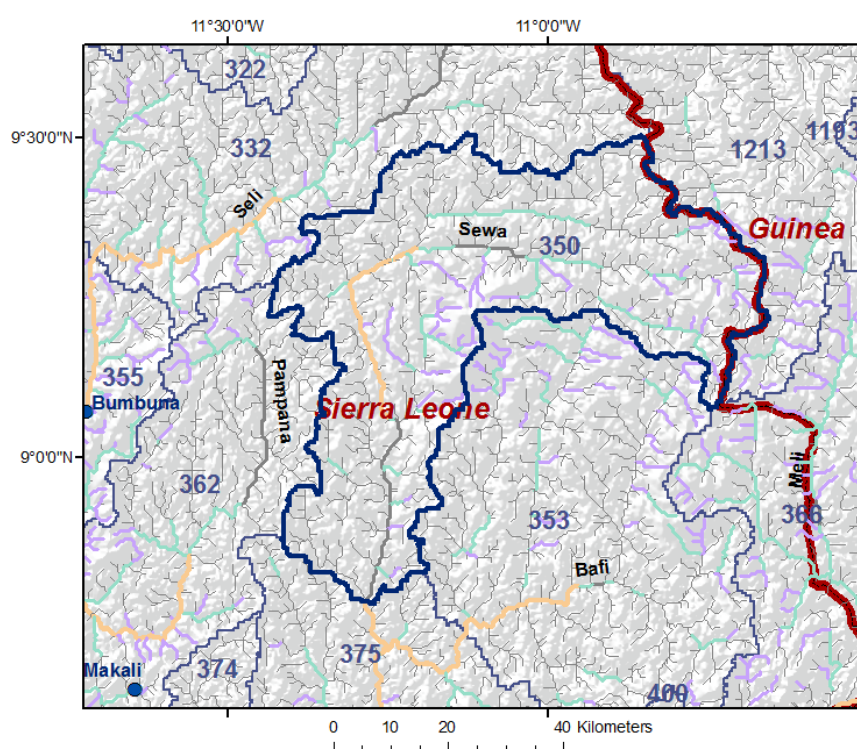




#### Theoretical Hydropower Potential of Rivers in Sub-Catchment #375

Pico/micro/mini HPP	14.8 MW
Small HPP	78.1 MW
Medium/large HPP	414.5 MW

This sub-catchment of the Sewa River is located in the central parts of Sierra Leone. The Sewa River upstream and downstream of the Bekongor 3 HPP site has high potential for medium/large HPP. The considerable potential for pico/micro/mini and small HPP is located at tributaries of the Sewa River.



#### Theoretical Hydropower Potential of Rivers in Sub-Catchment #350

Pico/micro/mini HPP	15.1 MW
Small HPP	24.0 MW
Medium/large HPP	19.6 MW

This sub-catchment is located in the headwater region of the Sewa River. Several tributaries of the Sewa River have considerable potential for pico/micro/mini HPP and small HPP.

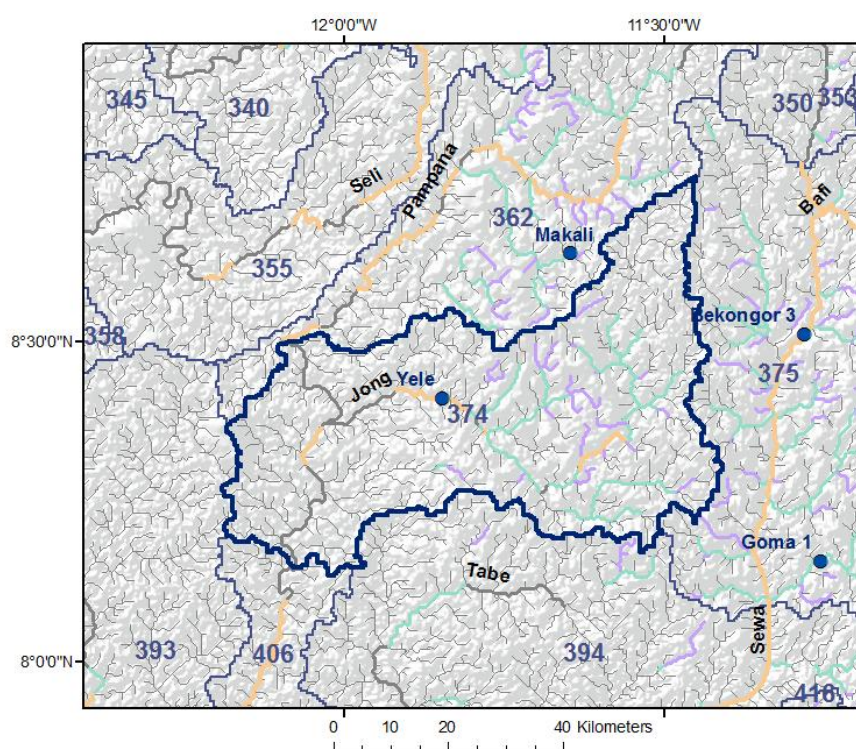
#### River network showing preferred hydropower plant size

