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# MAPPING IRRIGATION POTENTIAL FROM RENEWABLE GROUNDWATER IN AFRICA – A DEVELOPMENT PERSPERCTIVE

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# Presentation outlines

1. Introduction

2. Mapping sustainable groundwater irrigation potential (GWIP)

(Article published in Hydrology and Earth System Sciences on the 26 February 2015)

3. Mapping the groundwater development potential (GWDP)

(On-going research)

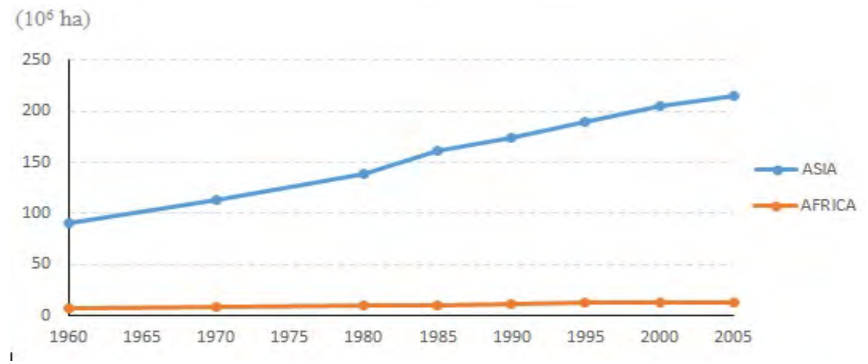
4. Conclusion

# MAPPING IRRIGATION POTENTIAL FROM RENEWABLE GROUNDWATER IN AFRICA INTRODUCTION

- Need to increase crop production in Africa to meet future food demand:
  - Population is projected to reach at 1 634 million by 2030 ( + 500 million)
  - Undernourished population increases by 35 million over the last 20 years
  - Crops represent 89% of the diet in Sub-Sahara Africa (SSA)
  - Human food commodity to increase by 15% in the next 40 years

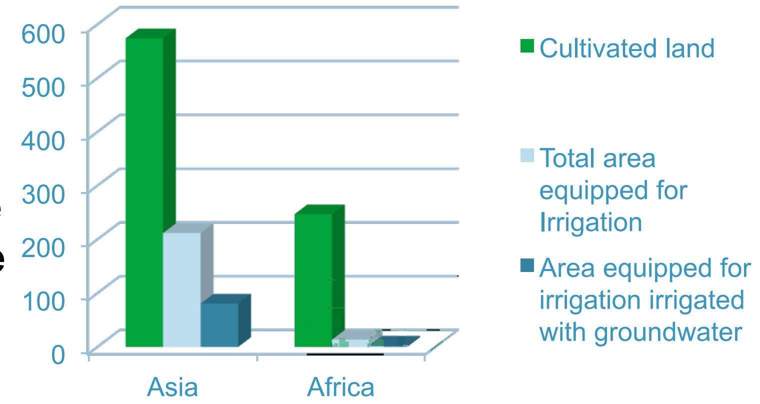
- Crop production growth in SAA is mainly due to extension of cultivated area and cropping intensities while crop yield improvement is low

- Irrigation can play significant role in increasing crop yield but development of area equipped for irrigation is slow in Africa (+ 6.2 million hectare over 45 years)



# MAPPING IRRIGATION POTENTIAL FROM RENEWABLE GROUNDWATER IN AFRICA
# INTRODUCTION

- Groundwater: the under-utilized water source for irrigation
  - 1% of cultivated land is equipped for irrigation with GW in Africa (Siebert et al., 2010)
  - Huge groundwater storage in Africa (MacDonald et al., 2012) but not all available for abstraction, and unevenly distributed
  - Groundwater provides an important buffer to climate variability and change. It is relatively affordable, safe and reliable, especially in rural Africa
  - Yields of groundwater irrigated areas are typically much higher than under surface water schemes




→ Where and how much of an area can renewable groundwater potentially irrigate over Africa? (GWIP)

→ Where should groundwater irrigation be developed in Africa? (GWDP)

# MAPPING IRRIGATION POTENTIAL FROM RENEWABLE GROUNDWATER IN AFRICA GWIP - METHODOLOGY

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- Based on water balance calculation done annually over a 41 year period (1960 – 2000) at a resolution of 50 km x 50 km

$$\boldsymbol{GWIP}\,(m2) = GW\ Available\,(m3\ year-1) / Irrig.\ Water\ Demand\,(m\ year-1)$$

(calculated annually)

$$\boldsymbol{GW\ Available} = GW\ Recharge - Human\ GW\ Demand - Environ.\ GW\ Req$$

(calculated annually then averaged over 41 years to consider buffer effect of GW)

$$\boldsymbol{Irrig.\ Water\ Demand} = \left\{\sum_{i=1}^{n}\left(\left[\sum_{j=1}^{m}(Crop\ Water\ Demand - Green\ Water)_j \ldots\right]\,[\%\ of\ Area]_i\right)\right\} / Irrig.\ Efficiency = Net\ Irrg.\ Water\ Demand / Irrig.\ Efficiency$$ (n= cro

(Calculated monthly then summed for annual value)

- Some assumptions in computations
  - GW is the only water source for irrigation (no conjunctive use with SW)
  - GW is usable and accessible (no quality, yield, or socio-economic constraints)
  - GW is locally available

