LIBERIA
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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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.

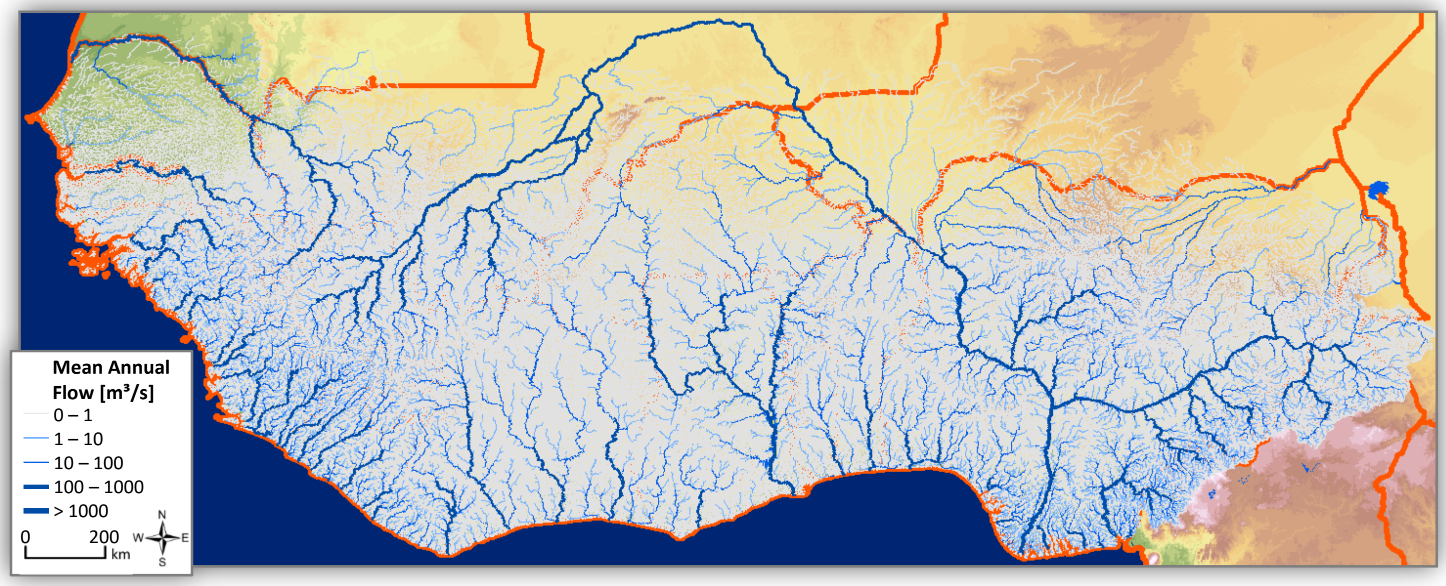
The ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE), founded in 2010 by ECOWAS, ADA, AECID and UNIDO, responded to these challenges and developed the ECOWAS Small-Scale Hydropower Program, which was approved by ECOWAS Energy Ministers in 2012. In the frame of this program ECREEE assigned 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 Liberia and includes:

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



GENERAL INFORMATION

Liberia is located at the coast of West Africa and has 4.4 Mio inhabitants. The capital of Liberia is Monrovia. The neighboring countries include Sierra Leone in the north-west, Guinea in the north and Côte d'Ivoire in the east (see map below).

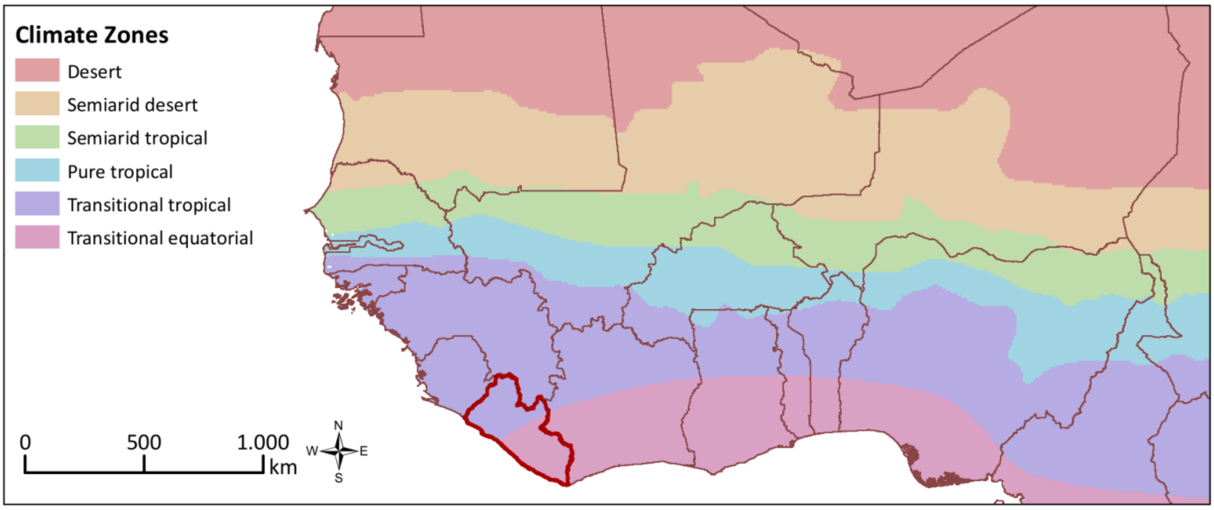
Electrification rate in the country is quite low. About 20% of the electricity generation is supplied by hydropower. Currently there are two existing hydropower plants in Liberia (see table below).

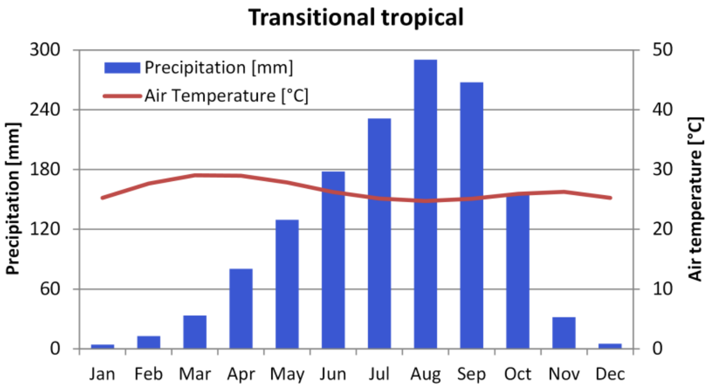
General Information for Liberia	
Inhabitants (2014)	4.4 Mio.
Area (2014)	111,370 km²
GDP per capita (2014)	457 USD
Electrification rate total/urban/rural (2012)	6/10/2 %
Hydro installed capacity (2012)	6 MW
Electricity generation (2010)	190 GWh
Electricity generation from hydropower (2010)	40 GWh
Number of existing hydropower plants with installed capacity < 1 MW (2016)	2
Number of existing small hydropower plants with installed capacity 1-30 MW (2016)	1
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)	0

