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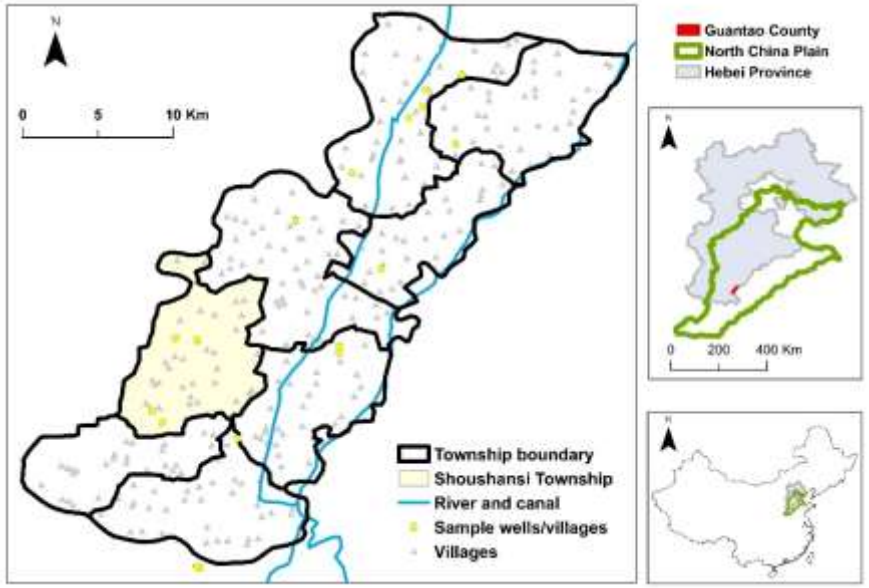
Program:
Contribution of Technology to Groundwater Resilience

Monitoring groundwater abstraction using electric energy as proxy in an area of intensive agricultural pumping

Lu Wang [1],*, Wolfgang Kinzelbach [1], Huaixian Yao [2], Jakob Steiner [3] and Haijing Wang [4]
1 Institute of Environmental Engineering, ETH Zurich, Switzerland;
2 Guantao Department of Water Resources, Guantao, Hebei, China
3 Utrecht University, Utrecht, The Netherlands
4 hydrosolutions Ltd., Zurich, Switzerland

Background and Study Area



- Groundwater abstraction monitoring is usually absent in areas of intensive agricultural pumping.
- Large number of users operating small-scale wells with primitive equipment.
- Electricity consumption for pumping is metered by existing electricity monitoring grid.

Guantao County in the North China Plain

- Groundwater is overpumped due to the irrigation of winter wheat.
- Groundwater control policy: Water tax is generated when users pump a volume of groundwater exceeding the prescribed quota.
- All irrigation wells are equipped with electricity meters.

Guantao County
Area: 456 km^2
Number of wells: > 8000
Irrigation area per well: ~ 3.3 ha
Water quota: 296 m^3/mu/year (1 mu=1/15 ha)

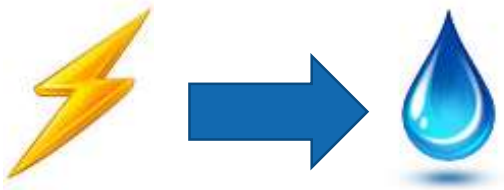
Indirect groundwater abstraction monitoring using electricity consumption as proxy

