Research Assessment Exercise 2020
Impact Case Study

University: The University of Hong Kong (HKU)
Unit of Assessment (UoA): 10 - Earth Sciences (incl. oceanography, meteorology) and other physical sciences (incl. environmental science)

Title of case study:
Coastal groundwater: Its implications for the environment, engineering, and water resources

(1) Summary of impact

Coastal cities are home to roughly 25% of the world's population and are rapidly growing. Hence coastal groundwater is important because of its resource, environmental, and engineering implications. HKU's Hydrogeology Research Group (HRG), led by Prof. Jiao, has researched the impact of land reclamation on groundwater. This work has provided a theoretical framework leading to globally adopted practical guidance. The HRG's findings on offshore groundwater have been used in Hong Kong to inform the way this resource is used, and to understand the connection between submarine groundwater discharge (SGD) and red tides, prompting the Hong Kong government to reduce groundwater-induced nutrient sources to better manage the red-tide problem. The findings have also helped to identify cost-effective reliable groundwater resources in Singapore, and to reduce the adverse engineering and environmental impacts of land reclamation in Sri Lanka and China.

(2) Underpinning research

Since 2005, HRG has studied coastal hydrogeology, including natural and reclaimed coastal areas, shallow coastal groundwater, and deep offshore groundwater, focusing on the following aspects:

a) Land reclamation and groundwater. Land reclamation (placing fill into the sea to gain land) has played a significant role in the urban development of coastal areas globally, including Singapore, China, Korea, the Netherlands, and the United States. In Hong Kong, over 10% of the developed land is reclaimed. In China, about 1,000 km^2 is reclaimed annually. HRG has pioneered research on the impact of land reclamation on groundwater systems. Using analytical and numerical approaches, as well as field case studies, HRG has demonstrated that groundwater level, the groundwater divide, SGD, and the saltwater-freshwater interface change with the scale of reclamation and fill permeability [R1–R3]. An unintended advantage of reclamation is an increase in fresh groundwater resources because the reclaimed land can be an additional aquifer [R2]. HRG used a case study in Shenzhen to show that reclaimed land experiences complicated physiochemical interactions between terrestrial groundwater, seawater, original marine mud, and fill materials [R3]. The concentration of heavy metals in the mud decreases gradually, but increases in the groundwater. Once released into the sea, this leads to adverse effects on the coastal environment. HRG suggested that these changes should be investigated to predict possible engineering challenges and environmental consequences [R1–R3].

b) Submarine groundwater discharge. To alleviate nutrient loading and reduce the harmful algal bloom, the Hong Kong government implemented the Tolo Harbour Action Plan in 1988 (a HKD752 million project). The plan reduced the nutrients from point sources by over 80%, but red tide frequency has not been reduced proportionally and still causes great environmental damage (e.g., in March 2016, a series of red tides killed 220 tonnes of high-value fish). HRG suggested that nutrients from groundwater may explain the continuing frequent occurrence of red tides. Using

various geotracers, HRG demonstrated that land-derived groundwater discharge into Tolo Harbour is at least comparable to river discharge and contains nutrients two orders of magnitude higher than rivers [R4], suggesting that riverine nutrients are not the main contributor as previously thought. HRG showed that the spatial-temporal distributions of SGD and red tide occurrence are correlated. They suggested that the current policy and practice for managing and predicting red tide outbreaks had to be reviewed and that measures to control groundwater contamination were much needed [R4].

c) Offshore groundwater. HRG has studied offshore groundwater as potential useable water in Hong Kong, but there are limited quality data on the chemistry of offshore groundwater. HRG extracted pore-water from cores drilled offshore near Lantau Island for conventional geological studies and provided the first comprehensive chemical profiles that confirm there is relatively fresh or brackish water in the offshore aquifers [R5 and R6]. HRG further studied the spatial distribution of the aquifers using borehole and geophysical information, estimating offshore fresh/lightly brackish water to be 4–6 billion m^3, equivalent to up to six years of Hong Kong's needs [R6].

