NIGERIA
COUNTRY REPORT

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

ECOWAS Centre for Renewable Energy and Energy Efficiency
www.ecreee.org

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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.

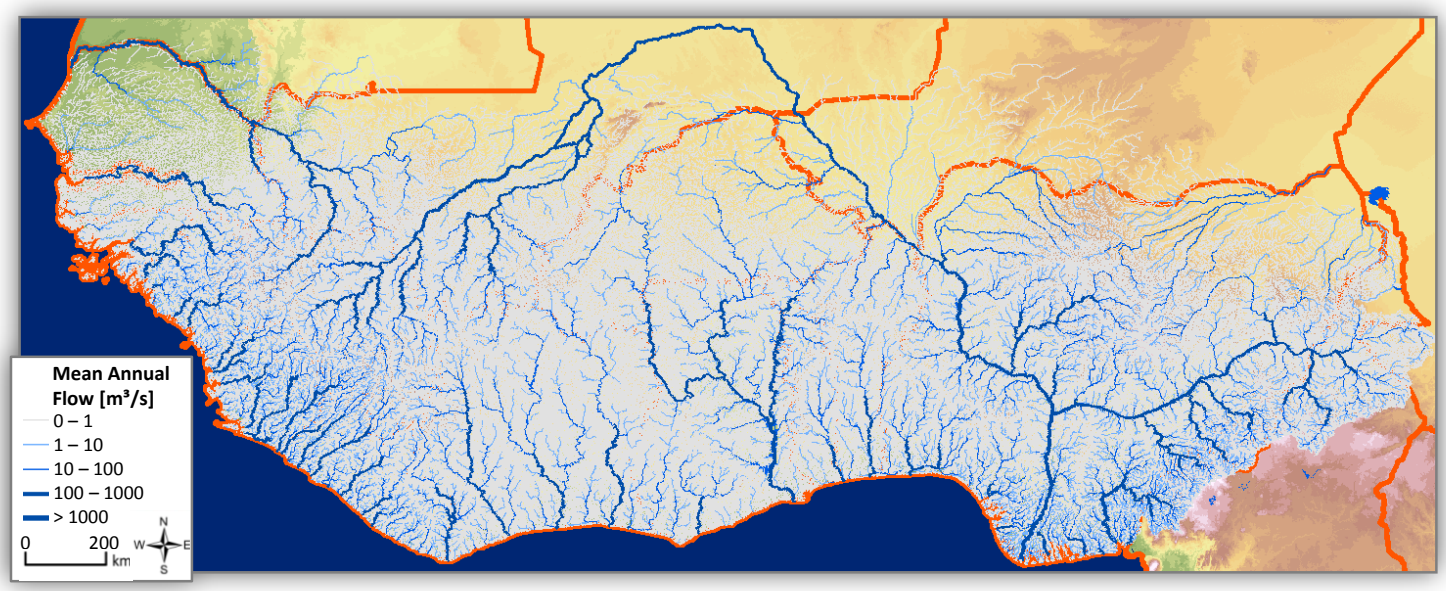
The ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE), founded in 2010 by ECOWAS, ADA, AECID and UNIDO, responded to these challenges and developed the ECOWAS Small-Scale Hydropower Program, which was approved by ECOWAS Energy Ministers in 2012. In the frame of this program ECREEE assigned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

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



GENERAL INFORMATION

Nigeria is the most populous country in West Africa with 178 Mio inhabitants. The capital of Nigeria is Abuja in the central part of the country and major urban centers include Lagos in the south and Kano in the north. The neighboring countries are Benin in the west, Republic of Niger in the north, and Cameroon in the east (see map below). At Lake Chad in the extreme north-east of the country Nigeria shares a short section of border with Chad.

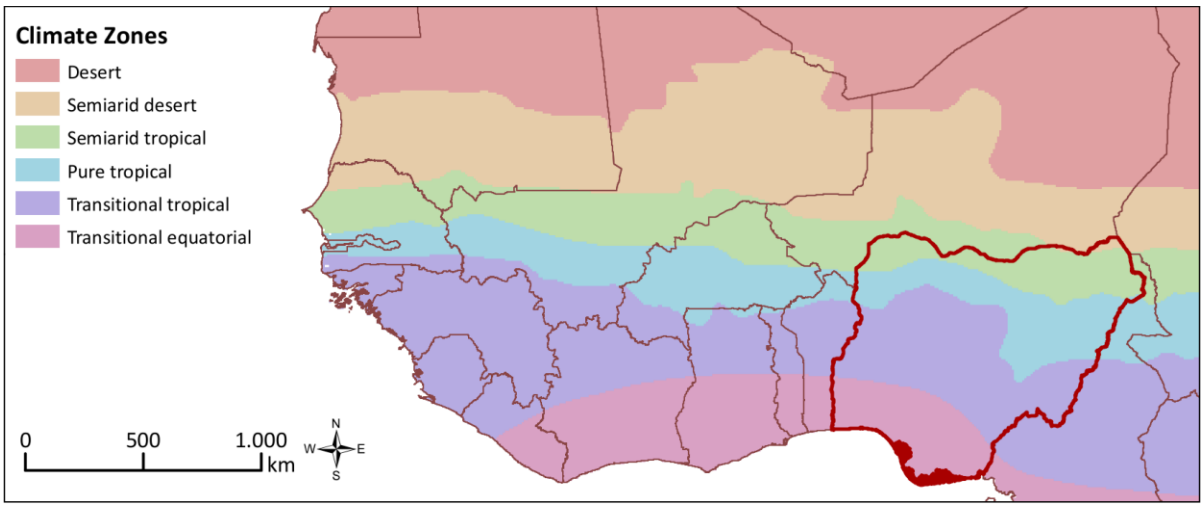
Hydropower plays an important role for energy generation in Nigeria. Currently there are 34 existing hydropower plants, including small, medium and large hydropower plants (see table below).

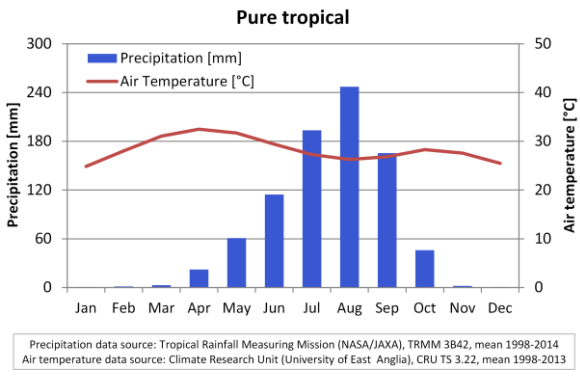
General Information for Nigeria	
Inhabitants (2014)	177.5 Mio.
Area (2014)	923,770 km²
GDP per capita (2014)	3,202 USD
Electrification rate total/urban/rural (2013)	16/62/14.7 %
Hydro installed capacity (2014)	1,787 MW
Electricity generation (2013)	28,961 GWh
Electricity generation from hydropower (2013)	5,326 GWh
Number of existing hydropower plants with installed capacity > 1 MW (2016)	34
Number of existing small hydropower plants with installed capacity 1-30 MW (2016)	23
Number of existing medium hydropower plants with installed capacity 30-100 MW (2016)	5
Number of existing large hydropower plants with installed capacity >100 MW (2016)	6

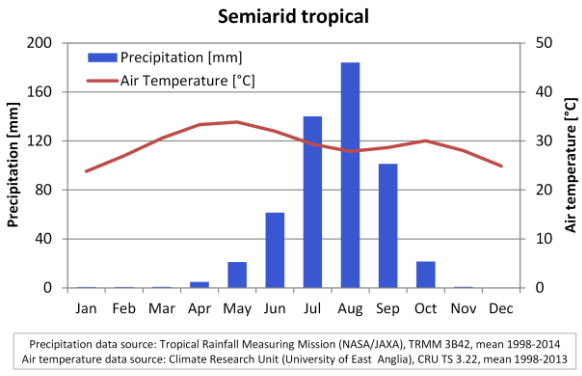
Source: ECOWAS Country Profiles (www.ecowrex.org)
Reference year given in brackets.

