

# Large scale Groundwater Assessments in Context of the Global Water-Food-Climate- Environment Nexus

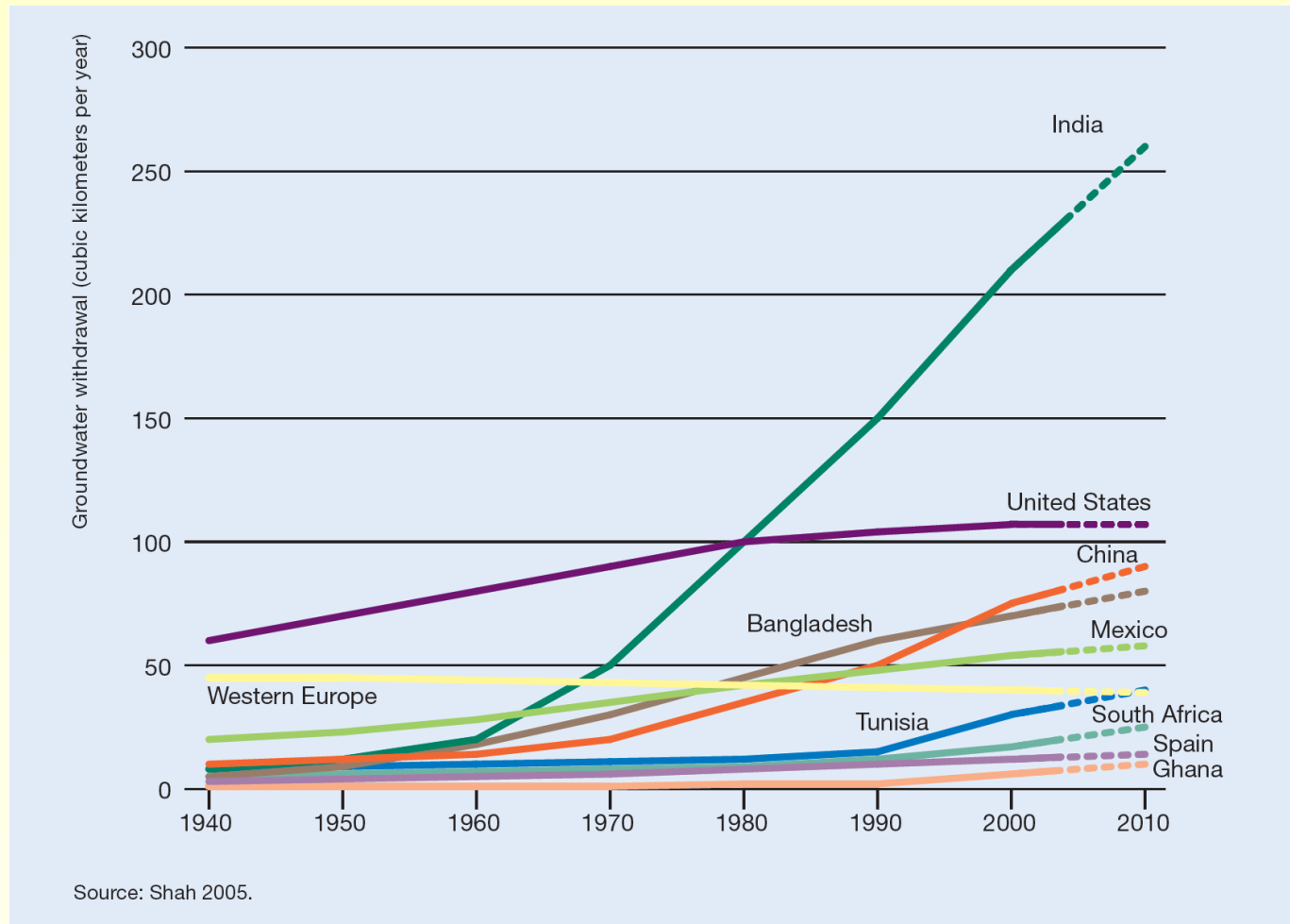
**Karen G. Villholth**

*Principal Researcher and  
Sub-Theme Leader  
IWMI, South Africa*

# Outline

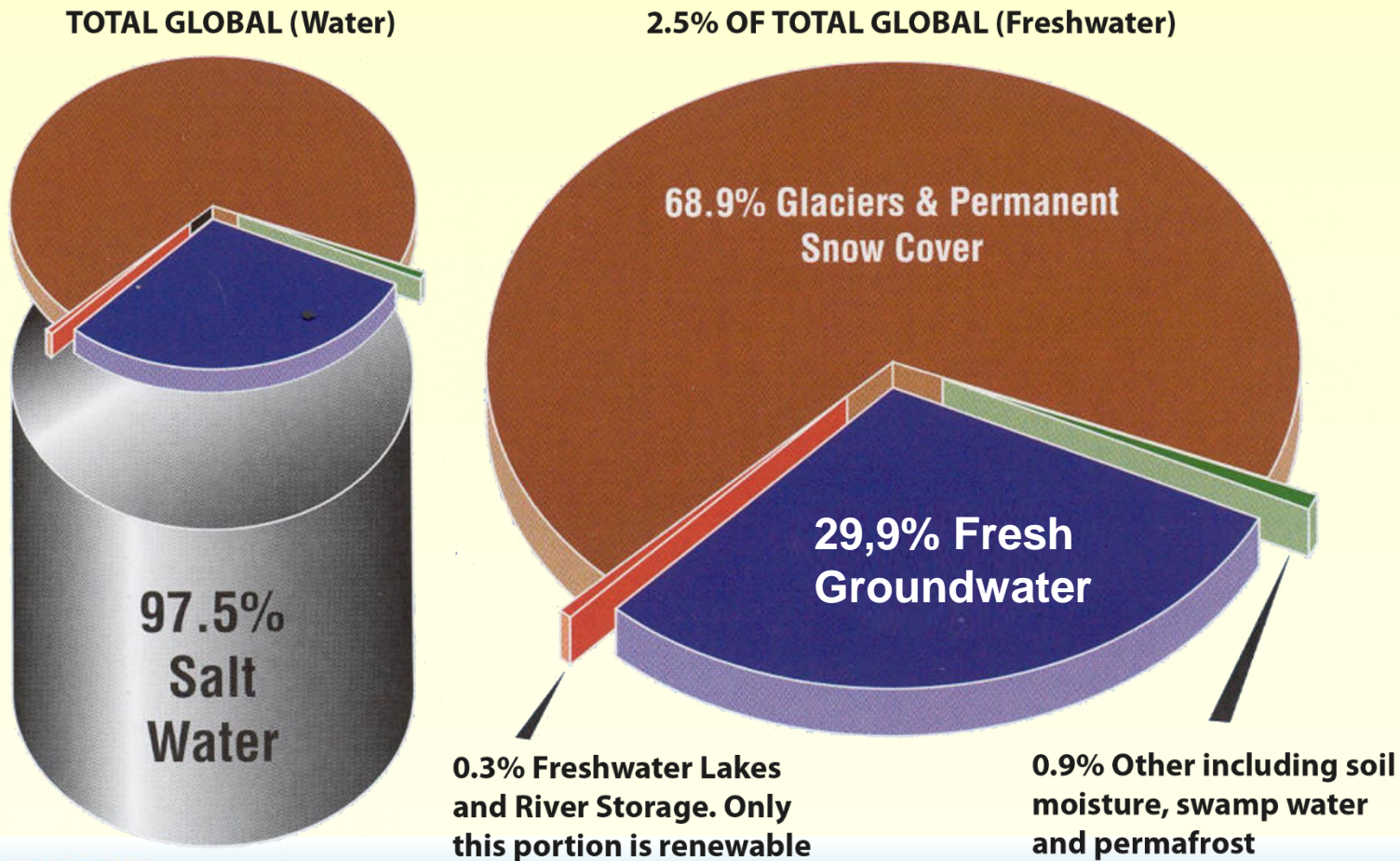
- Bringing groundwater into global debate, why?
- Groundwater as a unique system
- Challenges in global dynamic GW modelling
- Groundwater in the global water-food-climate-environment nexus, examples