- 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

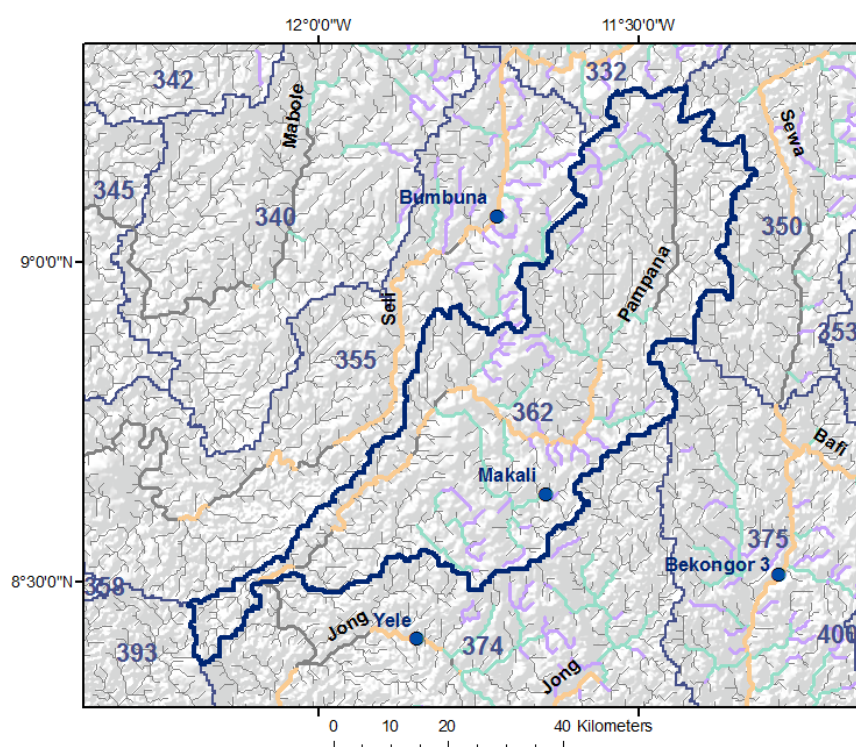




#### Theoretical Hydropower Potential of Rivers in Sub-Catchment #374

Pico/micro/mini HPP	6.9 MW
Small HPP	47.8 MW
Medium/large HPP	35.8 MW

This sub-catchment of the Jong River also includes the lowest section of the Pampana River. The Jong River has some potential for medium/large HPP near Yele. The considerable potential for pico/micro/mini and small HPP is located at tributaries of the Jong River.



#### Theoretical Hydropower Potential of Rivers in Sub-Catchment #362

Pico/micro/mini HPP	10.7 MW
Small HPP	42.5 MW
Medium/large HPP	130.4 MW

This sub-catchment forms the headwater region of the Pampana River. All of the potential for medium/large HPP is located at the Pampana River, whereas the considerable potential for pico/micro/mini and small HPP is located at short, but steep tributaries of the Pampana River.

