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Climate Resilient Sponge Cities – Concepts and Tools to Integrate Green-Blue and Grey Systems

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1 ABSTRACT

Climate hazards from increased frequency and severity of extreme weather events require urgent urban adaptation action to increase resilience against flooding, landslides and extreme urban heat, as some of the highest risks. Nature-based solutions (NbS) in the form of functional urban green can effectively reduce disaster risks (IUCN, 2020; L. Arjan et. al., 2021). Ideally such green-blue infrastructure would form networks and be systemically integrated with gray infrastructure like drainage pipes to optimize resilience against flood risk. This paper looks at the Sponge City program in the People's Republic of China (PRC), which incorporates a range of water-related nature-based solutions to manage natural water cycles in cities and reduce urban runoff and flood risk, locally capturing, retaining infiltrating, and harnessing rain- and stormwater reused as water resources, increase local natural infiltration and threrby also cleaning stormwater. Technical guidelines were issued and 30 pilot cities were supported in 2015 and 2016, followed by 60 demonstration cities in 2021 and 2022 (Ministry of Housing and Urban–Rural Development, 2014). The key indicator set by the government has been to capture 70% of annual rainwater in the pilot areas. A recent study suggests that this has been achieved in the three cases used (J. Wu, 2022).

While this concept is not new, it is now being applied by an increasing number of cities around the world using this name (for eaxample: Hamburger Stadtentwaessering, 2015). Sponge cities in the PRC and elsewhere should be mainstreamed and better integrate with gray infrastructure to be most effective and efficient resilience systems to reduce flooding and extreme heat while also delivering a whole range of other ecosystem services as co-benefits, including contributions to climate change mitigation (for example: G. Browder et al. 2019). Not least public health, recreational benefits and land value increase can be captured. Planning and implementing green-blue systems as retrofitting of existing urban areas is challenging and requires strong stakeholder and community participation. Mainstreaming NbS and sponge cities as part of risk-informed and integrated urban and regional planning of new urban areas in urbanizing Asia and Pacific and Africa is essential considering the reality of rapid temperature increase and increased climate variability. The Asian Development Bank (ADB) is committed to be the climate bank for the Asia and Pacific region. ADB supports, among others, green city development, climate risk assessment, resilience investments inclusive of NbS and sponge cities, and contributed with advancing methods and pilot projects (ADB, 2016a, 2016b and 2019).

This paper offers an overview of sponge city in the PRC, technical and policy dimenions and initial observations on strengths and weaknesss of implementing the 30 plus 60 pilot and demonstration cities. A key conclusion is: it is essential for cities to establish effective green-blue NbS resilience systems. Effective gray engineeering infrastructure systems in cities are very much also needed. Systemically integrating both, green-blue and gray systems is essential to delivers best results. With the required urgent comprehensive transformation, all needs to be planned well across sectors, to ensure that investments in NbS contribute simultaneously to both, mitigation and adaptation. And it is critical that planning integrates with other objectives inclusive of compact city, healthy and age-friendly city, among others (N. Habib et.al., 2020) Because physical structures, industries, standards, governance, regulatory and educational institutions, and mindsets can't change overnight, a holistic strategy and the collective will to fast forward implementation is most needed. Some of the below findings were described in a prior publication by the author (S. Rau, 2022) and updated with results from new literature and projects, especially on effectiveness evaluation and new methods applied.

Keywords: risk-informed planning, advanced planning tools, sponge city, nature-based solutions, urban climate resilience

2 THE CHALLENGE: CLIMATE CHANGE RISKS TO CITIES

Cities and their residents are most affected by the fast changing climate and they also significantlty exacerbate its adverse impacts from its carbon emissions. East Asia is expected to be disproportionally more affected by climate impacts compared to global average. Weather extremes will be more likely and frequent, including torrential rains, cyclones, lomg dry periods and heat waves, that cause flooding, landslides, desertification, sea-level rise, drought and extreme urban heat (IPCC, 2021). At risk are human lives and health, livelihoods, families' life savings, infrastructure and assets. Disasters are exacerbated by unsuitable land use and urban form, i.e., in areas at risk of exposure to hazards and as carbon-intensive urban patterns and economies. Paved land and buildings generate stormwater runoff that requires management and they absorb and store heat.

Densely built-up urban areas without or with limited green spaces are up to 10 degrees hotter in the summer. This has already claimed premature deaths in many cities including in high-income countries and is a significant risk in developing economies. Vulnerable social groups are more affected, including poor, low-income and elderly people, which requires adaptation to be inclusive. Urban investents, public and private must contribte to the dual transformation need of resilience and low-carbon development.

Existing cities and urban areas require comprehensive and fast adaptive retrofitting action (S. Rau, 2021). This is a prime task around the world, and it is the most challenging. It requires participation and new forms of partnership among adinistration, communities, businesses and individuals. It involves risk analysis, planning, design and orchestrated public and private investment planning and careful implementation. A key obective is to establish effective resilience systems (while also reducing carbon emissions) covering the whole urban territory of an urban region and reaching beyond for building effective ecosystem networks. Newly developed urban areas in rapidly urbanizing regions especially in south and south-east Asia and in Africa require practical methods for risk-informed integrated urban planning aiming at comprehensive resilience - as well as low-carbon, resource-efficient development. Concerted swift transformation is challenging in all aspects, institutionally, technically, societal, economical and financial.