# Groundwater development is unprecedented

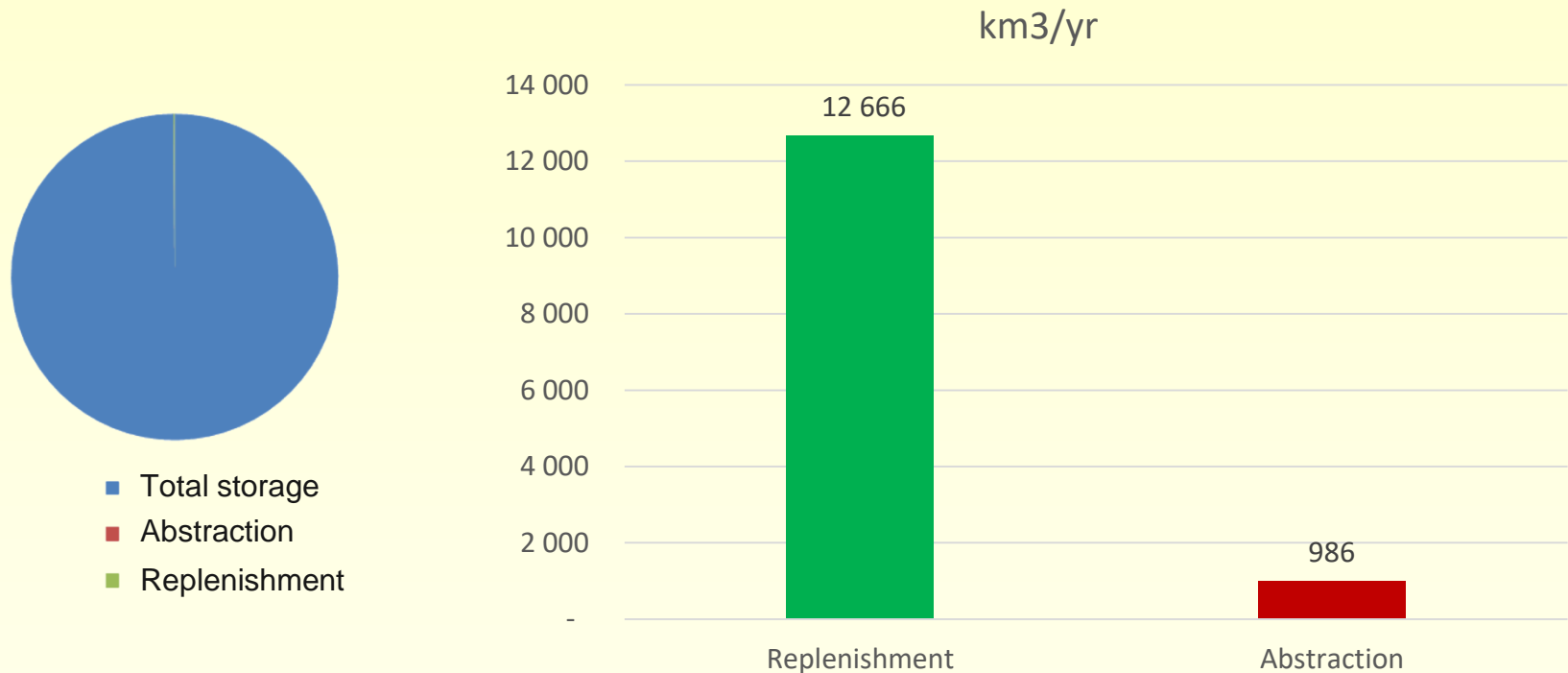




# How much groundwater is there?



# Renewable fresh groundwater resources

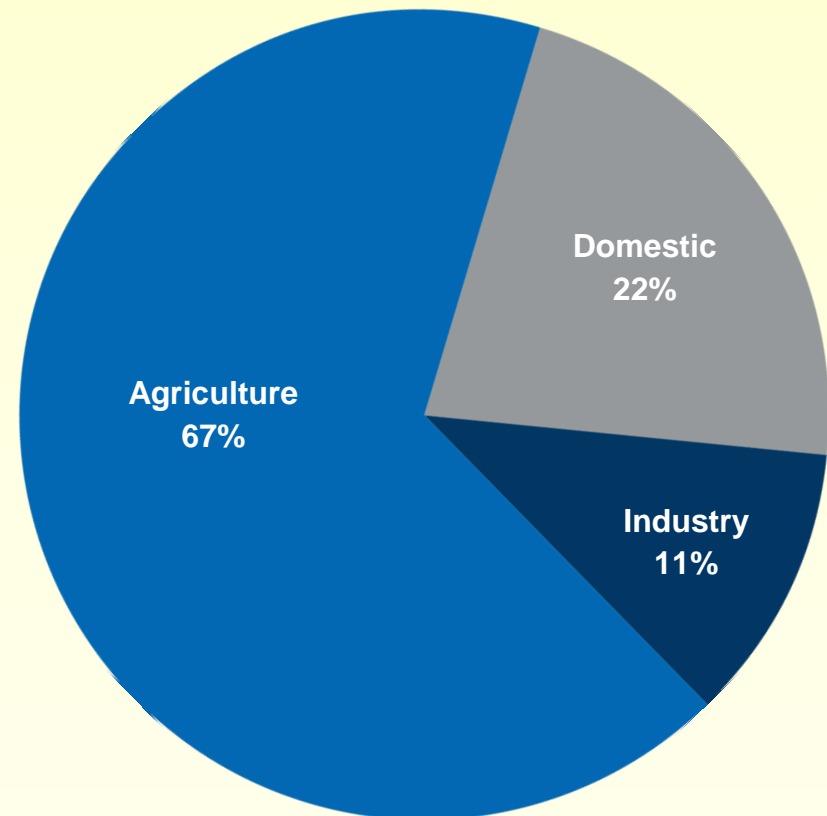


van der Gun (2012)

# Agriculture is the largest groundwater user



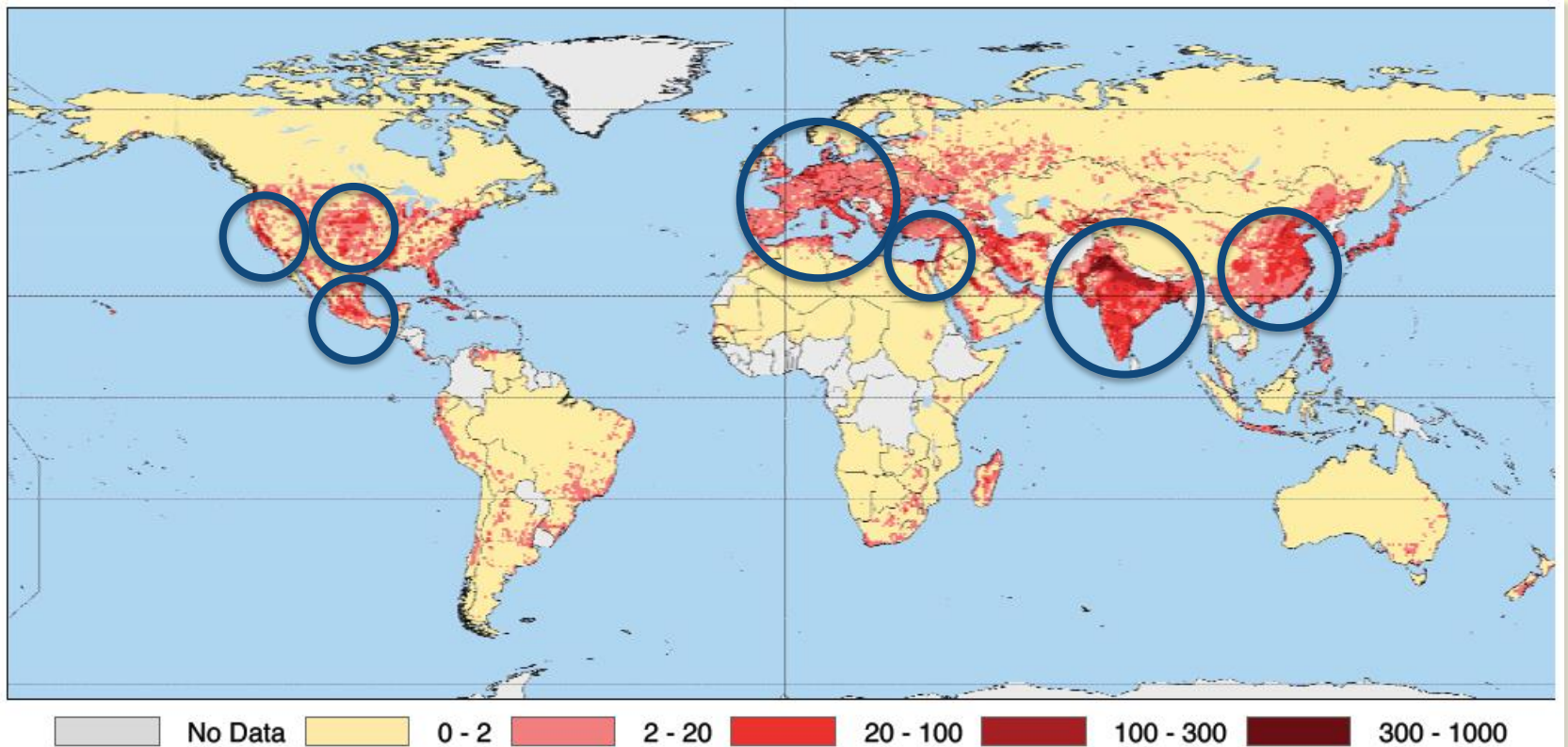
**Globally**



van der Gun (2012)

Photo: David Bricker/Wikimedia/IWMI

# Global groundwater abstraction

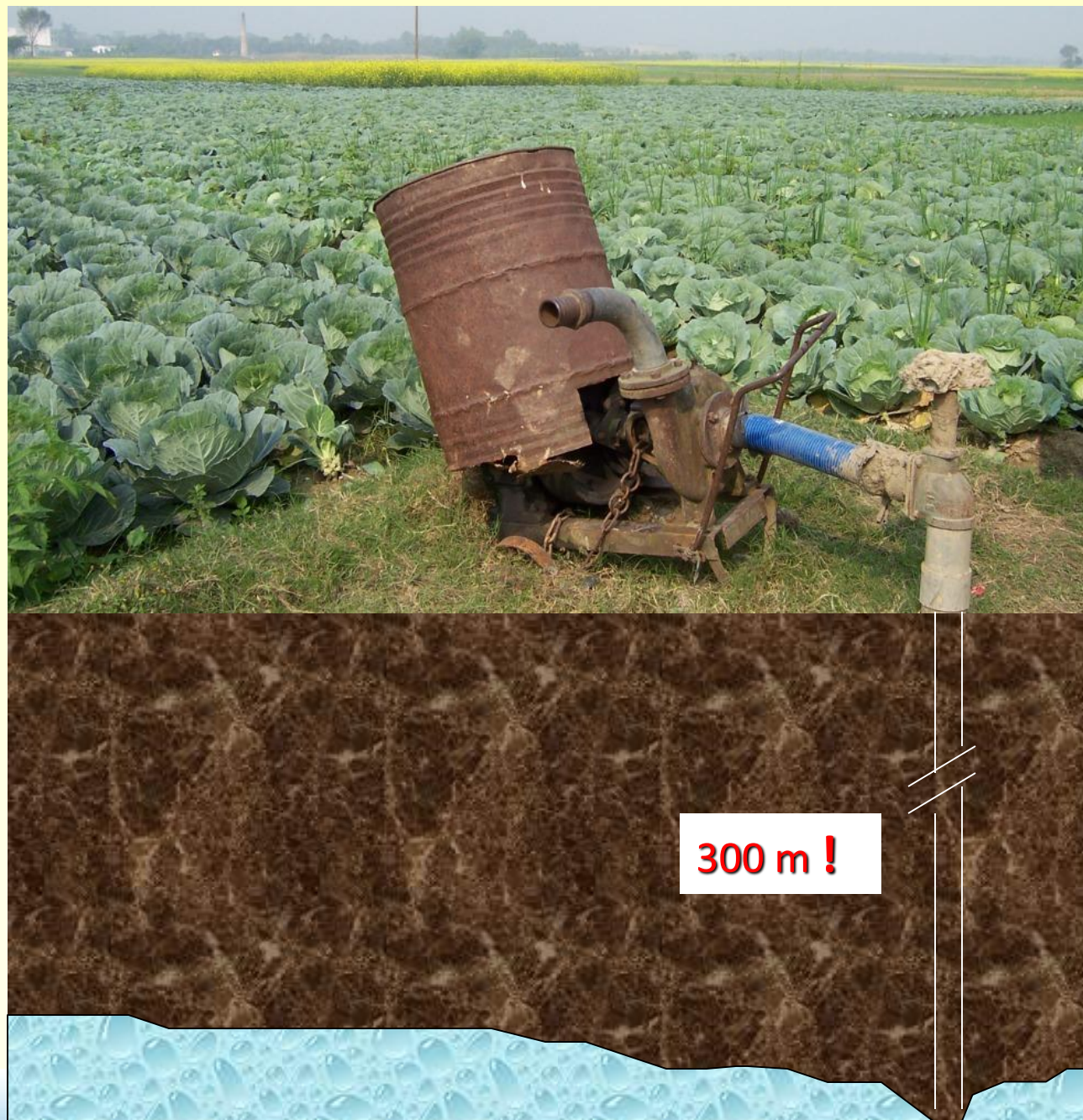


Source: Wada et al. 2010. ©2010 American Geophysical Union. Reproduced by permission of the American Geophysical Union.

