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CASE STUDY

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The Three-Point Sponge Policy approach for integrating Blue-Green-Grey Infrastructure by Design: Lessons from the 2021 Extreme Flood in Zhengzhou, China

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Abstract

The increasing frequency and intensity of extreme weather events, coupled with rapid urbanization, are placing unprecedented pressure on urban environments. The Three-Point Sponge Policy Approach (3PSPa) integrates the Three-Point Approach (3PA) with Sponge City principles to enhance urban flood resilience through design-driven, adaptive, and multifunctional solutions. This paper applies the 3PSPa framework to Zhengzhou, China, which experienced devastating flooding in 2021, to assess its current flood resilience measures and explore pathways for improvement. Two contrasting urban districts in Zhengzhou were analysed: B1, a newly developed, low-density district offering high potential for implementing large-scale blue-green-grey infrastructure (BGGI); and B2, a dense, older district where interventions are limited, typically emerging incrementally through targeted retrofitting associated with urban renewal activities. By applying the 3PSPa's five-step design process, this study identifies resilience gaps and proposes tailored interventions, balancing short-term, localized strategies with long-term, catchment-wide transformations. It emphasizes the importance of shifting from a conveyance-based water management approach to a diversified strategy that integrates infrastructure with natural hydrological processes.

Keywords Extreme weather events, Green infrastructure, Nature-based solutions, Sponge Cities, Three-Point Approach, Urban flood resilience, Research-by-design

1 Introduction

The increasing frequency of extreme weather events, combined with rapid urbanization, is placing unprecedented pressure on cities worldwide [1, 2]. Recent catastrophic floods, such as those in Europe and China,

highlight the urgent need for revisiting the current urban water management strategies [3, 4]. Traditional grey infrastructure, designed for stable climatic conditions, has proven inadequate in managing extreme weather events. At the same time, despite widespread advocacy, nature-based and multifunctional solutions face challenges regarding their effectiveness in extreme conditions and the feasibility of integrating them into existing urban landscapes [5, 6].

China's Sponge City Program, introduced in 2014, aims to enhance flood and drought resilience by integrating natural hydrological processes [7, 8]. Initially focusing on improving water quality and addressing urban water system degradation, its role in flood mitigation has

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gained increasing prominence, particularly after the 2021 Zhengzhou floods [5–7]. This program promotes the widespread adoption of Nature-based solutions (NBS) in both newly developed and existing urban areas to strengthen stormwater management capacity and reduce flood risks.

Nature-based solutions (NBS)—such as constructed wetlands, green roofs, permeable pavements, and rain gardens—provide multiple benefits beyond traditional grey infrastructure by replicating natural water retention and infiltration processes [9, 10]. These solutions help mitigate peak runoff, enhance groundwater recharge, and strengthen overall water resilience while also supporting biodiversity, improving urban cooling, and enhancing aesthetics [11]. Moreover, the decentralized nature of NBS enables more flexible and localized flood mitigation interventions, complementing or upgrading engineered drainage systems in what is known as Blue-Green-Grey Infrastructure (BGGI) [12].

This integrated approach enhances urban resilience by combining natural and engineered solutions for more sustainable water management. Despite their advantages, the scalability and effectiveness of BGGI within the Sponge City framework to address extreme weather events remain underexplored [13]. In addition, challenges persist in retrofitting NBS into high-density urban areas, where land availability is limited. Addressing these gaps is crucial for fully exploiting and benefitting from the multifunctionality of NBS and enhancing the resilience of Sponge Cities against extreme weather events, such as extreme rainfall.

Despite being designated as a Sponge City, Zhengzhou suffered devastating impacts from the July 2021 extreme flood, which resulted from record-breaking rainfall of over 600 mm in three days, overwhelming the city's drainage capacity [4–14]. The disaster caused severe urban flooding, extensive property damage, and the tragic loss of nearly 400 lives, exposing critical gaps in existing flood resilience measures. In response to recurrent flood disasters, such as the Zhengzhou floods, the Chinese government and local authorities called to prioritize upgrading of drainage and flood conveyance infrastructure, improving flood forecasting systems, and promoting permeable surface initiatives. Additionally, new regulations now require cities to meet higher flood protection standards (e.g., a 1-in-50-year return period for urban areas and a 1-in-100-year standard for Central Business Districts and government zones) [15, 16].

The Three-Point Approach (3PA) provides a structured framework for urban water management, aiming to minimize risks (such as extreme rainfall) while maximizing benefits. It categorizes water management into three domains to cover the full span of rain events from

small frequent events to catastrophic rare downpours: the Day-to-Day Domain, the Technical Design Domain, and the Extreme Domain, and encourages decision makers to set targets and identify an integrative strategy encompassing the three domains. Recently, inspired by 3PA, the Three-Point Sponge Policy Approach (3PSPa) has been proposed to enhance China's Sponge City initiative, improving resilience against various hydrological challenges [17]. At its core, 3PSPa is a design-driven framework that promotes multifunctional stormwater management and the adoption (although not exclusively) of BGGI, through an iterative, design-based learning process [18]. However, its practical implementation requires further refinement and clearer guidance. Strengthening 3PSPa's design-based approach is crucial to bridge the gap between policy ambitions and on-the-ground implementation, ensuring more responsive and resilient urban water management systems.

