



BUILDING CLIMATE RESILIENCE AND WATER SECURITY IN CITIES: LESSONS FROM THE SPONGE CITY OF WUHAN, CHINA

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Summary

Cities are increasingly adopting nature-based solutions – that is, interventions that rely on providing, restoring, protecting and/or sustainably managing natural or modified spaces and ecosystems – as alternatives to conventional urban development. In 2013, China’s national government launched the “Sponge City Programme” in response to its urban water management challenges. The programme encouraged cities to adopt green and blue infrastructure (based on natural areas and water elements) rather than grey infrastructure (based on concrete and steel). Wuhan – a pilot “sponge city” – has shown that green and blue infrastructure can be employed both quickly and cost-effectively to increase the resilience of urban areas to a changing climate.

Wuhan’s sponge city programme is more than CNY 4 billion (almost US\$ 600 million) cheaper than an alternative (i.e. grey infrastructure-based) approach to increasing the city’s resilience to flooding. The case study also shows that the Sponge City Programme generates wider social and environmental benefits, such as reduced carbon emissions, improved public health, enhanced natural cooling and improved biodiversity conservation. The city’s successes were made possible by an implementation framework, put in place by the national government, which incentivised and enabled lower levels of government to adopt sponge city measures. This involved establishing basic laws and regulations relating to sponge infrastructure; outlining compulsory standards and targets that had to be met; providing support in the form of technical guidelines, direct funding and favourable financing instruments; and peer-to-peer learning across cities.

CONTENTS

Summary	1
Highlights	3
1. Flooding in a time of water scarcity	5
2. Methodology	7
3. The policy context	8
4. The case study	10
5. Policy recommendations	17
6. Conclusions	20
Endnotes	21

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ABOUT THIS WORKING PAPER

This policy brief was prepared by the University of Leeds. It was developed in partnership with the Coalition for Urban Transitions, which is a major international initiative to support decision makers to meet the objective of unlocking the power of cities for enhanced national economic, social, and environmental performance, including reducing the risk of climate change. The research presented here was conducted in support of the Coalition's Economics workstream, and builds on previous University of Leeds and Coalition research on the economic and social benefits of low-carbon cities. The opinions expressed and arguments employed are those of the authors.

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Lake in Wuhan. Credit: Shutterstock/Hao Wan



To scale these further, national governments should ensure that every city has a transformative, locally appropriate climate-resilient water management plan that encourages the integration of nature-based solutions, such as green infrastructure, with more traditional grey infrastructure. National governments should explore innovative ways to incentivise investment in green infrastructure, for example by offering tax incentives and utility rate reductions, while also mandating that all new developments adhere to green building standards. They should continue to enable experimentation and city-to-city sharing of good practice for harnessing the multiple co-benefits of nature-based solutions in cities.

This policy brief is one of a series on frontrunning climate actions in cities around the world. The objective of this series is to strengthen the evidence on the economic and social implications of low-carbon, climate-resilient urban development. The series focuses on providing robust data on ex post outcomes of climate action, ranging from better public health to job creation to greater equity. Each case study explores some of the preconditions for the successful design and delivery of urban climate action and provides national policy recommendations that could enhance their effectiveness and the scale of their benefits.

Highlights

- China's rapid urban growth has been accompanied by serious water issues. Drainage does not meet national flood-prevention safety standards in half of its cities, meaning flooding and contamination of the water supply are common.¹ And climate change is bringing more frequent extreme rainfall events.² Moreover, China is especially susceptible to natural disasters: between 2004 and 2014 it experienced more recorded natural disasters than any other country in the world.³
- Many cities are growing in areas that are especially vulnerable to water-related climate risks, such as low-elevation coastal zones and near to major rivers.⁴ Sprawling, poorly managed urban expansion in these areas generates various social, economic and environmental problems. Access to clean water, and protection against rising waters, are two of the most significant challenges in these urban areas.
- Conventional approaches to urban development and infrastructure provision can be carbon-intensive, polluting and lead to the loss of green spaces and degradation of ecosystems. Increasing attention is being paid to the potential of nature-based solutions to address societal challenges while simultaneously providing human well-being and biodiversity benefits. Nature-based solutions can offer cost-effective and sustainable alternatives to grey or technology-based infrastructure.⁵
- China's national government launched the "Sponge City Programme" in 2013 to promote the wider adoption of measures such as absorptive roads and permeable pavements, green infrastructure such as rain gardens, parks and wetlands and built

environment measures such as green roofs and rainwater reuse facilities. Between 2015 and 2017, the national government dedicated CNY 20.7 billion (US\$3 billion)^a for 16 pilot sponge cities, with ambitious targets that 20% of each pilot city's land should be constructed to sponge city standards by 2020 and 80% by 2030.