Unit: mm/yr in  $0.5^\circ \times 0.5^\circ$  grid cells



# The hidden drought





# When GW depletion is felt

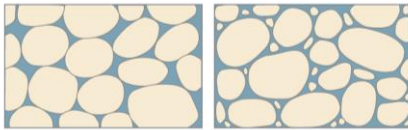


# Groundwater typically neglected

- Groundwater is invisible
- Groundwater is developed incrementally
- Groundwater difficult to manage

# Spatial scale

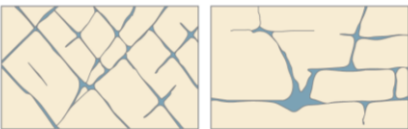
## porosity in granular rocks



High porosity unconsolidated sand or gravel

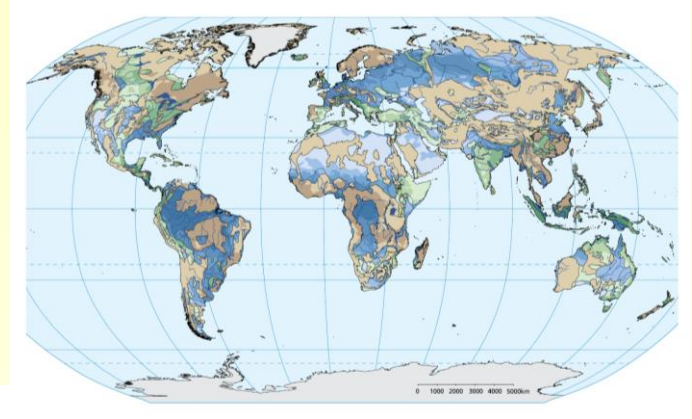
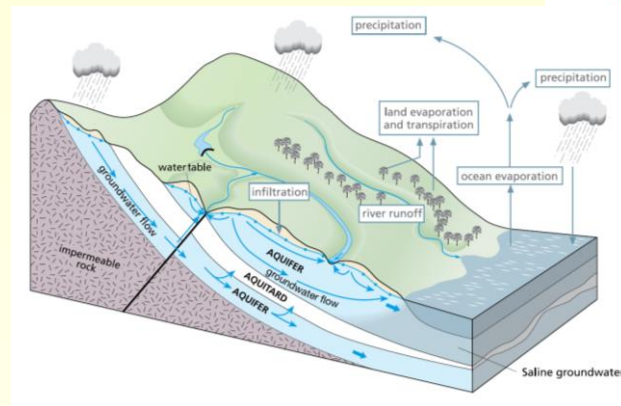
Porosity reduced by cementation or the presence of clays and silts

## porosity in fractured rocks



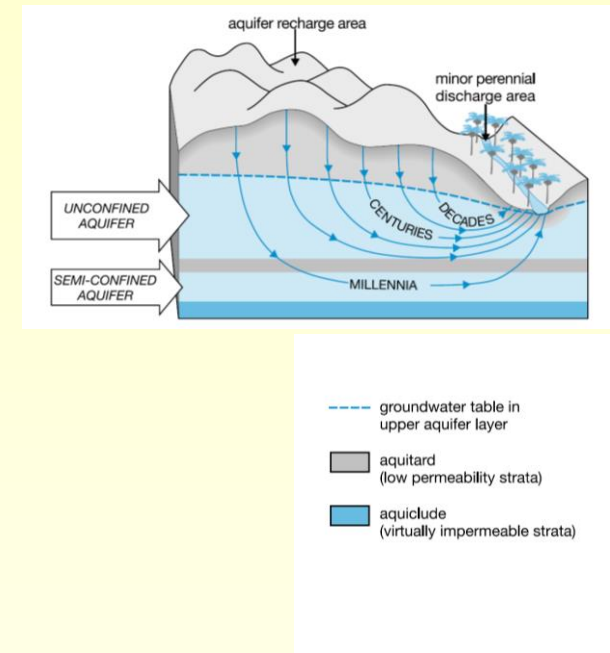
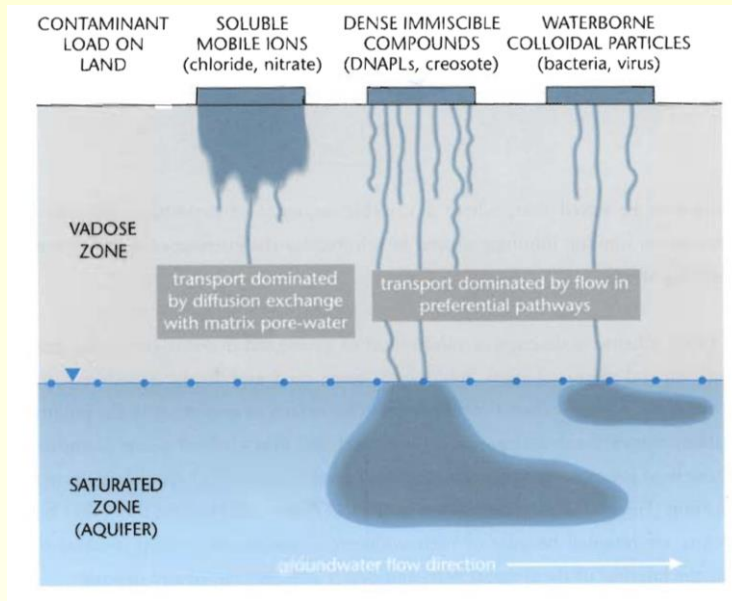
Consolidated crystalline rock rendered porous by the presence of fractures (e.g. crystalline basement)

Consolidated fractured rock with porosity increased by dissolution (e.g. limestones)

