Mapping Irrigation potential from renewable groundwater in Africa
A quantitative hydrological approach

- **Background**
  - Huge GW volume in Africa (MacDonald et al, 2012) but not all available for abstraction, and unevenly distributed
  - 5.5% of cultivated land is equipped for irrigation and GW for irrigation only contributes to 18.5 % of the total area equipped for irrigation (Siebert et al., 2010)
    to compare with Asia which has similar climate and where 37 % of the croplands are irrigated (GW contributes to 38% of the total area equipped for irrigation
  - Groundwater provides an important buffer to climate variability and change
- **Questions:**
  - Where is GW irrigation potential in Africa?
  - How many cropland GW can irrigate?
- **Objective**
  - estimate the cropland area that GW can irrigate in Africa in a sustainable way
    (using Pavelic' et al.'s water balance approach)
- **Some assumptions**
  - GW is the only water source for irrigation (no conjunctive use with SW)
  - GW is usable (no quality or yield issue)
  - GW is accessible (no economic issue)

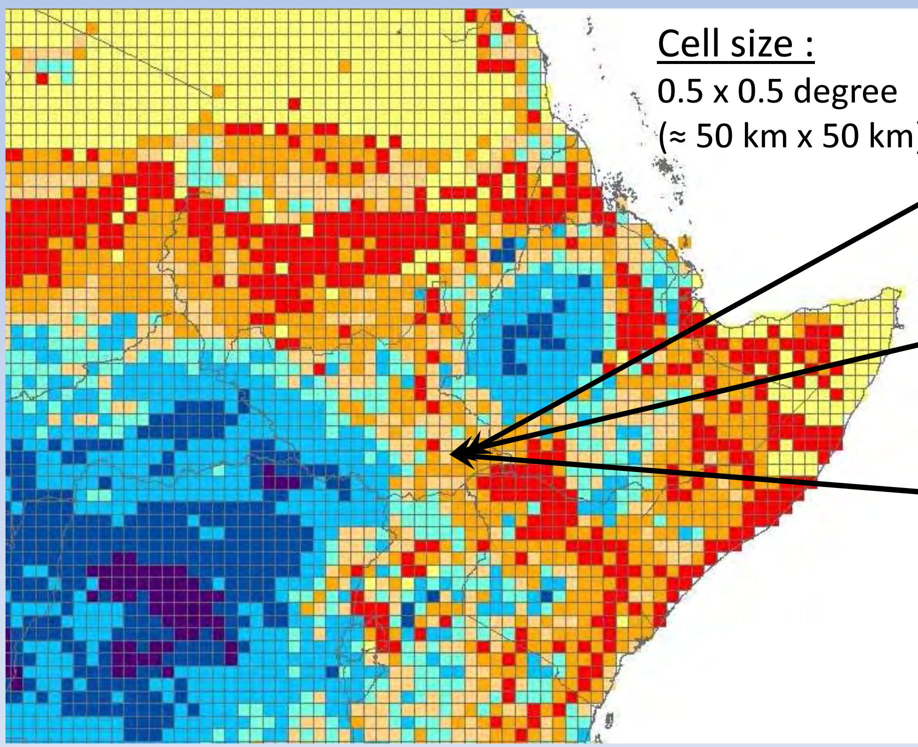
Methodology

$$\text{Area of cropland irrigable } (m^2) = \frac{\text{GW available} (m^3/yr)}{\text{Irrig. Water Demand } (m/yr)}$$

GW available = recharge – human GW demand – environmental GW req.

$$\textbf{Irrig. Water Demand} = \frac{\sum_{i=1}^{n}\left([\text{Crop Water demand}]_i \text{ x } [\text{\% of Area}]_i \right) - \text{Green water})}{\text{Irrig.Efficiency}}$$

n = crop types



- Hydrological data
  - Recharge
  - Water available for crop from rain (green water)
- Other GW uses
  - human activities
    (domestic, livestock, industrial)
  - environment
- Crop data
  - Surface of cropland
  - Crop distribution
  - Crop water need
  - Irrigation efficiency

➡ **Different geographical data compiled in GIS**

Methodology

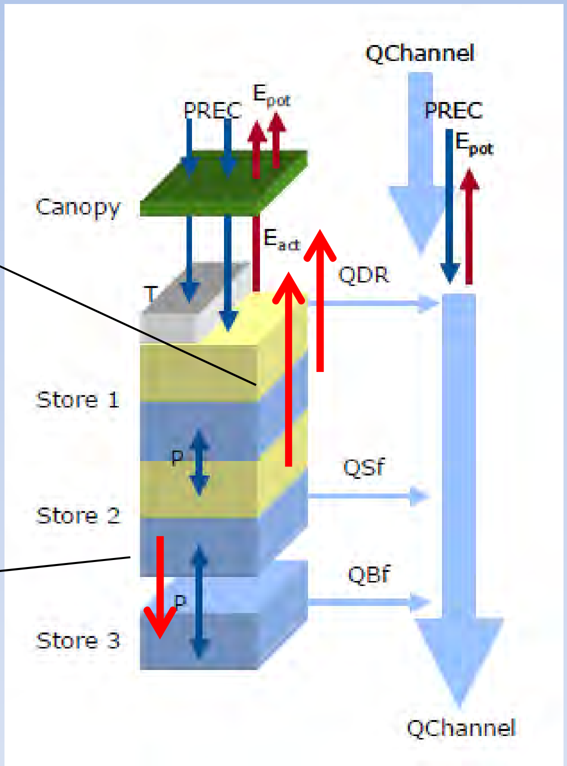
Hydrological data

from the PCR-GLOBWB model (Utrecht University, the Netherlands, Wada et al.)

- Leaky bucket type of model applied on cell by cell basing
- cell size of 0.5 x 0.5 degree ≈ 50 x 50 km
- Daily step time
- Data from 1960 to 2001 (41 years)

Green water (monthly value)
= Transpiration from soil 1
+ Transpiration from soil 2

Recharge (annual value)



QDR = Direct Runoff
QSf = Interflow
QBf = baseflow
Store 1 = soil 1 (0 – 0.3 m deep)
Store 2 = soil 2 (0.3 – 1.2 m deep)
Store 3 = GW storage