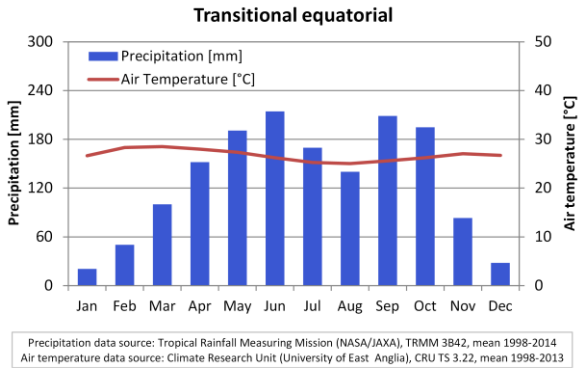
CLIMATE

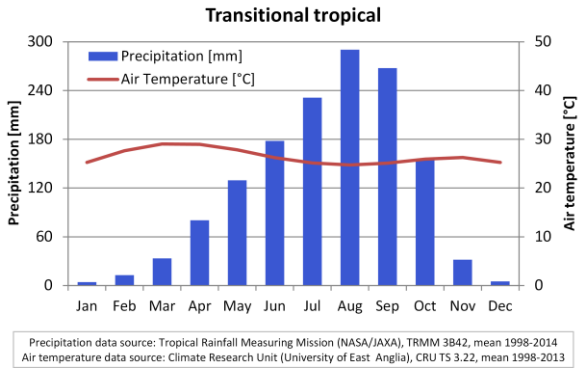
The climate in West Africa can be grouped into six zones with distinctive seasonal rainfall patterns (L'Hôte et al., 1996). In Nigeria the climate ranges from "Transitional equatorial" in the south, "Transitional tropical" in the central parts, "Pure tropical" in the north to "Semiarid tropical" in the extreme north. The diagrams below summarize the mean monthly rainfall and air temperature in these climate zones.







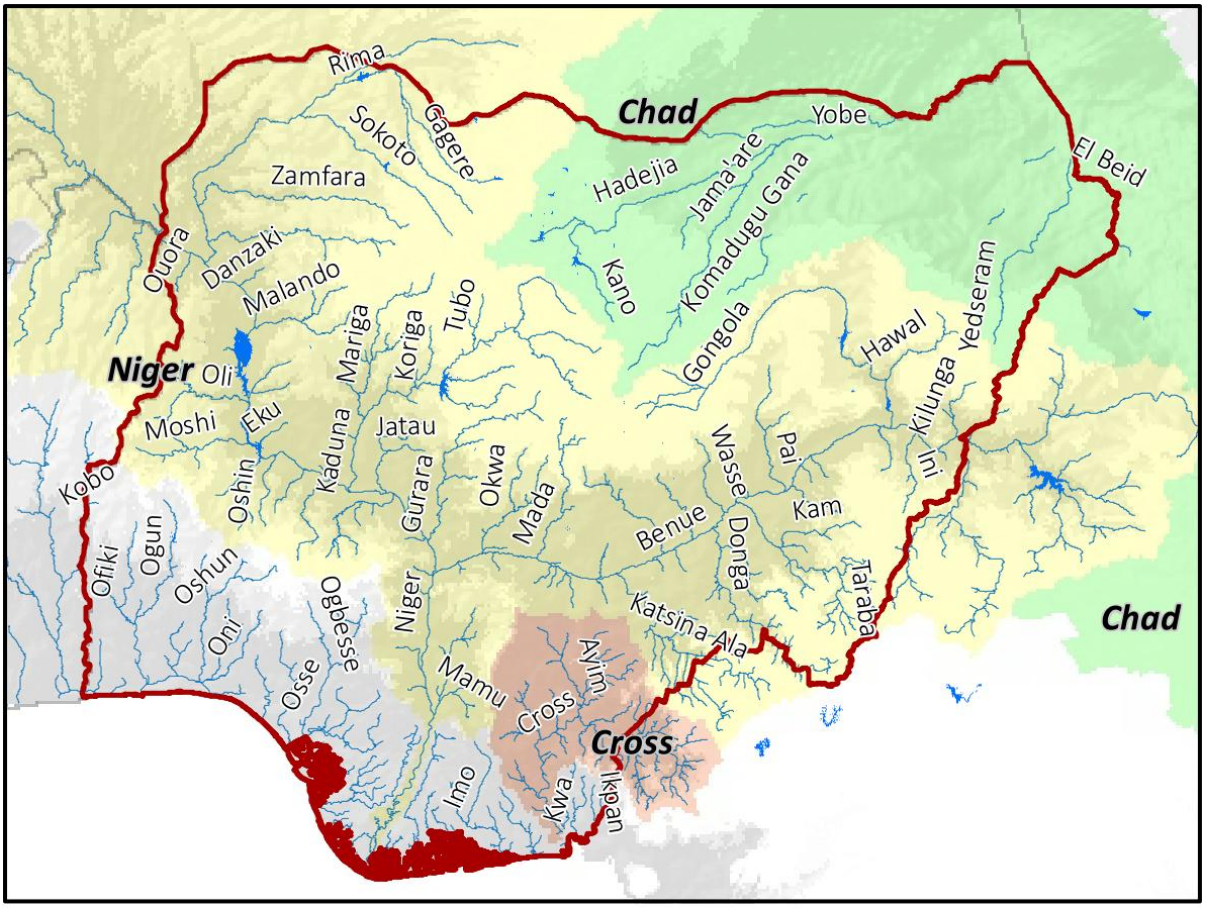




HYDROLOGY

The Niger River is the largest river in Nigeria. About 61 % of the country is located in the Niger basin. The Niger River enters Nigeria in the western part and receives inflow from several tributaries such as the Kaduna River. The Benue River enters Nigeria in the eastern part and joins the Niger River in the centre of the country from where the water flows south to discharge into the Gulf of Guinea. Rivers in the north-eastern part of the country discharge to Lake Chad. About 20 % of the country is located in the Lake Chad basin. In the south-east of Nigeria the Cross River enters Nigeria from Cameroon (see map and table below).

The figures on the following page illustrate the annual and seasonal variations in discharge for the Cross River, the Benue River and the Kaduna River. 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 high flows from August to October. Rivers in the central and southern parts of the country are perennial, whereas in the north of the country rivers may fall dry between January and May.



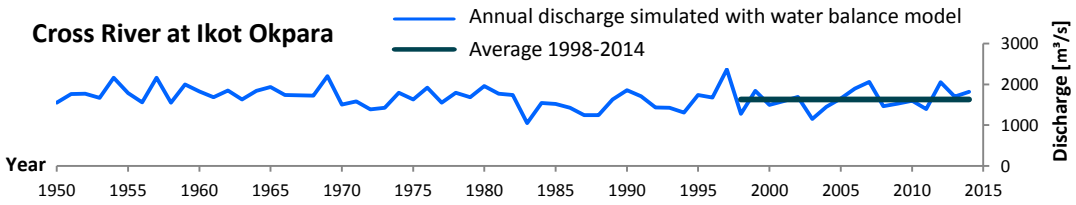
Basins

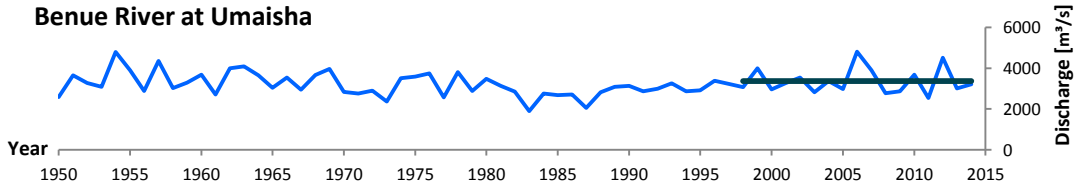
- Chad
- Cross
- Niger
- Main Rivers
- Reservoirs
- Country borders

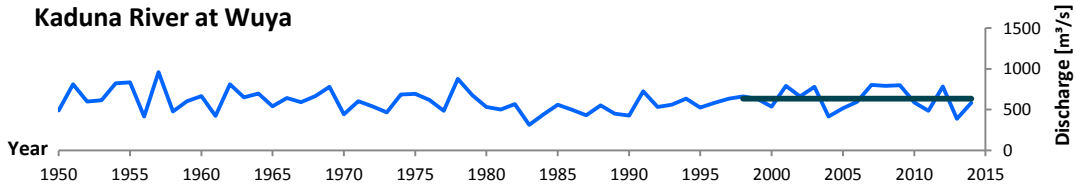
0 200 km N W E S

Percentage of country's area located in the three largest river basins	
Lake Chad basin	19.5 %
Cross River basin	9.5 %
Niger River basin	60.6 %

