Reclaimed Water for Managed Aquifer Recharge: Managing Conventional and Emerging Water Quality Risks

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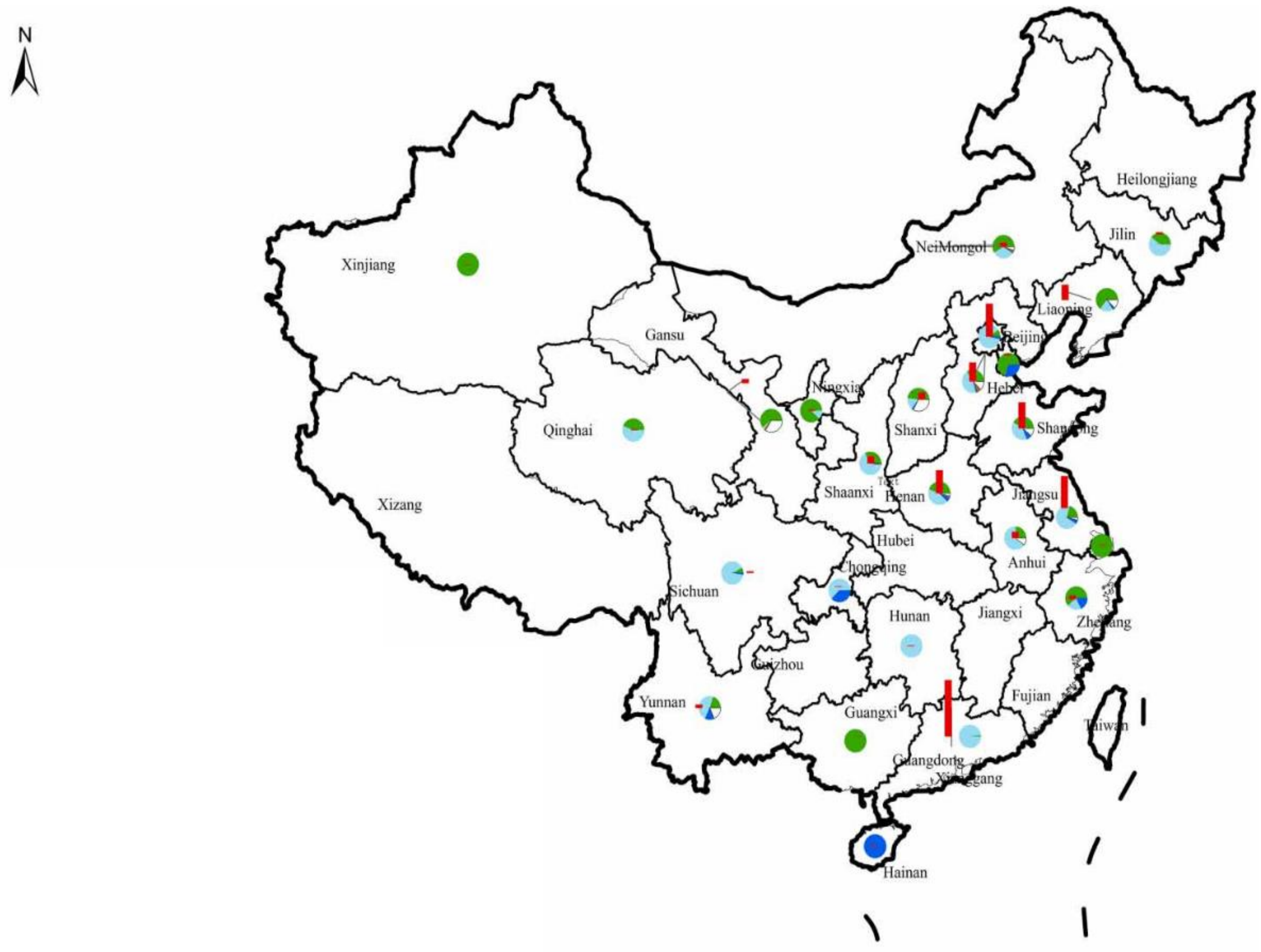
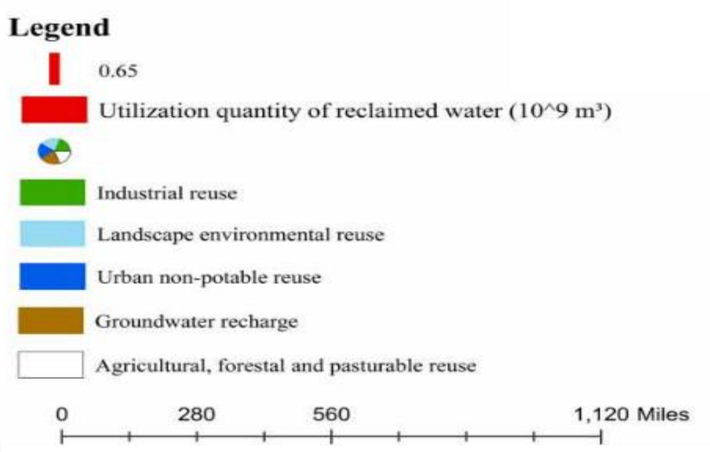
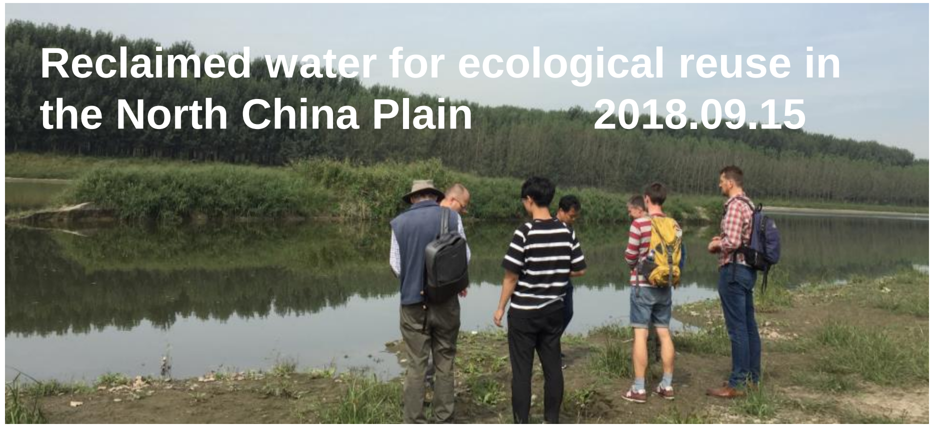
Utilization of reclaimed water in China

Reclaimed water *is a water resource generated by processing treated sewage effluents that can be reused for other purposes.*







Utilization quantity and different utilization objectives of reclaimed water across China in 2015. *Zhu and Dou (2018)*