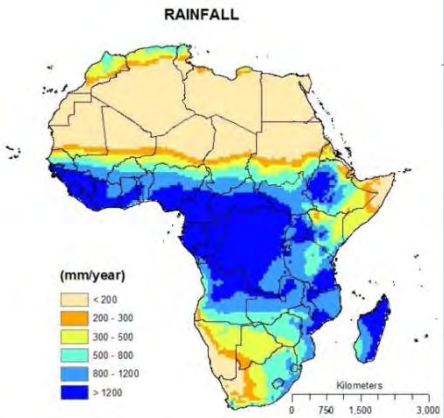
Methodology

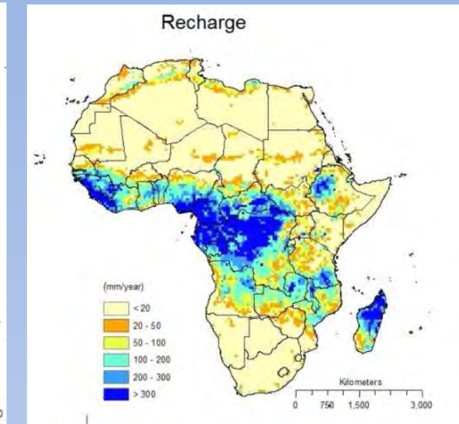
Other GW uses

- *human activities from FAO (geonetwork)*
  - Domestic water need:
    - Density of population x cell area
    - 50 l per day per inhabitant
    - 75% of domestic water need satisfied by groundwater
  - Industrial water need :
    - 50% of domestic water
  - Livestock water need
    - Density of livestock (big ruminant, small ruminant, pig and poultry) x cell area
    - Big ruminant = 40 l/day Small ruminant = 20 l/day
    - pig= 30 l/day Poultry = 0.2 l/day

- *Environmental water need*

  3 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



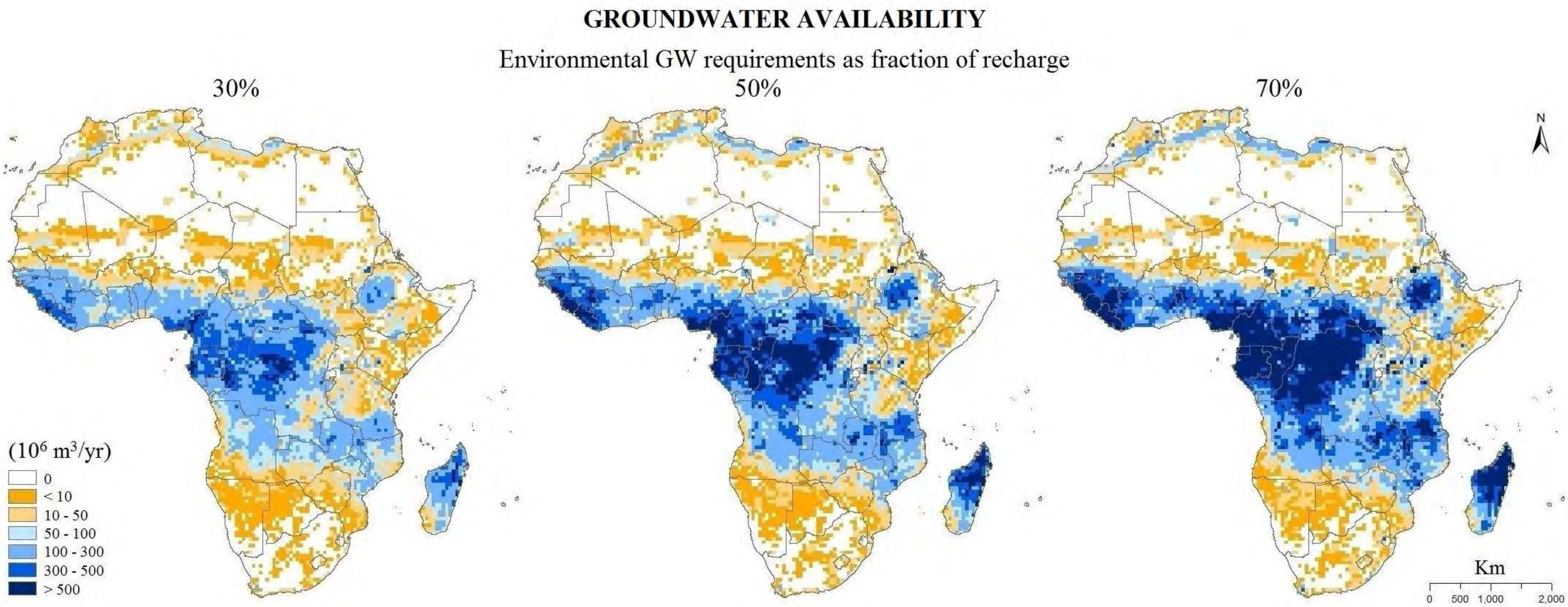


Groundwater Availability

(yearly calculations then average)

GW available = recharge
– human activity water need
– environmental water need

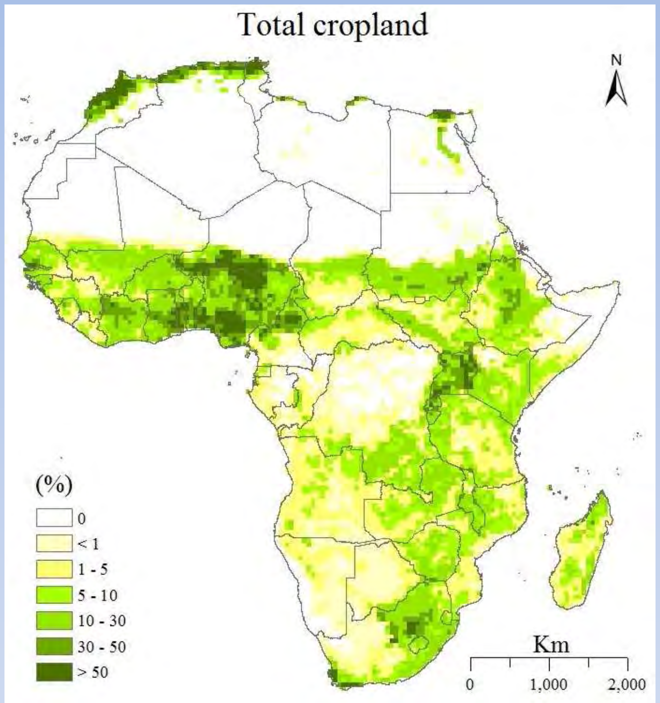
From 692 to 1644 km^3 available for irrigation per year