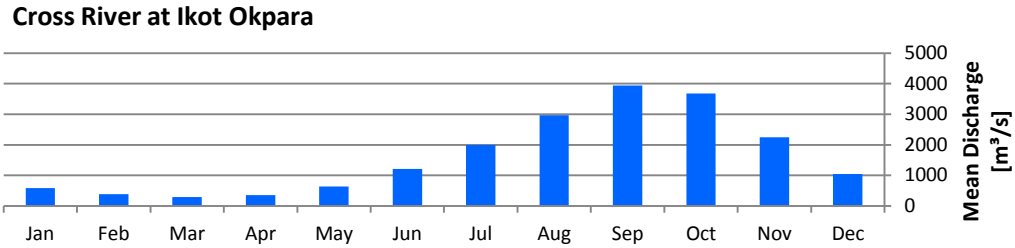
Historic Variation in Annual Discharge

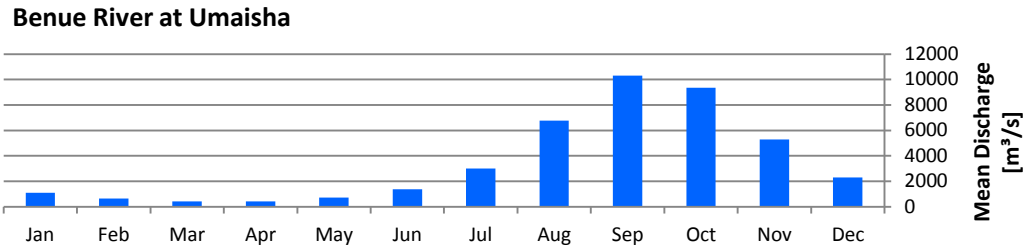


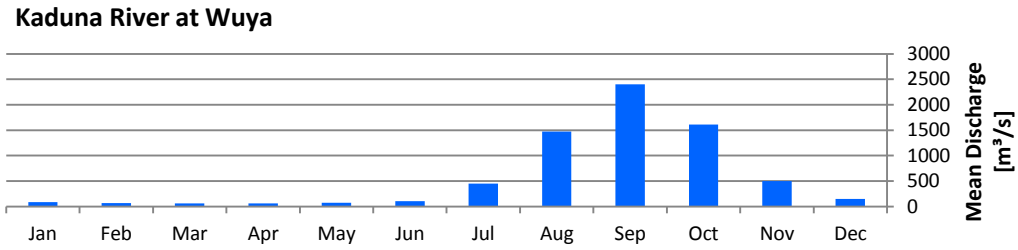




Seasonality in Discharge







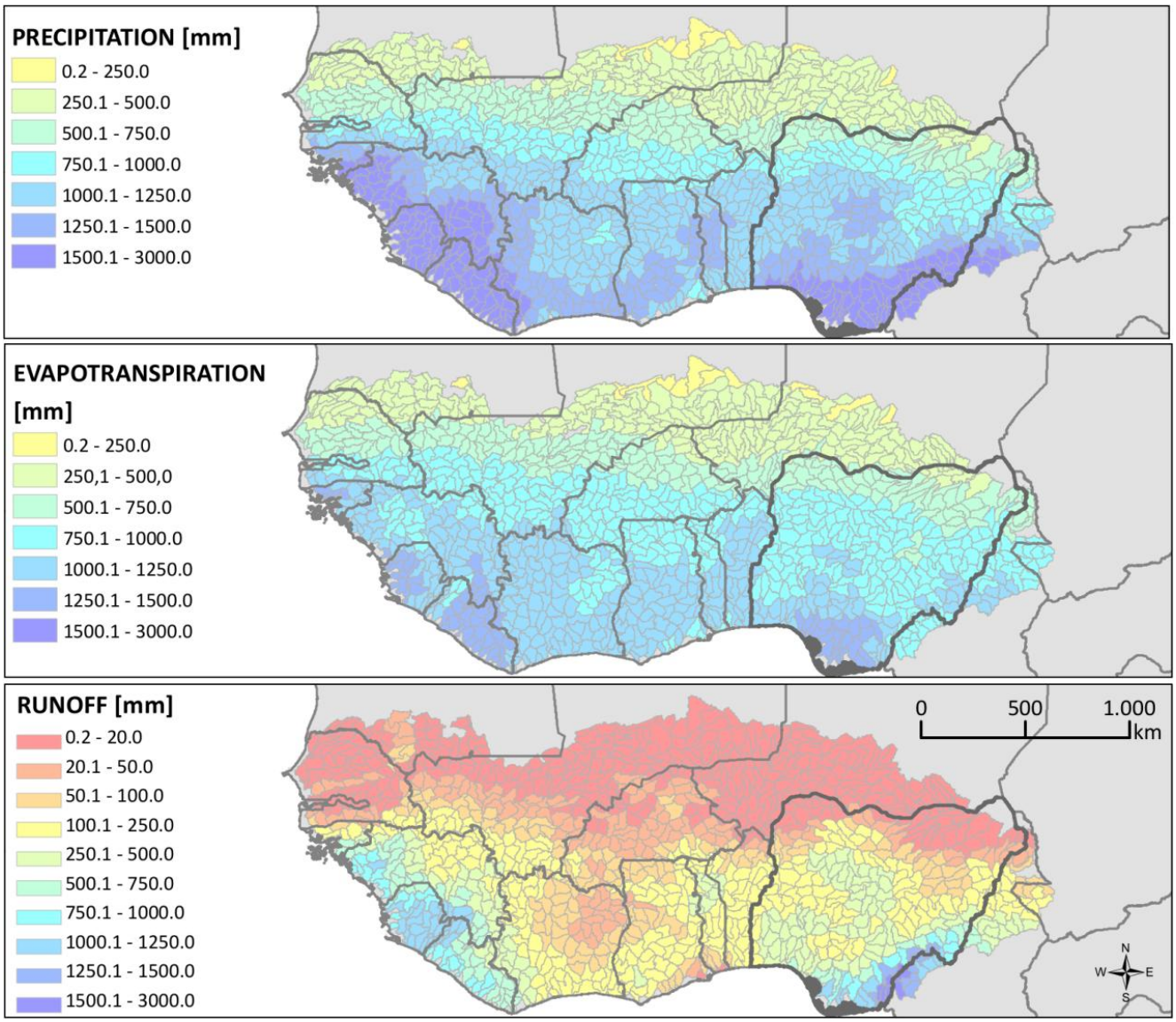
Annual Water Balance

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.

This is also the case for the mean annual water balance in most parts of Nigeria. In the north of the country only about 5 % of rainfall generates runoff and 95 % of rainfall is lost via evapotranspiration. The highest mean annual runoff is found in the south-east of the country along the border with Cameroon. In this region about 40 % of rainfall generates runoff and 60 % of rainfall is lost via evapotranspiration.

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

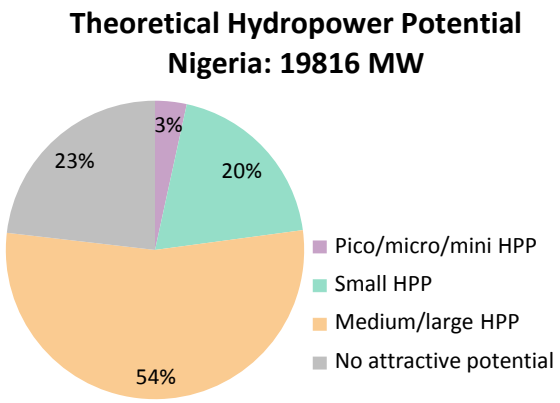


HYDROPOWER POTENTIAL

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 Nigeria is estimated to be 19816 MW (reference period 1998-2014), which is the total of all rivers in the country. Nigeria has by far the highest theoretical hydropower potential of all countries in West Africa.

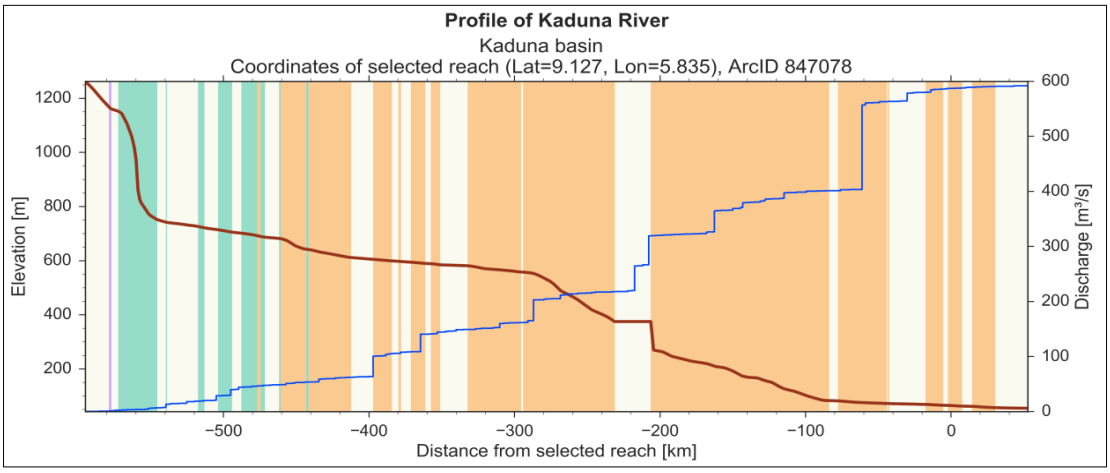
The following table and figure show how the total potential of the country is subdivided into theoretical potential for hydropower plants (HPP) of different plant size. A classification scheme based on mean annual discharge (m^3/s) and specific hydropower potential (MW/km) was applied to determine the preferred plant size for river reaches with a typical length of 1-10 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.