3 CONCEPTS AND INSTRUMENTS: NATURE-BASED GREEN-BLUE INFRASTURCTURE

Urban resilience through nature-based solutions (NBS) can be an effectice, efficient and widely accepted approach and applied through the sponge city concept in its comprehenive understanding. A sponge city soaks in rainwater and retains excess stormwater, then filters and releases the cleaner water slowly, much like a sponge does. A sponge city aims at improving urban rainwater management reducing runoff from bildings and paved areas and increase retention and natural infiltration applying nature-based solutions and green-blue infrastructre (i.e. K. Yu, 2016). NbS applied in sponge cities include preserved floodplains, stormwater retention lakes and ponds, wetlands, greenways, parks, rain gardens, green roofs, and bioswales. And also pervious pavement and underground water storages are applied. A comprehensive city-wide and river-basin wide plan for sponge city would deliver both resilience to various climate risks and simultaneoulsy contribute to climate mitigation.

Cities require both structural measures, like gray and green infrastructure system investments, and non-structural measures, like disaster preparedness and early warning systems for floods and other potential disasters (United Nations Office for Disaster Risk Reduction, 2015, 2019). Structural measures have traditionally been gray infrastructure, e.g., concrete walls, dykes, drainage pipes, canals, deep tunnel systems and large storage tanks.

Natural green-blue systems and their self-regulating capacity have been rediscovered as effective resilience measures and have been applied as ecosystem-based adaptation in more and more cities around the globe (for example: European Commission, 2015; UN Water, 2018). In the People's Republic of China (PRC) the concept of sponge cities is based on NbS and green infrastructure. It has been a national government program supported by the Minsitry of Housing and Urban-Rral Development since 2014 through 30 pilot cities (an evaluation was done by D. Yin et al, 2020). Support continues with a more systematic and systemic approach and as better intregration of green-blue and gray systems for additional 60 demonstration cities since 2021. Outside the pilot cities program every city in the country was obliged to prepare and implement sponge city masterplans.

Further integration with the objective of low-carbon and comprehensive climate-resilient development is critical for resource efficiency and can be achieved though systematic urban planning, urban design, and integrated investments. Systematic urban planning and urban design can take into account the needs for both low-carbon development and risk-informed planning for resilience against more natural hazards in a changing climate that will impact the PRC disproportionally more than other regions (IPCC, 2021, World Bank and ADB, 2021). Integration will effectively avoid redundant constructions and deliver more value and benefits for each dollar invested, as opposed to scattered unintegrated sector-wise investments. This will promote long-term sustainable green transformation. Planning of urban patterns with compact mixed-use development based on public transport, walking, and cycling with small blocks and small streets and public green spaces will reduce the need for transport as people may choose to live near where they work, shop, and go for recreation in parks.

PRC's Technical guidelines for Sponge Cities provide a catalogue of NbS options. The Ministry of Housing and Urban–Rural Development published Technical Guidelines for Sponge City Construction in 2014. 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 community, site, road and building design, construction, and maintenance. 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 overall national target of an 80% reduction of urban runoff is regionally differentiated according to precipitation levels and overall 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 engineered soil infiltration enablers. Sponge city program is not isolated. It is embedded within a range of policies. It is aligned with the national adaptation strategies of the PRC (Government of the PRC, 2013 and 2022). And it aligns with the PRC's urban adaptation action plan (Government of the PRC, 2016).

Systematic, intergated multi-scale planning and scenario comparison. A comprehensive approach involves intergated risk assessment and risk-informed urban and regional planning on watershed, urban region, city, district and neighborhood scales. It considers natural and manmade systems like surface and groundwater, existing topography and forests, green spaces, as well as land cover, land use and built infrastructure and assets. As a key feature of sponge city planning is decentralization of drainage aiming at local rainwater retention and infiltration, cumulative local action in many places can contribute significantly to reduce flooding of the drainage system, while local actions also need to be part of a larger hydrological system and climate system for cooling effects.

Advanced planning and simulation tools. The use of locally shared GIS platforms with data-feeding and use by local administration and researchers across sectors offers many opportunities to analysis and applying science to planning and action. Climate models that localize global and regional models allows better understaning of local hazard risks. The use of tate-of-the-art hydrological and hydraulic modeling allows comparative assessment of planning scenarios to guide policy makers on most effective and efficient adaptation options. Local climate and wind models help understand areas of high risk to extreme urban heat and allow conceptualizing systems of cool air pathways for natural ventilation of cities. Their comprehensive integration enables optimization of green-blue system layout for reaping most benefits from available land and financial resources. They are useful instruments in the process to promote the best solutions in the consultation and participation process.

Optimize multiple ecosystem-service benefits from NbS through systematic planning and design. Results from implementing integrated sponge city concepts on the ground start to show improved resilience against urban flooding and water scarcity, as well as additional benefits from ecosystem services like reduced heat in the summer, enhanced biodiversity, improved livability - and increased land value. Studies show that residents welcome actions for reducing risks and for their increased urban liability from the green spaces, green roofs and facades etc.