# MAPPING IRRIGATION POTENTIAL FROM RENEWABLE GROUNDWATER IN AFRICA
# GWIP - METHODOLOGY

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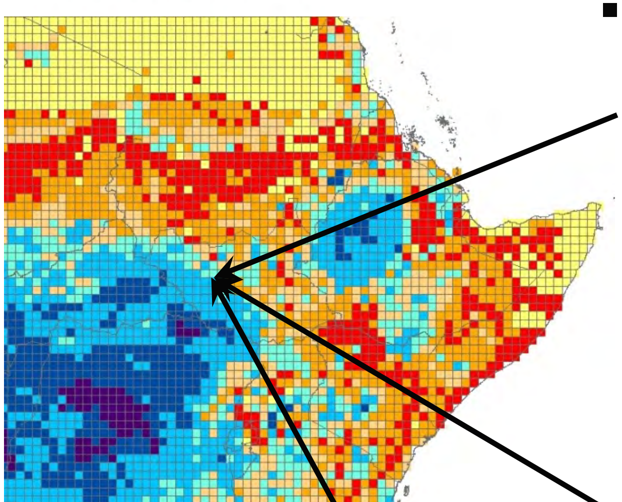
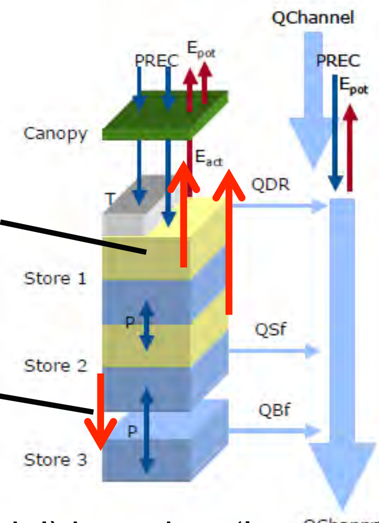


**Resolution:**
0.5 degree
(≈ 50 km x 50 k cell)

- Hydrological data from the PCR-GLOBWB model (Utrecht University, the Netherlands, Wada et al., 2011)
  - Reference Evapotranspiration
  - Water available for crop from rain (green water = transpiration soil 1 and 2)
  - Recharge




- Other GW uses
  - human activities (domestic, livestock, industrial) based on ''present'' human water demand derived from density of population and livestock, and unit requirement (FAO, geonetwork)
  - environment based on according to three different scenarios:
    - Scenario 1 : 70 % of the recharge goes to environment
    - Scenario 2 : 50 % of the recharge goes to environment
    - Scenario 3 : 30 % of the recharge goes to environment

- Crop data
  - Crop distribution
  - Crop water demand
  - Irrigation efficiency

  ➔ monthly calendar for crop group water demand

➔ **Different geographical data compiled in GIS**

# MAPPING IRRIGATION POTENTIAL FROM RENEWABLE GROUNDWATER IN AFRICA GWIP - METHODOLOGY

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- Crop data
  - Crop distribution based on crop distribution for the year 2000 from Center for Sustainability and the Global Environment (SAGE), University of Wisconsin, USA (worldwide, resolution 5 minutes, 11 major crops/ groups)
  - Selection of 6 crop groups (cereal, oil, root, pulse, vegetable and sugarcane)
  - Crop group water demand based on individual crop water demand from compilation of FAO database on crop coefficient and length of crop growth stage

$$\text{Crop Water Demand}_j = \text{Crop Group Coefficient} \times E_{0,\max_j}$$

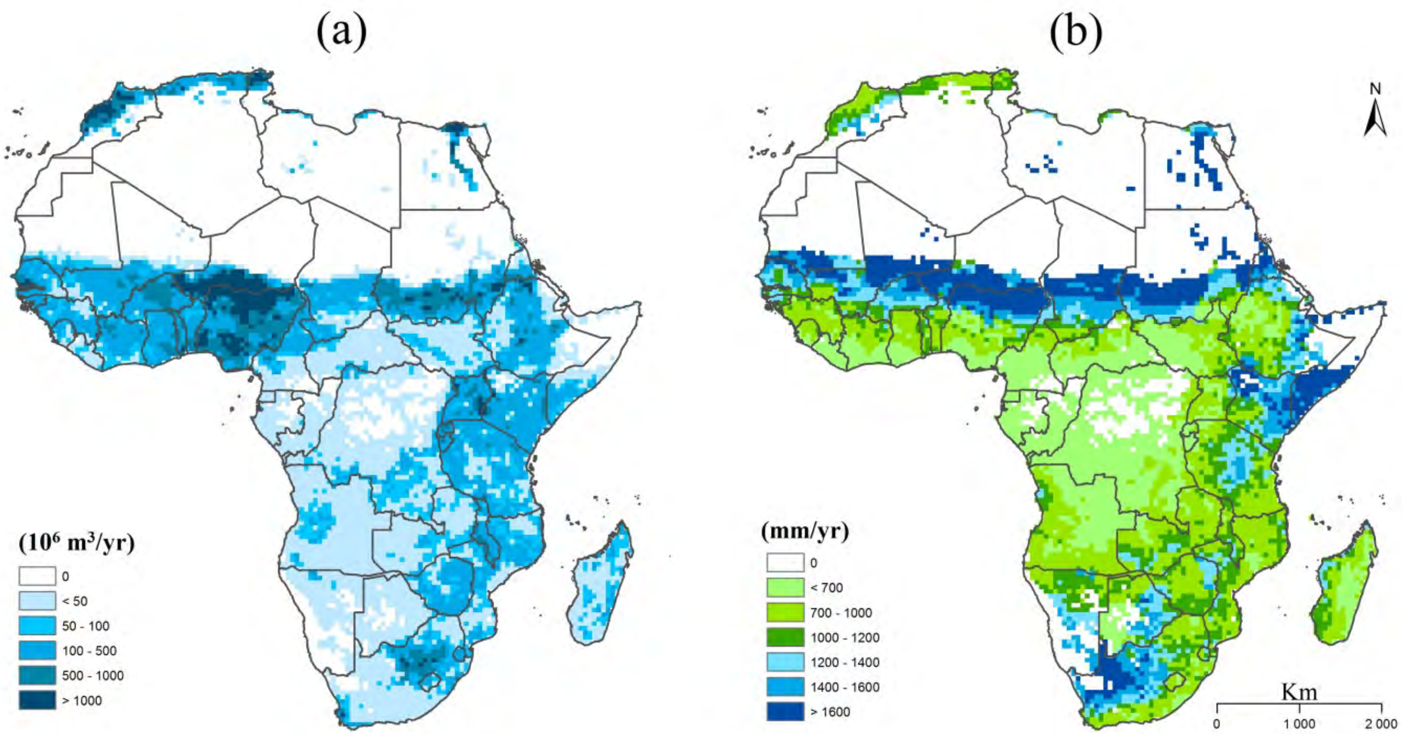
with $E_{0,\max_j}$ = reference evapotranspiration for each calendar month

