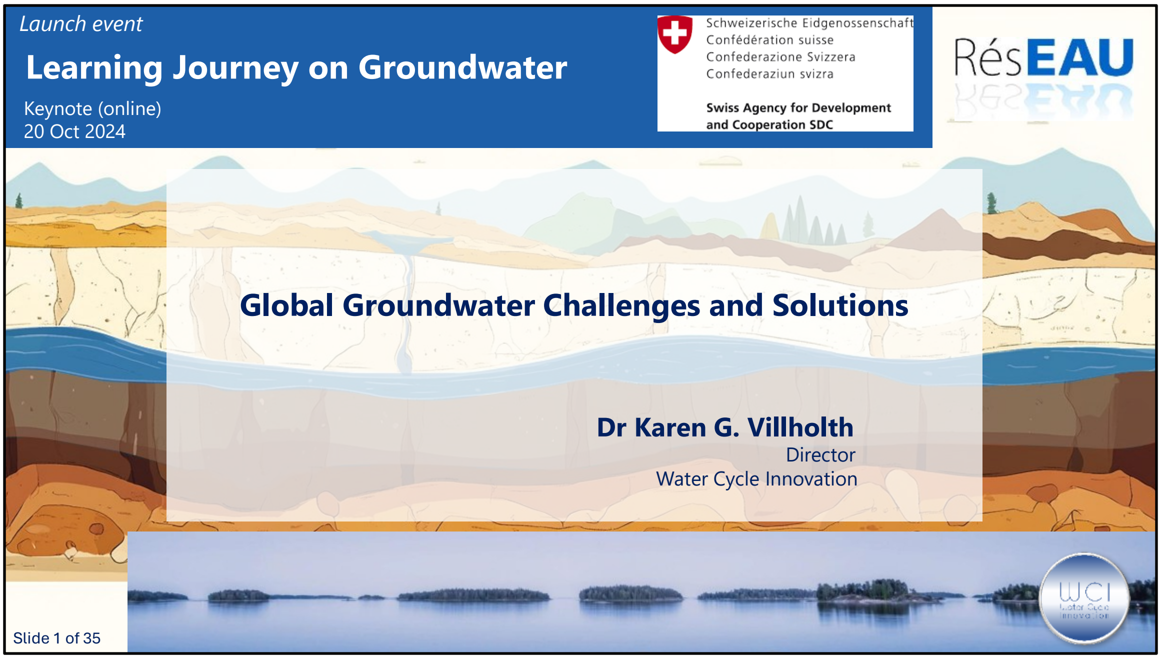


ResEAU is the water network of the Swiss Agency for Development and Cooperation (SDC). The Learning Journey is (for professionals in the international development cooperation community) to:

1. Explore the state of the art of groundwater projects
2. Discuss upcoming trends on how to **sustainably** manage this valuable resource across the globe

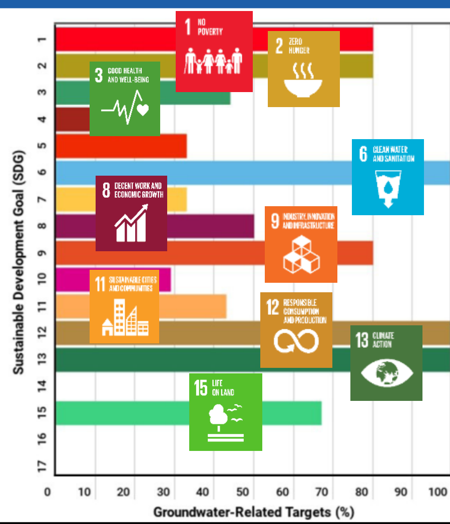
I see a growing interest among development partners in addressing groundwater (GW), whether coming from a WASH, water resources management, or climate adaptation perspective. This is good news.

Drivers:

1. Continued population growth, anticipated to reach 8.5 billion by 2030
2. Global food demand is projected to increase by 1.4% annually over the next decade, concentrated in low- to middle-income countries, versus a 1.1% per annum increase in production
3. Strong relationships and two-way linkages between natural resource crises and other risks, such as destabilization of economies, regimes, and global cooperation
4. These drivers and risks are exacerbated by climate change

My focus is on water quantity, and less on water quality, which is however, an equally, if not increasingly more concerning, factor related to sustainable GW management, as poor quality may make the resource unusable, multiply environmental impacts, and because reversing poor GW quality is costly, and long-term.

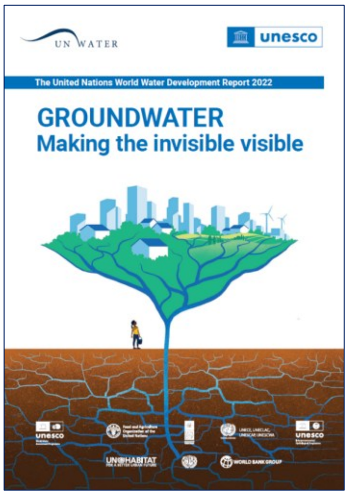
Groundwater and the SDGs



Guppy et al. (2018)

GW is essential for most SDGs - like water in general. GW, however, is generally not explicit in the SDG indicators, while this could be a central tool to monitor the status of this critical resource.

Groundwater - Making the Invisible Visible



United Nations (2022)

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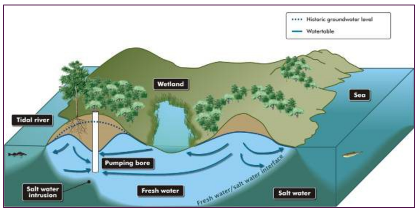
- This flagship report is a milestone in terms of Making GW visible, part of a campaign run in 2021-2022 by the UN system, culminating in the first global Groundwater Summit in Paris in Dec. 2022 as well as critical presence at the UN 2023 Water Conference in New York in Mar. 2023.
- GW is a local resource, but its management has implications at multiple scales, all the way to global.

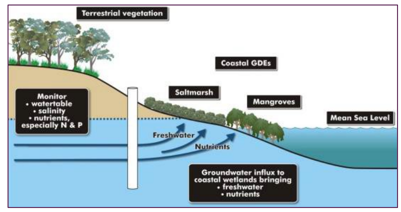
Groundwater facts and figures

GW provides drinking water to 33%
of the global population

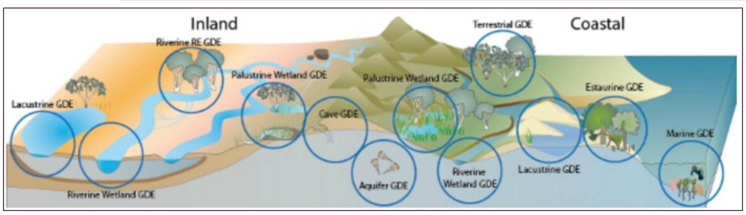
GW is the only source of freshwater for all human needs in many parts of the world, especially in remote and dry areas.

