XVIII World Water Congress
International Water Resources Association (IWRA)

Overdraft of deep groundwater resources and its resulting land subsidence in the North China Plain

Rong Liu, Yong Zhao, **Xin He (hex@iwhr.com)**

China Institute of Water Resources and Hydropower Research (IWHR)

XVIII WORLD WATER CONGRESS
Water for All
Harmony between Humans and Nature

第18届 世界水资源大会
水与万物：人与自然和谐共生

XVIII World Water Congress
International Water Resources Association (IWRA)

Outline

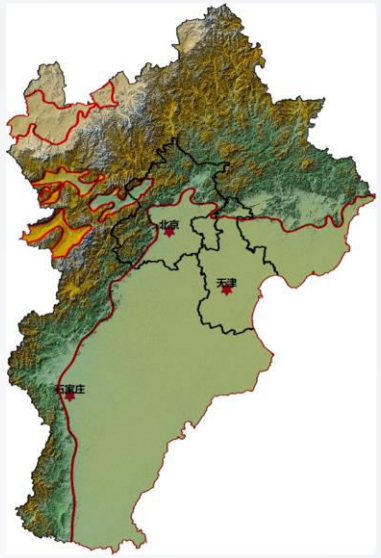
- Background
- Method
- Results
- Conclusions

Outline

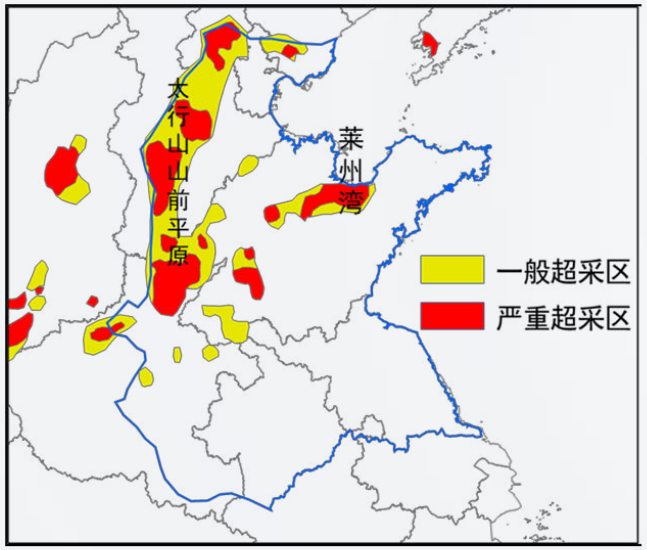
- Background
- Method
- Results
- Conclusions

Groundwater overdraft

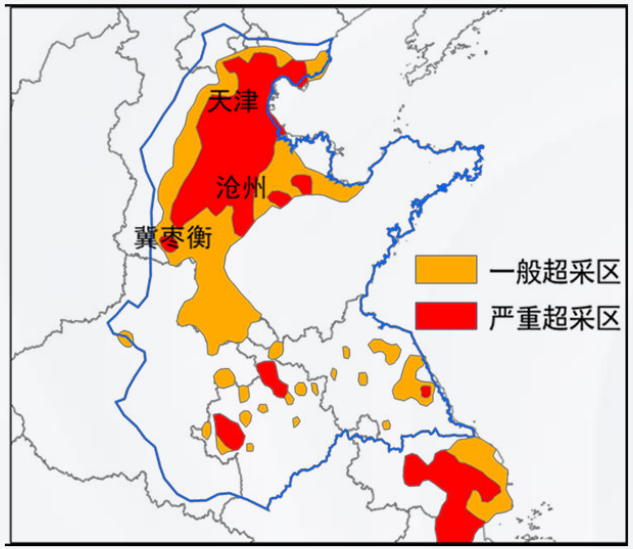
- The Beijing-Tianjin-Hebei (BTH) region has severe water scarcity problem
- Average water resources per capita 240 m^3/yr
- Groundwater overdraft area 82,000 km^2, overdraft amount 7 bil. m^3
- Some of the largest groundwater depression cones in the world



- GDP 8500 bil. CNY
- Total area 217,000 km^2
- Cultivated area 52,000 km^2
- Population 85 mil.
- WR availability 240 m^3/yr PC



Overdraft area in the shallow aquifer



Overdraft area in the deep aquifer

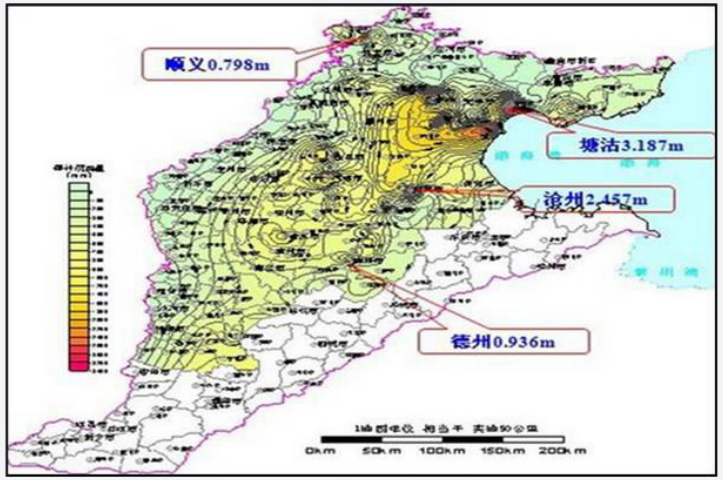
Environmental and ecological consequences

Dried up river bed (Hutuo River)

Dried up natural springs (Yuquan Mt.)

