Sustainable groundwater management in Anthropocene

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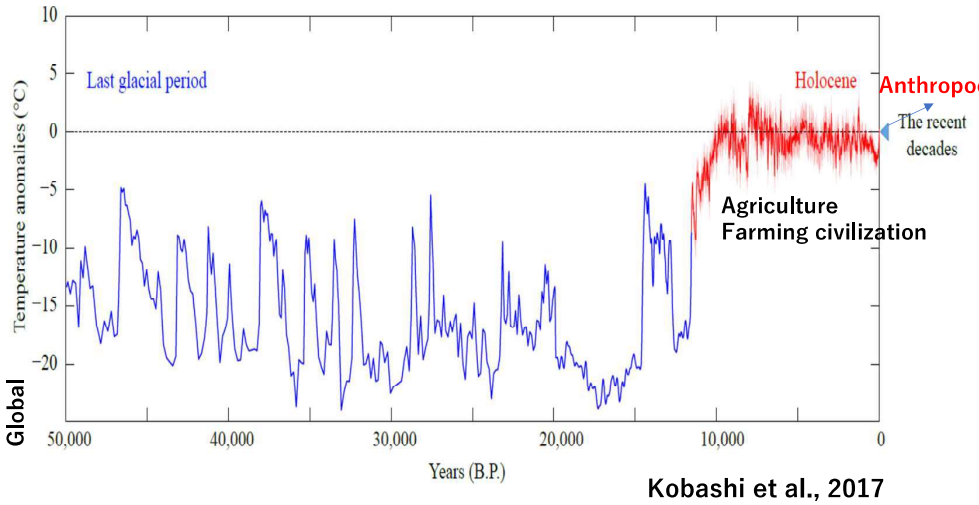
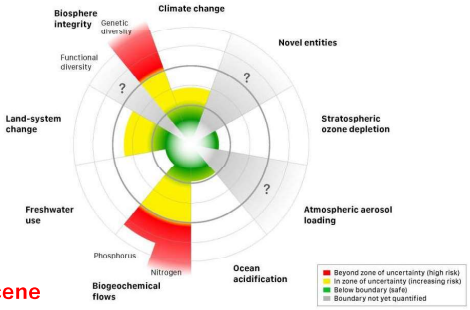
Holocene → *Anthropocene*