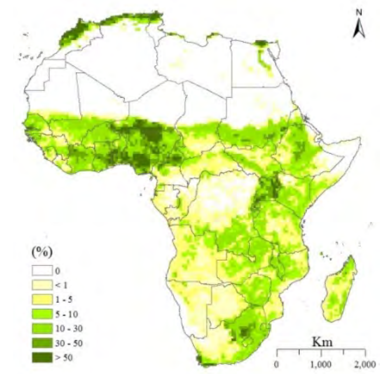
  - 23 irrigation cropping pattern zones associated with irrigation efficiency
  - Planting and harvesting calendar from FAO

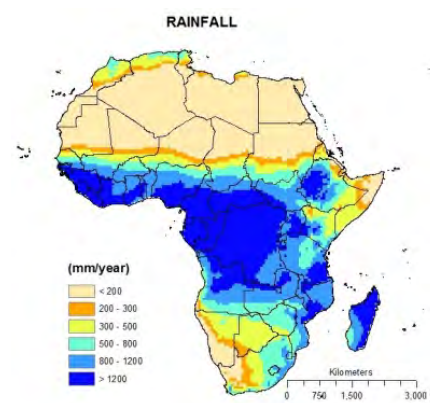
**Building of a monthly calendar for crop group water demand**

# MAPPING IRRIGATION POTENTIAL FROM RENEWABLE GROUNDWATER IN AFRICA GWIP - RESULTS

- Average Net Irrigation Water Demand (1960-2000)



# MAPPING IRRIGATION POTENTIAL FROM RENEWABLE GROUNDWATER IN AFRICA GWIP - RESULTS

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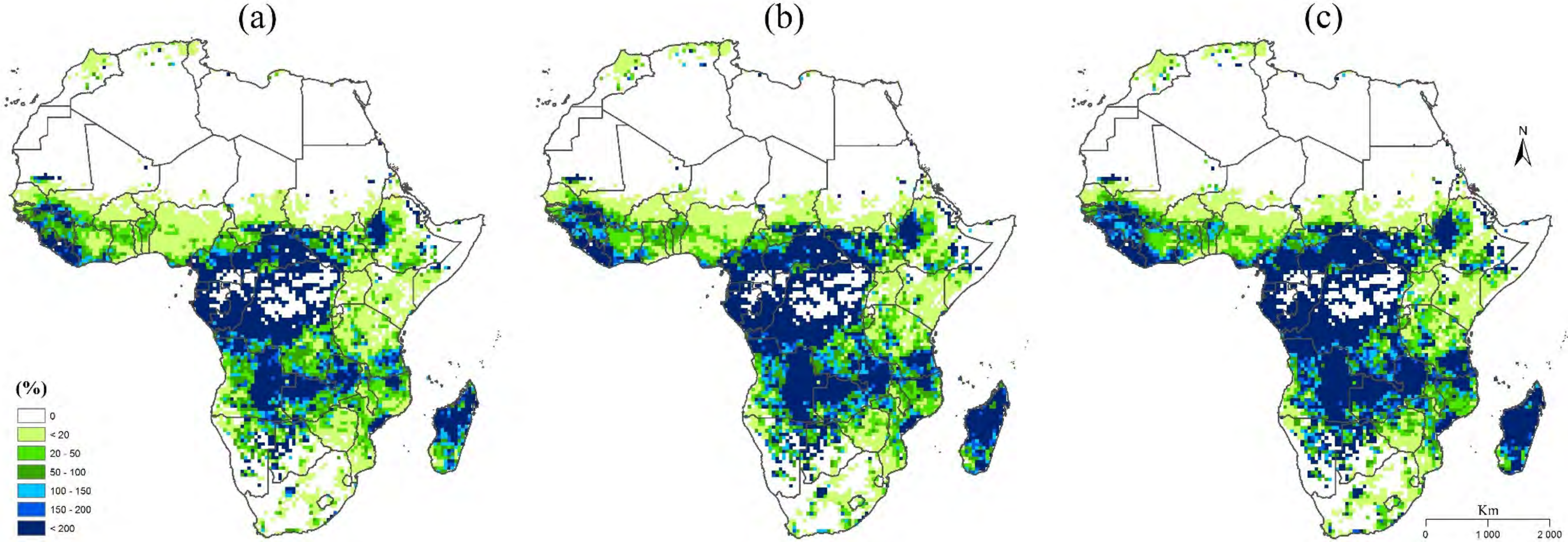
- Proportion of cropland irrigable with groundwater

(environmental groundwater requirements as (a) 70 %, (b) 50 % or (c) 30 % of the recharge)