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

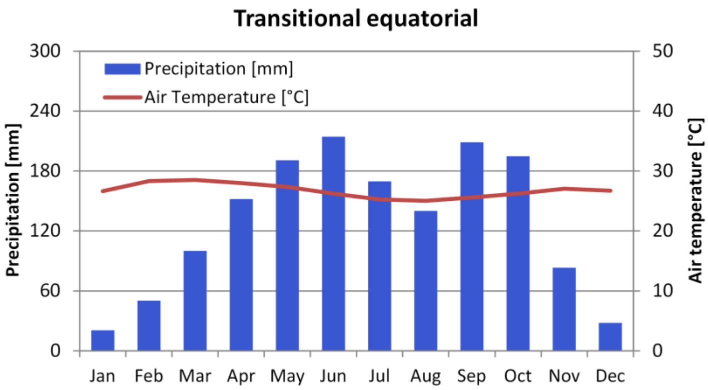
CLIMATE

The climate in West Africa can be grouped into six zones with distinctive seasonal rainfall patterns (L'Hôte et al., 1996). In Liberia the climate ranges from "Transitional equatorial" in the south-east to "Transitional tropical" in the north-west. The south-eastern regions have two rainfall peaks in June and September, whereas in the north-west 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 the 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



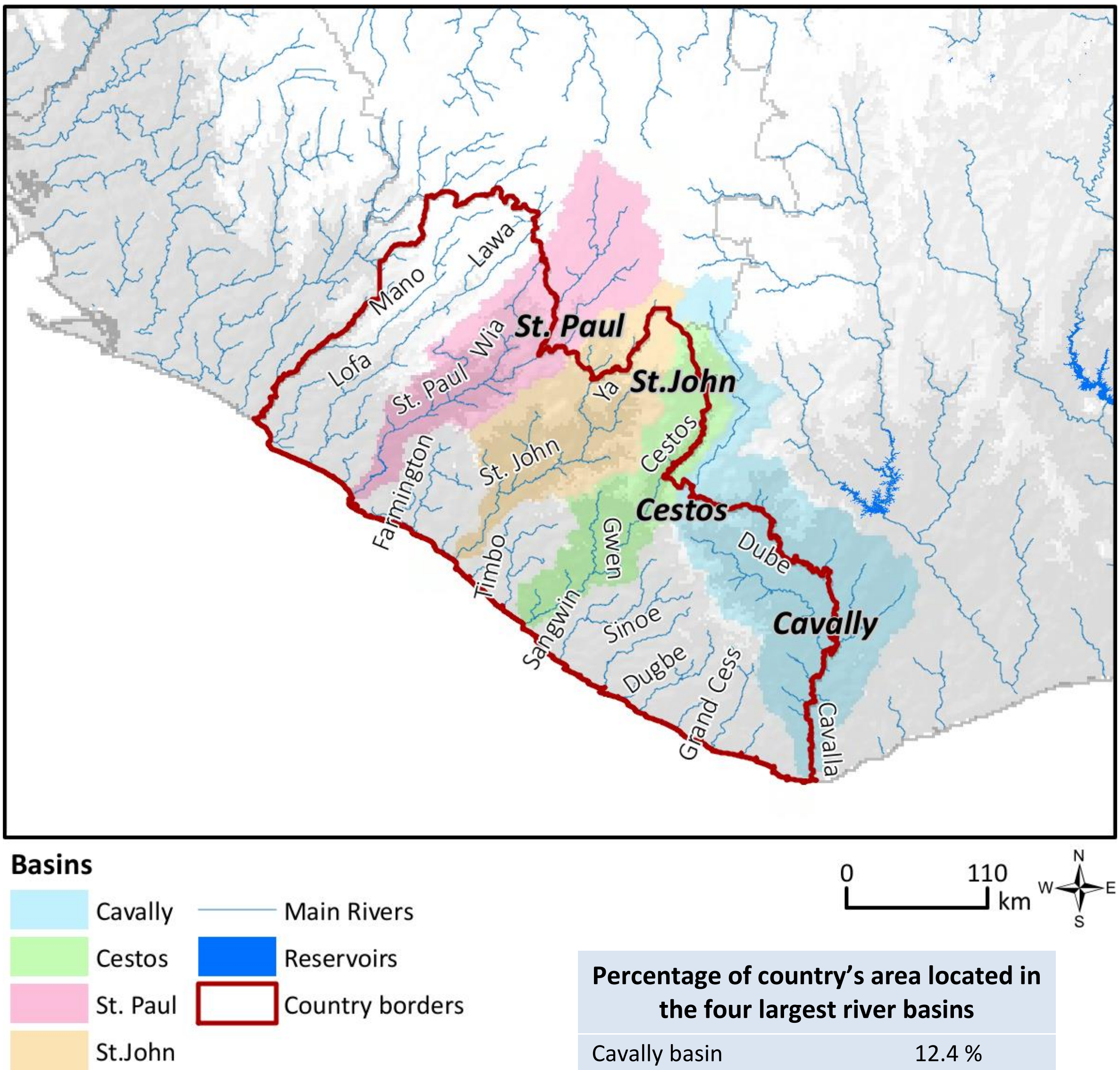
Precipitation data source: Tropical Rainfall Measuring Mission (NASA/JAXA), TRMM 3B42, mean 1998-2014
Air temperature data source: Climate Research Unit (University of East Anglia), CRU TS 3.22, mean 1998-2013

HYDROLOGY

There are several large rivers in Liberia that have their source in the border area between Liberia and Guinea and flow from north-east to south-west discharging into the Atlantic Ocean. The main rivers include the Mano, Lofa, St. Paul, St. John, Cestos and Cavally. None of these rivers covers more than 15 % of the country (see map and table below).

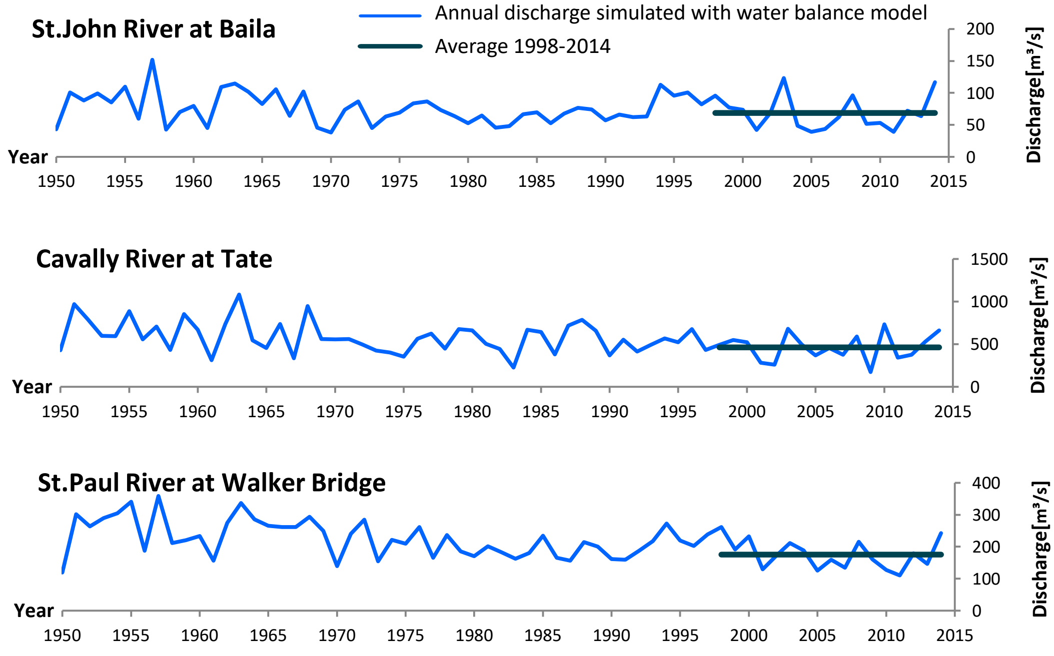
The figures on the following page illustrate the annual and seasonal variations in discharge for the St. Paul, St. John and Cavally rivers. Discharge observations covering long time-periods are not available in Liberia. Therefore, the figures are based on simulation results with a water balance model using rainfall as the main input.

