Water Accounting Plus (WA+): une nouvelle méthode pour la quantification des ressources en eau depuis l’espace
Le cas du bassin de la Volta

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Supervision:
Prof. Bettina Schaefli
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The Volta River Basin – Overview

Latitudes: 5°45’ N and 14°10’ N
Longitudes: 2°17’ E and 5°20’ W

Area ≈ 410,000 km²

2010: 23.8 million inhabitants
2030: 38.4 million (Williams et al., 2016).

70% of rural population

Growth rate: 2.4% per year (van de Giesen et al., 2001)

Mean annual Temperature
27°C in the south
36°C in the north

Mean annual Rainfall
500 - 1,500 mm

ET = 88% of rainfall

Water Management in the Volta River Basin

**Economic development**
- Electricity production
- Irrigation
- Aquaculture
- Livestock watering
- Domestic water supply
- Livelihood for rural populations

**Constraints**
- Urbanization
- Rapid population growth
- Economic development
- Climate Change

**Water scarcity**
Water demand is projected to increase by more than 1000% between 2000 and 2025 (Biney, 2010).
Existing Water Accounting Frameworks

1999

IWMI water accounting framework (Molden and Sakthivadivel)

2006

Australian Water Accounting Conceptual Framework (Water Accounting Standards Board, SKM)

2009

UNEP’s Water Footprint, Neutrality, and Efficiency (WaFNE) (Morrison and Schulte)

2010

Water-use accounts framework of the Challenge Program on Water and Food (CPWF) (Kirby, et al.)

2012

UN Statistics Division has developed recently the System of Environmental-Economic Accounting for Water (SEEAW)
Schortcomings in Major Water Accounting Frameworks

- Complex results and difficult to understand
- High requirement of input data ⇒ Not suitable for data scarce regions
- Consider abstracted water but not consumptive use and return flows
- No link between land use and water flows
- Land use impact on water is unknown

WA+ framework has been developed to address most of these shortcomings
Water Accounting Plus (WA+)

A new framework that summarizes complex hydrological processes and water management issues using public domain data

- Stocks
- Flows
- Benefits and Services
- Reports
- Consumption
- Interventions
Input data to WA+

- Soil moisture
- Land use
- Agriculture data
- River flow
- Water storage
- ET
- Rainfall
- Biomass
- Statistics...
WA+ Sheets

8 sheets for results with key indicators

Sheet 1 Resource Base
Water allocation

Sheet 2 Evapotranspiration (ET)
Water consumption

Sheet 3 Agricultural Services
Water productivity in agriculture

Sheet 4 Utilized Flow
Manmade and natural withdrawals

Sheet 5 - Surface Water
Water availability and river flow

Sheet 6 Groundwater
Availability and withdrawals

Sheet 7 Ecosystem Services
Land and atmosphere interactions

Sheet 8 Sustainability
Reliability, resilience and vulnerability

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**WA+ Land/Water Use Classes**

<table>
<thead>
<tr>
<th>Protected Land Use (PLU)</th>
<th>Utilized Land Use (ULU)</th>
<th>Modified Land Use (MLU)</th>
<th>Managed Water Use (MWU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• tropical rainforests</td>
<td>• forests</td>
<td>• urban encroachment</td>
<td>• irrigation</td>
</tr>
<tr>
<td>• wetlands</td>
<td>• natural pastures</td>
<td>• built-up areas</td>
<td>• urban water supply</td>
</tr>
<tr>
<td>• mountainous vegetation</td>
<td>• savannas and deserts</td>
<td>• rainfed croplands</td>
<td>• industrial extractions</td>
</tr>
<tr>
<td>• national parks</td>
<td>• woodlands</td>
<td>• bio-fuel crops</td>
<td>• diversion dams</td>
</tr>
<tr>
<td>• RAMSAR sites</td>
<td>• lakes</td>
<td>• timber plantations</td>
<td>• canals, ditches, gates, weirs, pipes</td>
</tr>
<tr>
<td>• etc.</td>
<td>• shrublands</td>
<td>• etc.</td>
<td>• etc.</td>
</tr>
<tr>
<td></td>
<td>• grasslands</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• etc.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Source: adapted from Karimi et al. (2013), Bastiaanssen et al. (2015)*
WA+ Land Use Land Cover Map