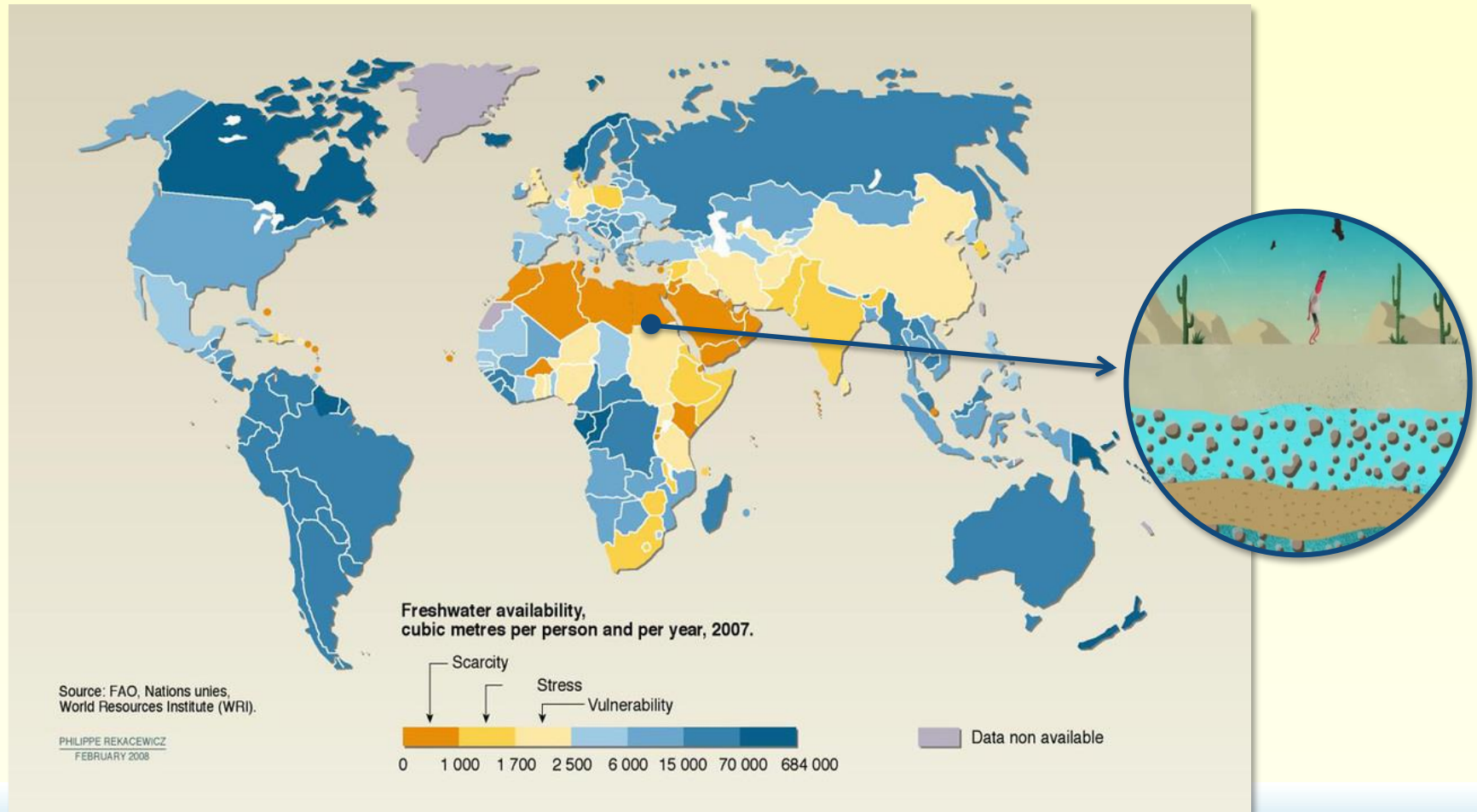




# Temporal scale



# Global freshwater availability



# Challenges in Global Dynamic GW modelling

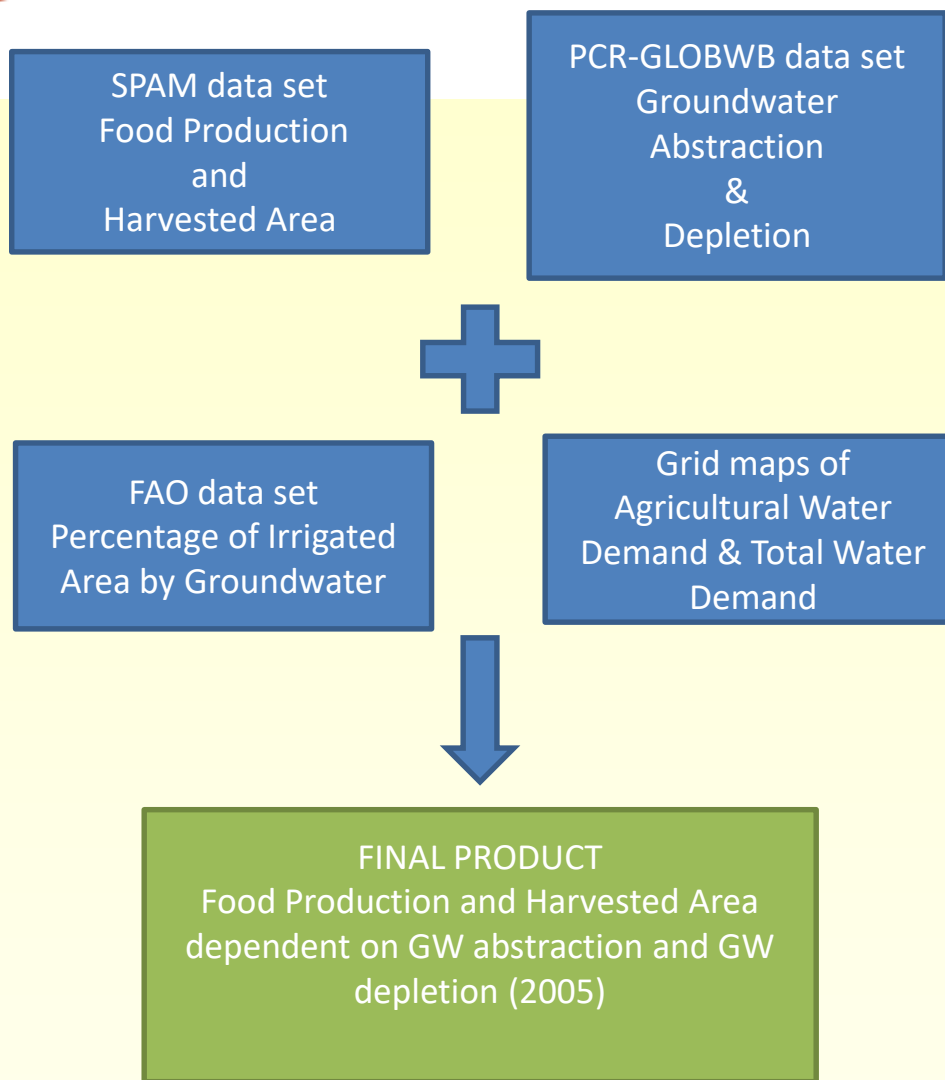
- Computations involving physically-based approaches are computing-intensive
- Knowledge on aquifers are limited
- GW abstractions are not known
- Simplifications in crop-water demand applied
- Finer resolution is required to capture local flow patterns, but processes at finer scale uncertain
- Climate change impacts on GW are unknown



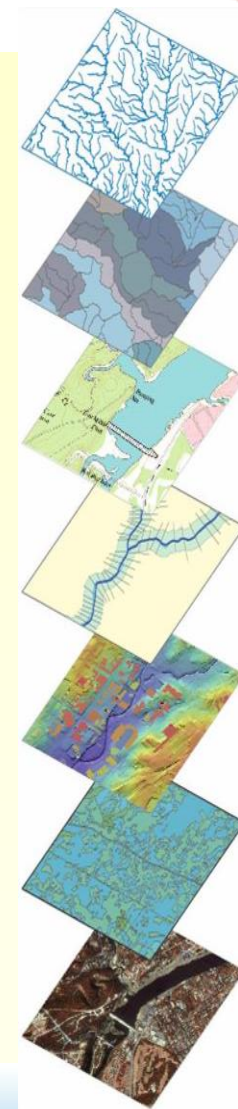
## Examples of Groundwater in the Global Water-Food-Climate-Environment Nexus

1. Assessing global food production from GW and GWD
2. Assessing GW irrigation potential in Africa
3. GW drought risk mapping in Southern Africa
4. GW abstraction and environmental flow assessment

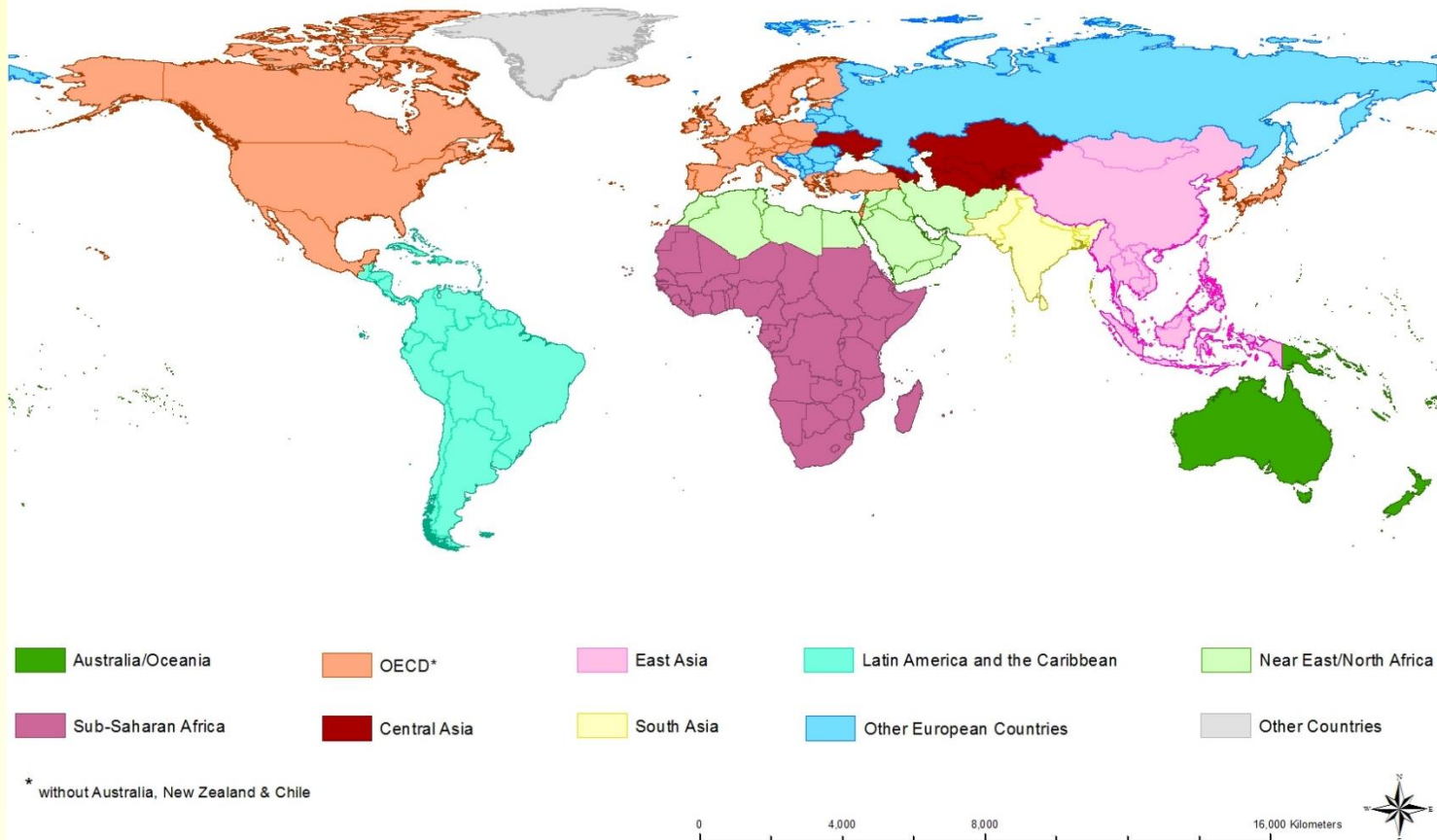
# 1. How much food derives from GW and GWD?



LED BY IFPRI



# Regional aggregation





# Crop aggregation

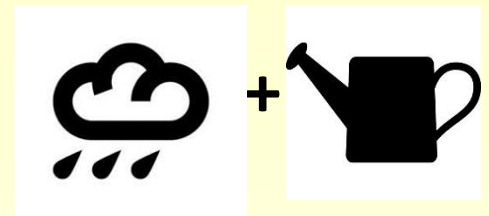
Crop Group	Crop Name
Beverage and spice crops	Arabica coffee
	Cocoa
	Robusta coffee
	Tea
Cereals	Barley
	Maize
	Other cereals
	Pearl millet
	Rice
	Small millet
	Sorghum
	Wheat
Leguminous crops	Other pulses
	Bean
	Chickpea
	Cowpea
	Lentil
	Pigeon pea
Non-Food Crops	Cotton
	Other fiber crops
	Tobacco

Crop Group	Crop Name
Oilseed Crop	Coconut
	Groundnut
	Oil palm
	Other oil crops
	Rapeseed
	Sesame seed
	Soybean
	Sunflower
Other Crops	Rest of crops
Roots and Tubers	Cassava
	Other roots
	Potato
	Sweet potato
	Yams
Sugar Crops	Sugar beet
	Sugarcane
Vegetables and Fruits	Banana
	Plantain
	Temperate fruit
	Tropical fruit
	Vegetables

## Key findings

- Groundwater irrigated areas globally comprise about 83.1 mill. ha, or about 41% of total irrigated areas
- Of the groundwater irrigated areas, 15.5 to 18.5% are supplied by depleting aquifers
- GW depletion rate in agriculture: 129.3 – 165.6 km<sup>3</sup>/a, accounting for approx. 89% of total GW depletion

