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Water-Energy-Food-Nexus-Accounting for the Eastern Nile Basin

Lars Ribbe, Muhammad Khalifa, Mohammed Basheer, Zryab Babker, Saher Ayyad, Alexandra Nauditt

Technische Hochschule Köln (TH Köln - University of Applied Sciences), Institute for Technology and Resources Management in the Tropics and Subtropics, Cologne, Germany

CNRD Centers for Natural Resources and Development

ITT Institute for Technology and Resources Management in the Tropics and Subtropics

Technology Arts Sciences TH Köln

BACKGROUND

- Demand for Water (W), Energy (E) and Food (F) is growing – globally, but above average in the region of the Eastern Nile Basin (ENB)
- need to provide quantitative assessment of the resources base in order to determine current levels of W-E-F security as well as the interrelation between these three domains.
- ENB is a data scarce region, thus the use of public domain and remote sensing based data could create a useful addition to understand the current resources situation and to develop future scenarios for planning.

In line with the above the **objectives** of this study are:

1. To quantify Water, Energy, and Food-Security for the Eastern Nile Basin including resources availability and potential, use and demand
2. To quantify interrelationships between the three security areas

STUDY AREA

The Eastern Nile Basin has an area of 1.7 * 10^6 km^2 and comprises five countries. In this study we focus on the part of the basin covered by Egypt, Sudan and Ethiopia due to poor current data availability in South Sudan and Eritrea.

Water availability per capita in the three countries is characterized as "stressed" (<1500 m^3 cap^{-1}), with predicted values of < 800 m^3 cap^{-1} in Ethiopia and Sudan, and < 400 m^3 cap^{-1} in Egypt by 2050 (UN, 2018).

Country	Total area (Km^2) [2]	Area within ENB (km^2)	Total population 2018/2050 (10^6) [1]	Arable land (10^6 ha) [2]	Electricity consumption (kWh cap^{-1}) [2]	Average cereal yield (ton/ha) [2]
Egypt	1,001,450	326,751	(99.4/153.4)	2.89	1658	7.1
Sudan	1,879,400	1,823,018	(41.5/80.4)	19.82	190	0.7
Ethiopia	1,104,300	353,376	(107.5/190.9)	15.11	70	2.4

1) UN 2018 population statistics; 2) FAOSTAT

Table 1: Summary statistics of three riparian countries

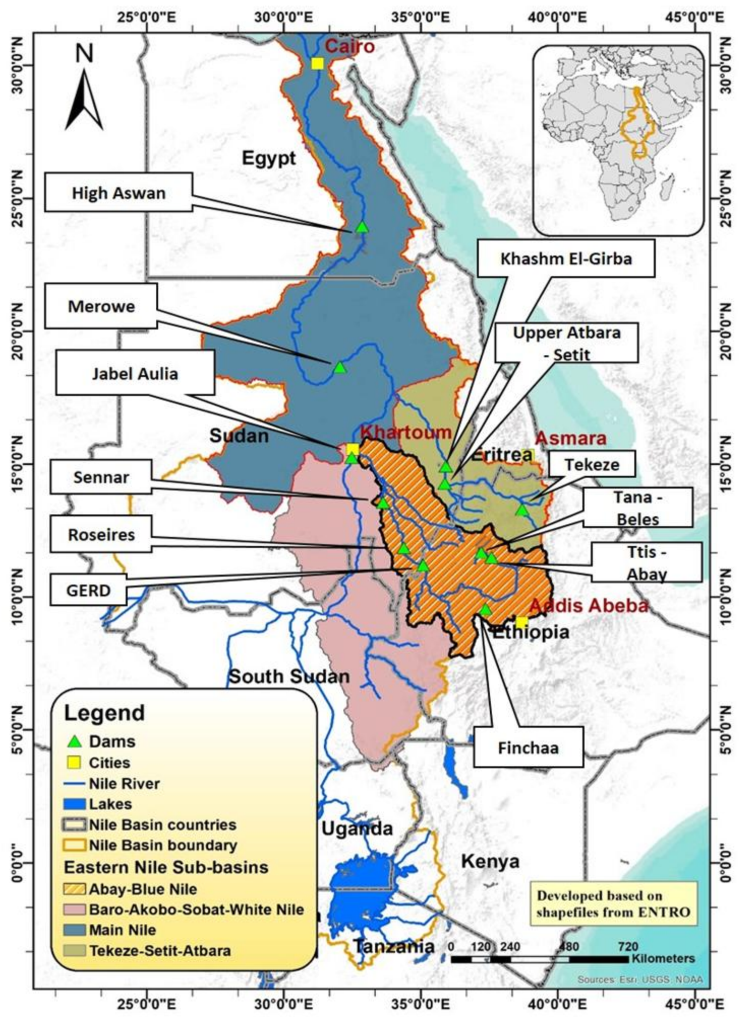

Figure 1: Overview of study area

METHODS AND DATA

Public domain and remote sensing based data were used to estimate the individual securities as well as their interactions. A river basin model was set up to estimate hydropower production.