Shrunken wetland (Baiyangdian)

Seawater intrusion



Land subsidence

Ground crack (Longyao)

Groundwater regulations

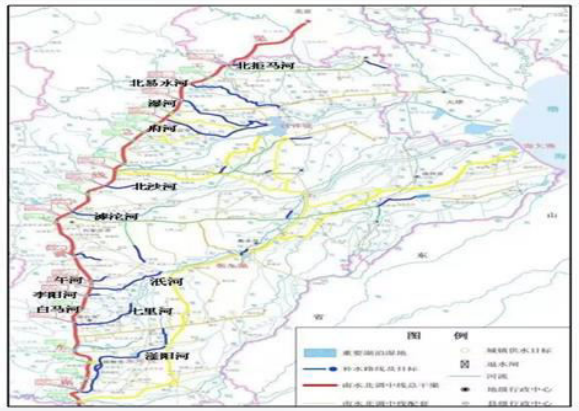
- **"The Comprehensive Management of Groundwater Overdraft Action Plan" (2019)**
- **"Groundwater Management Act" - first groundwater law in China (2021)**

Management goals

- By 2022, groundwater overdraft amount reduced by 1.7 bil. m^3
- By 2035, groundwater budget from deficit to surplus

Agricultural water saving

Replace gw. pumping with transferred water

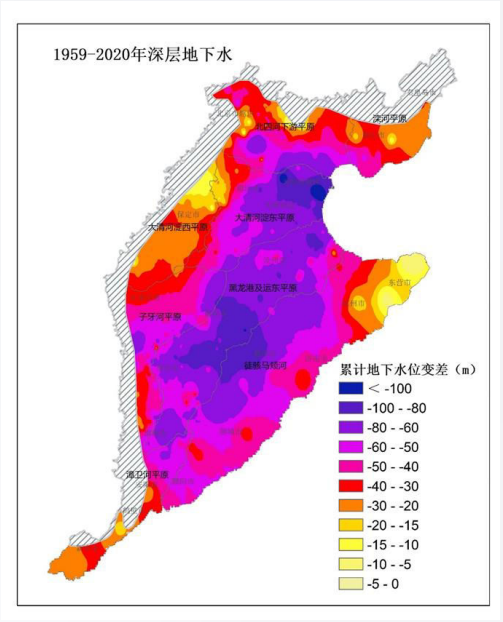


MAR at key rivers and lakes

Difficulties in the mid-east plain

XVIII World Water Congress
International Water Resources Association (IWRA)

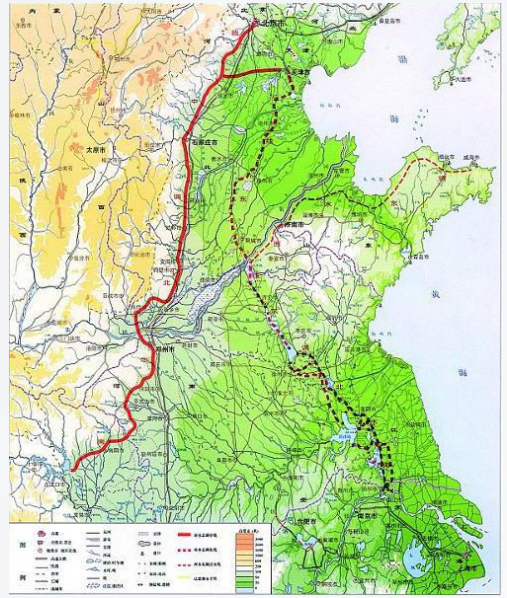
- **Groundwater management measures achieved great success**
- **Mid-east BTH plain faces more difficulties than the piedmont area**
  - Shallow groundwater is salty, thus deep confined aquifer is exploited
  - South-to-North middle route cannot reach that far to the east
  - Distributed pumping for irrigation is hard to monitor and control
- **Groundwater table is still declining in many parts of the mid-east plain**