# Contribution of GW to global food production



**From GW  
abstraction**

**100%**

**43.5%**

**13.0%**

**From GW  
depletion**

**14.0-16.9%**

**6.1-7.4%**

**1.8-2.2%**

# Regional distribution

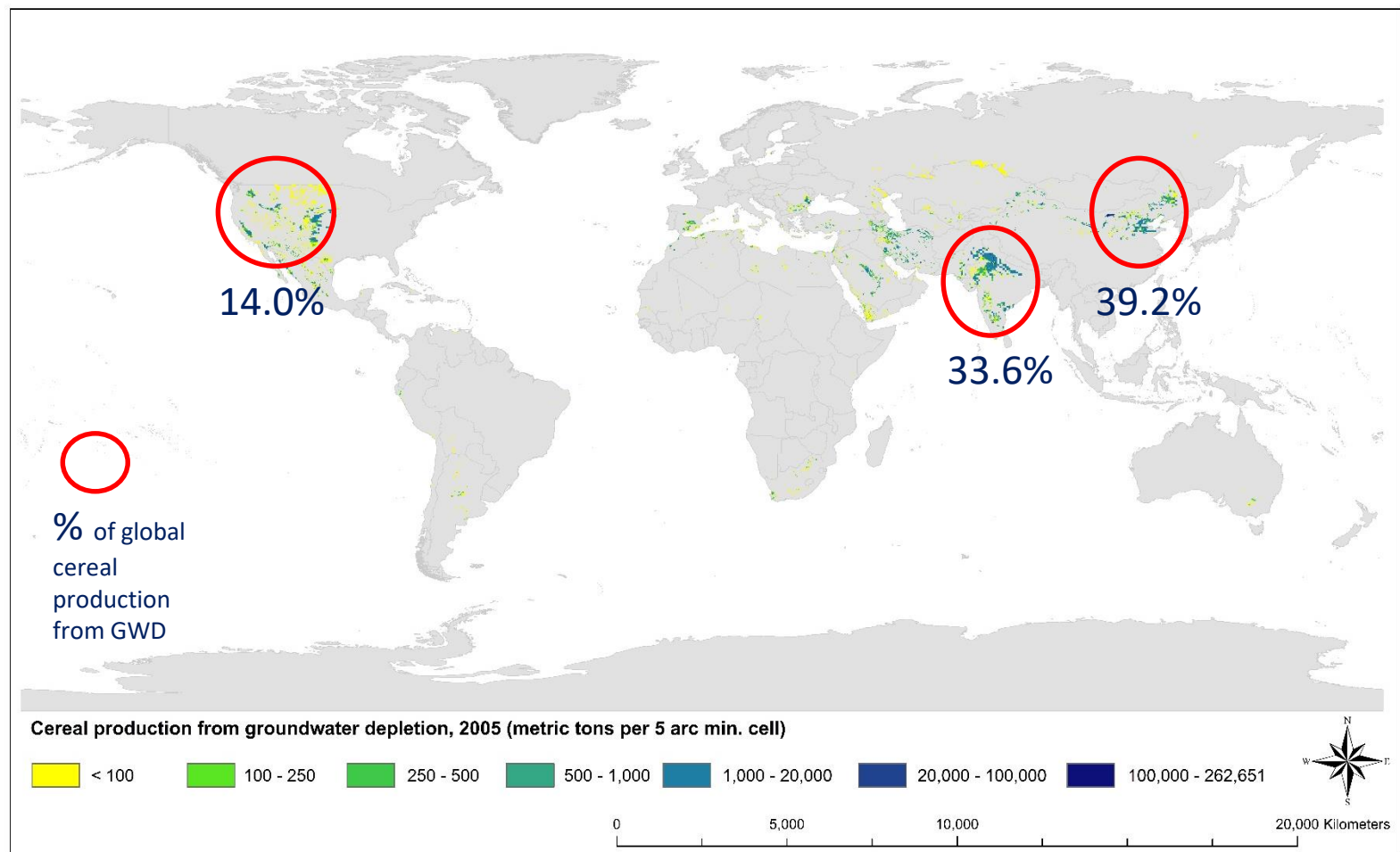
	Food production (10 <sup>6</sup> t/a)				Food production from GWD as a fraction of	
Region	From GWD	From GWD (% of total)	From irrigation	From irrigation and rainfed	Irrigated production	Total production
Australia/Oceania	0.06	0.0%	28.58	96.28	0.2%	0.1%
Central Asia	0.12	0.1%	23.57	151.96	0.5%	0.1%
East Asia	30.55	22.3%	595.02	1997.86	5.1%	1.5%
Latin America and the Caribbean	0.66	0.5%	287.38	1063.58	0.2%	0.1%
Near East/North Africa	10.94	8.0%	113.04	207.72	9.7%	5.3%
OECD	32.77	23.9%	310.35	1593.73	10.6%	2.1%
Other European Countries	0.56	0.4%	16.09	277.09	3.5%	0.2%
South Asia	61.32	44.7%	605.73	904.33	10.1%	6.8%
Sub-Saharan Africa	0.20	0.1%	62.76	518.41	0.3%	0.0%
Total or average	137.17	100.0%	2042.52	6810.96	6.7%	2.0%



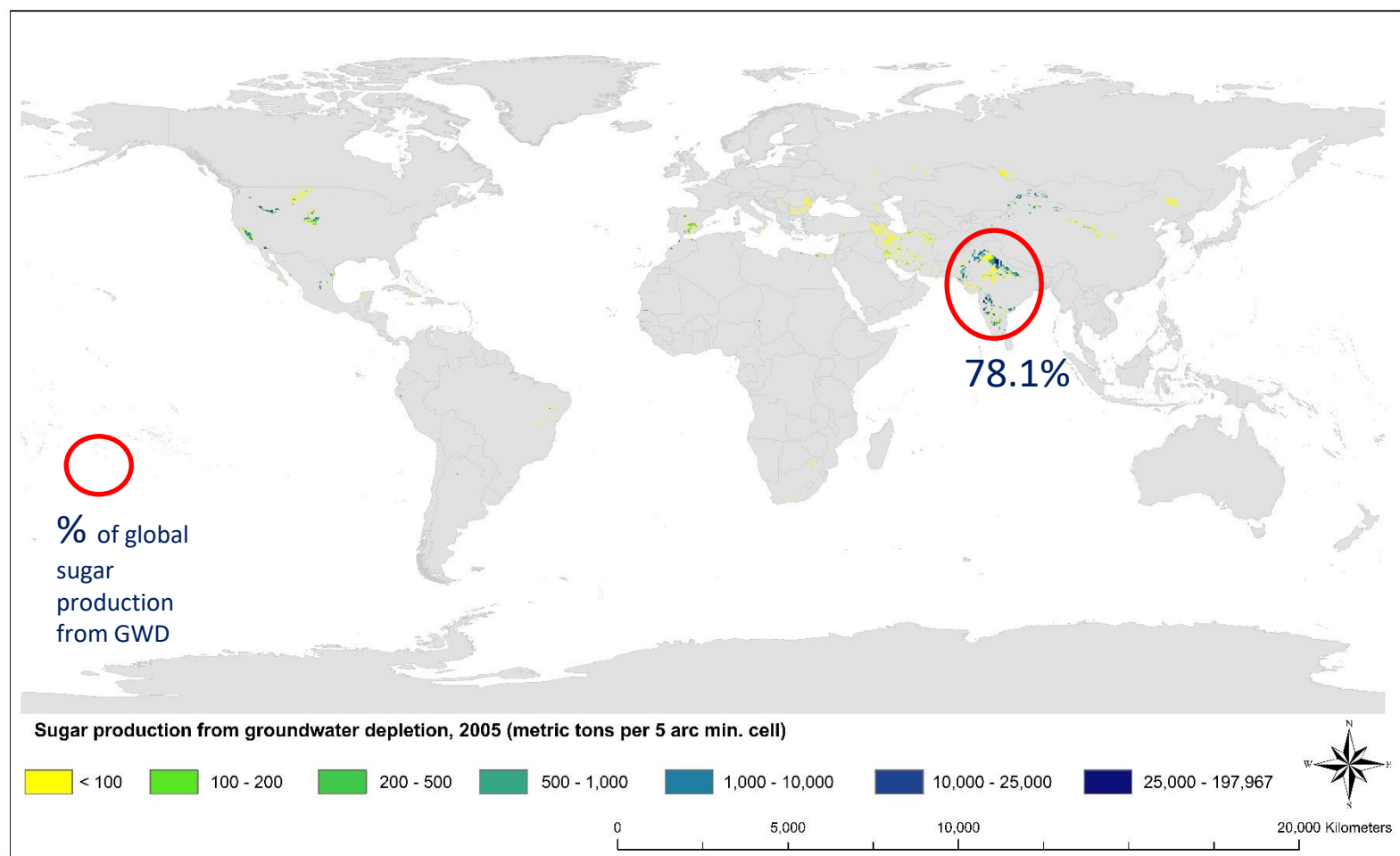
# Crop distribution

Crop group	Food production (10 <sup>6</sup> t/a)				Food production from GWD as a fraction of	
	From GWD	From GWD (% of total)	From irrigation	From irrigation and rainfed	Irrigated production	Total production
Beverages	0.00	0.0%	0.63	15.32	0.0%	0.0%
Cereals	60.41	44.0%	902.23	2260.27	6.7%	2.7%
Leguminous crops	0.85	0.6%	9.25	60.63	9.1%	1.4%
Non-food crops	4.03	2.9%	41.16	82.64	9.8%	4.9%
Oilseed crops	2.65	1.9%	42.91	593.75	6.2%	0.4%
Other crops	0.32	0.2%	1.68	29.60	19.0%	1.1%
Roots and tubers	15.45	11.3%	109.17	723.58	14.2%	2.1%
Sugar crops	43.04	31.4%	801.26	1613.48	5.4%	2.7%
Vegetables and fruits	10.48	7.6%	134.21	1431.70	7.8%	0.7%
Total or average	137.21	100.0%	2042.50	6810.97	6.7%	2.0%

