NO. 222
NOVEMBER 2022

ADB BRIEFS

Sponge Cities: Integrating Green and Gray Infrastructure to Build Climate Change Resilience in the People's Republic of China

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KEY POINTS

- Rapidly increasing urbanization, together with climate change-related hazards from increased frequency and severity of extreme weather events, requires urgent urban adaptation.
- Nature-based solutions (NbS) can enhance climate resilience, effectively reducing disaster risks such as those from floods, droughts, urban heat islands, desertification, and landslides.
- The Sponge City program in the People's Republic of China (PRC) supports water-related NbS and green infrastructure—such as wetlands, water retention parks, rain gardens, bioswales, pervious pavement, and green roofs—to improve water management and reduce urban runoff and flooding, while delivering many other ecosystem benefits.
- NbS and sponge cities should be mainstreamed, deepened, and combined with gray infrastructure. To do this requires policies that reprioritize adaptation; technical support for analysis; risk-informed planning to retrofit urban areas; and the prioritization of functional green space planning. It also requires education to overcome reservations toward, and inertia against, implementing NbS.

ISBN 978-92-9269-771-6 (print)
ISBN 978-92-9269-772-3 (electronic)
ISSN 2071-7202 (print)
ISSN 2218-2675 (electronic)
Publication Stock No. BRF220416-2
DOI: http://dx.doi.org/10.22617/BRF220416-2

Urbanization and climate change have led to a dramatic increase in hazards such as sea-level rise, storm surges, floods, droughts, extreme heat, and desertification. Adapting to the risks of a changing climate is imperative for national and local governments, and it requires both structural measures (such as infrastructure investments) and nonstructural measures (such as disaster preparedness and early warning systems for floods and other potential disasters). Structural measures have traditionally been gray infrastructure, i.e., concrete walls, dikes, drainage pipes, and storage tanks. Green infrastructure and the application of nature-based solutions (NbS) however are now valued more and are being used increasingly around the world. The People's Republic of China (PRC) has been supporting the development of so-called sponge cities since 2014. A sponge city essentially soaks in rainwater and retains excess stormwater, then filters and releases the water slowly, much like a sponge. Sponge cities primarily utilize NbS like wetlands, greenways, parks, rain gardens, green roofs, and bioswales. Ideally, gray and green measures are systemically integrated and mutually reinforce one another to achieve resilience, such as by using harnessed rainwater during dry periods. NbS provide a range of additional benefits from ecosystem services, like improvement of air and water quality, more cooling microclimates, and recreational green spaces for people.

This note provides an international perspective on the evolution of the PRC's Sponge City program and lessons learned. It offers possible avenues for improving the concept and integrating it into the broader context of urban and regional planning, infrastructure development, and integrated disaster and flood risk management for the PRC and the rest of Asia and the Pacific.

Note: ADB recognizes "China" as the People's Republic of China.

* The author is grateful for inputs via project and technical assistance work, cases, discussion, and peer review from, among others, Tian Yongying, Herbert Dreiseitl, Philip Enquist, Peter Kindel, Zuo Heping, Zheng Nengshi, Charles Rodgers, Virinder Sharma, Arghya Sinha Roy, Steven Goldfinch, Isao Endo, Sonia Chand Sandhu, Lara Arjan, Rabindra Osti, Mingyuan Fan, John Matthews, Steve Gawler, Christina von Haaren, and Jeremy Dawkins.

A. CHALLENGES OF URBANIZATION AND CLIMATE CHANGE

Cities are heavily affected by climate change. Urbanization and industrialization along with opening-up policies since 1978 led to rapid economic and urban growth in the PRC, with an urbanization rate of 64.7% (2021).[1] Urban areas are seriously affected by a rapidly changing climate, threatening human life and health, infrastructure and assets, and also ecosystems and nature. Higher variability and more extreme weather events lead to more frequent and severe floods with higher human and economic losses. Increasing numbers of cyclones, landslides, heat waves, droughts, and desertification, as well as sea-level rise, adversely impact livelihoods and local economies. Disaster risks are exacerbated by unsuitable land use and urban development in flood-prone areas, and unintegrated flood protection structures as opposed to watershed-wide flood risk management. Future impacts are expected to be even more frequent and severe.[2, 3]

Flooding. We distinguish three types:

- *Urban flooding (pluvial flooding).* Covering land with roads, buildings, and impermeable hard pavement reduces natural infiltration and increases runoff from rainwater and stormwater.
- *River flooding (fluvial flooding).* Straightening rivers with hard embankments and walls, and new roads limiting space and reducing flow capacity of rivers, increases the risk of flash flooding downstream.
- *Coastal flooding, storm surges, and cyclones.* The PRC's coastal region is heavily urbanized, and includes low-lying megacities. Cyclones have increased over the last 20 years, and the rate of polar ice melting suggests sea-level rise will be faster than previously estimated.