Accumulated gw drawdown

Area with salty shallow aquifer

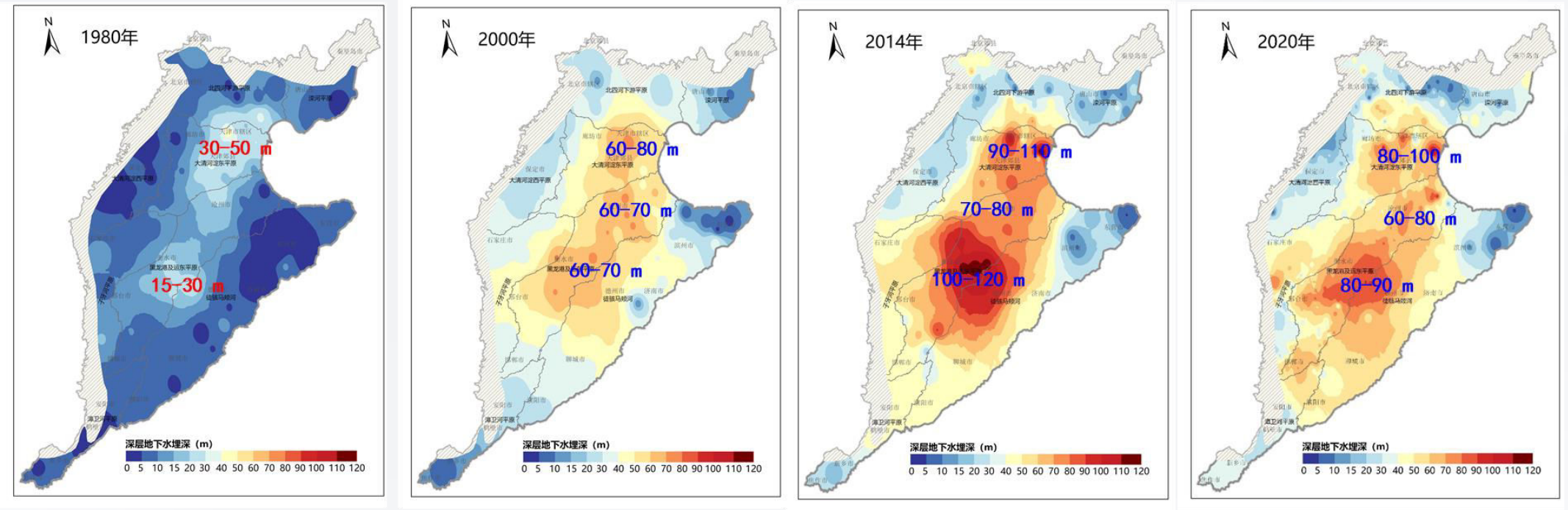
Area with deep aquifer overdraft



South-to-North middle route

Objectives

- Focusing on the mid-east plain, assess the extent and consequences of deep groundwater overdraft
- Quantify the relationship between pumping and land subsidence
- Explore the possibility of safety pumping threshold (depletion of resources but not causing geological hazards)