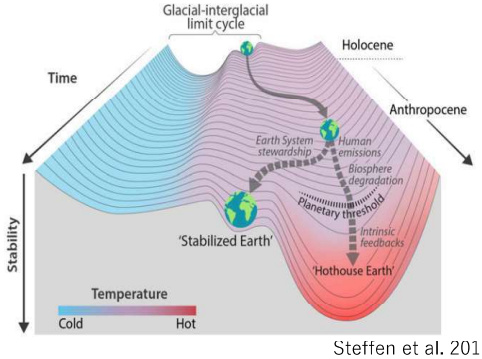


Kobashi et al., 2017

Planetary Boundary

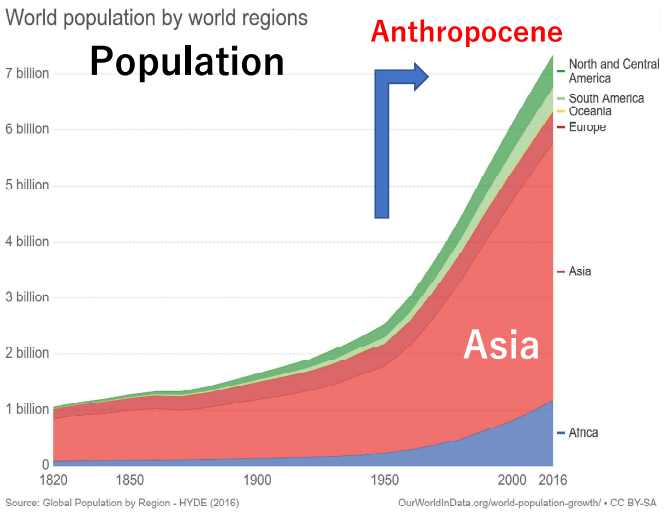


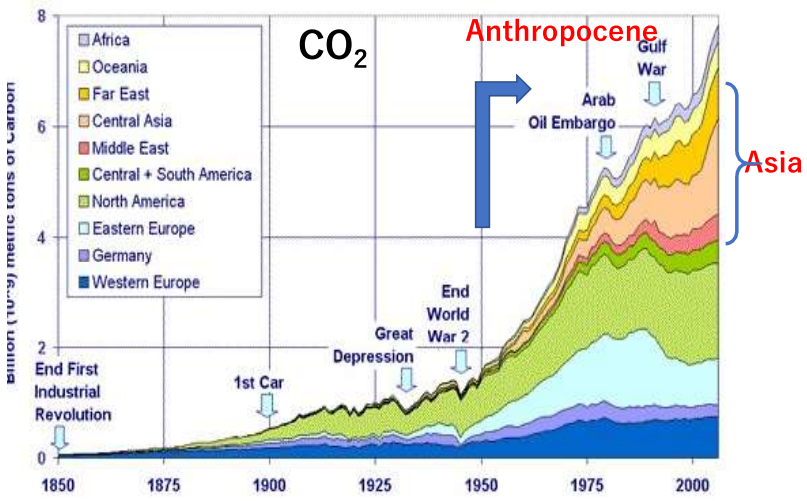
Hothouse Earth



Steffen et al. 2018

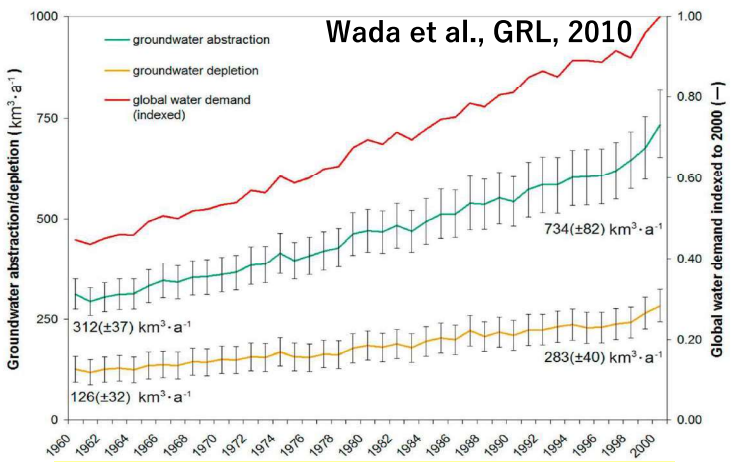
Holocene → Anthropocene



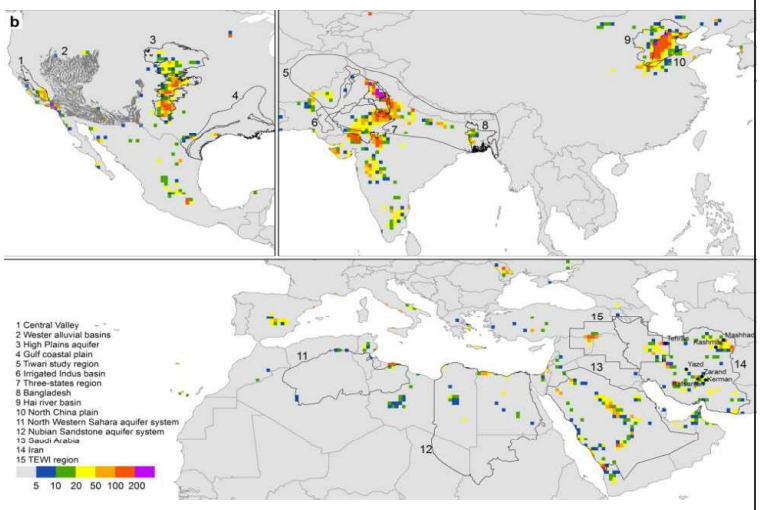


Combining fossil fuels and large population support with abundant water, including groundwater in Asia, created a huge economic development and global environmental problems in Anthropocene

Global Groundwater Depletion in Anthropocene

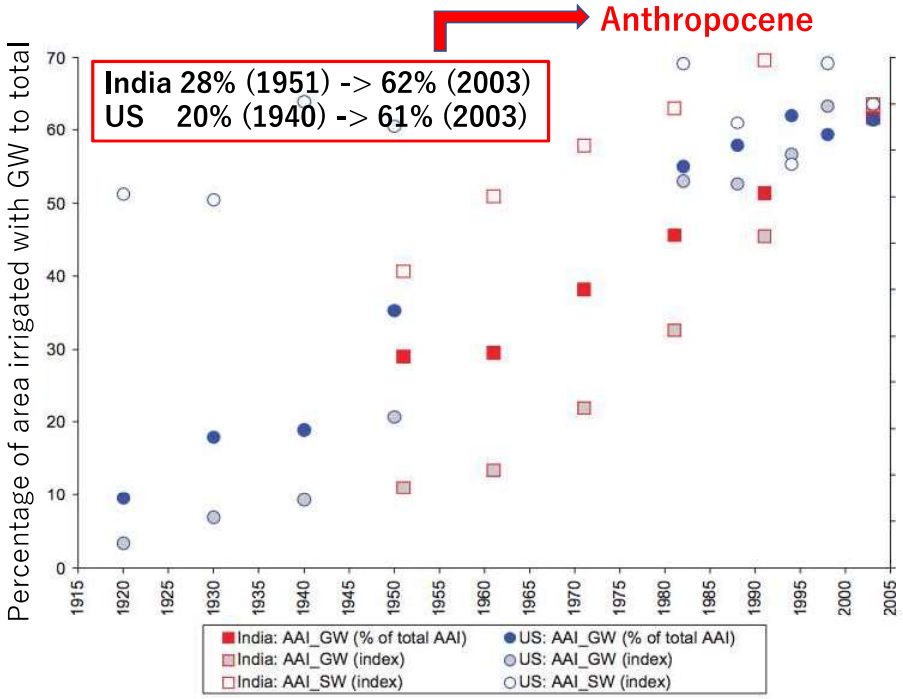


Increase of Groundwater Depletion in Anthropocene
126 billion ton/y (1960)
283 billion ton/y (2000)