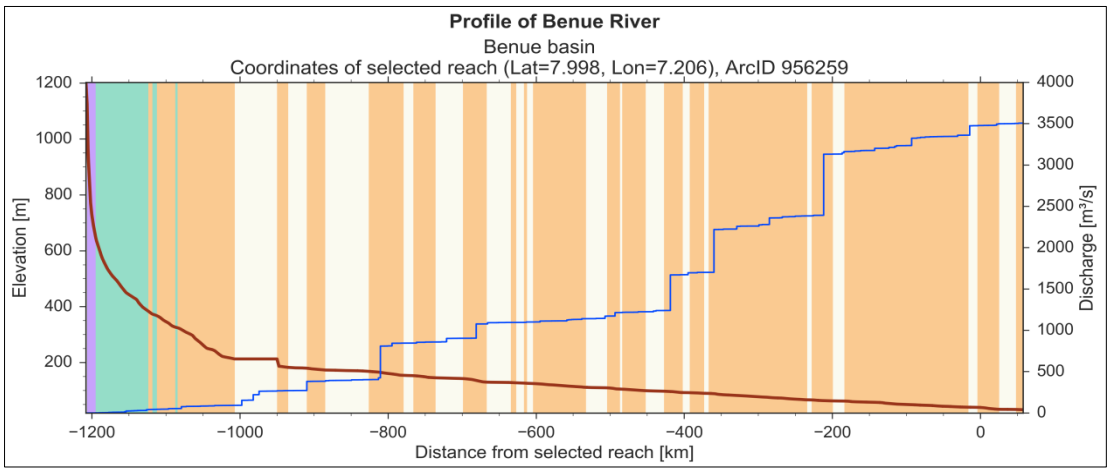


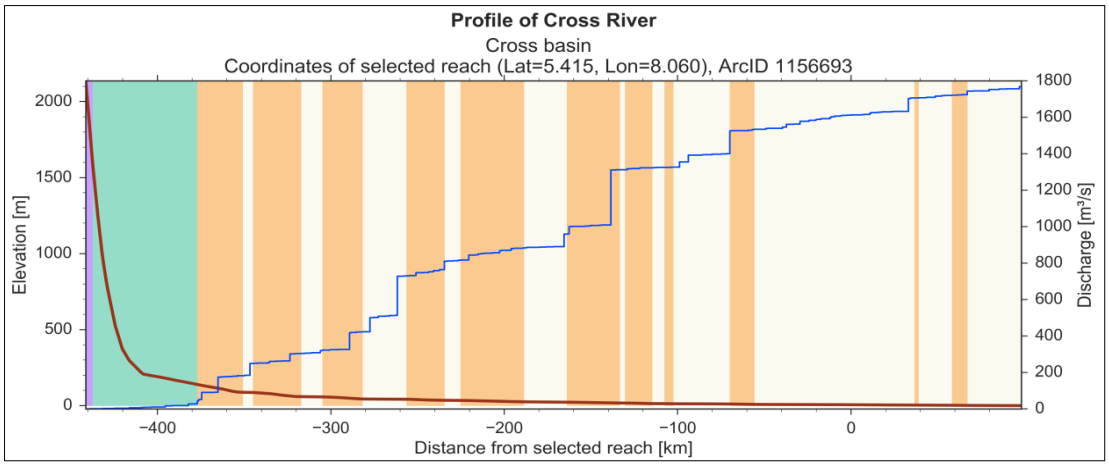
Theoretical Hydropower Potential of Rivers in Nigeria	
Pico/micro/mini HPP	678 MW
Small HPP	3856 MW
Medium/large HPP	10691 MW
No attractive potential	4591 MW
Total of all rivers in country	19816 MW
Total of rivers with attractive theoretical potential for pico/micro/mini, small, or medium/large HPP	15225 MW

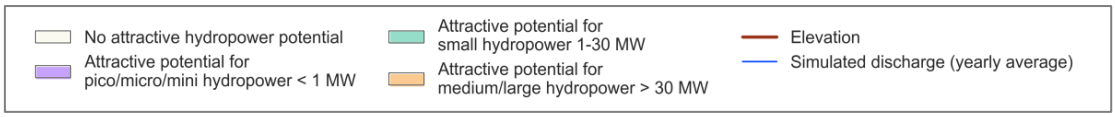
Longitudinal Profiles of Selected Rivers

The following graphs show longitudinal profiles of the Kaduna, Benue and Cross 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 Kaduna and Benue 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).





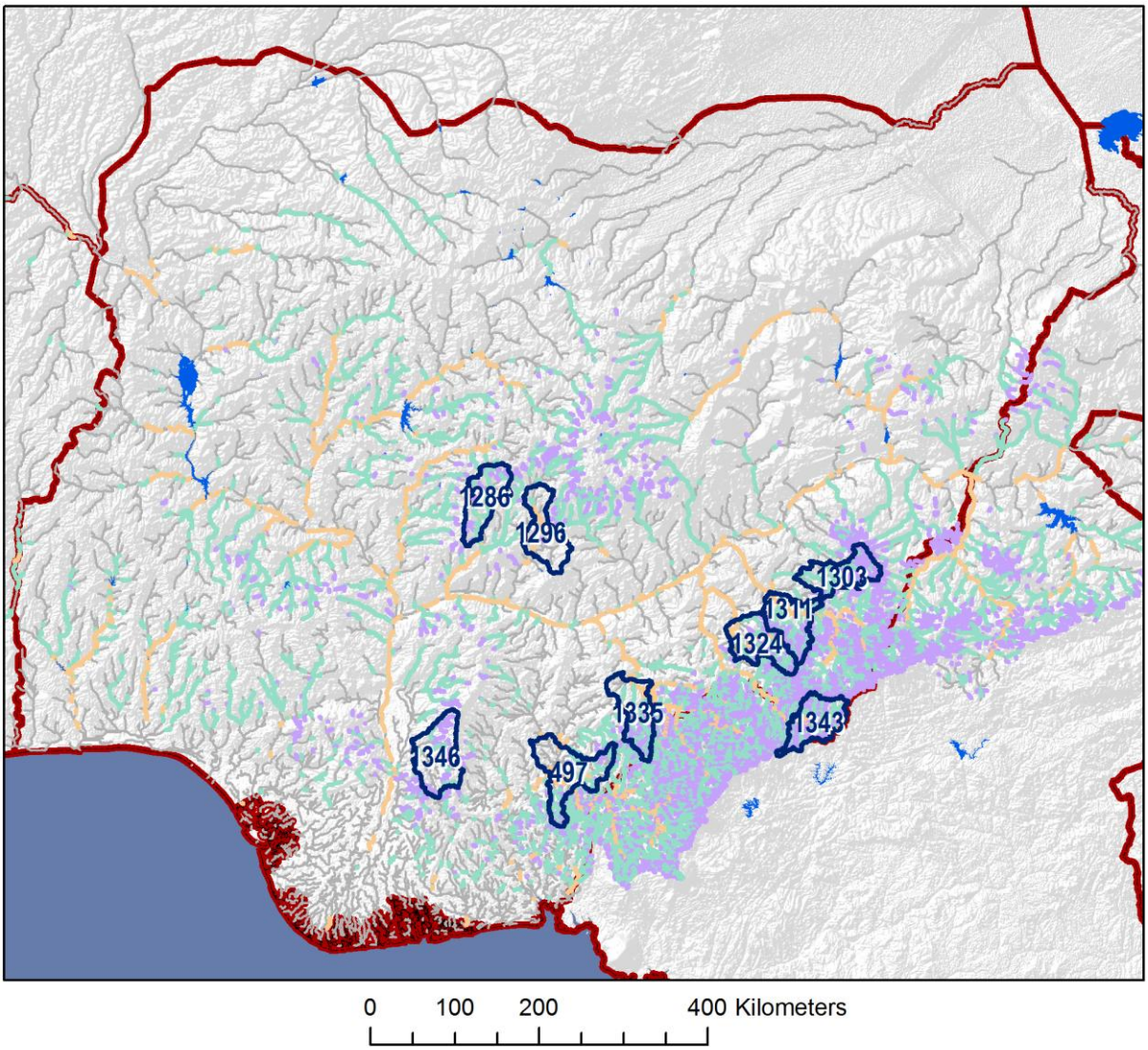




Hydropower Potential in Selected Sub-catchments

The following maps and tables give information about the theoretical hydropower potential of selected sub-catchments in Nigeria. Sub-catchments were selected as illustrative examples in the central and south-eastern parts of Nigeria. There are numerous additional sub-catchments that have attractive theoretical hydropower potential, especially for medium/large HPP.