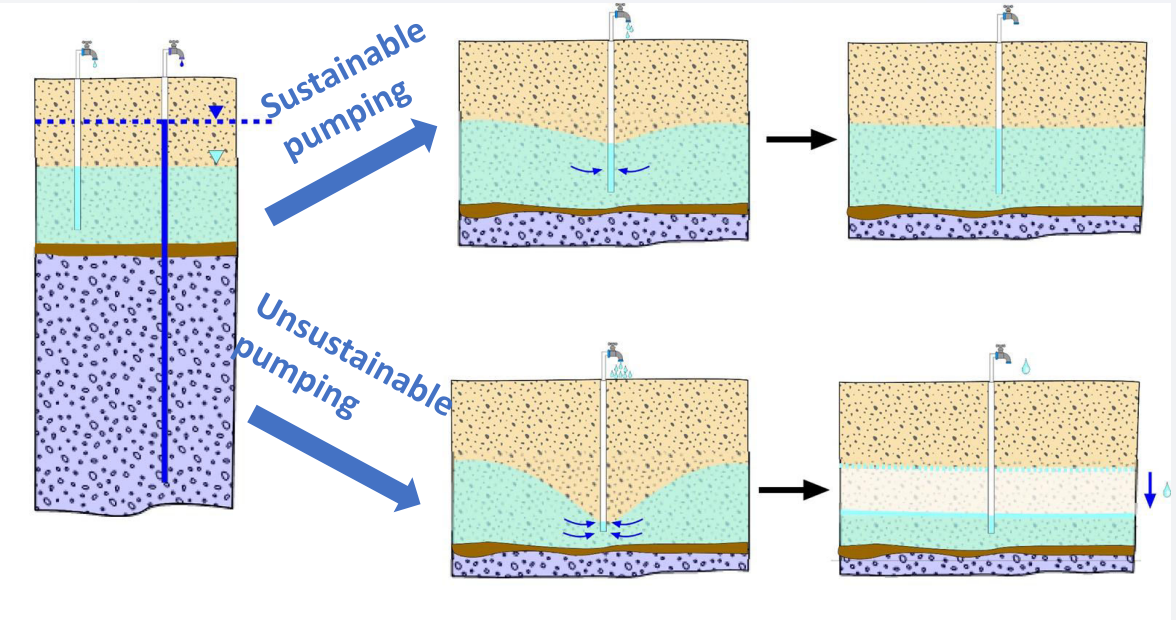
Outline

- Background
- Method
- Results
- Conclusions

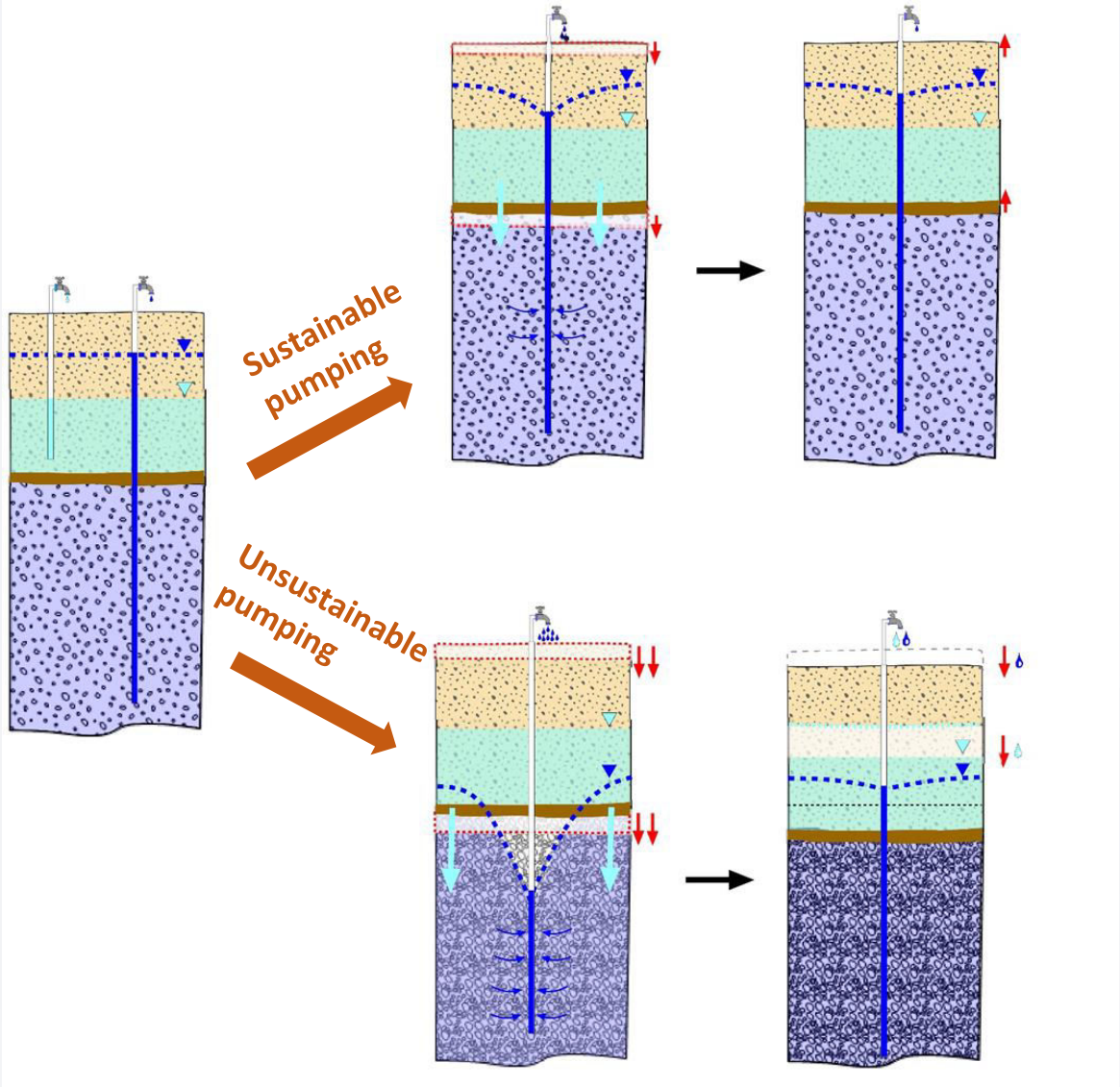
Pumping of deep confined aquifer

XVIII World Water Congress
International Water Resources Association (IWRA)