The objective of this paper is to apply the 3PSPa framework to the case of Zhengzhou to evaluate the measures taken in the aftermath of the 2021 flood and assess potential options for further enhancing urban flood resilience. By analyzing Zhengzhou's urban water challenges and opportunities through the lens of 3PSPa, this study also aims to provide insights into the strengths and limitations of this framework for applying the China's Sponge City Program to effectively address extreme weather events.

2 Background

2.1 Origin and current practice of the 3PA

Current urban water management policies often focus primarily on the technical engineering aspects of stormwater infrastructure performance and include specific targets (design standards) for these engineered systems. These limitations result in missed opportunities to maximize intervention benefits in daily conditions and insufficient strategies to mitigate the risks of rare, high-impact flood events.

The Three-Point Approach (3PA) was originally introduced by Geldof and Kluck in 2008 [19]. The 3PA aims to enhance a more integrated perspective on flood risk by considering the full spectrum of rainfall events and their associated risks and benefits [13]. Additionally, it takes into account the potential co-benefits of interventions, including social advantages (e.g., enhanced public amenities) and ecological improvements (e.g., biodiversity and ecosystem services). However, its practical implementation has been hindered by ambiguities in defining event magnitudes, spatial scales, and leaning from best practices, limiting its effectiveness in real-world applications [20]. To address these gaps, Randall et al. [21] proposed to define targets as water

depth thresholds within the 3PA framework to promote better integration across the three domains and to enhance transdisciplinary and transnational knowledge exchange among cities. Establishing a common reference framework such as the 3PA based on water depth thresholds, is essential for facilitating communication and shared learning among diverse professionals and stakeholders within and across different cities and regions. This, in turn, supports the development of more coherent and integrated policies to enhance water security and liveability of cities requiring a transition from the traditional, single standard risk-based approach to a resilience-based approach.

This transition from a single and static standard (dotted line) to multiple, performance-based (solid line) indicators following 3PA, is illustrated in Fig. 1 [22]. The horizontal axis represents rainfall frequency, ranging from frequent, low-intensity rainfall to rare, high-intensity events, while the vertical axis indicates system performance or potential impacts. In this figure, the conventional approach is shown as a single design standard, often based on a fixed return period (e.g., a 1-in-50-year storm). The 3PA moves beyond a single-value focus by integrating grey, blue, and green (BGGI) solutions across multiple rainfall frequencies: Day-to-Day, Technical

Design, and Extreme events. By adopting multiple design standards, it enables a more comprehensive and flexible approach to stormwater management, ensuring that a diverse range of interventions effectively address the full spectrum of rainfall intensities and urban water challenges.

A key enabler for 3PA implementation is a design-based approach such as advocated in the planning and engineering design approach of Water-Sensitive Urban Design (WSUD) [23]. WSUD integrates urban planning with management, protection, and conservation of the urban water cycle to include the storage-discharge balance as a steering mechanism in the design and to take into account the co-benefits such as water quality improvements, habitat creation, and urban cooling. WSUD provides design principles and practical solutions for managing stormwater locally by enhancing water retention, infiltration, and reuse. These principles closely support the objectives of the Three-Point Approach (3PA) which offers a structured framework for categorizing stormwater interventions and guiding their application across different rainfall regimes. For instance, 3PA's Day-to-Day Domain focuses on managing small, frequent rainfall events while enhancing urban liveability. This aligns with WSUD's core principle of improving everyday