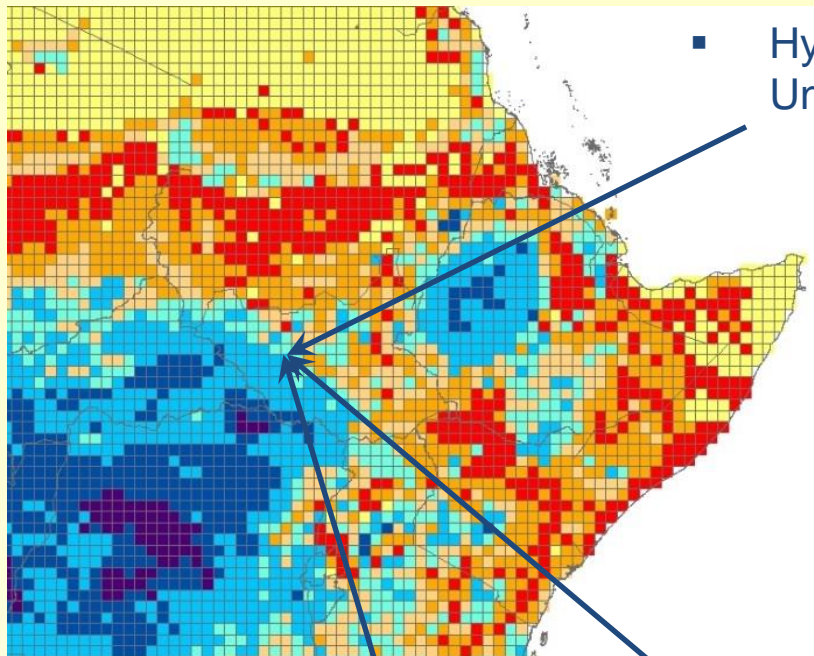
# Cereal production from GWD



# Sugar production from GWD

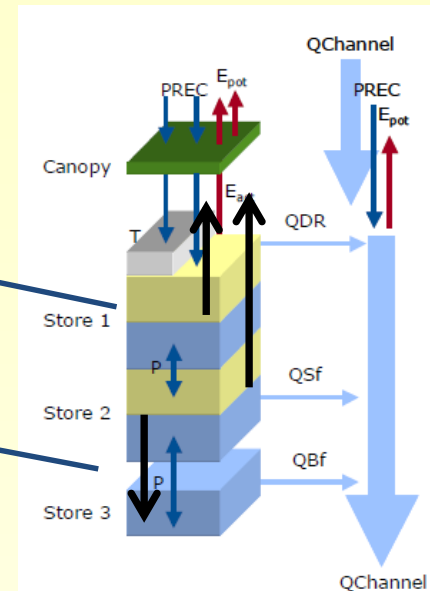


# 2. GW Irrigation Potential in Africa



- 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

Resolution:  
0.5 degree  
( $\approx 50 \text{ km} \times 50 \text{ km}$  cell)

- Crop data
    - Crop distribution
    - Crop water demand
    - Irrigation efficiency
- monthly calendar for crop  
group water demand



Different geographical data compiled in GIS



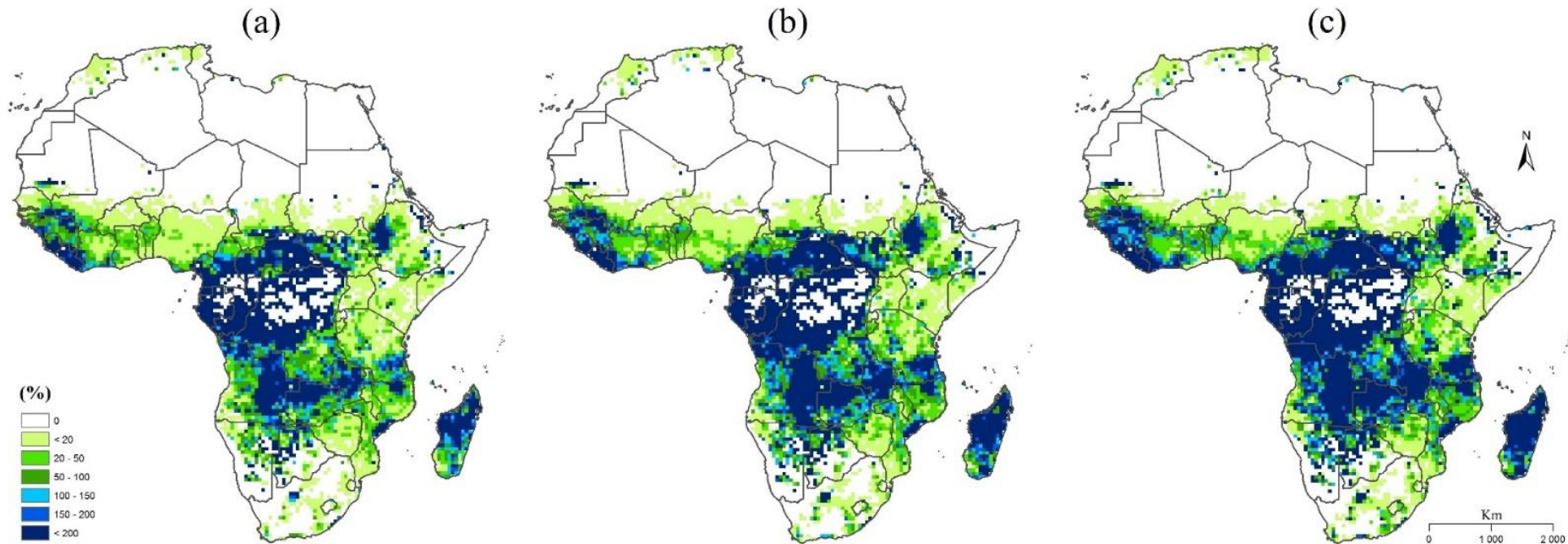
# GWIP - Results

- Proportion of cropland irrigable with groundwater:

when environmental requirements represent :

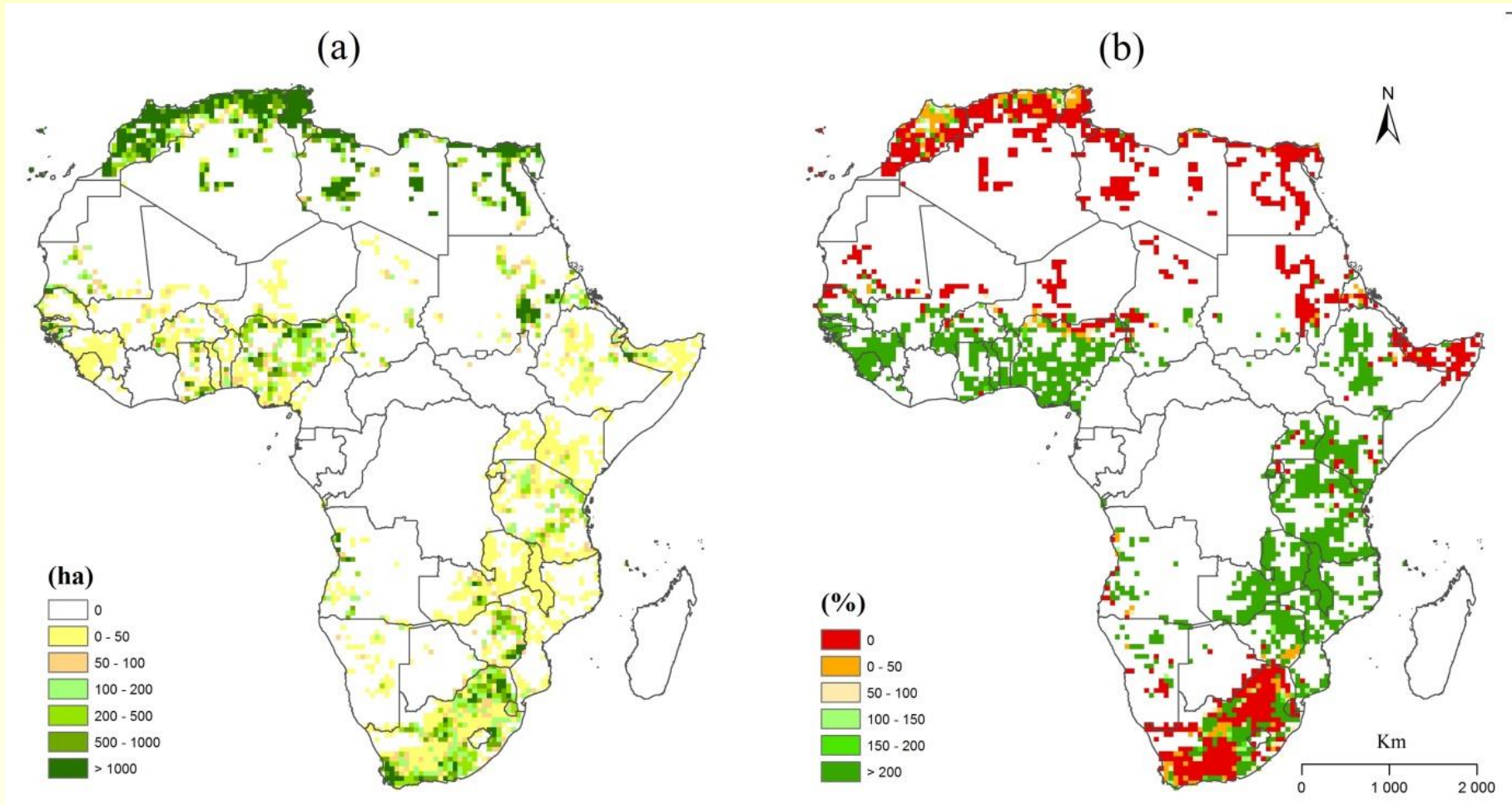
	(a) 70% of recharge	(b) 50% of recharge	(c) 30% of recharge
Area (10 <sup>6</sup> ha)	44.6	74.9	105.3
% of cropland	20.5%	34.5%	48.5%

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



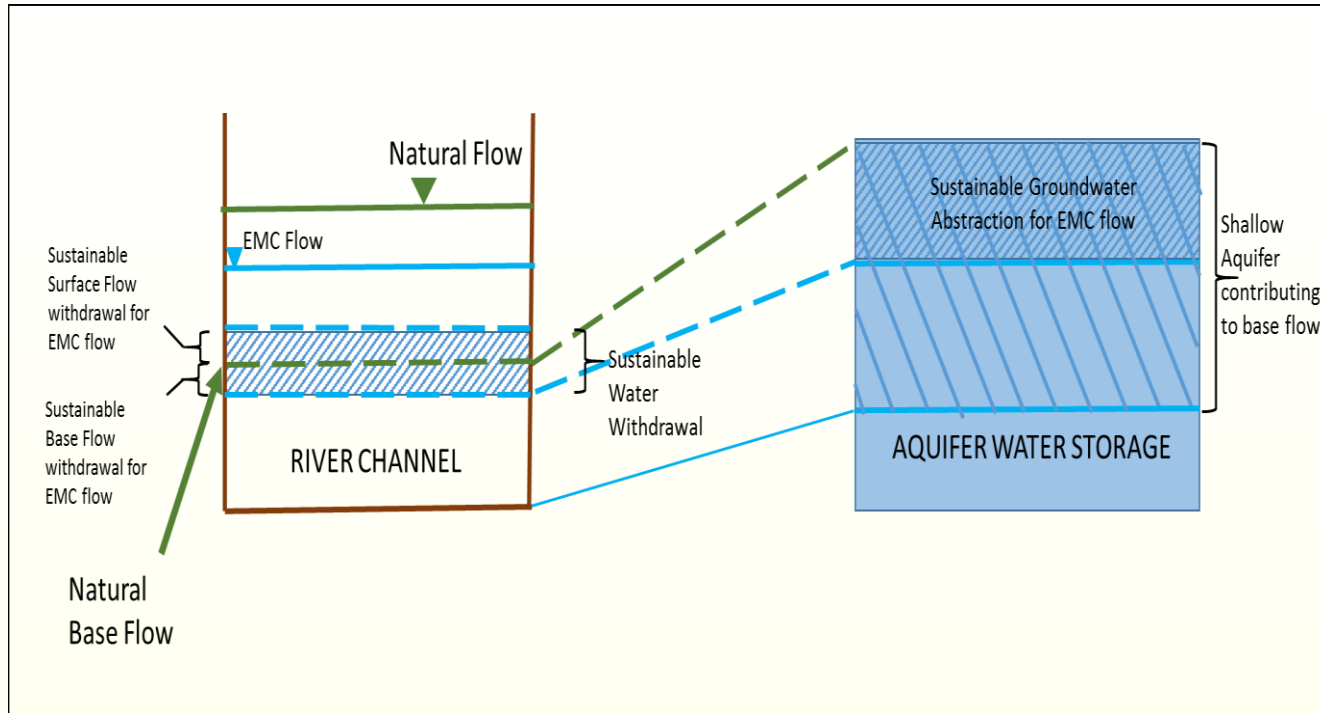
# GWIP - Results

- 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)** physical groundwater irrigation potential for scenario b for the year 2000 expressed as the percentage of the area irrigated with groundwater in 2005