Heat waves, droughts, and wildfires. Summers are getting hotter and longer, and urban heat island effects result in higher incidents of premature deaths from extreme heat. Temperatures in densely built-up areas can be several degrees higher than in urban parks and rural areas. Outside cities, droughts and wildfires cause loss of ecosystems, life, and damage to assets.[4]

Losses and damages. Asia and the Pacific is highly exposed to hazards and climate change impacts and suffers more disasters and losses than other regions.[5] Globally, during 2000–2019, climate-related disasters killed almost 716,000 people and affected 3.3 billion people. Direct losses to physical assets totaled $676 billion, of which 27% was in Asia and the Pacific. Flooding has accounted for about 40% of all losses from disasters triggered by natural hazards since 1980, with 4,588 flood disasters across 172 countries leading to more than 250,000 people killed, and damages exceeding $1 trillion.[6]

Recent events provide a grim glimpse into the future. Globally, in 2020, there were 26% more storms than the annual average of 102 events, 23% more floods than the annual average of 163 events, and 18% more flood deaths than the annual average of 5,233 deaths. The PRC faced significant flooding across the country that killed 397 people, affected 14.3 million people, and caused $21.8 billion in economic losses (footnote 3). Droughts and heat waves are expected to be very severe with most premature deaths caused by climate change already attributed to heat waves globally.[7]

The PRC faces increasing disaster risk from climate change. Climate change-related temperature increases in the PRC will likely be above the global average. Risk of droughts, floods, and heat waves will increase, resulting in greater losses and more damage. These losses will be challenging to avoid without major adaptation plans and investments in effective disaster risk management. The impacts will likely be experienced most strongly by low-income households and communities. Increased urban heat island effect is a significant threat to human health, productivity levels, and energy demand.[8]

B. EVOLUTION FROM GRAY TO GREEN INFRASTRUCTURE AND SPONGE CITIES

Throughout history, villages and towns were located close to rivers. Aside from being a water source, rivers were also used for energy generation supporting agriculture and craftsmanship. Early communities balanced the risk of being

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1 S. Rau. 2021. Bridge to Future Livable Cities and City Clusters in the People's Republic of China: Policy Opportunities for High-Quality Urban Development. *ADB East Asia Working Paper Series.* No. 40. Manila: ADB. This publication provides an overview, extensive resource list, and policy options including for climate change adaptation and mitigation and for green development.

2 A. Revi et al. 2014. Urban Areas. In Intergovernmental Panel on Climate Change (IPCC). *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects.* Contribution of Working Group II to the Fifth Assessment Report of the IPCC.

3 The IPCC's Sixth Assessment Report expects the climate to change much faster than to date, with an increased number and severity of hazards. IPCC. 2021. Regional Fact Sheet Asia. In V. Masson-Delmotte et al., eds. *Climate Change 2021: The Physical Science Basis*. Contribution of Working Group I to the Sixth Assessment Report of the IPCC. Cambridge University Press.

4 The National Aeronautics and Space Administration (NASA) recorded massive wildfires in 2021. NASA EarthData. *Fire Information for Resource Management System (FIRMS)* (accessed 23 August 2021).

5 T. Kessler and A. Chatterjee. 2021. Building Disaster Resilience in Cities in Asia and the Pacific. In B. Susantono and R. Guild, eds. *Creating Livable Asian Cities*. Manila: ADB.

6 M. McLennan. 2021. Sunk Costs: The Socioeconomic Impacts of Flooding. *Rethinking Flood Series, Report 1.*

7 United Nations Office for Disaster Risk Reduction. 2019. *Global Assessment Report on Disaster Risk Reduction*. Geneva. (With a special section on drought risk, often underestimated and "hidden").

8 World Bank and ADB. 2021. *Climate Risk Country Profile: China*. Washington, DC and Manila.

flooded with being near this essential public good. Today, large sprawling cities with cars and paved surfaces everywhere cause significant urban runoff and increase risk of flooding. Flood defense typically consisted of the construction of gray infrastructure, i.e., concrete, steel, or PVC flood walls and dikes, drainage pipes, deep tunnel systems, and storage tanks. Hydrology engineering handbooks and simulation software were developed for these engineered flood defense systems, which are largely still in place.

Nature-based solutions were rediscovered as effective and efficient means to manage climate change-related hazards and disaster risks. In 2016, the World Conservation Congress and International Union for the Conservation of Nature defined NbS as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits."[9] Similar concepts are applied around the world under different names, including low-impact design, water-sensitive urban design, green infrastructure, or sustainable rainwater management.[10]

A sponge city is one that acts like a sponge, soaking up and retaining water during rain and storms and releasing it slowly. The idea borrows concepts from prior low-impact development approaches from around the world, and the term "sponge city" was popularized in the PRC since 2013. A national government program supporting pilot sponge cities started in 2015, and a directive requesting all cities to prepare sponge city master plans followed in 2017. Developing a sponge city helps respond to four key water challenges facing highly urbanized areas in the PRC: too much water, too little water, polluted water, and muddy water. The PRC's term has inspired other cities, e.g., Germany's Berlin and Hamburg, where initiatives using that name are being planned and implemented.

