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

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Abstract

Water-Energy-Food Nexus assessments at river basin scale make sense in particular if hydropower is an important source of energy in a given region. The Blue Nile Basin is a major source for Water in the Nile river basin. It provides around 65 % of the flow of the Nile entering Egypt, and occupies a mere 10% of the total basin area. The Blue Nile water is primarily used for irrigation, hydropower, and domestic supply in Ethiopia, Sudan, and Egypt. Climate variability and long-term climate and socio-economic changes pose a growing challenge to the provision of water, energy, and food security within the Blue Nile Basin as well as downstream. Thus, the scientifically sound quantification of available natural resources sustaining water, energy, and food security, and the development of different future scenarios can be helpful for decision-makers in the region. We suggest a new method of WEF Nexus accounting based on quantification of Nexus indicators derived mainly from public domain data. As observed data on water and land resources in the Blue Nile Basin are scarce, this study uses diverse remote sensing-based data sources to derive essential environmental information validated by using ground data, where possible. This includes land cover data, different precipitation products, actual evapotranspiration, net primary productivity (NPP), among others. Furthermore, several data analysis and modeling tools, such as WA+, various hydrological models, RiverWare, CropWat, etc., are employed to quantify the natural resources availability, variability, and productivity as a basis for a comprehensive WEF accounting based on selected indicators which were developed by a team of experts and scientists. The currently constructed Grand Ethiopian Renaissance Dam (GERD) as well as other planned hydropower and irrigation schemes are also considered for the future scenarios. The result is a comprehensive WEF Nexus accounting estimating water availability and uses with a focus on irrigation as the dominant water user, productivities (based on NPP and derived yield estimates), water use efficiency, energy production from hydropower and estimation of security levels compared to the required current and future demands. Finally, the derived nexus indicators are put into context of selected SDG target indicators.

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CNRD Centers for Natural Resources and Development

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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 km² 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 m³ cap^{-1}), with predicted values of < 800 m³ cap^{-1} in Ethiopia and Sudan, and < 400 m³ cap^{-1} in Egypt by 2050 (UN, 2018).

Country	Total area (Km²) [2]	Area within ENB (km²)	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

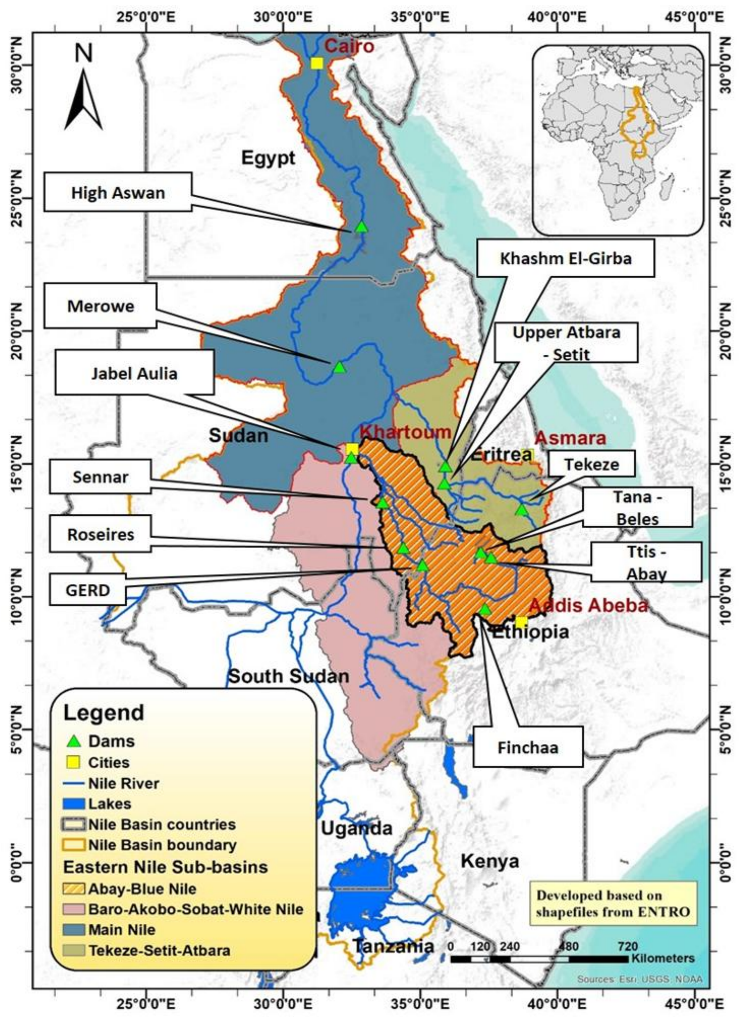

Figure 1: Overview of study area

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.