Groundwater-dependent ecosystems





http://www.bom.gov.au/water/groundwater/gde/GDEToolbox_PartOne_Assessment-Framework.pdf



GDE types:
- Aquatic
- Terrestrial
- Sub-surface

https://wetlandinfo.des.qld.gov.au/wetlands/ecology/aquatic-ecosystems-natural/groundwater-dependent/

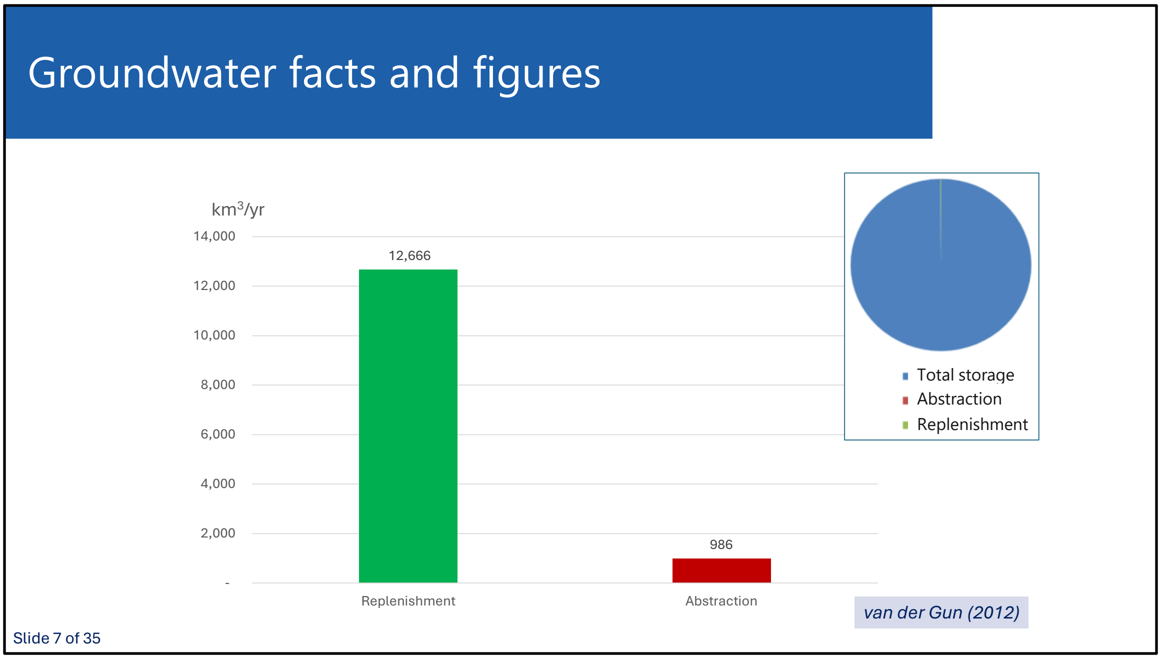
- Reminding us of the water cycle and the critical interlinkages between the different parts.
- Basically 3 kinds of GDEs:

(I) Ecosystems reliant on surface expression of GW (rivers, lakes, wetlands)

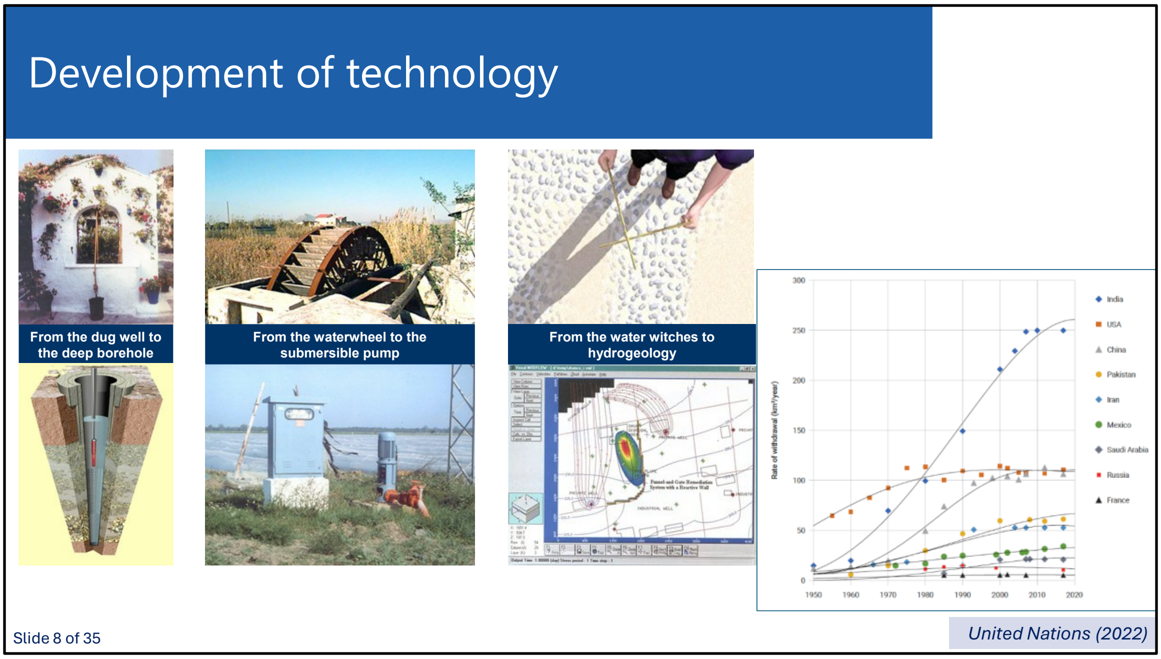
(II) Ecosystems reliant on sub-surface presence of GW within the rooting depth of the ecosystem

(III) Aquifer (inter-porous and cave ecosystems)

- GW strongly contributes to river flow and wetlands, which is often understated/misunderstood.
- From an environmental perspective: GW abstraction is sustainable, as long as essential barriers (often GW levels) are not transgressed. Sustainable systems cannot support GW abstraction exceeding average recharge over a long time.



- GW constitutes the largest freshwater resource on Earth - more than 95% of all (unfrozen) freshwater globally, yet only a fraction of this is accessible without affecting ecosystems or the resource itself and without exceeding large pumping costs. Hence, although the volume of GW stored on our planet is huge, only a small portion can be used annually without depleting this vital resource.
- Abstraction-wise, GW constitutes about 40% of global water use. Sector-wise, GW is estimated to globally provide 40-50% of potable water, 43% of water for irrigated agriculture, and 24% of industrial supply (FAO, 2024).
- The large volumes of GW can send a misleading signal: Like we have plenty of the resource, which is true, but not all is accessible - in the place needed and at the right cost and quality.



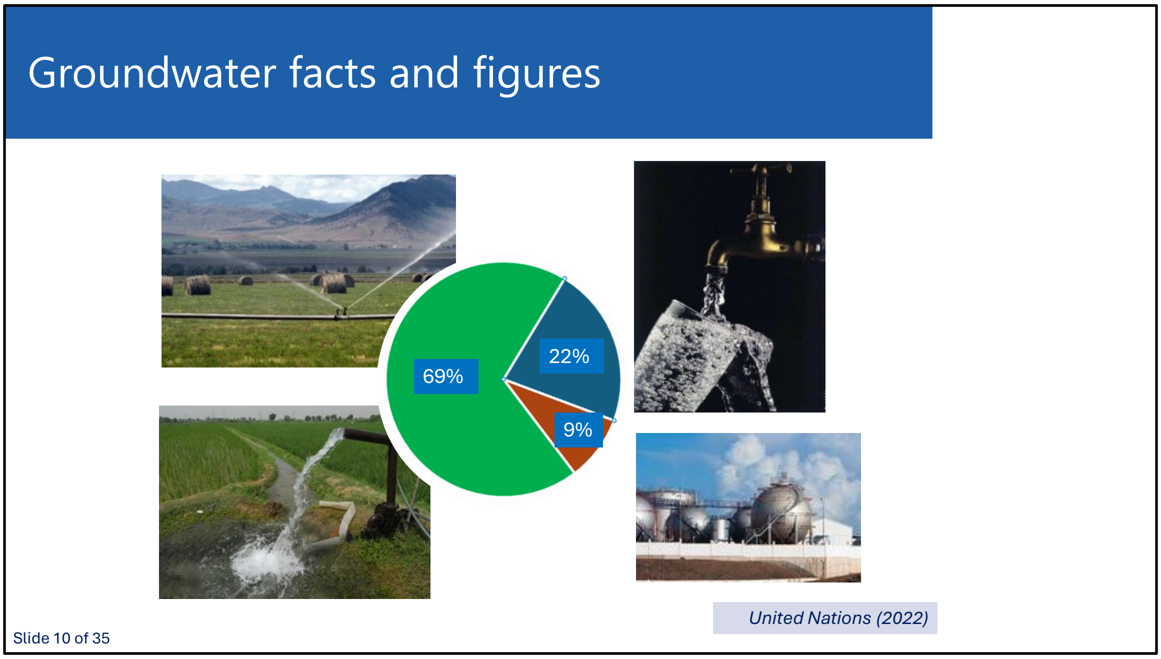
- GW development was facilitated in many regions by support and subsidies from governments to increase GW pumping (ironically sometimes due to waterlogging in surface water (SW)-irrigated areas).
- Significant increase in GW abstraction since the 1960's and 1970's.
- Global GW abstraction has increased more than fourfold in the last 50 years (FAO, 2016).

