Front. Environ. Sci. Eng. 2018, 12(1): 16
https://doi.org/10.1007/s11783-018-1027-x

VIEWS & COMMENTS

An emerging market for groundwater remediation in China: Policies, statistics, and future outlook

Deyi Hou (✉)[1], Guanghe Li[1], Paul Nathanail[2]

1 School of Environment, Tsinghua University, Beijing 100084, China
2 School of Geography, University of Nottingham, Nottingham NG7 2RD, UK

Abstract There is a rapidly emerging and potentially huge market for the remediation of contaminated groundwater in China. The Chinese government published a Water Action Plan in April 2015, a Soil Action Plan in May 2016, and a draft Soil Pollution Prevention and Control Law in June 2017. All of these new policies and regulations put pressures on local governments and contaminated site owners, obliging them to conduct site investigation and to cleanup contaminated groundwater. The Chinese population in northern regions heavily depend on groundwater, with nearly 70% of water supply coming from aquifer sources in the Beijing-Tianjin-Hebei region. However, poor groundwater quality due to natural geochemical background and anthropogeic pollution is a serious concern, with poor or very poor quality water observed in nearly 80% of groundwater monitoring wells in 17 northern provinces. Shallow groundwater in many areas has been contaminated by toxic pollutants such as heavy metals and chlorinated organic compounds. There is an urgent need to better understand the situation and to conduct groundwater remediation at contaminated sites. The Chinese government is investing heavily in the research and development for groundwater remediation, which is expected to greatly add to the quality and quantity of groundwater remediation projects in the near future.

Keywords Groundwater pollution, Contaminated land, Groundwater remediation, Emerging market

Groundwater is exploited as a valuable resource for socio-economic development in modern societies. Currently, groundwater accounts for 18% of China's 610 billion m^3 water supply [1]. Of this, shallow groundwater accounts for 86%, and deep confined aquiers account for the remaining 14%. In five northern provinces (Hebei, Henan, Beijing, Shanxi, and Inner Mongolia), groundwater provides approximately 50% of the total water supply. However, significant levels of groundwater pollution in China represents a major concern.

As Fig. 1 shows, based on the Ministry of Land and Resource's national groundwater monitoring network (~5000 wells in 31 provinces across China), ~60% of the nation's groundwater is of poor or very poor quality (i.e. class IV or V). As such, this groundwater is not safe for use as a potable water without treatmment. Similarly, a monitoring network provided by the Ministry of Water Resources (~2000 wells installed in 17 provinces where groundwater is more extensively utilized), showed that approximately 80% of the groundwater was of poor or very poor quality [2].

In response to social and environmental pressure, the Chinese government launched a grand plan on May 31, 2016 to clean-up contaminated land, including contaminated groundwater (see Table 1). The plan, entitled Soil Pollution Prevention and Control Action Plan ("Soil Action Plan"), creates a demanding schedule for both national and local governments. This includes conducting a detailed investigation of operating and former industrial sites by 2020, and utilizing 95% of the nation's contaminated land in a safe manner by 2030. It was estimated that the Soil Action Plan will generate 450 billion RMB of revenue for the environmental industry by 2020 and will stimulate 2.7 trillion RMB of GDP growth [3]. Even though this plan was primarily designed to protect soil, it will also have profound implications for groundwater protection and cleanup [4]. In addition to the Soil Action Plan, a Water Action Plan was published on April 2, 2015. This plan mandated research and development in groundwater remediation, establishing an inventory of sites with serious groundwater pollution for remediation. A specific mandate was included for ground-

Received December 19, 2017; Revised December 21, 2017; Accepted December 21, 2017; Available online January 21, 2018