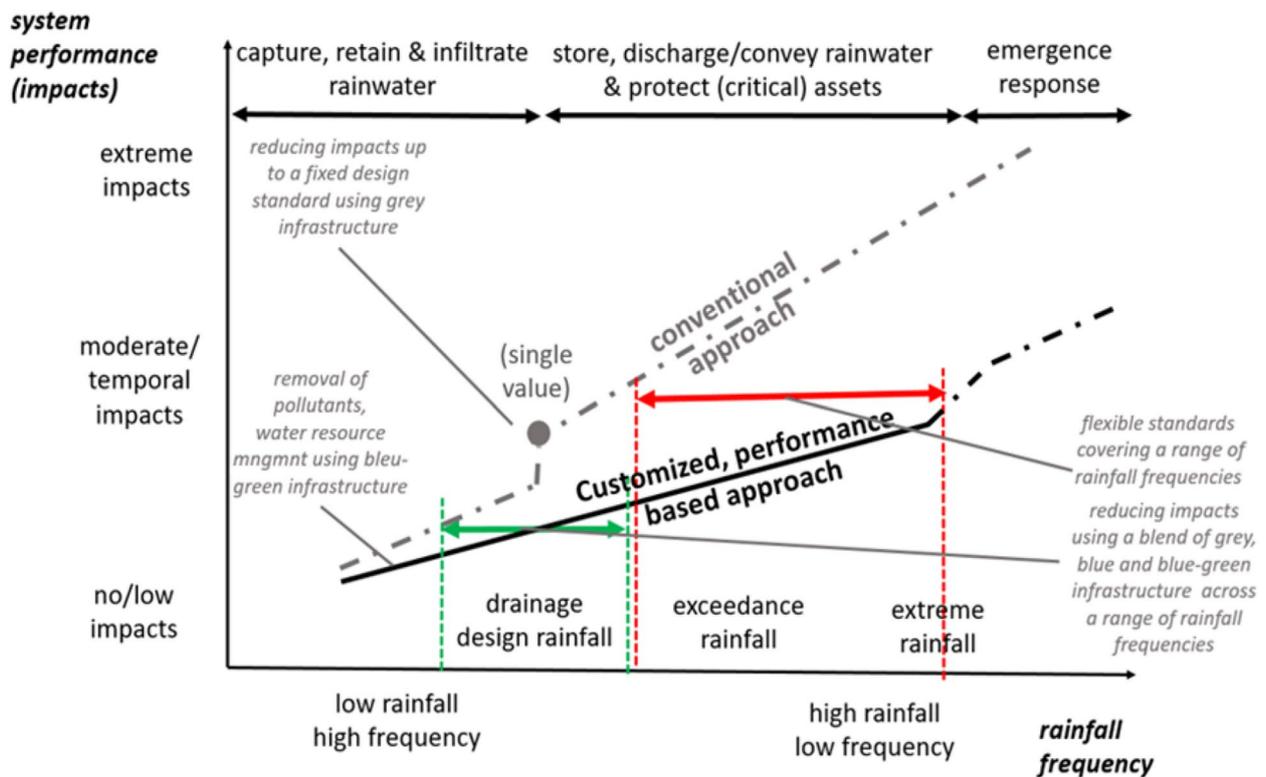


Fig. 1 This transition from a single and static standard (dotted line) to multiple, performance-based (solid line) indicators following 3PA (Zevenbergen, 2021)

water management through decentralized, nature-based solutions. The Technical Design Domain of 3PA aligns with WSUD's emphasis on ensuring that urban infrastructure efficiently accommodates stormwater, reducing peak runoff and improving drainage capacity. While the Extreme Domain of 3PA explicitly focuses on managing severe flood events, WSUD does not emphasize extreme events as a primary objective. However, WSUD strategies do support flood resilience through measures such as flood retention basins, floodable public spaces, and multifunctional urban landscapes, which provide emergency water storage during extreme rainfall events.

2.2 Sponge city standards and 3PSPa design requirements

The Sponge City regulations, which require cities to absorb 70% of annual rainfall and mandate that over 80% of urban areas meet these targets by 2030, primarily focus on annual precipitation volumes. They do not account for short-duration peak rainfall events, which can cause severe urban flooding. Relying solely on annualized targets is insufficient for addressing extreme rainfall scenarios to mitigate pluvial flood risks.

To strengthen urban water management, the General Office of the Ministry of Housing and Urban-Rural Development (MoHURD) issued recently (2024) a partially revised draft of the national standard "Code for Urban Wastewater and Stormwater Engineering Planning" [16]. This draft aims to update existing guidelines by enhancing urban wastewater and stormwater management practices, with a strong emphasis on improving infrastructure planning and promoting sustainable water resource utilization. A significant improvement is the increased focus on pluvial flood resilience, ensuring that urban drainage systems effectively balance water retention and controlled discharge during extreme rainfall event.

The Three-Point Sponge Policy Approach (3PSPa) has recently been introduced as a design framework to integrate new insights from the 3PA—such as balancing water storage and discharge—into the Sponge City Concept (SCC) guidelines. This approach seeks to strengthen urban resilience against extreme rainfall (pluvial flooding) while also addressing riverine and coastal flooding, thereby promoting a more comprehensive and integrated application of the Sponge City Concept (SCC). The 3PSPa framework incorporates six key design requirements. These requirements have been formulated under the China-Europe Cooperation on Sponge Cities (CECoSC) initiative, which operate as part of the China-Europe Water Platform (CEWP) and are inspired by the design principles of WSUD (CEWP, 2021).¹ These requirements are:

1. Design for all types of floods and droughts – Use water as a steering principle, accounting for extreme scenarios.
2. Embrace multifunctionality and nature-based solutions (NBS) – Ensure water serves multiple functions, such as flood control, recreation, and ecological support.
3. Work across spatial scales – Apply water-sensitive design from individual blocks to entire catchments.
4. Align short-term actions with long-term aspirations.
5. Integrate water management into the broader urban landscape – Consider interactions with transportation, energy, housing, and green spaces.
6. Foster local knowledge and expertise – Incorporate the perspectives and needs of various stakeholders.
7. Seize opportunities – Leverage renewal and maintenance projects to transform conflicting requirements into synergies for more effective water management. This includes integrating GGI interventions into existing urban upgrades, repurposing underutilized spaces for stormwater management, and aligning economic, social, and environmental objectives to maximize long-term benefits.