- Wuhan in Hubei Province is a sponge city and a leading example of a nature-based approach to increasing urban resilience to climate change. Wuhan has initiated 389 separate sponge city projects covering 38.5 square kilometres (km²) of the city, including urban gardens, parks and green space designed to allow water to infiltrate during regular precipitation and to direct water away from urban areas during flooding. Other projects include artificial lakes that draw water away from populated areas and water channels that can safely handle large volumes of water during flooding.
- Wuhan's nature-based approach to resilience was more than CNY 4 billion (almost US\$600 million) cheaper than upgrading the city's drainage system. There were also significant co-benefits, including improved local air quality, biodiversity and conservation benefits, health and lifestyle benefits, and increased land value. The city's Yangtze River Beach Park showcases this: temperatures in the park can be 3 degrees cooler than in the city; the vegetation sequesters 724 tonnes of carbon annually; and the value of land in surrounding areas has more than doubled to CNY 10,218 (US\$1,471) per square metre.⁶
- China's national government has put in place an implementation framework that enables lower levels of government to adopt sponge city measures. This included establishing basic laws and regulations, and compulsory standards and targets, and providing support in the form of technical guidelines, direct funding and favourable financing instruments. The sharing of successful examples from other cities, accompanied by financial and technical support from national government, has built enthusiasm for the concept in lower levels of government and in non-pilot cities. Preliminary estimates suggest a total investment of CNY 10 trillion (US\$1.5 trillion) in sponge measures across 100,000 km² nationwide.⁷
- To scale up the development of sponge cities, national governments – in China and internationally – should ensure that every city has a transformative, holistic and locally appropriate climate-resilient water management plan that integrates green and grey infrastructure. Governments must explore innovative ways to incentivise investment in green infrastructure, while also mandating that all new developments adhere to green building standards. They should continue to enable experimentation and city-to-city sharing of good practice for nature-based solutions.

^a All conversions in this brief are based on an exchange rate of approximately CNY 7 to US\$ 1 (5 Feb at xe.com).

1. Flooding in a time of water scarcity

THE GLOBAL CHALLENGE

The United Nations (UN) 2030 Agenda for Sustainable Development recognises that sustainable water management will be critical for achieving the Sustainable Development Goals (SDGs). Water management is directly linked to human well-being (SDG 3), clean water and sanitation (SDG 6), sustainable cities and communities (SDG 11), climate adaptation and mitigation (SDG 13) and the health of ecosystems (SDGs 14 and 15).⁸ Global commitments to address water-related challenges are further recognised by the Paris Agreement, the New Urban Agenda and the Sendai Framework for Disaster Risk Reduction 2015–2030.

However, areas that are most vulnerable to water-related risks are also home to some of the world's largest and fastest growing cities.⁹ As the urban population continues to rise towards more than 6 billion by 2050, cities too are expanding – often in low-elevation coastal zones and near to major rivers.¹⁰ In these cities, access to water, but also protection from it, are among the most pressing basic needs for many of these urban dwellers.

Particularly in low-income countries, public services are struggling to keep pace with growing populations,¹¹ leaving an estimated one in three people worldwide without access to an adequate supply of safe water and sanitation systems.¹² Inefficient water management leads to unsustainable levels of consumption, over-extraction and contamination of water sources.¹³ The expansion of the built environment increases the area of impermeable surfaces. Coupled with insufficient drainage and sewage systems, this leads to drastically increased urban runoff, worsening the impacts of water-related events such as flooding and drought. According to the UN, 157,000 people worldwide died due to floods between 1995 and 2015, and another 2.3 billion were affected, accounting for more than half of all those affected by weather-related disasters in the same 20-year period.¹⁴

Global climate change greatly exacerbates these threats. The Intergovernmental Panel on Climate Change (IPCC) predicts an increasing incidence of water-related disasters in many cities worldwide. Extreme rainfall events are becoming more frequent, with an increasing number of days each year recording heavy rainfall¹⁵ and more short duration rainfall events of high intensity.¹⁶ Sea-level rise poses a severe risk to coastal cities, and many delta cities face the dual threat of increased riverine and coastal flooding.¹⁷ Inland flooding caused by increasingly heavy rainfall will likely result in the destruction of properties and public infrastructure, contamination of water sources, water logging, loss of business and livelihood options, and an increase in waterborne and water-related diseases.¹⁸

Areas that are most vulnerable to water-related risks are also home to some of the world's largest and fastest growing cities.

Water management was a challenge facing policy-makers long before the combined effects of climate change and urbanisation made climate resilience a critical issue for cities. The conventional approach, originating more than 2,000 years ago in ancient Greece,¹⁹ has involved building physical barriers such as dykes and dams, above- and below-ground drainage and diversion systems including pipes and culverts, and draining and removing lakes and rivers. Collectively these “grey” solutions, so-called because they typically require large amounts of concrete, use technologies to anticipate and counter rising waters.

However, increasing attention is being paid to an alternative approach: nature-based solutions that provide, restore, protect and sustainably manage natural or modified spaces and ecosystems. These nature-based solutions address societal challenges, such as water management, while simultaneously providing human well-being and biodiversity benefits.²⁰ Examples include: green walls and roofs; permeable roads and pavements; expanded green space, both for flood management and to reduce the urban heat island effect; and the conservation and restoration of ecosystems such as mangroves and wetlands, which help to reduce the impact of storm surges and sea-level rise. These interventions often offer cost-effective and sustainable alternatives to grey and technology-based infrastructure by reducing upfront capital costs and ongoing operational expenses, and by generating a wide range of social and environmental co-benefits (see Table 1).²¹

Table 1: Green versus grey infrastructure for improved water management

PRACTICE	Benefit				
	REDUCED FLOOD RISK ²²	IMPROVED WATER QUALITY ²³	INCREASED WATER SUPPLY ²⁴	IMPROVED AIR QUALITY ²⁵	HABITAT AND AESTHETIC CO-BENEFITS ²⁶
Green infrastructure e.g. vegetative parks and riverbanks, green roofs and walls, wetlands, permeable pavements, urban forests	Yes	Yes	Yes	Context dependent	Yes
Grey infrastructure e.g. dams, dykes, floodwalls, water pumps and drainage facilities, sewage treatment plants	Yes	Context dependent	Context dependent	No	No

Adapted from Browder, G.S. Ozment, I. Rehberger Bescos, Gartner, T. and Lange, G.-M., 2019. Integrating Green and Gray: Creating Next Generation Infrastructure. World Bank and World Resources Institute, Washington, DC, US.