E-mail: houdeyi@tsinghua.edu.cn

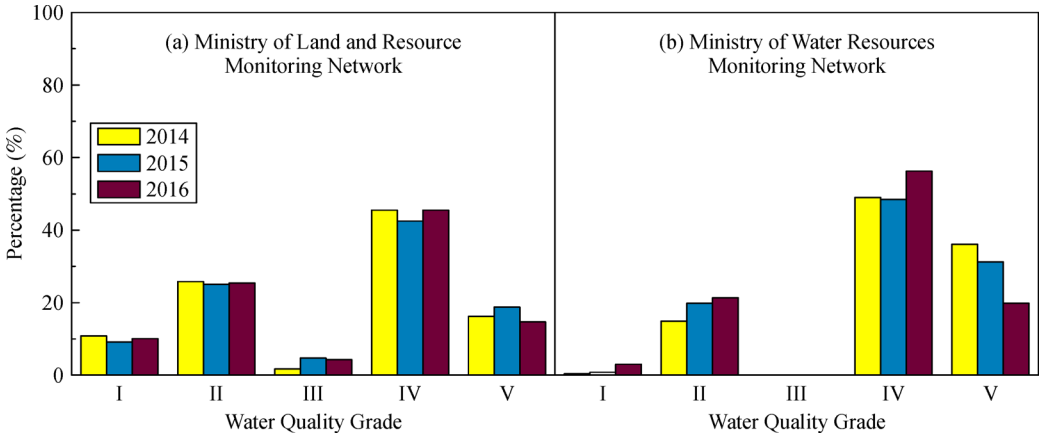

Fig. 1 Groundwater quality monitoring results in 2014–2016 based on two national groundwater monitoring networks (Class I: low natural background; Class II: natural background; Class III: not exceeding human health standards; Class IV: suitable for agricultural and industrial usage, and may be used as drinking water after appropriate treatment; Class V: not suitable for drinking; it is also noted that the definition of the grades above is regarding single groundwater quality indicator, while the overall groundwater quality grade is based on a weighted averaging of single indicators)

water remediation in the Beijing-Tianjin-Hebei region (population > 100 million), where nearly 70% of the region's potable water is drawn from local aquifers. A draft Soil Pollution Prevention and Control Law, published in June 2017 for public comment, also requires groundwater investigation and remediation for both agricultural land and industrial sites.

Due to a strong will from the central government and the above regulatory forces being put in place, we expect a rapidly emerging and potentially huge market for groundwater remediation in China. Groundwater monitoring in China has historically focused on traditional water quality indicators traditionally used for water supply purposes such as hardness, pH, COD, ammonia, iron, magnesium, etc. There is a paucity of data in the public domain regarding more toxic contaminants that derive from anthropogenic sources. Based on the authors' experience, published and unpublished data on local and regional scales have shown groundwater pollution at contaminated sites to be alarming. There are extensive volumes of groundwater existing that are significantly contaminated with heavy metals (particulary, Arsenic, Mercury, Lead, and Chromium), and organic pollutants (particularly, Carbon Tetrachloride, Chloroform, Tetrachloroethylene, Trichloroethylene, and Benzene).

Currently, the site remediation market is growing rapidly in China. It has been estimated that there are over one million contaminated sites to be remediated [5]. Most of these sites also have various levels of groundwater contamination issues. Based on USA Superfund program data, groundwater remediation will be required at over half of these contaminated sites for the pollution hazards to be fully addressed [6]. Due to the new ordinances and regulations from the central government, it is expected that groundwater remediation at contaminated sites will soon grow exponentially.

However, there are many complexities and challenges facing the investigation and remediation of contaminated groundwater [7]. Many highly toxic organic contaminants can tightly adsorb onto low-permeability soil matrices and then slowly "back-diffuse" repolluting the groundwater after remediation efforts are considered to be completed [8]. This back-diffusion process is still not well understood and has resulted in failures in the remediation of many complex sites in the USA [9]. Moreover, conducting groundwater remediation will have externalities that are not accounted for in traditional decision making processes. For instance, cleaning-up one kg of contaminants in soil and one kg of contaminants in groundwater may result in secondary greenhouse gas (GHG) emissions of up to 5 tons and 130 tons, respectively [10]. Therefore, it is essential for regulators and practitioners in China to better understand the complexities of contaminant fate and transport, as well as the life cycle impacts of remediation operations, in order to make informed decisions and to achieve sustainable remediation goals.

Scientific research will be a leading driver for future success in the remediation field in China – as has already proven to be the case in the USA and the UK. The Ministry of Science and Technology (MoST) recently awarded the largest groundwater pollution research and development grant to date in China. The project, as part of the National Water Pollution Control and Treatment Science and Technology Major Project, will be undertaken by a consortium of 19 research institutes with research funding of approximately 94 million RMB (~US$14 million). In addition, 321 million RMB in demonstration funding will be allocated to this project, totaling 415 million RMB (~US$63 million).

