Regional assessment of the hydropower potential of rivers in West Africa

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1. Introduction

The 15 countries of the Economic Community of West African States (ECOWAS) face a constant shortage of energy supply, which limits economic growth. Currently there are about 50 operational hydropower plants and 40 more are under construction or refurbishment. The potential for future hydropower development – especially for small-scale plants in rural areas – is assumed to be large, but exact data are missing.

Objectives of the project:

- Support the energy initiatives of the "ECOWAS Centre for Renewable Energy and Energy Efficiency" (ECREEE)
- Assess the hydropower potential of all rivers in West Africa
- Integrate the results into the interactive ECOWREX website of ECREEE.

2. Study area & Data basis

This study focusses on all river basins in the 15 countries of ECOWAS in West Africa (Fig. 1). The climate ranges from tropical humid to arid. The study area covers about 5 Mio km² including 500,000 river reaches. Major river basins include Niger, Volta, and Senegal.

The main data sources for this study are:

- Observed discharge data (see Fig. 1 & 2)
- Precipitation data (GPCC, TRMM, RFE, see Fig. 3)
- Potential evapotranspiration (CRU)
- Digital elevation models (Hydrosheds/SRTM, ASTER)
- River network (Hydrosheds)

Data acquisition and pre-processing were major tasks of this project, as most of the basins are located in data sparse regions with often limited data quality.

Challenges for data availability are:

- Only few gauges for such a large region.
- Biased observed discharge data.
- Inaccurate geo-referencing of discharge gauges.
- Uncertainty in precipitation data.
- Different observation periods for various Precip data sets and each discharge gauge.
- Decadal variations between wet and dry periods.
- Inconsistencies in digital elevation models.

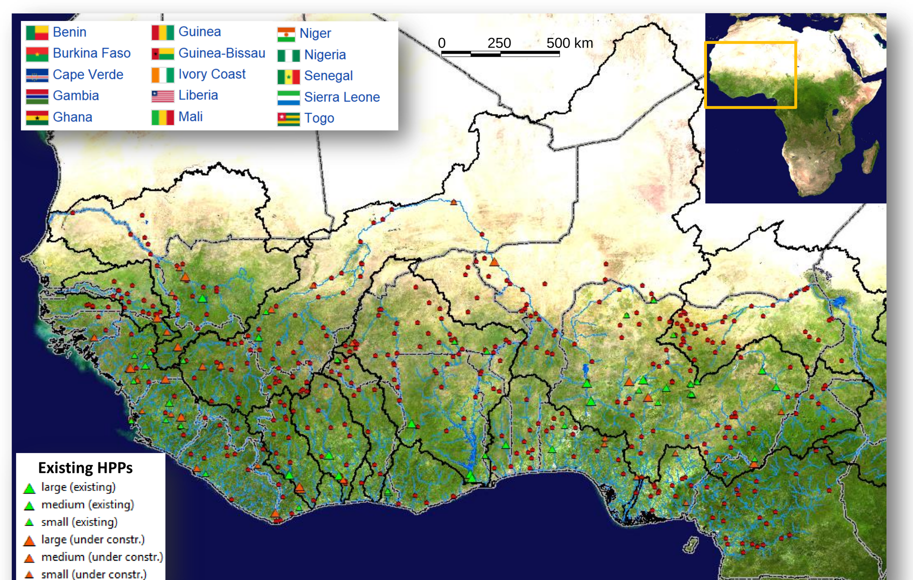

Fig. 1: Study area

West Africa. Blue lines: major rivers. Black lines: major basin divides. Grey lines: Country borders. Red circles: used gauges. Colored background: satellite image showing vegetated areas in green.