Groundwater depletion (mm/y) for various regions (1980-2009, taken from Döll *et al*. (2014))

Increase in percentage of area irrigated with GW

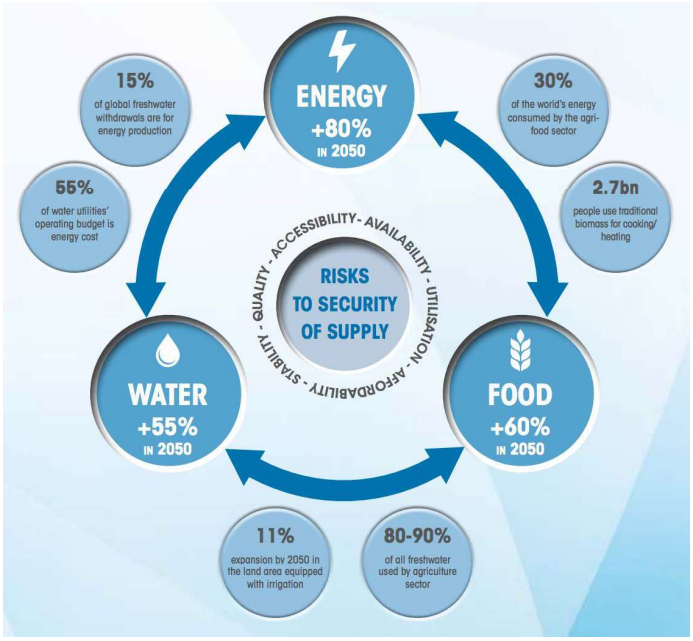


(after **Siebert et al., 2010**).

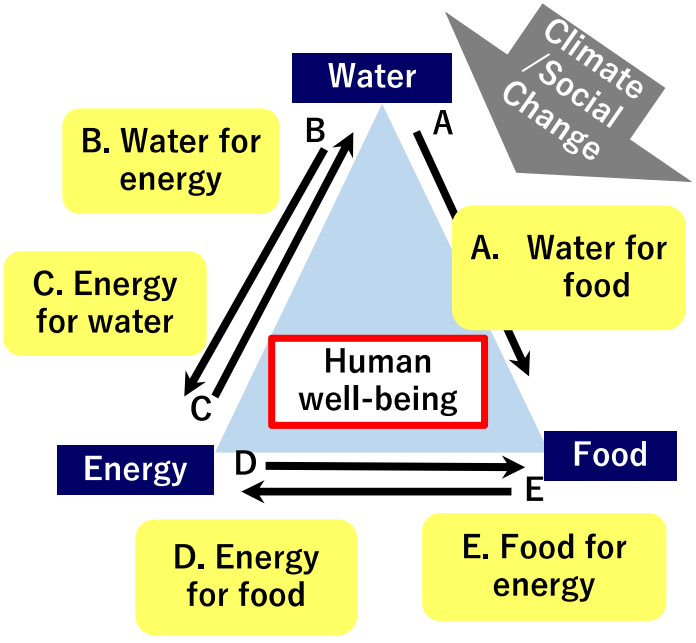
- **90% of human freshwater consumption is through agriculture,**
- **About 40% of this consumption is now from groundwater,**
- **The percentage of areas irrigated with groundwater has increased rapidly since the 1960s (Anthropocene), particularly in the USA and India**

(Dallin, Taniguchi, Green, submitted to *Global Sustainability*)