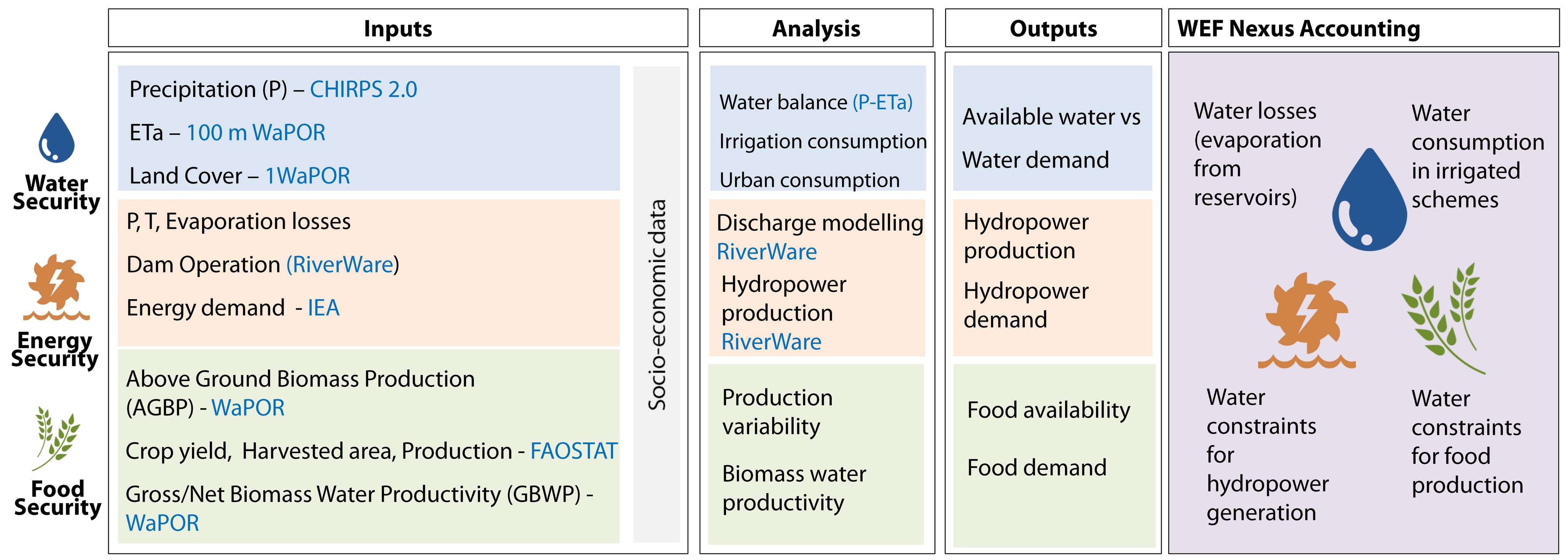

Figure 2: Methodological overview

WATER BUDGET USING P AND ETa ESTIMATES

The annual water balance was estimated using precipitation data from CHIRPS and ETIa from WaPOR data for the years 2009-2017. This simple water balance shows an approximate water availability in the main four sub-basins in the Eastern Nile region. While the Blue Nile sub-basin generates the largest quantities of blue water (~204 mm/year), the Main Nile and Baro-Akobo-Sobat and White Nile sub-basins have a negative water balance (~-94 and -91 mm/year, respectively). Thus, river flow in these basins can only be observed seasonally or due to upstream contributions. A comparison with observed discharge validates the annual discharge estimates: 54.4 km^3 (Ministry of Water, Sudan), compared with 62.9 km^3 (P-ET estimate).

For water security concerns the per capita water availability is an approximation. Fig. 3 shows the decreasing trend.