Why is GW an often-preferred resource?

GW provides a reliable and suitable water source:

- Prevalent across the landscape
- All-year availability and drought resilience
- In-built distribution and storage
- Individual access and management possible
- Little loss from evaporation
- Normally a safe source of drinking water

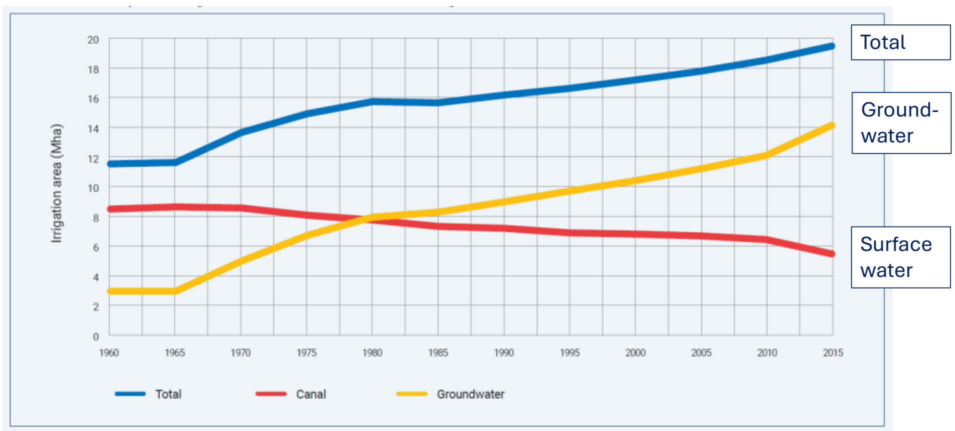
Once technology is in place and economic barriers to develop GW are surpassed, GW provides a multitude of benefits – but also risks.



Most water globally goes into agriculture/food production:

- Irrigated agriculture accounts for 70% of freshwater withdrawals (in some countries up to 90%), and an estimated 90% of all water evaporation (also called 'water consumption').
- It is plausible to assume that more than 43% of global food production relies on GW (Foster et al., 2015).
- One billion farmers in India, China, Bangladesh and Pakistan are dependent on GW for irrigation (Villholth et al., 2006).
- 20% of global irrigation from GW is causing GW depletion (Wada et al., 2012).
- 15% of global food production from GW is unsustainable (Villholth et al., 2015), a lot of this traded internationally, with implications for global food security.
- Extraction rates in GW-depleted regions/aquifers are 20 to 50 times higher than required for sustainable GW use (Dalin et al., 2017).

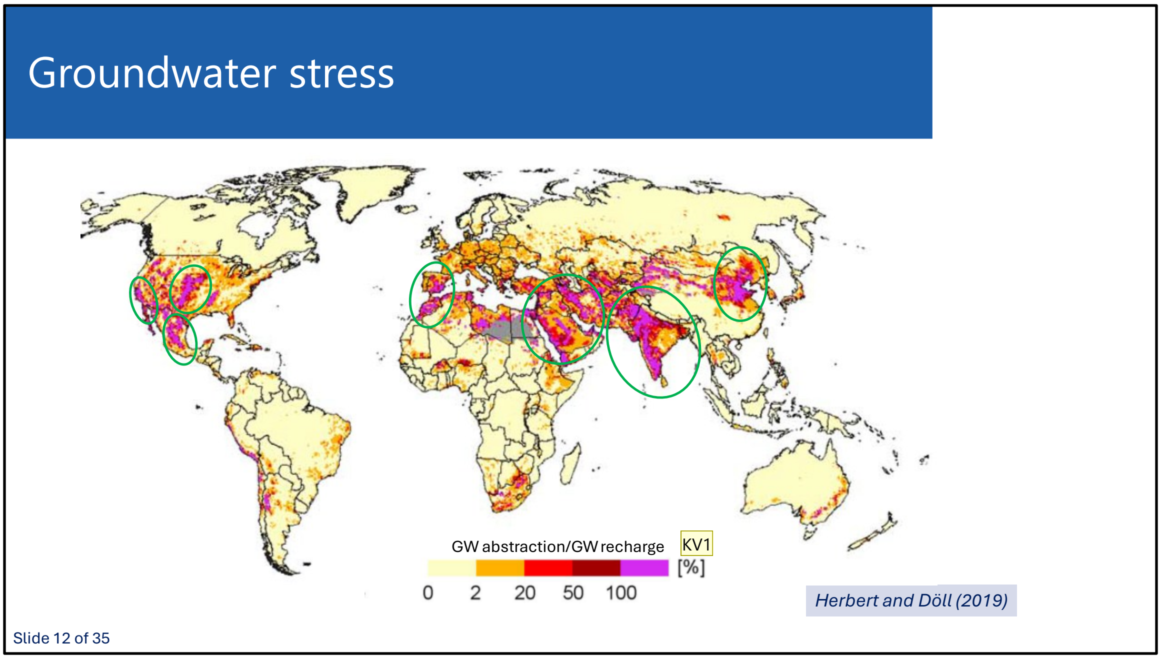
Groundwater facts and figures



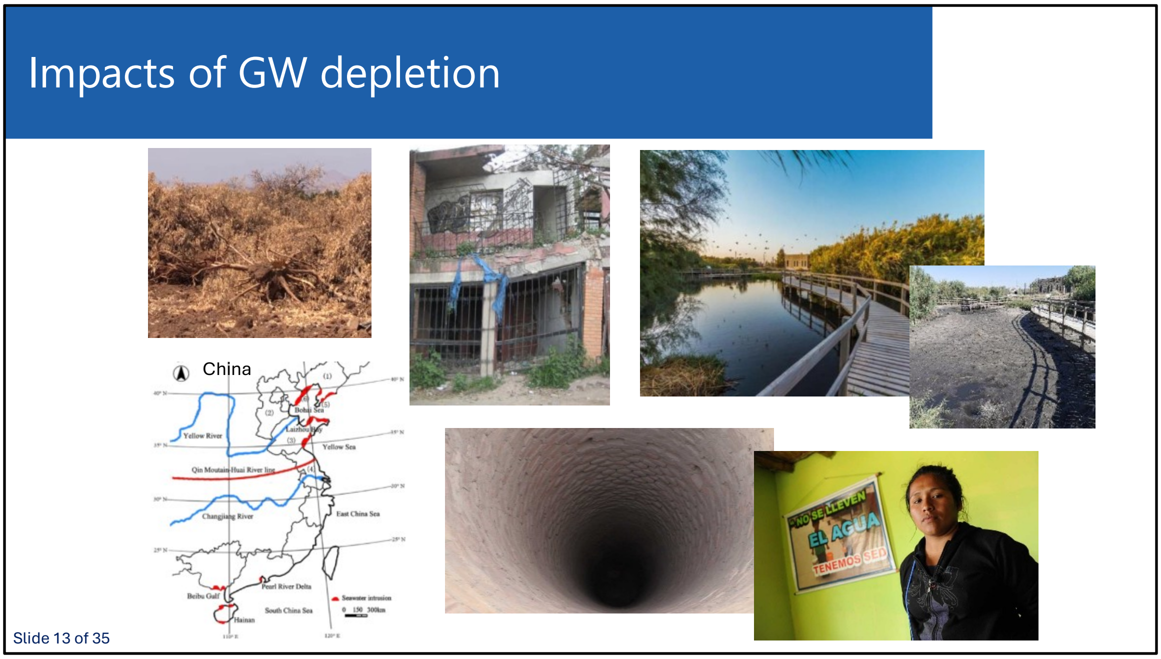
Source: Qureshi (2020, fig. 4, p. 6).