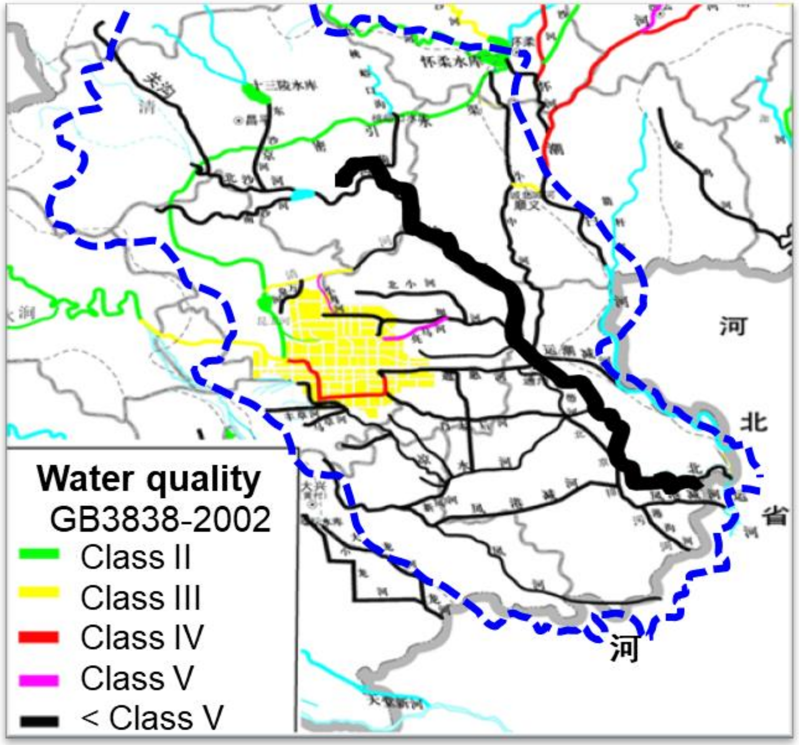
Water quality risks in unmanaged aquifer recharge

- The discharge of reclaimed water to recover ecological flow and further infiltrate into groundwater is **incidental aquifer recharge**.

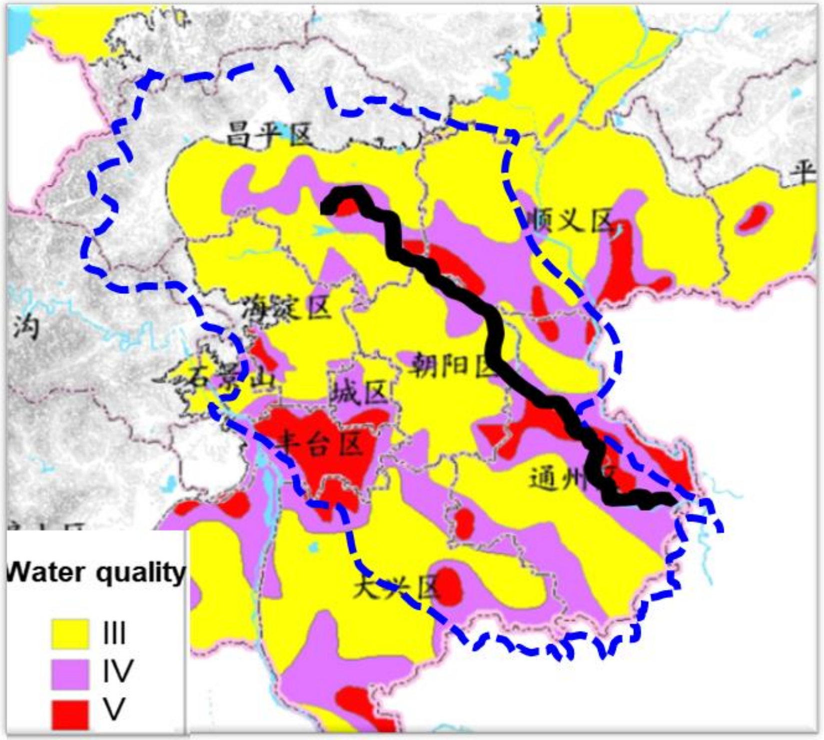
- **Groundwater quantity!** vs. **Groundwater quality**?

- An example of the Beiyun River in the North China Plain, where > 90% of the river flow is reclaimed water.

Sources: Beijing Institute of Geo-Environment Monitoring

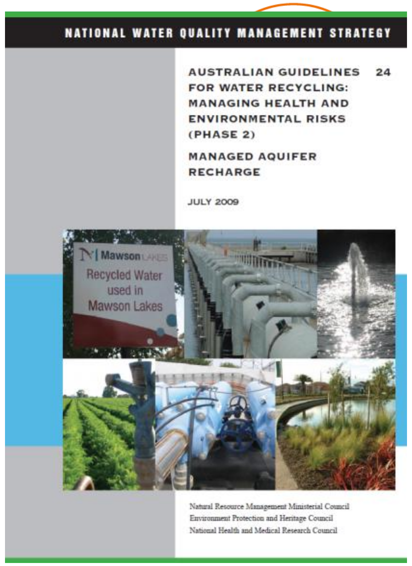


Surface water quality



Shallow aquifer water quality

Water quality risks associated with reclaimed water

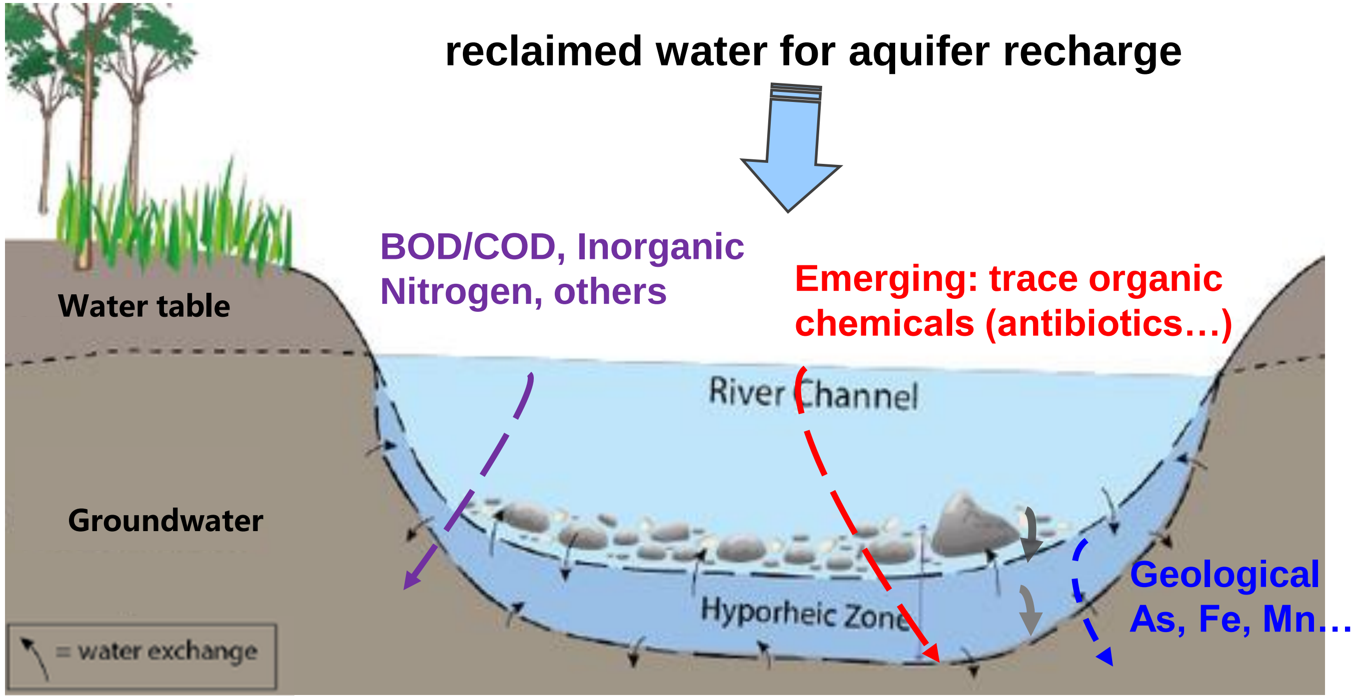


According to the "Australian Guidelines for Water Recycling: Managed Aquifer Recharge 2019", the following must be considered:

- *source water for recharge*
- *native groundwater*
- *aquifer minerals reacting with recharge water*
- *byproducts of treatment processes or maintenance practices.*

Contaminants in reclaimed water for MAR

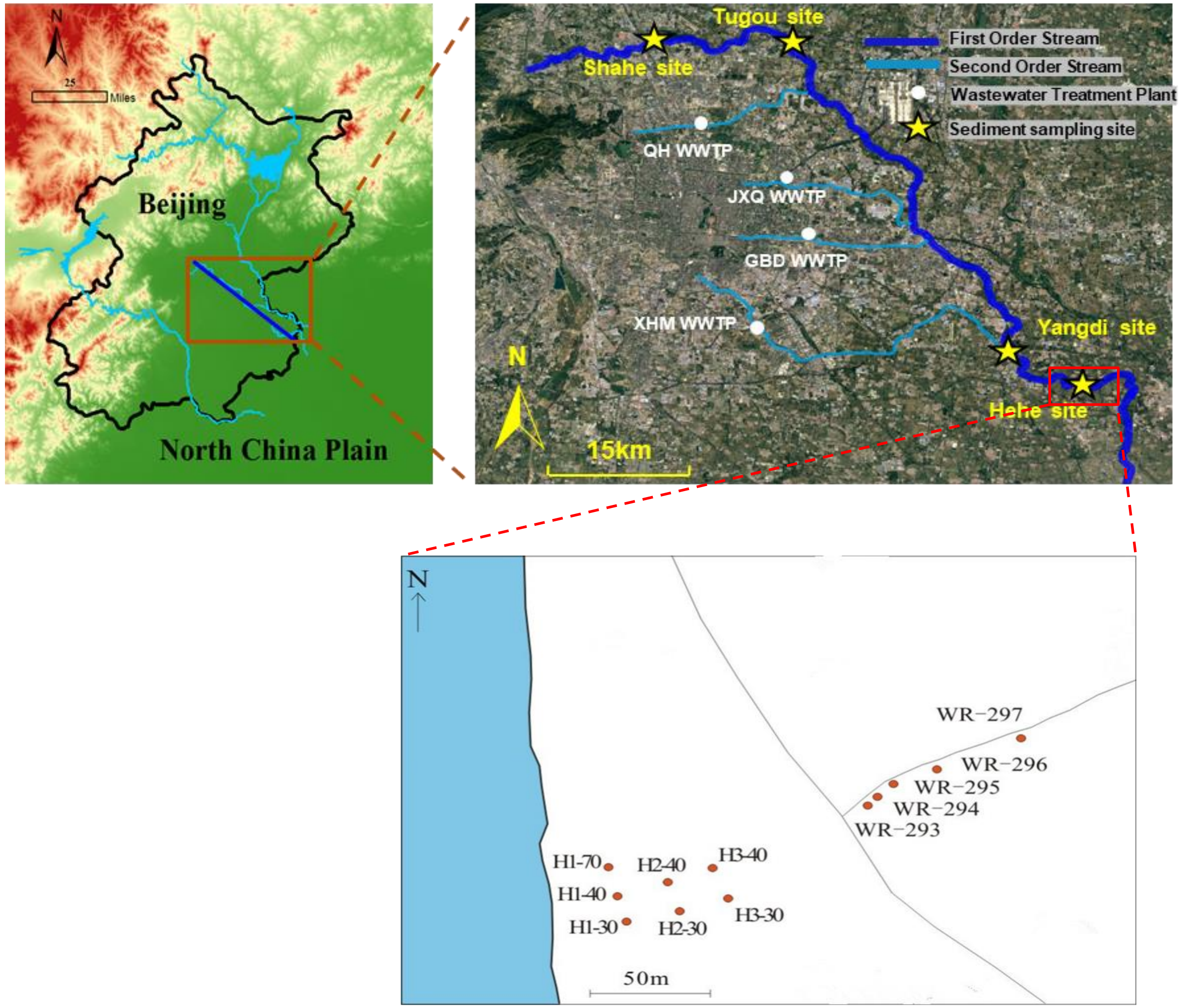
1. **Conventional**
2. **Emerging**
3. **Pollutants from reactions with aquifer minerals**



Clarke and Neild "Geomorphological Techniques 2015"

1. Contaminants in reclaimed water-affected groundwater

- The Beiyun river flow is maintained by reclaimed water.
- Water sampling of surface water and groundwater (2018-2019)



Cross-section of groundwater monitoring sites

- **Conventional**

	Dissolved TOC	Dissolved TN	Nitrogen		
			NH_4^+	NO_2^-	NO_3^-
	mg/L	mg/L	mg-N/L		
Surface water	6.1 ± 2.1	6.6 ± 2.8	1.8 ± 2.0	0.17 ± 0.15	6.4 ± 4.0
Groundwater	3.8 ± 2.0	5.0 ± 5.5	3.8 ± 5.3	0.01 ± 0.00	1.5 ± 2.9