#### River network showing preferred hydropower plant size

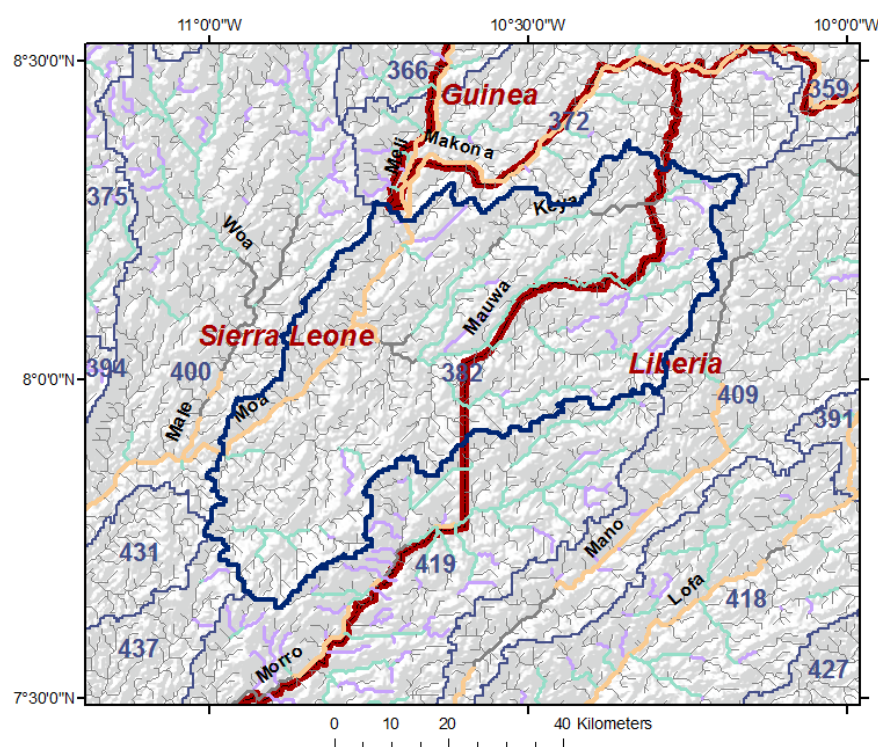
- Pico/micro/mini HPP
- Small HPP
- Medium/large HPP
- No attractive potential

#### Map overlays

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



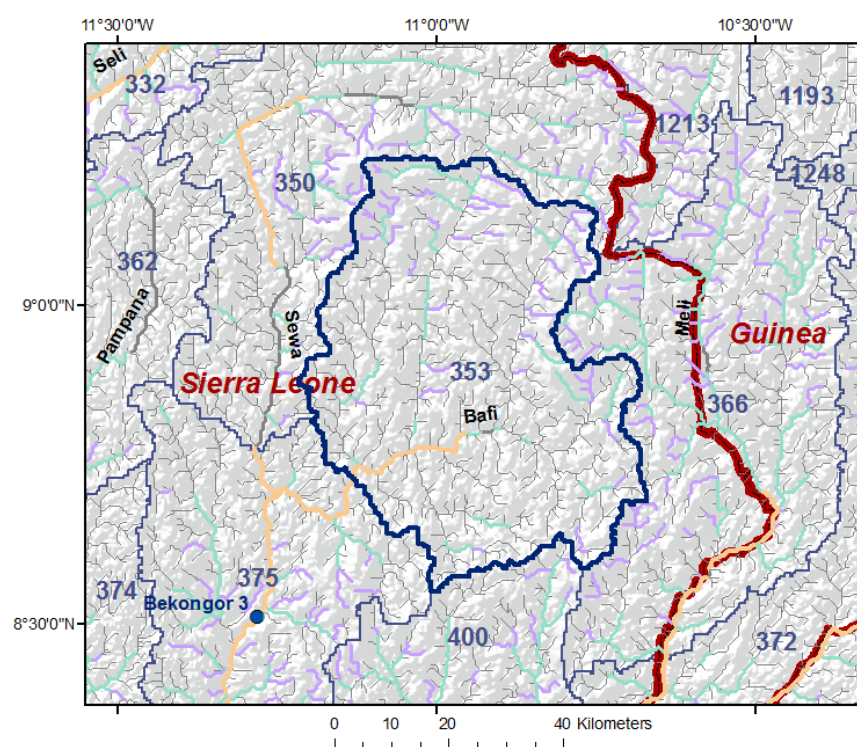




#### Theoretical Hydropower Potential of Rivers in Sub-Catchment #382

Pico/micro/mini HPP	6.9 MW
Small HPP	67.7 MW
Medium/large HPP	159.0 MW

This sub-catchment of the Moa River includes the Keya and Mauwa rivers near the border with Liberia. All of the potential for medium/large HPP is found at the Moa River, whereas the potential for small HPP is mainly located at the Keya and Mauwa rivers. About half of the sub-catchment's potential for pico/micro/mini HPP is found in neighboring Liberia.