Sponge cities aim to improve management of local water cycles. Rainwater and stormwater is managed locally as opposed to being centralized for the whole city. Management of flood risk, water scarcity, and pollution are integrated. When planning a sponge city for an urban area, climate change and the extreme storms, longer dry periods, and extreme heat it causes should be considered. One main principle is to use functionally designed green spaces, such as wetlands, floodplains, and gentle embankment slopes, to increase detention and flow capacity to improve management of river flooding. To improve management of urban flooding, green infrastructure is applied, designed to retain and decelerate stormwater before it flows into drainage pipes and canals. Before the first-flush of stormwater goes into rivers it should be treated in vegetated sedimentation ponds and earth filters.

The destructive force of stormwater is removed by storing it and slowing it down. To reduce damage and health impacts, rainwater is captured during storms and reused in dry periods when less water is available for watering green spaces and cleaning streets, and for use by industry. This concept contributes to water security in the northern PRC, where water resources are scarce, through harnessing rainwater for later reuse, while in the southern PRC, where precipitation is high, it is used mainly to reduce flooding. As extreme weather events are projected to increase, heavier storms with floods in the north and more droughts in the south are expected. Therefore, sponge city objectives are converging across the PRC, while each city has its specific climate risks to be considered in its planning as a resilient sponge city.

C. POLICY CONTEXT

The National New-Type Urbanization Plan (2014–2020) included the construction of sponge cities and other related objectives, like building an "ecological civilization" through sustainable development and improved environmental protection and management. It also included climate mitigation and adaptation through energy conservation and emissions reductions. Further urban–rural integration and socially inclusive development with stronger social protection and improved rural opportunities, and institutional and tax reform, were also included in the plan.

The National Climate Change Adaptation Strategy (2013) and the recently amended strategy (June 2022) include a whole range of adaptation measures and actions, disaster risk management and response.[11] Specifically, they include (i) environmental protection and ecological restoration; (ii) coastal region adaptation and coastal wetland and reef rehabilitation; (iii) urban flood, drought, heat wave, and desertification risk management, inclusive of ecosystem-based adaptation; (iv) improved farmland irrigation, water safety, and efficiency; (v) urban and rural water security and safety; and (vi) infrastructure upgrade and resilience.

The Urban Climate Change Adaptation Action Plan (2016) covered 28 pilot cities.[12] The national government requested all cities to enact policies, regulations, systems, and mechanisms

[9] World Conservation Congress and International Union for the Conservation of Nature. 2016 Resolution. *WCC-2016-Res-069-EN: Defining Nature-Based Solutions*.

[10] L. Arjan, S. Rau, and S. C. Sandhu. 2021. Increasing Urban Resilience through Nature-based Solutions and Total Asset Management. In B. Susantono and R. Guild, eds. *Creating Livable Asian Cities*. Manila: ADB.

[11] Government of the PRC, State Council. 2013. *National Climate Change Adaptation Strategy*. Beijing; and Government of the PRC, State Council. 2022. *National Climate Change Adaptation Strategy*. Beijing.

[12] Government of the PRC, National Development and Reform Commission, and Ministry of Housing and Urban–Rural Development. 2016. *Action Plan for Urban Adaptation to Climate Change*. Beijing.

to improve and integrate adaptation action into their overall urban planning. They were asked to develop and enhance standards and construction and management specifications to improve resilience. Furthermore, the plan called for cities to improve institutions and develop an integrated adaptation concept to link urban planning, land use, transport, infrastructure, energy, water, drainage, and open space planning, and improve ecology and resilience of buildings and infrastructure. Concepts should strengthen urban green space systems aligned with rivers and ventilation corridors.[13]

The Urban–Rural Environmental Redline was required at the municipal level in the 13th Five-Year Plan, 2016–2020. It had been included on a large scale in the national 11th Five-Year Plan, 2006–2010, defined as four functional areas, including urban concentration zones and environmental protection zones, or "redlines" with rigorous restrictions of human activities. Asian Development Bank (ADB) technical assistance supported the development of technical guidelines and methods and preparation of urban–rural environmental redline plans for pilot cities.[14]

D. SPONGE CITY GUIDELINES AND PILOT PROGRAM

The Ministry of Housing and Urban–Rural Development published *Technical Guidelines for Sponge City Construction in the People's Republic of China* in 2014.[15] These guidelines call for the integration of sponge city principles in all levels of planning, design, and construction. It calls for analysis and conservation of surface water and green spaces, and green engineering responses. It includes recommendations for local institutional coordination, scientific approach to risk analysis, risk-informed planning, and a catalogue of potential measures (Box 1).

Box 1: Technical Guidelines for Sponge City Construction in the People's Republic of China

These comprehensive guidelines instruct cities to assess and plan a comprehensive sponge city approach on integrating all levels of planning and design, from strategic urban and regional planning to detailed site, road and building design, construction, and maintenance. Specifically, it provides guidance on integrating sponge city in (i) strategic urban master planning, (ii) land use planning, (iii) water and green space systems planning, (iv) detailed control planning, (v) site design, (vi) building planning and construction, and (vii) road design.

The overarching principle is low-impact development, conservation and protection of rivers, wetlands, and other water-related and green-space ecosystems; the enhancement of the hydrological functions of these areas; and the integration of them into urban areas.