United Nations (2022)

- GW use for irrigation has surpassed that of SW in many countries, like India, and here Pakistan. SW is increasingly over-exploited, polluted, or not reliable in time.



- GW dependence and use varies globally. GW stressed/overdraft areas coincide with areas of high abstraction levels, little recharge (arid to semi-arid areas), and high GW-irrigation intensity.
- Globally, GW depletion (GWD) volumes have been estimated to around 200 km3/yr (Bierkens and Wada, 2019), corresponding to 20% of GW abstraction, but this can be up to 100% locally, where GW is mined in non-renewable aquifers (Dőll et al., 2014).
- The majority of GWD is taking place in ag. GW is also an increasingly important source of drinking water for cities. Some major urban centers are largely or entirely dependent on GW.
- GWD is becoming more pronounced on the African continent.
- Other measures/indicators of GW stress:
    - human-induced change in GW discharge to SW bodies
    - long-term decline of GW storage (GWS) due to GW withdrawals



1. Farmers abandoning their fields due to too high costs or inaccessibility of sufficient-quality GW
2. Land subsidence - irreversible
3. Depletion of SW water bodies (rivers/lakes/wetland)
4. Seawater intrusion (up to 50 km inland in China) – irreversible!
5. Social unrest due to lack of basic water access (violation of the human right to water and sanitation)
6. Loss of resilience against drought

Challenges to groundwater management

- Difficult to control the use, and make users comply with regulations and restrictions in use
- Difficult to determine/decide the sustainable use
- GW use is often associated with land use
- GW impacts are slow to appear and slow to remediate
- GW dependence is difficult to reverse
- GW is a complex 3-dimensional resource
- GW is developed as a ‘new’ or ‘alternative’ or ‘last-resort’ resource
- GW is developed/managed ‘in the dark’

=> Gaps in knowledge, capacity, regulations, and incentives
=> GW problems/solutions can be longterm/intergenerational

- Challenges are unique to GW because of its specific characteristics that are different to those of SW.
- The lack of effective GW governance is one of the root causes of GW depletion and degradation of aquifers.
- GW is *de-facto an* open access common-pool resource, non-excludable but subject to competitive abstraction.
- ‘GW sustainability’ cannot be uniquely defined – requires solid information on the resource, potential impacts, and an evaluation of trade-offs and priorities, ideally based on consensus among stakeholders.

Solar-powered irrigation – a new challenge

1: On grid: SPICE
Dhundi, Gujarat, India

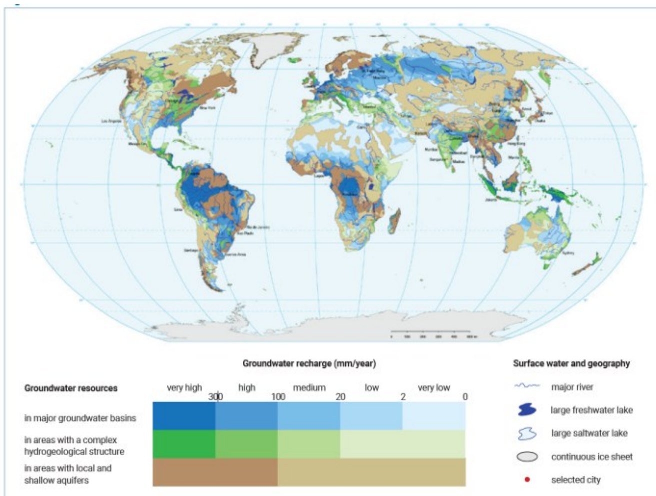
2: Off grid: Irrigation Service Provider (ISP Model) – Bihar, India

3: Off grid: Micro-irrigation
Ethiopia/Ghana, Africa

4: Decentralized grid: Solar Irrigation + Home enterprise

- The advance of solar-powered irrigation is causing another generation of GW management problems.
- Solar power is basically free, once it has been implemented, risking uncontrolled depletion.
- When supporting ag. water use through solar technologies, there is a risk of enhancing GW use, rather than controlling and protecting it.

Groundwater is complex



BGR and UNESCO (2008)

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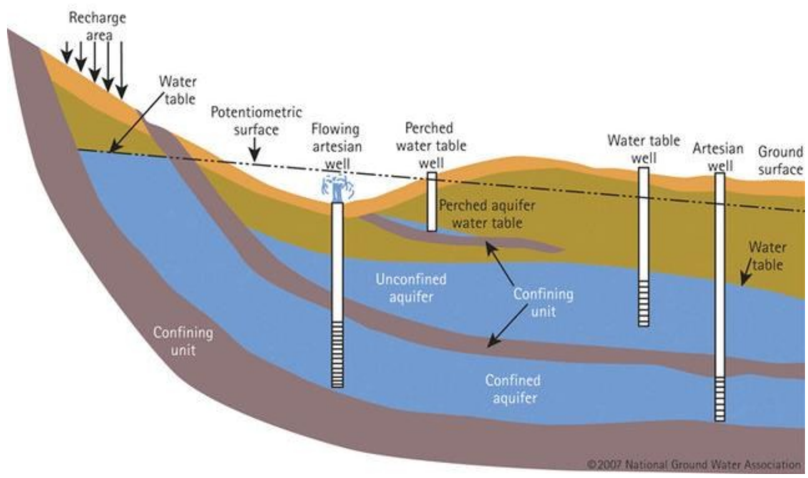
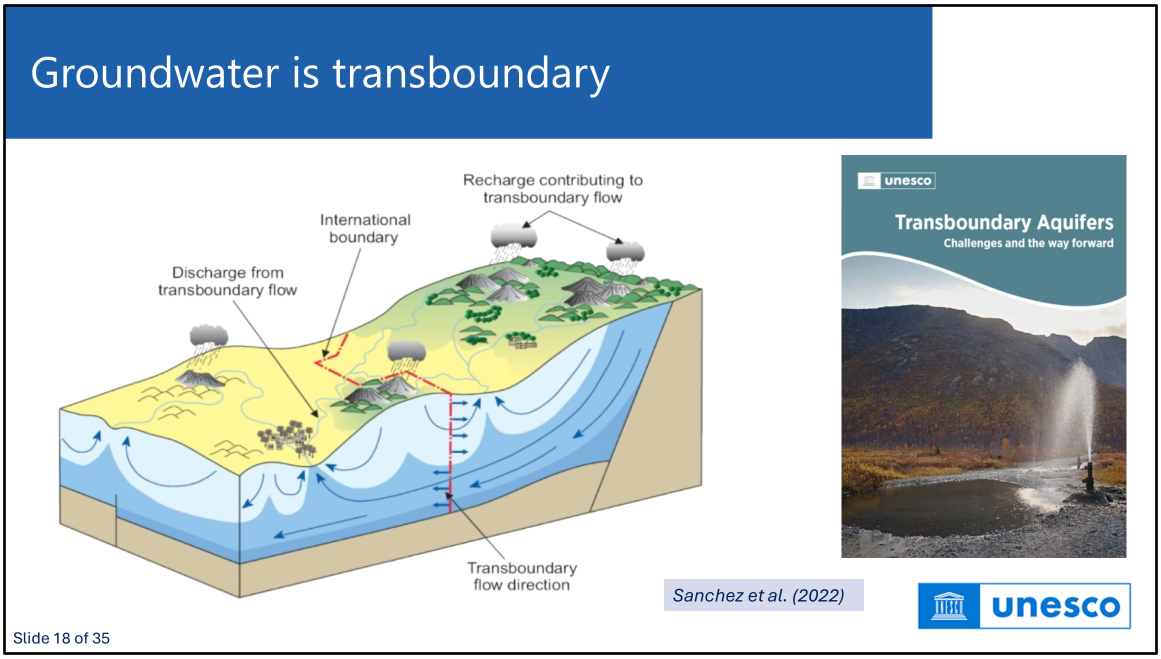
GW is found under highly variable conditions (here only aquifer type and recharge is shown), significant for the management and governance.