Key questions to be answered

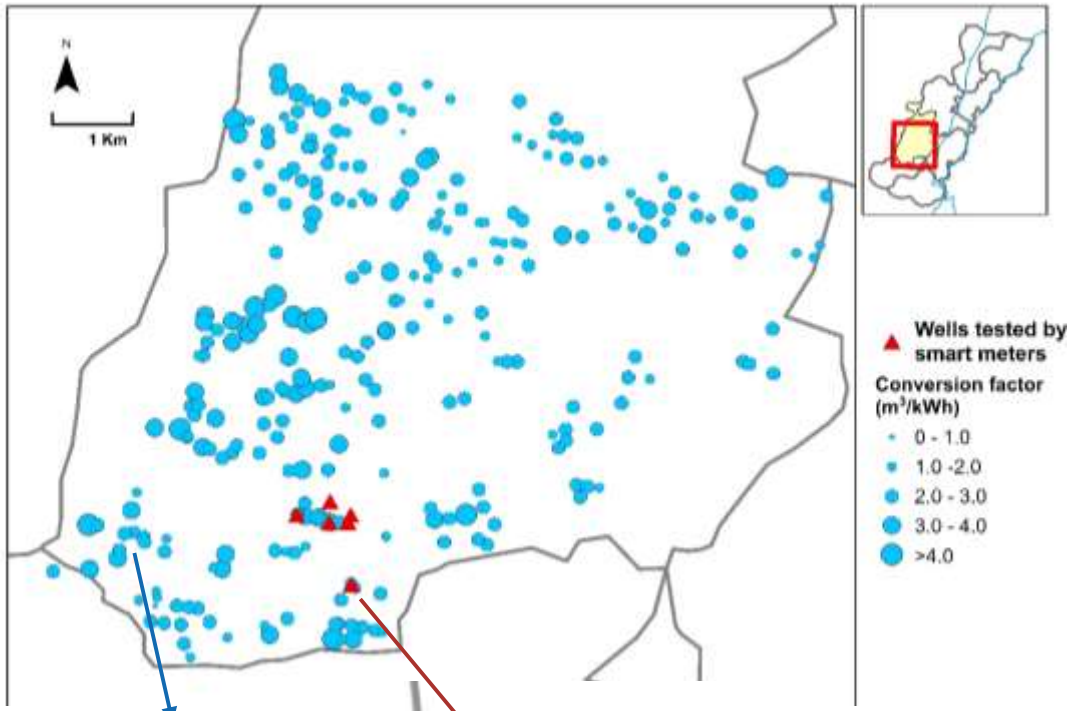
1. How to convert the proxy of electric energy consumption to groundwater abstraction?
   - Electricity-to-water conversion factor measured by field tests: c_f (m^3/kWh)

     $$V = E \cdot c_f$$

2. What is the accuracy of the conversion?
   - Trade-offs between accuracy and efforts in data collection
3. Is the monitoring method feasible and sustainable?
   - Comparison of monitoring methods regarding cost, ease of implementation, etc.



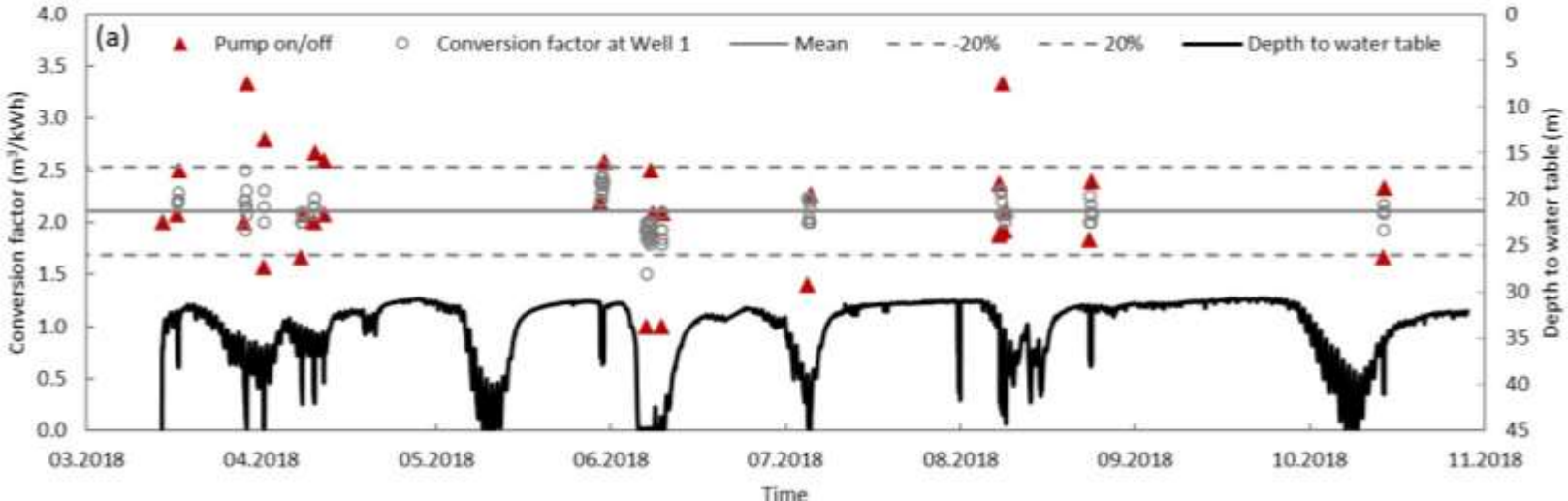
Q1 Converting the proxy of electricity consumption to groundwater abstraction