The HKU researchers are Profs. Jimmy Jiao (1997–present), Wyss Yim (1985–2014), and Shouye Yang (Visiting Scholar, 2012); post-doctoral fellows Drs Lei Shi (2011–2013), Xingxing Kuang (2013–2017), and Xin Luo (2015–present); PhD students Drs Subhas Nandy (1998–2002), Kouping Chen (2003–2007), and Haipeng Guo (2004–2008); and MPhil students Ms Hiu-Tung Kwong (2013–2015) and Mr Chun-Ming Lee (2010–2012).

(3) References to the research

[R1] Jiao, J. J., S. Nandy, and H. Li, 2001, Analytical studies on the impact of land reclamation on groundwater flow, *Groundwater*, 39(6), p912–920

[R2] Guo H. P. and J. J. Jiao, 2007, Impact of coastal land reclamation on ground water level and the seawater interface, *Groundwater*, Vol. 45, No. 3, May–June, pp 362–367

[R3] Chen K. P. and J. J. Jiao, 2008, Metal concentrations and mobility in marine sediment and groundwater in coastal reclamation areas: a case study in Shenzhen, China, *Environmental Pollution*, 151 (3), p576–584

[R4] Luo, Xin, and J. J. Jiao, Submarine groundwater discharge and nutrient loadings in Tolo Harbour, Hong Kong using multiple geotracer-based models, and their implications of red tide outbreaks. *Water Research* (2016), 102, Pages 11–31

[R5] Jiao, J. J., Shi, L., Kuang, X., Lee, C. M., Yim, W. W. S., & Yang, S. (2015), Reconstructed chloride concentration profiles below the seabed in Hong Kong (China) and their implications for offshore groundwater resources. *Hydrogeology Journal*, 23: 277–286

[R6] Kwong H. T. & Jiao J. J. (2016), Hydrochemical reactions and origin of offshore relatively fresh pore water from core samples in Hong Kong. *Journal of Hydrology* 537: 283–296

(4) Details of the impact

Providing a theoretical framework and practical guidance for groundwater studies in reclamation sites in China and Sri Lanka. HRG's research on groundwater and reclamation has been cited in at least nine environmental assessment reports for reclamation in China. For example, the Zhoushan City Land and Resources Bureau completed a report in 2015 about the need for a groundwater environment assessment of 6.5 km^2 of reclaimed land in Zhoushan, Zhejiang [S1]. The report acknowledged that Prof. Jiao initiated groundwater studies in reclaimed land (p3), summarized his findings about engineering and environmental impact to justify the need for their assessment (p5), and further discussed the possible chemical processes based on Prof. Jiao's research in Shenzhen (p8). As recommended by the assessment, more than 20 boreholes were installed to monitor the possible adverse physiochemical effects of reclamation.

In 2016, Sri Lanka started a USD1.4 billion project to reclaim 5.76 km^2 in Colombo Port City for a central business district. Its impact on groundwater, as well as the engineering and environmental consequences, has been hotly debated since December 2017 (e.g., newspaper clips S2b–2d). The debate was initiated by a presentation [S2a] by a senior civil engineer at the Institute of Engineers, Sri Lanka. On the basis of Prof. Jiao's findings [R1], he calculated the water-level rise after reclamation, which could have had very adverse effects, damaging the stability of historic buildings. The engineer said: "*If the water table rises, structures built on simple footings may be subjected to loss of bearing capacity, which in turn reflects as building settlement – mostly as differential settlement*." This put huge pressure on the reclamation company and the city government, forcing them to pay serious attention to the problem and take preventive and mitigating action [S2c].