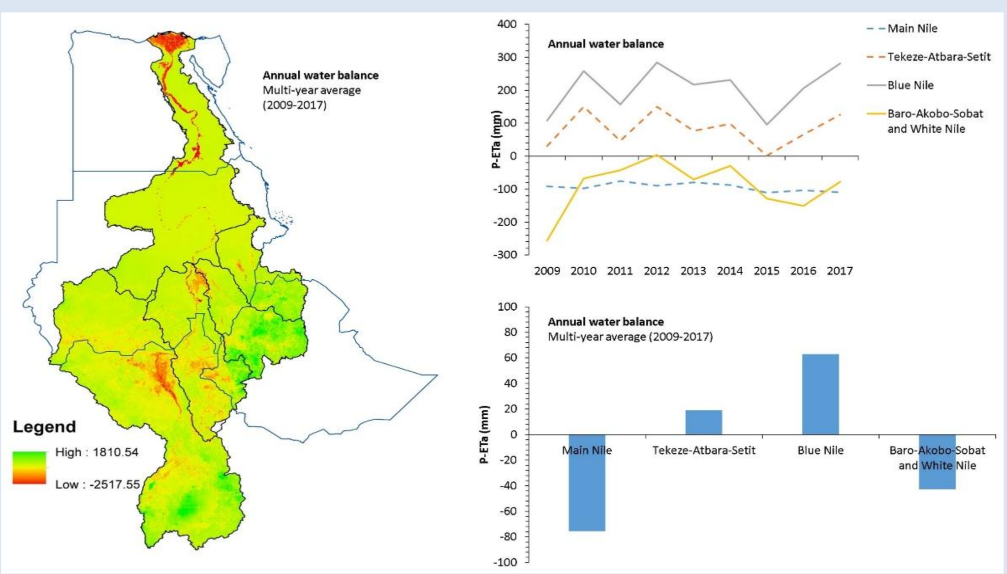

Figure 3: Simple water balance based on P-ET

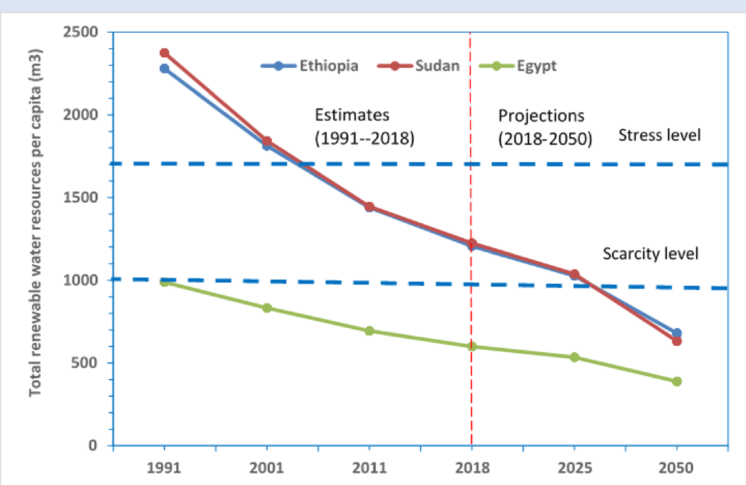

Figure 4: Water availability per capita

ENERGY: HYDROPOWER DEVELOPMENT & INCREASING TREND

Electricity generation increases in the three riparian countries in line with population growth (Fig 5).

Simulations for wet, average and dry years suggest a significant additional energy production due to the Grand Ethiopian Renessaince Dam (GERD) of 16,771 GWh (average hydrological year; compare Fig 6).