These key requirements serve as both the foundation for the design process underlying 3PSPa and a framework for evaluating its outcomes, ensuring that its core objectives are effectively achieved. These objectives include (i) maximizing benefits in daily conditions while minimizing risks from rare, high-impact flood events, and (ii) integrating short-term actions with long-term transformation to enhance resilience and adaptive capacity.

2.3 The 3PSPa design process

Currently, no standardized design process has been defined for 3PSPa. To address this gap, we have developed a step-by-step design framework that effectively aligns with the two core objectives of 3PSPa as mentioned above.

This design process builds upon the principles of Water Sensitive Urban Design (WSUD) and the Adaptive Pathways Approach (APA) and is structured around five key steps. These steps, illustrated in Fig. 2, include:

1. Assessing the current situation and resilience gaps, identifying vulnerabilities and opportunities for intervention.
2. Envisioning a future that balances social, economic, environmental, and technological considerations, ensuring a holistic and adaptable approach.
3. Identifying short-term interventions that address immediate risks while maintaining flexibility for future adjustments.

¹ CEWP (2021). Policy Report on China-Europe Cooperation on Sponge Cities (CECoSC). China-Europe Water Platform (CEWP). Accessed December 2021

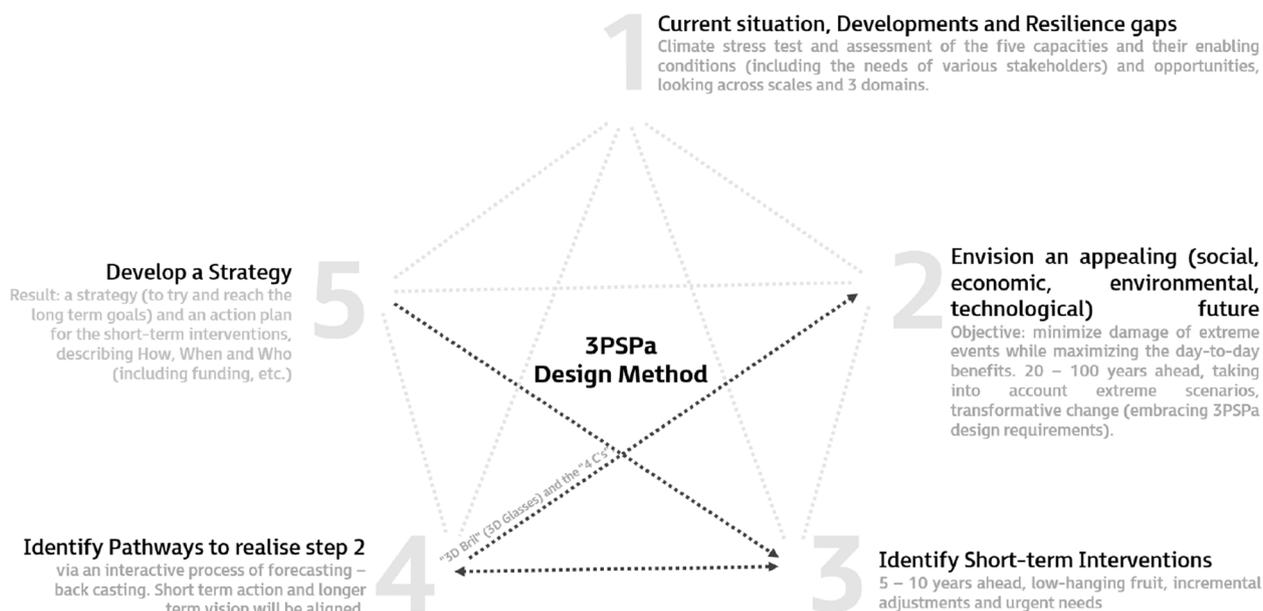


Fig. 2 5 steps of the 3PA design process

4. Defining pathways to achieve long-term goals through forecasting and backcasting, enabling proactive and adaptive planning.
5. Developing a strategy that integrates both short-term actions and long-term transformation, ensuring a cohesive, forward-looking approach to flood resilience.

By structuring the 3PSPa design process in this way, we provide a design framework that enhances urban resilience and water-sensitive planning. This sequential representation emphasizes the progressive nature of the process and illustrates how the steps are interlinked rather than strictly linear, highlighting the importance of continuous feedback loops, stakeholder engagement, and adaptation.

3 Methodology

This section describes the methodology which consists of two parts: the case study selection and description and the methods used underlying the 5 steps of the 3PSPa design process.

3.1 Case study selection and description

Zhengzhou is located in the Central China Plains, between the Yellow and Huai River basins. The late twentieth century saw rapid urban expansion in the city [24]. Positioned on the southern bank of the Yellow River, Zhengzhou spans 7,446 km² and is home to over 12 million people. The city experiences a humid subtropical climate with distinct seasons and is particularly vulnerable

to weather-related risks, including flash floods during the rainy summer months.

