Potential of rainwater in city groundwater recharge

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Contents

1. Urbanization in China and major environmental challenges
2. Rainwater and groundwater recharge
3. Challenges and opportunities
1. Urbanization in China and major environmental challenges

- China is a big construction site in the past thirty years
- Urbanization at present: 56.1%
- By 2030, another 390 million rural population living in urban areas
- Probably another 20 years fast urbanization
Environmental challenges in urbanization

• Replacement of vegetation with impermeable lands/buildings
• Effects on surface water quality and runoff
  • Increasing magnitude of peak flood runoff
  • Causing deterioration in water quality
• Changes in groundwater recharge regime
  • Reduced surface runoff infiltration period
  • Reduced recharge quantity
Urbanization changes underlying surface

- Natural land surface with vegetation enhance infiltration and reduce runoff. Hardened (indurative) ground increases runoff
  - Vegetation slow down runoff, hardened surface increases runoff (both rate and amount)
  - Increased runoff for the same rain
  - Completely change conventional groundwater recharge regime
  - Increased city flooding risks

- A complete change in land surface
  - Increased impermeable area
  - Reduced permeable area
Urbanization changes water cycle in urban areas

- Surface runoff
  - Increased by 65%
- Evapotranspiration
  - Reduced by 25%
- Groundwater
  - Reduced by 40%
Urbanization changes hydrology

- Increased surface runoff
- Increasing flooding events
- Higher flood peak
A slightly higher than average rainfall event may cause flooding in cities. *Come to see “sea”* in many inland cities.
Continuously declining groundwater “sources” in cities

• Rainfall is important source for groundwater recharge but urbanization has changed this.
  • Increased impermeable land area causes large amount of surface runoff to drain out of cities, leading to highly insufficient groundwater recharge

• Changes in city underlying surface is the main factor contributing to increasing flooding in cities
Increased groundwater exploitation

• Increasing exploitation of groundwater resources to meet increasing need of increasing urban population
• Overuse of groundwater causes declining groundwater resources
• Construction of flood control channels and massive sewage system can also cause drawdown of groundwater table

• Therefore, a result of continued reducing recharge and continued over-exploitation of groundwater is great drawdown of groundwater table.
• Continued over-exploitation of groundwater causes similar groundwater drawdown in nearby areas

• Largely due to over-exploitation of groundwater, land subsidence is common in many cities
2. Rainwater and groundwater recharge

• **Strange resource exploitation**: highly prioritizing on resources exploitation but little focusing on resources saving. Compared with many other countries:
  • Agricultural irrigation ratio: 0.4 VS 0.7-0.8
  • Industrial water use: 222 m³/RMB 10 000 yuan GDP
  • Industrial wastewater recycle: 40% VS 75-85%
• Use of rainfall in groundwater recharge is rare in China
Is this feasible for Chengdu?

• Urbanization has been fast in Chengdu

• Groundwater status (2010) (Chengdu Bureau of Water Resources)
  • Whole Chengdu: reduced by 17.6%
  • Metropolitan area: reduced by 18.4%

• Quantity?
• Quality?

Chen et al., 2011, Plos One 6(9): e25008
Quantity

• Urban land area 529 km² (2014)

• Impermeable rate 45%, runoff coefficient 0.85, annual rainfall 1000 mm
  • Annual available: $3.3 \times 10^8$ m³

• In addition, rainwater drain directly from roof, road and residential compound is about $2.5 \times 10^8$ m³

• Total: $5.8 \times 10^8$ m³

• Total water consumption in 2015: 1.23 billion.
Ways to increase rainwater harvesting and storage

• Increasing permeability
  • Natural: green areas
  • Artificial: permeable ground, parking area, etc

• Use green areas to recharge groundwater
  • Increase groundwater recharge by rain water
  • Save water for irrigating vegetation
  • Reduce runoff peak
Role of vegetation in rainwater harvesting

- Vegetation can increase infiltration
  - 25 years natural forest: 150 mm/h
  - Grassland: 10 mm/h
  - Bare land: < 5 mm/h

- Forest
  - 25% canopy interception
  - 35% groundwater

- Grassland
  - Infiltration 15-20% higher than bare land

- On bare land
  - 55% runoff
  - 5% groundwater

- Rainfall infiltration: 7 time in forested land as much as in bare land
Use of green areas to harvest and store rainwater

• Some preliminary results (% of infiltration to rainfall)
  • High grassland (0.3 m above ground): 6%
  • Level grassland (same level as ground): 19%
  • Lowered grassland (0.1-0.2 m lower than ground): 30%
Use of rivers to harvest and recharge groundwater

- Rivers play an important role in groundwater recharge. But in Chengdu and other cities, most channels/canals are cemented.
- Promote ecological riparian ecosystem to restore recharging function of groundwater recharge.
Use of roads and green belts

- Impermeable land is efficient in rainwater harvesting
- All harvested rainwater drains out of city
- Almost all green belts are higher than ground
Potential ways

• Lower playground, green land, parks, green belts, 0.1-0.5 m lower than ground, enhancing rainfall infiltration

• Construct permeable ground in parking lot, public ground

• Leave slits along roadside to increase infiltration

• Restore river ecosystem
Some preliminary results on infiltration (infiltration/rainfall)

- Green areas 0.3 m higher than land surface: 6%
- Green areas on land surface: 19%
- Green areas 0.1-0.2 m lower than land surface: 30%
Quality

Groundwater pollution by hydrocarbon fuels, industrial chemical spillages

• Soil and vegetation help

• Rainwater goes through 3-4 layers: plant, land surface, plant roots and microorganism, soil

• Rainwater going through green areas
  • $\text{NH}_4$ -N: reduced from 2.1 to 0.8 mg/L
  • Sulphate and nitrate reduced greatly
3. Opportunities and Challenges

• Changes from no to poor and then to better planning in urban development
Opportunities and Challenges

Urbanization and urban development involves a number of government agencies. Each agency works on its own, poor inter-agency collaboration. In terms of groundwater recharge, at least the following are involved:

• Bureau of Water Resources
• Urban-Rural Development Commission
• Bureau of Environmental Protection
• Bureau of Forestry and Horticulture
• Bureau of Planning
• Bureau for City Management and Administrative law-Enforcement
Plant species test

- 10 species, flooded 15 cm for 2, 4, 6 days
- No effects are observed 14 days after flooding
  - 2 days: 9 species
  - 4 days: 7 species
  - 6 days: 4 species
- Hydrological data indicate very rare flooding in Chengdu, if so, mostly 1 day
• Most constructed wetlands are lined to prevent leaking
• Many artificial lakes are lined to prevent leaking
• Many lakes in public parks
Conclusion

• Urban ecosystem is controlled, managed by people.

• Management philosophy and idea change is crucial to make fully use of ecological ways to recharge groundwater.

• In China, the program promoted by the top leader will go quickly. As President Xi Jinping has specific instructions on sponge city development, it will go quickly.

• More research opportunities available
Thanks for your intention!