# 3. Sustainable GW Abstraction from Stream Flow and Environmental Flows



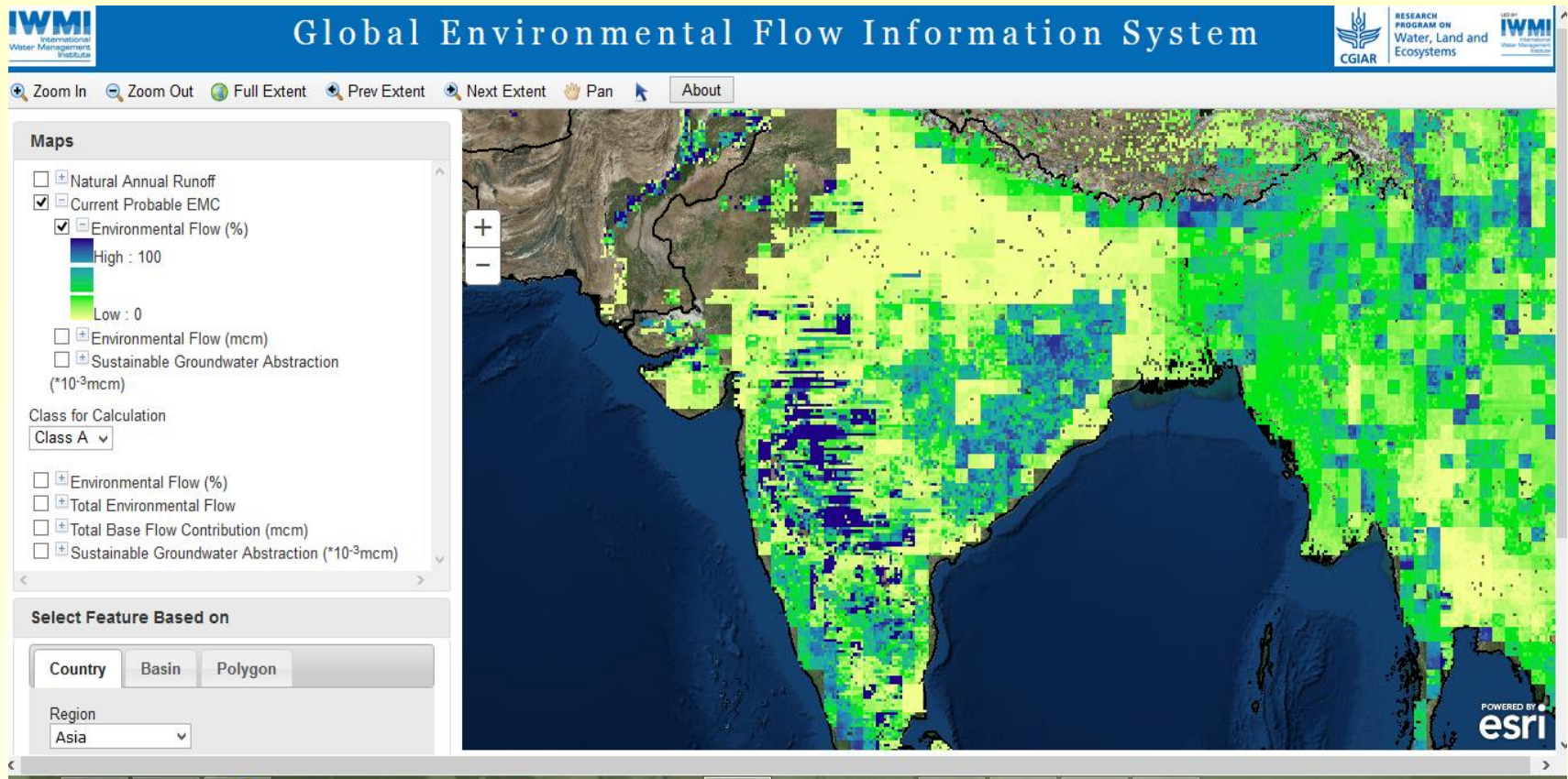
$$\Delta S = K \Delta BF$$

where "K" is the inverse of recession constant and has a unit of  $T^{-1}$  (derived from PCR-GLOBWB model)

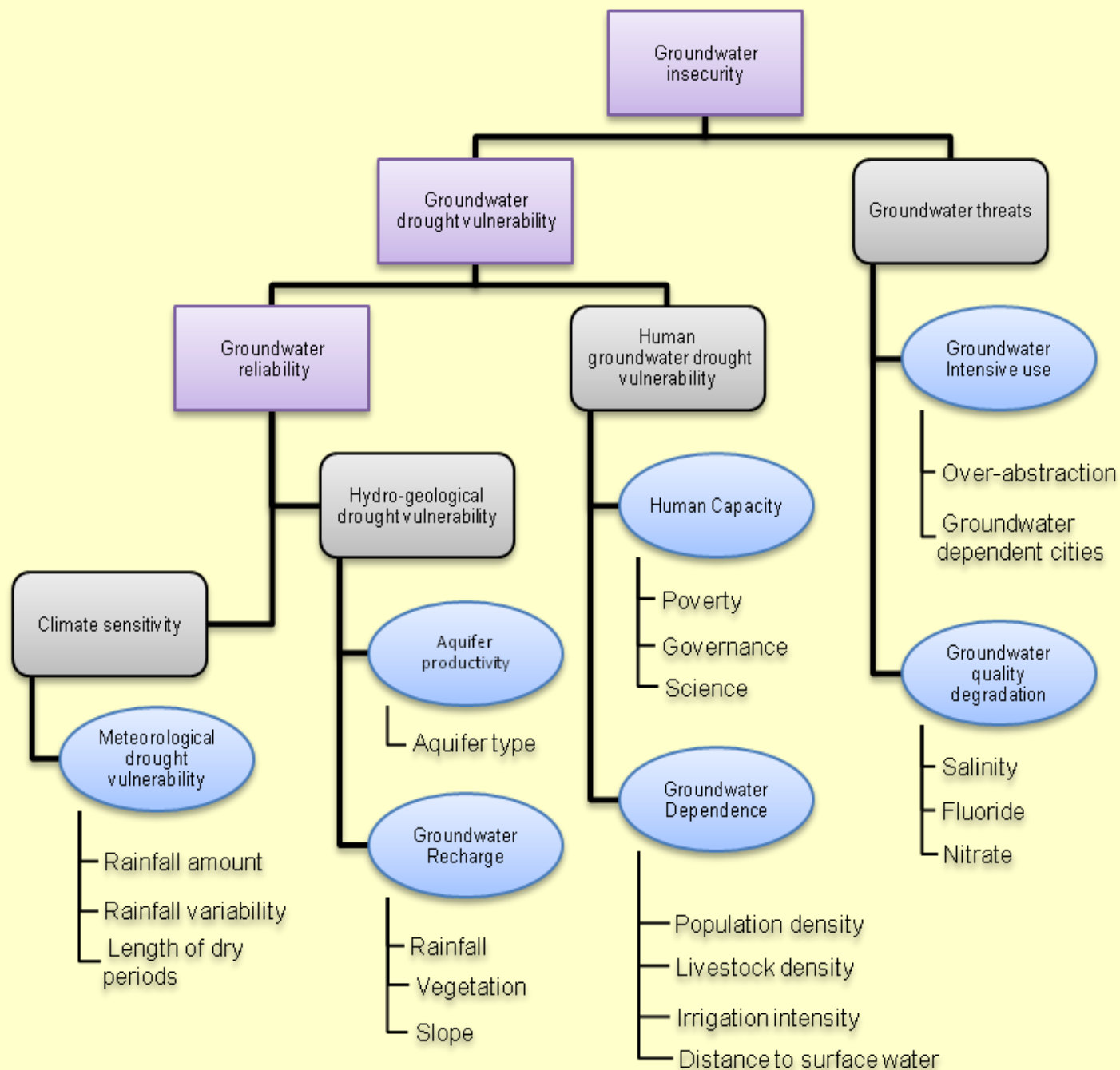
Region	Sustainable groundwater abstraction (km <sup>3</sup> /a)			
	EMC "A"	EMC "B"	EMC "C"	EMC "D"
Asia	77.9	133.0	170.0	194.0
North America	24.0	41.6	54.0	62.4
Europe	12.0	20.9	27.3	31.7
Africa	11.0	18.9	24.2	27.6
South America	17.1	29.4	37.8	43.1
Oceania	5.2	8.9	11.4	13.2
Australia	1.7	2.9	3.7	4.15
Global	148.9	255.5	328.4	376.2