An additional funding scheme specifically for contami-

Table 1 Key National Policies Mandating Groundwater Pollution Prevention and Remediation

Ordinance/Regulation	Publisher	Publish Year	Description
WAP	SC	2015	Revise the national groundwater quality standards; ensure the proportion of worst groundwater quality (Class VI) is less than 15% by 2020.
WAP	SC	2015	Publish a list of priority sites with groundwater contamination in Beijing-Tianjin-Hebei region; conduct groundwater remediation demonstration.
SAP	SC	2016	Conduct site investigation of industrial facilities (~100000 sites) by 2020, monitor groundwater quality.
SAP	SC	2016	Complete demonstration remediation projects at 200 contaminated sites by 2020.
SAP	SC	2016	Safely use 90% of contaminated land by 2020; safely use 95% of contaminated land by 2030.
WAP/SAP	SC	2015/ 2016	Provide funding to support scientific research on groundwater remediation.
O-42	MEP	2016	Local governments should establish a list of "potentially contaminated sites," and site owners shall conduct screening level investigation within 6 months to determine whether they are "contaminated sites," for which detailed site investigation, risk assessment, risk management and/or remediation shall be conducted.
SPPCL	NPC	2017	Local governments shall conduct investigation and remediation as necessary for groundwater pollution on agricultural land.
SPPCL	NPC	2017	For key industry sectors, when land use is changed, site users shall conduct soil and groundwater investigation, determine the extent of groundwater contamination, and conduct groundwater remediation.

Notes: WAP = Water Pollution Prevention and Control Action Plan; SAP = Soil Pollution Prevention and Control Action Plan; O-42 = Administrative Measures on Soil Environmental Management of Contaminated Sites (Ordinance 42); SPPCL = Soil Pollution Prevention and Control Law (Draft); SC = State Council; MEP = Ministry of Environmental Protection; NPC = National People's Congress

nated site remediation is also expected to be released later this year or early 2018. The funding for soil and groundwater remediation is likely to amount to billions of RMB in total. R&D projects are expected to fund the research of thousands of MS and PhD students. In addition, many reseachers and practitioners with experience in other fields will gain experience in groundwater remediation. This "knowledge growth" is expected to significantly improve the quality and quantity of groundwater remediation projects in China.

Acknowledgements This work was supported by the National Water Pollution Control and Treatment Science and Technology Major Project (No. 2018ZX07109-003), the Thousand Talents Program of the Chinese government and Tsinghua University.

References

1. Ministry of Water Resource of China. China's Water Resource Bulletin 2014. Beijing: Ministry of Water Resource of China, 2015 (in Chinese)
2. MEP, 2016 China's Environmental Conditions Report. 2017
3. People's Daily. "Soil Ten" propose to curb deteriorating soil pollution by 2020 (2016). 2016 (in Chinese)
4. Hou D, Li F. Complexities Surrounding China's Soil Action Plan. Land Degradation & Development, 2017, 28(7): 2315–2320
5. CSER. China's Soil Remediation Technology and Market Development Research Report 2016–2020. Beijing: CSER, 2016 (in Chinese)
6. USEPA. Superfund Remedy Report 15th Edition EPA-542-R-17–001. Washington DC.: USEPA, 2017
7. Qi S, Hou D, Luo J. Optimization of groundwater sampling approach under various hydrogeological conditions using a numerical simulation model.Journal of Hydrology (Amsterdam), 2017, 552(Supplement C): 505–515
8. Liu C, Ball W P. Back diffusion of chlorinated solvent contaminants from a natural aquitard to a remediated aquifer under well-controlled field conditions: predictions and measurements.Ground Water, 2002, 40(2): 175–184
9. Chapman S W, Parker B L. Plume persistence due to aquitard back diffusion following dense nonaqueous phase liquid source removal or isolation.Water Resources Research, 2005, 41(12)
10. Hou D, Al-Tabbaa A. Sustainability: A new imperative in contaminated land remediation.Environmental Science & Policy, 2014, 39: 25–34