Globcover 2009

Land cover type
- 11 - Irrigated croplands
- 14 - Rainfed croplands
- 20 - Mosaic Croplands/Vegetation
- 30 - Mosaic Vegetation/Croplands
- 50 - Closed broadleaved deciduous forest
- 60 - Open broadleaved deciduous forest
- 70 - Closed needleleaved evergreen forest
- 110 - Mosaic Forest-Shrubland/Grassland
- 120 - Mosaic Grassland/Forest-Shrubland
- 130 - Closed to open shrubland
- 140 - Closed to open grassland
- 150 - Sparse vegetation
- 90 - Open needleleaved deciduous or evergreen forest
- 100 - Closed to open mixed broadleaved and needleleaved forest
- 40 - Closed to open broadleaved evergreen or semi-deciduous forest
- 160 - Closed to open broadleaved forest regularly flooded (fresh-brackish water)
- 170 - Closed broadleaved forest permanently flooded (saline-brackish water)
- 180 - Closed to open vegetation regularly flooded
- 190 - Artificial areas
- 200 - Bare areas
- 210 - Water bodies

LULC classes for WA+

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## Evapotranspiration Sheet

**Year: 2008**

<table>
<thead>
<tr>
<th>Category</th>
<th>Unit</th>
<th>ET</th>
<th>T</th>
<th>Unit</th>
<th>ET</th>
<th>T</th>
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<tbody>
<tr>
<td><strong>Non-Manageable Protected Land Use</strong></td>
<td>km³/yr</td>
<td>38.0</td>
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<td>1.11</td>
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<td><strong>Shrublands</strong></td>
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<td>16.16</td>
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<td>99.36</td>
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<tr>
<td><strong>Forest Woodland</strong></td>
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<td>km³/yr</td>
<td>0.10</td>
<td>0.07</td>
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<td>1.11</td>
<td>km³/yr</td>
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<td>1.11</td>
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<td><strong>Water Bodies</strong></td>
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<td>5.69</td>
<td>1.17</td>
<td>km³/yr</td>
<td>5.69</td>
<td>1.17</td>
</tr>
</tbody>
</table>

**Units:** [km³/year]

- **Evaporation:** 37.7 km³/year
- **Interception:** 57.9 km³/year
- **Non-Beneficial:** 41.4 km³/year
- **Beneficial:** 264.7 km³/year
- **Agriculture:** 106.9 km³/year
- **Environment:** 128.2 km³/year
- **Economy:** 11.2 km³/year
- **Energy:** 6.1 km³/year
- **Leisure:** 12.3 km³/year

**Total Evapotranspiration:** 306.1 km³/year

**Managed Land Use:** 106.7 km³/year

**Non-Managed Land Use:** 145.4 km³/year

**Non-Beneficial Uses:** 26.7 km³/year

**Beneficial Uses:** 279.4 km³/year

**Utilized Land Use:** 161.5 km³/year

**Non-Utilized Land Use:** 144.6 km³/year

**Managed Water Use:** 7.1 km³/year

**Non-Managed Water Use:** 2.3 km³/year

**Units:** [km³/year]
Input Data Validation - Rainfall

**Climate zones**

- Sahel Savanna
- Sudano-Sahelian Zone
- Sudanian Savanna Zone
- Guinean Savanna Zone
- Volta Lake
- Basin boundary
- International Boundary
- Meteo stations
- Towns
- Rivers
- Isophytes

**RFE**

Rain [mm/year]

- 1950
- 450

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Input Data Validation - Rainfall

$R^2 = 0.92$

2001–2014

<table>
<thead>
<tr>
<th>$r$</th>
<th>ME</th>
<th>RMSE</th>
<th>Bias</th>
<th>Eff</th>
<th>POD</th>
<th>FAR</th>
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<td>0.96</td>
<td>-2.25</td>
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<td>0.96</td>
<td>0.62</td>
<td>0.95</td>
<td>0.10</td>
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</tbody>
</table>

Source: Dembélé & Zwart (2016)
Input Data Validation - Evapotranspiration

Satellite-derived ET products and ETens in the VRB in 2008

Evapotranspiration data

- GLEAM (27.9km)
- SEBS (5.6km)
- CMRSET (5.6km)
- ALEXI (5.6km)
- ETMODIS (0.94km)
- SSEBop (0.93km)
- ETmonitor (0.57km)
- ETens (0.28 km)
Research axes

Climate Change Scenarios + Land Use Change Scenarios → Hydrological Model → WA+
Summary and conclusion

- Join effort from IWMI, UNESCO-IHE and FAO
- Being adopted by international organizations (World Bank, ADB...)

- Widely used (Africa and Asia)
- Powerful tool accessible to everyone and everywhere
Danke!
Merci

www.wateraccounting.org
WA+ Land Use Land Cover Map

WA+ classes

Area (%)

- Managed Water Use (2)
- Modified Land Use (36)
- Protected Land Use (12)
- Utilized Land Use (50)

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Budyko Framework Analysis – Results

The diagram illustrates the relationships between potential evapotranspiration (PET) and precipitation (P), along with various land cover types and their moisture constraints. The Budyko curve, moisture constraint, and energy constraint are highlighted, along with the climate limit. Different symbols denote various land cover categories, such as protected forests, utilized forests, modified forest woodlands, protected water bodies, utilized water bodies, managed water bodies, modified rainfed croplands, managed irrigated croplands, protected grasslands, utilized grasslands, protected bare areas, utilized bare areas, modified urban areas, protected shrublands, and utilized shrublands.