Optimize resilience improvement from systemic integration of green-blue and gray systems. The sponge city program in the PRC has been improved to deepen and better integrate gray and green measures so they mutually reinforce one another and work as optimized system together. Existing gray infrastructure systems like drainage pipe networks were analyzed and assessed for improvement opportunities, i.e. along with other system improvements, like separating existing combined sewers into sanitary sewers and drainage pipes. Drainage pipes can be more directly discharing stormwater into rivers, as opposed to the detour through the wastewater treatment plant. This results in more effectiveness and efficiency. The more polluted first flush of the stormwater can be cleansed through NbS as guided into sand and earh filters before discharging into the river. Integrating this with comprehenive stormwater retaining cascading at-grade green-blue systems showes in digital simulation that urban flooding can be very significantly reduced in the future. What is true for reduced floood risk is also true for impproved water management for irrigation and for improved urban microclimate and the carbon sequestration and air quality improvement impacts.

4 PROJECT CASES: PILOTS ADVANCING METHODS AND TECHNIQUES

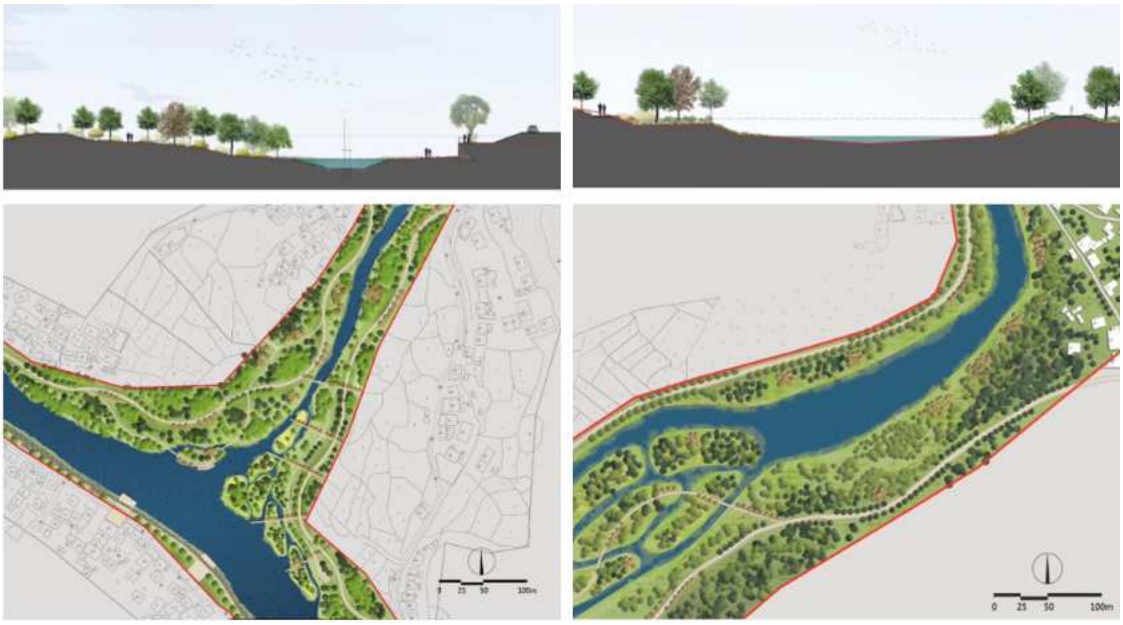
There are many cases in the PRC – and also elsewhere as the concept is applied in many places, that have been studied and evaluated. A few have been supported by the ADB in the PRC, including in Jiangxi Pingxiang, Jilin Yanji and Shanxi Changzhi. They were also used to advance methods and techniques. For eample, digital analysis tools of hydrological and hydraulic models linked with GIS were used to develop and simulate scenarios for design storm events and drainage design scenarios. Gray and green-blue infrastructure systems were integrated and simulated together. Ecological river rehabilitation and flood risk management preserving floodplains and rehabiliting wetlands for water retention and cleansing and biodiversity enhancement. Other measures include instream river training for flow management and reduce pressure on embankments. Further measures include design of cascading systems of green roofs, rain gardens, bioswales, earth filters and wetlands for first-flush stormwater treatment.

Jiangxi Pingxiang Intergated Rural-Urban Infrastructure Development Project Case: Flood risk reduction is a top priority in Pingxiang, in Jianxi Province of the People's Republic of China. Flood frequency and severity have increased significantly since 1998. Floods in 1998, 2001, 2002, 2010, and 2014 affected more than 496,000 people, caused the collapse of more than 2,600 houses, and resulted in significant economic losses in agriculture. A major flood on 25 May 2014 severely impacted public safety and health and caused an estimated $115 million in economic losses. As a headwater municipality where all rivers originate within its territory, Pingxiang is prone to fluvial flooding, a key risk aggravated in combination with pluvial flooding in urban areas. Most riverbanks in Pingxiang have inadequate flood protection, sediment accumulation from riverbank erosion, and raised riverbeds from mining sediments, further reducing the flood discharge capacity of rivers. Urban drainage systems, the gray infrastructure, in Pingxiang are made of combined sewer and drainage pipes. These challenges were addressed by an ADB supported project (ADB, 2015).

