British Geological Survey
TỔNG CỤC ĐỊA CHẤT VÀ KHOÁNG SẢN VIỆT NAM
General Department of Geology and Minerals of Viet Nam

THE FIFTEENTH REGIONAL CONGRESS ON GEOLOGY, MINERALS AND ENERGY RESOURCES OF SOUTHEAST ASIA (GEOSEA XV)

13-21 OCTOBER 2018
VIETNAM

SMART GEOLOGY FOR FUTURE HANOI – UNDERSTANDING THE ROLE OF GEOLOGY FOR SUSTAINABLE DEVELOPMENT

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Asia is the second most rapidly urbanising region globally, currently 48% of the Asian population resides in urban areas. Disturbance to the natural environment as a result of urbanisation is expected to be significant since natural resource consumption (e.g. water, energy) and the physical expansion of cities are both outpacing population growth. While cities have been characterised in terms of their economic, social and environmental situation, the role of geology for city resilience and sustainability is under-appreciated.

Using Greater Hanoi - a soft-sediment city lying in the Red River Catchment, contrasted with Greater London, a riverine city located in the Thames River Catchment - we illustrate how an understanding of the urban geological environment supported by data informatics, sensor technologies and modelling systems, may be used to underpin urban development and sustainable use of the subsurface. The priority urban challenges identified as part of Hanoi's Master Planning - including future transport infrastructure, groundwater management & drainage, subsidence, and shallow geothermal energy utilisation are used as case studies to highlight the potential benefits of 3D urban geology approaches and digital data workflows. The benefits of geoscience knowledge-exchange networks across government and private sector partners are also highlighted.

Keywords: Urban geology, Hanoi, sustainable development, digital data, 3D models

Introduction

Asia is the second most rapidly urbanising region global, currently 48% of the Asian population resides in urban areas; by 2050 this is expected to reach 64% (UN 2014). Disturbance to the natural environment as a result of urbanisation is expected to be significant since natural resource consumption (e.g. water, energy) and the physical expansion of cities are both outpacing population growth (Hunt et al. 2016). The pace of urbanisation is overwhelming many cities, globally 60% of the area expected to be urban by 2030 hasn't been built yet (WEF 2016), and as a result the UN-Habitat New Urban Agenda proposes strategies for urban planning, governance and urban design to inform city expansion. Urban planning, infrastructure and environment are highlighted as key challenges for developing cities but importantly transformation around these challenge areas is expected. For Asia, urban planning, infrastructure, environmental resource management and hydrological hazards are identified as key challenge areas (WEF 2016).

In Greater Hanoi the population is expected to increase from ~7.5 million (2020) to 10.8 million by 2050 in response to both population growth and expansion of the urban boundary. To accommodate this expansion the masterplan for Hanoi includes the development of five satellite towns, 3 eco cities, 10 small towns with supporting transport infrastructure to improve connectivity with central Hanoi. A green corridor will separate central Hanoi and the new urban centres. The construction of five underground railway routes in central Hanoi, with a total length of ~50km, is included in Hanoi's masterplan as part of the infrastructure development. The urban underground space will be further developed through the construction of subterranean walkways and basements for e.g. car parks.

In contrast London's population exceeds 8.5 million people with additional ~1 million households expected by 2035. Significant investment in infrastructure, of the order of £1.3 trillion, is anticipated by 2050 most of which is allocated for transport and housing, though investment in water infrastructure and green infrastructure is also accounted for (Bricker et al., 2017). Urban underground space in London has been exploited significantly through the construction of transport tunnels and mega basements, with further underground transport (Cross-rail metro and highspeed rail) and wastewater (Thames Tideway tunnel) infrastructure planned.

Sustainable development can only be achieved if an appreciation of the close links between the environment and society are understood. While cities have been characterised in terms of their economic status, resilience and readiness for transformation the role of geology for city resilience and sustainability is under-appreciated. Furthermore geoscience information has traditionally been under-utilised in planning and development, as its significance is often misunderstood or underappreciated (Royse et al., 2013).

Taking a city geology-typologies approach, the broad geological constraints and opportunities that the city faces can be evaluated and communicated to city practitioners (Krabbendam et al., 2016), for example soft sediment cities are more prone to subsidence and flooding, while hard rock cities have variable weathering profiles and fracture networks with implications for e.g. underground infrastructure and contaminant migration. To further improve this understanding the relationship between the geology (lithology), its properties (physical, chemical or hydrological characteristics) and the dependant city functions needs to be defined. These characteristics are not uniformly distributed in the subsurface; they vary both vertically and horizontally and thus have a particular distribution in 3D. Without sufficient geological data and modelling capability the 3D distribution of geological properties is difficult to characterise and predict, this leads to uncertainty in resource modelling and management, and difficulties and risks in urban planning and development.

Using case studies from London and Hanoi this paper discusses how an improved understanding of the urban geology, in combination with technological developments, such as improvements in GIS technologies and 3D modelling software, can drive more sustainable urban growth.