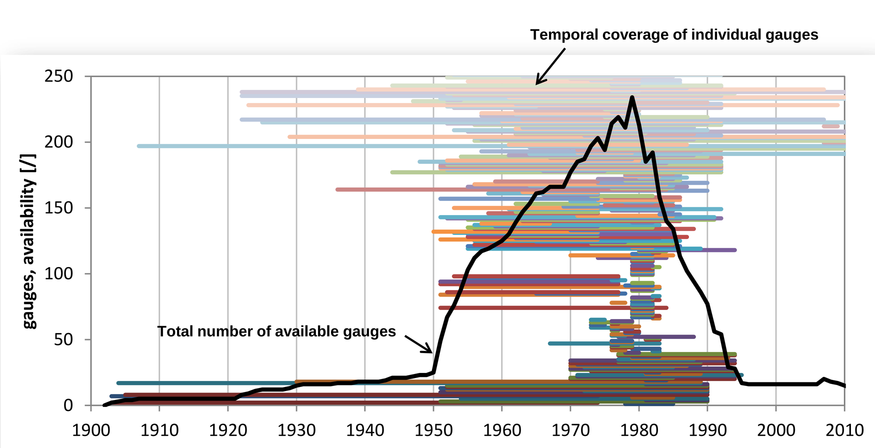

Fig. 2: Availability of discharge data

Temporal coverage of observed daily discharge data at 361 gauges of GRDC. Only 250 out of 361 gauges are displayed. The colored lines only show the start and end of the observation periods, but not (often numerous and extensive) data gaps.

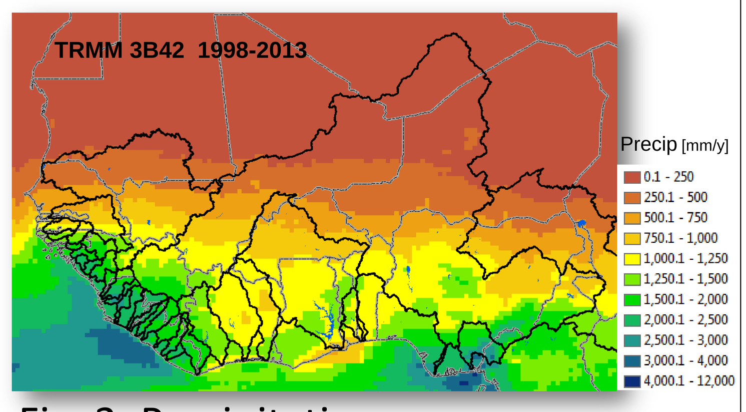

Fig. 3: Precipitation

Mean annual precipitation computed from TRMM (satellite based).

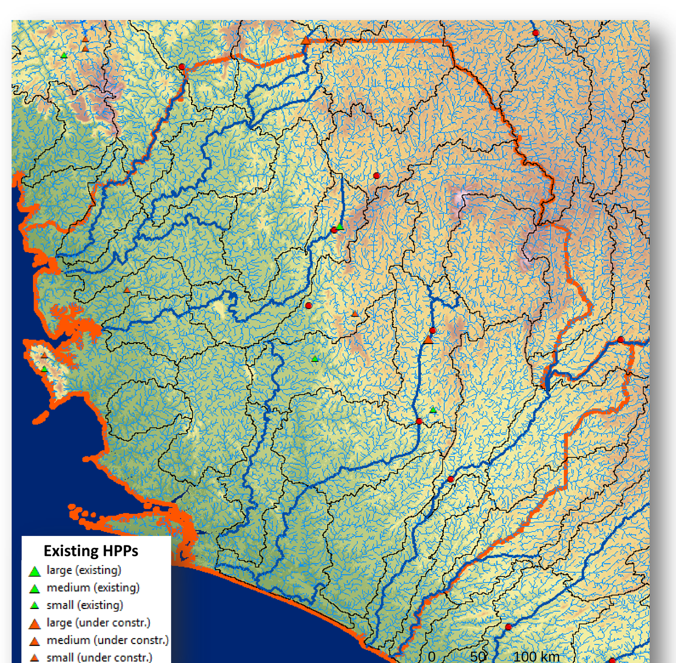

Fig. 4: Detailed river-network

Example for Sierra Leone. Blue lines: river network. Red circles: available gauges. Black lines: sub-catchments. Orange lines: Country borders. Colored background: elevation.

3. Annual Water Balance Modelling

Water balance modelling is applied to estimate the annual discharge in 500,000 reaches.

The annual water balance describes the partitioning of precipitation into actual evapotranspiration and runoff (Fig. 5). The aggregation of runoff (units of mm/y) along the river network yields discharge (units of m³/s).

The Budyko curve (Budyko, 1974) is a simple method to estimate the mean annual water balance. Observed discharge data of 410 gauges were used for a regional calibration of the Budyko curve parameter.