THE CHALLENGE IN CHINA

China's urbanisation has been rapid, with the share of the population living in cities growing from 19% in 1980 to 51% in 2012.²⁷ Between 2000 and 2014, China accounted for 32% of all urban land expansion globally: its built-up area has increased from 7,438 km² in 1981 to 52,102 km² in 2015.²⁸ This is roughly equivalent to an area the size of Denmark encroaching into agricultural land and natural ecosystems such as lakes and wetlands.

Serious water issues have accompanied China's rapid urban growth. More and bigger cities have replaced swathes of absorptive green space with impermeable surfaces.²⁹ Storm water drainage is largely considered inadequate: in half of all China's cities, drainage does not meet national flood-prevention safety standards.³⁰ Up to 80% of storm water in cities becomes urban runoff, polluting bodies of water by drawing off pesticides and fertilisers from fields, and garbage and human waste from urban waste systems, and feeding this into rivers and streams.³¹

China is also particularly susceptible to natural disasters. Between 2004 and 2014, it experienced the most recorded natural disasters of any country in the world, including 15 floods and landslides, 15 storms, eight earthquakes and two droughts.³² Second only to India and Bangladesh, China is estimated to have the third largest proportion of its population exposed to river flooding, which commonly causes serious damage to property and even loss of life, and costs up to 1% of annual Gross Domestic Product (GDP).³³ With climate change bringing more frequent extreme rainfall events, this exposure is increasing.³⁴

China has made responding to urban water management challenges a national priority and the government is seeking to progress "from the traditional sector based, engineering oriented paradigm to a nature-based, holistic approach".³⁵ In doing so, it is promoting changes to traditional infrastructure, for example: absorptive roads and permeable pavements; the implementation and expansion of green infrastructure, such as rain gardens, parks and wetlands; and built environment measures such as green roofs and rainwater reuse facilities. The key design feature of this new paradigm – known as the "Sponge City" – is "blending natural features and the city together as seamlessly as possible".³⁶

2. Methodology

This policy brief is based on research conducted by a partnership involving the University of Leeds in the United Kingdom (UK), Utrecht University in the Netherlands and Shanghai Jiao Tong University in China.

The research builds on interviews conducted with various stakeholders (see Table 2) and on participation in two workshops organised by the Wuhan Municipal Construction Commission and by the Wuhan Water Affairs Bureau. The researchers

also analysed primary sources including political speeches, public policies and regulations, and secondary sources including academic publications and media reports, and built on a secondary analysis of sponge city governance in the city of Wuhan.³⁷

Table 2: List of interviewees

STAKEHOLDERS	METHODS
Consultants (private-sector project workers)	2 interviews
Academia	3 interviews
Local government	1 interview
Miscellaneous – including Wuhan Municipal Construction Commission and Wuhan Water Affairs Bureau plus architects and researchers	2 workshops

3. The policy context

Following China’s rapid growth in the 1990s and 2000s, national development plans are now prioritising social and environmental outcomes, including an ambition to peak greenhouse gas emissions by 2030, a focus on green industry, targets for air quality and recognition of the challenges created by rising inequality.³⁸

For cities, specific chapters of the National New Urbanization Plan emphasise green urbanisation, with water management a key part of this. The Chinese government’s 13th Five-Year Plan (2016–2020) highlights water conservation as the nation’s top built environment priority, emphasising aspects such as the reuse of rainwater and the construction of flood-control facilities.³⁹

In response to the fact that its cities are growing rapidly, China’s State Council launched a new set of national-level urban design guidelines in 2016.⁴⁰ Among other things, these guidelines state that new urban developments should have sponge-city-like water-retention capabilities, essentially making this strategy a new national standard.

THE SPONGE CITY PROGRAMME

The “sponge city” concept originated when Chinese President Xi Jinping declared at the Central Government Conference on Urbanization in 2013 that cities should “act like sponges”. The President also announced that the government would allocate CNY 20.7 billion (US\$3 billion) to 16 pilot cities between 2015 and 2017, so that they could test different ways of becoming a sponge city.

The Sponge City Programme was developed over just two years: conceived in 2013, its first batch of funding for 16 cities was released in 2015. The programme was inspired by existing concepts and best practices in storm water management, such as low-impact development in the United States (U.S.) and Canada, sustainable urban drainage systems in the UK and Europe, and water-sensitive urban design in Australia and New Zealand.⁴¹ In April 2016, the pilot programme was expanded to another 14 cities.

The Sponge City Programme sets out ambitious targets: 20% of each pilot city’s land should be constructed to sponge city standards by 2020, and 80% by 2030. To support this, the national government offers co-funding intended as start-up capital, from CNY 400 million (US\$59 million) for regular cities up to CNY 600 million (US\$88 million) for municipalities that sit directly beneath the state government. In most cities, this is equivalent to 15–20% of costs, with local governments and private investors expected to fund the remainder.⁴² A further 10% subsidy is awarded if the pilot city successfully engages in a public-private partnership, and financial institutions are mandated to prioritise credit for sponge city projects.

The Sponge City Programme is guided by the Ministry of Housing and Urban-Rural Development, the Ministry of Finance and the Ministry of Water Resources, who are jointly responsible for selecting candidate cities and assessing sponge city performance.⁴³ According to the national-level Guidelines for Promoting Sponge City Construction, the primary goals for China’s sponge city construction are: retaining 70–90% of average annual rain water onsite by applying the green infrastructure concept and using low-impact development measures, eliminating water logging and preventing urban flooding, improving urban water quality, mitigating impacts on natural ecosystems and alleviating urban heat island effects.⁴⁴

THE MUNICIPAL CONTEXT

China is a unitary country wherein local governments implement policies based on national guidelines.⁴⁵ These guidelines are usually relatively broad, with scope for local experimentation and adjustment. Built into implementation programmes are feedback and learning loops, whereby lessons from pilot cities are used to refine national policies or guidelines before programmes are scaled across the country.