Methodology

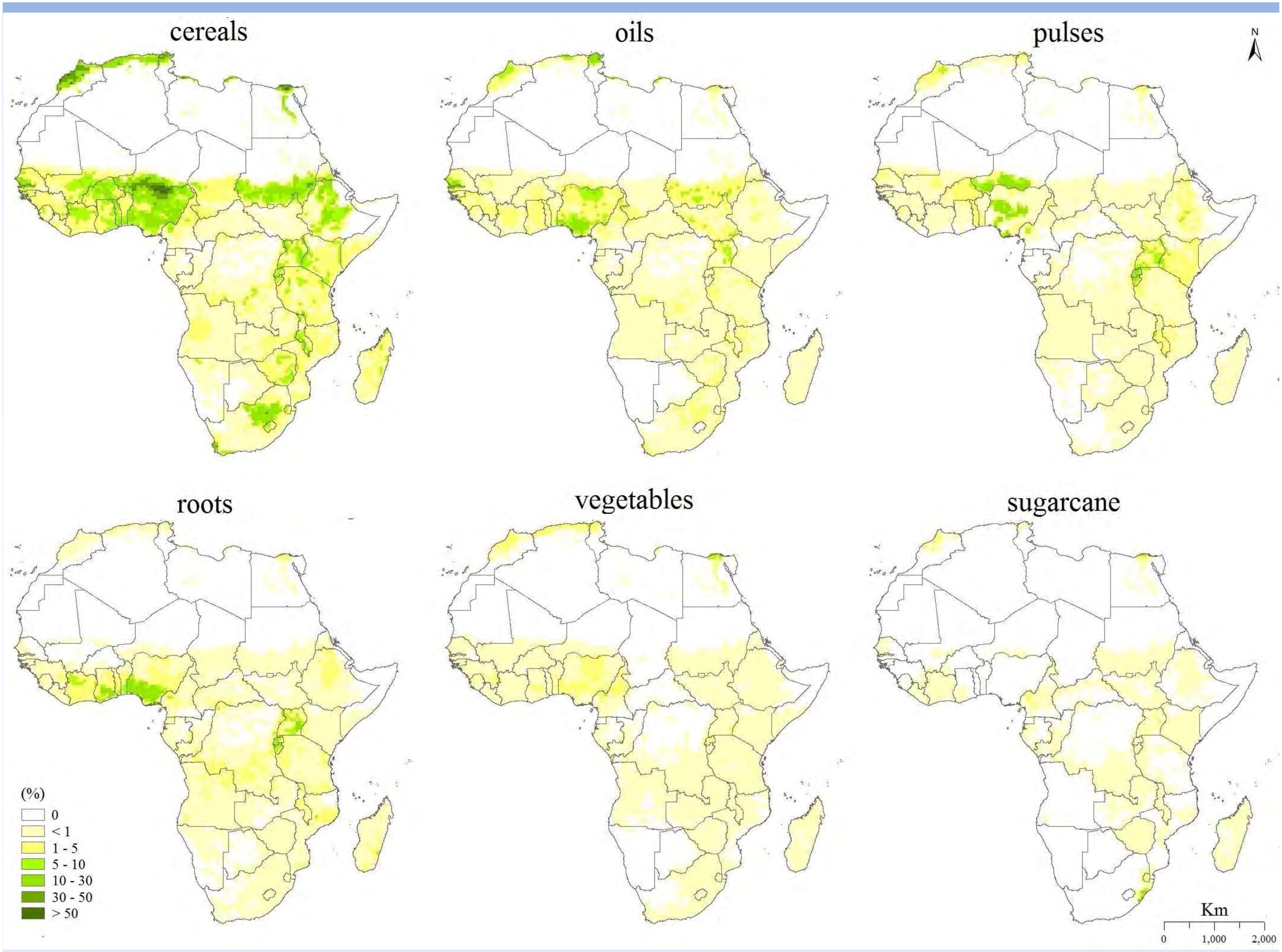
Crop data

- *Surface of cropland - Crop distribution from Center for Sustainability and the Global Environment (SAGE), University of Wisconsin, Madison, Wisconsin, USA*
  - World map
  - Cell: 5 minutes
  - 11 major crops
  - Geographic crop distribution for the year 2000



- *Crop water need from compiled FAO database (Crop calendar, Irrigation and drainage paper 56, Irrigation Water Management Training manuel 3, irrigation pattern)*

→ Monthly crop water need calendar for 6 crop types


cereals
oils
pulses
N
roots
vegetables
sugarcane
(%)
0
< 1
1 - 5
5 - 10
10 - 30
30 - 50
> 50
Km
0
1,000
2,000

Methodology

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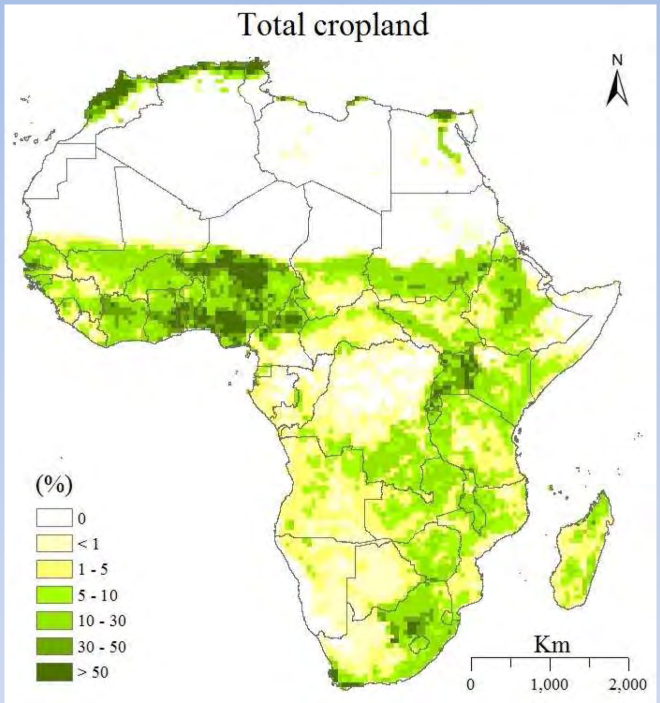

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Methodology

Monthly crop water demand based on

- Theoretical crop water need
- Length of crop growing stage (initial, development, mid-season, end)
- Single crop coefficient ($Kc_{initial}$, $Kc_{development}$, $Kc_{mid\text{-}season}$, Kc_{end})

  Example: millet

  - Theoretical water need: 650 mm

Growing stage	initial	development	mid-season	end
Growing length (days)	20	30	55	35
Crop coefficient	0.35	0.7	1.1	0.7