Groundwater is complex

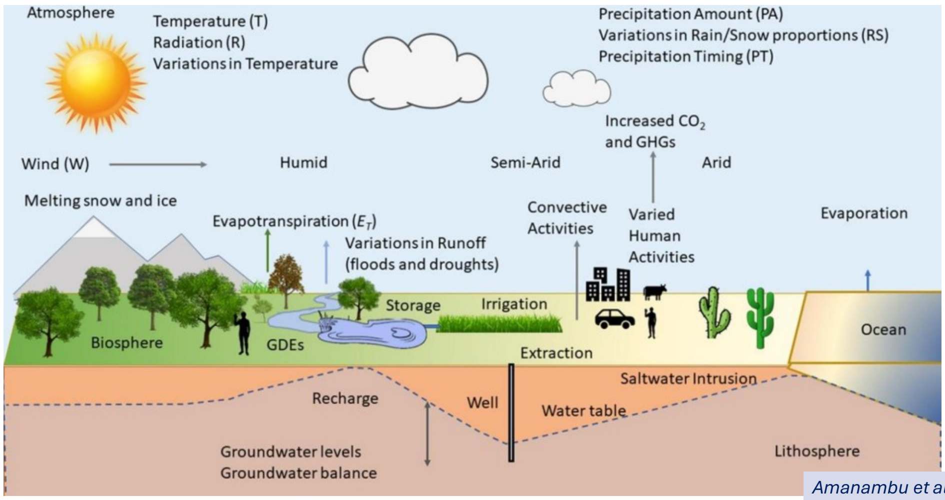


- Locally, GW conditions need to be well-known.
- Generally, complexity stands in the way of sustainable management, but not (unsustainable) use.



- Complexity in GW governance is compounded by the fact that aquifers oftentimes are transboundary.
- Globally, 468 transboundary aquifers (TBAs) have been identified. 106 TBAs (approx. a quarter) of these have been mapped in Africa. In Central Asia, TBAs abound, and work has only just started. Likewise in most regions.
- The UNECE Water Convention is accompanied by a set of Model Provisions for Transboundary GW (UNECE, 2014) and advocates for the conjunctive mgt. of SW and GW. Conjunctive water mgt. (CWM) should address the unique attributes of each resource and aim to take advantage of their individual benefits in the planning of water development, use and management.
- Examples of formalized CWM are limited (nationally, and in particular transboundary). Examples to integrate GW into transboundary water governance is the Orange-Senqu (2017) and the Limpopo (2019) River Basin Organizations in Southern Africa.
- Transboundary cooperation on water (incl. on TBAs) may counteract transboundary conflict and enhance diplomatic ties, based on joint knowledge generation/sharing. Local cooperation on shared GW is also observed but typically more informally, and dealing with smaller-scale issues (like WASH).

Groundwater and climate change



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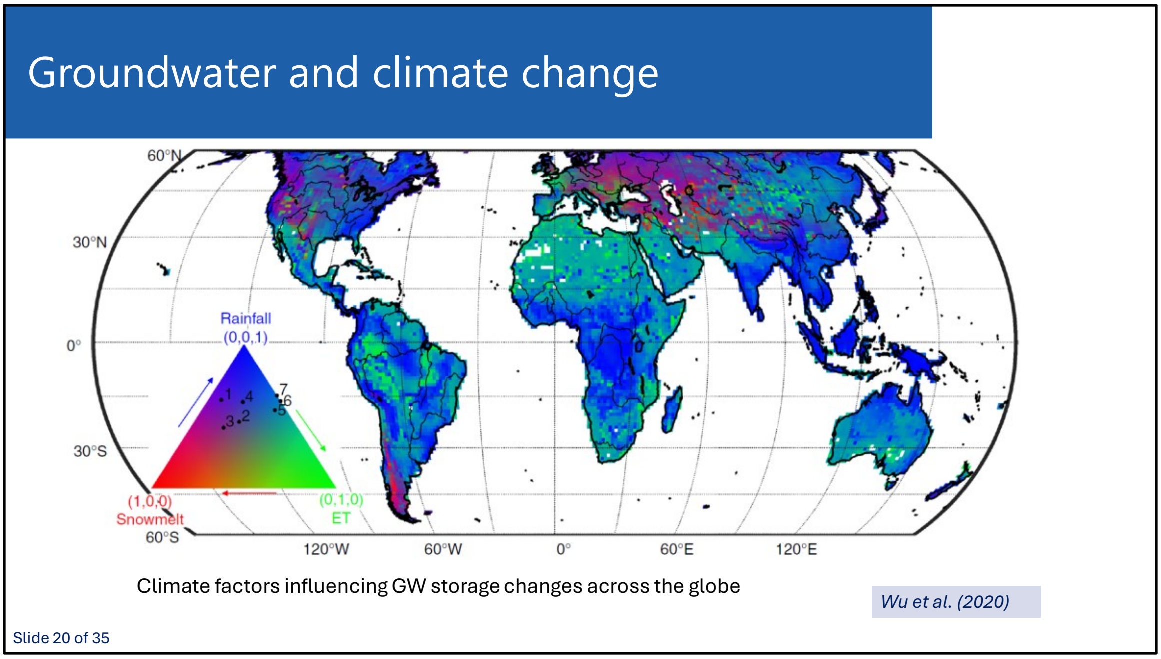
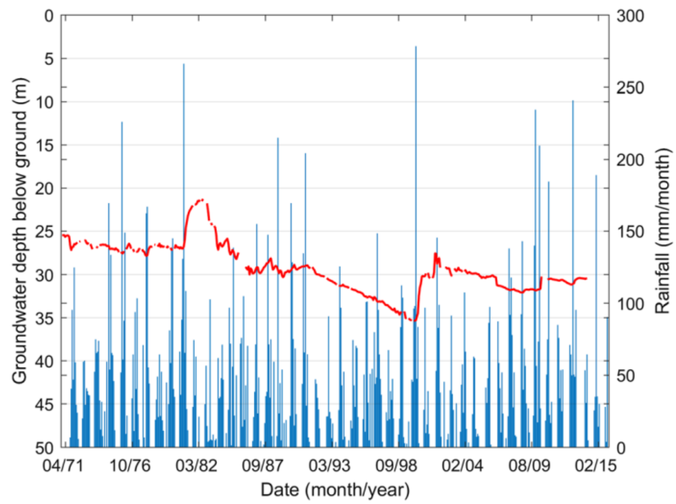
Amanambu et al. (2020)

- GW provides a buffer to climatic variability, can support CC adaptation and DRR.
- GW is affected through many processes that are governed by climate, importantly recharge.
- CC affects GW recharge through changes in T, P (rain vs. snow), and ET. Other factors influencing GW recharge are: precipitation intensity, land cover/land use, soil properties, and soil freeze-thaw cycles.



- Impacts of CC on GW (simulated with the CESM-CLM and using scenario RCP8.5) depend on many factors but may likely be overridden by the increased human demand for water (Wu et al., 20220).
- With only CC acting, Central Valley in Calif. would not experience long term trends in GW storage (GWS), Euphrates/Tigris, and the Southern US Plains would experience a decrease, while the GWS in the Indo-Gangetic Basin and the North China Plains an increase.

Groundwater is the saviour – and long-term victim of climate change



Ebrahim et al. (2019)

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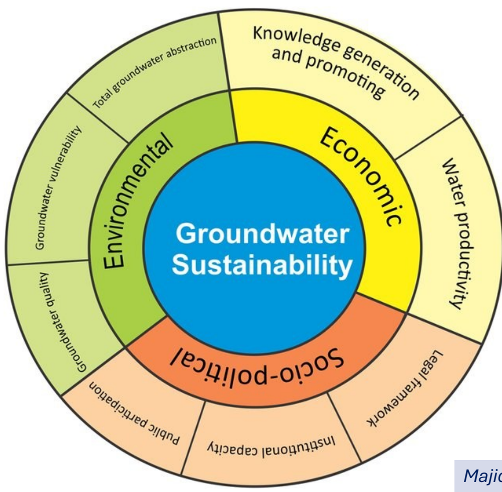
In arid areas, higher variability of climate could be generating more decadal patterns of GWS (rather than annual), with sudden replenishment during episodic events, while undergoing interim depletion over extended periods.