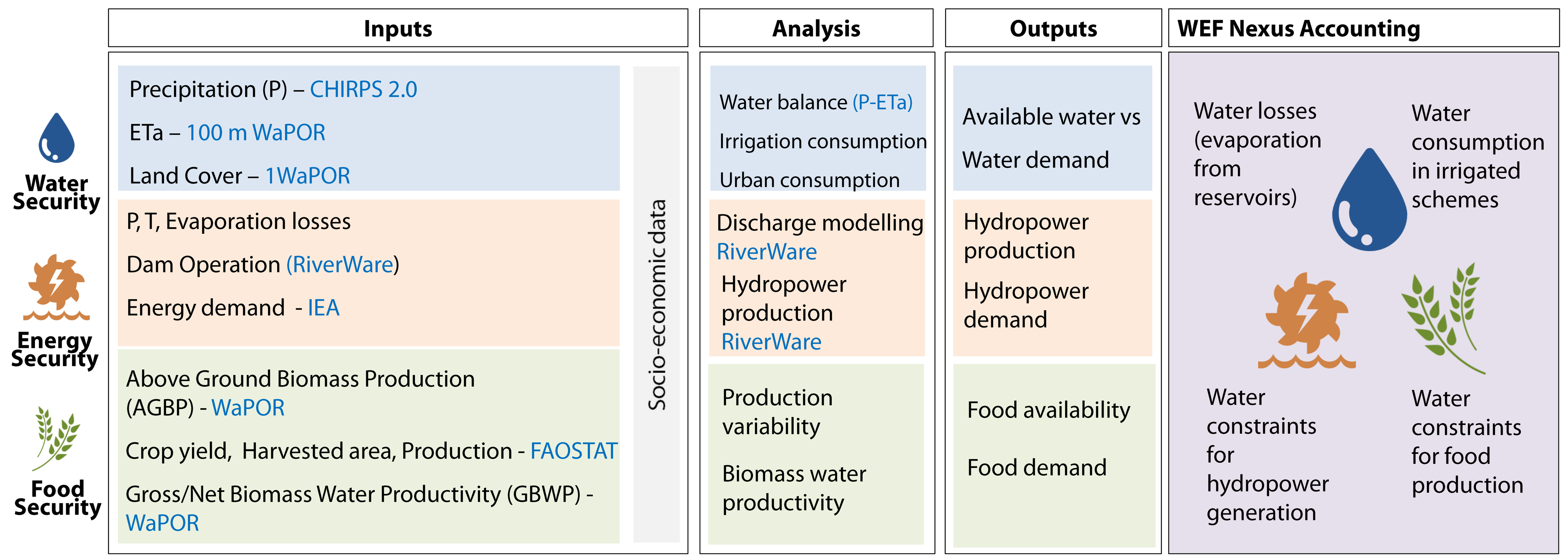

Figure 2: Methodological overview

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 km³ (Ministry of Water, Sudan), compared with 62.9 km³ (P-ET estimate).