Zhengzhou was selected as the case study due to its exposure to recent extreme flood events, such as the 2021 “7.20” flood, and its prominent role as a vanguard city of the Sponge City Program. Zhengzhou has implemented Sponge City projects across the city and received substantial national financial support (up to \$80 million) (ref). The city is highly vulnerable to both pluvial and riverine flooding, and its continued urban expansion and development further amplify these challenges. These features make Zhengzhou a highly relevant candidate for evaluating the potential of the 3PSPa framework in enhancing urban flood resilience (see Fig. 3).

In July 2021, Zhengzhou experienced an extreme flood event with an estimated return period of 1,000 years. The city received over 200 mm of rainfall within a single hour, and the total precipitation over a 72-h period exceeded 600 mm, far surpassing historical records. The disaster resulted in more than 300 fatalities and caused widespread damage to buildings, infrastructure, and transportation networks. In response, the Chinese government launched a large-scale rescue and recovery effort, mobilizing emergency services, military personnel, and extensive financial resources for relief and reconstruction. The recurrence of severe flooding in Zhengzhou has underscored the urgent need to reassess existing policies and practice on disaster preparedness and resilient infrastructure.

Within the city of Zhengzhou, two contrasting case study areas (referred to as B1 and B2) were selected at



Fig. 3 Location two case study areas B1 and B2 (right)

the district level based on their distinct characteristics. B1 represents a modern, low-density urban area, while B2 is the Shangdu Historical and Cultural District, a densely constructed, older district in Zhengzhou’s historic city core (see Fig. 4).

B1 comprises an area with modern urban buildings with low building coverage (7%) and high-rise structures, creating ample public space (33% of the total area). Its location and design attract a predominantly young population, reflected in the public space design. Water is primarily managed along the island’s perimeter (37% of the area). The area is low-lying. B2 is a densely

built, historic district with limited public spaces located up streams of B1.

3.2 The 5 steps of 3PSPa

Steps 4 and 5 of the 3PSPa methodology fall beyond the scope of this study, as they involve extensive stakeholder engagement, consensus-building, and close alignment with Zhengzhou’s existing urban planning policies and frameworks. These steps necessitate iterative consultation processes with local communities, city planners, policymakers, and technical experts to

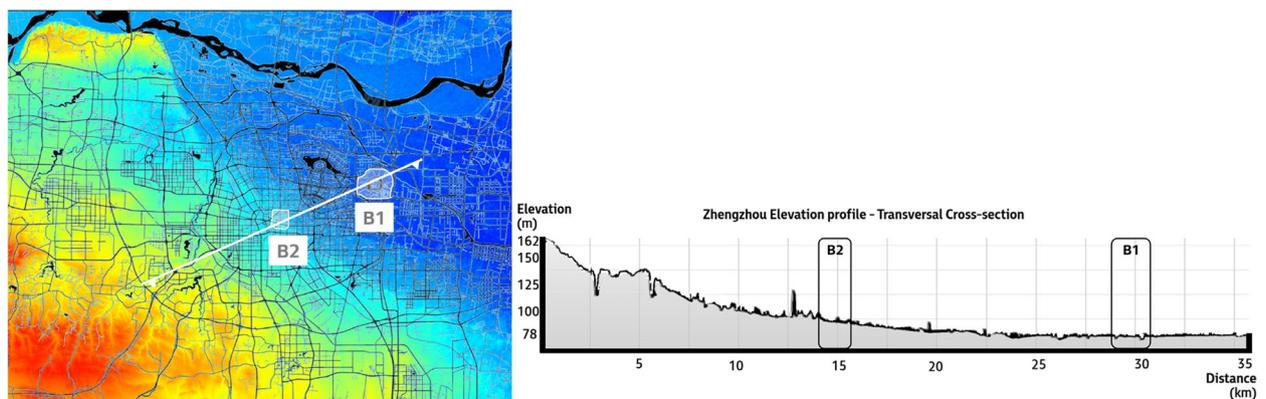


Fig. 4 Topography and elevation profile of B1 and B2 within the urban area

develop detailed designs and implementation strategies tailored to local contexts (see Table 1).

4 Results

4.1 Step 1—Assessing the current situation and resilience gaps

4.1.1 Expert and community perspectives

Interviews with experts and local residents revealed significant concerns about the post-2021 flood response in Zhengzhou, particularly regarding the prioritization of grey infrastructure (e.g., reinforcing levees, expanding drainage pipes) over nature-based solutions (NBS). Zhengzhou's flood response has leaned heavily on grey infrastructure, raising concerns about long-term sustainability. Nature-based solutions remain underutilized, despite expert recommendations for a catchment-wide, adaptive, and community-driven approach. Implementation challenges include conflicts with traditional engineering approaches, limited public awareness, and fragmented planning efforts.

4.1.2 Spatial analysis

The results of the spatial analysis are summarized in Table 2 and Fig. 5. B1 and B2 exhibit distinct spatial characteristics that influence their flood resilience and urban functionality (see Table 2).