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

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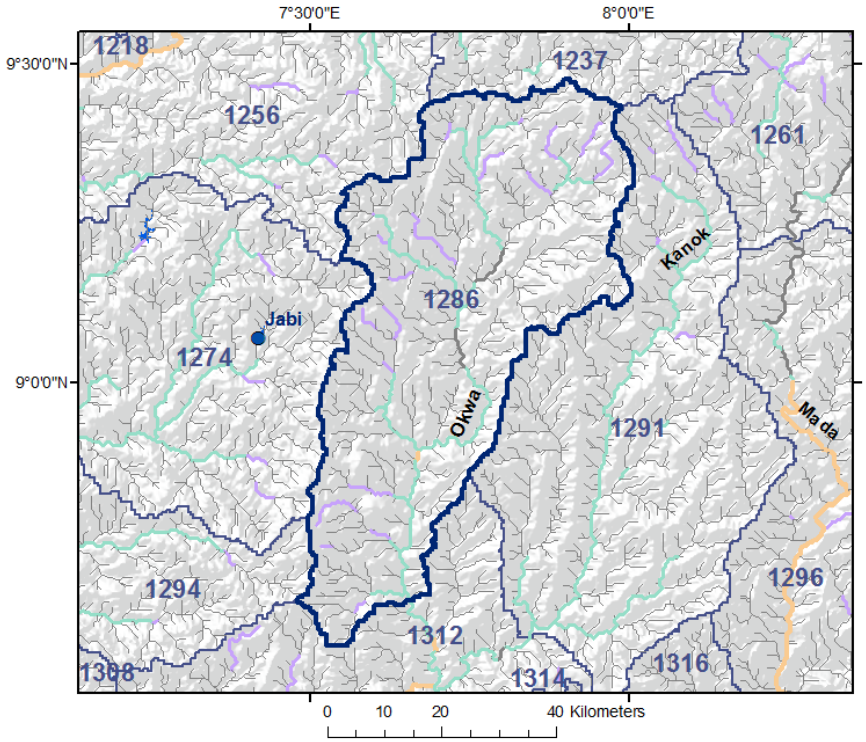
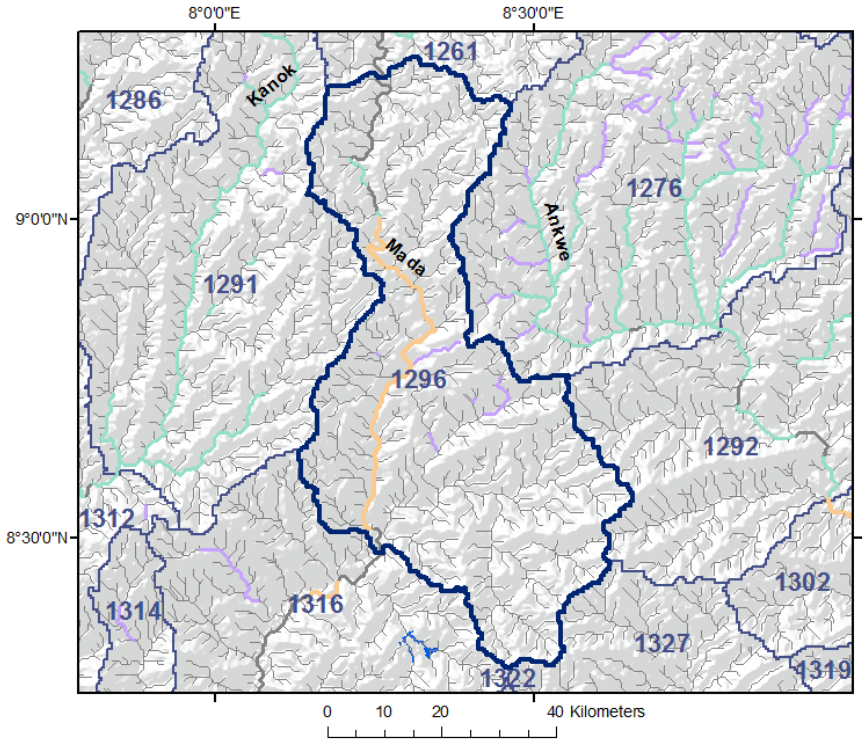


Theoretical Hydropower Potential of Rivers in Sub-Catchment #1286	
Pico/micro/mini HPP	7.5 MW
Small HPP	51.8 MW
Medium/large HPP	1.6 MW

This sub-catchment east of Abuja forms the headwater region of the Okwa River, which is a tributary to the Benue River. The Okwa River and the streams that feed into it have considerable potential for pico/micro/mini HPP and for small HPP.



Theoretical Hydropower Potential of Rivers in Sub-Catchment #1296	
Pico/micro/mini HPP	2.3 MW
Small HPP	3.0 MW
Medium/large HPP	155.6 MW

The Mada River is one of the northern tributaries of the Benue River. This sub-catchment in the middle stretches of the Mada River has high 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

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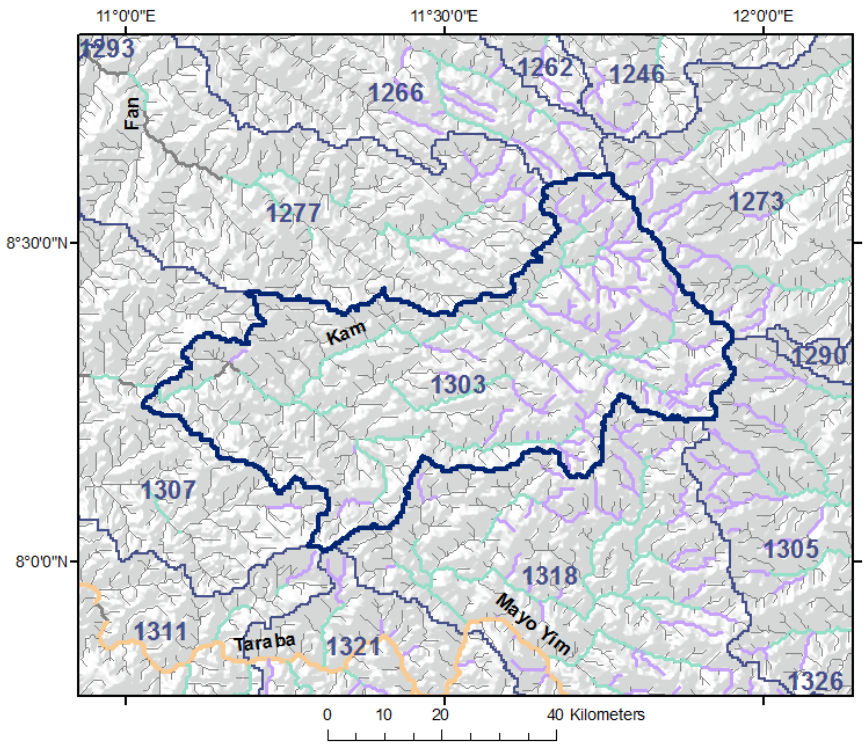
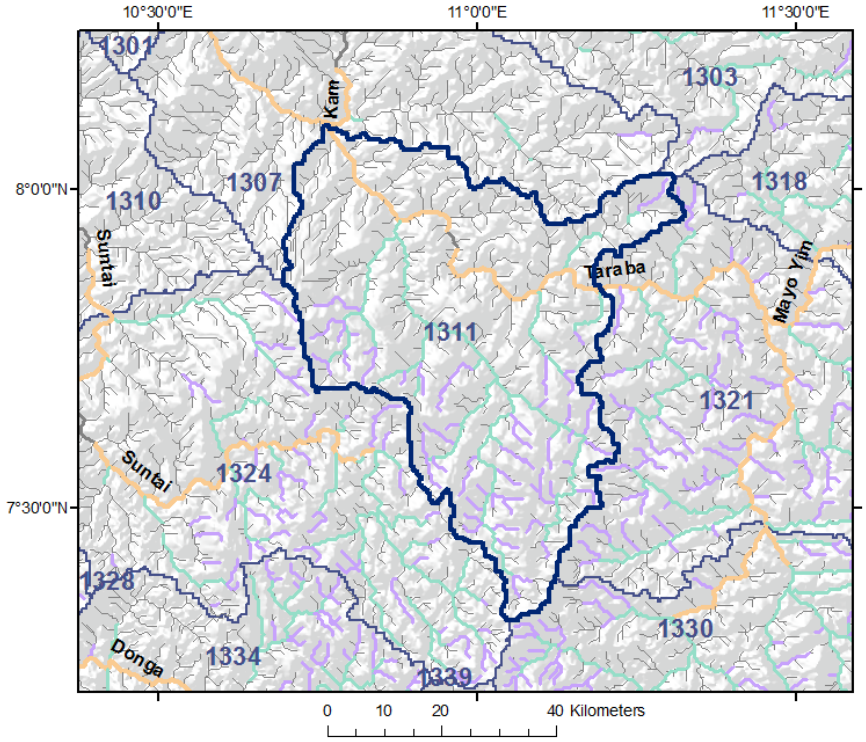


Theoretical Hydropower Potential of Rivers in Sub-Catchment #1303	
Pico/micro/mini HPP	29.3 MW
Small HPP	48.7 MW
Medium/large HPP	0 MW

The Kam River is located in south-eastern Nigeria and is a major tributary to the Taraba River. This sub-catchment, which forms the headwater region of the Kam River, has considerable potential for pico/micro/mini HPP and small HPP.