Pingxiang was selected as one of 16 first generation national pilot sponge cities in 2015. ADB prepared and supported a project that contributes to making the sponge city concept more comprehensive and greener. The ADB project contributes with the river related infrastructure to Pingxiang's Pilot as an overall strategy by piloting sponge city design principles and green infrastructure development in the four key sub-centers and the respective urban and river areas of influence of Pingxiang Municipality in Xiangdong District urban center, Lianhua County (county seat), Luxi County (county seat) and Shangli County (county seat and Tongmu township), while the national government program focused on areas in Pingxiang's core urban area. It consolidated planning and investment for integrated river rehabilitation and flood risk management to improve climate resilience, enhance biodiversity, and contribute to urban greening as an amenity for citizens, thereby increasing livability and value of a city. The various features include green embankments, publicly accessible river greenways, floodplain protection, wetland rehabilitation, and wetland parks for stormwater retention, as well as sewer and drainage separation and wastewater interceptor pipes along project rivers.

The project changed the conventional gray infrastructure approach of flood control through channeling the river with walls and/or hard embankments to a green infrastructure ecosystem-based adaptation approach. More green space is provided to the rivers. Floodplains and wetlands are maintained and/or rehabilitated, and green embankments with soft water edges are applied to allow for natural and seasonal fluctuations in water levels and to reduce flooding impacts of more frequent and severe storm events, while also contributing to enhanced ecology and water quality. Climate risk and vulnerability assessment and hydraulic modeling of anticipated storm events were developed during the preparation of the project. Specific additional adaptation measures were included in the design. During the implementation of the project lessons learnt were applied in new subproject designs and replicated in other locations. Lessons were also shared with others in the country for replication. Below are sample design illustrations and pictures of the implemented project. Local residents and visitors already enjoy the river greenways and reduced flooding, and the government benefits from increased tax revenue of increased property values and more people and businesses attracted to the greener towns.

Aerial Foto of a completed wetland restoration that doubles as urban park for recreation and for improving microclimate in Pingxiang. Source: Pingxiang Government.



Design of green embankments, riparian landcape and rehabilitated wetlands with increased flow capacity and enhanced biodiversity. Source: ADB consultants for Asian Development Bank.

Jilin Yanji Low-Carbon Cimate-Resilient Healthy City Project Case: For this project, ADB used the design of sponge cities as a platform for mitigation and adaptation elements, such as public transport to promote walking and cycling and healthy lifestyles (ADB, 2019). It further piloted innovative approaches, including advanced computer modelling, demonstrating that integrating green and gray infrastructure can significantly reduce urban flooding (pluvial flooding).

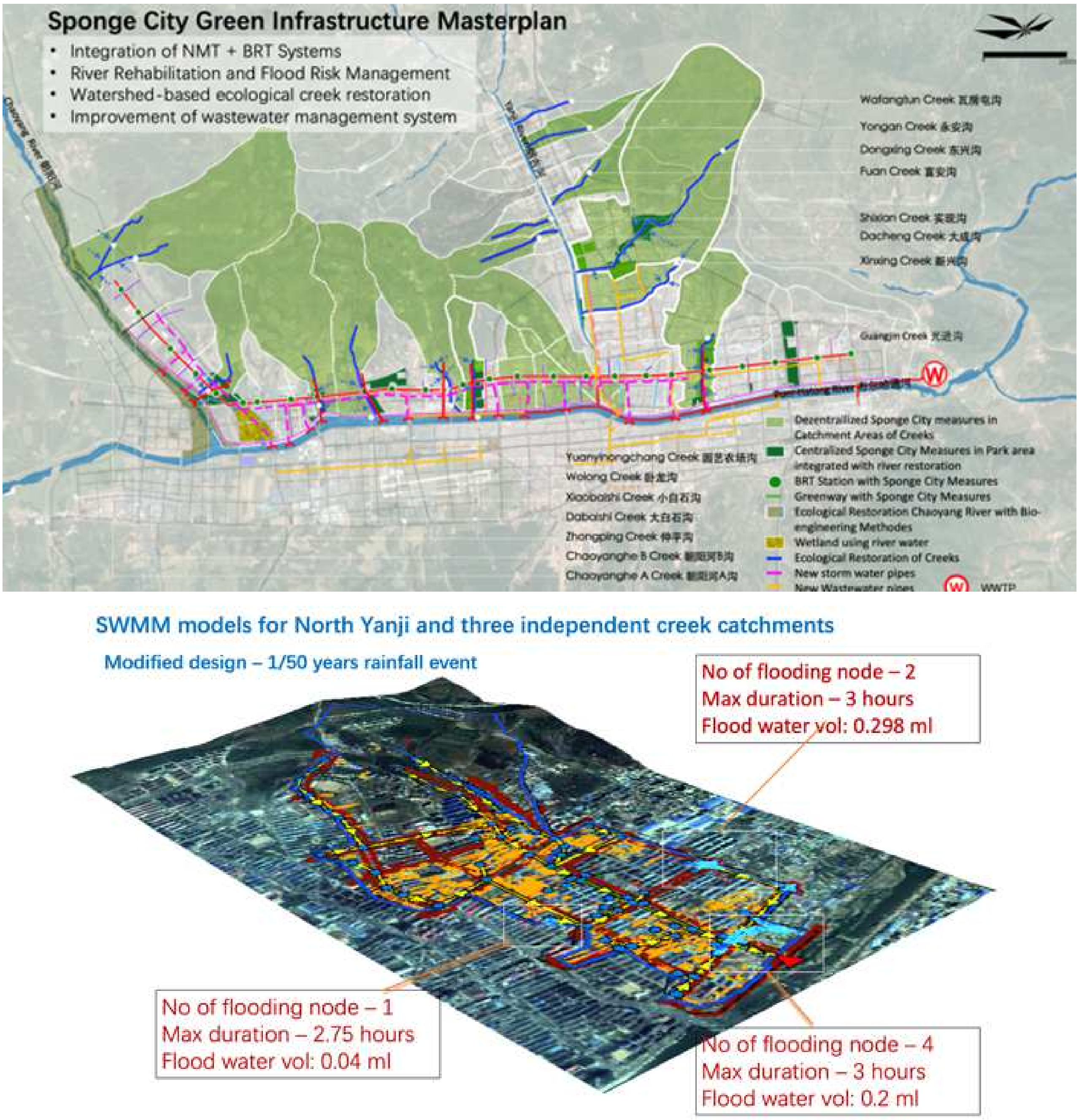
Flooding is a significant problem during the rainy season in June and July. Flooding occurs for about 5 days per year on average in recent years. River flooding, flash floods, and urban flooding endanger lives, property, and livelihoods, and disturb traffic and public life. The combined sewer and drainage pipe system is outdated. Only 11.6% of the pipe network meets the required 1-in-3-year flood design standard, causing pluvial flooding during heavy summer rains. The Chaoyang River urban catchment area is currently exposed to flood risks of 1-in-20-year flood events.