Pumping from a shallow unconfined aquifer

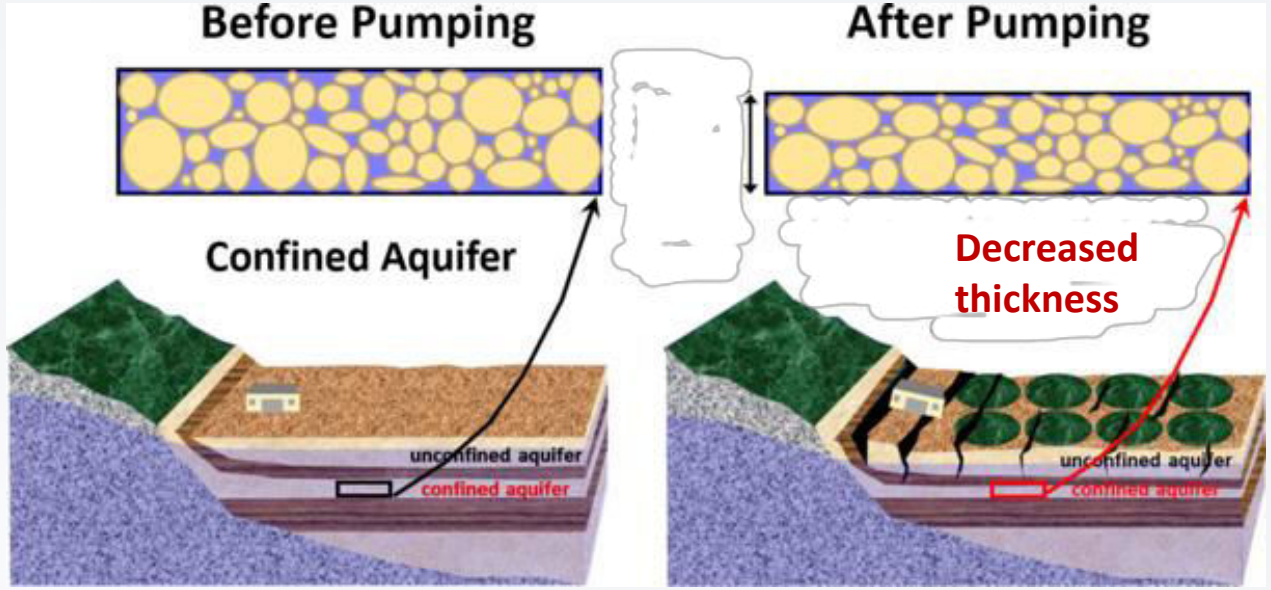


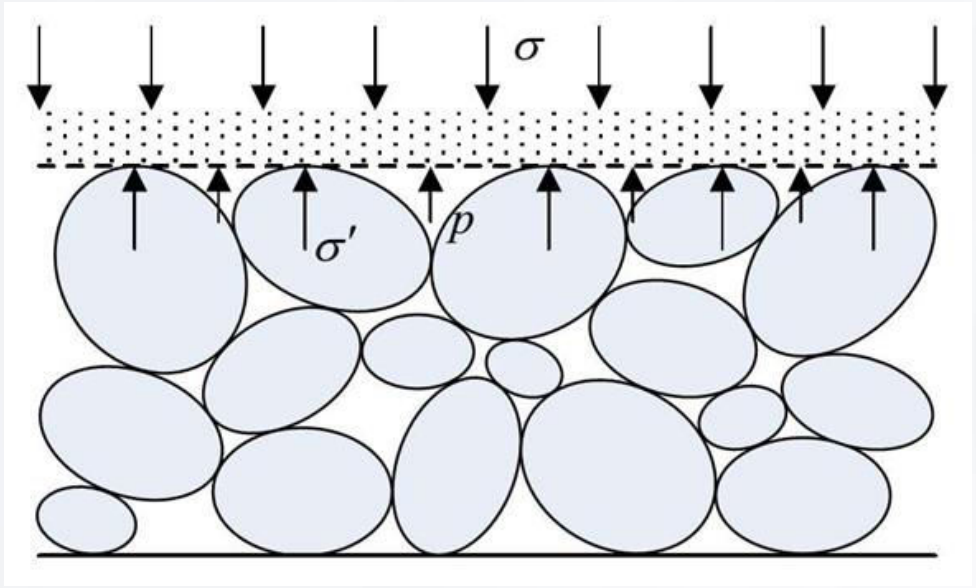
Pumping from a deep confined aquifer



Pumping induced land subsidence

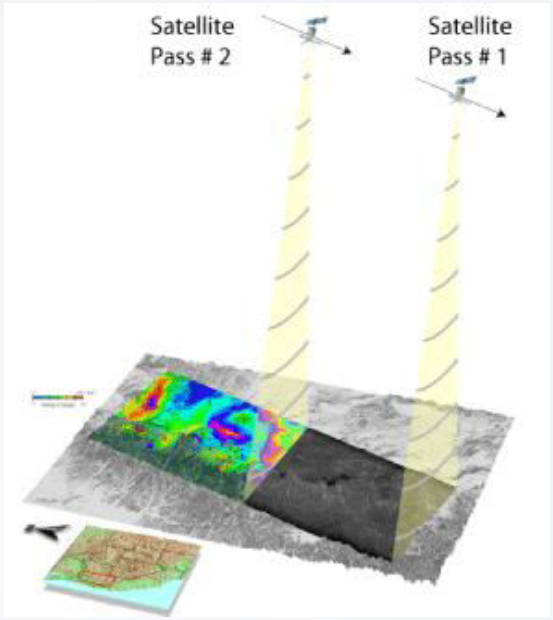
- The total overlaying stress of the saturated soil is mainly sustained by two parts: soil skeleton, and water in the pores between the soil particles
- When pumping a confined aquifer, the internal water pressure drops, the stress is transferred to the soil skeleton, causing the aquifer to compress to release water
- Such compression is elastic to begin with, but later becomes inelastic (permanent deformation) when pumping exceeds a certain threshold => Land subsidence

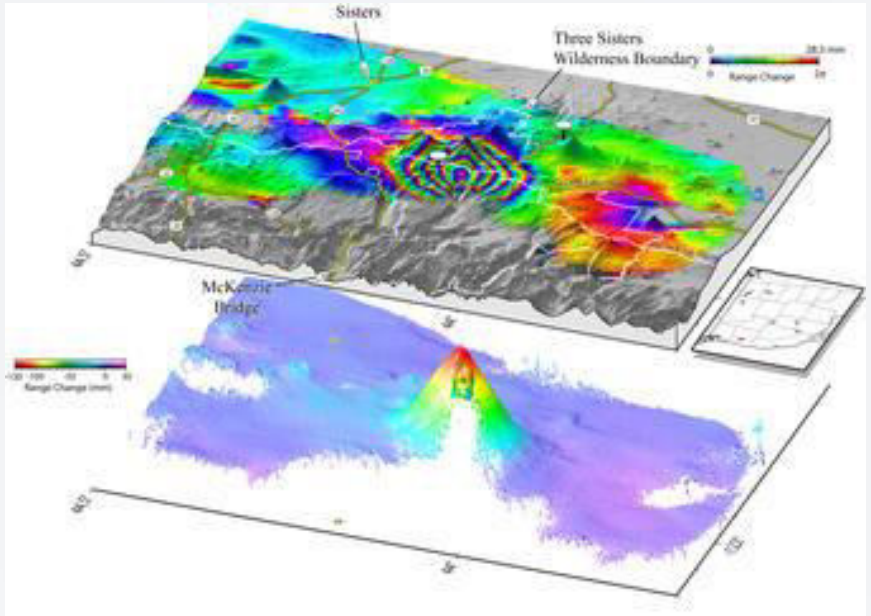




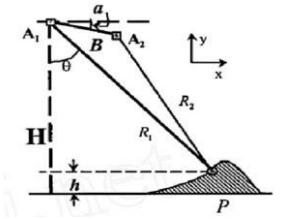
Estimation of land subsidence

- Many different methods to measure land subsidence
- InSAR (Interferometric Synthetic Aperture Radar) is a technique for mapping ground deformation using radar images onboard of earth orbiting satellites
- Two radar images of the same area are collected at different times and compared, thus any movement of the ground surface toward or away from the satellite can be measured
- InSAR advantages: fully automated, large coverage, high precision, all-weather conditions