Theoretical Hydropower Potential of Rivers in Sub-Catchment #1311	
Pico/micro/mini HPP	30.7 MW
Small HPP	86.8 MW
Medium/large HPP	131.4 MW

This sub-catchment is located in the middle section of the Taraba River, just upstream of the confluence with the Kam River. There is considerable potential for pico/micro/mini HPP, small HPP and medium/large HPP. In further upstream sub-catchments of the Taraba River there is even higher hydropower potential, but the upstream region is located in the Gashaka Gumti National Park.

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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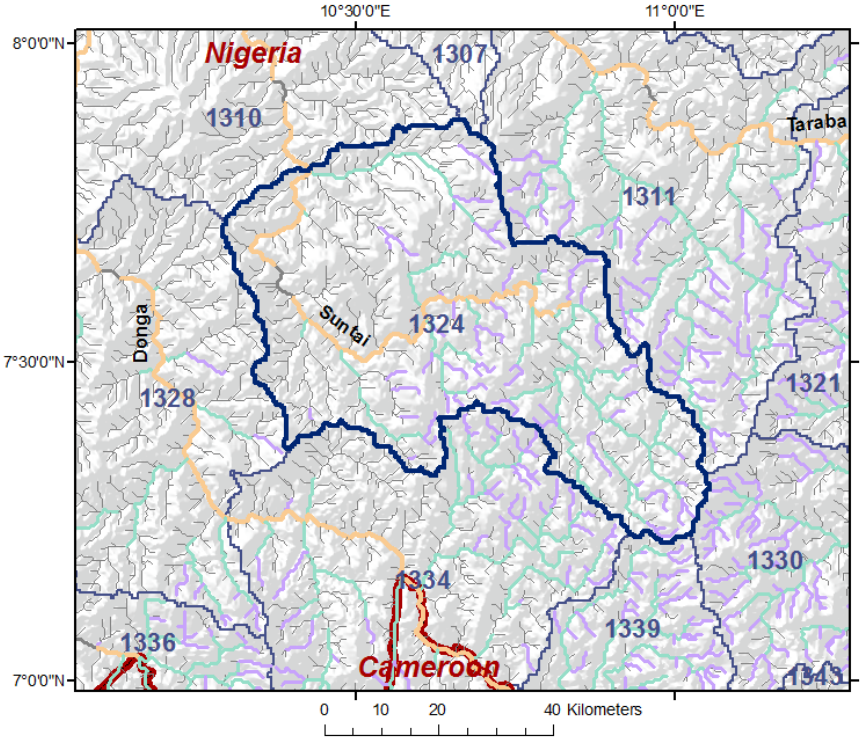
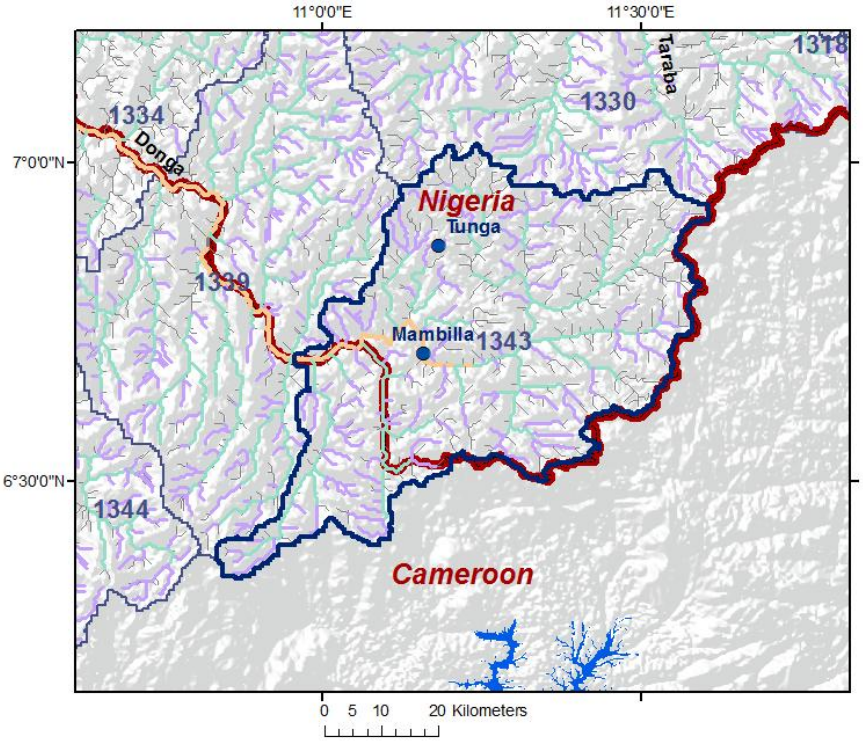


Theoretical Hydropower Potential of Rivers in Sub-Catchment #1324	
Pico/micro/mini HPP	23.0 MW
Small HPP	75.4 MW
Medium/large HPP	173.0 MW

This sub-catchment is located in the headwater region of the Suntai River, which is a tributary of the Donga River in southern Nigeria, not far from the border with Cameroon. There is considerable potential for pico/micro/mini HPP, small HPP and medium/large HPP.



Theoretical Hydropower Potential of Rivers in Sub-Catchment #1343	
Pico/micro/mini HPP	50.1 MW
Small HPP	132.9 MW
Medium/large HPP	315.4 MW

The headwater region of the Donga River is shared between Nigeria and Cameroon. This sub-catchment includes the Mambilla hydropower plant site, which utilizes the high potential for medium/large HPP. In addition, there is also considerable potential for pico/micro/mini HPP as well as 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

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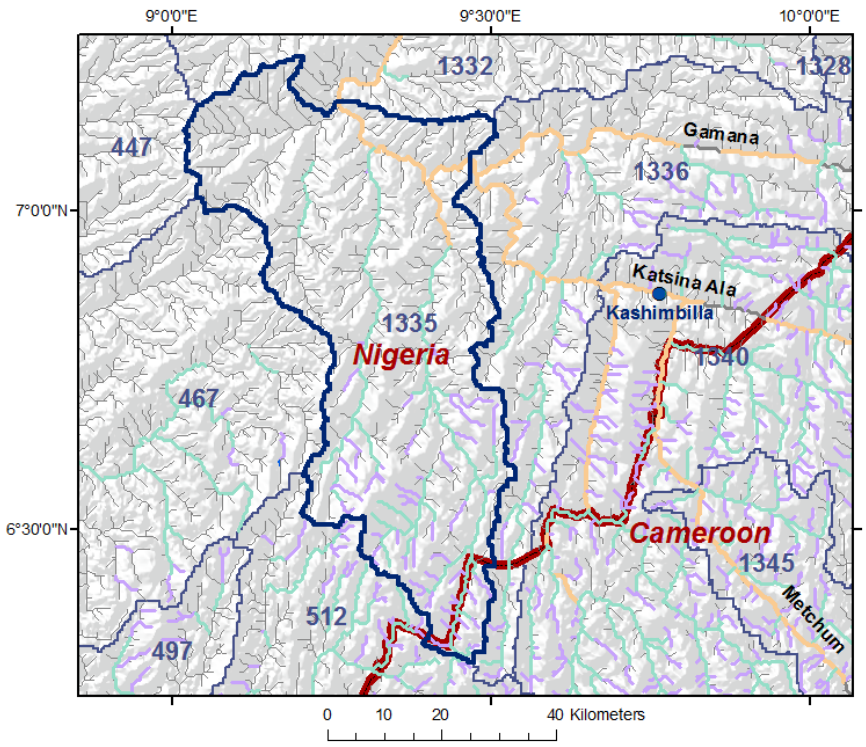
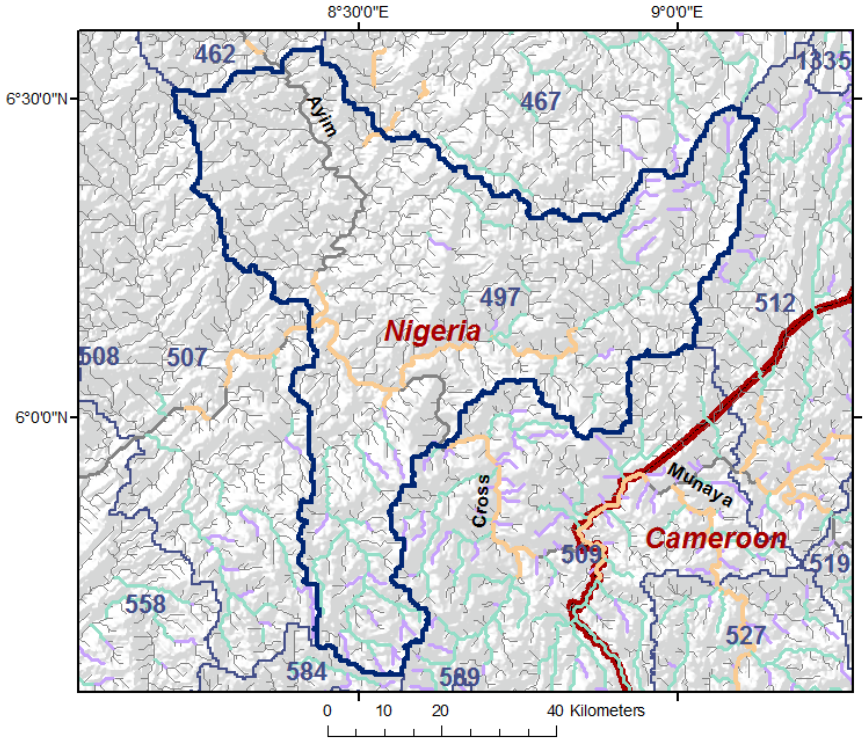


Theoretical Hydropower Potential of Rivers in Sub-Catchment #1335	
Pico/micro/mini HPP	27.6 MW
Small HPP	111.6 MW
Medium/large HPP	182.7 MW

This sub-catchment of the Katsina Ala River includes two major tributaries from the south. Both have a high potential for small HPP. The local streams feeding into the tributaries have considerable potential for pico/micro/mini HPP. The high potential for medium/large HPP is located at the Katsina Ala River.