#### Theoretical Hydropower Potential of Rivers in Sub-Catchment #353

Pico/micro/mini HPP	14.3 MW
Small HPP	24.8 MW
Medium/large HPP	21.1 MW

This sub-catchment represents the Bafi basin in eastern Sierra Leone. At the tributaries of the Bafi River there is considerable potential for pico/micro/mini HPP and small HPP. The Bafi River itself has some potential for medium/large HPP.

#### River network showing preferred hydropower plant size

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

#### Map overlays

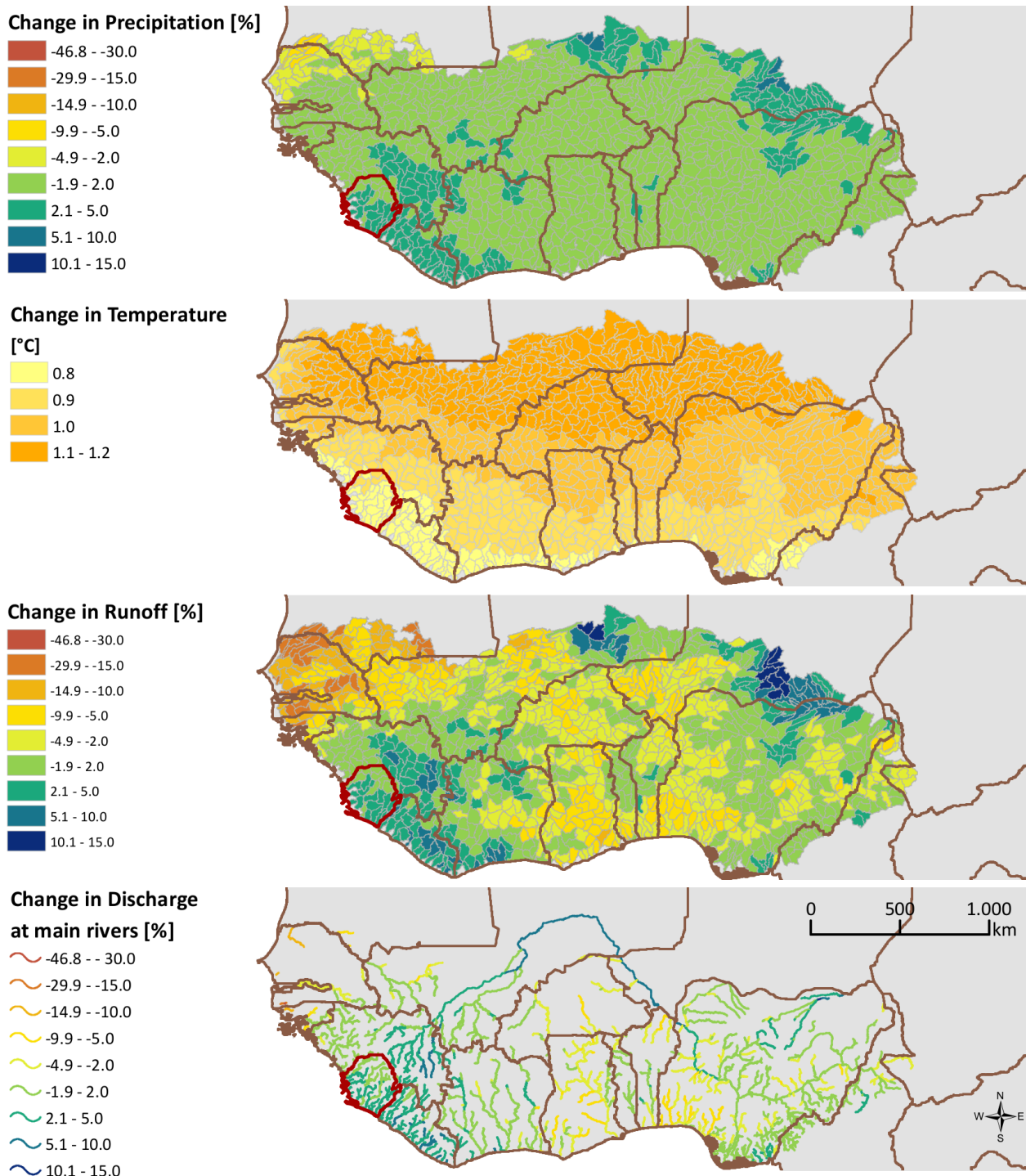
- Existing hydropower plant
- Lake or reservoir
- Sub-catchment boundary
- Country border