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 at most rivers, whereas the Cavally River, which is the eastern most river of the country, shows a slightly different flow seasonality due to different rainfall patterns in rainfall (see climate on previous page).

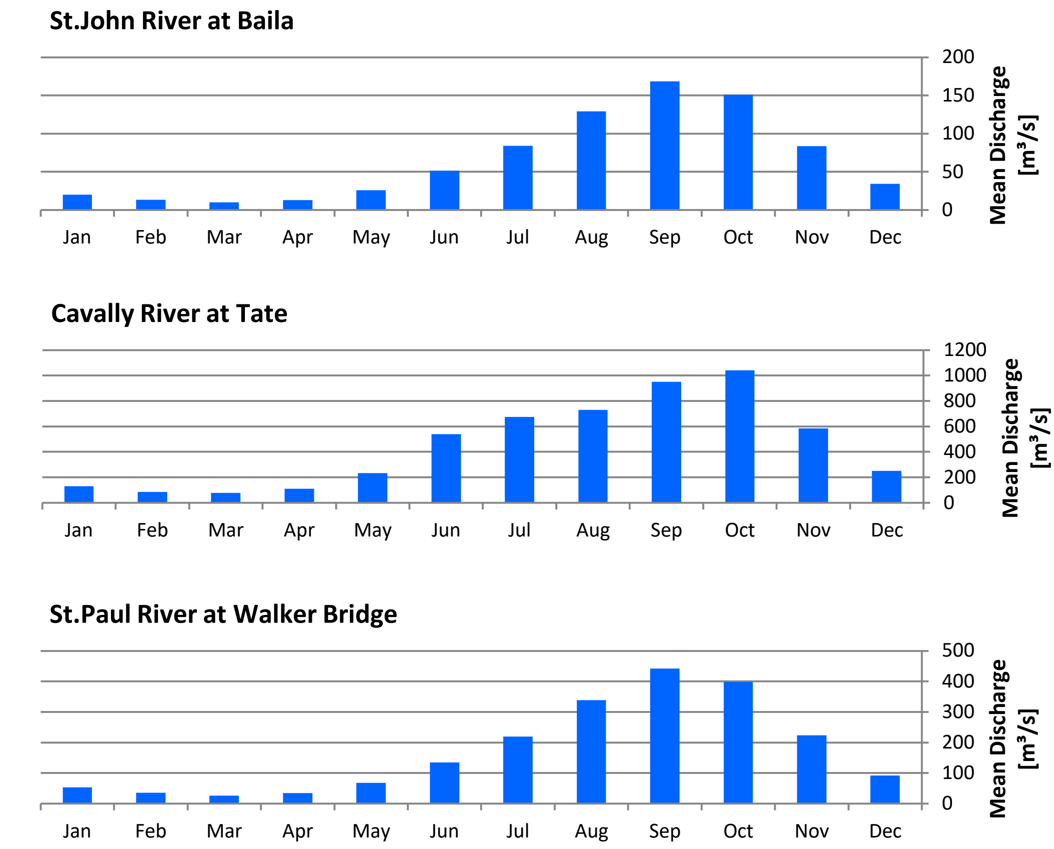


Percentage of country's area located in the four largest river basins	
Cavally basin	12.4 %
Cestos basin	10.9 %
St. Paul basin	11.5 %
St. John basin	14.1 %

Historic Variation in Annual Discharge



Seasonality in Discharge



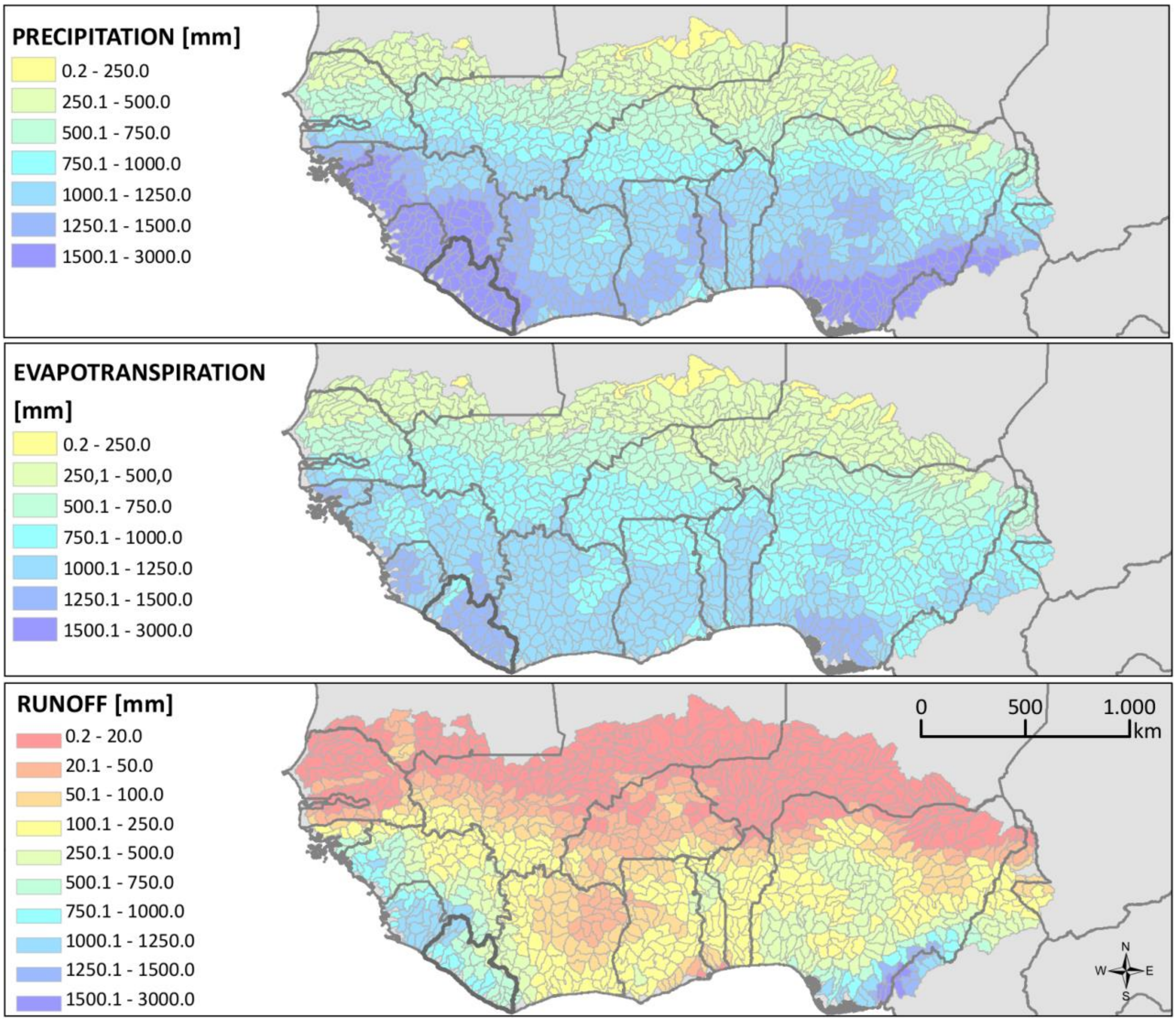
Annual Water Balance

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 Liberia mean annual runoff amounts to about 40 % of precipitation, which is of similar magnitude as actual evapotranspiration (60 % of precipitation). Runoff in coastal areas is slightly higher than in the mountainous inland, which is the result of the spatial distribution of precipitation.