Data inversion



- Phase difference

$$\varphi = \varphi_1 - \varphi_2 = -\frac{4\pi}{\lambda}(R_1 - R_2) \approx -\frac{4\pi}{\lambda} B \sin(\theta - \alpha)$$

- Untangling

$$\varphi = \varphi_{flat} + \varphi_{topo} + \varphi_{def} + \varphi_{atm} + \varphi_{noise}$$

Outline

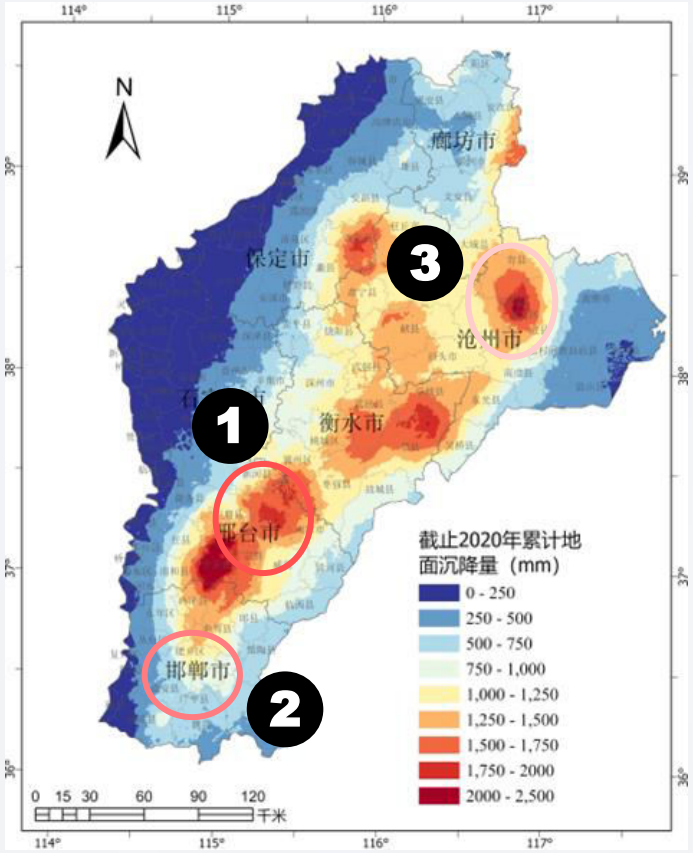
- Background
- Method
- **Results**
- Conclusions

Land subsidence inversed from InSAR

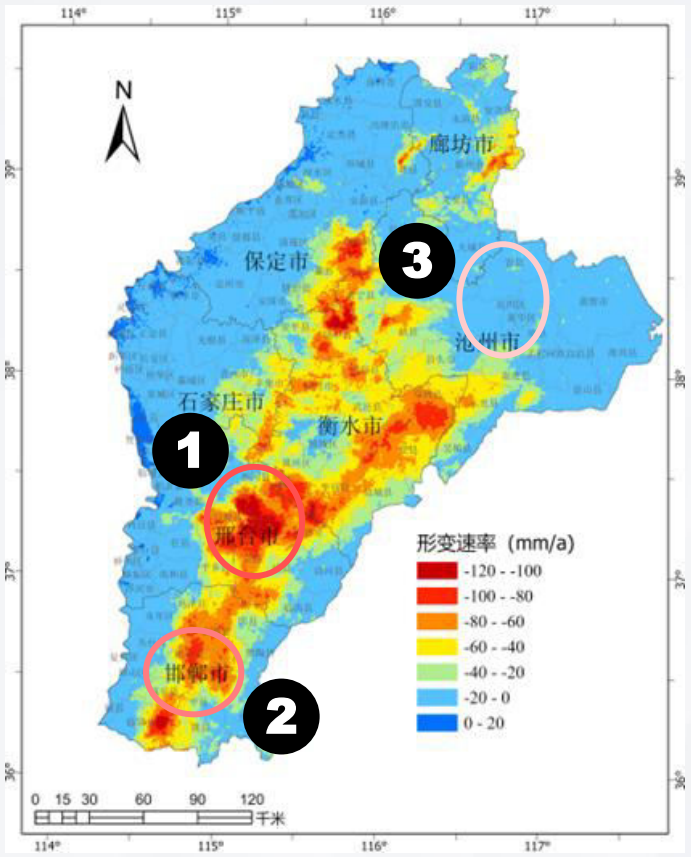
XVIII World Water Congress
International Water Resources Association (IWRA)

- Largest accumulated subsidence (past 30 years) in North Xingtai and Cangzhou, both over 2000 mm
- Current subsiding rate (averaged over past 5 years) highest in South Xingtai (115 mm/year)
- Two figures do not coincide exactly, in several different situations