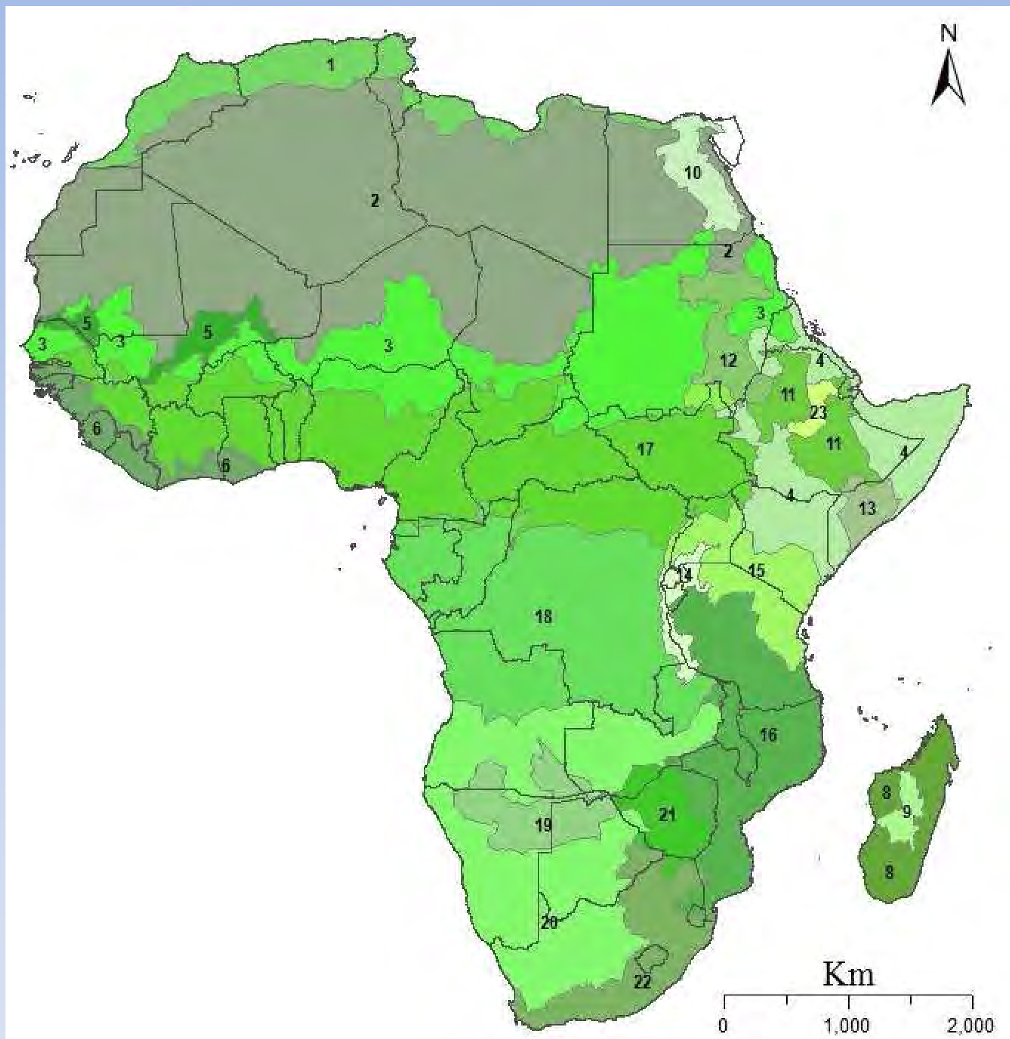
  - Calculation of monthly need

month	1	2	3	4	5
Water need (mm)	135	155	140	135	85

- Planting and harvesting calendar

Methodology

Irrigation cropping pattern zones and irrigation efficiency



Zone code	Zone name	Irrigation Efficiency (%)
1	Mediterranean coastal zone	60
2	Sahara oases	70
3	Semi-arid to arid savannah West-East Africa	50
4	Semi-arid/arid savannah East Africa	50
5	Niger / Senegal rivers	45
6	Gulf of Guinea	50
7	Southern Sudan	50
8	Madagascar tropical lowland	50
9	Madagascar highland	50
10	Egyptian Nile and Delta	80
11	Ethiopian highlands	50
12	Sudanese Nile area	80
13	Shebelli-Juba river area in Somalia	50
14	Rwanda - Burundi - Southern Uganda highland	50
15	Southern Kenya - Northern Tanzania	50
16	Malawi - Mozambique - Southern Tanzania	45
17	West and Central African humid areas	45
18	Central African humid areas below equator	45
19	River affluents on Angola / Namibia / Botswana border	50
20	South Africa - Namibia - Botswana desert & steppe	65
21	Zimbabwe highland	60
22	South Africa - Lesotho - Swaziland	60
23	Awash river area	50

Methodology

Compilation:

Example: zone 15 (en mm)

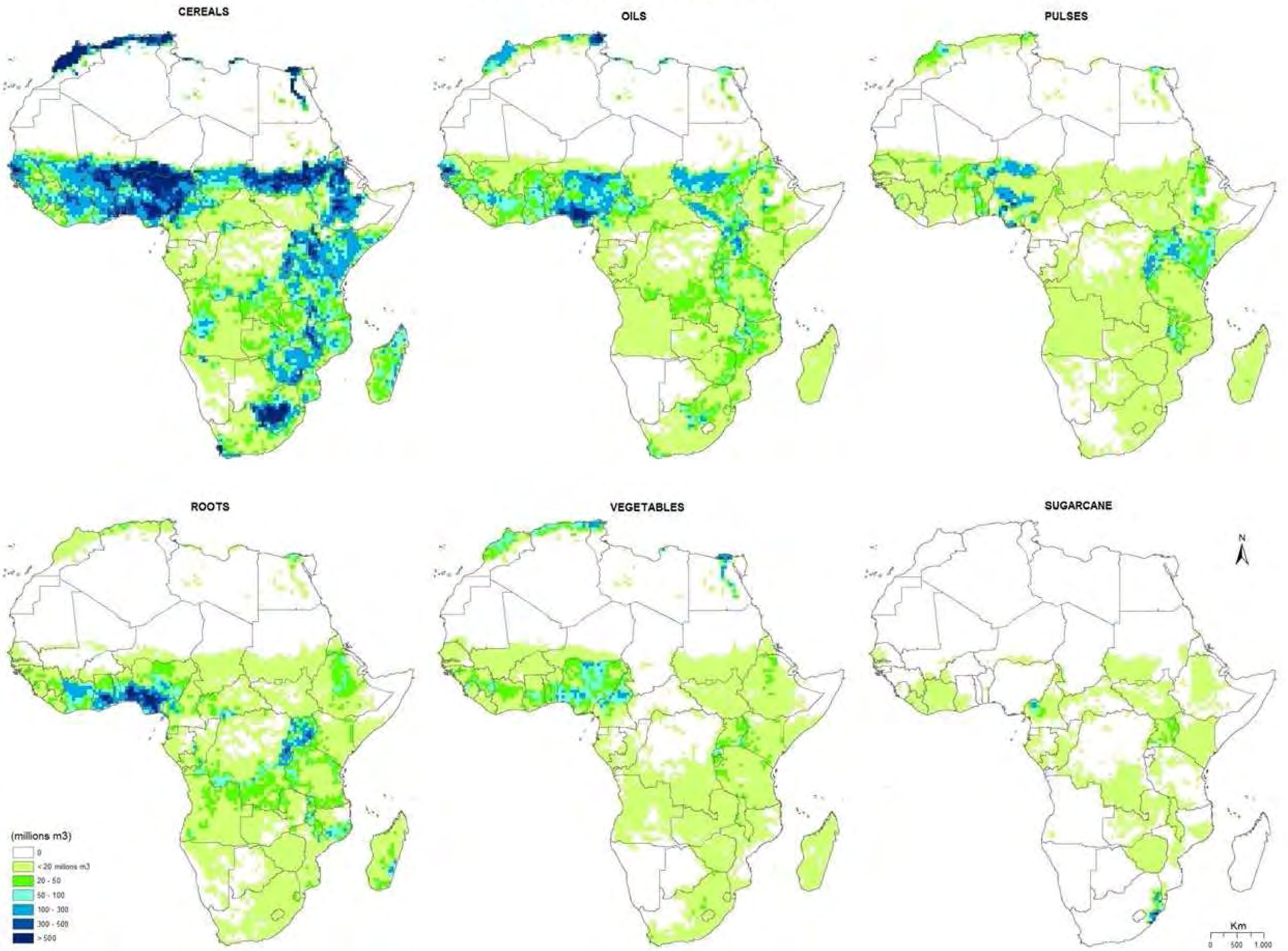
Crop type	Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Cereals	Maize/Rice/Sorghum				175	185	165	150	125	135				935
	Maize/Rice/Sorghum	150	125	135							175	185	165	935
Oil	Sunflower/Groundnut/Soybean	150								150	170	205	210	885
	Sunflower/Groundnut/Soybean			150	170	205	210	150						885
Roots	Potatoes			100	140	150	155	155						700
	Potatoes	155								100	140	150	155	700
Pulses	Bean	60									120	150	165	495
	Bean			120	150	165	60							495
Vegetables	Onion/Tomato/Eggplant/Cucumber			115	140	270	260	200						985
	Onion/Tomato/Eggplant								115	140	270	260	200	985
Sugarcane	Sugarcane	185	225	230	135	120	120	120	120	120	150	150	125	1800