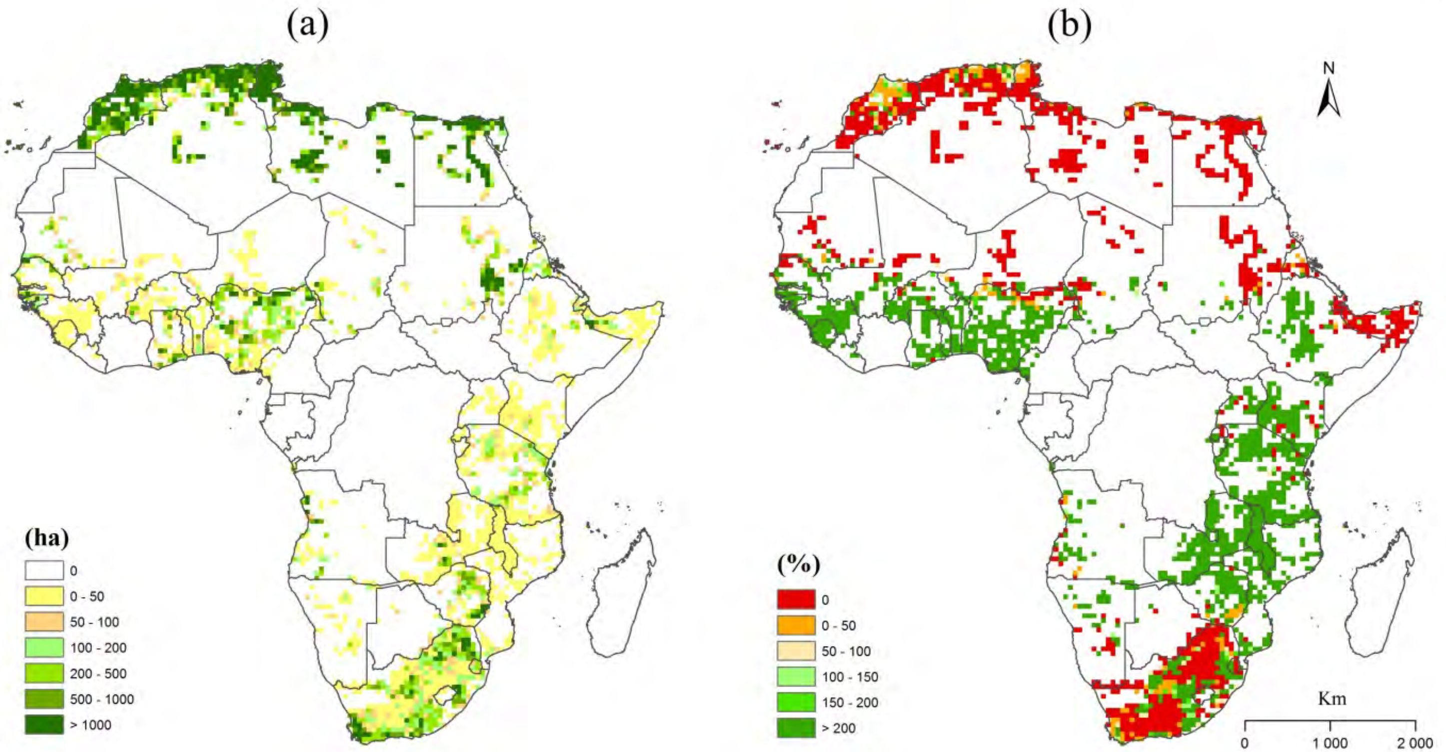
| | Environmental requirements represent | | |
|---|---|---|---|
| | 70% of recharge | 50% of recharge | 30% of recharge |
| Area ($10^6$ ha) | 44.6 | 74.9 | 105.3 |
| % of cropland | 20.5% | 34.5% | 48.5% |

A factor of 20 increase in overall GWI area possible (from 2 to ≈ 40 mill ha.)



# MAPPING IRRIGATION POTENTIAL FROM RENEWABLE GROUNDWATER IN AFRICA GWIP - RESULTS

- Comparison with GW irrigated cropland in 2005 (Siebert et al., 2010)




**(a) Actual** area irrigated with groundwater in 2005 expressed in ha. per cell adapted from Siebert et al. (2010) and **(b)** groundwater irrigation potential for scenario 2 for the year 2000 expressed as the percentage of the area irrigated with groundwater in 2005

# MAPPING IRRIGATION POTENTIAL FROM RENEWABLE GROUNDWATER IN AFRICA GWDP - METHODOLOGY

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- Identification of parameters, which promote or constraint groundwater irrigation development
  - 5 distributed parameters
    - Distance to surface water
    - Distance to market
    - Soil suitability for agriculture
    - Drilling cost: depth of groundwater
    - Distance to electricity

- Building parameter dataset at 0.005 degree resolution (0.5 x 0.5 km cell)

- Ranking the dataset into 5 classes (very poor, poor, moderate, good and very good)