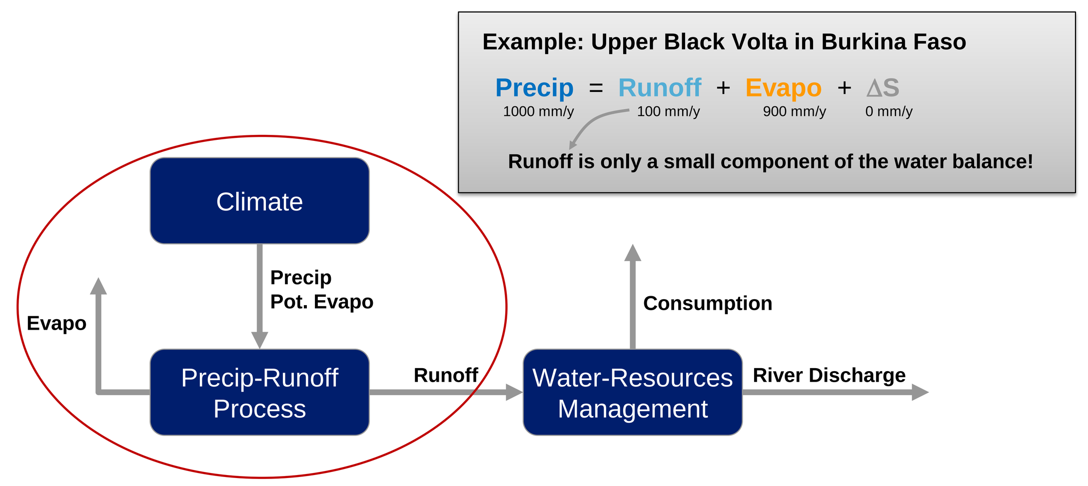

Fig. 5: Water balance

Simplified schematic for main drivers of the annual water balance.
Major irrigation schemes and floodplain losses are considered as "Consumption".

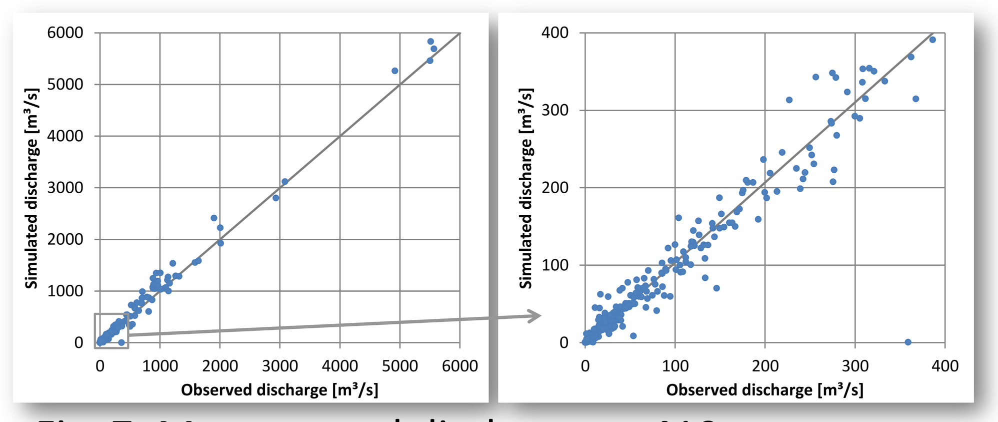

Fig. 7: Mean annual discharge at 410 gauges

Comparison of simulated and observed long-term mean annual discharge at 410 gauges. Evaluation period depends on Q data availability in the period 1950-2014.