Flood risk reduction. Restored riverside wetlands and green water edges along gentle slopes along the river reduces the risk of flooding. At the same time, they provide a habitat for a diversity of plant and animal species and serve as an amenity for residents during non-flood times. (Photos: Stefan Rau) Source: Asian Development Bank.

ADB financed the first bus rapid transit (BRT) corridor in the northeast of the PRC and integrated it with comprehensive stormwater management and water supply system improvements. The overall concept follows the principles of transit-oriented development, focusing on higher density mixed-use and pedestrian-friendly center areas including green spaces around BRT stations, thereby promoting low-carbon urban mobility. New green spaces that are designed as sponge city green infrastructure will link station areas with project-supported riverfront greenways. These spaces will create a network of sponge city infrastructure enhancing climate resilience and urban livability. These green spaces apply universal design principles to ensure accessibility and also promote healthier lifestyles for residents and tourists, hence contributing to a healthy and children and age friendly city development.

During project design, a catchment-based sponge city master plan for the northern part of the city was developed along with a climate risk and adaptation options assessment. A detailed digital topographic urban and hydraulic model was developed for the project. The model was piloted as an expert tool that simulates future storm scenarios and adaptation options integrating existing and newly proposed drainage pipe network improvements with at-grade sponge city green infrastructure. Improvements to drainage and flow capacity, combined with increased stormwater retention and infiltration capacity, were quantified, visualized, and evaluated to optimize flood risk reduction, investments, and green space benefits. Investments include sponge city green infrastructure along streets with permeable paving and tree plantings in large planters with increased space for roots and more infitration capacity. It includes rain gardens and bioswales in residential areas within the catchment of creeks, integrated with improved and separated drainage pipes (at least 43 km) and wastewater pipes (at least 40 km), using results from a detailed integraeted 3D hydraulic modeling. The project significantly reduces the climate-related pluvial and fluvial flood risks (according to the project's hydraulic model up to 1-in-50-year flood events). It also improves the water quality through the construction of end-of-pipe sedimentation tanks and reed-bed sand filters. Fluvial flooding is reduced through ecological river rehabilitation of the Chaoyang River, improving the flood protection standard from 1-in-20-year floods to 1-in-50-year flood events. Bio-engineering is adopted, which includes in-stream solutions in the riverbed and green embankments as well as building pedestrian and bicycle paths with tree planting along the greenway.

This intergation of improving gray drainage pipe systems by short and direct alignments to the river with end-of-pipe solutions and the systemic integration with newly introducded above-grade and at-grade green-blue measures retaining and cascading stormwater effeectively reduces urban and river flood risk. The benefits of improving public transport, linking with expanded bicycle and pedestrian networks and green spaces are already transforming the city. The BRT system is a great success with ridership of public transport significantly increased and pupulating the enhanced and new functional green spaces. Below are planning diagrams and the visualization of the system.



Sponge City Green Infrastructure Master Plan for Yanji City. (Plan graphics is based on river and creek catchment areas for the area north of the Buer Hatong River, image by Nengshi Zheng, SWMM model image by Heping Zuo). Source: Asian Development Bank.

Shanxi Changzh Low-Carbon Climate-Resilient Circular Economy Transformation Project Case: Changzhi was selected as a national demonstration sponge city in 2021 for deeper application of the concept. ADB prepared an integrated support project. Changzhi is located in southeast Shanxi Province and is part of the Yellow River Ecological Corridor, which had a total population of about 160 million in 2021. Changzhi's permanent resident population grew to 3.15 million in 2021, with about 899,000 living in the center area of the municipality's urban districts. Similar to most of Shanxi Province, the economy is dominated by carbon-intensive heavy industry, such as coal and energy; this impacts Changzhi's air quality, which is slightly worse than other cities of similar size. Heavy industry generates about 77% of the city's total revenue but employs only 11% of the workforce (ADB. 2023).