This approach to policy-making can be seen in the Sponge City Programme, with a commitment of funding from local municipalities as one of basic preconditions for applying for a sponge city project. Municipalities are responsible for planning and constructing sponge city infrastructure at the city level.

The city of Wuhan was selected as a recipient of pilot funding for the national government's Sponge City Programme. A provincial capital city, it received CNY 500 million (US\$73 million) annually between 2015 and 2017, and the municipal government pledged an additional CNY 10.2 billion (approximately US\$1.4 billion) of public funds into its sponge city construction. The municipal government identified the reduction of waterlogging, the control of water pollution and rainwater collection as priority investment areas under the programme.

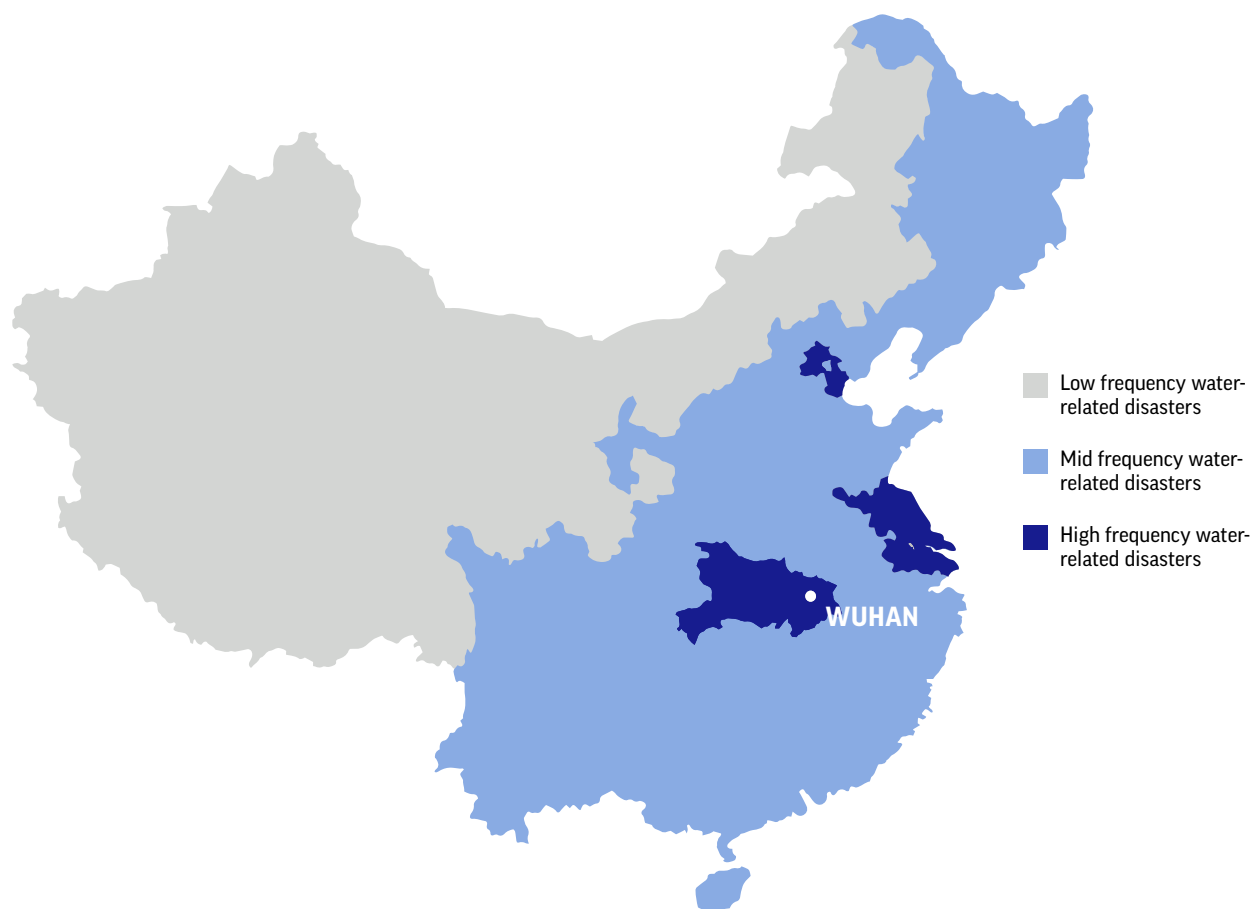
4. The case study

Wuhan is the capital city of Hubei Province and the most populous city in central China. Water accounts for a quarter of Wuhan's total territory, resulting in it being known as the "River City" or the "city of hundreds of lakes."⁴⁶ 8.5 million residents occupy around 8,500 km² of land on the Jiangnan floodplain, where the Yangtze and Han rivers meet.

Abundant water resources have driven the city's development, but the resulting urbanisation has exacerbated flooding and increased water pollution. Of the city's 11 rivers, four did not meet prescribed water quality standards as of 2014. In July 2016, Wuhan was hit by torrential rains. More than 600 millimetres of rain fell on the city within a week – which is more than half of Wuhan's average annual rainfall. Floods affected more than a million residents, of whom 263,000 had to be temporarily relocated.⁴⁷ Economic losses totalled CNY 5.3 billion (approximately US\$750 million) and 15 people were killed.⁴⁸ These issues are expected to worsen as the risks associated with climate change increase.