$$\textbf{Irrig. Water Demand} = \frac{\sum_{i=1}^{n}(\text{[Crop Water demand]}_i \text{ x } [\text{\% of Area}]_i) \quad - \text{Green water})}{\text{Irrig.Efficiency}}$$

i = crop types

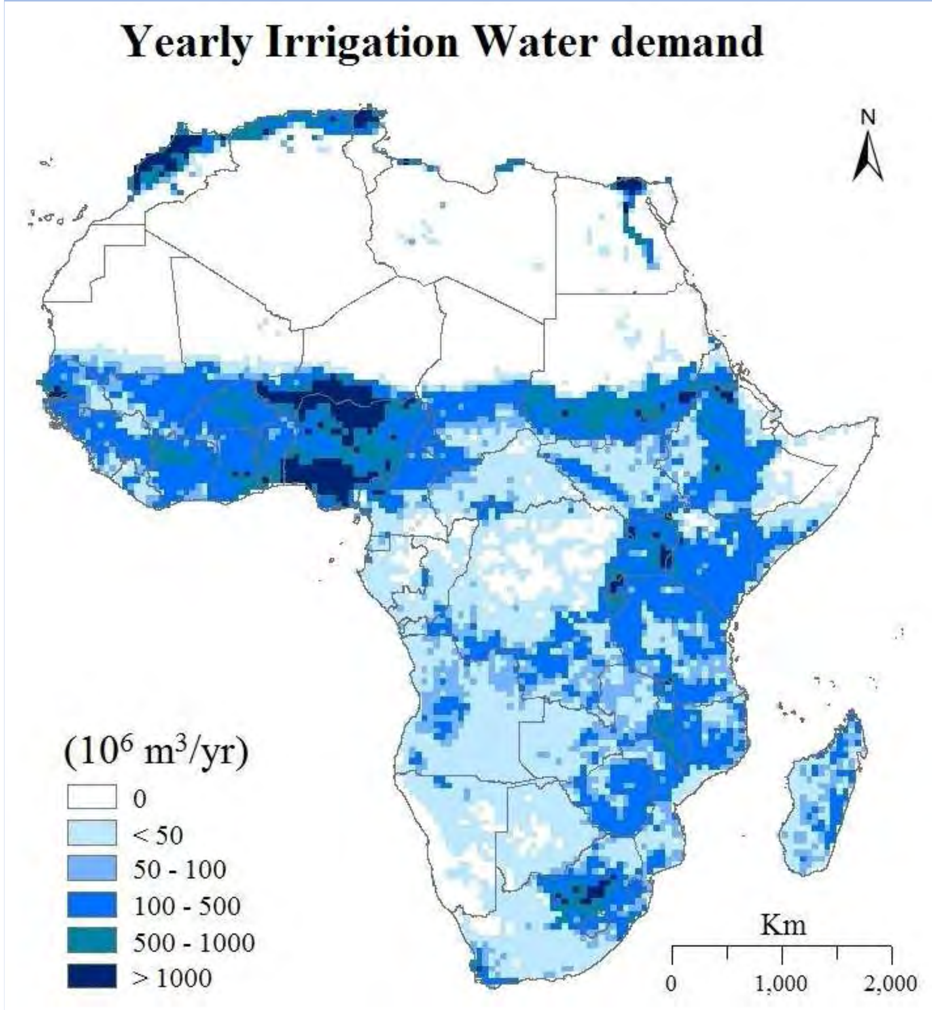
(monthly calculations then sum)