Implemented first phase of the bus-rapid transit with bike paths and sponge city tree planting and road median landscape linking to green parks. Source: Yanji City Government

Annual rainfall in Changzhi is low (534 millimeters), with more than 60% falling in summer. Groundwater resources are widely used. Changzhi is exposed to wildfire, drought, and seasonal flooding risks, all of which will be exacerbated by climate change. By 2050, the average temperatures in Changzhi are expected to increase by 2.3˚C, which will likely cause a potential increase in evaporation. The changing climate will also increase extreme weather events, with long dry periods and heavy rainstorms, and increased water scarcity, droughts, and floods. Continued groundwater use has caused a significant depletion in the water table, which has dropped by more than 10 meters in some areas since 2000. In Qinyuan and Licheng counties, recent floods damaged riverbanks with over 300 households significantly affected. Changzhi's institutional capacity on climate-resilient planning and green financing are weak and fiscal resources are limited. Lack of cross-sector coordination within the government along with a lack of information and communication technology (ICT) platforms hinders the modernization of governance. Poor urban and transport planning have resulted in climate-vulnerable urban patterns.

The project carried out climate risk assessment and proposed and included adaptation measures to reduce the risk of flooding, drought, urban heat, and wildfire. The main approach is applying nature-based solutions using green infrastructure while also improving gray infrastructure systems and systemically integrating both to manage climate-related risks. These physical measures are complemented with non-structural measures like monitoring and early warning systems, disaster risk preparedness, and institutional capacity building to further plan for resilience and effective management inclusive of insurance schemes will increase Changzhi's resilience against climate-related risks.

The project provides strengthening of government institutions and engaging the private sector to transform a carbon-based economy toward a low-carbon and zero-waste resilient city and contributing to climate resilience and building green capital through integrated planning and by implementing compact city and transit-oriented development principles with pedestrian-friendly green urban environments. The project reduces waste and explores lifecycle assessment to further reduce environmental impacts, reduces carbon emissions, and optimizes resource use efficiency. The sponge city contributions of the project include new green parks to function as flood retention areas as well as cool air pathways to reduce extreme urban heat. These green spaces will benefit local residents and visitors and also be home to a diversity of plant and animal species. The projetct's integrated planning and design will create synergies that generate more value from every dollar invested for climate mitigation, adaptation, public health and other ecnomic benefits. Below are illustrations of project location and concepts. The project also integrates landscaping and tree-planting in public spaces and along roads as medians, bioswales, applying the sponge city principles of increased planting areas, more space for tree-roots and infiltration enablers.

The project applies an advanced method of ecological river rehabilitation integrated with soil bioengineering to all project rivers. This innovative method of instream river training allows improvement of rivers naturally and it allows their ecological condition under both dry weather and low water flow level conditions as well as for river flood protection during flood events. The principle of this method of instream river training is to work with rocks and boulders that are carefully placed on the riverbed below the water line. This creates local turbulences which lead to riverbed alterations, slower and faster flows within the river stream, and temperature differentials which increase habitat and biodiversity of fish and other plant and animal species. During a heavy rainstorm event, the instream river training method will lead to a physical build up and acceleration of water masses through such hydrodynamics. This in turn will reduce need for river embankment enforcement and allows soft and green river edges with enhanced ecology and biodiversity.

The project contributes to and complements domestic activities. Changzhi City was the only city selected as part of 20 demonstration cities for the new national sponge city program to systematically promote sponge city planning and construction. The key tasks in this action plan include ecological restoration and governance projects, flood prevention and drainage construction projects, water environment governance projects, water resource utilization projects, urban renewal and transformation projects, industrial base construction and control, and strengthening sponge city capacity building.

Planning support included land use planning for a higher density mixed use urban core area based on transit and walking. ADB proposed a central green space and a pattern of small blocks and streets. Investments include roads with bus lanes and bus stops, proper sidewalks and bicycle lanes, green medians and trees and a major central green space between the rail station and the airport. A green network for hydraulic functions and public open spaces. Blue arrows show principle of cool air pathways as ventilation corridors from the mountain to the Zhangzi lake and along the project green spaces.

For another subproject area a network of streets with greenways and green connections and pocket parks all designed with sponge city functions were proposed by ADB, as well as on-site sponge city measures for buildings. Reuse of treatet wastewater is also supported as part of water security and circular economy concept. Source: Nengshi Zheng, Zuo Heping, Du Yipeng and Stefan Rau for Asian Development Bank, based on Google Earth.

Qinyuan County Subproject and Proposed Blue-Green Network Masterplan. Project investment components are marked in red lines or outlines with ecological river rehabilitation and flood risk management and greenway development as green capital investments, and as solid dark red line for the road. These projects will contribute to a functional blue-green network that provides multiple ecosystem services benefits including flood risk reduction and urban cooling improving climate resilience and they also serve as amenities for people and sink carbon emissions. The road will provide a bypass for the county seat and complete a public transport and bicycle and pedestrian network. Source: Nengshi Zheng, Design Institute based on google earth for Asian Development Bank.

5 STRENGTHENED INSTITUTIONS ENGAGE WITH PRIVATE SECTOR AND PEOPLE

The worsening climate challenge and increasing numbers of disasters mandate transformational change quicker and beyond what may have been anticipated previously. Relevant, swift, deep, and ubiquitous change of the way we are used to think about and 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. This requires changes in many areas and institutions and in the way public and private stakeholders, communities and individuals communicate and collaborate. And it needs changes in the way engineers are trained and contractors work. In other words a lot of system inertia needs to be overcome.