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## Input data to WA+

<table>
<thead>
<tr>
<th>Input</th>
<th>Source(s)</th>
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<tbody>
<tr>
<td>Rainfall</td>
<td>TRMM, GSMaP, GPCP, FEWSNET, PERSIANN, CMORPH, APHRODITE, CRU, ECMWF</td>
</tr>
<tr>
<td>Evapotranspiration</td>
<td>MOD16, GLEAM, CMRSET, ALEXI, ETens</td>
</tr>
<tr>
<td>Soil moisture</td>
<td>SMAP, ASCAT</td>
</tr>
<tr>
<td>Land use</td>
<td>Globcover, AfriCover, Corine, MIRCA, GIAM, GMIA</td>
</tr>
<tr>
<td>Lake levels</td>
<td>Global Reservoir and Lake Monitoring (GRLM), River Lake Hydrology (RLH),</td>
</tr>
<tr>
<td></td>
<td>Hydroweb, Global Land Surface Altimetry data (ICESat-GLAS)</td>
</tr>
<tr>
<td></td>
<td>program, Aquedect</td>
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## Comparison between SEEAW and WA+

<table>
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<tr>
<th>Process</th>
<th>Low end performance description</th>
<th>High end performance description</th>
<th>WA+</th>
<th>SEEAW</th>
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<tr>
<td>Field measurements involved</td>
<td>Few</td>
<td>Intensive</td>
<td>*</td>
<td>*****</td>
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<tr>
<td>Remote sensing measurements</td>
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<td>*****</td>
<td>**</td>
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<tr>
<td>Land use classes</td>
<td>Minimum attention</td>
<td>Maximum attention</td>
<td>*****</td>
<td>*</td>
</tr>
<tr>
<td>Economy</td>
<td>No attention</td>
<td>Maximum attention</td>
<td>*</td>
<td>***</td>
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<tr>
<td>Water quality</td>
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<td>Included</td>
<td>*</td>
<td>***</td>
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<tr>
<td>Temporal scale</td>
<td>Annual</td>
<td>Weekly</td>
<td>***</td>
<td>*</td>
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<tr>
<td>Consumptive use</td>
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<td>Minimum attention</td>
<td>*****</td>
<td>**</td>
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<tr>
<td>Hydrological cycle</td>
<td>A few terms only</td>
<td>All terms</td>
<td>*****</td>
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<tr>
<td>Natural vegetation</td>
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<td>Fully explored</td>
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<tr>
<td>Withdrawals general</td>
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<td>Maximum attention</td>
<td>****</td>
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<tr>
<td>Withdrawals domestic &amp; industry</td>
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<td>Maximum attention</td>
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<td>Return flow</td>
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<td>Maximum attention</td>
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<td>Surface water</td>
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<td>****</td>
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<tr>
<td>Groundwater</td>
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<td>Estimated</td>
<td>***</td>
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<tr>
<td>Crop production</td>
<td>Detailed estimates</td>
<td>Not accounted for</td>
<td>*****</td>
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<tr>
<td>Crop water productivity</td>
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<td>Greenhouse gas emissions</td>
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<td>Carbon sequestration</td>
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<td>Communication tool</td>
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<td>Yes</td>
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</tr>
</tbody>
</table>

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# Input Data Validation - Evapotranspiration

Satellite-derived ET products and ETens in the VRB in 2008

<table>
<thead>
<tr>
<th>ET products (mm/year) / WA+ LULC</th>
<th>GLEAM (27.9 km)</th>
<th>SEBS (5.6 km)</th>
<th>CMRSET (5.6 km)</th>
<th>ALEXI (5.6 km)</th>
<th>ETMODIS (0.94 km)</th>
<th>SSEBop (0.93 km)</th>
<th>ETmonitor (0.57 km)</th>
<th>ETens (0.28 km)</th>
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</thead>
<tbody>
<tr>
<td>Protected Water Bodies</td>
<td>905</td>
<td>1900</td>
<td>1031</td>
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<td>807</td>
<td>745</td>
<td>1117</td>
<td>836</td>
<td>897</td>
</tr>
</tbody>
</table>
Many river basins experience issues of water stress and populations live with an inadequate level of water security.

Water stress affects:

- food production
- energy production
- ecological status of the basin

Climate change as well as other global and regional changes are expected to exacerbate water issues.

There is an increasing uncertainty in water availability in declining rainfall areas such as the Volta basin.