- **Emerging**

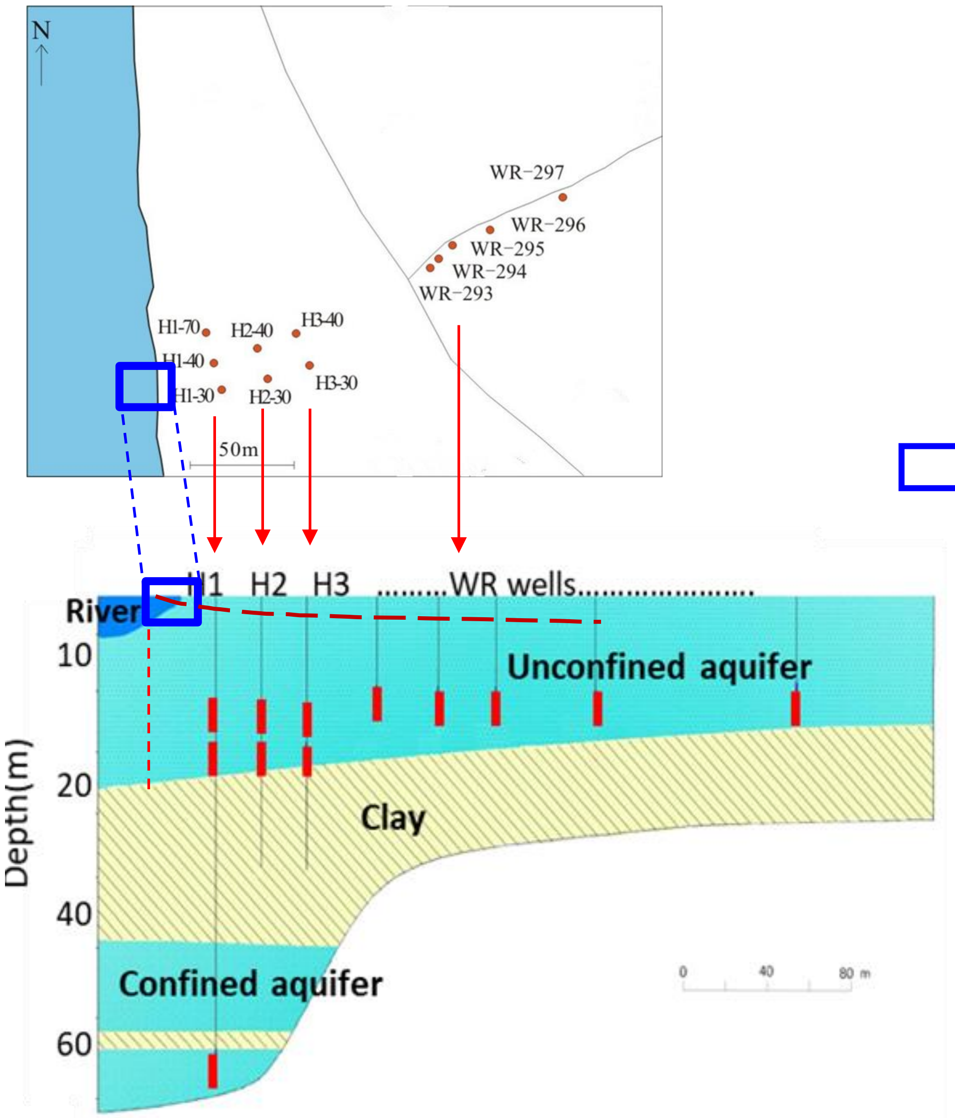
	Trace Organic Chemicals (TrOC)*			
	SMX	SMZ	CAF	IBU
	ng/L			
Surface water	10 ± 4	3 ± 1	343 ± 72	239 ± 92
Groundwater	2 ± 3	202 ± 294	155 ± 131	71 ± 50

- **Pollutants from reactions with aquifer minerals**

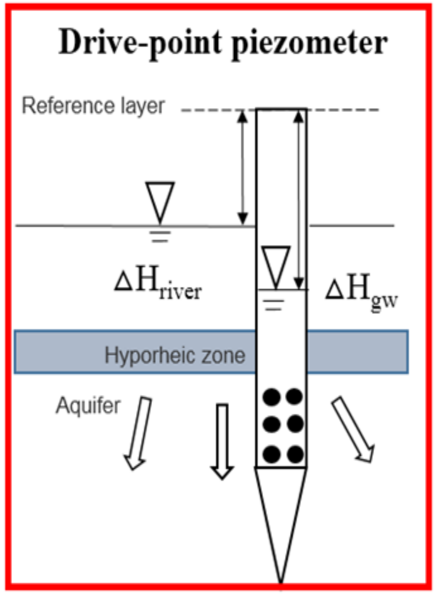
	Conductivity	Fe		Ca^{2+}
		Fe (II)	Total Fe	
	uS/cm	mg/L		
Surface water	650.3 ± 121.5	0.01 ± 0.00	0.04 ± 0.03	45.2 ± 6.8
Groundwater	1056.9 ± 320.4	2.05 ± 1.85	3.25 ± 2.84	92.1 ± 25.3

Contaminant profiles at the river cross section

- A riverbank filtration site at Hehe (2019)

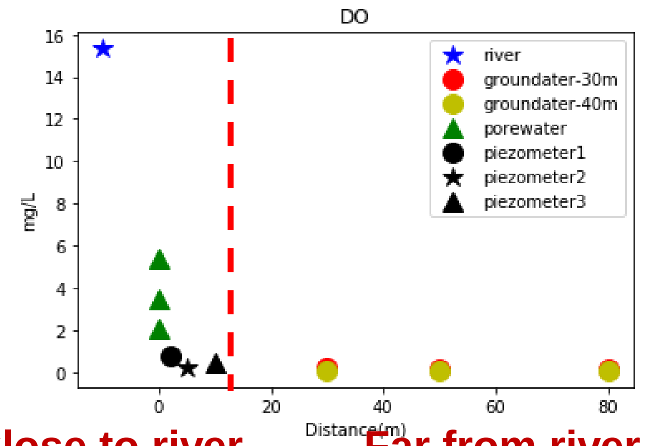


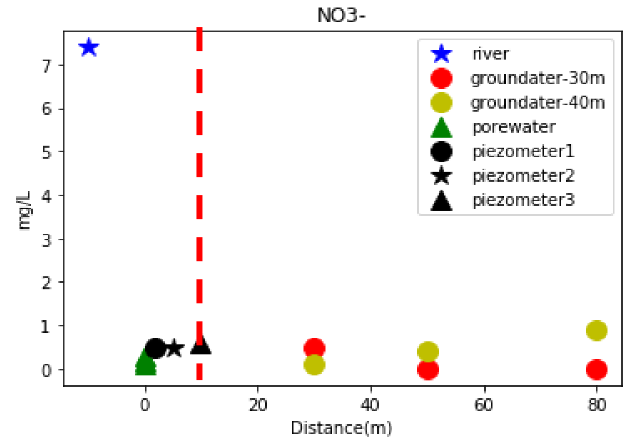
Beijing Institute of Geo-Environment Monitoring

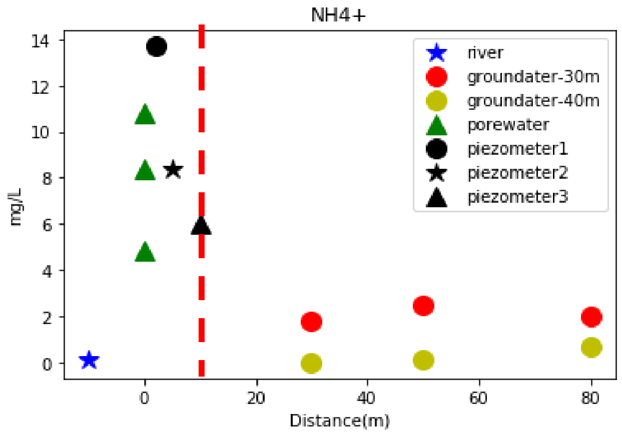


Cross-section monitoring:

- **Conventional…**
(inorganic N…)