Theoretical Hydropower Potential of Rivers in Sub-Catchment #497	
Pico/micro/mini HPP	10.0 MW
Small HPP	52.9 MW
Medium/large HPP	80.0 MW

This sub-catchment of the Cross River includes the lower section of the Ayim River. The Cross River and a tributary from the east have considerable potential for medium/large HPP. A southern tributary has considerable potential for pico/micro/mini and small HPP, but is located in the Cross River National Park.

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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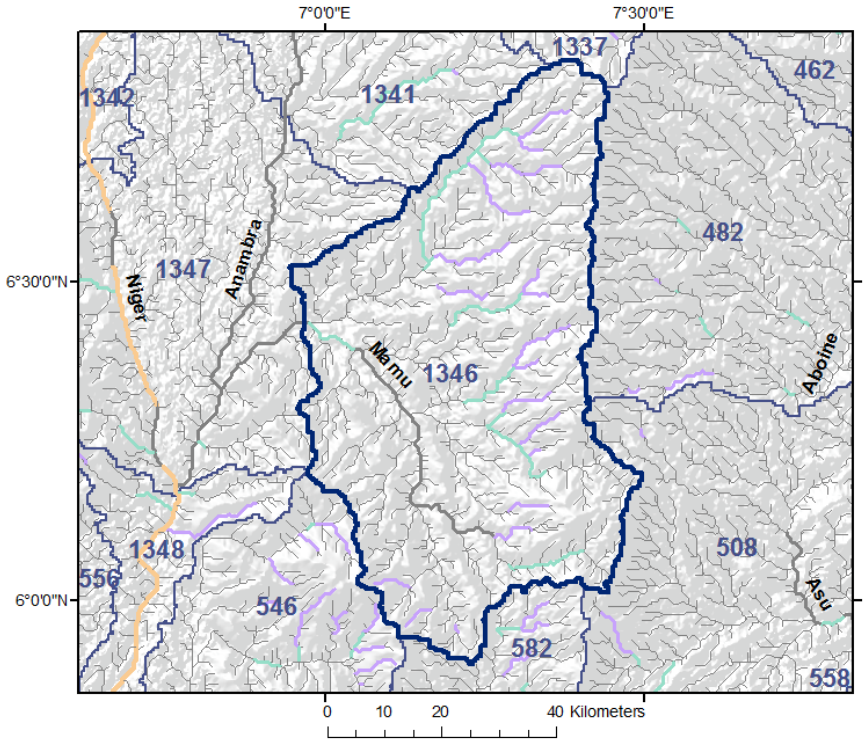


Theoretical Hydropower Potential of Rivers in Sub-Catchment #1346	
Pico/micro/mini HPP	10.8 MW
Small HPP	18.4 MW
Medium/large HPP	0 MW

This sub-catchment represents the Mamu basin in south-central Nigeria. Several tributaries of the Mamu 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

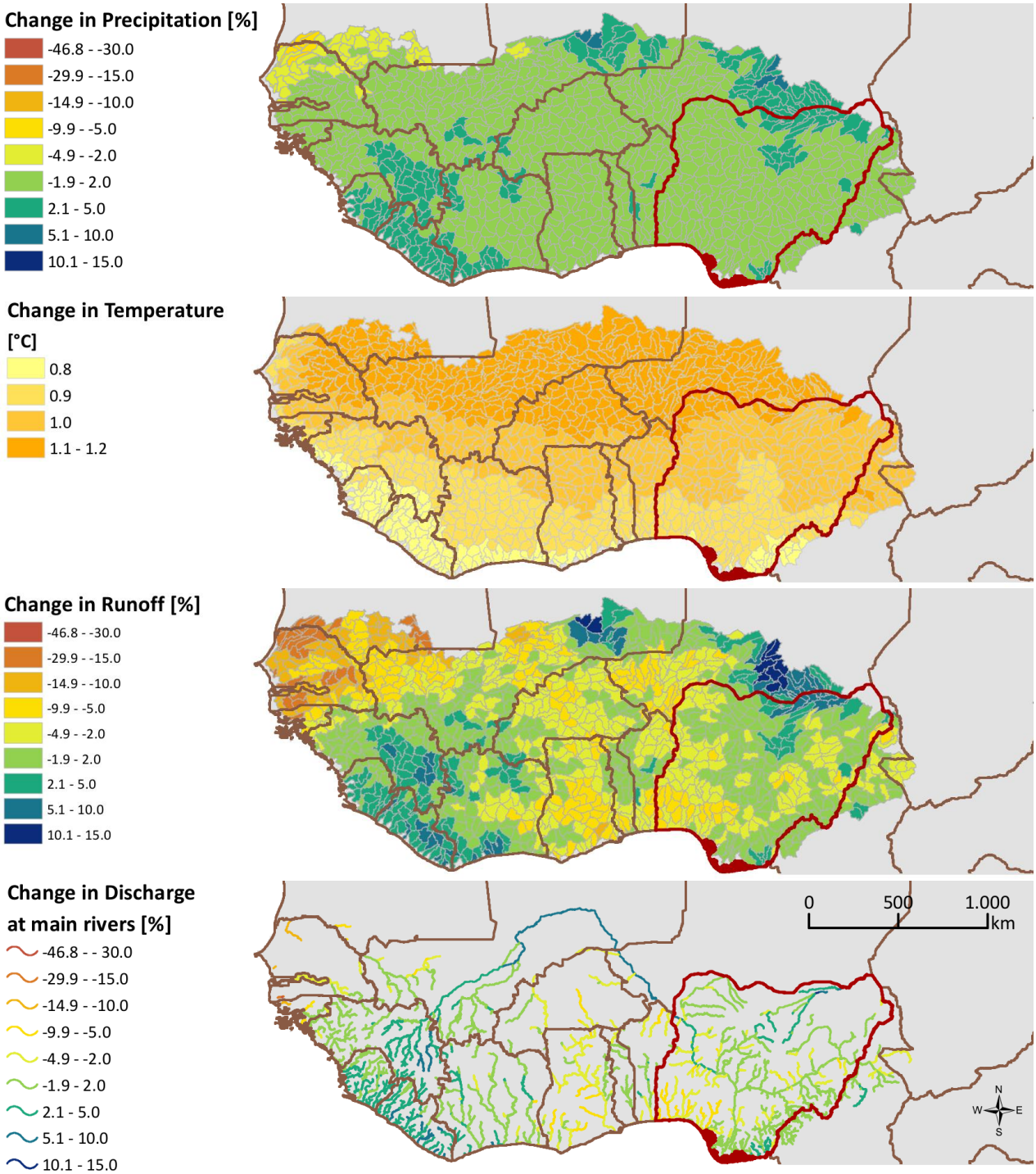
- Existing hydropower plant
- Lake or reservoir
- Sub-catchment boundary
- Country border

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.