Wuhan has invested heavily in green and blue infrastructure to tackle its water issues and has since become China's "leading Sponge City".⁴⁹ As part of the city's efforts, 389 separate sponge projects covering 38.5 km² in two demonstration areas of the city – Qingshan and Sixin districts – were planned. These projects include the construction of urban gardens and (artificial) waterbodies in parks, roads and buildings; the construction of two rainwater pumps; the repair of 13 water channels; and the ecological restoration of at least one lake.⁵⁰

Figure 1: Map of China's water-related disasters



Based on data from Jiang, Y., Zevenbergen, C. and Ma, Y., 2018. Urban pluvial flooding and stormwater management: A contemporary review of China's challenges and "sponge cities" strategy. *Environmental Science & Policy*, 80. 132-143.

SUCCESSSES

Wuhan's sponge city investments offer an opportunity to assess both the narrow financial and wider socio-economic considerations facing policy-makers as they assess different approaches to increasing the resilience of urban water management systems. When the Sponge City Programme is compared to an alternative set of grey infrastructure investments a clear financial case for investing in green infrastructure emerges.

Wuhan's Sponge City Programme cost a total of CNY 15 billion (US\$2.1 billion) (see Table 3). Specific projects included urban gardens, parks and greenspace designed to allow water to infiltrate during regular precipitation and to direct water away from urban areas during flooding, artificial lakes that draw water away from populated areas during downpours, and water channels that can safely handle very large volumes of water during flooding.⁵¹

A more conventional approach could have been to increase the city’s drainage capacity. This would involve upgrading existing drainage infrastructure, as well as building, operating and maintaining a new system of underground pipes and new discharge and treatment facilities, at an estimated cost of CNY 19 billion (US\$2.7 billion) (see Table 3). This does not include costs for other measures, such as the construction of or improvements to floodwalls, dykes, and reservoirs, that may need to be pursued concurrently and is therefore likely a conservative estimate of the cost of updating Wuhan’s drainage to the required national standards.

Table 3: Comparing the costs of Wuhan’s Sponge City Programme (green infrastructure) and estimated upgrade of drainage system (grey infrastructure)

MEASURES	COST (CNY, MILLIONS)	COST (US\$, MILLIONS)
SPONGE CITY PROGRAMME		
Citywide sponge measures, including 389 separate projects covering 38.5 km ²	14,915	2,139
TOTAL	14,915	2,139
DRAINAGE SYSTEM UPGRADE		
Total cost over 30-year concessional period, unless otherwise stated		
Upgrade of existing underground discharge system	13,000 (one-off, upfront investment)	1,850
Upgrade of discharge facility	1,080*	154
Operation discharge facility	2,409*	344
New pipes and maintenance	2,400*	342
TOTAL	18,826	2,700

* Data from Koester, S., Moritz, R. and Zuo, J., 2019. Urban water management for future cities. Springer International Publishing, Basel, Switzerland.

The cost analysis presented in Table 3 suggests that a focus on nature-based solutions has saved Wuhan approximately CNY 4 billion (almost US\$600 million). Importantly, the actual cost of grey investments is likely to be higher than these projections. This is because large-scale public projects – especially those related to water management – have a long history of going significantly over budget.⁵²

The financial case for the nature-based approach to water management is compelling enough on its own, but is further strengthened by the host of universal co-benefits green infrastructure can generate (see Table 1). Sponge infrastructure helps to reduce flooding by, for example, serving as a storage reservoir for what would otherwise become runoff, instead allowing water to infiltrate slowly. It can also increase the water supply through retention of precipitation via green roofs and rain gardens, improve water quality by acting as a natural filter for sediment and impurities, and help to improve air quality – both directly by removing pollutants and indirectly by reducing the energy requirements for water treatment, thus reducing emissions from local power plants.⁵³