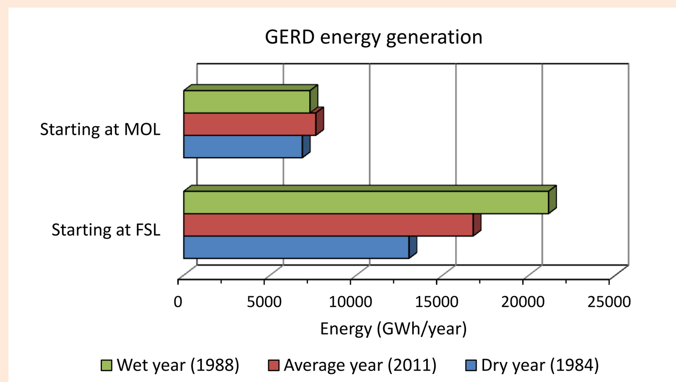

Figure 6: Future Hydropower generation at GERD

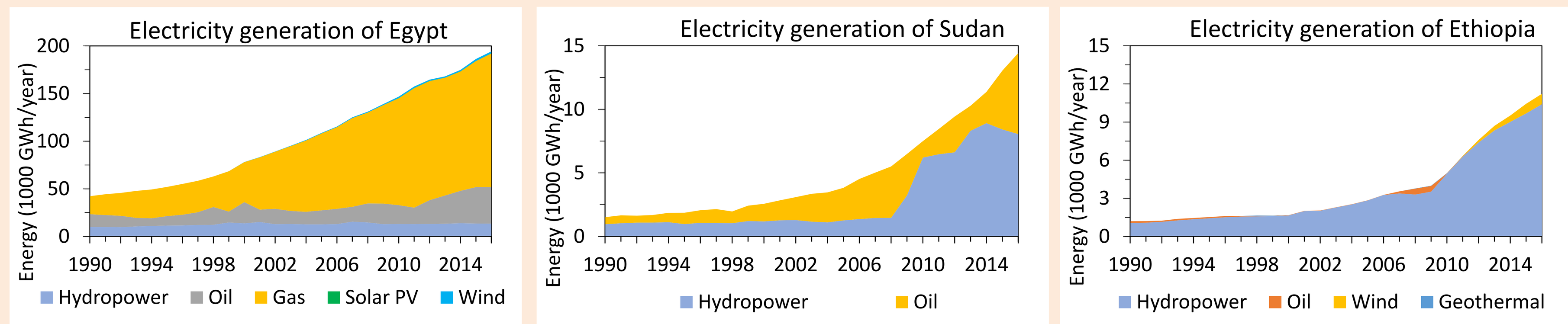

Figure 5: Electricity generation & share of Hydropower

FOOD: AGBP AND CROP PRODUCTIVITY

Aboveground Biomass Production (AGBP) levels were found to be highest in Ethiopia (Fig. 7). This is in accordance with precipitation levels. Correlation of temporal variation in AGBP with agricultural parameters (i.e. harvested area, yield and production) was highest in Ethiopia, lowest in Sudan.

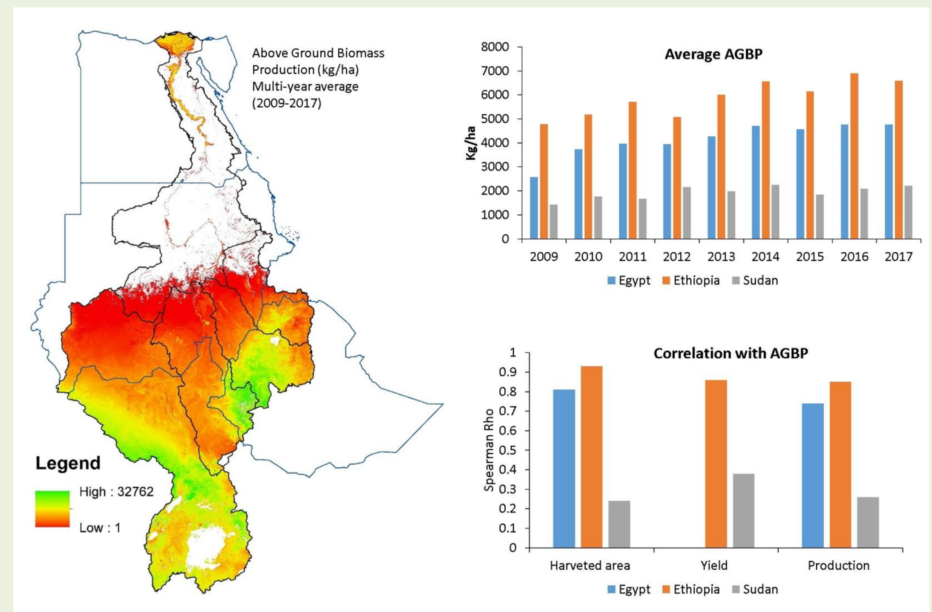

Figure 7: Aboveground biomass production

W-E NEXUS: EVAPORATION LOSSES FROM HYDROPOWER DAMS AND IRRIGATION AREAS

Actual evapotranspiration and evaporation were quantified for major irrigation zones and for reservoirs (estimates in Fig. 9, location in Fig. 8) in order to evaluate the impact of irrigation and hydropower on water abstraction and downstream water availability. While hydropower generation is not considered a consumptive water use, the associated storage can be related to evaporation losses.