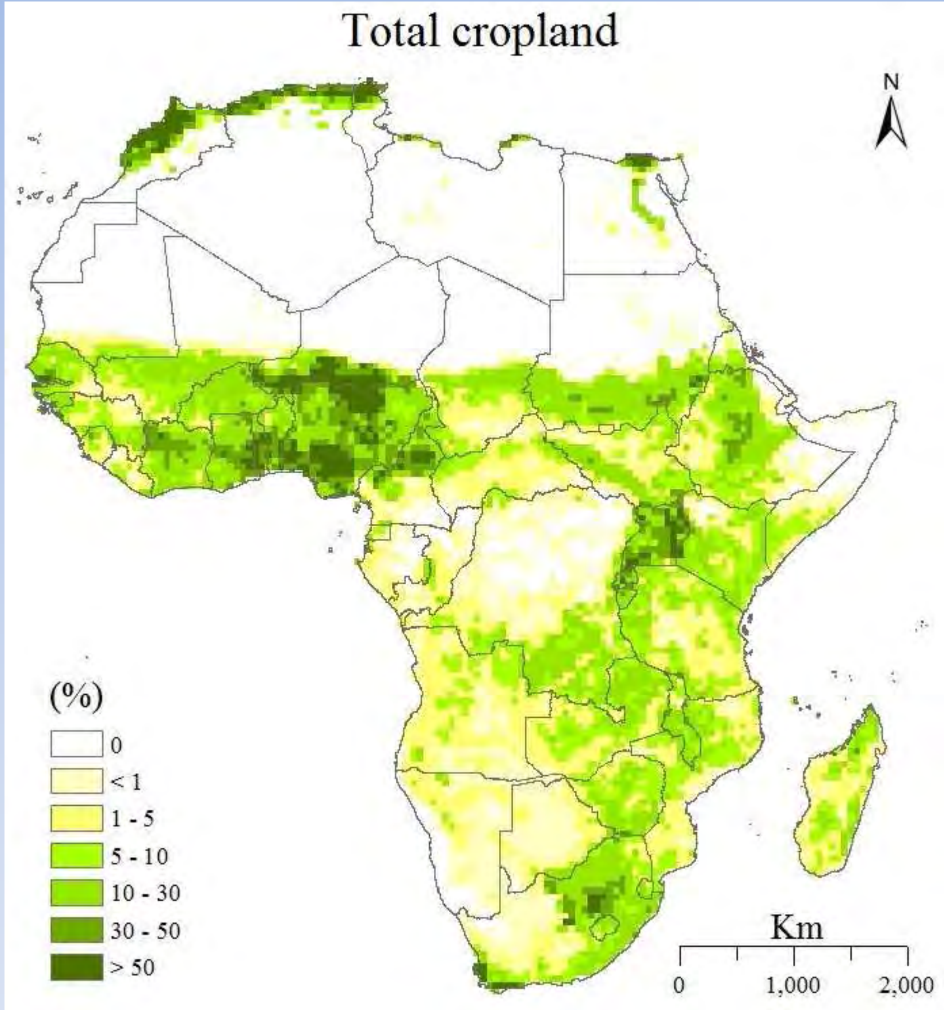
Net Irrigation requirement



Methodology

<u>Net Irrigation Water demand</u>

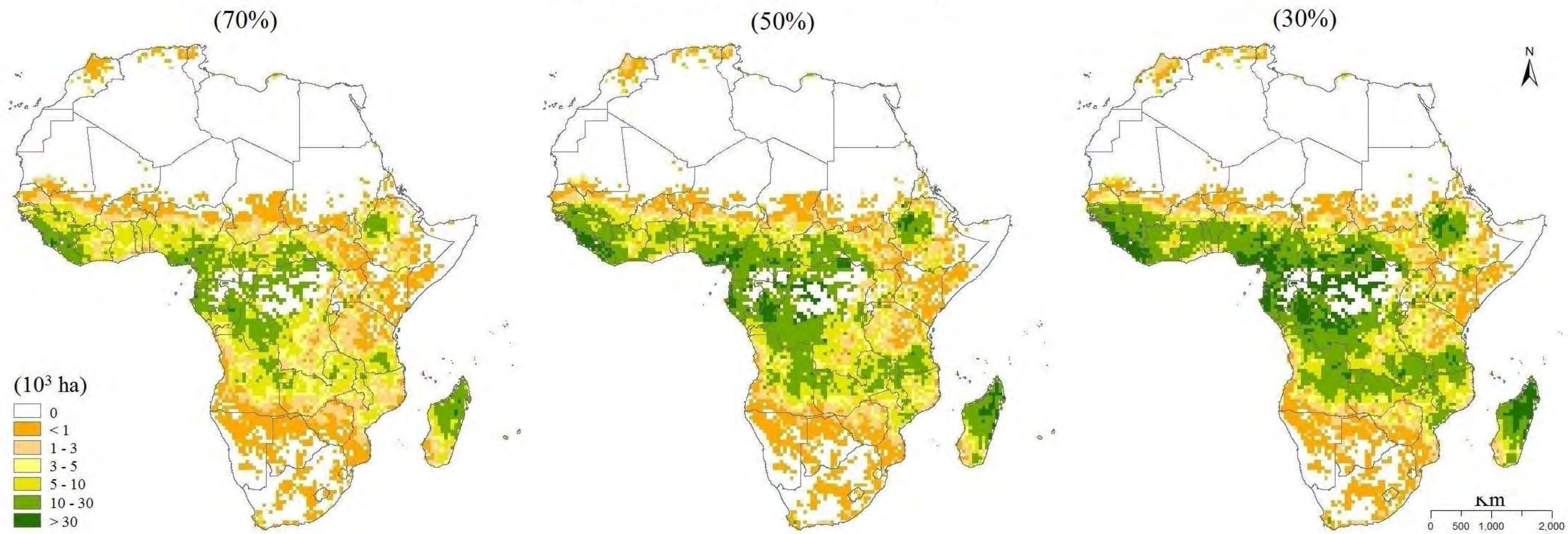




Results

$$\text{Area of cropland irrigable } (m^2) = \frac{\text{GW available}(m^3/yr)}{\text{Irrig. Water Demand } (m/yr)}$$

Total Area Irrigable with Renewable Groundwater
(fraction of recharge to environment)

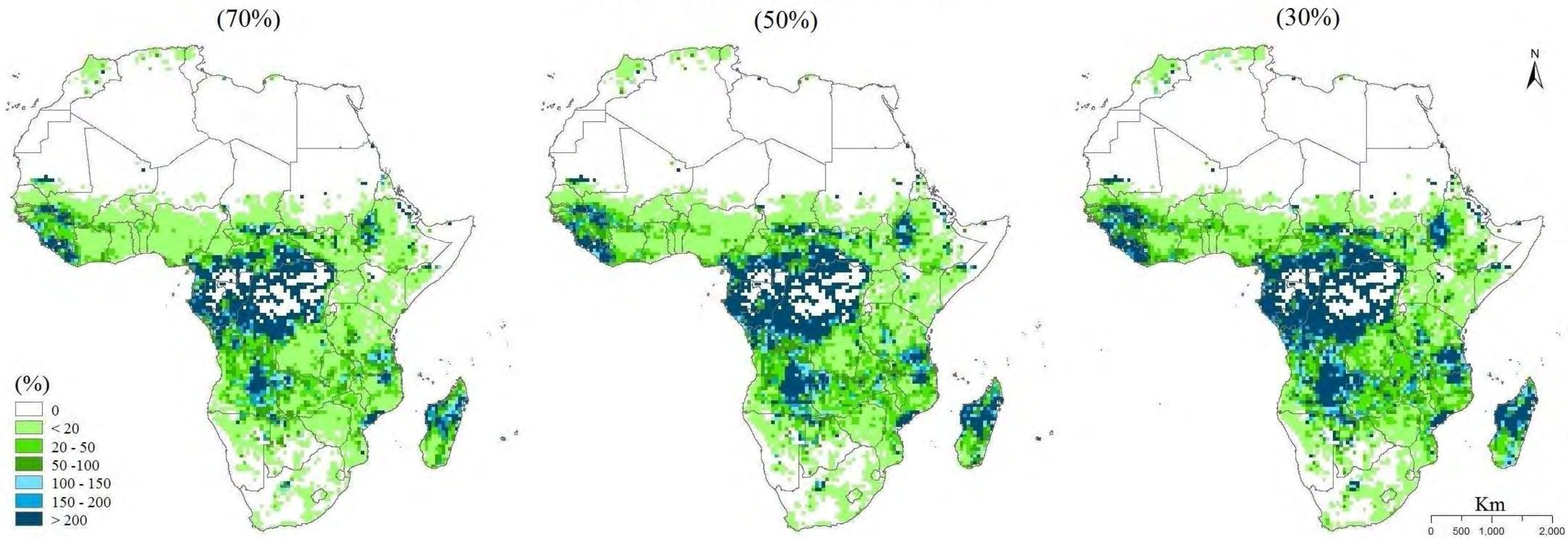


Results

AFRICA	Environmental requirements represent		
	30% of recharge	50% of recharge	70% of recharge
Area (millions ha)	64.3	45.7	27.2
% of cropland	29.6%	21.0%	12.5%