- Combining the 5 distributed parameter dataset through equal weight method

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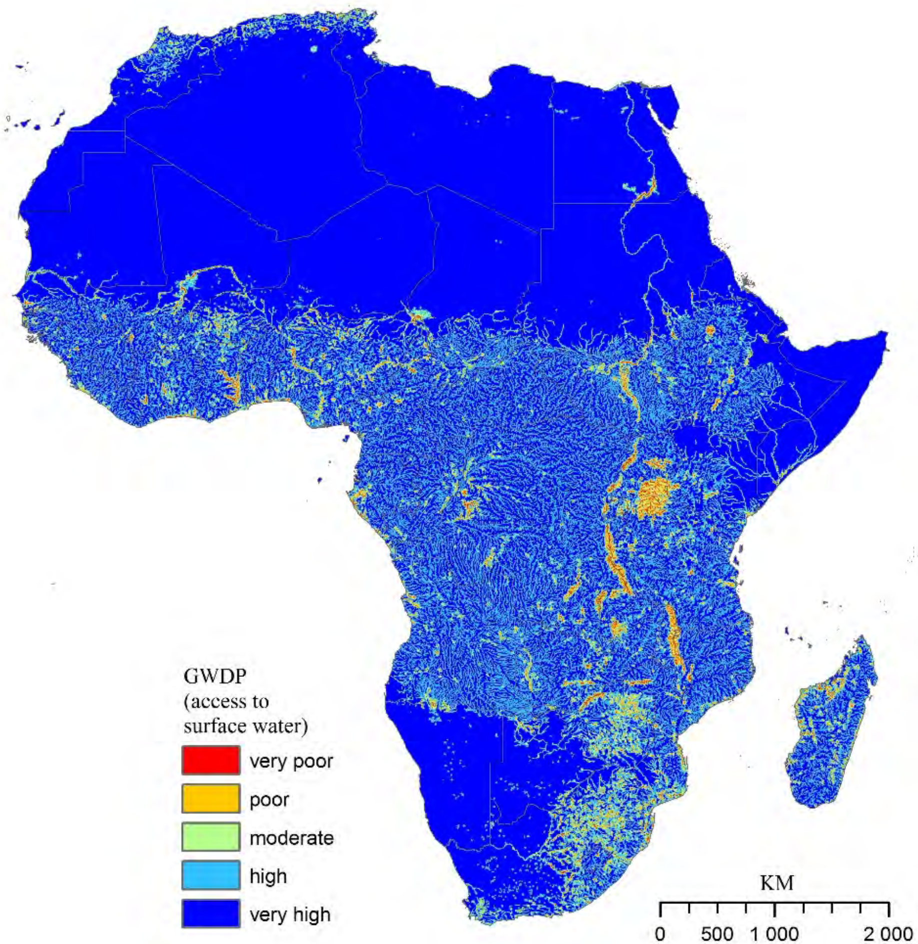
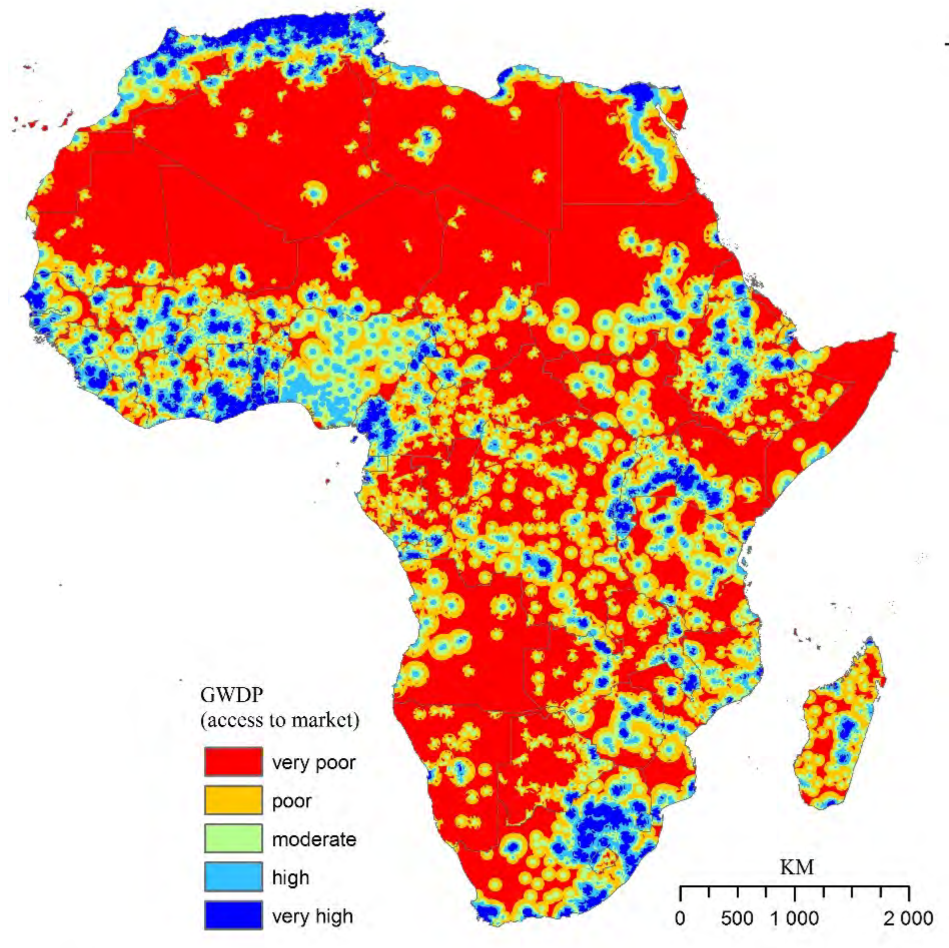
# MAPPING IRRIGATION POTENTIAL FROM RENEWABLE GROUNDWATER IN AFRICA GWDP - RESULTS