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

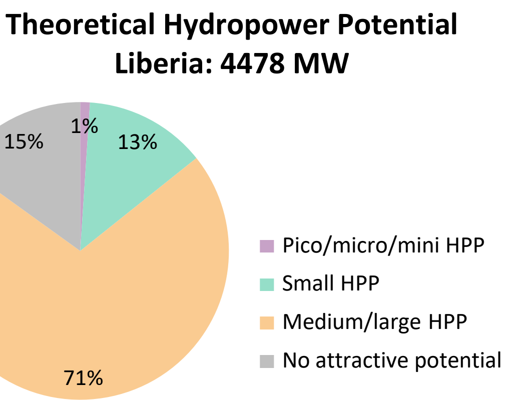


HYDROPOWER POTENTIAL

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 Liberia is estimated to be 4478 MW (reference period 1998-2014), which is the total of all rivers in the country.

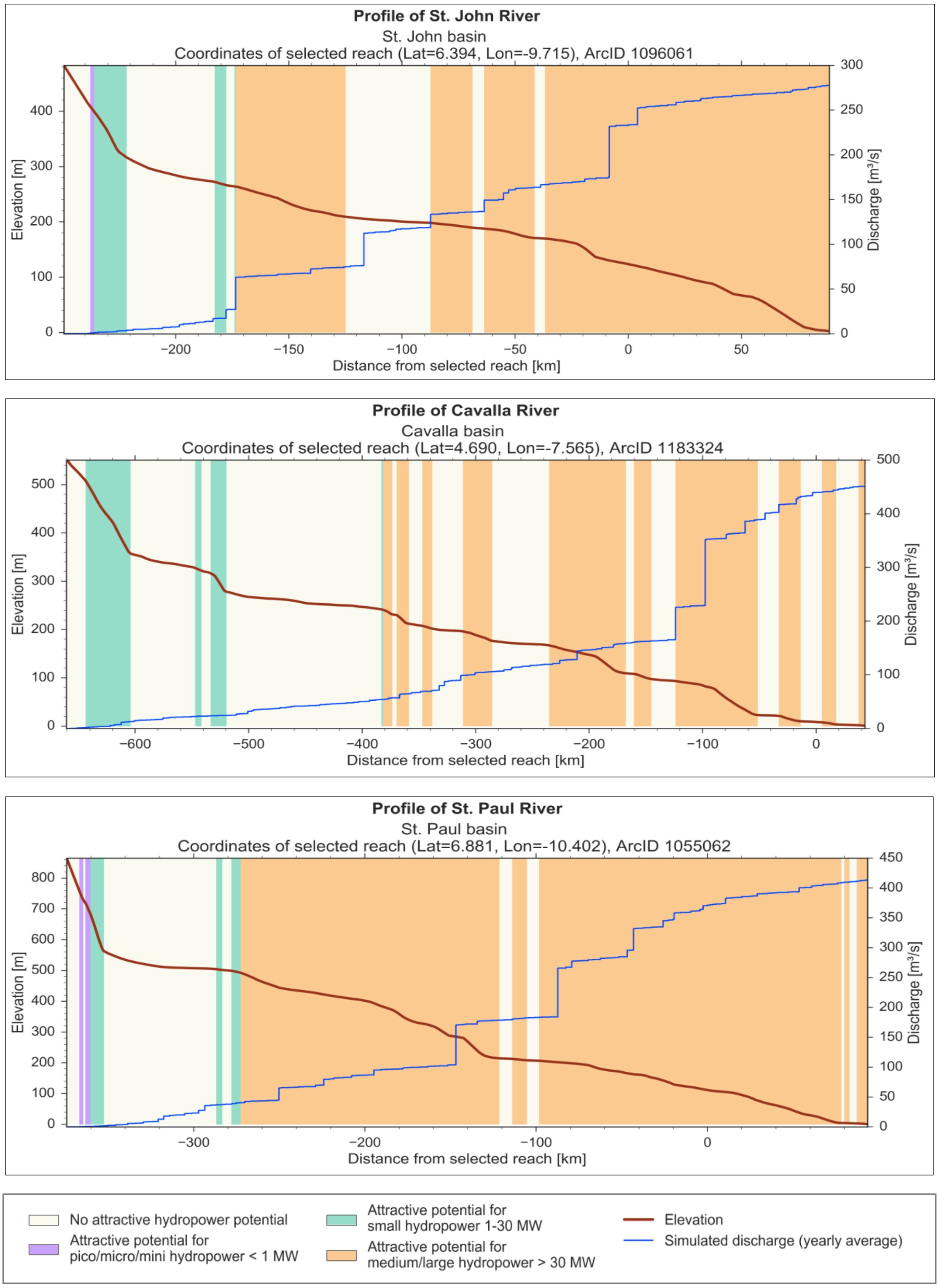
The following table and figure show how the total potential of the country is subdivided into theoretical potential for hydropower plants (HPP) of different plant size. A classification scheme based on mean annual discharge (m^3/s) and specific hydropower potential (MW/km) was applied to determine the preferred plant size for river reaches with a typical length of 1 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 of Rivers in Liberia	
Pico/micro/mini HPP	47 MW
Small HPP	592 MW
Medium/large HPP	3164 MW
No attractive potential	675 MW
Total of all rivers in country	4478 MW
Total of rivers with attractive theoretical potential for pico/micro/mini, small, or medium/large HPP	3803 MW