Reform government institutions and integrate sponge city with comprehensive risk management. Creating sponge cities by using NbS, like other climate adaptation and mitigation actions, will be effective only if all concerned 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 needs to be treated as an important part of the overall strategies of a city. It is also important to integrate disaster risk management (both as physical and non-physical 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 natural or manmade disaster risks through an integrated and inclusive, multihazard, multilevel, and cross-sector approach to reduce loss of lives, assets, and economic damage.

Governance improved to enable cross-sector and cross-risdictional coordination for resilience with low-carbon urban transformatioon to optimize co-benefits. Multilevel and cross-sector governance mechanisms need to be improved to: ensure that open space and ecosystems are protected, and for the planning of new urban areas integrate flood and drought resilience planning – while also integrating low-carbon urban form principles. Adapt existing urban areas to introduce NbS with green spaces that are optimized for both resilience and to reduce greenhouse gas emissions. 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. These and more aspects are under the responsibility of different agencies and private sector contributors and effective coordination is critical for the success of sponge city.

Governance improved to enable integrated cross-sector and cross-risdictional green-blue and gray infrastructure applied 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 and urban region have the capacity to reduce flood risk while also improving the local management of rainwater and urban heat risks. 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 dykes can be most effectively linked with green roofs, rainwater harvesting, rain gardens, sunken parks and sport fields, bioswales, wetlands, and protected floodplains. As urban areas im many cases go beyond local jurisictions it is important to enable mechanisms for cross-jurisdictional coordination, through higher government mandates or voluntary cooperation.

Integrate flood and drought risk management on river-basin level. 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 and be part of formalized governance and planning coordination (S.P. Groff and S. Rau, 2019).

Revise education curricula, engineering handbooks and standards. Academic institutions should include NbS, bio-engineering and biomimicry in civil and environmental engineering curricula. Professionals, universities, thinktanks 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.

Engage public and private sectors, new partnerships with communities, and land- and asset-owners. It is important to also engage early on and with a broader section of the population is important. People of all ages and walks of life should be educated on the risks of climate change to promote low-carbon lifestyles. Thinktanks, 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. 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.

Mobilize sustainable finance, public finance priorities and leverage private funds. Urban climate change adaptation and the sponge city approach deserves 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.

6 APPLICATION OF SPONGE CITY OUTSIDE THE PRC

The sponge city concept existed both in the PRC and elsewhere before the term was coined for example as low-impact design, water-sensitive design, integrated rainwater management, among others. It is being applied with this same name in many places outside of the PRC i.e. in Asia, Europe, the Americas and Oceania. The city of Copenhagen in Denmark has been a pioneer. Some cities in Germany like Berlin and Hamburg have developed complrehensive implementation plans and even established specific agencies and continue to implement retrofitting and new-development pilots (Berlin Regenwasseragentur, 2019; Hamburger Stadtentwässerung, 2015). The United States' Environmental Protection Agency published a seminal technical guide for local governments and private stakeholders and home owners to inspire green infrastructure and NbS (United States EPA, 2015). Vienna in Austria, Zurich in Switzerland and many other cities around the world adopt the concept (Stadt Wien, 2023). The proof of the sponge city concept stimulates other ciites around the world to apply the principle, like for example Berlin and Hamburg in Germany.

The principles and design elements are more or less the same or similar adjusted for local conditions and space availability, while the mechanism of planning, public communication and consultation are adapted to the local conditions and cultures. Retrofitting existing urban areas is challenging everywhere in the world, also in the PRC. And for new urban areas it is challenging with many stakeholders and land owners for integrating sponge city planinng as part of risk-informed planning. The PRC's practice of establishing sponge city offices directly reporting to the Mayor allows them to cooperate across agencies for planning and implementation of projects and building systems. The cases of Hamburg and Berlin where the local public water companies drive the sponge city initiatives and have also established separate agencies to prepare comprehensive city-wide drainage plans and promote the concept demonstrates that it can be successfully implemented outside of the PRC. The Berlin and Hamburg governments' authority to mandate local rainwater interception, retention and/or infiltration and educating and promoting local incremental projects to decouple territories from the gray drainage systems are impresive cases for the concept's relevance for building urban water and -heat related resilience successfully. Of course these two cases are examples only and there are many others, at various stages of planning and implementation.

7 CONCLUSIONS

Rapidly increasing urbanization together with climate change-related hazards from increased frequency and severity of extreme weather events require urgent urban adaptation. Nature-based solutions (NbS) can enhance climate resilience, effectively reducing disaster risks including 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, urban cooling, better air, carbon sequestration and improved air quality while delivering many other ecosystem benefits for livability and urban competitiveness. People enjoy green spaces and the diversity of flowers and birds and are willing to pay for improvements. Cities enjoy higher tax incomes from increased land value.

NbS and sponge cities should be mainstreamed, deepened, and combined and systemically integrated with improved gray infrastructure like optimized drainage pipe networks. To do this requires refotm and transformation and overcoming significant policy, institutional and industry inertia. Strides are needed in policies that prioritize 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 towards, and inertia of of engineering and contracting industry to enable rapid acceotance and uptake of sponge city and NbS.