## 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



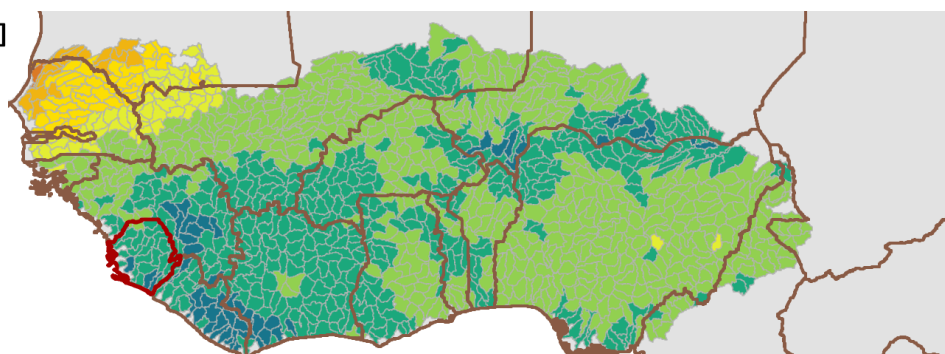
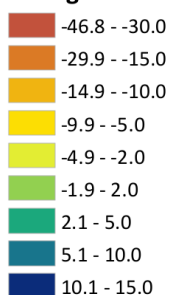


## Projections for the Far Future 2046-2065

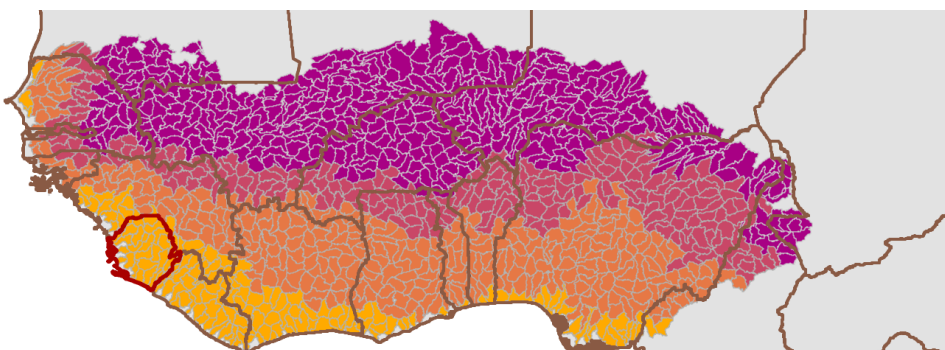
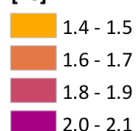
The maps below show the expected impact of climate change on future mean annual water resources. From the 30 climate model runs the median result was computed to generate the maps, which show change signals comparing the future periods 2026-2045 (previous page) and 2046-2065 (this page) vs. the reference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

Future precipitation is projected to increase in Sierra Leone. The combined effects of future precipitation and considerable warming (which affects evapotranspiration) were simulated with a water balance model to compute future runoff. In Sierra Leone an increase is projected for future runoff (median of 30 model runs). The same applies to river discharge.

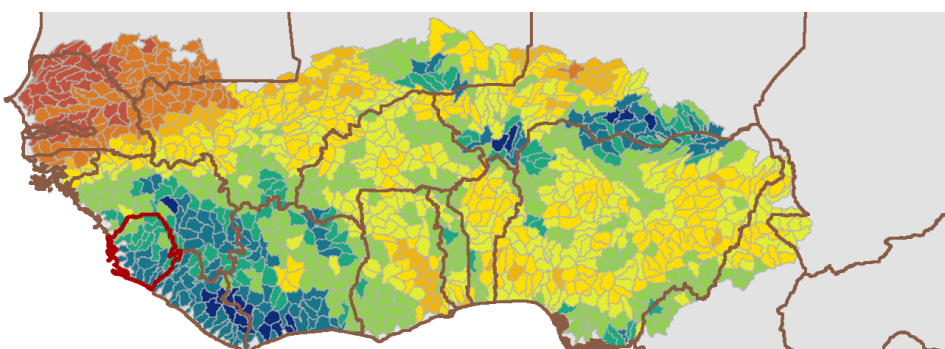
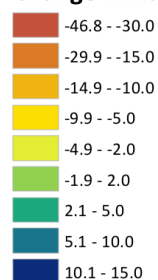
### Change in Precipitation [%]