Total Area Irrigable with Renewable Groundwater

(fraction of recharge to environment)



Results in SADC region

Cropland area

	Area (thousand ha)	
	From this study	From SADC statistics yearbook (2008)
Total land	977 210	964 614
Total cropland	52 362	52 904

SADC target:
Double cropland under irrigation from 3.5% to 7% as percentage of the total by 2015

GW irrigation potential

	Environmental requirements represent		
	30% of recharge	50% of recharge	70% of recharge
Area (x 1000 ha)	30 084	21 429	12 779
% of cropland	57%	41%	24%

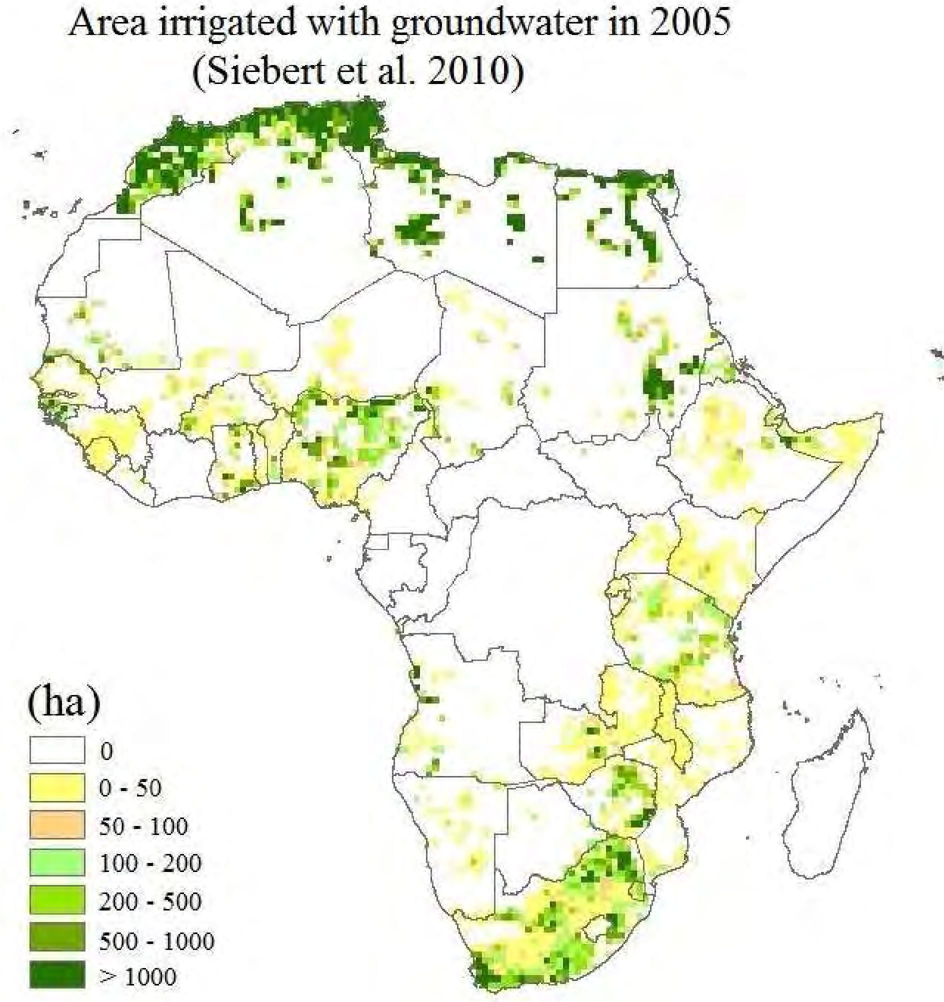
Results

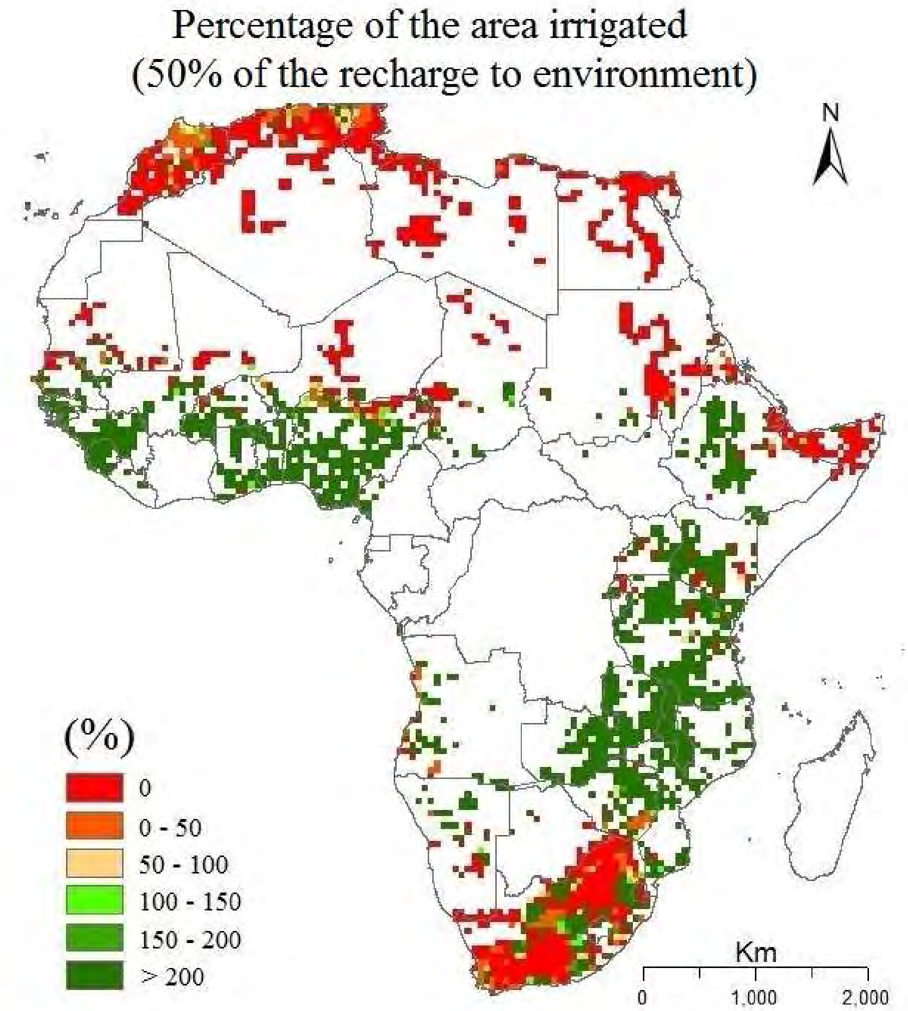
Comparison with Pavelic et al. (2013)