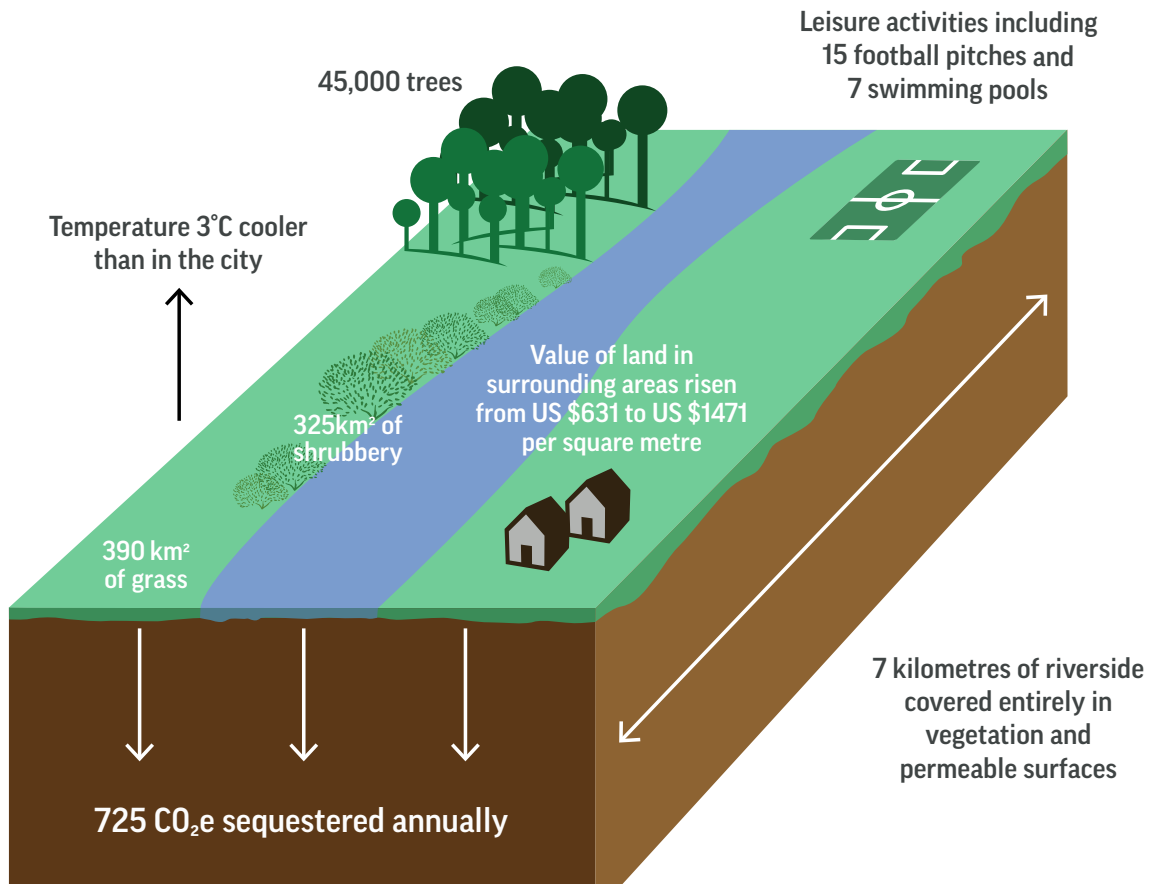
Green infrastructure can also contribute significantly to human well-being by providing healthy, green public spaces within dense cities, the positive social and environmental outcomes of which are well-documented.⁵⁴ Urban green spaces can help to mitigate the effects of climate change by operating as carbon sinks – natural systems that absorb and store carbon compounds – and can help citizens to adapt by offering a cool local microclimate.⁵⁵ Wuhan’s residents are already experiencing the quality-of-life improvements that come with living in a greener neighbourhood (see Box 1), and anecdotally report that their happiness has gone up since the completion of the project.⁵⁶ This result is especially significant in China, where public green space is lacking.⁵⁷

BOX 1 Showcasing the sponge city concept

Developed on the site of what was once Asia’s largest refuse landfill site, the sponge city infrastructure in the Wuhan Garden Expo Park is considered exemplary.⁵⁸ Completed in 2015, the park covers 30 km² of public green space. Of the rainwater that falls there, 70% is collected by rainwater gardens, which are home to more than 400 plant species, saving the municipality CNY 1.5 million (US\$220,000) every year in watering costs.⁵⁹

Before the Sponge City Programme, Wuhan’s river defences consisted primarily of walls lining the riverbanks. Now, the city is embracing the protective qualities of nature by expanding parkland, vegetation, green buildings and permeable pavements. The Wuhan Garden Expo Park and the city’s popular Yangtze River Beach Park (see Figure 2), are both “low-carbon” parks that have been developed to showcase the potential of sponge city and green architecture design. These parks are award-winning showcases of international good practice and are emblematic of the wider benefits that sponge city projects are having in Wuhan and other cities worldwide.

Figure 2: Award-winning example of sponge design: Yangtze River Beach Park



Source: Authors' own, based on C40, 2017. *Cities 100: Wuhan – rehabilitated river embankment becomes beach park*. Available at: https://www.c40.org/case_studies/cities100-wuhan-rehabilitated-river-embankment-becomes-beach-park.

Notes: °C = degrees Celsius; tCO₂e = tonnes of carbon dioxide equivalent.

OVERCOMING CHALLENGES AND SCALING UP THE BENEFITS

China's national government has put in place an implementation framework that enables lower levels of government to adopt sponge city measures. This involved establishing basic laws and regulations relating to sponge city infrastructure, outlining compulsory standards and targets, and providing support in the form of technical guidelines, direct funding and favourable financing instruments. The sharing of examples of success from other cities, accompanied by financial and technical support from national government, has generated enthusiasm for the concept among lower levels of government and non-pilot cities. Preliminary estimates suggest a total investment of CNY 10 trillion (US\$1.5 trillion) in sponge measures across 100,000 km² nationwide.⁶⁰

Tailoring sponge city design to local contexts

However, implementation has not been without difficulties. China's sponge city model has faced some criticism because sponge projects are rarely located in built-up in urban centres, where they are particularly necessary,⁶¹ due to the concentration of people, assets and land. The sponge city model has also been criticised for not providing sufficient flexibility to accommodate locally-specific priorities and goals. Meteorological and hydrological conditions vary greatly across China, and even across the 30 pilot cities.⁶² Water-related challenges therefore differ from city to city, yet the interventions used are informed by the same set of guidelines. These tools include the Sponge City Application Guidelines, Technical Guidelines and numerous documents designed to encourage and support public-private partnerships.⁶³ Provided by national government, they are an essential foundation but there must be room for flexibility so that cities can design projects suited to their own environmental and socio-economic characteristics.

Tailoring sponge city design to local conditions is crucial. In Wuhan, the municipality used the national guidelines as a departure point from which to develop their own construction manual, the Planning and Design Guidelines for the Sponge City Programme.⁶⁴ Supporting local governments in such endeavours – for example by providing a menu of options and offering technical expertise – will enable sponge cities to go beyond just building green infrastructure and instead significantly build their resilience to the water-related risks they face.