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

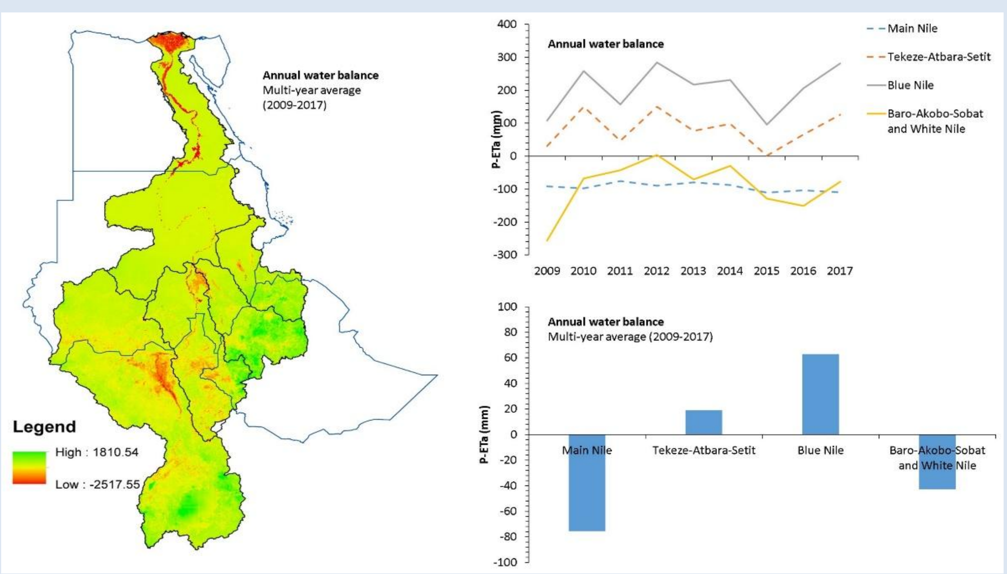

Figure 3: Simple water balance based on P-ET

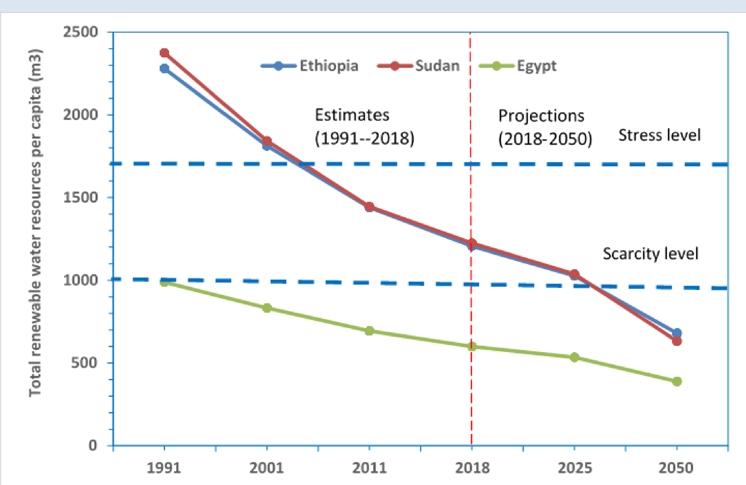

Figure 4: Water availability per capita

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).