Groundwater-Energy-Food Nexus



Ferroukhi et al., 2015

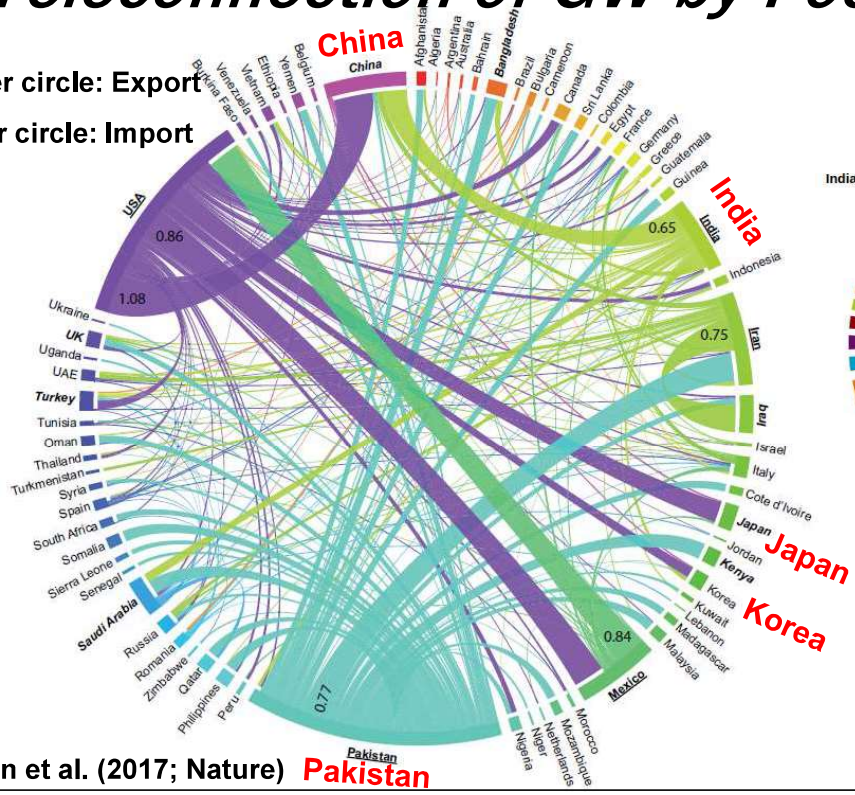


Taniguchi et al., 2015

Teleconnection of GW by Food Trade (GW footprint)

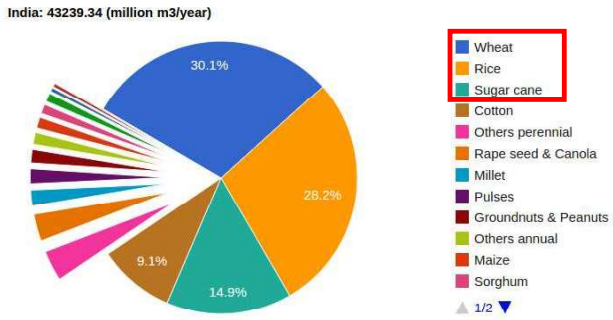
Outer circle: Export

Inner circle: Import



Dalin et al. (2017; Nature)

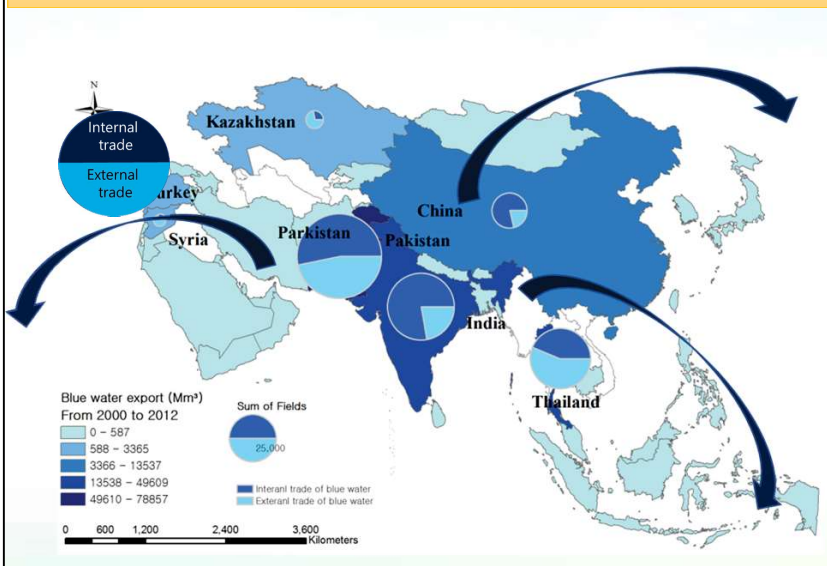
Contribution of Non-renewable Groundwater to Irrigation for India



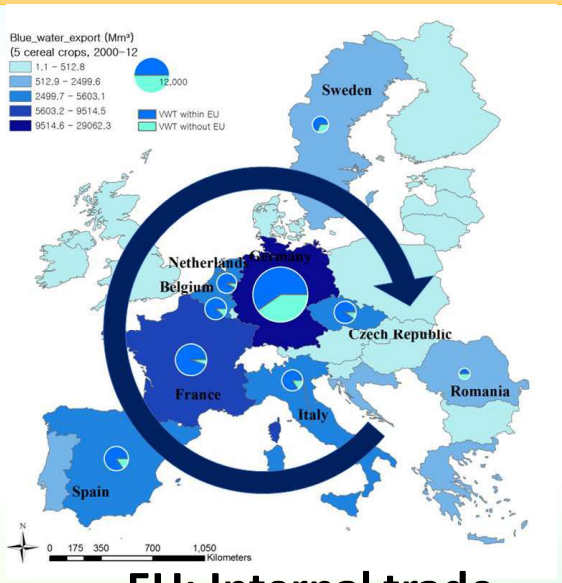
Asia is both causing (China, Japan, Korea) and suffering (India, Pakistan) from groundwater depletion due to food trade.