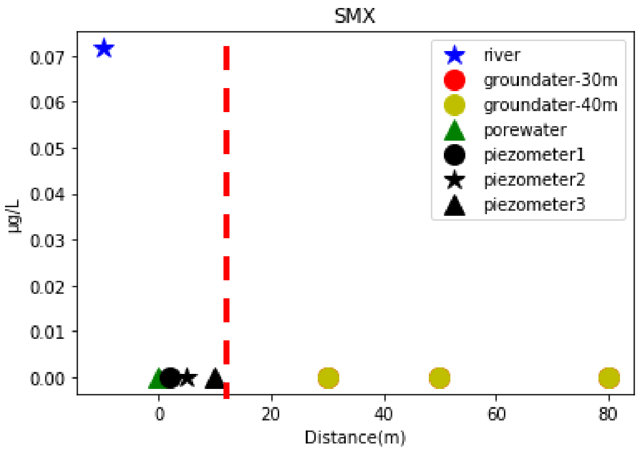


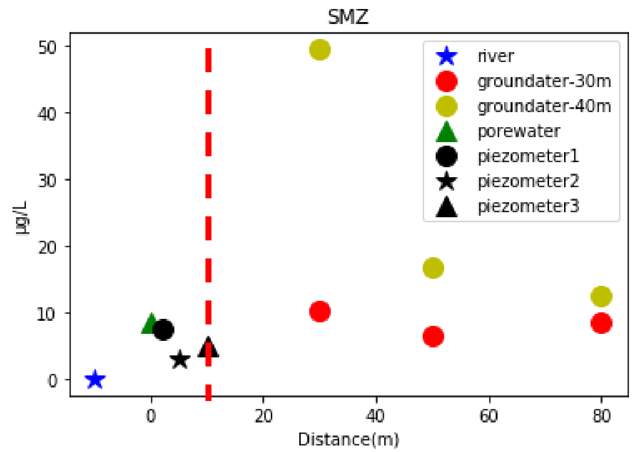


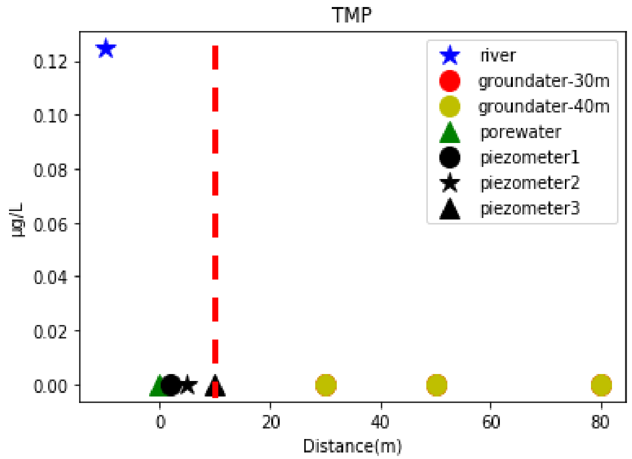
Close to river

Far from river

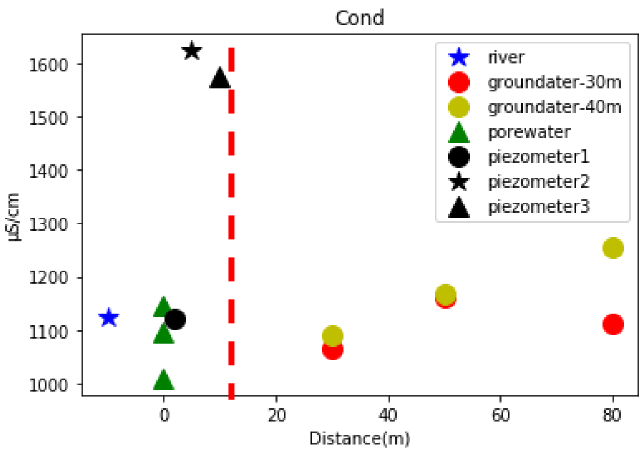
- **Emerging trace organics…**
(three antibiotics)

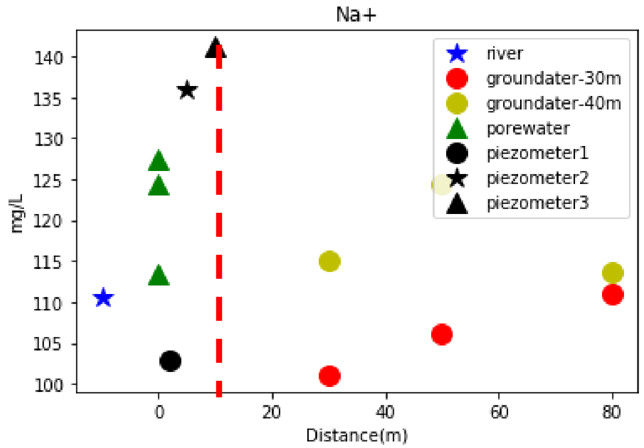


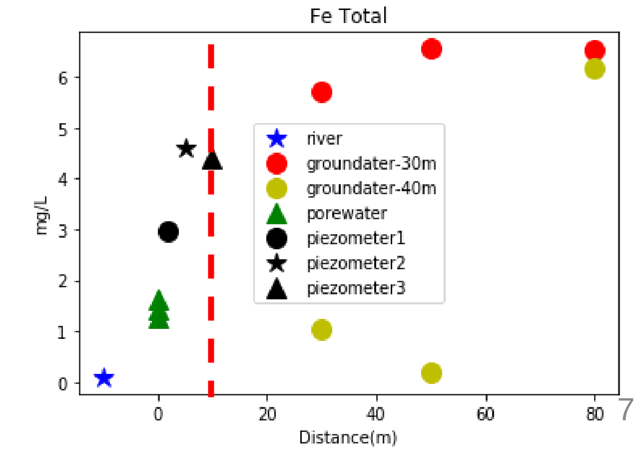




- **Pollutants of geological origins**
(conductivity, Na^+, Fe)





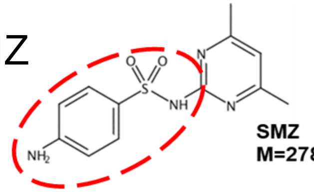


2. Antibiotics selected as emerging contaminants for investigation

- **Antibiotics** – persistent and toxic trace organic pollutants.
- 70% is excreted unchanged into wastewater, and **high-frequently detected** in the Beiyun river (up to ppb levels).
- Low concentrations (ng/L ~ µg/L) – increase **antibiotic-resistant** microorganisms and spread antibiotic resistance genes.

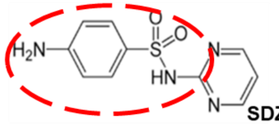
3 sulfonamide antibiotics:

- Sulfamethazine- SMZ



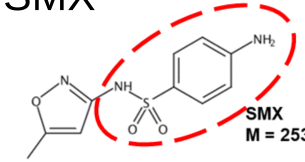
SMZ
M=278.33

- Sulfadiazine- SDZ



SDZ
M = 250.28

- Sulfamethoxazole- SMX

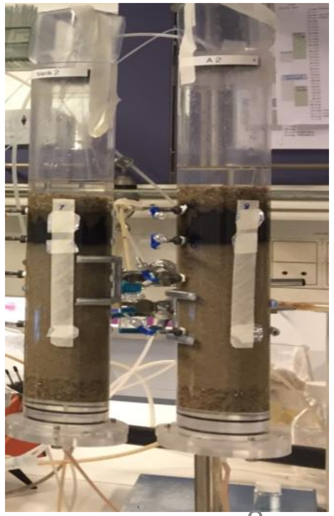


SMX
M = 253.28

riverbank and riverbed sediments

- $n_{riverbank} = 3$
- $n_{riverbed} = 4$

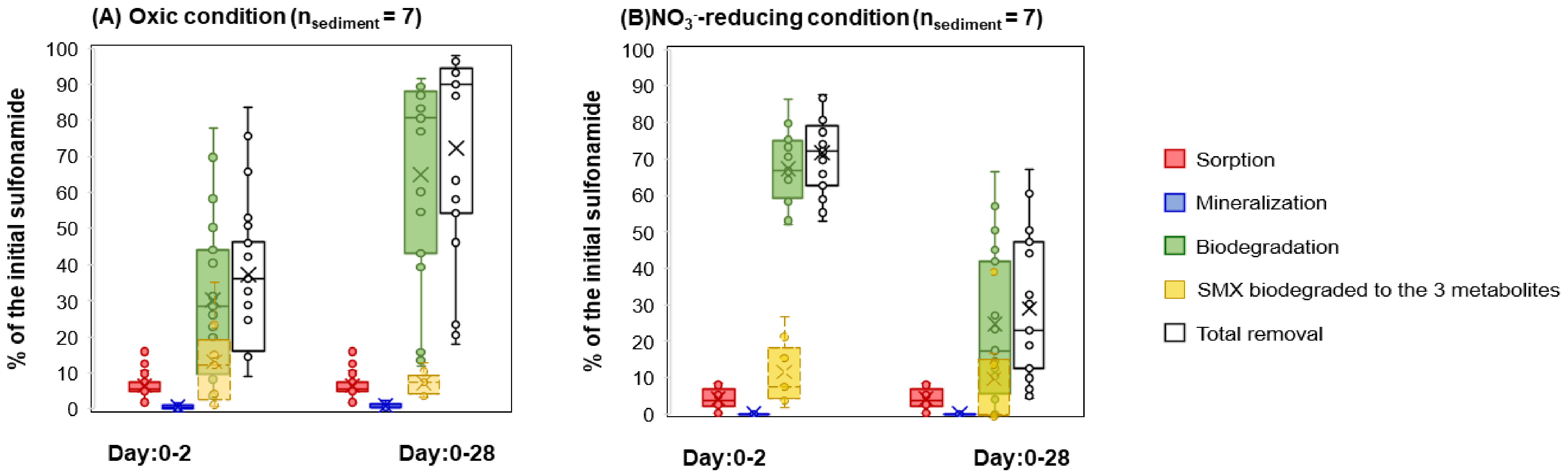
Batch and column tests



Biodegradation: the main removal process for sulfonamide

- Three batch tests (28 days): Sorption-desorption, Mineralization, Biodegradation
- Two redox conditions: **Oxic and Anoxic**

- Sulfonamide removal from different processes in the degradation batch,
- **The persistence of sulfonamides and derivatives** led to the prolonged antimicrobial impacts of reclaimed water.

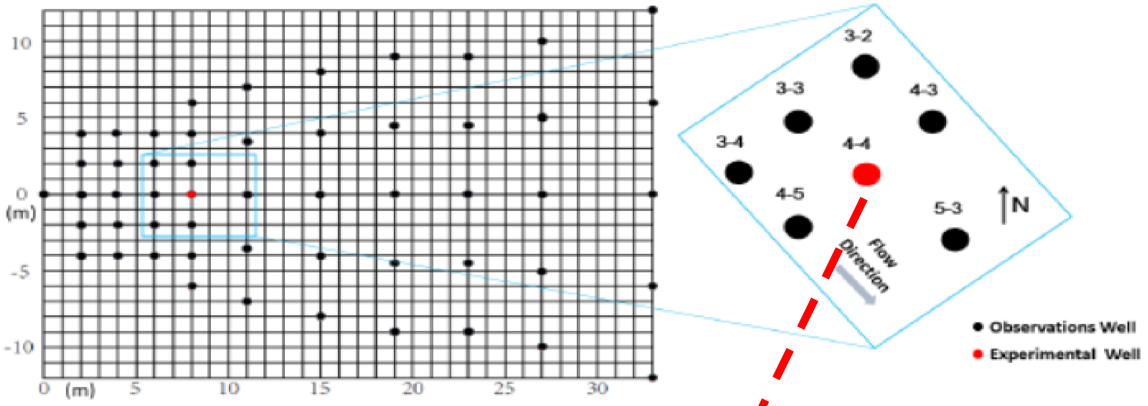


(Ma, Manuscript in preparation)

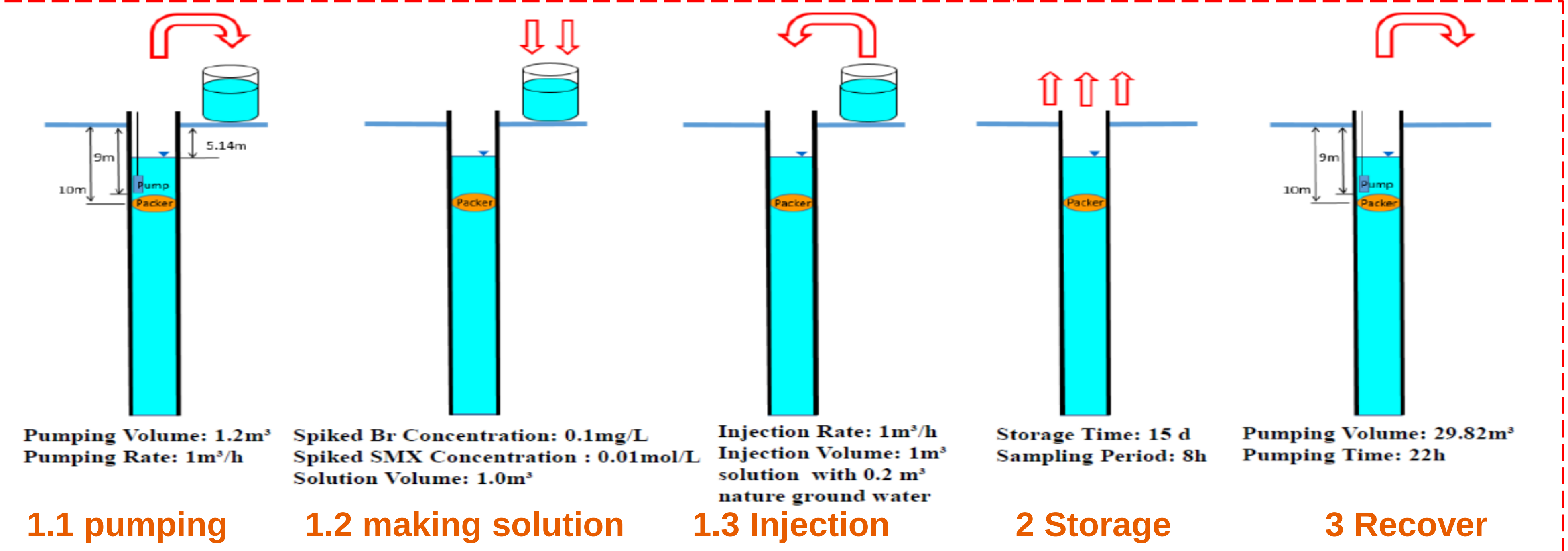
3. Field biodegradation of sulfonamide antibiotics