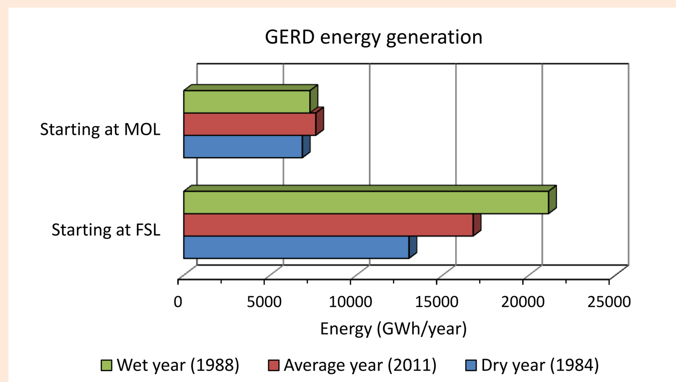

Figure 6: Future Hydropower generation at GERD

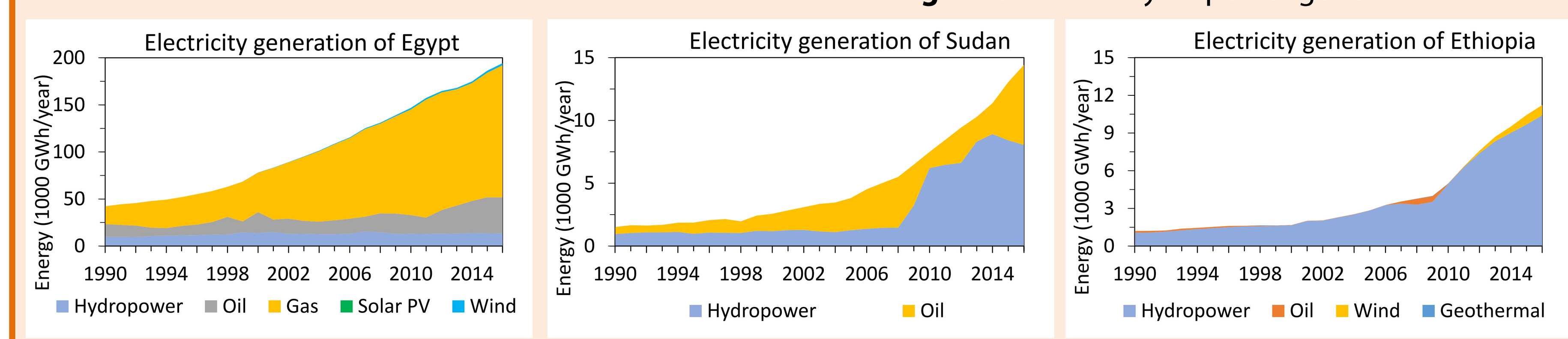

Figure 5: Electricity generation & share of Hydropower

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.

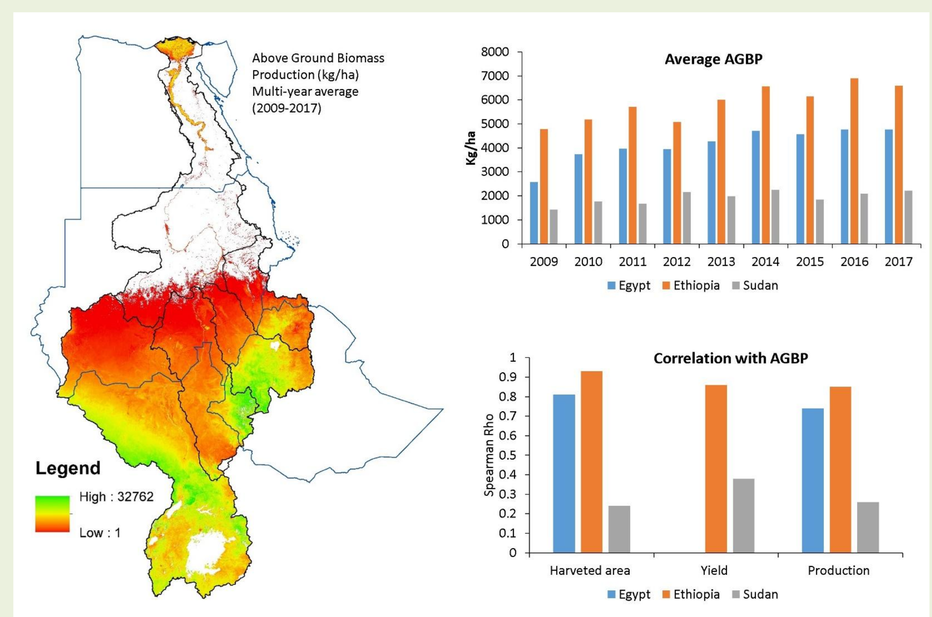

Figure 7: Aboveground biomass production

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 km³ 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 m³KWh^{-1}. For Egypt this would convert to an estimated water demand of 0.5 km³ yr^{-1} (2016)

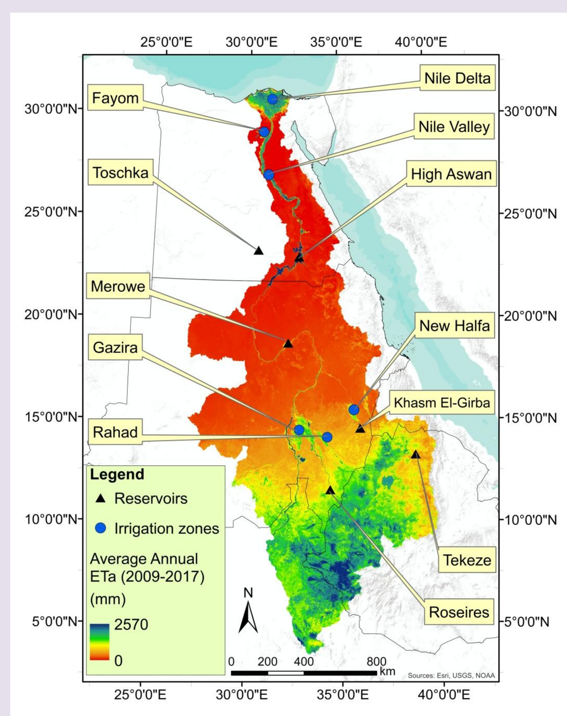

Figure 8: Spatial distribution of the actual evapotranspiration (Multi-year average, 2009-2017)