- Distance to surface water




- Distance to market



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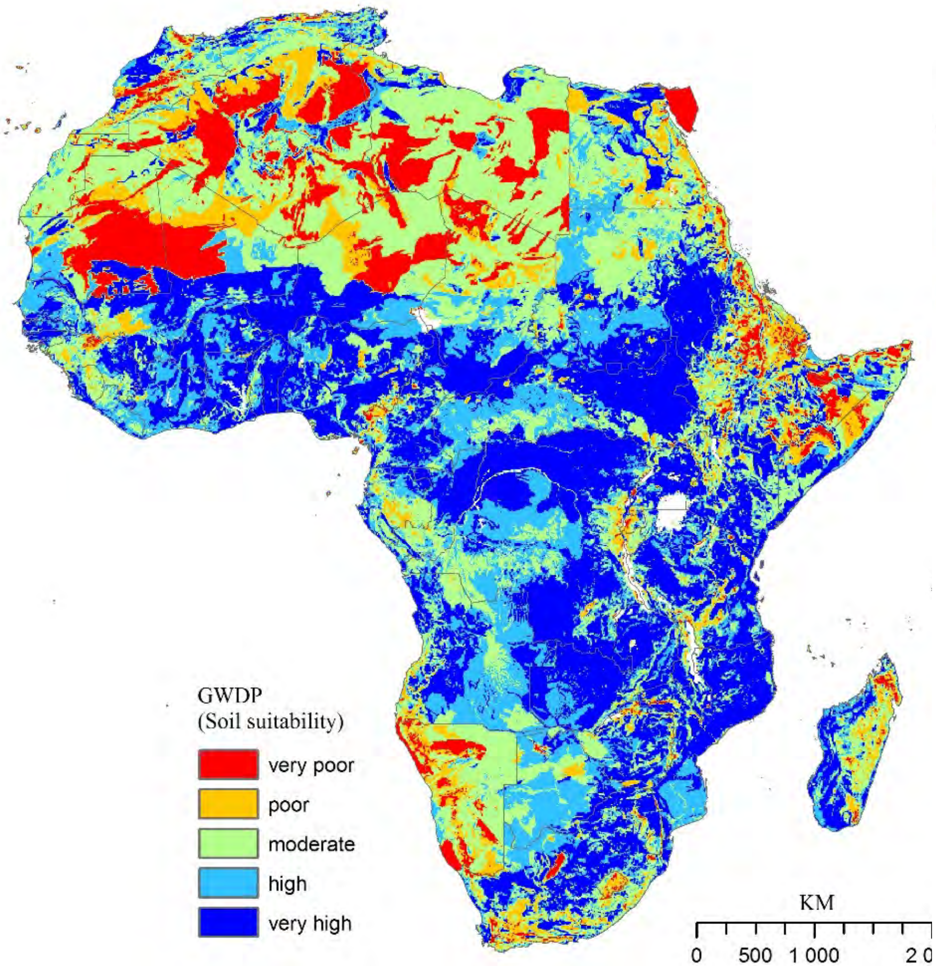
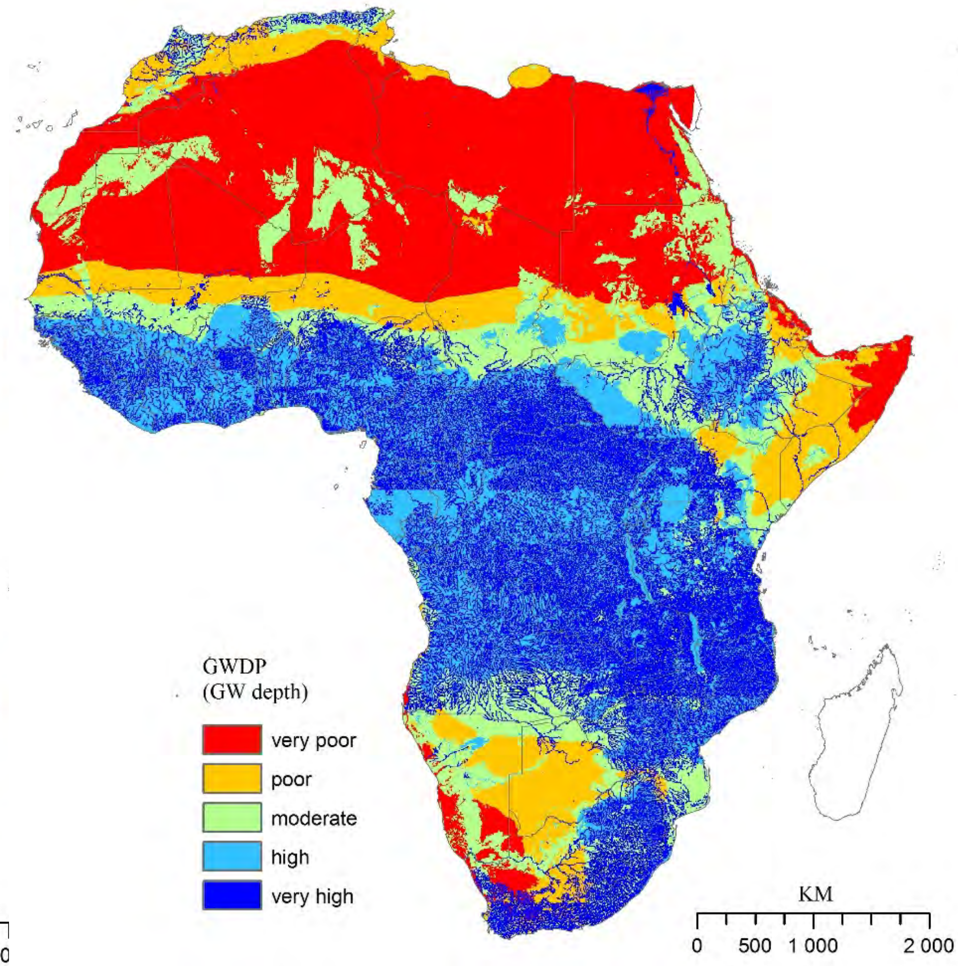
# MAPPING IRRIGATION POTENTIAL FROM RENEWABLE GROUNDWATER IN AFRICA GWDP - RESULTS