Accumulated subsided amount



Current subsiding rate



1 **Large** accumulated subsidence **High** subsiding rate now

Guangzong county, Xingtai

2 **Small** accumulated subsidence **High** subsiding rate now

Feixiang county, Handan

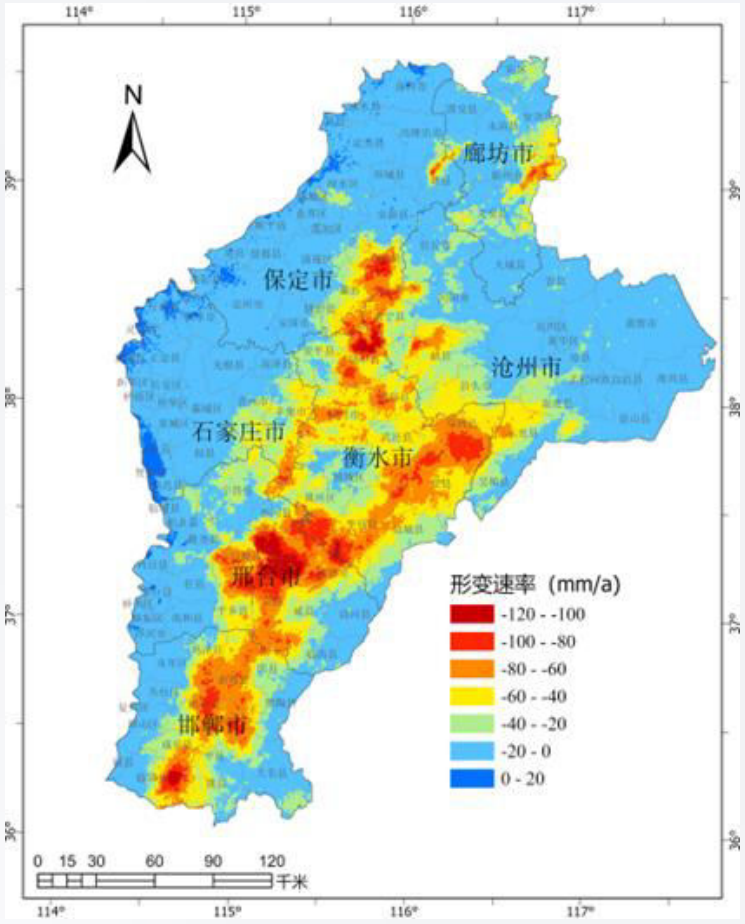
3 **Large** accumulated subsidence **Low** subsiding rate now

Cang county, Cangzhou

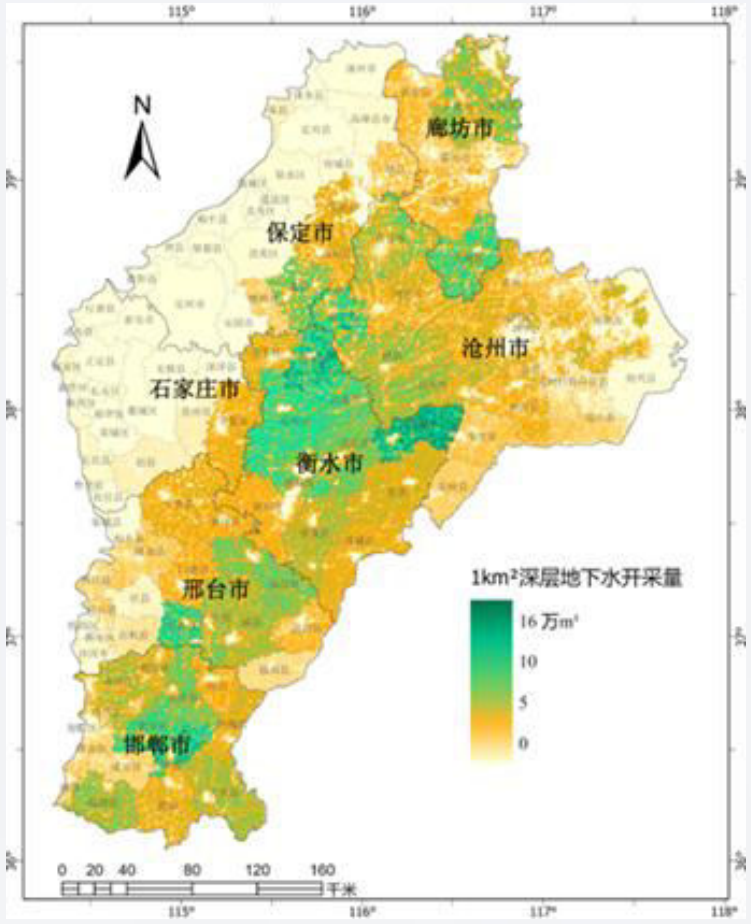
Land subsidence vs. Pumping amount

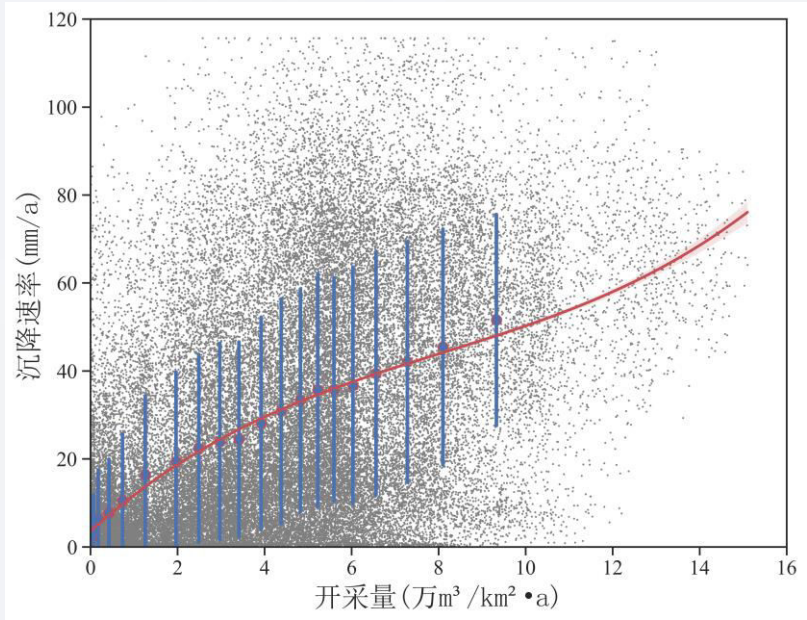
XVIII World Water Congress
International Water Resources Association (IWRA)