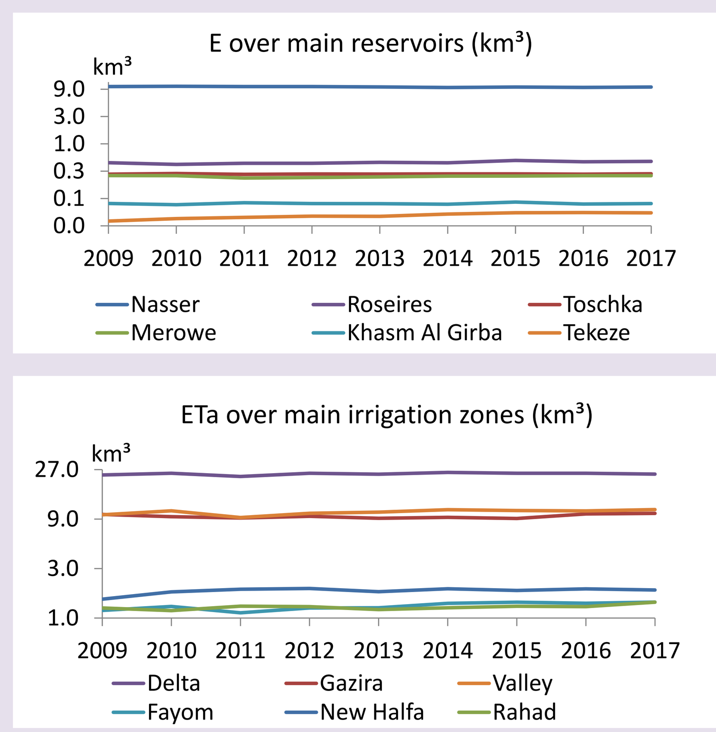

Figure 9: Evaporation and evapotranspiration losses of major reservoirs and irrigation zones determined by remote sensing based estimates

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/m³) 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.

REFERENCES

1. Al-Zayed, I.S., Elagib, N.A., Ribbe L., Heinrich, J. (2016): Satellite-based evapotranspiration over Gezira Irrigation Scheme, Sudan: A comparative study. Agricultural Water Management 177, 66 – 76.
2. Basheer M., Wheeler K.G., Ribbe L. et al. 2018. Quantifying and evaluating the impacts of cooperation in transboundary river basins on the Water-Energy-Food nexus: The Blue Nile Basin. Science of The Total Environment, 630, 1309-1323.
3. Basheer M., and Elagib N.A., 2018. Sensitivity of Water-Energy Nexus to dam operation: A Water-Energy Productivity concept. Science of the Total Environment, 616-617, 918-926.
4. Bastiaanssen W.G.M. et al. , 2014. Earth Observation Based Assessment of the Water Production and Water Consumption of Nile Basin Agro-Ecosystems. Remote Sens. 2014, 6(11), 10306-10334.
5. Khalifa M., Elagib N.A., Ribbe L., and Schneider K., 2018. Spatio-temporal variations in climate, primary productivity and efficiency of water and carbon use of the land cover types in Sudan and Ethiopia. Science of The Total Environment 624, 790-806.
6.Salih A.A.M., Elagib, N.A., Tjernström M., and Zhang Q., 2017. Characterization of the Sahelian-Sudan rainfall based on observations and regional climate models. Atmospheric Research, 202, 205-218.
7. Woldesenbet, T.A., Elagib, N.A., Ribbe, L., Heinrich, J. 2016. Hydrological responses to land use/cover changes in the source region of the Upper Blue Nile Basin, Ethiopia. Science of The Total Environment. 575, pp. 724-741