- Soil suitability for agriculture

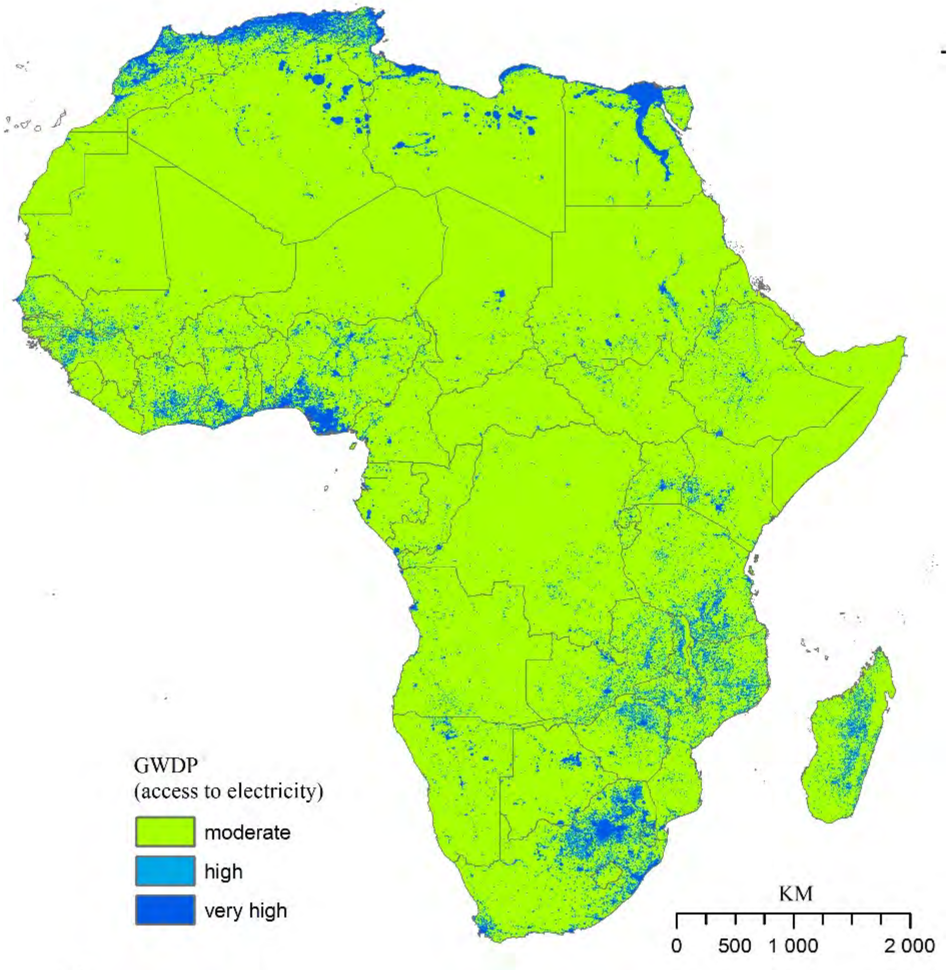



- Drilling cost



# MAPPING IRRIGATION POTENTIAL FROM RENEWABLE GROUNDWATER IN AFRICA GWDP - RESULTS

- Access to electricity



# MAPPING IRRIGATION POTENTIAL FROM RENEWABLE GROUNDWATER IN AFRICA RESULTS

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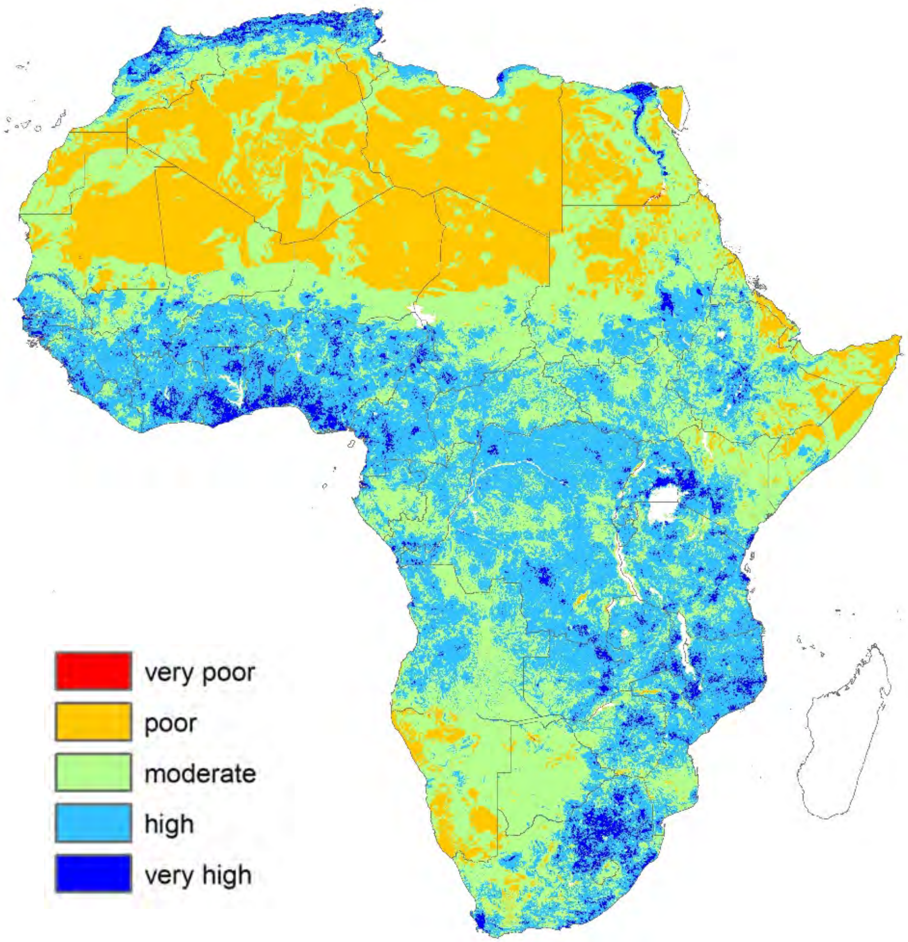
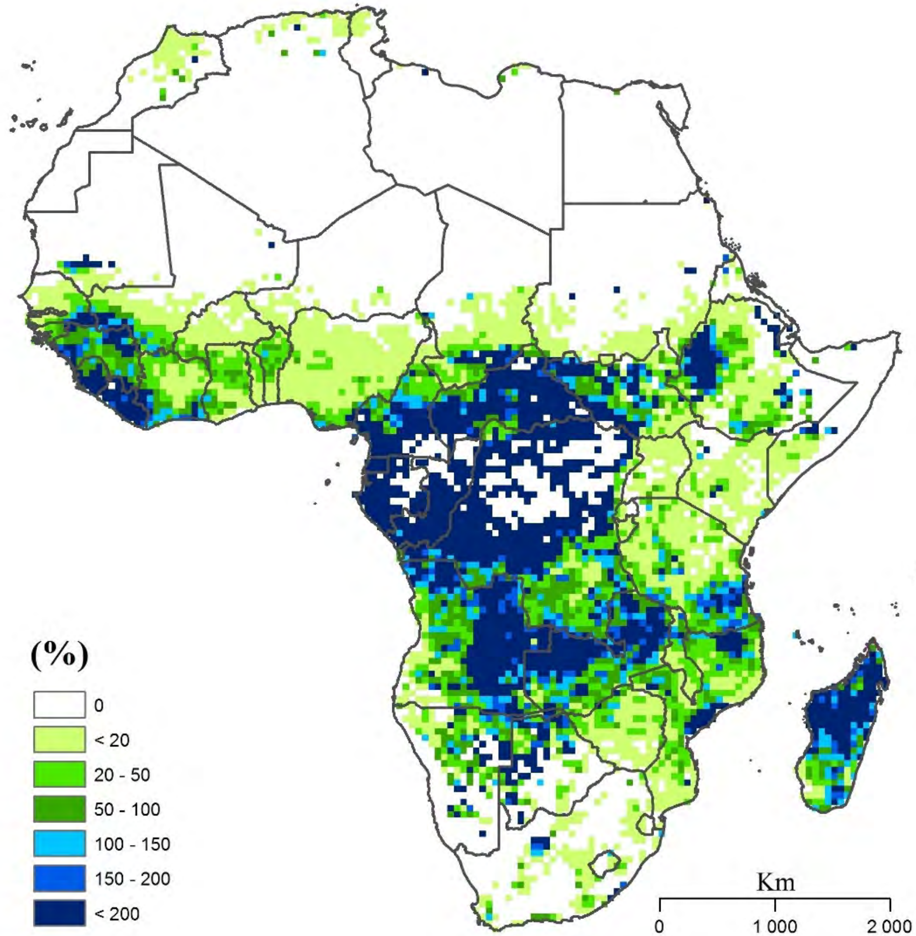
GWDP