Teleconnection of GW by Food Trade (GW footprint)

Water export via five crops traded in Asia and EU from 2000 to 2012 (Lee et al., 2017)



Asia: external trade



EU: Internal trade

Groundwater Depletion

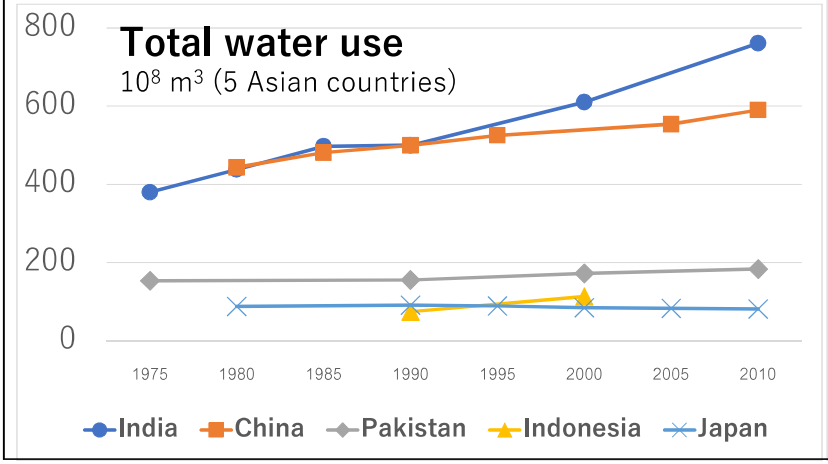
Table 1 | Estimates of global- and continental-scale groundwater depletion.

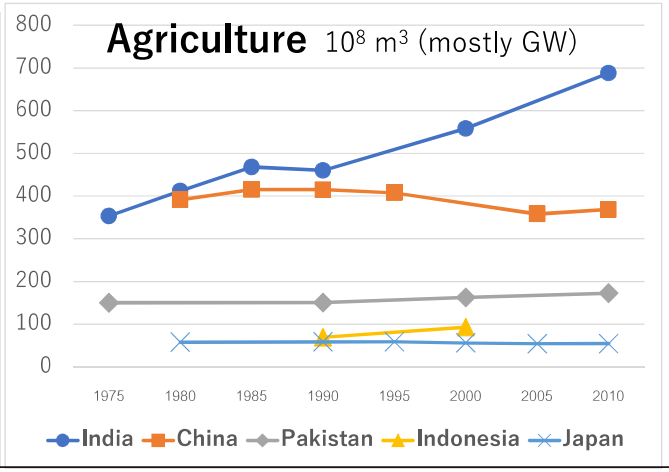
	Flux-based method[91]*		Volume-based method[92]†	
Region	Groundwater depletion	Sea-level rise	Groundwater depletion	Sea-level rise
World	204 ± 30	0.57 ± 0.09	145 ± 39	0.40 ± 0.11
Asia	150 ± 25	0.42 ± 0.07	111 ± 30	0.31 ± 0.08
Africa	5.0 ± 1.5	0.014 ± 0.004	5.5 ± 1.5	0.015 ± 0.004
North America	40 ± 10	0.11 ± 0.03	26 ± 7	0.07 ± 0.02
South America	1.5 ± 0.5	0.0042 ± 0.0014	0.9 ± 0.5	0.002 ± 0.001
Australia	0.5 ± 0.2	0.0014 ± 0.0006	0.4 ± 0.2	0.001 ± 0.0005
Europe	7 ± 2	0.02 ± 0.006	1.3 ± 0.7	0.004 ± 0.002

Flux-based and volume-based estimates of global and continental-scale groundwater depletion ($km^3 yr^{-1}$) and their contributions to global sea-level rise ($mm yr^{-1}$). *Year 2000. †Period between 2001 and 2008.