Longitudinal Profiles of Selected Rivers

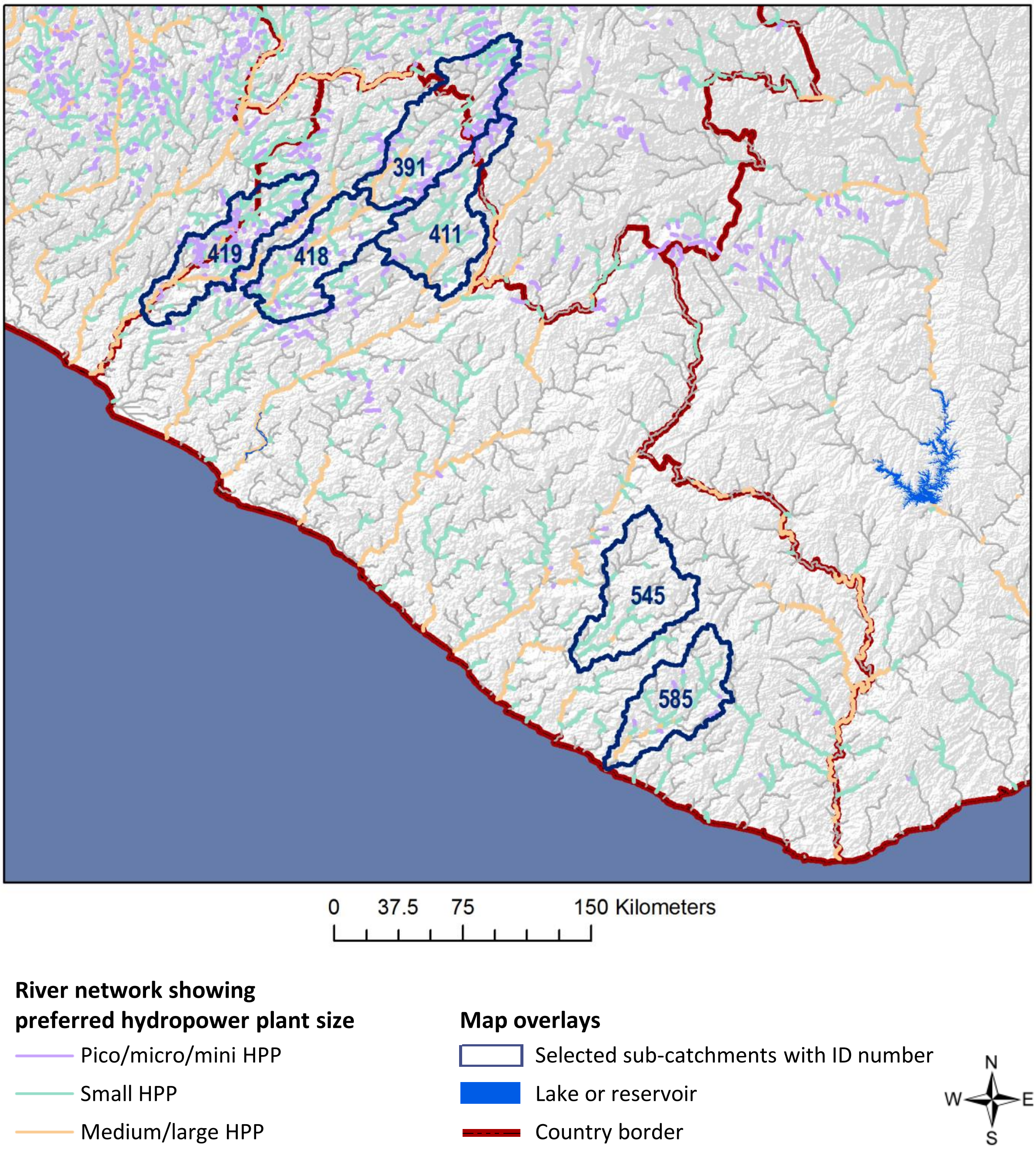
The following graphs show longitudinal profiles of the St. John, Cavalla and St. Paul rivers, plotting elevation (red) and mean annual discharge (blue) from the source to the mouth of the river. Inflow from tributaries is clearly identifiable as sudden increase in river discharge. The background color 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).

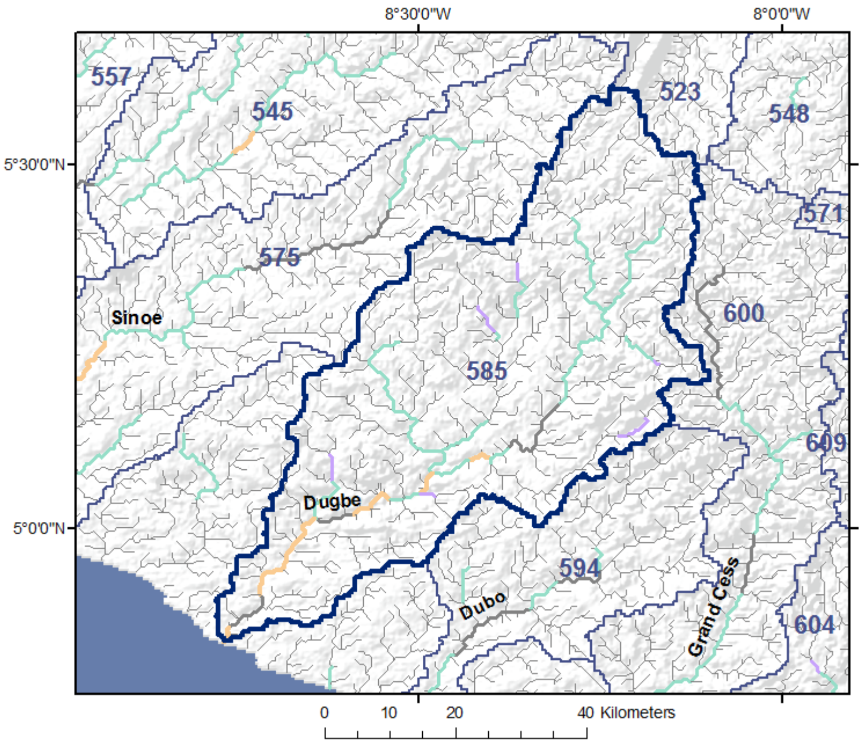


Hydropower Potential in Selected Sub-catchments

The following maps and tables give information about the theoretical hydropower potential of selected sub-catchments in Liberia. Sub-catchments were selected from the north-west and southern parts of Liberia.

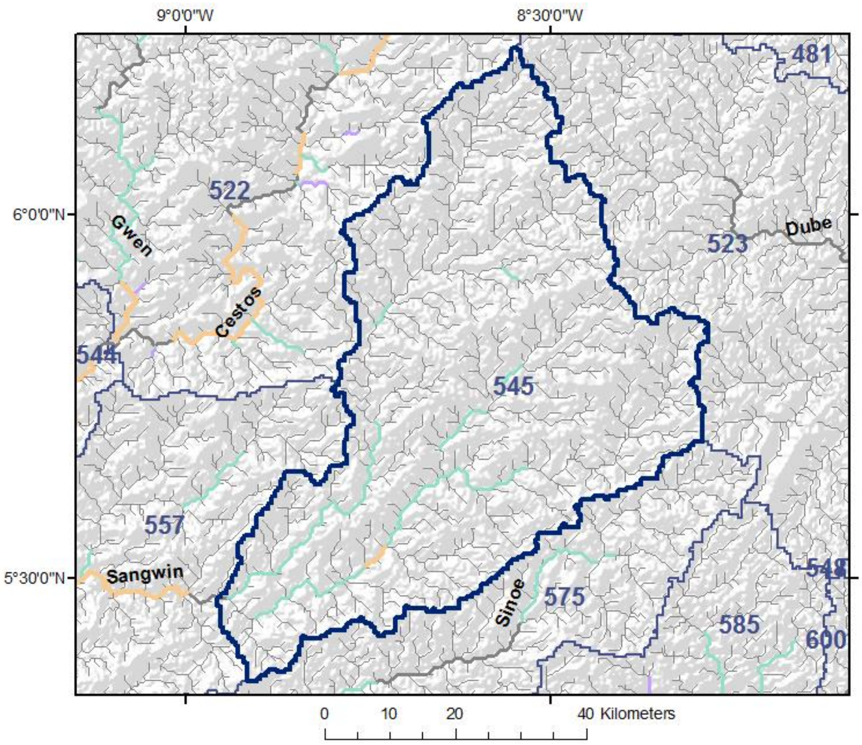
The table data summarizes the total theoretical hydropower potential of all river reaches within the sub-catchment. River reaches were grouped according to preferred plant size for pico/micro/mini HPP (< 1 MW installed capacity), small HPP (1-30 MW installed capacity), or medium/large HPP (> 30 MW installed 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.