The guidelines include establishment of national, regional, and city-specific targets for runoff reduction, and storage capacities of rainwater and stormwater. The overall national target of an 80% reduction of urban runoff is very ambitious.

The guidelines recommend specific measures that should be considered and integrated, such as permeable paving, green roofs, sunken green spaces, biological retention facilities, infiltration, wet and regulating ponds, seepage wells, rainwater wetlands, rainwater tanks, conditioning tanks, grass ditches, seepage pipes/drains, vegetation buffer zones, initial rainwater abandonment facilities, and artificial soil infiltration.

Source: Ministry of Housing and Urban–Rural Development. 2014. *Technical Guidelines for Sponge City Construction in the People's Republic of China.* Beijing.

The National Sponge City Pilot Program was launched in 2015 in two phases and supported 30 pilot cities. The pilot cities completed almost 5,000 projects contributing to flood risk reduction. Across cities in the PRC, approximately 56,000 kilometers of greenways and 72,400 square kilometers of green parks were built, contributing to resilience and improved livability. The Government of the PRC requested that all cities in the country prepare sponge city master plans in 2016, and by 2018, 538 cities had completed their first sponge city plans.

Pilots and cases of ADB support. ADB supported about seven projects that involved sponge city infrastructure, including a loan to one of the original 16 sponge city pilots—Pingxiang in Jiangxi Province (Box 2).

[13] ADB. *PRC: Mainstreaming Urban Climate Change Adaptation in the People's Republic of China*.
[14] ADB. PRC: Institutionalization of Urban–Rural Environmental Master Planning to Guide Environmentally Sustainable Urbanization in the People's Republic of China.
[15] Ministry of Housing and Urban–Rural Development. 2014. *Technical Guidelines for Sponge City Construction in the People's Republic of China.* Beijing.

Box 2: Jiangxi Pingxiang Integrated Rural–Urban Infrastructure Development Project

Flood risk reduction is a top priority in Pingxiang, Jiangxi Province. Since 1998, flooding has significantly increased in frequency and severity. An Asian Development Bank (ADB) project contributed to Pingxiang's pilot sponge city design by aiming to reduce river flooding to four key subcenters,[a] while the national government program focused on Pingxiang's core urban area. The ADB project shifted the conventional approach to flood control away from purely considering gray infrastructure. Ecological river rehabilitation was integrated with management of flood risk, improving climate resilience and biodiversity, and increasing urban green areas, thereby also improving livability and competitiveness of the city. More publicly accessible green space was provided to the river surrounds, with gently sloped green embankments and water edges that allow for changes in water levels throughout the year and reduce floods after heavy rains, while also enhancing water ecology and quality. Climate risk and vulnerability assessments and hydraulic modeling were carried out and proposed adaptation measures were included in the project. Meanwhile, protected floodplains and wetlands retain stormwater, and separate drainage and sewer pipes were installed.

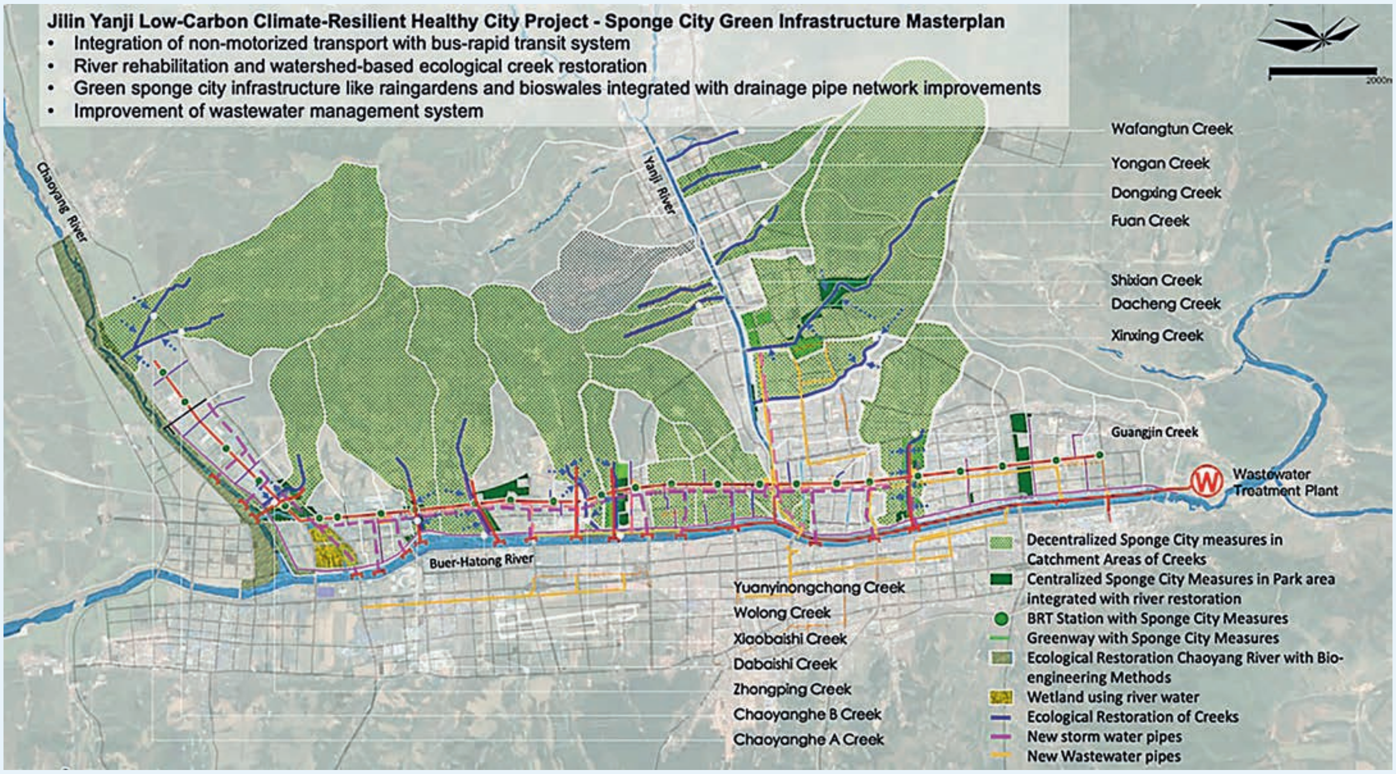
Restored riverside wetlands and gentle green slopes along the river reduce flood risk. They also create a habitat for biodiverse flora and fauna and are enjoyed by local communities during times of normal water levels (photos by Stefan Rau).