Asia > N. America > Africa ≒ Europe > S. America > Australia

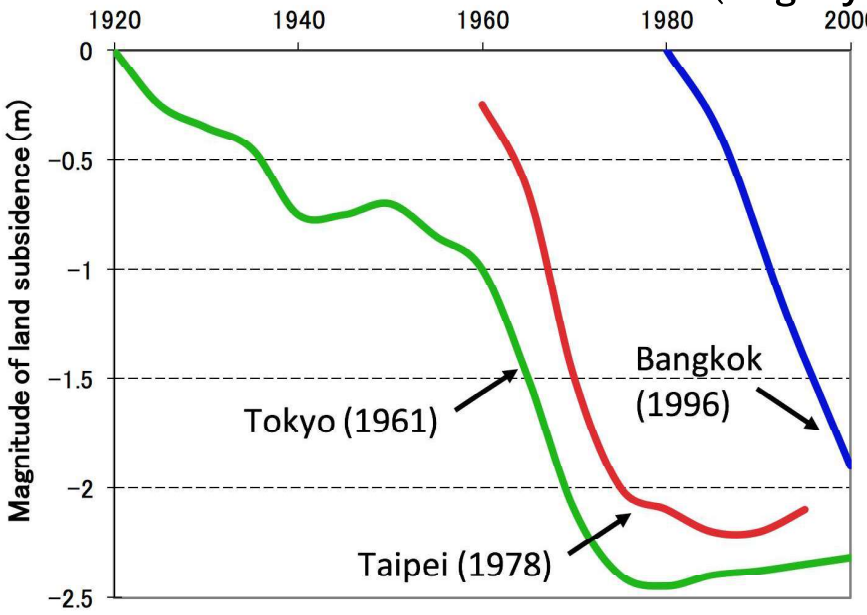
Taylor et al., 2012





Land Subsidence in Asian Cities

(tragedy of the commons)



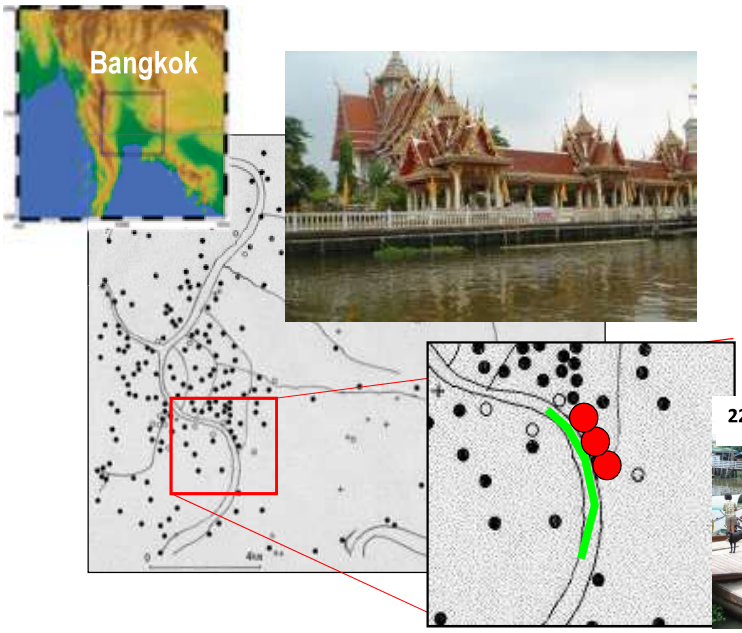
Regulation of GW pumping had started
41 years later in Tokyo
>18 years later in Taipei
16 years later in Bangkok
→ Follower's Benefit

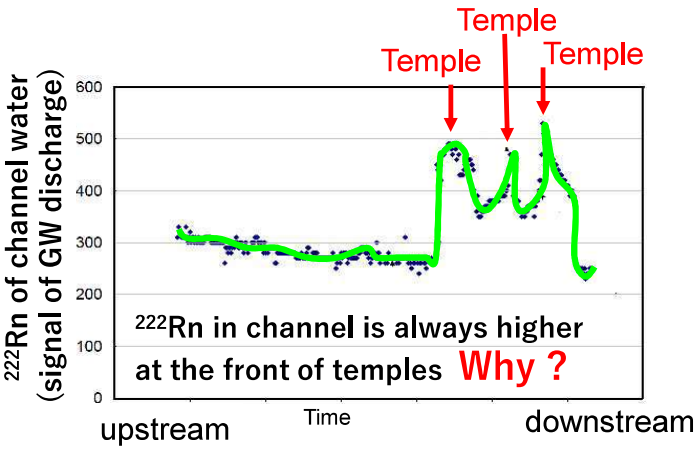
Regulation of GW pumping had started when the land subsidence reached to 1.4-2.1 m.
→ Tipping Point

Magnitudes of land subsidence in Tokyo, Taipei, and Bangkok, and years of the regulation of groundwater pumping. (after Taniguchi, 2011)

Human & Nature Interaction

RIHN-C05 project (2007-2011)