# Global Environmental Flow Calculator

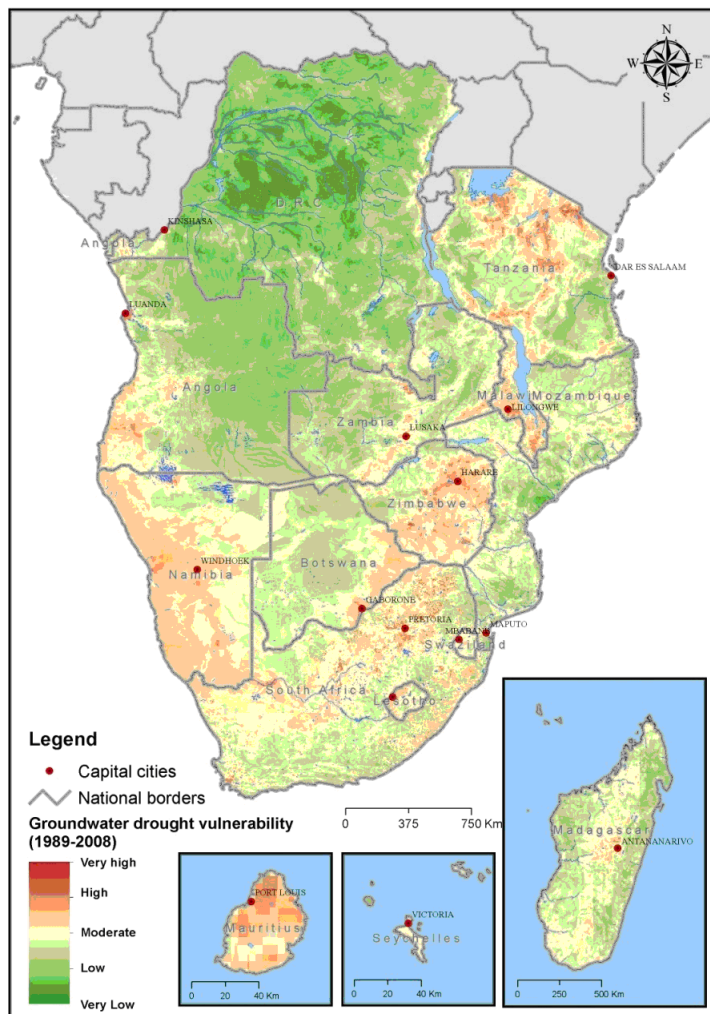


<http://gef.iwmi.org/>

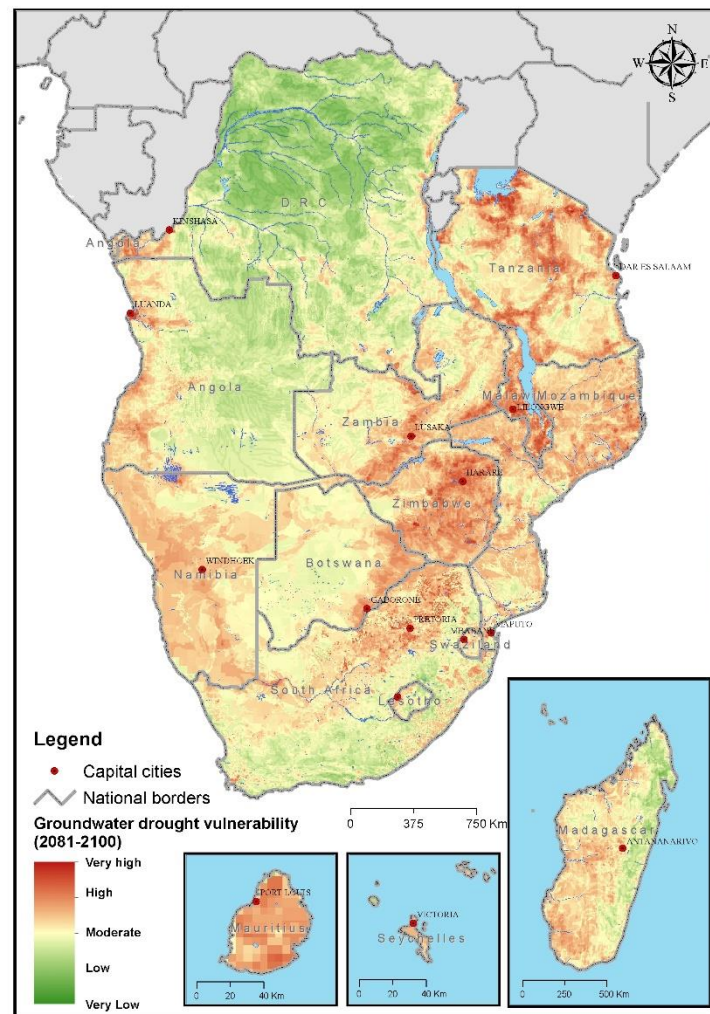


# 4. Groundwater Drought Risk

Present climate (1989-2008)



Future climate (IPCC SRES A1B, 2081-2100)



# Conclusions

- The increasing dependence on GW, and associated impacts on hydrological and environmental/climate processes warrant intensification of research on groundwater systems
- Large-scale integrated GW assessments are becoming increasingly important tools in understanding and managing groundwater systems
- Linking knowledge at local to global scale will be important for reliable global tools



# References, 1

- Döll, P., H. Hoffmann-Dobrev, F.T. Portmann, S. Siebert, A. Eicker, M. Rodell, G. Strassberg, and B.R. Scanlon, 2012. Impact of water withdrawals from groundwater and surface water on continental water storage variations. *J. Geodyn.* 59-60, 143-156.
- Döll, P. and M. Flörke, 2005. Global-scale estimation of diffuse groundwater recharge. Frankfurt Hydrology Paper 03, Institute of Physical Geography, Frankfurt University, Frankfurt am Main, Germany, 21 pp.
- Foster, S., G. Tyson, L. Konikow, E. Custodio, K. Villholth, J. van der Gun, and R. Klingbeil, 2015. Groundwater in Food Security. International Association of Hydrogeologists. Professional Strategic Overviews, 6 pp.
- Siebert, S., J. Burke, J.M. Faures, K. Frenken, J. Hoogeveen, P. Döll, and F.T. Portmann, 2010. Groundwater use for irrigation - a global inventory. *Hydrol. Earth Syst. Sci. Discuss.*, 7, 3977–4021.
- van der Gun, J., 2012. Groundwater and Global Change: Trends, Opportunities and Challenges. UN World Water Assessment Programme. WWDR. 38 pp. ISBN 978-92-3-001049-2.
- Wada, Y., L.P.H. van Beek, and M.F.P. Bierkens, 2012. Nonsustainable groundwater sustaining irrigation: A global assessment. *Wat. Res. Resear.*, 48, W00L06, doi:10.1029/2011WR010562.
- World Bank, 2005. India's Water Economy: Bracing for a Turbulent Future. Report No. 34750-IN. 82 pp. Washington, DC: World Bank.
- World Water Commission, 2000. A Water Secure World. Vision for Water, Life and the Environment. Vision Commission Report. World Water Commission, Marseille, 70 pp.

# References, 2

- Altchenko Y. and Villholth K.G (2015) Mapping irrigation potential from renewable groundwater in Africa – a quantitative hydrological approach. Hydrol. Earth Syst. Sci., 19, 1-13, Doi: 10.5194/hessd-19-1-2015
- Döll P. and Fiedler K. (2008) Global-scale modeling of groundwater recharge, Hydrol. Earth Syst. Sci. 12, 863–885 pp
- MacDonald A., Bonsor H., Dochartaigh B., and Taylor R. (2012) Quantitative maps of groundwater resources in Africa. Environ. Res. Lett. 7, doi:10.1088/1748-9326/7/2/024009
- Pavelic P., Smakhtin V., Favreau G., and Villholth K.G. (2012) Water-balance approach for assessing potential for smallholder groundwater irrigation in Sub-Saharan Africa. Water SA, 38(3), 399-406. doi.org/10.4314/wsa.v38i3.18
- Siebert S., Burke J., Faures J.M., Frenken K., Hoogeveen J., Döll P., and Portmann F.T. (2010) Groundwater use for irrigation - a global inventory. Hydrol. Earth Syst. Sci. Discuss., 7, 3977–4021.
- Wada Y., Van Beek, L., Viviroli D., Dürr H., Weingartner R., and Bierkens M. (2011) Global monthly water stress. 2. Water demand and severity of water stress, Water Resour. Res., 47, W07517, doi:10.1029/2010WR009792.

# References, 3

- Acreman, M. and Dunbar, M.J. (2004). Defining Environmental River Flow Requirements – A Review. *Hydrology and Earth System Sciences*, 8(5):861-876.
- Ebrahim, G.Y. and Villholth, K.G. (2016). Estimating shallow groundwater availability in small catchments using streamflow recession and instream flow requirements of rivers in South Africa. *J. Hyd.* doi:10.1016/j.jhydrol.2016.07.032.
- Nathan, R. J., and McMahon, T. A. (1990). Evaluation of automated techniques for base flow and recession analyses: *Water Resources Research*, 26 (7): 1465-1473.
- Smakhtin, V.U., Anputhas, M., (2006). An Assessment of Environmental Flow Requirements of Indian River Basins. IWMI Research Report 107. International Water Management Institute, Colombo, Sri Lanka.
- Sood, A., V. Smakhtin, N. Eriyagama, K.G. Villholth, N. Liyanage, Y. Wada, G.Y. Ebrahim, and C. Dickens, 2016. Environmental Flow Information for Global Sustainable Development Goals. IWMI Research Report. In revision.
- Vörösmarty CJ, McIntyre PB, Gessner MO, Dudgeon D, Prusevich A, Green P, Glidden S, Bunn SE, Sullivan CA, Liermann CR, Davies PM.(2010). Global threats to human water security and river biodiversity. *Nature*, 467(7315):555-61.

# References, 4

- Calow, R.C., Robins, N.S., MacDonal, A.M., MacDonald, M.J., Gibbs, B.R., Orpen, W.R.G., Mtembezeka, P., Andrews, A.J. and S.O. Appiah, 1997. Groundwater management in drought-prone areas of Africa. *Water Resour. Dev.*, 3, 2, 241 - 261.
- Kleemeier, E.L., 2010. Private operators and rural water supplies. A desk review experience. *World Bank Water Papers*, 57831.
- Turton, A.R., Hattingh, H., Claassen, M. & Roux, D. 2005. Towards a Model for Ecosystem Governance: An Integrated Resource Management Example. Paper presented at the International Symposium on Ecosystem Governance, Kwa Maritane, South Africa 10-13 Oct. 2005. Forthcoming chapter in Turton, A.R., Roux, D., Claassen, M. & Hattingh, H. (Eds.) *Governance as a Dialogue: Government-Society-Science in Transition*. Berlin: Springer-Verlag.
- Villholth, K.G., Tøttrup, C., Stendel, M. & Maherry, A. 2013. Integrated mapping of groundwater drought risk in the Southern African Development Community (SADC) region. *Hydrogeol. J.*, 21(4), 863-885. DOI: 10.1007/s10040-013-0968-1.
- World Bank, 2005. *Natural disaster hotspots - A global risk analysis*. 132 pp. ISBN 0-8213-5930-4.



# Thank you!

Contact:  
[k.villholth@cgiar.org](mailto:k.villholth@cgiar.org)