Utilising land value capture

Fundamental fiscal and governance issues, particularly growing concerns around increasing municipal debt, further restrict opportunities for scaling the Sponge City Programme.⁶⁵ Leveraging private investment is therefore critical, but is difficult to incentivise where there is no immediate or even long-term yield; in several of the pilot cities, including Wuhan and Beijing, municipalities have instead collaborated with state-owned enterprises, some of which are owned even by the municipality itself.⁶⁶

Utilising land value capture around new green and blue infrastructure could help to fill these financing and governance gaps. Sponge sites and green infrastructure help to increase the value of land in nearby areas – around the Wuhan Expo Park, for example, the value of land has risen from CNY 4,383 to CNY 10,218 (US\$631 to US\$1,471) per m². Applying betterment charges or auctioning development rights can help to offset upfront costs.

To further boost private sector participation, the national government could mandate that all new developments adhere to sponge standards. For example, Singapore's "mandatory roadside plantings" ensured that tree cover increased dramatically despite urban and population growth.⁶⁷ Similarly, governments could consider mandating that all new roads be lined with permeable pavements and a border of vegetation, and that all new buildings have green walls or roofs.

Based on the scale of China's existing urban development, retrofitting would also be necessary.⁶⁸ More buildings could be encouraged to be disconnected from the central drainage network by using inexpensive rainwater harvesting systems, raingardens and permeable pavements.⁶⁹

Integrating sponge city approaches into the wider system

When incorporating a growing number of actors, it will be important to overcome the challenge of coordination – of stakeholders, across programmes and beyond jurisdictional boundaries. Currently, tasks are fragmented among municipal departments, and are treated as handovers: projects are designed by one subdivision, for example, before being transferred elsewhere for construction, with no single entity participating in the programme from beginning to end. Sponge city development has not yet been studied at the basin level, meaning the wider ecosystem impacts remain uncertain.

As a result, the Sponge City Programme comprises many discrete projects, rather than being a holistic approach that is mainstreamed into regional urban planning and design practices.

It is also key to approach water management at an integrated watershed scale (i.e. the entire drainage basin or catchment area), and to better incorporate sponge projects into other infrastructural and urban developments in the region.⁷⁰ This is particularly important as the effects of climate change become more acute.

In Wuhan, sponge interventions are able to capture around 32 millimetres of rainfall every 24 hours, effectively increasing the city's drainage system by one-third without pouring a single drop of concrete.⁷¹ However, extreme weather events like that in July 2016 have been known to bring rainfall in excess of 200 millimetres over the same time frame.⁷² Therefore sponge interventions are already not sufficient to compensate for inadequate drainage systems; a changing climate that brings even more damaging storms may require a more ambitious approach, with green and grey infrastructures working together.

To work towards this, the national government has mandated that, to be eligible for central funding, sponge city projects coordinate with related programmes. This includes the Pilot Urban Tunnels project, which aims to establish and expand tunnel networks for utility infrastructure, and the Urban Black Odorous Water Clean Up project, which aims to improve the water quality of the rivers in provincial capital cities.⁷³ Further, having a coordinating body – like the existing Headquarters of Pilot Projects for the Construction of the Sponge City in Wuhan – oversee the sponge programme in its entirety could help stakeholders to break out of silos and work across divisions and disciplines, moving towards a more holistic plan for urban water management.

A changing climate that brings even more damaging storms will require a more ambitious approach.

Improving data sharing

Another barrier to effective coordination, and for learning, is the inadequate sharing of data relating to sponge city construction. Designing, constructing and operating a sponge city involves highly complex engineering, requiring a high volume of environmental and socio-economic information that has multiple sources.⁷⁴ Widely available data regarding the long-term performance of sponge city measures,⁷⁵ including data on the lifecycle costs of sponge city projects, is not yet available – largely because the programme is so new – and this makes operation and maintenance costs difficult to predict.

China's national government has created the Sponge City Development Committee, a multi-stakeholder panel of experts who both provide technical assistance to municipalities and track best practices.⁷⁶ The national government, perhaps through this Committee, could commission or facilitate scientific research, knowledge exchange and city-to-city learning.⁷⁷ Efforts could be made to understand and promote learning about more innovative governance arrangements and information sharing techniques. An important concurrent strategy is to enhance engagement in global city learning networks, tapping into existing experiences to improve capacity for building water-resilient smart cities.⁷⁸

Assuming the national government is able to continue its work towards overcoming these challenges, lessons from China's sponge city programme can offer other cities in other countries the opportunity to avoid the environmental cost often associated with urban development.

5. Policy recommendations

Five main policy recommendations emerge from this case study.

1. **Ensure that every city has a transformative, holistic and locally appropriate climate-resilient water management plan in place**

Policies and plans for every aspect of urban development need to be “climate proofed” so that they are ready for the more frequent and intense weather events that are predicted. This is especially true for the water sector: the most severe impacts of climate change are “often mediated through water”.⁷⁹ It is key that national governments encourage every city to develop appropriate place-based water management strategies that are formulated in response to varying local meteorological and hydrological conditions locally. To achieve this, sponge measures should be fully integrated into all areas of future urban policy and planning. National governments can support this by, for example, creating menus of green and grey infrastructure options from which local governments can draw and by offering technical support in selecting and implementing these options. Local governments can then develop their own construction manuals, as demonstrated in Wuhan.