[a] ADB. People's Republic of China: Jiangxi Pingxiang Integrated Rural–Urban Infrastructure Development Project.

Source: Stefan Rau.

Since learning lessons from involvement in early projects, ADB evolved to adopt a more comprehensive approach to climate risk and adaptation options assessments, inclusive of climate forecasting through localizing global climate models and scenarios. Later projects have applied hydrological and hydraulic modeling, integrating fluvial and pluvial flooding risks, and systemically integrating green and gray infrastructure, which was developed and demonstrated in the Jilin Yanji project (Box 3). Meanwhile, a project in Anhui Province has demonstrated the multiple benefits from rehabilitated wetlands (Box 4).

Box 3: Jilin Yanji Low-Carbon Climate-Resilient Healthy City Project



In recent years, Yanji has suffered from urban flooding for about 5 days annually due to an outdated combined network of sewer and drainage pipes and to paving areas added during urban expansion. With Asian Development Bank support, Yanji is set to build the first bus rapid transit (BRT) corridor in the northeast of the People's Republic of China.[a] The BRT will be integrated with comprehensive stormwater management and water supply system improvements. The project concept applies transit-oriented development principles. These include developing mixed-use, high-density, and pedestrian-friendly urban subcenters around BRT stations, with more public green spaces. This enables low-carbon lifestyle options and mobility. These subcenters will be connected by newly established green spaces also linking project-supported improved riverfront greenways. All are planned as green infrastructure, applying sponge city principles. All these spaces will result from the application of universal design principles contributing to a healthy and age-inclusive city, ensuring accessibility, and enabling healthy lifestyles for all people.

The project prepared a sponge city master plan and climate risk and adaptation options assessment. The project developed an advanced digital tool comprising a hydraulic model that can simulate future storms and include adaptation measures. This model integrates into the system the current and newly proposed green and gray infrastructure, mainly the improved layout of underground drainage pipes and channels combined with the new sponge city green infrastructure on the ground. The capacities of the drainage network and flow capacity to retain and infiltrate stormwater were quantified and modeled optimizing reduction of flood risk, and maximizing benefits of public green spaces and ecosystem benefits.

Sponge City. Sponge City Green Infrastructure Master Plan for Yanji City based on river and creek catchment areas for the area north of the Buer Hatong River was developed for the ADB supported project and integrated with the drainage pipes and other project investments (image by Nengshi Zheng and Heping Zuo for ADB).

BRT = bus rapid transit, NMT = non-motorized transport.

[a] ADB. People's Republic of China: Jilin Yanji Low-Carbon Climate-Resilient Healthy City Project.

Source: Stefan Rau.

Box 4: Anhui Huangshan Xin'an River Ecological Protection and Green Development Project

Urbanization, intensified agriculture, and tourism have made maintaining the water quality in the upstream of Xin'an River increasingly difficult. Increased flooding resulted from increased stormwater and soil erosion, while an increased pollution load resulted from first-flush stormwater entering the river basin.[a] The Asian Development Bank supports pollution management caused by urban and rural settlements and by agricultural chemicals.[b]

The project includes construction of river embankments; wetlands, and other structural and nonstructural measures to control stormwater pollution; separate systems for sewerage and drainage; stormwater management modeling; and green infrastructure. The project is piloting an integrated approach to first-flush runoff and stormwater management through cost-effective and space-efficient stormwater drains, and advanced detention pond–wetland systems. The wetland systems are adapted to equalize stormwater runoff flows to mitigate urban flooding, reduce pollutants, and remove suspended solids in the runoff. A wetland removes soluble pollutants like organic matters, total phosphorus, total nitrogen, and heavy metals, before the stormwater is discharged into receiving waters. Other installations are (i) stormwater tree trenches to collect runoff from sidewalks, (ii) cleaning inlets at the entrance to stormwater drains, (iii) removal of silt and sediments in some sections of the storm drains, and (iv) infiltration trenches to store stormwater runoff and remove pollutants.