Groundwater governance components



Majidipour et al. (2021)

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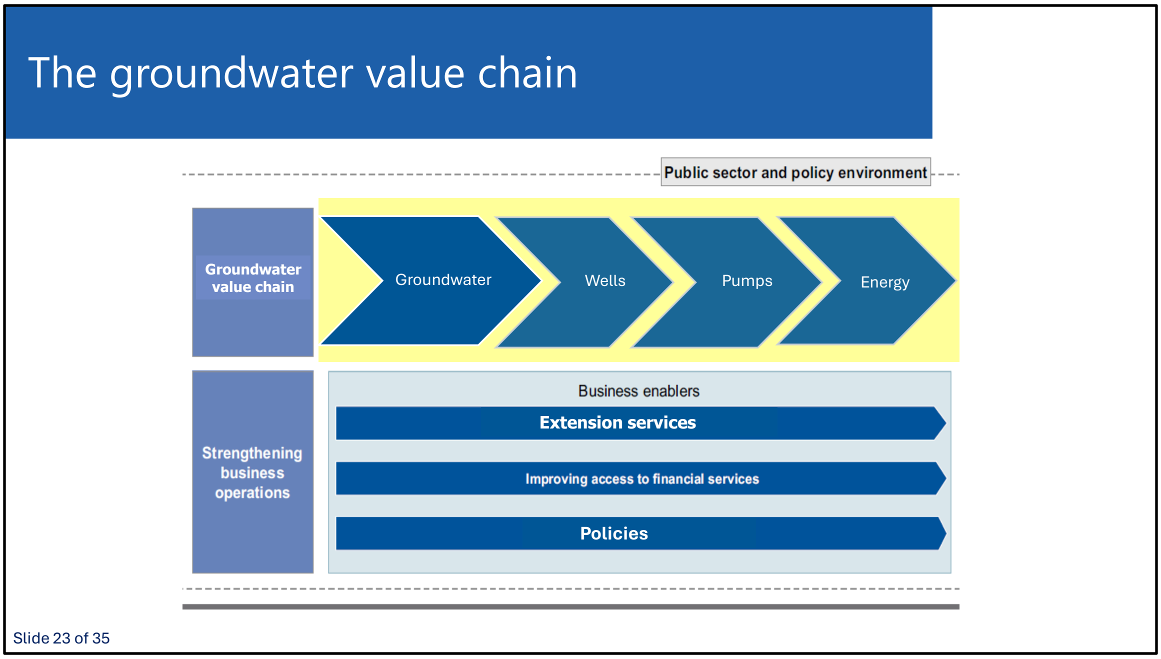
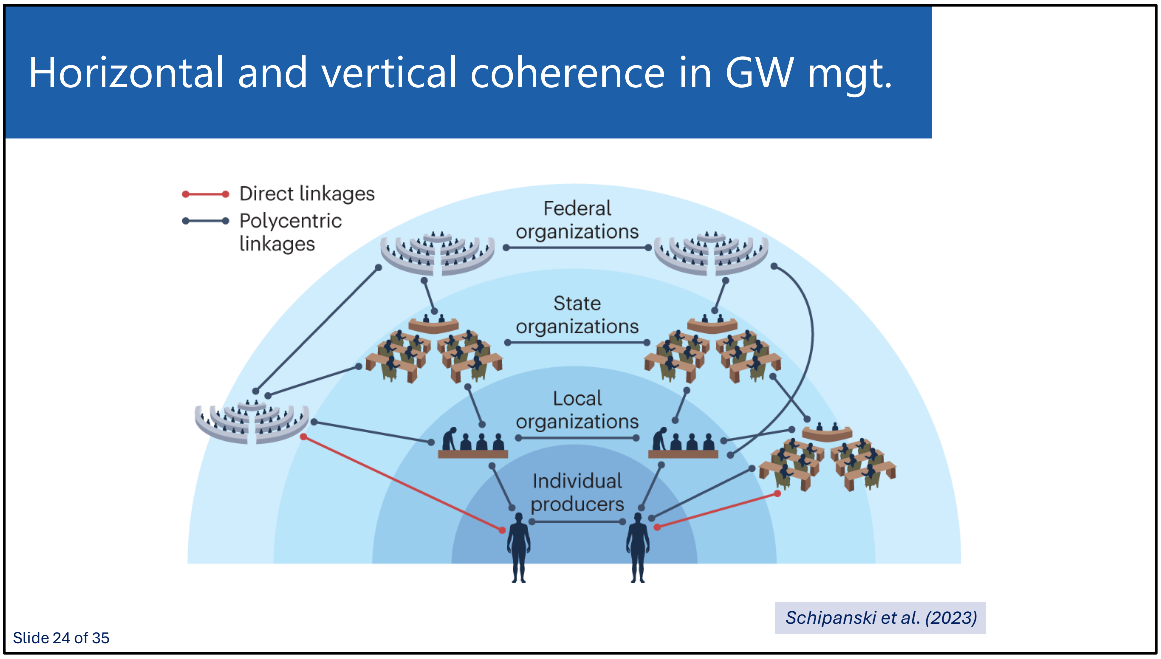
- GW governance is defined in accordance with the UN set of eight core tenets: (1) responsibility, (2) accountability, (3) transparency, (4) efficiency, (5) legitimacy, (6) participation, (7) equity and inclusiveness, and (8) rule of law.
- Definition of GW governance: *Groundwater governance is the framework encompassing the processes, interactions, and institutions, in which actors (i.e., government, private sector, civil society, academia, etc.) participate and decide on management of groundwater within and across multiple geographic (i.e., sub-national, national, transboundary, and global) and institutional/sectoral levels, as applicable* (Villholth et al., 2018).
- Good governance is a lot about managing tradeoffs and engaging stakeholders.

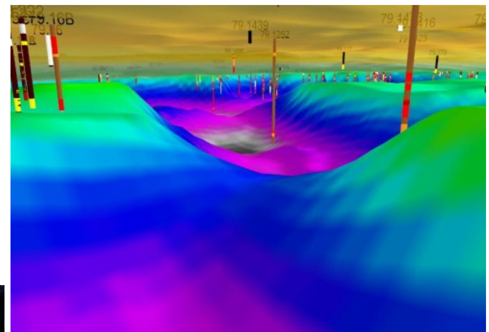


- Another framework to use for GW management is the GW value chain, which builds on the food value chain concept, as well as the nexus approach.
- E.g., pumping uses huge amounts of energy, but energy is often heavily subsidized, so the true cost of GW extraction is hidden.



- Polycentric governance capacity and strategic planning tools are key.
- Realizing that all stakeholders have different incentives, agendas, and capacities.
- The state as coordinating and rule setting entity and promoter of decentralization, and knowledge generation, sharing and application.