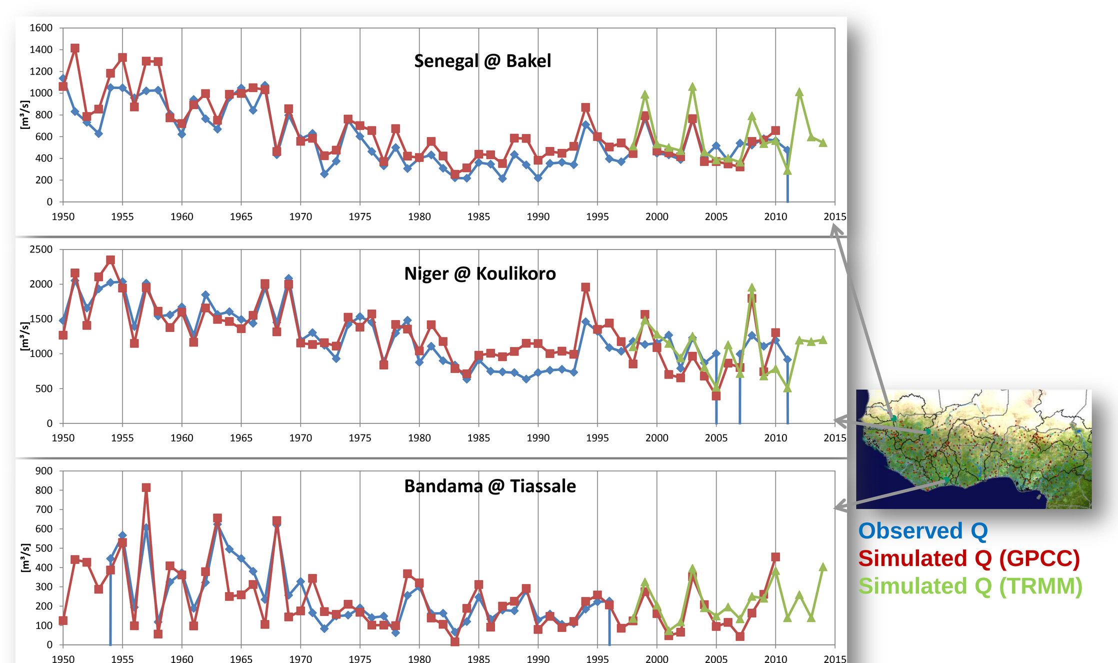

Fig. 8: Historical variations in annual discharge

Comparison of simulated and observed variations in annual discharge due to variations in rainfall. Simulation results for three representative gauges using GPCC and TRMM rainfall data.

As hydropower plants are investments with a lifetime of several decades also the possible changes in future discharge due to climate change were assessed (Fig. 9). To this end the water balance model was driven with bias-corrected climate projections of 15 Regional Climate Models for two emission scenarios of the CORDEX-Africa ensemble.

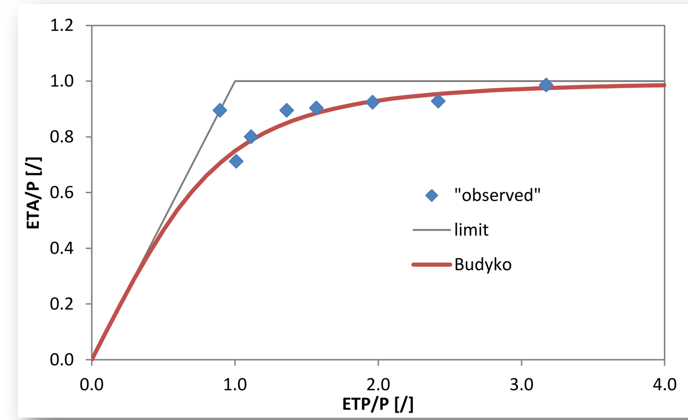

Fig. 6: Water balance with Budyko

Blue points: observed data of eight example sub-basins (Volta basin)
Red line: Budyko relationship
P: mean annual precipitation [mm/y]
ETP: mean annual potential evapotranspiration [mm/y]
ETA: mean annual actual evapotranspiration [mm/y], ETAobs = P – Qobs
Q: mean annual runoff [mm/y], Q = P – ETA (assuming ΔS = 0)
c: curve parameter (calibrated, default value c=2.0, in Fig. 6 c=2.4)

Formulation of Choudhury (1999) to describe the Budyko relationship:

$$\frac{ETA}{P} = \left[1 + \left(\frac{ETP}{P}\right)^{-c}\right]^{-1/c}$$

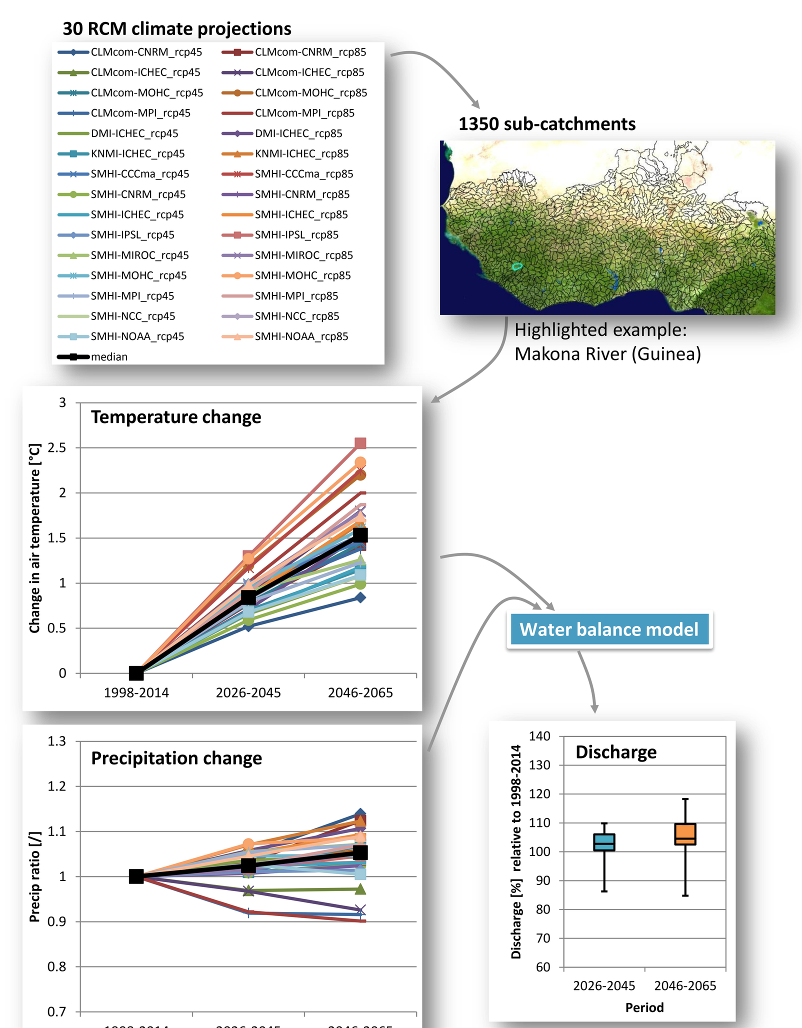

Fig. 9: Expected future annual discharge under climate change projections

Data of CORDEX-Africa 30 Regional Climate Model (RCM) runs processed for 1350 sub-catchments. Application of 11-year moving average to smooth RCM annual data before computation of annual climate change signals for different reference periods. Water balance modelling to estimate future annual discharge (delta-change method).

4. Hydropower Potential

The gross theoretical hydropower potential is assessed for each reach *i* from the following data:

- Annual discharge Q (m³/s) from the water balance model for the period 1998-2014
- Height difference ΔH (m) from DEM
- Length of reach L (km) from river-network
- Hydropower line potential LP (kW)
- Hydropower specific potential SP (kW/km)

$$LP_i = 8.5 \cdot Q_i \cdot \Delta H_i \qquad SP_i = LP_i / L_i$$

To give a better regional overview the results of the reaches are aggregated for:

- 1350 sub-catchments
- 14 ECOWAS countries (excluding Cabo Verde)

Reaches with attractive hydropower potential are identified if they exceed a threshold, which was derived from an empirical analysis of annual discharge and specific hydropower potential at existing hydropower plants.

The results of the study will be published on the ECOWREX website (Fig. 12). The website can be used to identify attractive regions, thus enabling more detailed studies and targeted discharge measurement campaigns currently under preparation by ECREEE.