First-flush stormwater runoff management. Bioswales as shown on the left side receive runoff from urban roads and a stormwater overflow tank with wetland cleans the polluted first-flush stormwater as shown on the right side (photos by Stefan Rau, left; and Yuanping Yang, right).

[a] First-flush refers to the initial volume of stormwater runoff from rainfall events in urban areas. Such runoff typically contains more concentrated pollutants than runoff produced during the remainder of a storm.

[b] Asian Development Bank. People's Republic of China: Anhui Huangshan Xin'an River Ecological Protection and Green Development Project.

Source: Mingyuan Fan.

E. CHALLENGES OF IMPLEMENTING THE SPONGE CITY PROGRAM

Government think tanks, experts, and media have identified the key challenges to successfully implement sponge cities, mainly related to the following three concerns.

(i) **Low priority for sponge city and climate change adaptation planning and investments.** Despite increased severity and frequency of extreme weather events, local governments' priority has shifted from climate change adaptation and developing sponge cities to other investment areas, perhaps reflecting a trickling down of national policy priority shifts in recent years.

(ii) **Fragmented investments and lack of citywide systematic and systemic implementation.** Investments in the pilot sponge cities are mostly small and fragmented without systematic and systemic analysis, planning, and investment prioritization. In some of the sponge city pilots, flooding occurred as before or even worsened, leaving the perception that the concept failed. After a devastating flood disaster in Zhengzhou in July 2021, many questioned the sponge city concept. It is important to consider that sponge city infrastructure coverage is far from sufficient to significantly reduce the risk of urban flooding in a city as a whole, and a lot more systematic planning, investment, and implementation is needed.

(iii) **Lack of integration across sectors and departments.** Effective coordination across concerned local administrative departments or bureaus and connecting related experts is essential for adaptation work. The analysis, planning, investment prioritization, and construction of sponge city green infrastructure need close coordination that must be continued during operation and maintenance once completed. The sponge city program has not substantially overcome the departmentalization of responsibilities in local governments in the PRC so far.

F. OPPORTUNITIES TO ADVANCE SPONGE CITY CONCEPT AND POLICIES

The worsening climate challenge and increasing numbers of hazard events mandate transformational change quicker and beyond that previously anticipated. Relevant, swift, deep, and ubiquitous change of the way we used to do things is imperative to mitigate and adapt to the changing climate, but also to decisively act to stop and reverse ecological, biodiversity, and pollution challenges. The PRC can build on its achievements to further advance its ambitious concepts and its commitments to carry out transformational change. The sponge city experience offers four areas with opportunities for creating more impact and benefits for the PRC and elsewhere in Asia and the Pacific.

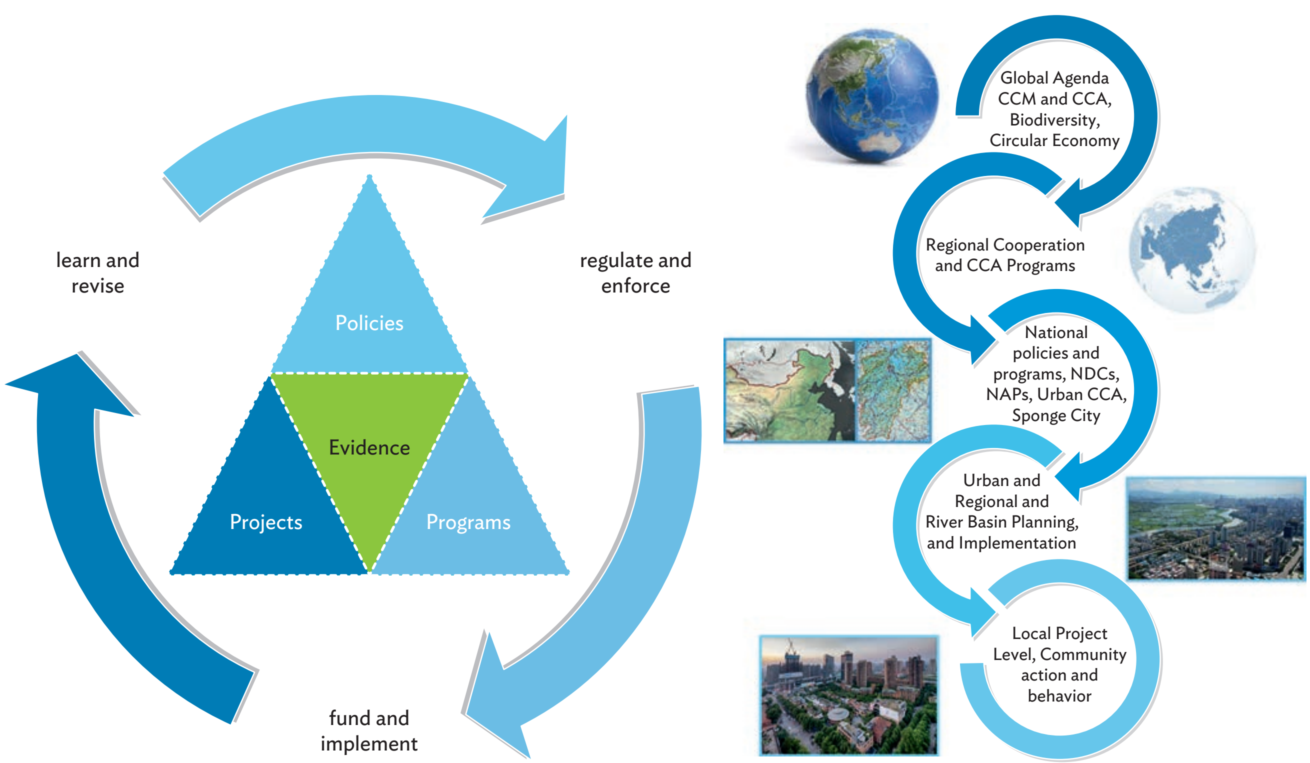
1. Policies and Institutions to Transform and Upscale