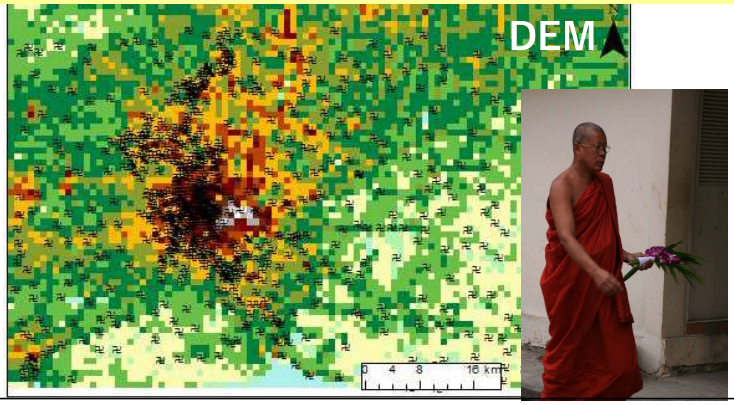
Higher ^{222}Rn concentration in channel is the signal of GW discharge (scientific knowledge)

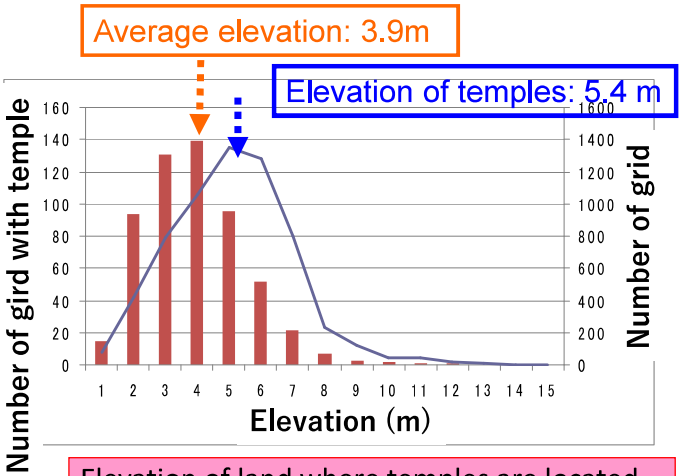
Towards sustainability with groundwater

【Hypothesis】

1) The people who live in Bangkok respect "Buddhism and temples." Therefore they build the temples on relatively stable land (such as sandy soil with high permeability and/or relatively higher elevation) to prevent flooding.

2) GW discharge (^{222}Rn) into the channel occurs in micro GW flow system from higher elevation.



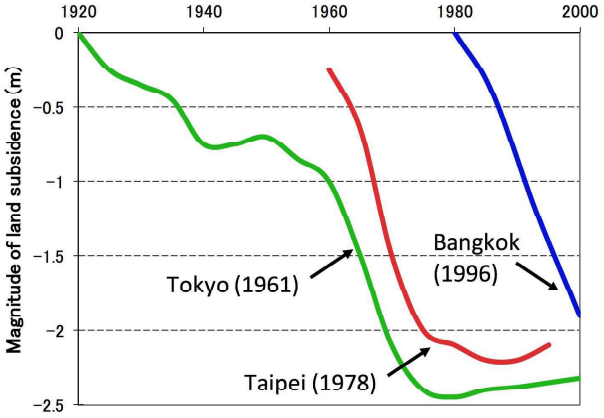


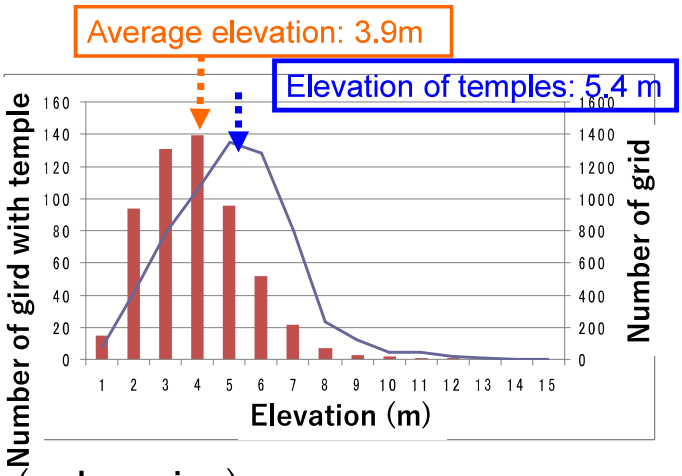
Elevation of land where temples are located is 1.5 m higher than average elevation

Culture dependency of land use

* Religious respect for Buddhism may be reflected in the quality of water in channels, as a **human – nature interaction** in Bangkok.