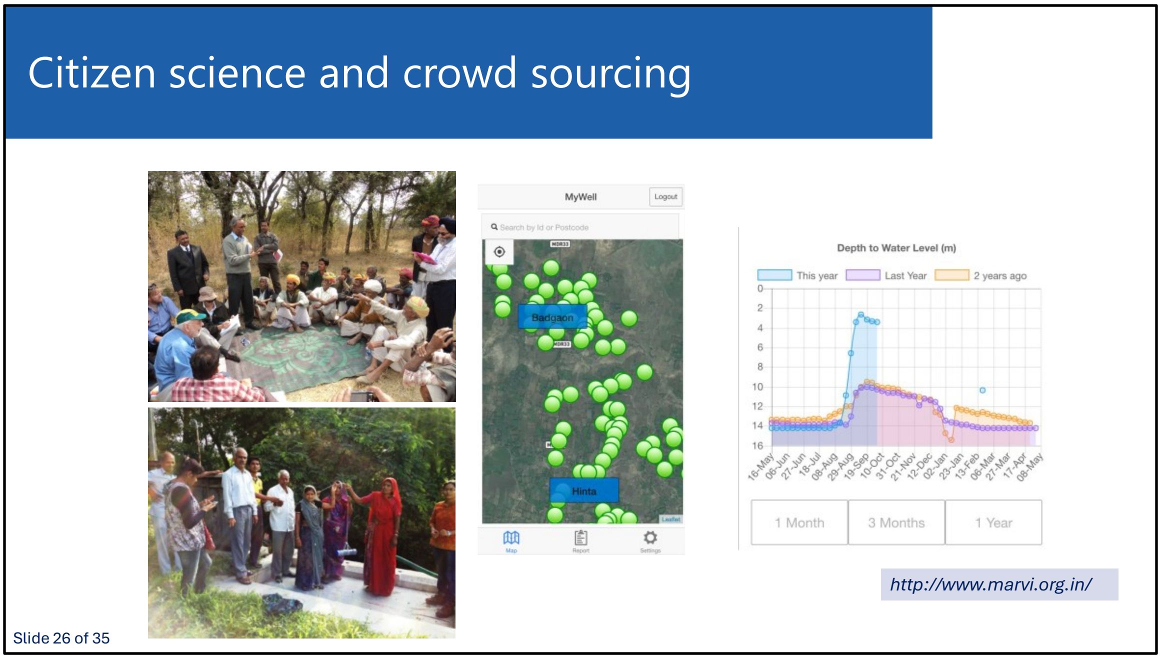
Big data, IoT, AI, machine learning



Courtesy: GEUS and SkyTEM

GRACE twin satellites

- Increasingly, GW science and management undergoes ‘datafication’. Also called the 4th industrial revolution. Significant new knowledge and tools are generated. Downsides: Costs, proper interpretation of data (fundamental hydrogeological knowledge cannot be replaced), and risk of digital divide.
- Enhanced information systems must be understood and conceptualized as a system.
- Data can also be sensitive and contested.



- Another growing trend in GW management is to involve local stakeholders in self-management of GW, including monitoring of the resource and adjusting use accordingly, enhancing rainwater harvesting and recharge, and managing land use. In India, Pakistan, Spain, Mexico, or the Western US where GW use is intensive, the governments are already investing a lot in citizen education (Lopez-Gunn et al., 2024).
- GW serious games are also new initiatives (e.g., https://savethewater-game.com/).
- Following issues should be considered (Lopez-Gunn et al., 2024):

(1) Incentives for stakeholders to participate should be in place (by design or by outer factors, like drought)

(2) Due attention is given to the social and institutional frameworks in which the adoption takes place

(3) Building trust between stakeholders (users, informal and formal institutions)

(4) The need for adequate resources in terms of time, coordination costs, and education (ideally, decentralization should be accompanied by financial self-sufficiency)

(5) How the use of technology could influence power balance/social justice

Southern Colorado case

'It seems stupid to actually tax yourselves and cost yourself more money," Messick says. "But the big picture is you stay in business, you keep your community whole, and everybody gives a little.'

https://www.npr.org/sections/thesalt/2017/11/18/562912732/to-save-their-water-supply-colorado-farmers-taxed-themselves?t=1556724394170

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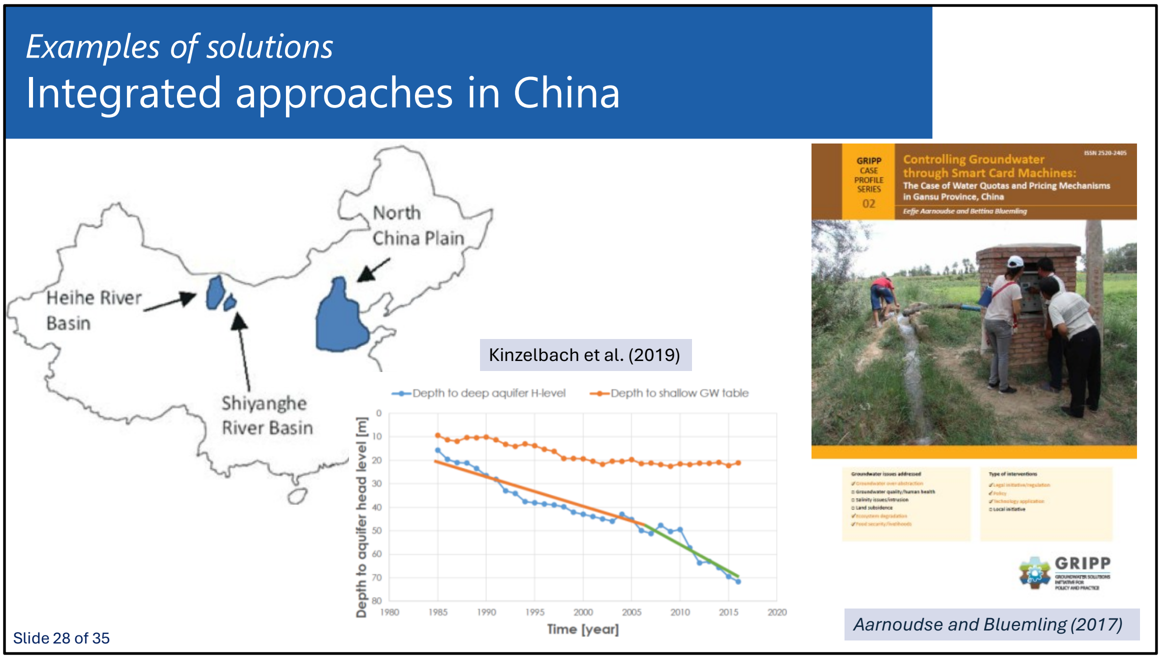
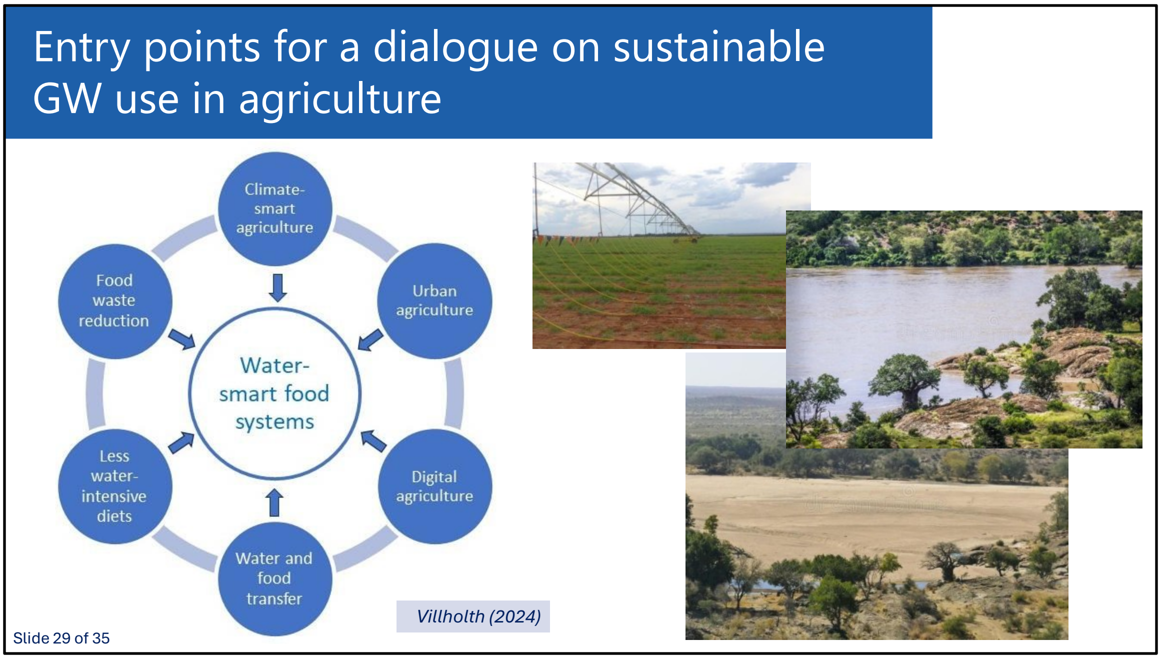
- Farmers are facing exhaustion (termination of productive lifetime) of aquifers in parts of USA. Options are to migrate, change livelihood (rainfed farming, cattle ranching, etc.), or like here, try to maintain the aquifer through agreeing to be subjected to state taxes, which are returned into protection of the aquifers.
- Re-orient priorities to sustaining aquifer-dependent communities instead of maximizing productivity at the scale of individual farms or industrial users.