Reprioritize, continue, and scale-up climate change adaptation and sponge city investments to unleash transformation for effective resilience. Urban climate change adaptation and the sponge city approach deserve a continued high level of priority and adequate resource allocation. Doing nothing will be both costly and fatal, based on climate-related disasters in recent years. It is imperative to secure adequate funding and government attention to ensure people and cities are resilient and safe. This applies to retrofitting existing urban areas with risk-mapping and risk-informed planning of new areas.

Institutionalize iterative mechanisms of learning, upscaling, and multilevel integration to expedite progress. Evidence-based learning is at the core of this proposed mechanism in which lessons from projects trigger learning and revision of policies as needed (Figure). Updated regulations will help in further improvements in new programs and projects. This should simultaneously occur at local, provincial, national, and even global levels to accelerate learning and widespread replication of good practices.

Align policies and remove contradictory objectives of different line agencies. Administrative alignment in the PRC as done in 2018 with the clarification of roles of national ministries in areas of environmental management and climate change should continue. There should be clarity of responsibilities and policies

Figure: Institutionalize Progress through Learning Iteration and Multilevel Integration



CCA = climate change adaptation, CCM = climate change mitigation, NAP = national adaptation plan, NDC = nationally determined contribution.
Source: Stefan Rau.

related to environmental protection, master planning, land-use change management, land allocations for urban development, environmental and farmland protection, water source protection, water-resource quality and flood-risk management, etc. For example, farmland protection as prioritized by a land and resources department may not allow sufficient space for sponge city green infrastructure along rivers to manage flood risk, while resilience is a priority of the housing and urban–rural development department. Local solutions satisfying both farmland and resilience needs can be found through cross-sector cooperation.

Reform institutions and integrate sponge city features with comprehensive resilience and disaster risk management. Creating sponge cities by using NbS will be effective only if all administrative sectors and all government levels are coordinating. They should engage businesses and communities for resilience and resource and land-use efficiency. All risk mapping, climate adaptation and mitigation planning, and operational work in a city should be coordinated at a high level and the sponge city goal must be an important part of the overall strategies of a city. It is also important to integrate disaster risk management (both as physical and nonphysical interventions) into spatial planning, investment prioritization and operations, as well as climate risk insurance. The Sendai Framework for Disaster Risk Reduction provides guidance on reducing disaster risks through an integrated and inclusive, multihazard, multilevel, and cross-sector approach to reduce loss of lives, assets, and economic damage.[16]

Promote river basin-wide rural–urban climate risk partnerships, enabling effective cross-departmental and cross-jurisdictional cooperation. Creating sponge cities and climate resilience needs working-level, cross-jurisdictional coordination of analysis, scenario development, options generation and assessment, prioritization, planning, and detailed design. The construction, operation, and maintenance of these new types of infrastructure must be managed across sectors and local boundaries to be effective.

Transform the policy–regulation–engineering–construction nexus. The system inertia that prioritizes gray over green infrastructure must be overcome. Policies, administrative regulations, engineering and construction standards and handbooks, university curricula, and construction companies have created a system and mindset that still largely considers hard engineering as the only form of infrastructure. To convince local government officials, engineers, and contractors of the benefits and advantages of NbS, it is important to demonstrate that they deliver clear benefits, and best practice case studies should be compiled to illustrate this. Cost–benefit and economic analyses need to assess NbS and compare them with gray infrastructure scenarios.

2. Technical Analysis, Planning, and Design to Integrate and Innovate

Integrate resilience with low-carbon urban development through urban form and management to optimize co-benefits. Ensure that open space and ecosystems are protected, and for the planning of new urban areas integrate flood and drought resilience planning. Adapt existing urban areas to introduce NbS with green spaces. Urban land use and form should be based on compact city concepts with recreational green spaces that increase resilience while also serving as recreational areas, reducing the need for travel to find respite for residents.