- Pumping tests for measuring Electricity-to-Water Conversion Factor, c_f (m³/kWh)
  - Electricity-to-water pumping tests on single wells [at 281 locations] $c_f = \frac{Q}{N}$
  - Continuous pseudo pumping tests using smart flow meters and electricity meters [at 6 locations]

➢ A uniform conversion factor will lead to large errors in the abstraction estimates of single wells.

➢ Pumping tests performed in whichever irrigation season result in a conversion factor with a relative error of less than 20% for a single well.



Q2 Accuracy of the electricity-to-water conversion
Trade-off between accuracy and efforts in data collection

More wells tested → More accurate

- How many wells in a region should be tested to obtain an average conversion factor with a relative error less than a threshold ε, e.g., 20% or 10%?
  - ❖ Analysis using the theory of interval estimation

Regions	Total Number of Wells	Number of Samples n	Number of Wells to Be Tested (Confidence Level: 95%)	
			$\varepsilon < 20\%$	$\varepsilon < 10\%$
Village 1	49	29	11	34
Village 2	66	27	11	34
Village 3	51	25	16	54
Village 4	41	20	16	53
Shoushansi District	600	281	14	46

- Taking the average conversion factors of 17 measurements evenly distributed over the county, the average conversion factor of shallow wells in Guantao County is estimated as 2.62 m^3/kWh ($\varepsilon < 20\%$).

Q3 Is the monitoring method sustainable? – Method Comparison

- Direct water monitoring by smart water meters
- Indirect monitoring using electric energy as proxy
  - Pumping tests at **All** wells or at **Selected** wells

❖ Guantao County in 2018
Water volume exceeding water quota:11.7 million m^3
Water tax: 2.34 million CNY.

Criterion	**Direct Water Metering** 	**Energy Metering + Pumping Tests on All Wells** 	**Energy Metering + Pumping Tests on Selected Wells**
Cost	High (Investment: 9.6 Mio. CNY/a Maintenance: 17.2 Mio. CNY/a)	Medium (Operation cost: 3.6 Mio. CNY/a)	Low (Operation cost: 6300 CNY/a)
Ease of implementation	Very difficult	Medium	Easy
Accuracy	High (±5%)	Medium (±20%)	Low (±50%) (or Median for areal abstraction at county level, ±20%)
Equitability	Equitable	Equitable	Low equitability (regarding abstraction estimates) or Equitable (regarding energy-saving)

Conclusions

- Direct water metering is presently infeasible in the North China Plain.
- Indirect groundwater abstraction metering using energy consumption as proxy substantially reduces the investment and efforts required in system maintenance and data collection.
- Field tests in Guantao revealed the large variability of the electricity-to-water conversion factors between individual wells. But the error of electricity-to-water conversion for an individual well based on field test is within 20%.
- A trade-off between data accuracy and efforts in data collection can be made by selecting the number of pumping tests.

Thank you!

- **Contact**: lu.wang@ifu.baug.ethz.ch; lu.wang.apple@gmail.com.
- **Reference:** Wang, L.; Kinzelbach, W.; Yao, H.; Steiner, J.; Wang, H. How to Meter Agricultural Pumping at Numerous Small-Scale Wells?—An Indirect Monitoring Method Using Electric Energy as Proxy. Water 2020, 12, 2477. https://doi.org/10.3390/w12092477
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