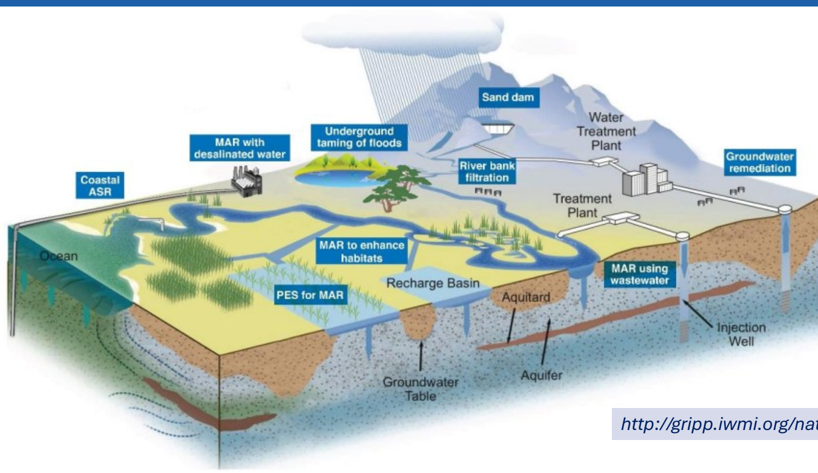


- **North China Plain**: Subsidized seasonal fallowing (taking out irrigated winter wheat), subsidies for drip irrigation, SW import from south, water metering and prizing, remote sensing of cropping, integrated decision support tool (using electricity as proxy) (Kinzelbach et al., 2022). Changes in food imports?
- **Heihe River Basin**: water fees and quotas, along with strict monitoring of GW levels and pumping
- Significant success, but uncertainty related to climate change, demographic/socioeconomic changes (small farmers exiting, larger farmers coming in), diet changes, and science on new water-saving crops. Reversing salinity intrusion is critical and GWQ in general.



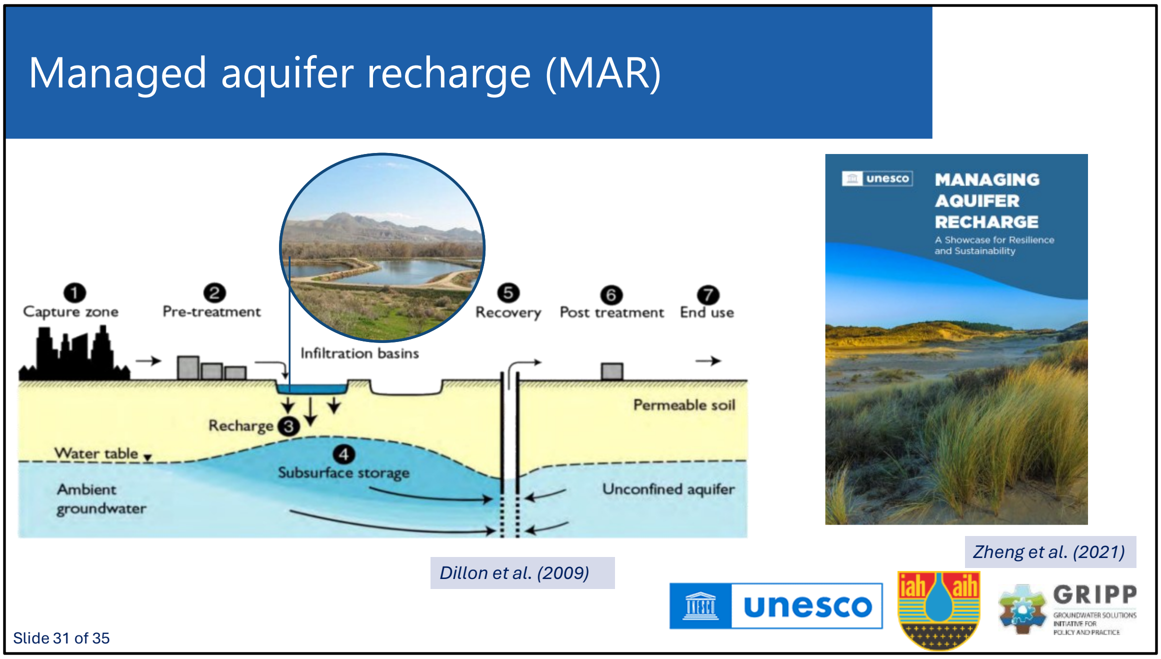
- GW importance in food security is partly neglected, because of broader narratives, linked to sustainability, health, climate, global economics and geopolitics. However, it is important to raise the flag for GW in dialogues of food security and safety, especially as we know the fact that significant GWD will become a black joker in future food supply.
- The discourse of ‘efficient’ irrigation is a double-edged sword. It may lead to higher water productivity (food produced per volume of water used), but overall water may not get saved in the process (the Jevon complex).

Groundwater-based natural infrastructure



http://gripp.iwmi.org/natural-infrastructure/

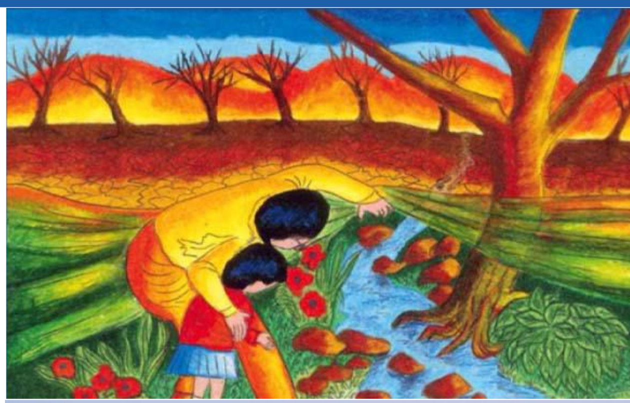
- The interaction between GW and SW water systems (rivers, wetlands, lakes) has not been adequately considered nationally or in most transboundary river basin management initiatives.
- SW and GW needs to be managed together – what is often termed "conjunctive water management" (CWM) - to increase resilience and counteract critical depletion.
- A wealth of integrated nature-based solutions, where GW is actively and purposefully planned and integrated, has been developed, sometimes called GW-based natural infrastructure (GBNI).
- Very critical for CC adaptation.



MAR (manged aquifer recharge) is one of the most well-known examples of GBNI. It is widely implemented across the globe, in various climates, settings and for various purposes (urban-rural, water supply-agriculture). The proper planning and management of these systems are paramount.

GW efforts/projects should not become siloed, but be part of integrated efforts/projects, but with strong/dedicated emphasis on GW. Capacity development among and for all partners is paramount.

Thank you for your attention



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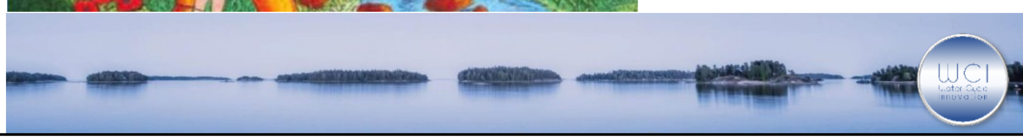

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