Theoretical Hydropower Potential of Rivers in Sub-Catchment #585	
Pico/micro/mini HPP	1.3 MW
Small HPP	37.2 MW
Medium/large HPP	18.7 MW

This sub-catchment represents the Dugbe basin in southern Liberia. The Dugbe River and some of its tributaries have considerable potential for small HPP.



Theoretical Hydropower Potential of Rivers in Sub-Catchment #545	
Pico/micro/mini HPP	0 MW
Small HPP	41.7 MW
Medium/large HPP	3.9 MW

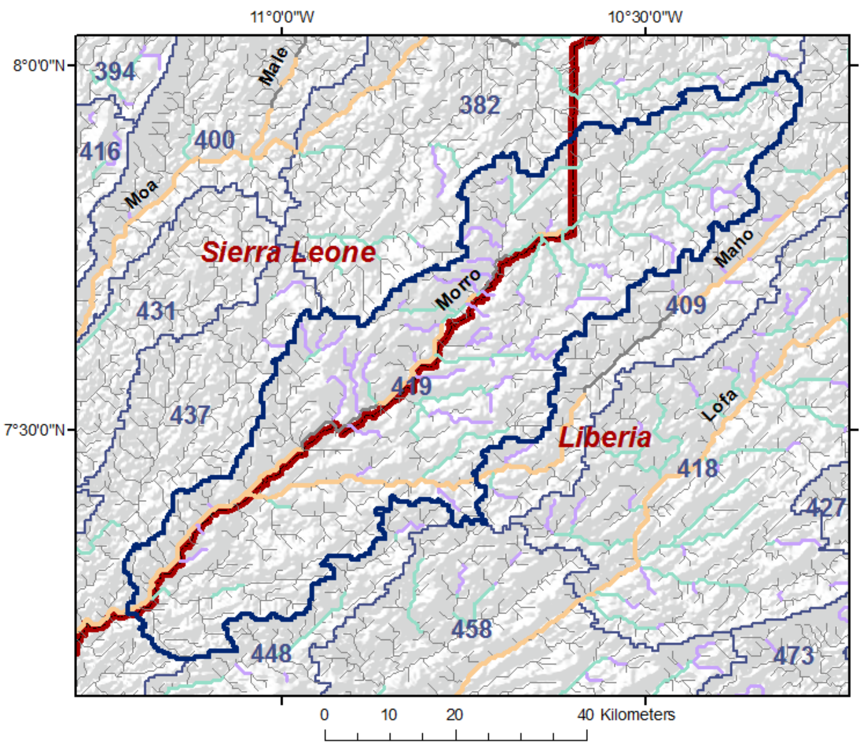
This sub-catchment forms the headwater region of the Sangwin River. The two main tributaries of the Sangwin River have considerable potential for small HPP.

River network showing preferred hydropower plant size

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

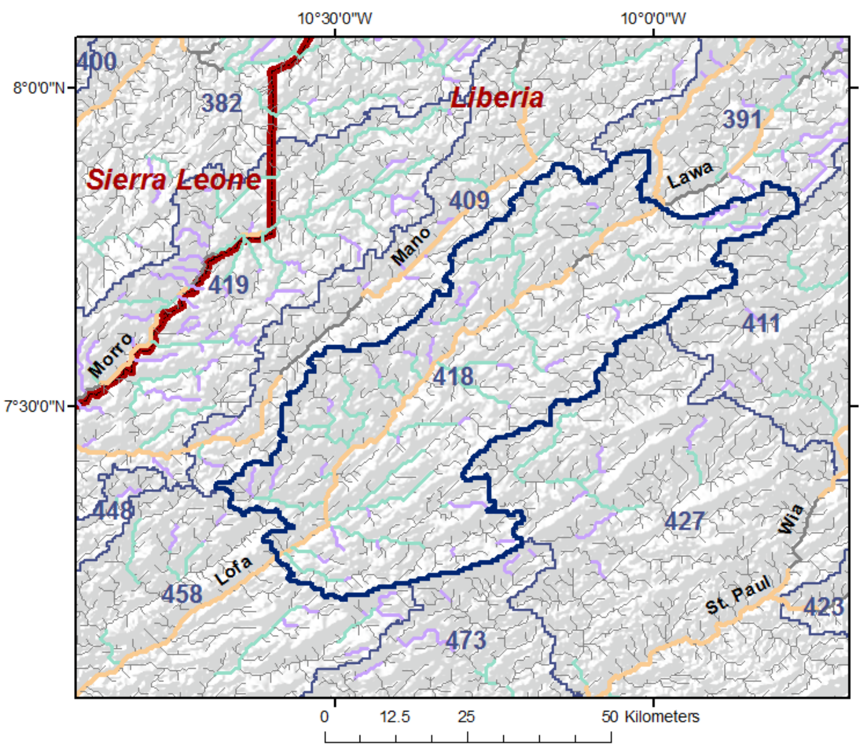
Map overlays

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



Theoretical Hydropower Potential of Rivers in Sub-Catchment #419	
Pico/micro/mini HPP	16.5 MW
Small HPP	44.8 MW
Medium/large HPP	208.7 MW

This sub-catchment of the Mano basin is shared with Sierra Leone, where the Morro River (a tributary of the Mano River) forms the international border. Short tributaries on both sides of the border have considerable potential for pico/micro/mini HPP. The potential for small HPP is mostly located at the Morro River, whereas the high potential for medium/large HPP is mostly located at the Mano River.



Theoretical Hydropower Potential of Rivers in Sub-Catchment #418	
Pico/micro/mini HPP	6.1 MW
Small HPP	50.9 MW
Medium/large HPP	385.7 MW

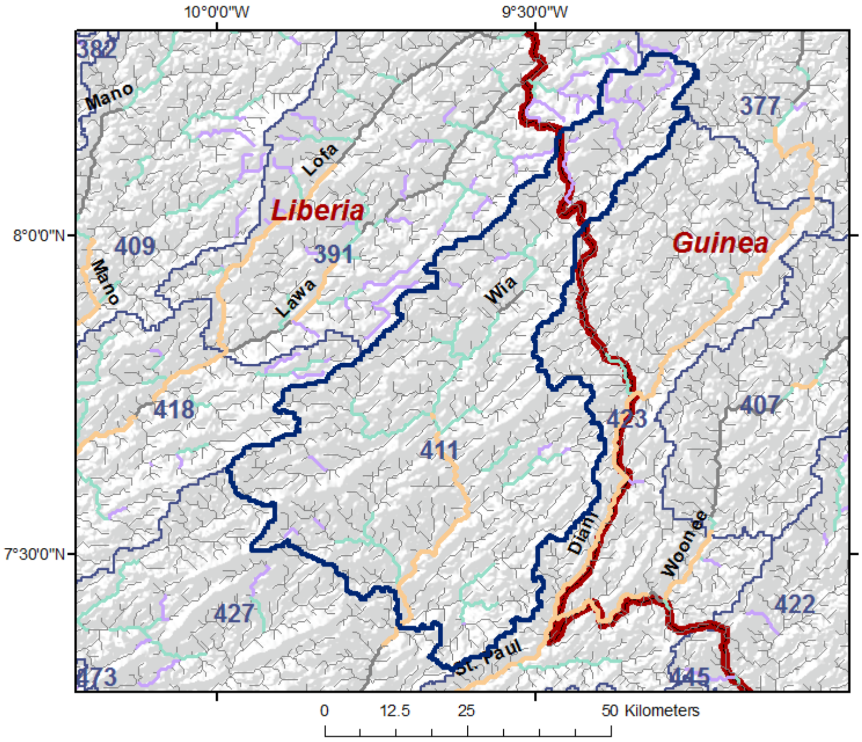
The Lofa River shows high potential for medium/large HPP in this sub-catchment. Short, but steep tributaries have considerable potential for small HPP.