- Tongzhou site in the NCP

Layout of experimental (4-4) and observational wells



- Push-pull experiment with Sulfamethoxazole (SMX)



(Ma 2020 PhD thesis)

In situ biodegradation kinetics

Environmental Science & Technology
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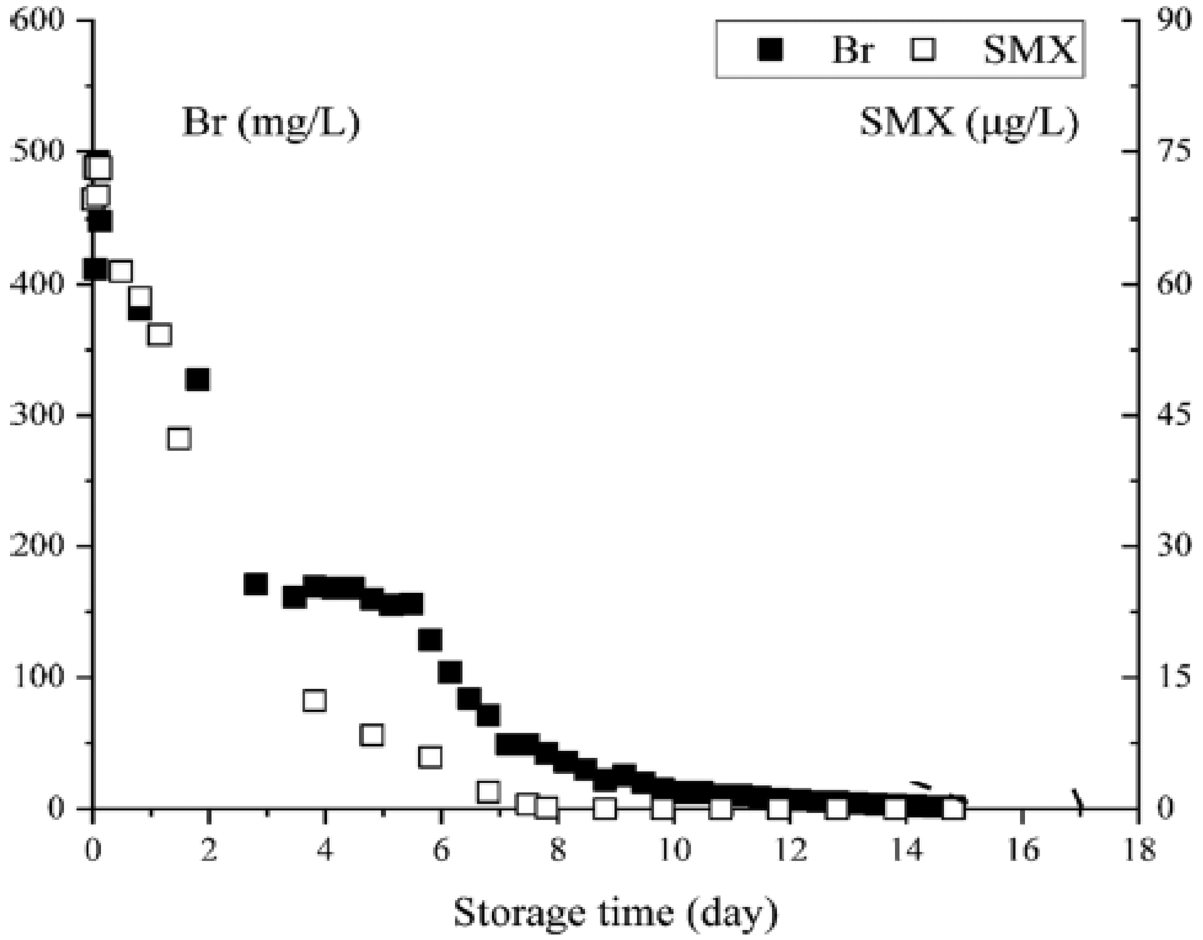
Determination of Sulfamethoxazole Degradatio
Experiment in a Reducing Alluvial Aquifer of th

Meng Ma,[†,‡,§] Peter Dillon,[‡,§,∥] and Yan Zheng[*,‡,§]

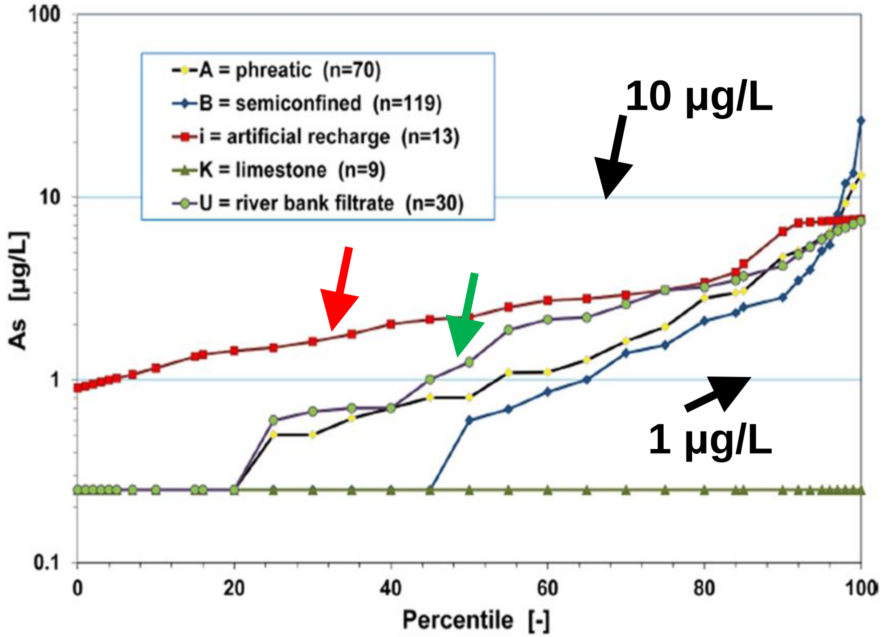


Concentration profiles of **SMX** (open squares) and **Br** (solid squares) in the experimental well.

The first-order degradation kinetics ($t_{1/2}$ is the half life):

- **$t_{1/2,\text{experiment well}}$ = 3.6 days**
- **$t_{1/2,\text{observation well}}$ = 8.0 days**

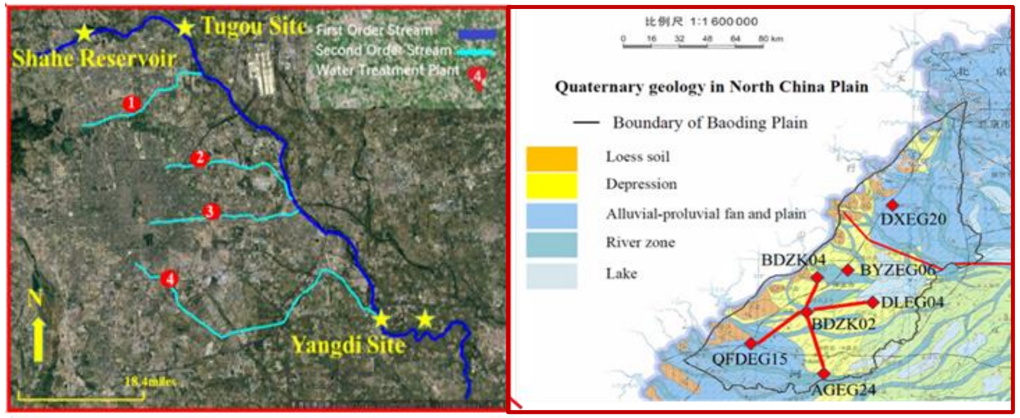
4. Contaminants from reactions with aquifer minerals