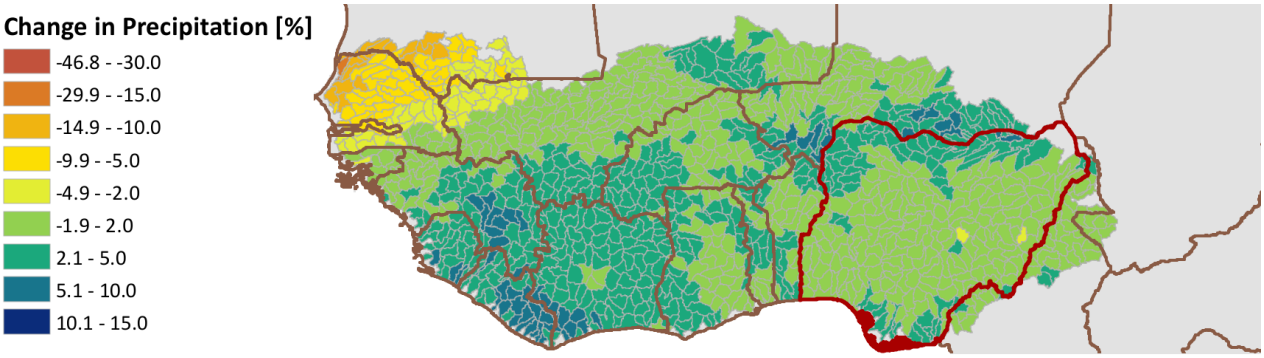
Projections for the Near Future 2026-2045

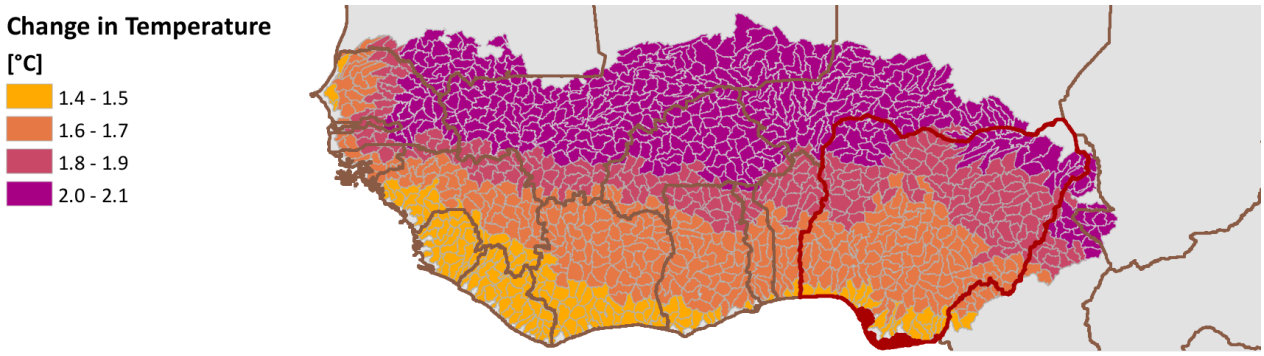


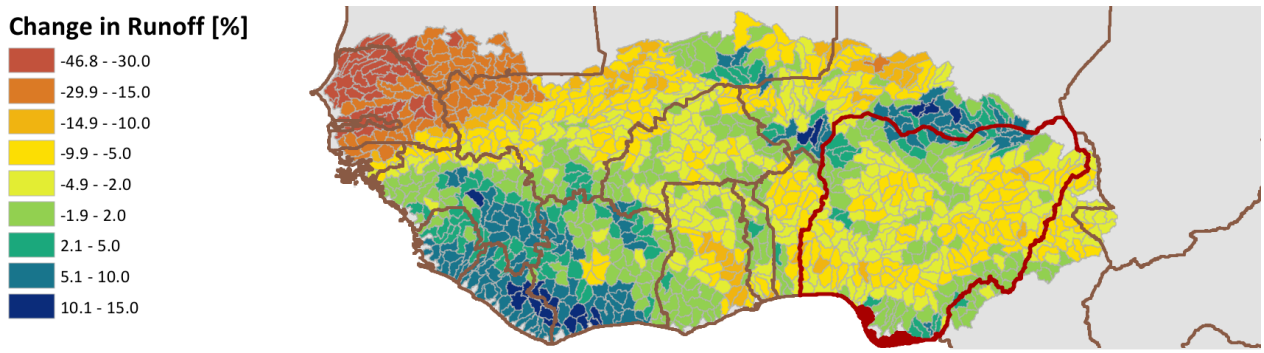
Projections for the Far Future 2046-2065

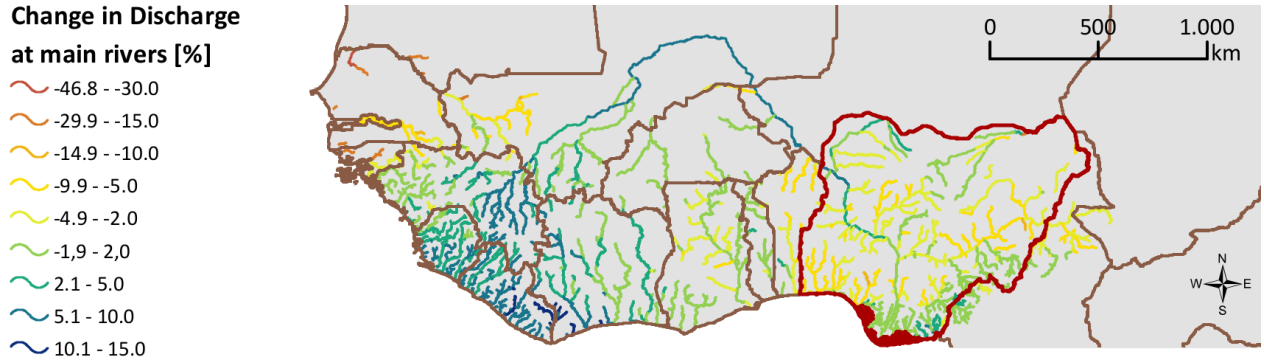
The maps below show the expected impact of climate change on future mean annual water resources. From the 30 climate model runs the median result was computed to generate the maps, which show change signals comparing the future periods 2026-2045 (previous page) and 2046-2065 (this page) vs. the reference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

In large parts of West Africa increase or almost no change is projected for future precipitation. This is also the case for Nigeria. The combined effects of future precipitation and considerable warming (which affects evapotranspiration) were simulated with a water balance model to compute future runoff. In most parts of Nigeria a slight decrease is projected for future runoff (median of 30 model runs). However, for the Niger River, which has its headwater region in Guinea, future discharge is projected to increase in Nigeria for the river sections before the confluence with the Benue River.









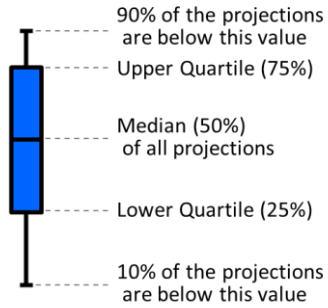
Projected Change in Discharge for Selected Gauges

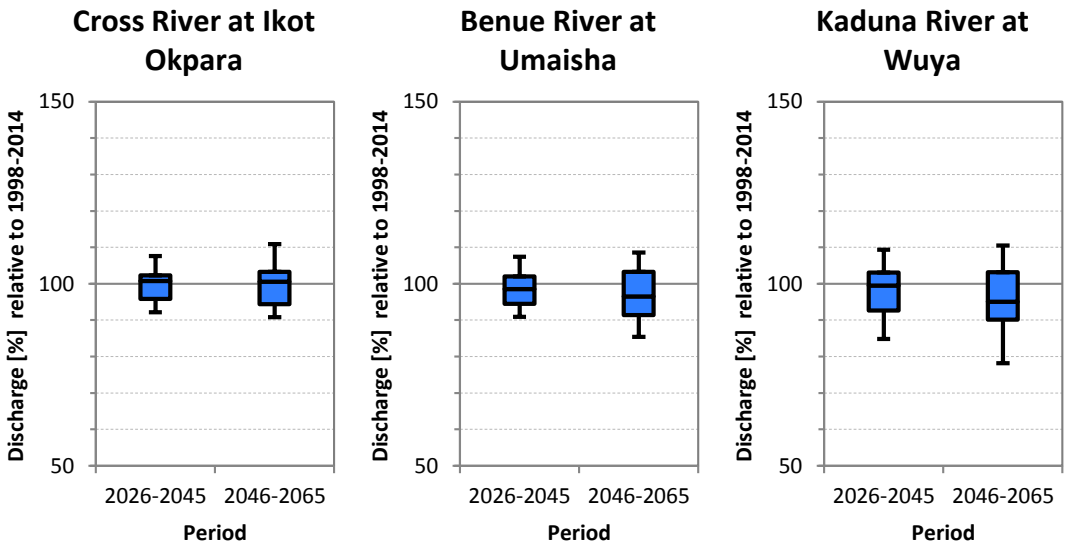
Future mean annual discharge was estimated with data from 30 different climate model runs. Boxplots are presented to summarize the spread in the simulation results (see explanation at right).

The figures below show discharge projections for the Cross, Benue and Kaduna rivers. No considerable change is projected for the Cross River and the majority of climate models agree rather well (small size of box). For the Benue and Kaduna rivers discharge is projected to decrease by about -7 % in the far future. Here the uncertainty in the climate model projections is slightly higher, which is signified by the larger size of the box.

Overall the climate change impact assessment shows that given the projections with the most detailed climate models currently available (CORDEX-Africa) either no or only slight decrease is projected for future discharge. This means that climate change is not a 'worst-case' scenario for hydropower development in Nigeria.

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.