Geology typologies

A city's industrial history, urban fabric and natural resource utilisation is strongly influenced by its underlying geology. Specifically environmental risks, constraints and opportunities that cities face are strongly related to its geographic location (e.g. upland, coastal), its geomorphology (e.g. deltaic, fluvial) and its underlying geology (e.g. hard rock, soft sediment).

The challenges and opportunities related to use of the subsurface depend in essence on the physical and chemical characteristics of the unconsolidated sediments and the bedrock that form the subsurface. Physical characteristics include load-bearing capacity (intact rock strength, rock-mass strength), ductility, shrink-and-swell, grain size, porosity, permeability, presence and character of any fractures. Chemical characteristics include sensitivity to weathering, solubility (e.g., leading to karst formation) and occurrence of natural pollutants (e.g. arsenic or fluoride).

The essence of the geological-typology approach is the premise that particular geological and geomorphological settings lead to particular broad patterns in the distribution of rock or sediment packages that have particular physical and chemical attributes. By analysing the broad patterns of the distribution of different rock/sediment packages in different settings, the approaches for modelling and field surveys can be better defined and the constraints and opportunities for urban development can be better assessed and investigated. Example geological typologies for soft-sediment and hard rock cities along with the geological constraints and opportunities they present are described in Table 1.

Table 1. Example geological typologies for soft-sediment and hard rock cities along with the associated geological constraints and opportunities

Geological Setting	**Potential Geo-Constraints**	**Potential Geo-Opportunities**
Soft bed cities (unconsolidated sediment)		
Deltaic	subsidence, flooding, sea level rise, salinisation of groundwater, high groundwater vulnerability to pollution, problematic building conditions.	flat,uniform ground conditions, high yielding aquifers, aggregate resources shallow geothermal energy
Alluvial	subsidence, flooding, high groundwater vulnerability to pollution, problematic building conditions	flat,uniform ground conditions, high yielding aquifers aggregate resources shallow geothermal energy
Coastal plain	subsidence, flooding, sea level rise, salinisation of groundwater, problematic building conditions coastal erosion	aggregate resources shallow geothermal energy
Hard-bed cities (bedrock)		
Low relief	highly irregular weathering front / rockhead, variable ground conditions, low yielding aquifers, high groundwater vulnerability to pollution	reduced subsidence risk, aggregate and mineral resources, no sea level rise risk,
High relief	highly irregular weathering front / rockhead, variable ground conditions, low yielding aquifers, high groundwater vulnerability to pollution landslide risk	aggregate and mineral resources, reduced subsidence risk, no sea level rise risk,

‘Smart’ geology for sustainable urban development

Using case examples from London and Hanoi we describe the city’s geological typology and show how the geology influences some the key urban challenges identified by the city’s planners (Table 2). Specifically, we consider ground conditions for construction, ground motion and shallow geothermal resource potential and how the application of ‘smart’ geology can help advance our understanding of the issues.

London

Ground conditions for underground construction: A 3D geology model of London and the River Thames valley was developed by the BGS to support improved understanding of the urban ground conditions and to inform subsurface management. The model occupies an area of approximately 4800 km^2 and extends to a depth of >200 m. More than 7000 boreholes, supplied to BGS by both public and private organisations, and contained within the BGS national borehole database were used to develop the model, which has a resolution of 1:50k, and a refined resolution around key urban development areas of 1:10k (Mathers et al 2014). The model has been used successfully to characterise the 3D geology ahead of construction of transport tunnels. For example, at Farringdon underground station the likely distribution of water-bearing coarse sand deposits and their faulted offsets were modelled to inform groundwater control and tunnelling methods (Aldiss et al 2012).

Groundwater abstraction and ground motion: The Chalk aquifer in London has been exploited for public and industrial supply since the 1850s and is one of the most monitored and managed aquifer-systems in the UK (Boni et al., 2016). However, a reduction in abstraction since the 1950s has led to problems with rising groundwater levels. The large fluctuations in groundwater level have resulted in ground displacement with areas of uplift and subsidence detected. Integration of the 3D geology model of London, groundwater level data supplied by the environmental regulator, and Persistent Scatterer Interferometry Synthetic Aperture Radar (InSAR) was applied to analyse the relationship between ground motion and abstraction induced hydraulic head changes. The relationship between ground motion and groundwater level change (indicative of groundwater released from aquifer storage) was further used as a proxy to derive aquifer storage coefficients. Derived storage coefficient values appear to be correlated with the hydro-geological setting and can be used to support refined modelling and management of the aquifer system (Boni et al., 2016).

Table 2. Geological typology of London and Hanoi.