River network showing preferred hydropower plant size

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

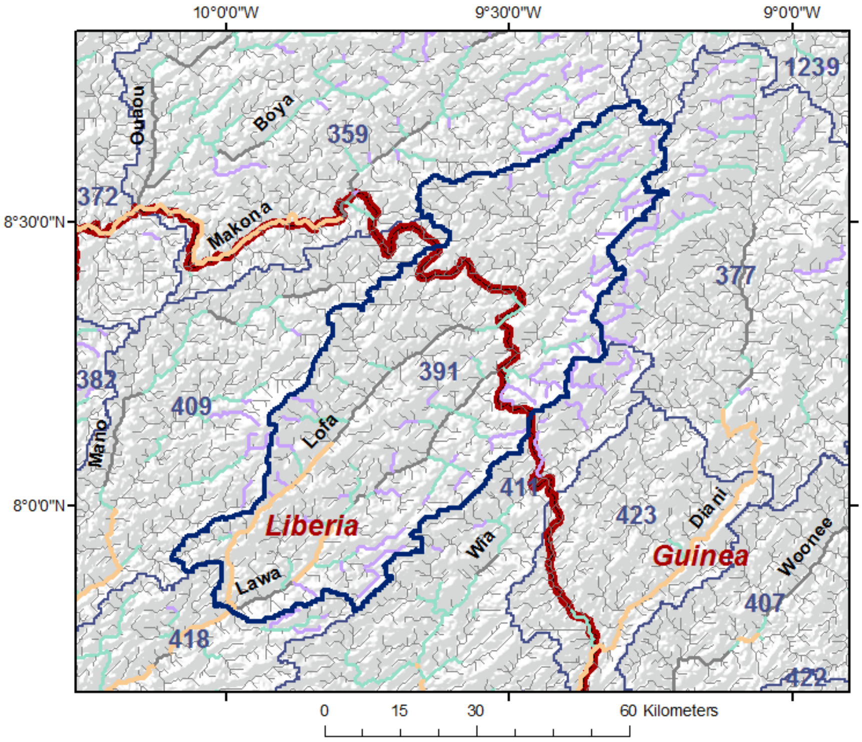
Map overlays

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



Theoretical Hydropower Potential of Rivers in Sub-Catchment #411	
Pico/micro/mini HPP	5.9 MW
Small HPP	33.1 MW
Medium/large HPP	42.5 MW

This sub-catchment in northern Liberia represents the Wia basin, which extends into Guinea. Most of the potential for pico/micro/mini HPP is located in Guinea, but the potential for small HPP and medium large HPP is located at rivers in Liberia.



Theoretical Hydropower Potential of Rivers in Sub-Catchment #391	
Pico/micro/mini HPP	19.4 MW
Small HPP	39.7 MW
Medium/large HPP	97.2 MW

The headwater region of the Lofa River is shared between Liberia and Guinea. The Lawa River is also included in this sub-catchment. About half of the potential for pico/micro/mini HPP and small HPP is located in Liberia, whereas all of the potential for medium/large HPP is located in Liberia (mainly at the Lofa 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

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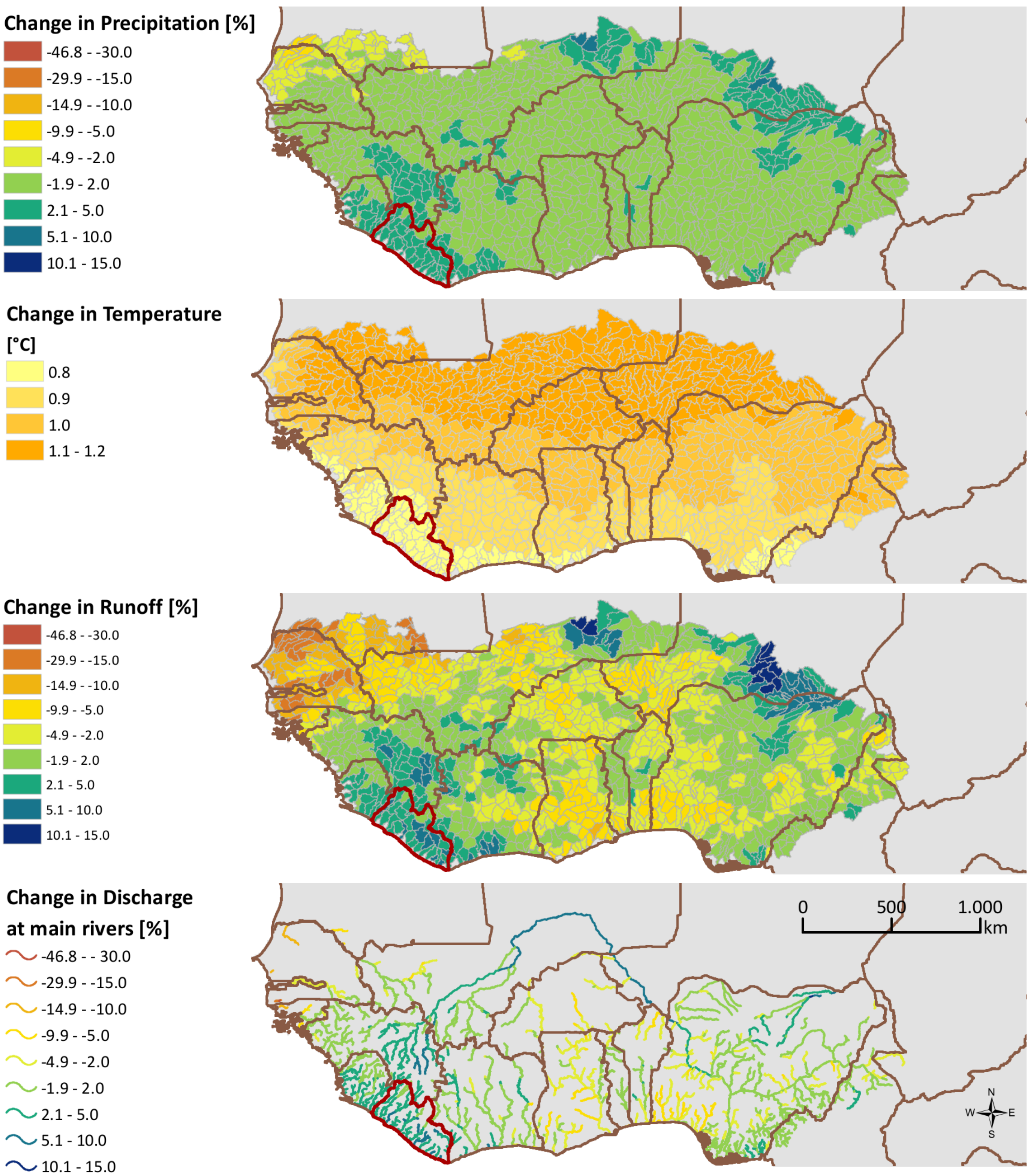
CLIMATE CHANGE

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.