The concept is proven, however, when applied holistically as a territorial principle of decentralization and decoupling from technical drainage systems. The main challenge is to apply this widely retrofitting urban areas with the realities of existing paving and structures and the need to engage stakeholders and owners. Communities, private sector and individuals. Scare public financial resources need to be spent effectiveley and efficiently and private resource leveraging is essential to build urban resilience. Priority is to be given to those measures that are well designed and deliver many benefits, i.e. NbS for low-carbon and resilient development for resource use effectiveness and efficiency. That is multiplying benefits from the investments.

The popularity of the concept reached well beyond the PRC. Through engaging stakeholders and communities it can also be applied in differenent institutional contexts, also for the much needed retrofitting of urban areas, sites and buildings. And the concept should be mainstreamed as key contribution to urban climate resilience and biodiversity enhancement as local and even global public good. The beauty of the concept is the effectiveness and efficiency of NbS with multiple co-benefits from the scarce resources invested. And the increasing engagement of private sector and real estate owners, i.e. in Berlin and Hamburg, and also in the PRC is most encouraging and urgently needed for effectiveness of resilience across urban regions.

8 REFERENCES

Asian Development Bank (ADB). Nature-Based Solutions for Building Resilience in Towns and Cities: Case Studies from the Greater Mekong Subregion. Manila. 2016a.

ADB. GrEEEn Solutions for Livable Cities. Manila. 2016b.

ADB. Nature-Based Solutions for Cities in Viet Nam. Manila. 2019.

ADB. People’s Republic of China: Jiangxi Pingxiang Integrated Rural–Urban Infrastructure Development Project. Manila. 2015

ADB. People’s Republic of China: Jilin Yanji Low-Carbon Climate-Resilient Healthy City Project. Manila. 2019

ADB. People’s Republic of China: Shanxi Changzhi Low-Carbon Climate Resilience Circular Economy Transformation Project. Manila. 2023

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

Berlin Regenwasseragentur. Abkopplng lohnt sich. Berlin. 2019. https://regenwasseragentur.berlin/. Berlin. 2019

G. Browder et al. Integrating Green and Gray: Creating Next Generation Infrastructure. Washington DC: World Bank and World Resources Institute. 2019.

European Commission (EC). 2015. Towards an EC Research and Innovation Policy Agenda of Nature-Based Solutions and Re-naturing Cities. Brussels.

Government of the PRC, State Council. National New-Type Urbanization Plan, 2014–2020. Beijing. 2014.

Government of the PRC, State Council. 2013. National Climate Change Adaptation Strategy. Beijing;

Government of the PRC, State Council. 2022. National Climate Change Adaptation Strategy. Beijing (in Chinese). Beijing.

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

S.P. Groff and S. Rau. China’s City Clusters: Pioneering Future Mega-Urban Governance. American Affairs Journal. May 20, 2019.

N. Habib, S. Rau, S. Roth, F. Silva, J. Sandro. Healthy and Age-Friendly Cities in the People’s Republic of China. Proposal for health impact assessment and healthy and age-friendly city action and management planning. Manila. 2020.

Hamburger Stadtentwässerung AöR und Behörde für Umwelt und Energie. Strktrplan Regenwasser 2030. Für ein Integriertes RegenWasserManagement (IRWM) in Hamburg. Hamburg. 2015.

International Union for Conservation of Nature (IUCN). IUCN Global Standard for Nature-based Solutions. First Edition. Gland, Switzerland. https://doi.org/10.2305/IUCN.CH.2020.08.en 2020.

IPCC. Regional Fact Sheet Asia. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the IPCC (V. Masson-Delmotte et al. [eds]). Cambridge University Press. 2021.

Ministry of Housing and Urban–Rural Development. Technical Guidelines for Sponge City Construction in the People’s Republic of China. Beijing, 2014.

S. Rau. Bridge to Future Livable Cities and City Clusters in the People’s Republic of China: Policy Opportunities for High-Quality Urban Development. Manila: ADB. 2021.

S. Rau: Sponge Cities: Integrating Green and Gray Infrastructure to Build Climate Change Resilience in the People’s Republic of China. Manila, ADB. 2022

United Nations Office for Disaster Risk Reduction. Sendai Framework for Disaster Risk Reduction, 2015–2030. Geneva. 2015.

United Nations Office for Disaster Risk Reduction. Global Assessment Report on Disaster Risk Reduction. Geneva. 2019.

UN Water. The United Nations World Water Development Report 2018: Nature-Based Solutions for Water. Paris: UNESCO. 2018.

United States Environmental Protection Agency (EPA). Tools, Strategies and Lessons Learned from EPA Green Infrastructure Technical Assistance Projects. Washington. 2015.

Stadt Wien. Wiener Stadtgärten. COOLing-Fibel Kühlende Maßnahmen für heiße Zeiten in Wien. Wien. 2023

World Bank and ADB. Climate Risk Country Profile: China. Washington and Manila. 2021.

J. Wu: Evaluation of the Chinese Sponge City Program: the Resilient Transition of Urban Stormwater Management, Wuhan, Chongqing, Zhenjiang, China, Case Studies. [Dissertation Clemson University.] 2022.

D. Yin, Y. Chen, H. Jia, Q. Wang, Z. Chen, C. Xu, Q. Li, W. Wang, Y. Yang, G. Fu, A. S. Chen. Sponge city practice in China: A review of construction, assessment, operational and maintenance. Elsevier Ltd. www.elsevier.com/locate/jclepro 2020.

K. Yu. Sponge City: Theory and Practice. China Architecture & Building Press. Beijing. 2016.