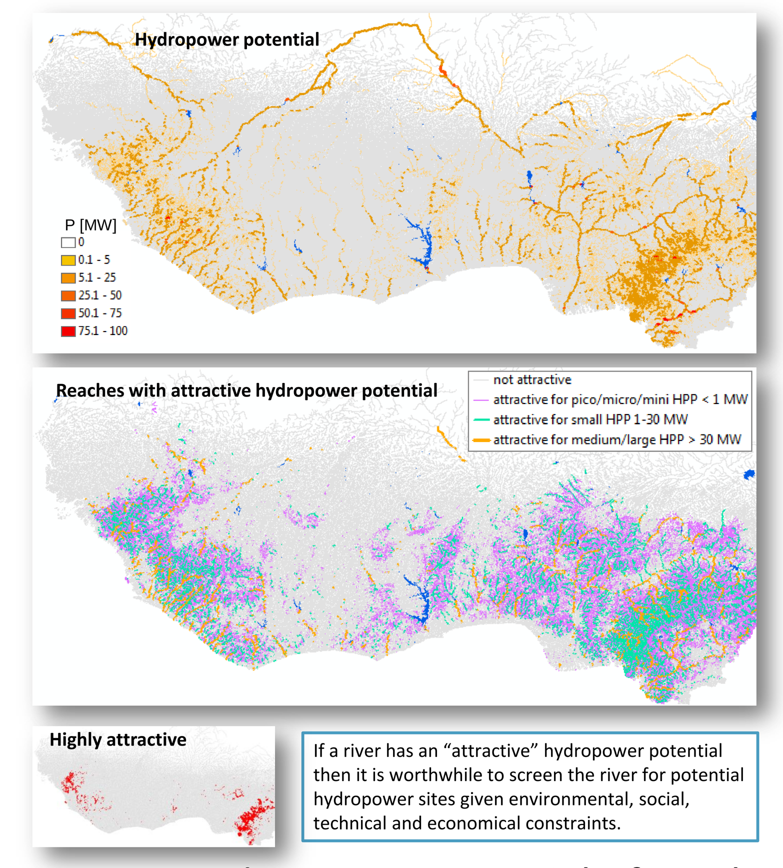

Fig. 10: Hydropower potential of reaches

The plots show preliminary results for 600,000 reaches. Given the sensitive nature of hydropower potential of rivers the final classification system still has to be elaborated.

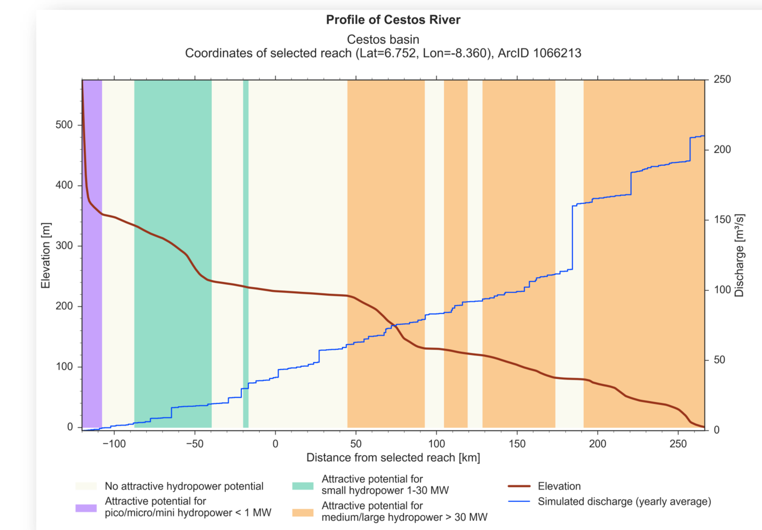

Fig. 11: Longitudinal river profiles

Longitudinal river profiles are automatically generated by selecting a river reach. The color codes show which regions of the river have an attractive hydropower potential for different plant sizes.

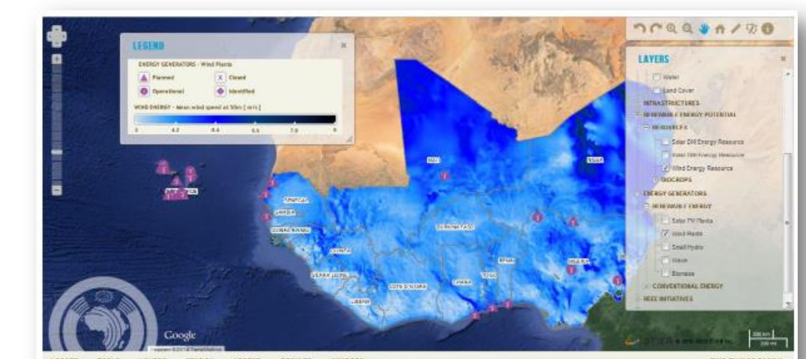

Fig. 12: ECOWREX website

Main interface of the ECOWREX observatory GIS viewer hosted by ECREEE. http://www.ecowrex.org/mapView/

5. Conclusions

The main conclusions of this study are:

• Availability and reliability of hydro-meteorological data are considerable challenges for water resources assessment in West Africa.

• A simple water balance model proved to be sufficient to estimate mean annual discharge. Consideration of floodplain losses are important.

• Climate change projections for West Africa do not show a 'worst-case' scenario. Future discharge may actually increase in some parts of West Africa.

• Several West African countries have regions that are attractive for hydropower development, especially Guinea, Sierra Leone, Liberia and Nigeria.

Acknowledgements

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