A comparison between B1 and B2 reveals significant differences in impermeable surfaces, runoff potential, building density, and population exposure, all of which influence flood risk and resilience. B1 has a 50% impermeable surface with a runoff coefficient of 0.7, while B2 exhibits a lower level of permeability (20%) and a runoff coefficient of 0.9. This suggests that B2 has a greater tendency for surface water accumulation due to reduced infiltration capacity, making it more susceptible to pluvial flooding during heavy rainfall events. In terms of building density and land use, B1 maintains a low-density urban form, with only 7% building coverage, allowing for greater permeability and potential flood mitigation strategies, such as green spaces and water retention areas. In contrast, B2 is significantly more built-up, with 28% building coverage, reducing the availability of open spaces for water absorption and drainage. The higher density of built structures in B2 further exacerbates flood risks, as stormwater runoff has limited pathways for natural infiltration. Additionally, B2 is both larger and more densely populated than B1. With a total area of 3.77 million m² and a population of 526,000, B2 experiences higher infrastructure demands and greater exposure to flood-related hazards. In comparison, B1 covers 2.36 million m² and accommodates 300,000 people, resulting in lower urban pressures and greater spatial flexibility for flood adaptation measures.

In conclusion, B1's more open and permeable urban layout provides better flood resilience, making it inherently less prone to severe flooding. Meanwhile, B2's denser and more impermeable urban fabric increases its flood vulnerability, necessitating targeted interventions to improve stormwater management, enhance water retention, and integrate sustainable drainage solutions.

4.1.3 Effectiveness of Sponge City pilot projects

A preliminary assessment of the effectiveness of a selection of Sponge City pilot projects which have been exposed to the 2021 flood (including B1 and B2) suggests that their placement does not fully align with the city's most flood-prone areas (see Figure 6). Severely flooded areas (darker blue regions) are often outside the pilot intervention zones, raising concerns about whether these projects are effectively targeting high-risk locations. Moreover, major flood-prone zones correspond to natural watercourses, depressions, and urban lowlands, indicating that topography plays a critical role in the flood distribution and depth. For B1 which is situated in a flood-prone zone, the water depths appear to be lower, suggesting potential mitigation effects, such as terrain elevation, in this location. However, the limited spatial coverage of these projects indicates that their impact on flood reduction is limited.²

4.1.4 Hydrology and hydraulic analysis

B1: Downstream, Elevated Island Design with Strong Flood Resilience B1 receives cumulative discharge from other sub-catchment cells, leading to higher water volumes compared to B2. Simulated flood maps indicate water levels rise from 0 to 2.5 m during extreme flood events. B1's urban design consists of an elevated island structure and robust building designs which have been effective in minimized damage during the 7:20 flood, with limiting impacts on localized street flooding. Hence, B1 complies with the Three-Point Approach (3PA) with respect to the Extreme Domain as it is designed to handle extreme rainfall. However, its day-to-day water management functions remain underutilized, indicating a disconnection between design intentions and practical implementation. Although public spaces are present, they are not designed for stormwater retention or detention, preventing full integration of Sponge City functionalities and limiting their effectiveness in enhancing urban water resilience (see Fig. 7).

² [1] Data collected from the Map of flood depth in Zhengzhou presented in the online article "Discovery of the Recent Zhengzhou urban flood disaster — Modelling with Open Source data". https://www.linkedin.com/pulse/discovery-recent-zhengzhou-urban-flood-disaster-modelling-open-source-?trk=organization-update-content_share-article

Table 1 Provide a brief overview of the activities and methods used for each step of the 3PSPa design process