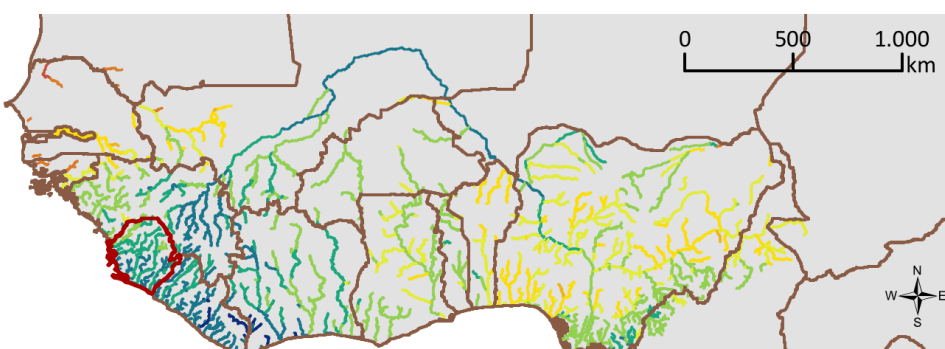
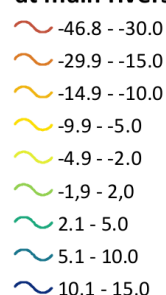
### Change in Temperature [°C]



### Change in Runoff [%]



### Change in Discharge at main rivers [%]



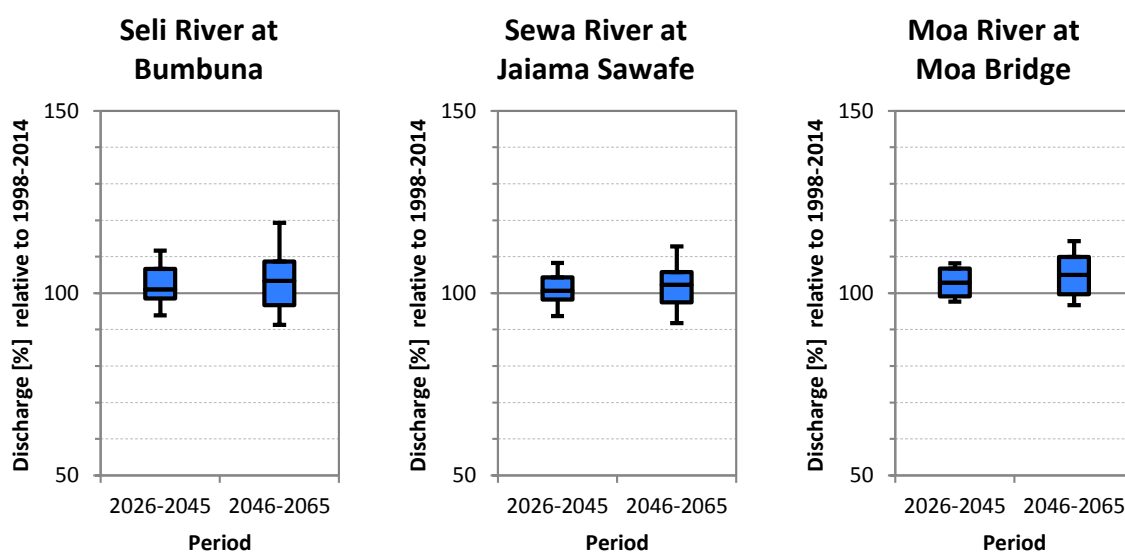
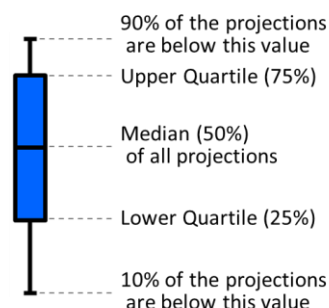
## Projected Change in Discharge for Selected Gauges

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).

The majority of projections with individual climate models show an increase in future discharge for rivers in Sierra Leone, as illustrated in the examples for the Seli, Sewa and Moa rivers below. Only a few outliers project a decrease in future discharge, whereas if the median result of 30 climate model runs is considered then discharge is expected to slightly increase by about +5 % in the far future (2046-2065 vs. 1998-2014).

Overall the climate change impact assessment shows that given the projections with the most detailed climate models currently available (CORDEX-Africa) future discharge is expected to increase for rivers in Sierra Leone. This would be beneficial for hydropower development.

**Boxplot summarizing projections with 30 climate model runs**



## ACKNOWLEDGEMENTS

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, Lericque 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.