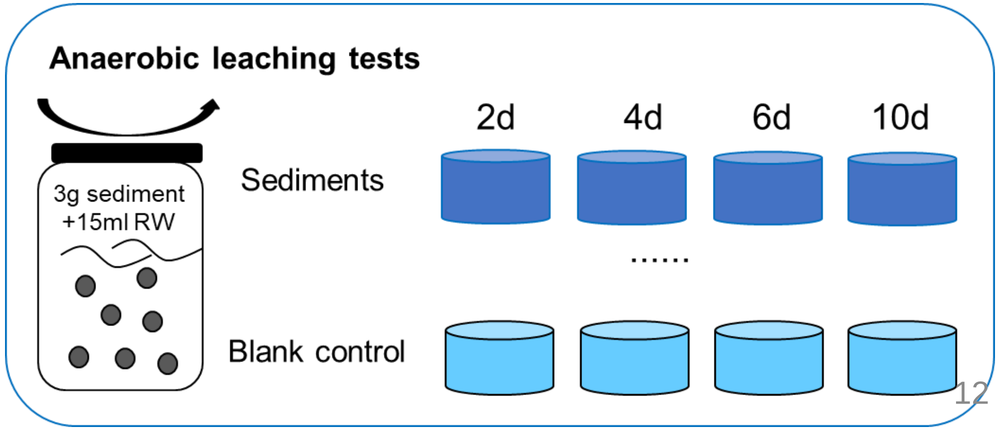
(Arslan Ahmad et al., Environment International, 2020)

- **Inorganic As** – carcinogen, the most significant chemical contaminant in drinking-water globally (WHO).
- **As risks:** cumulative frequency distribution of dissolved As (in the raw water pumped by the Public Supply Well Fields, the Netherland, 2008).
- **Reclaimed water with organic carbon** can lead to reductive dissolution of As from sediments.

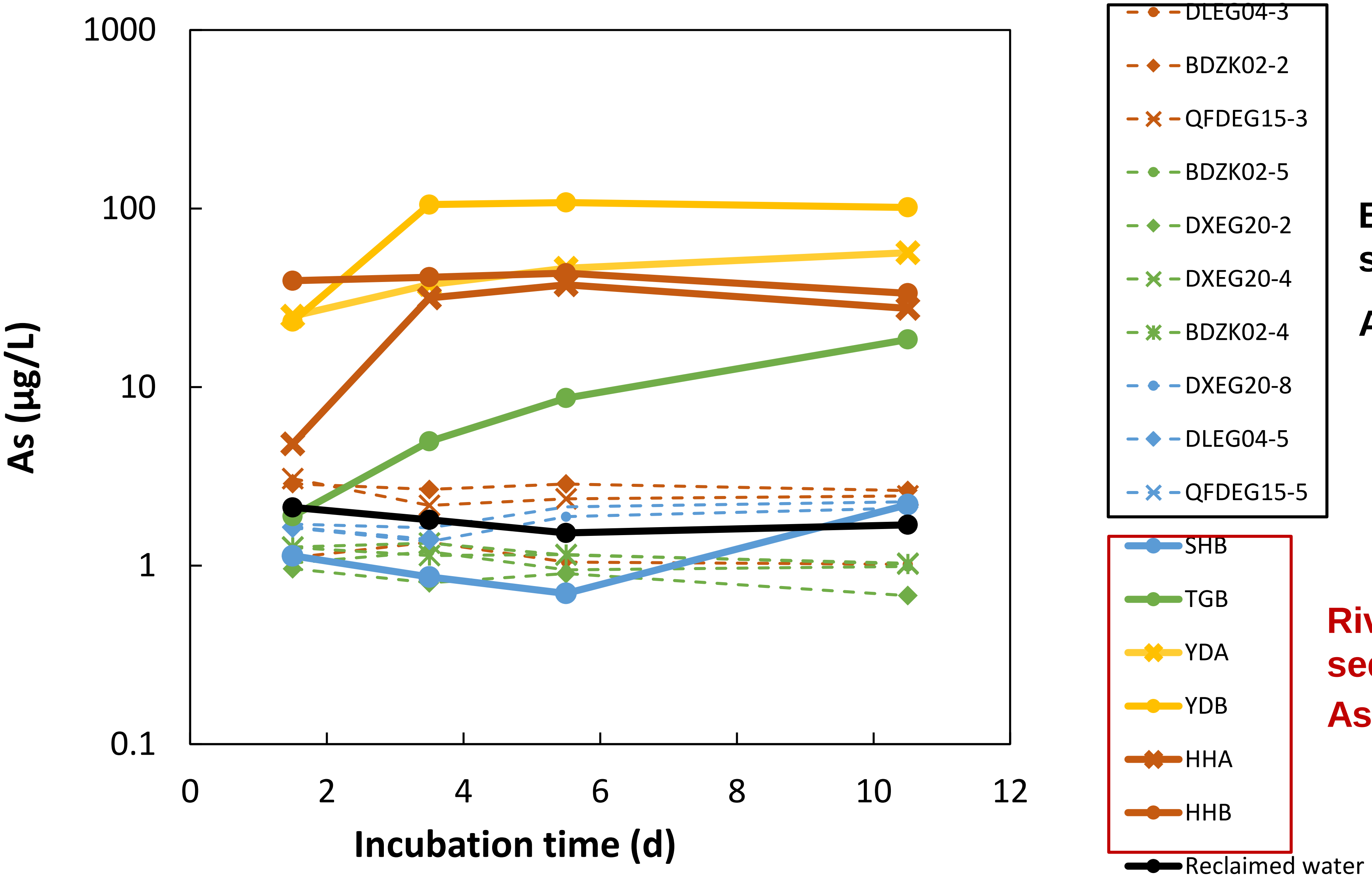
Riverbed sediments + Aquifer borehole sediments



- **Reclaimed water incubation**



As release in sediment incubation tests



(Yang 2020 Master thesis)

Borehole sediments

As: 1.6±0.7 µg/L

Riverbed sediments

As: 40±32 µg/L

Conclusions

- **Reclaimed water reuse** to restore ecological flows in the North China Plain has led to incidental or **unmanaged** aquifer recharge, posing significant risks for groundwater quality.

- These risks not only come from contaminants and other substances in reclaimed water, but also include their reactions with aquifer materials.

- On one hand, conventional contaminants are significantly removed during reclaimed water infiltrating to aquifer due to the natural assimilatory capacity.

- On the other hand, water quality risks, including the geological (As) and emerging (antibiotics) contaminants, cannot be ignored and need management.

- Large scale ecological reuse of reclaimed water and its recharge to aquifer must be **managed** to minimize the still poorly known and characterized risks.

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