2. Develop and deliver a broader, more integrated, multi-agency approach to watershed-scale management

The Sponge City Programme is not only about improving flood control, but also about water security, environmental restoration and improving the urban realm for citizens. This requires an integrated watershed-scale approach to water management. Agencies must work across governmental departments and should also engage a wide range of actors from both within and beyond municipal boundaries. This requires both internal and external coordination, which could be achieved by, for example, setting up cross-department platforms such as a sponge city steering group to oversee planning and programming. National governments can facilitate institutional coordination by putting in place effective data-sharing mechanisms, mandating data sharing between agencies, departments and municipalities, and disseminating data to relevant stakeholders and the public. Creating a national sponge city information sharing platform, with open and accessible data, could increase uptake in other cities and regions, and allow municipalities and engineering firms to design more robust and appropriate responses to flooding.

3. Ensure public buy-in and ownership of urban green infrastructure

Citizens and private actors should also be seen as partners in delivery and co-owners of the sponge city. National governments should look for opportunities for non-governmental stakeholders to participate in the design of sponge projects, and could ensure that post-implementation communities have a stake in maintaining interventions over the long term. This would not only fulfil social needs but would also expedite monitoring and evaluation processes, for which communities could assume some responsibility.

In China, a mechanism for participation could be the existing Residents' Committees.⁸⁰ Representatives from these neighbourhood associations could be invited to help design local sponge projects. Citizens could also be encouraged to vote on their favourite ideas or to identify urgent needs via online platforms. Offering as part of the sponge projects areas for recreational activities, such as swimming, playing sports and walking, can help to raise public awareness and ensure that citizens come to value these areas.

4. Leverage innovative fiscal and regulatory mechanisms to support green infrastructure and ensure private-sector participation in sponge interventions

National governments can help to create more favourable conditions for investments by offering tax incentives, utility-rate reductions and other, non-financial incentives such as the transfer of development rights or watershed

trading. They could, for example, mandate that a portion of revenue from utility companies is earmarked for sponge-related activities. This approach is similar to that of Peru's Sanitarian Sector Reform Law, which requires that water utilities reinvest revenue from water tariffs into watershed conservation and climate change adaptation, and has so far generated US\$30 million for green infrastructure.⁸¹ Furthermore, as urban land around green space rises in value, governments can capture a share of this through specific instruments such as tax-increments, development charges and land value capture.

Accompanying regulatory mechanisms can further incentivise or ensure private investment in sponge projects. National governments can mandate that all new developments include sponge measures and that existing buildings be retrofitted to sponge standards. They can control construction practices, for example, by regulating the impermeable surfaces on a given plot of land or building, thereby encouraging the use of green roofs and other sponge infrastructure.

5. Actively enable experimentation and city-to-city learning on nature-based solutions

Pilot projects like those in Wuhan are providing practical examples of how the sponge city concept can be applied and are generating much wider interest in rolling out such projects elsewhere. National governments should continue to foster this experimental approach to sponge project implementation, perhaps by issuing calls for proposals and offering seed funding to the winning ideas, or by endorsing cities that find innovative solutions to challenges. This should apply not only to technological development but also to innovations in governance strategies that support the implementation of customised responses.

National governments should encourage open dialogue and coordinate nationwide city-to-city networks that support the sharing of both new and established good practices and innovations, and allow knowledge to be institutionalised. There are many examples of good practice around the world, and opportunities for national and international exchange could accelerate the spread of the most effective solutions. National governments could support this by funding peer-to-peer learning and exchange visits; offering (online) courses that could be used by city governments; and financing research that integrates nature-based solutions into cities.

6. Conclusions

Urban development policies and practices in China have not always prioritised environmental sustainability. Coupled with climate change, this now makes China's cities particularly vulnerable to water-related disasters. In 2013, the Chinese government launched the nationwide "Sponge City Programme" to counter the devastating social, economic and environmental impacts of flooding, water scarcity and water pollution.

Wuhan was selected as one of 30 pilot cities to receive funding from the national government between 2015 and 2017, and now exemplifies some of China's leading green solutions to water management challenges. Sponge interventions – such as artificial waterbodies, permeable pavements, green roofs and walls, and the expansion of parkland – have increased the city's rainwater capacity by a third and created a pleasant living environment for residents.

Countries and their cities worldwide could learn from China's Sponge City Programme, which has both incentivised and enabled lower levels of government and other stakeholders to address water-related challenges. Political backing and a national framework that incorporates legal, fiscal and regulatory mechanisms has aided the design, financing and implementation of an estimated 100,000 km² of sponge infrastructure nationwide.⁸²

Nature-based solutions like those employed in the Sponge City Programme are cost-effective and sustainable alternatives to conventional carbon-intensive urban development. And, aside from their contribution to sustainable water management, they generate a host of social and environmental co-benefits including improved mental and physical health linked to public green space, biodiversity conservation and natural cooling. National governments should make green infrastructure a key component of integrated water management strategies, helping China's cities to move towards more holistic, transformative and climate-proof urban water management.

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ABOUT THE COALITION FOR URBAN TRANSITIONS

The Coalition for Urban Transitions is the foremost initiative supporting national governments to secure economic prosperity and reduce the risk of climate change by transforming cities. The Coalition equips national governments with the evidence and policy options they need to foster more compact, connected and clean urban development. The Coalition's country programmes in China, Ghana, Mexico and Tanzania provide models for other countries on how to effectively develop national urban policies and infrastructure investment strategies.

A special initiative of the New Climate Economy (NCE), the Coalition for Urban Transitions is jointly managed by C40 Cities Climate Leadership Group and World Resources Institute Ross Center. A partnership of 35+ diverse stakeholders across five continents drives the Coalition, including leading urban-focused institutions and their practice leaders from major think-tanks, research institutions, city networks, international organisations, investors, infrastructure providers, and strategic advisory companies.

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