Finding Tipping Points for Resilience





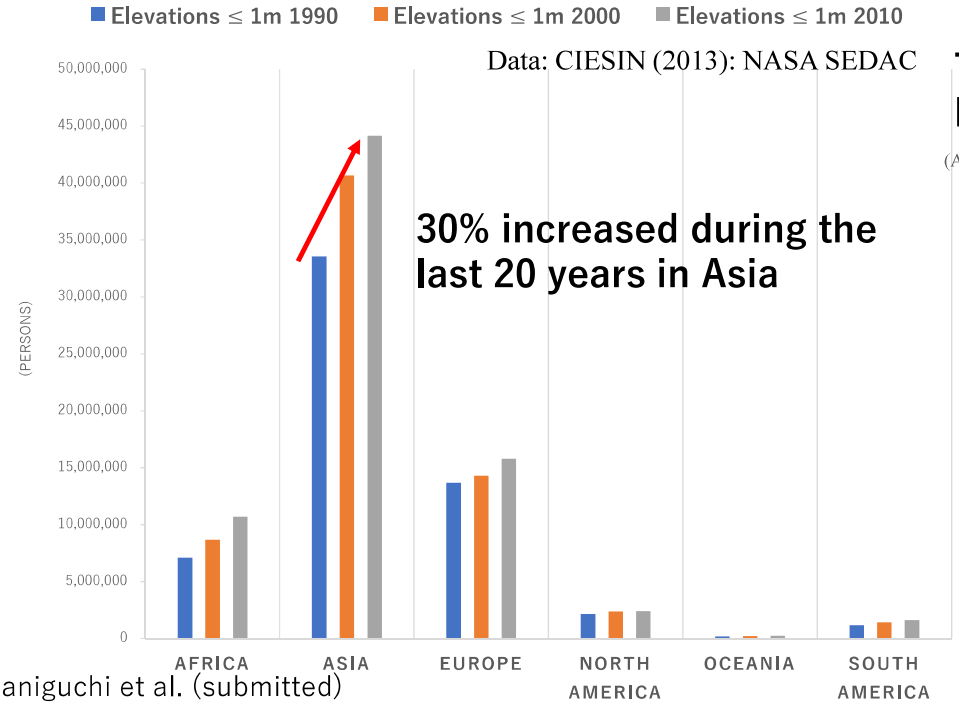
Taniguchi et al. (under review)

Prevention of land subsidence (1.4m -2.1 m)

Prevention of flooding (1.5 m)

Tipping point

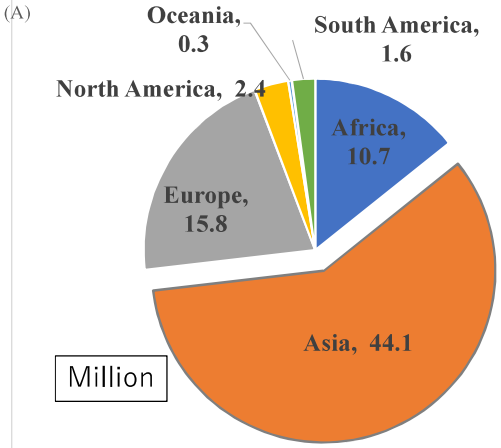
Population living in areas where elevation is below the tipping point (TP)



30% increased during the last 20 years in Asia

Taniguchi et al. (submitted)

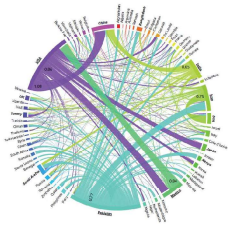
The majority of populations below TP was found in Asia



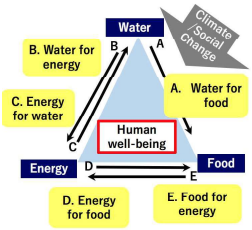
Taniguchi et al. (under review)

Groundwater for Sustainability in Anthropocene

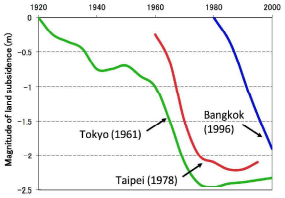
Connectivity | **Tipping Point/Resilience** | **Sustainability**



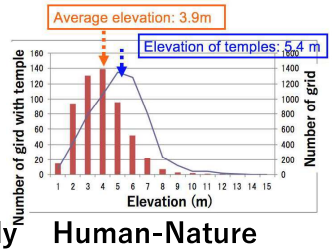
GW footprint
Teleconnection



GW-E-F Nexus



Beyond the Tragedy of the Commons



Human-Nature interaction

Culture Dependency

What do we need to progress towards global sustainability with groundwater ?

1) To understand the connectivity of groundwater as a "human-nature system"
2) To understand tipping points and resilience "beyond tragedy of the commons"
3) To understand groundwater as a "culture dependent resource"

Take home message

- Combining fossil fuels and large population support with abundant water, including groundwater in Asia, created a huge economic boom and global environmental problems in Anthropocene.
- Ratio of groundwater/surface-water consumption is increasing through globalization (e.g. food trade).
- Groundwater is connected to human/nature systems, such as WEF Nexus, land-ocean, land-atmosphere, GW dependent ecosystem, and so on.
- Groundwater is the key as a culture dependent and resilient resource for a sustainable society in the Anthropocene, particularly in Asia where populations below the tipping point are the largest in the world and increasing.