GWIP (70% to environment)



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# MAPPING IRRIGATION POTENTIAL FROM RENEWABLE GROUNDWATER IN AFRICA CONCLUSION

- A continental-scale distributed map of GWIP has been produced for the first time and map of GWDP is in progress for the first time
- Can we locate and quantify the groundwater irrigation development potential in Africa?
  - Yes, map shows spatial variability across Africa, and even within countries
  - Potential can be particularly significant in some areas (i.e West of Ethiopia, Sofala region in Mozambique, South-West of Western Africa, stripe between Tanzania/Kenya to Angola, …)
  - There is significant potential in Central Africa but it might be largely irrelevant
  - The potential is particularly significant and relevant in the semi-arid Sahel and East African corridor, especially for small-scale and smallholder irrigation, with huge poverty alleviation potential
  - Climate change might affect GW recharge and increase crop water demand
  - Actual potential will be greatly influenced by irrigation efficiency and crop choices

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# MAPPING IRRIGATION POTENTIAL FROM RENEWABLE GROUNDWATER IN AFRICA – A DEVELOPMENT PERSPERCTIVE


**Thank You**

**Merci**


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# MAPPING IRRIGATION POTENTIAL FROM RENEWABLE GROUNDWATER IN AFRICA REFERENCES


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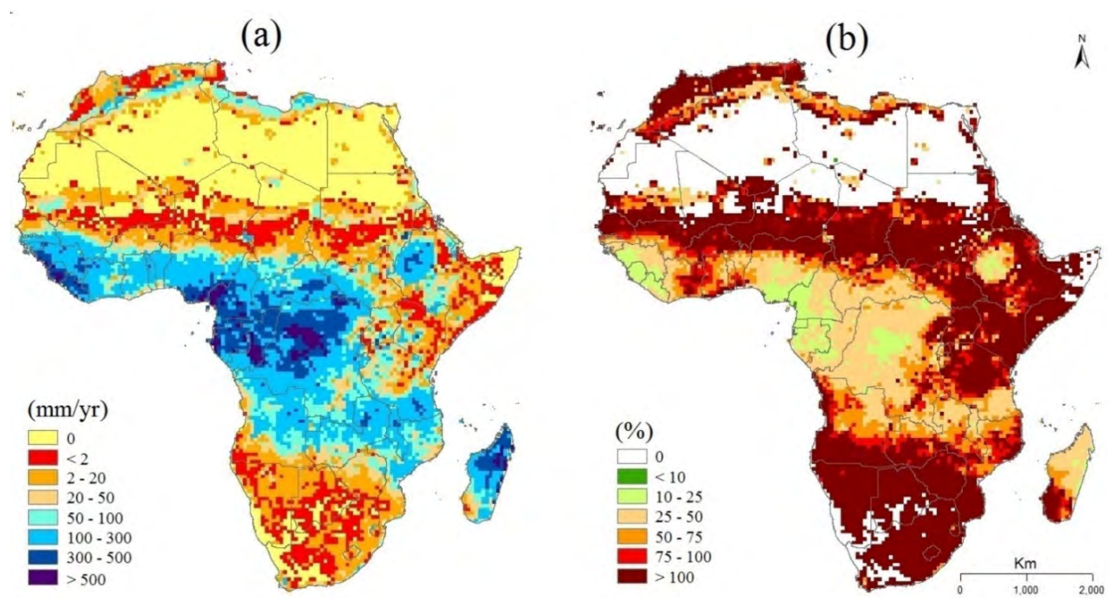
# MAPPING IRRIGATION POTENTIAL FROM RENEWABLE GROUNDWATER IN AFRICA GWIP - DISCUSSION

- Recharge uncertainty

| Country | Recharge (mm/yr) | | |
|---|---|---|---|
| | FAO, AQUAStat, 2009 | Döll and Fiedler, 2008 | This study |
| Burkina Faso | 34.6 | 39 | 39 |
| Ethiopia | 18.1 | 39 | 80 |
| Ghana | 110.3 | 105 | 127 |
| Kenya | 6.0 | 46 | 29 |
| Malawi | 21.1 | 164 | 170 |
| Mali | 16.1 | 22 | 23 |
| Mozambique | 21.3 | 104 | 82 |
| Niger | 2.0 | 12 | 4 |
| Nigeria | 94.2 | 163 | 154 |
| Rwanda | 265.8 | 68 | 78 |
| Tanzania | 31.7 | 93 | 90 |
| Uganda | 122.9 | 95 | 50 |
| Zambia | 62.4 | 108 | 117 |

- Recharge variability




**(a)** Average annual recharge (mm/year), and **(b)** its coefficient of variation (%), both over the period 1960-2000 (data from Wada et al., 2011)

# MAPPING IRRIGATION POTENTIAL FROM RENEWABLE GROUNDWATER IN AFRICA GWIP - DISCUSSION



- Recharge
  - Uncertainty
  - Variability

- Groundwater available
  - 3 scenarios (in km3 year-1)

| Scenario 1 | | | Scenario 2 | | | Scenario 3 | | |
|---|---|---|---|---|---|---|---|---|
| Min. | Average | Max. | Min. | Average | Max. | Min. | Average | Max. |
| 442.2 | 692.1 | 990.1 | 751.1 | 1168.3 | 1664.9 | 1006.1 | 1644.5 | 2339.7 |

- Limitations of approach
  - Non-limiting condition for other fundamental physical properties (e.g. soil, water quality, terrain slope, groundwater accessibility, …)
  - Socio-economics constraints (e.g. investment capacity, infrastructure, …)
  - Groundwater irrigation potential for 2000
  - No consideration of climate change and population/livestock growth, change in cropping pattern, improvement in irrigation efficiency