The values show that irrigation altogether > 50 km^3 yr-1. Interesting is that the annual variations are rather low and not trend is visible in recent years.

Water demand by energy production

Next to hydropower, electricity generation based on fossil energy has also an associated water demand. If we apply average energy consumption based on Macknick et al (2012) the value for natural gas steam is at average 3.13 m^3KWh^{-1}. For Egypt this would convert to an estimated water demand of 0.5 km^3 yr^{-1} (2016)

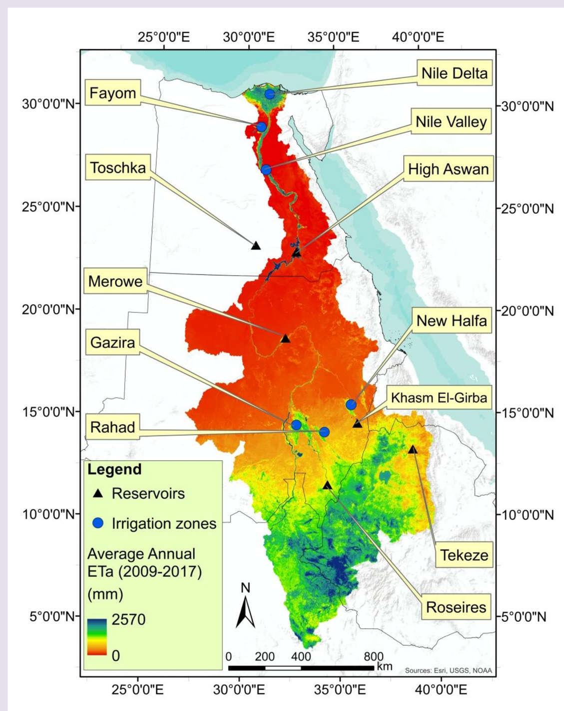

Figure 8: Spatial distribution of the actual evapotranspiration (Multi-year average, 2009-2017)

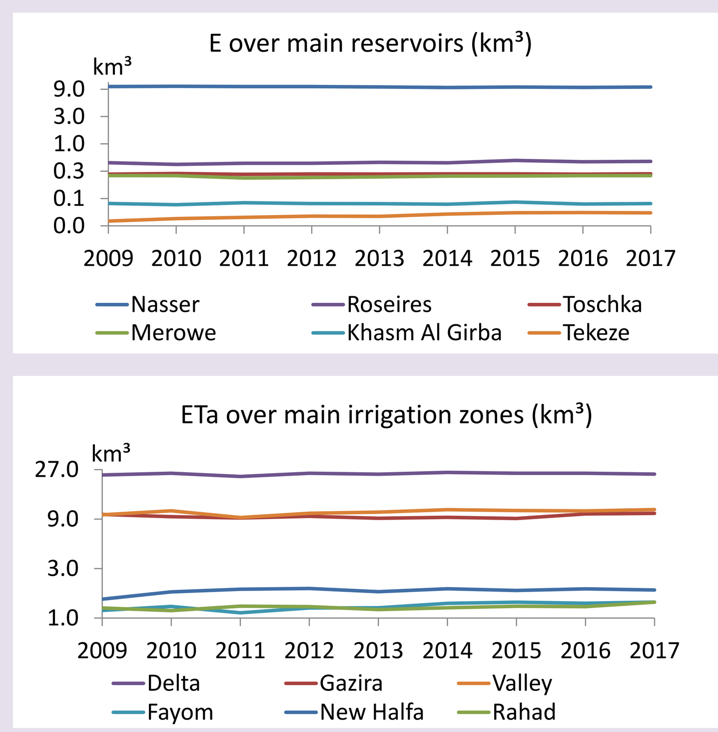

Figure 9: Evaporation and evapotranspiration losses of major reservoirs and irrigation zones determined by remote sensing based estimates

CONCLUSION

The results can be considered as mere approximations of W, E and F Security due to the limited ground truth data. However, interesting conclusions can be derived about the status and trend of water, energy and food security and their interrelations:

- Security is going down as demand (population growth) is increasing faster than supply
- Water productivity can potentially be improved as the current level is rather low – in particular in Sudan.
- Benefit sharing: The results show that W, E and F generation are currently at different efficiency and productivity levels: Evaporation is higher per GWh in Egypt and Sudan while productivity (Kg/m^3) is much higher in Egypt.

This study demonstrates the huge potential to quantify water-energy and food security as well as their interrelations by using remote sensing based data.

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