Step 3PSPa	Activity/methods
<p>Step 1 <i>Assessing the current situation and resilience gaps, identifying vulnerabilities and opportunities for intervention</i></p>	<p>Semi-structured Interviews: Interviews were conducted with nine stakeholders, including local residents affected by the 2021 flood and Sponge City (SC) experts, to assess the 2021 extreme flood impacts on residents and infrastructure, as well as the perceived effectiveness of existing flood mitigation measures. The purpose of the interviews was to assess the impacts of the flooding on residents and local infrastructure. Qualitative and semi-quantitative information provided by residents on flood locations and water depths was also used to evaluate the plausibility of the hydraulic modelling results.</p> <p>Field Visits: Identify the measures taken by the city after the 2021 flood.</p> <p>Document Analysis: Review policy documents, planning reports, and technical guidelines related to flood risk management, urban development and Sponge City projects in Zhengzhou.</p> <p>Spatial Analysis: Utilize GIS and remote sensing data to analyze the city's topography, drainage network, and land use patterns.</p> <p>Hydrological Modelling: Employ hydrological models to simulate flood scenarios and assess the effectiveness of different design interventions. 2D Flood Model: A 2D flood model was developed using open-source SRTM plus elevation data (30 m x 30 m grid). Empirical data from flood observations were integrated with the model. Information from local community interviews was used to check the plausibility of modelling results; this information was not detailed enough to be fully used for model validation.</p> <p>Macro-scale Analysis: Examine the broader context of the Yellow and Huai River basins, including their flood control strategies and inter-basin coordination.</p> <p>Meso-scale Analysis: Analyze the city's topography, drainage network, historical flood data, and existing flood mitigation measures.</p> <p>Micro-scale Analysis: Investigate two contrasting blocks within Zhengzhou, a modern, low-density development (B1) and an older, densely populated area (B2), to understand their specific flood vulnerabilities and opportunities for intervention.</p>
<p>Step 2 <i>Envisioning a future that balances social, economic, environmental, and technological considerations</i></p>	<p>Vision Development (Block Level): Vision exercises and scenario planning. Create long-term visions (20–100 years) for flood resilience in B1 and B2, incorporating 72 h self-sufficiency, minimizing extreme event damage, and maximizing day-to-day benefits.</p> <p>Vision Development (Meso Scale): Extrapolation of existing trends and design principles, scenario planning. Envision fully functional Sponge City by 2030, with interconnected pilot areas.</p> <p>Vision Development (Macro Scale): Extrapolation of existing trends and design principles, scenario planning (implied). Envision the city integrated into a major ecological corridor by 2122, restoring green-blue connections and implementing "Retain, Slow, Adapt" strategies.</p>
<p>Step 3 <i>Identifying short-term interventions</i></p>	<p>Intervention Identification (Block Level): Expert judgment, brainstorming, and prioritization. Identify "low-hanging fruit," incremental adjustments, and urgent needs addressable within 5–10 years for B1 (Standalone Proposal) and B2, considering 72 h self-sufficiency during extreme events for both cases.</p>
<p>Step 4 <i>Defining pathways to achieve long-term goals</i></p>	<p>Pathway Development (Block Level): Backcasting and strategic planning. Develop pathways linking short-term interventions to the long-term vision for each block, differentiating short-term and long-term actions and sequencing implementation, considering Block's characteristics.</p> <p>Pathway Development (Meso and Macro Scale): Backcasting and strategic planning. Develop pathways linking short-term interventions to the long-term vision at the city and catchment level.</p>
<p>Step 5 <i>Developing a strategy that integrates both short-term actions and long-term transformation</i></p>	<p>Strategic Synthesis: Combine findings from previous steps to create a comprehensive flood resilience strategy.</p> <p>Framework Development (City-level): Development of a multi-scale, multi-temporal framework. Articulate an overall strategic framework integrating catchment-level planning, Sponge City implementation, community engagement, data improvement, multifunctionality, and adaptive management.</p>

Table 2 Comparison of key-features of B1 and B2

	B1	B2
Impermeous surface ratio*	50%	80%
Estimated runoff coefficient	0.8	0.9
% Buildings	7%	28%
Total area (m2)	2.400.000	3.800.000
Population	300000	526000