Current subsiding rate



Current pumping rate





- Two images compared pixel by pixel
- Relatively correlated, but still very scattered
- 130 km³ of water loss to 1 mm of land subsidence

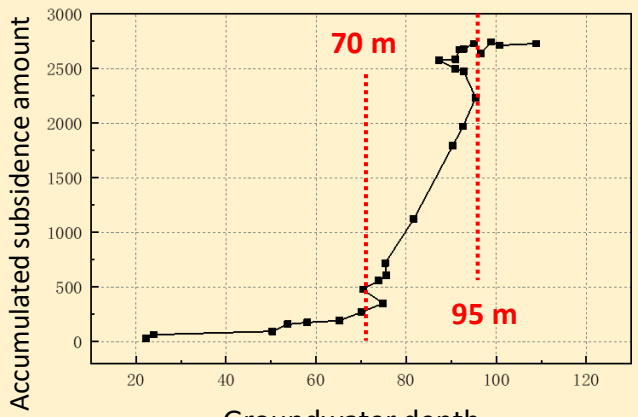
Land subsidence vs. Groundwater head

- How much land surface sink is caused by 1 m of hydraulic head decrease => Subsidence intensity
- On average, for 1 m of groundwater head decline, there is 12 mm of land subsidence
- High intensity locations are mainly in the middle part of the plain, most likely related to geology
- Certain groundwater head thresholds exist for subsiding speed

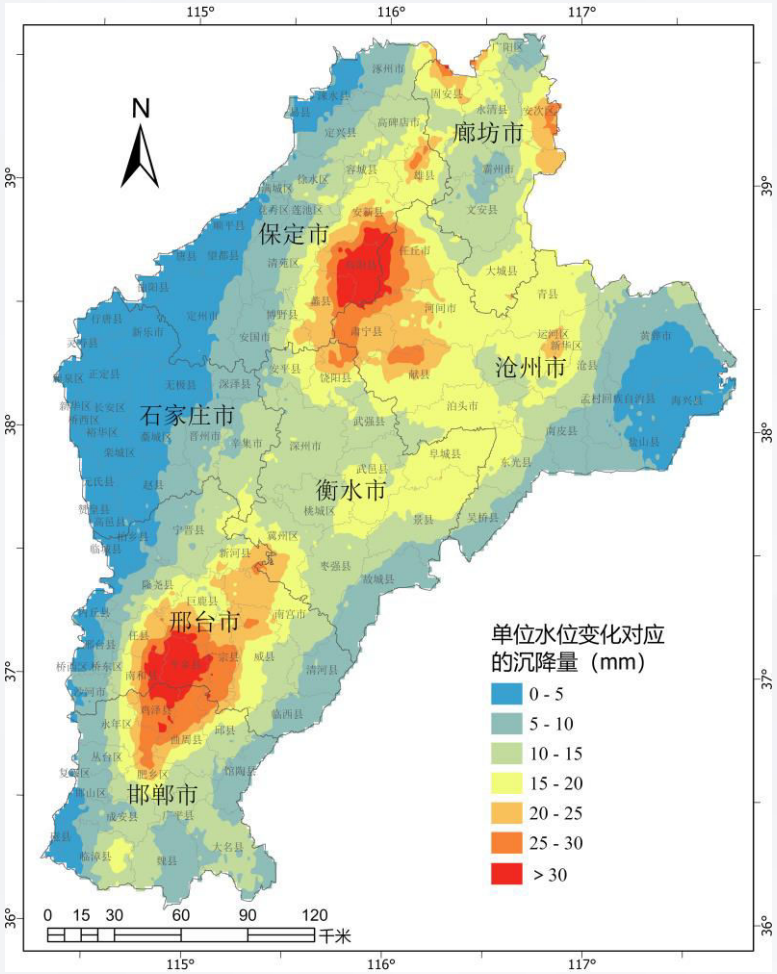
Subsidence intensity in major cities (mm/m)

Shijiazhuang	Handan	Xingtai	Baoding	Cangzhou	Langfang	Hengshui
5.0	13.0	15.1	11.9	13.6	15.0	14.1

Cangzhou city



Subsidence intensity in the plain area



XVIII World Water Congress
International Water Resources Association (IWRA)

Content

- Background
- Method
- Results
- Conclusions

Summary

- Land subsidence inversed from InSAR is assessed in mid-east BTH plain
- Accumulated subsided amount and current subsiding rate were compared, indicating that historic and current land subsidence locations do not coincide
- Land subsidence due to aquifer compaction is mainly related to groundwater head change
- It was calculated that 130 km^3 of water loss or 0.1 m of groundwater head drop leads to 1 mm of land subsidence
- Land subsiding rate may get slower after a certain groundwater head threshold, but management decisions need to be made with extreme care

XVIII World Water Congress
International Water Resources Association (IWRA)

Thank you for your attention!

Xin He (hex@iwhr.com)

XVIII WORLD WATER CONGRESS
Water for All
Harmony between Humans and Nature

第18届 世界水资源大会
水与万物：人与自然和谐共生