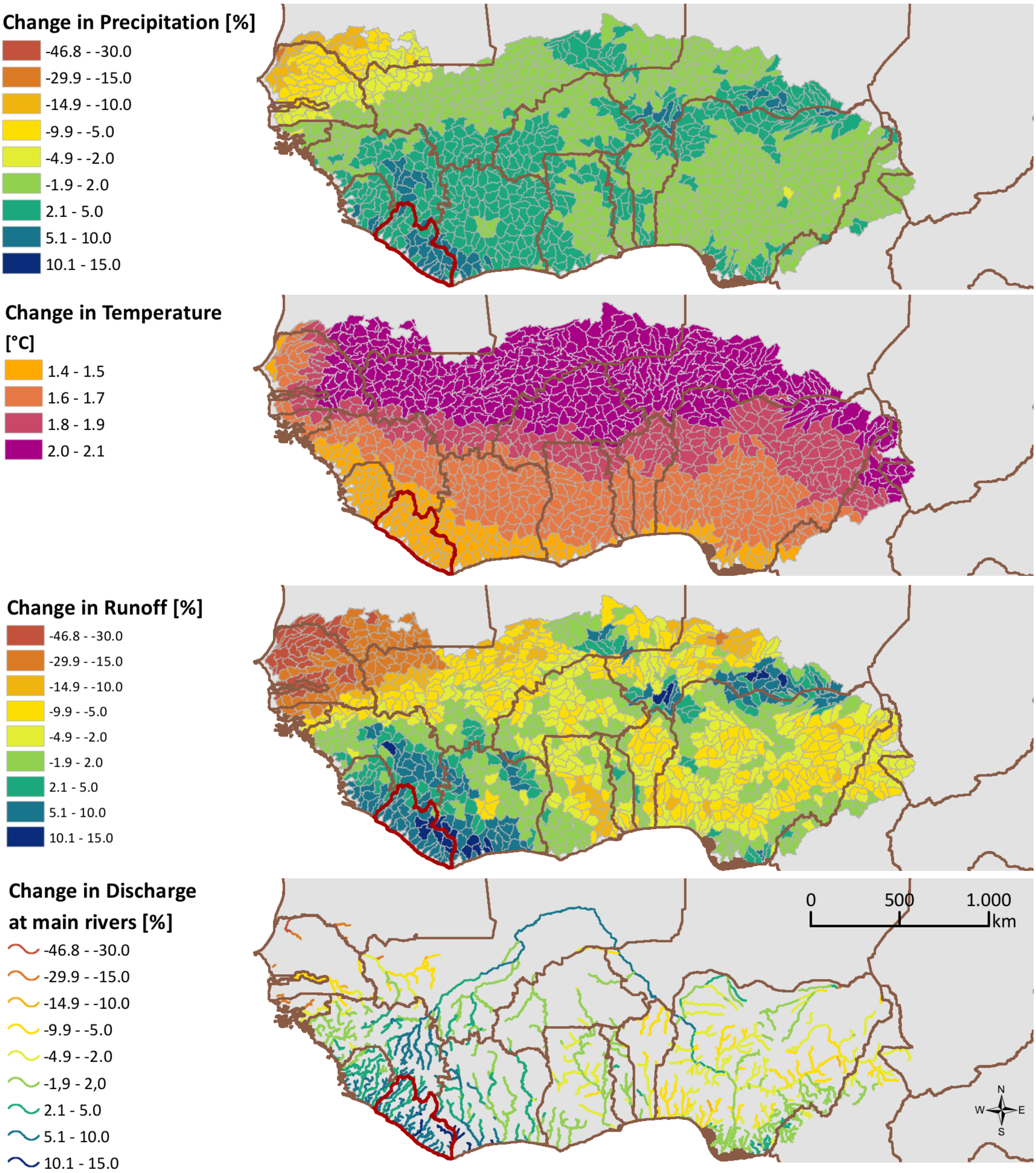
Projections for the Near Future 2026-2045



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



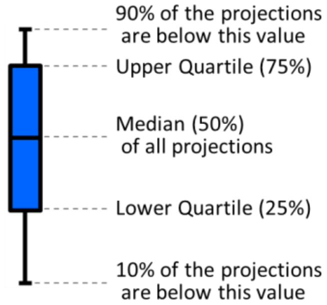
Projected Change in Discharge for Selected Gauges

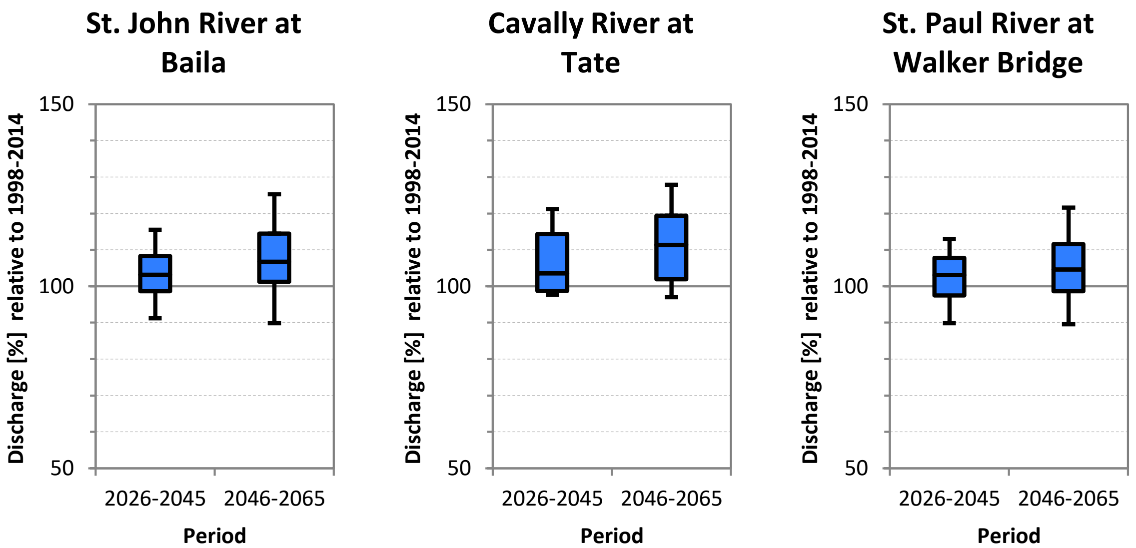
Future mean annual discharge was estimated with data from 30 different climate model runs. Boxplots are presented to summarize the spread in the simulation results (see explanation at right).

The projections with individual climate models consistently show an increase in future discharge for rivers in Liberia, as illustrated in the examples for the St. John, Cavally and St. Paul 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 increase by +5 % to +10 % in the far future.

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 Liberia. This would be beneficial for hydropower development.

Boxplot summarizing projections with 30 climate model runs





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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.