	Irrigable land with GW (Mha) from this study			Irrigable land with GW (Mha) from Pavelic et al. (2013)		
	Proportion of GW recharge to environment			Proportion of GW recharge to environment		
	30%	50%	70%	30%	50%	70%
Burkina Fasso	0.330	0.232	0.133	0.599	0.409	0.219
Ethiopia	3.161	2.233	1.306	1.114	0.714	0.314
Ghana	0.930	0.659	0.388	1.788	1.262	0.736
Kenya	0.447	0.310	0.173	0.121	0.051	-0.019
Malawi	0.511	0.363	0.214	0.136	0.086	0.036
Mali	0.784	0.556	0.329	1.338	0.938	0.538
Mozambique	1.764	1.256	0.748	1.133	0.793	0.453
Niger	0.032	0.020	0.010	0.110	0.060	0.010
Nigeria	4.281	3.023	1.766	5.678	3.938	2.198
Rwanda	0.073	0.050	0.028	0.463	0.323	0.183
Tanzania	2.390	1.696	1.003	1.969	1.369	0.769
Uganda	0.440	0.308	0.175	1.935	1.355	0.775
Zambia	2.976	2.122	1.268	3.257	2.317	1.377
TOTAL	**18.119**	**12.828**	**7.541**	**19.641**	**13.615**	**7.589**

Results

<u>Comparison with GW irrigated cropland in 2005</u>





Discussion

Recharge

- Uncertainty
- Variability

Groundwater Environmental Requirement

- 3 scenarios

Scenario 1			Scenario 2			Scenario 3		
Min.	Average	Max.[a]	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

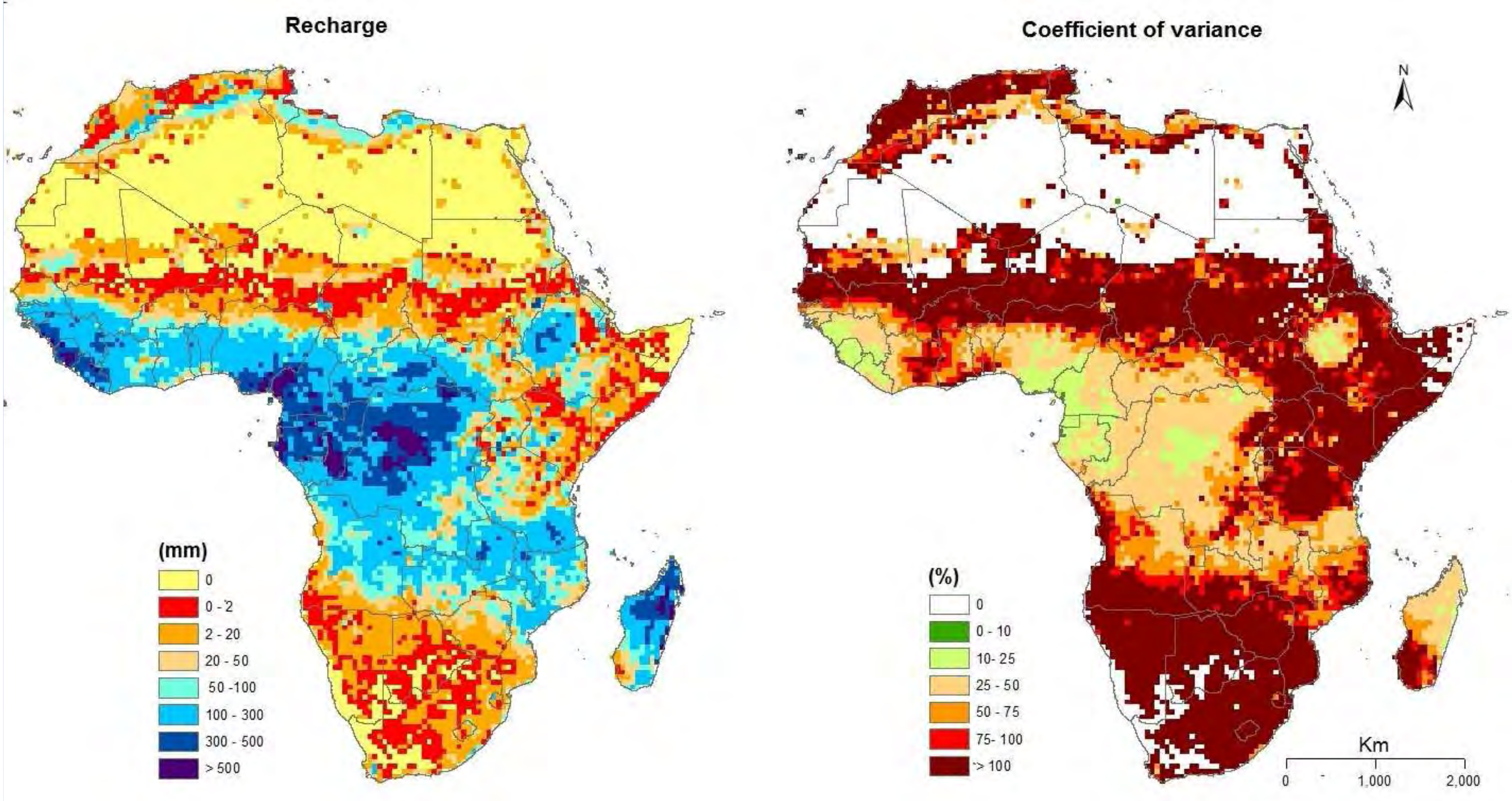
Discussion

Recharge uncertainty

Country	Recharge (mm/yr)		
	FAO, AQUAStat, 2009	Döll and Fiedler, 2008	This paper
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

Discussion

Recharge variability (1960 – 2000)



Discussion

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Conclusion

- **Is there potential for irrigation with groundwater?**
  - Yes, there is

- **BUT**
  - A continental scale study brings uncertainty at local scale
  - Is the best area with important GW irrigation potential the area where GW is needed?
  - Climate change might reduce GW recharge and increase crop water need
  - GW irrigation development is not only constrained by quantitative aspect (i.e. technical, social, policy and economic factor)
  - No guarantee on success of groundwater irrigation scheme (Mutiro and Lautze, 2013)
  - Study based on assumptions
    - Conjunctive use with surface water might increase the GW irrigation potential
    - GW quality and yield limit GW uses

→ **Need to improve results**

Thank You
Merci

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