	Geology typology	Geological constraints	Geological opportunities
London	Alluvial city, mixed-geology typology. Soft glacio-fluvial sediments overlying consolidated clay, interbedded sands, silts and clays, and fractured limestone.	Shallow groundwater necessitates dewatering for underground construction. Ground motion induced by groundwater abstraction. Anomalous ground conditions due to glacial history and faulting	Sand and gravel aggregate resources. Consolidated clays favoured for tunnel boring. Groundwater resources from fractured limestone. Shallow geothermal resources from fractured limestone.
Hanoi	Alluvial, soft-sediment city, upstream of a major delta system. Thick sequence of silt, sand and gravel overlying sandstone.	Shallow groundwater necessitates dewatering for underground construction. Subsidence induced by groundwater abstraction. Unconsolidated sediments induces difficult ground conditions for development.	Sand and gravel aggregate resources. Groundwater resources. Shallow geothermal energy.

Hanoi

While Hanoi and London have contrasting geology, the two cities share a common challenge of balancing integrated urban resource management (e.g. groundwater, energy) with increased underground urban development (e.g. tunnels, basements). The city of Hanoi is already utilising groundwater from aquifers within the catchment for public water supply but may further utilise the aquifer systems for the extraction of geothermal energy via ground-source heat pumps. This resource utilisation needs to countered against the risk of declining groundwater levels and associated ground subsidence. Assessment of these, and other, multiple and interacting pressures on Hanoi's subsurface, necessitates a more complete understanding of the urban ground conditions. In this regard, Hanoi is well-positioned for the development of a 3D geology model of the urban area. A scientific committee of government and academic bodies has been established to coordinate the cities subsurface data and information and innovative digital data systems and modelling technologies are being implemented to support data integration and utilisation across the geo-environmental community. Thus far in excess of 500 borehole logs have been obtained to facilitate the development of a 3D geology model of greater Hanoi. The development of the new data systems and modelling capability may be utilised to further investigate the urban geo-constraints and opportunities identified.

Subsidence: As with London, the aquifers beneath Hanoi have been exploited over a number where groundwater is currently the primary source for public water supply. Ground subsidence as a result of groundwater abstraction is a significant concern and has been investigated by the scientific community. The subsidence pattern in the Hanoi Capital Region area (Vietnam) has recently been analysed using Interferometric Synthetic Aperture Radar (InSAR) technique to process Sentinel-1 satellite data for the period April 2016 – July 2017. A total of ~2 million radar targets were obtained for the area of interest, providing an average density of 287 points/km^2. The ground motions appear related to groundwater abstraction, and construction activities due to the rapid urban development in the city, with maximum subsiding rates of 25 mm/year (along the satellite Line of Sight) in Trạm Trôi and localized deflations around Hoàng Văn Tú, Thanh Liệt and Quang Trung communes. The Sentinel-1 InSAR results confirm the magnitude, location and extent of the deformations observed in Hanoi by other L-band and X-band DInSAR studies during the 2010s. With plans for a reduction in the utilisation of groundwater supply from ~90% in 2000s to <30% by 2030, and with plans for additional underground transport tunnels, further fluctuations in groundwater level and ground motions are anticipated.

Shallow geothermal ground-source heating: Ground source heat pumps (GSHPs) exploit the temperature difference between above ground air temperatures and below ground (rock or groundwater) temperatures. The success of the system relying on the constant temperature of the ground which is typically equivalent to the mean annual air temperature. GSHPs are best implemented when there is a balanced thermal load, i.e. both heating and cooling is required and where advection is provided via groundwater flow. Initial investigations suggest that Hanoi has significant potential for the utilisation of shallow geothermal energy. Hanoi is underlain by a thick sequence of silt, sand and gravels which form locally exploitable aquifers for both groundwater supply and shallow geothermal energy. While regional groundwater gradients are low, historic over-abstraction and large groundwater level drawdown has caused steep hydraulic gradients beneath the city. Furthermore, preliminary inspection of climate data for Hanoi indicates that there is a requirement for both heating and cooling at different times of the year, although load not balanced as cooling requirement greater and this cannot be met entirely from the ground (table 3). A detailed investigation of the suitability of Hanoi for strategic exploitation of shallow geothermal energy is advised.

Table 3. Summary heating and cooling demand for Hanoi

No. of days in the year when average daily temperature exceeds indoor comfort temperature	198
No. of cooling degree-days in the year	888
No. of heating degree-days in the year	76.5
No. of cooling degree-days in the year that could be met from ground cooling	807.5
No. of heating degree-days in the year that could be met from ground heating	76.5

Conclusion

Using case studies from the cities of Hanoi and London we have shown that the underlying geological conditions is intimately linked to urban constraints and opportunities and that a greater appreciation of the ground conditions is needed to support sustainable development – specifically to reduce the risks associated with underground construction, and to support sustainable utilisation of natural resources.

Investigation of ground conditions at the city-scale to support development requires high resolution mapping accompanied by a good appreciation of the horizontal and vertical variation of the ground properties. This understanding is best captured in a 3D geology model framework and is dependant on the availability of a large number of high quality borehole logs and a digital data workflow to facilitate data integration and utilisation. The establishment of public-private data partnerships to facilitate the exchange of subsurface data have proven successful in the UK and is considered pivotal for an integrated urban geoscience project.

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