Integrate green and gray infrastructure and apply systemically and systematically. It is critical to cover entire urban areas to contribute to comprehensive climate resilience. Well-planned and protected blue (i.e., surface water) and green open spaces in a city have the capacity to reduce flood risk while also improving the local management of rainwater. Cities will also become greener and more livable. Most effective in reducing flood risk is the integration of green and gray infrastructure into a comprehensive system that works together and across rural and urban areas, combining water conveyance, retention, detention, and infiltration. Drainage pipes, channels, deep tunnel and storage facilities, walls, and dikes can be most effectively linked with green roofs, rainwater harvesting, rain gardens, sunken parks and sports fields, bioswales, wetlands, and protected floodplains.

Innovate through climate risk and adaptation options assessments, climate-risk informed planning, insurance, and disaster risk management. The sponge city concept should be further developed utilizing advanced hydrological and hydraulic modeling, simulation and visualization tools, and water resource management and irrigation management instruments. All these have experienced rapid advancement in recent years and their use should be promoted to benefit from detailed real-time flood early warning systems, forecasting, identifying hot spots for flooding, analyzing adaptation options, and the most effective solutions on a common geographic information system platform for local governments. The risk-information would serve as a basis for risk-informed planning, disaster risk management, and for options to cover incremental risks through insurance.

Plan resilience at city-cluster and river basin-wide levels, integrated with urban planning. Several urban areas in the PRC merged into mega-urban regions, and the PRC established 19 city clusters and completed initial cluster-wide plans and coordination mechanisms for them. Preparing resilience plans and green space conservation and protection on that city cluster level is critical. Benefits of functional ecosystem networks will go much beyond resilience and also be beneficial for biodiversity, forestry, agricultural, cultural, and recreational outcomes.

[16] United Nations Office for Disaster Risk Reduction. 2015. *Sendai Framework for Disaster Risk Reduction, 2015–2030*. Geneva.

Prioritize green space protection and planning to guide continuing urbanization. It is important to prioritize infill development in existing urban areas. The first thing to do is clean up and reuse brownfields for urban development, and only develop greenfields if brownfields and infill development potential are fully exhausted. Land, especially unpaved green land, is a scarce resource. If greenfield urban development cannot be avoided based on scientific and realistic projections, wider planning should begin with comprehensively assessing risks and mapping ecosystem functions as a basis for planning and protection of green systems in which construction will be forbidden. Future infrastructure should be integrated with blue–green networks to maximize resilience of cities.

Integrate state-of-the-art water resources management for water security and safety. The current practice of integrated water resources management should more strongly integrate future sponge city concepts. Infrastructure technology innovations can be included, such as with separation of black and gray water pipes in buildings and communities, and through the treatment and reuse of water integrated with green infrastructure. Also, creating decentralized local water clusters for water supply and wastewater management can generate increased efficiencies, forming a local water–energy–food nexus.

3. Management and Maintenance for Sustainability and Resilience

Integrate flood and drought risk management at a river-basin level as floods account for most losses of all climate-related disasters. Comprehensive operational integration of managing natural resources, water, land use, infrastructure, and climate resilience and disaster risk on a river-basin level across local administrative boundaries should be prioritized (footnote 13).[17]

Use stormwater as a resource during ensuing dry periods. As weather is expected to become more extreme, any precipitation, including that of extreme storm events and stormwater, should be considered as a water resource. A broader integration of green stormwater retention into infrastructure planning and deeper links with gray infrastructure for drainage, wastewater, treated wastewater reuse, and water supply systems may contribute to this objective.

Use native plant species and community traditions. This native biodiversity aspect is important when designing solutions for future sustainable management and maintenance of blue–green systems and functional open spaces. It is also an opportunity to engage communities on sustainability and provide livelihood opportunities for vulnerable groups.

4. Education and Engagement for Broad Ownership and Support

Broaden education and awareness throughout society. People of all ages and walks of life should be educated on the risks of climate change to promote low-carbon lifestyles. Think tanks, academic institutions, and professionals should promote study tours to best practice NbS and sponge cities to make tangible the benefits of these blue–green systems. Engage with children in kindergartens, schools, and adults at universities, and other education facilities.

Enable private sector investment and engage the community. It is essential to engage with communities, households, individuals, and private companies as they are the occupants of land parcels that should be made green to provide local stormwater retention functions, contributing to overall urban resilience. This can happen through awareness raising and capacity building as well as market-based instruments like incentives and disincentives and access to finance for blue–green system investments. Investments in green infrastructure can also be made through public–private partnerships.

Enhance professional education and update engineering handbooks. Academic institutions should include NbS, bioengineering and biomimicry in civil and environmental engineering curricula. Professionals, universities, think tanks and concerned national ministries should build a broad knowledge base and show evidence from best practice cases. Cost–benefit analysis of projects and programs should include NbS options and quantified benefits to help overcome acceptance and inertia challenges.

[17] Associated Programme on Flood Management, World Meteorological Organization, Global Water Partnership, and Deltares. 2017. Selecting Measures and Designing Strategies for Integrated Flood Management. A Guidance Document. *Policy and Tools Documents Series No.1*. Geneva: World Meteorological Organization.

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