Providing information for water management strategy for the Hong Kong government. HRG's studies on SGD in Tolo Harbour and offshore groundwater around Lantau Island are extensively cited in the government report: "Review of total water management strategy in Hong Kong feasibility study" [S4]. The report recommended that "*recent research indicated groundwater with low salinity could exist in the lower marine aquifer to Lantau Island… this groundwater body could be employed as a more cost-effective resource for desalination than seawater*" (p41). The report also recommends "*hydrogeological investigations… to provide information for further decisions on the potential for exploitation of submarine groundwater as a source for desalination.*"

Altering the Hong Kong government's view on holistic red-tide management. HRG's research on SGD and its impact on red tides were reported in great detail by the South China Morning Post (April and July, 2016): groundwater pollution is "*the source of mysterious red tide-inducing nutrient pollution*", and groundwater discharge "*could provide an explanation as to why the frequency of red tides… had not declined*". SCMP urged that attention be paid to groundwater sources and monitoring of groundwater around the harbour [S5a–5b]. As a result, the government has greater awareness of, and real concern about, any potential groundwater contamination-induced nutrient input to the harbour. For example, the Drainage Service Department is developing a huge cavern sewage treatment system (capacity of 340,000 m^3/day, a project of HKD30 billion) near the harbour. Prof. Jiao has been invited by DSD to assess the impact of this system on groundwater flow in order to avoid any potential groundwater contamination around the harbour by the system (HKD1.3 million, HKU Contract Research 200008694).

Running workshops to train environmental engineers/assessors in China and initiating groundwater assessment in Shanghai. China has tightened its policy on land reclamation, given the associated environmental problems. However, the impact on groundwater is the least-studied or assessed issue. Prof. Jiao was invited by the Appraisal Centre for Environment and Engineering, Ministry of Environmental Protection, to run a workshop on this subject on 26 April, 2018. Over 200 engineers and environmental assessors attended [S6a]. More intensive one-day workshops on the impact of human activities on groundwater were held on 15 August, 2018, organised by the Shanghai Geological and Mineral Engineering Investigation Co. Ltd (SGMEI) and the Shanghai Geological Society, and on 13 June, 2019, organised by the Shenzhen Geological Bureau [S6b]. In total over 180 geotechnical experts and practitioners attended the workshops. Inspired by Prof. Jiao's workshop, SGMEI launched a preliminary assessment to investigate the possible water-level increase in Shanghai as experienced in Hong Kong due to human activities, and found that there had indeed been a regional water-level increase of up to 26 m. SGMEI then proposed a major project to have a comprehensive assessment of the groundwater in the entire city, and to devise a scheme to alleviate various engineering and environmental impacts of the water-level increase. SGMEI has formed an expert panel, with Prof. Jiao as the chairman, to provide guidance to ensure the successful implementation of this project [S7].

(5) Sources to corroborate the impact

[S1] Investigation on monitoring and assessment of groundwater environment in the reclaimed land in East Port, Zhousha (report in Chinese), Zhoushan Land and Resources Bureau, Nov. 2015

[S2] Debate on water-level change in Colombo Fort in Sri Lanka

- [S2a] Slides (summarizing Prof. Jiao et al.'s findings) in the presentation for the Institute of Engineers Sri Lanka given by a senior civil engineer, Dec 2017
- [S2b] Sunday Times (17 Dec, 2017): The Port City: A response to right of reply (Ground water table in the Colombo Fort area influenced by port city reclamation)
- [S2c] Sunday Observer (10 Dec, 2017): Will the rise of groundwater table affect Colombo Fort?
- [S2d] Sri Lanka Mirror (03 Feb, 2018): Colombo at risk of sinking due to port city!

[S4] Topical Study Report on Use of Groundwater, Review of Total Water Management Strategy in Hong Kong Feasibility Study (Agreement No. Ce 2 /2014) (2015), Water Supplies Department and Black and Veatch

[S5] Newspaper articles on groundwater and red tides in South China Morning Post

- [S5a] SCMP (30 Apr, 2016): Hong Kong fish farmers claim proliferation of red tides is worst 'unnatural disaster' to hit industry in years
- [S5b] SCMP (30 July, 2016): Stem the red tide: researchers say human pollution is behind algal blooms and government should take charge

[S6] Web news summary of the workshop (in Chinese)

- [S6a] Training activities: Workshop on impact of land reclamation on groundwater and its environment, Appraisal Centre for Environment and Engineering (20 May, 2018)
- [S6b] Training activities: Workshop on impact of human activities on groundwater, Shenzhen Geological Bureau (19 June, 2019)

[S7] Letter from Chief Engineer, Shanghai Geological and Mineral Engineering Investigation Co. Ltd, 2019