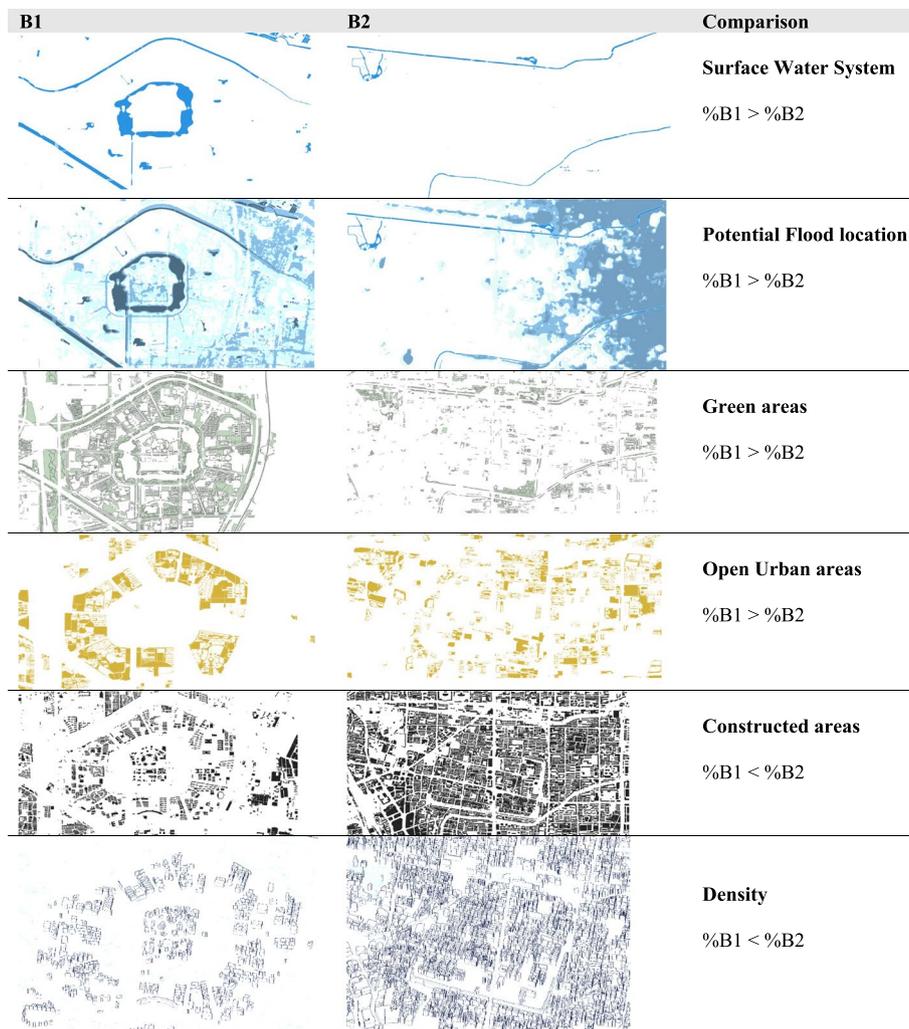


Fig. 5 Spatial analysis: comparison of B1 and B2

B2: High-Density, Flat Terrain with Limited Flood Resilience B2’s urban layout is dense, with 30% building coverage and only 18% urban open space. A topographical analysis (see Fig. 8) reveals that major flood flows align with terrain gradients, following the direction of existing road infrastructure and accumulating at the lowest-lying

areas. Several depressions act as water retention pockets during heavy rainfall, yet most of these depressions have impermeable surfaces, limiting the flood retention capacity. B2 suffered extensive damage during the 7:20 flood, leading to significant human loss and widespread infrastructure failures, particularly affecting Metro Line 5. Despite the severity of these impacts, no substantial flood mitigation measures have been implemented in

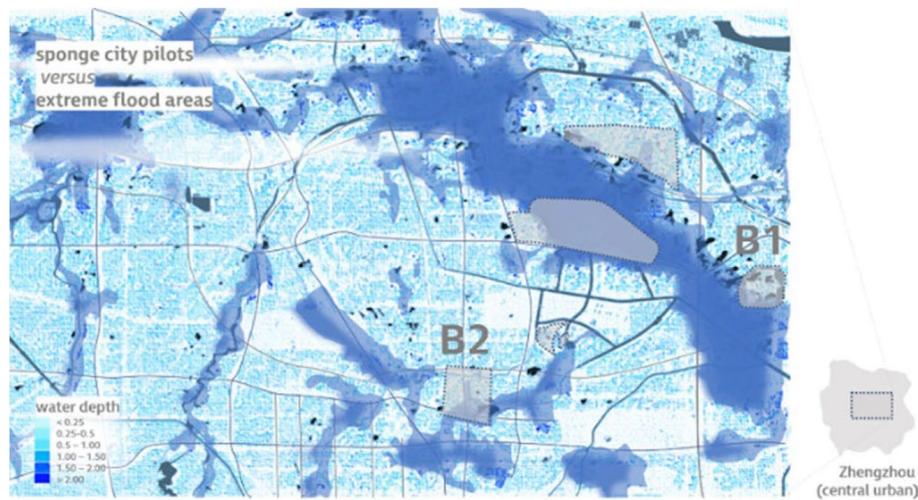


Fig. 6 Spatial relationship between Sponge City pilot projects (dotted lines) and extreme flood areas in Zhengzhou. B1 and B2 are indicated. The water depth legend at the bottom left categorizes flood severity, with darker blue shades indicating deeper floodwaters (> 2.0 m) and lighter shades representing shallower flooding (< 0.25 m). (source: data provided by the Yichang Environmental Technology Company)



Fig. 7 Topography, and 3D cross sections of the hydrologic dynamic during extreme flood in B1

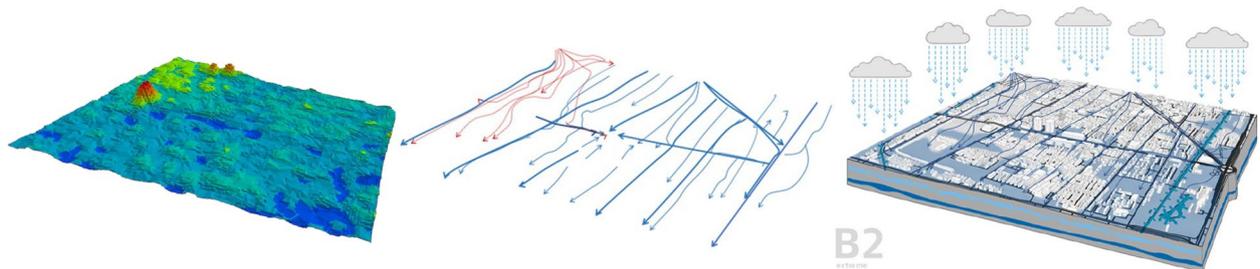


Fig. 8 Topography, water flows directions – blue generated within the area and red from upstream –, and 3D cross section of the hydrologic dynamic during extreme flood in B2

this area since the flood. Sandbags remain the primary defense at subway entrances, while mitigation efforts remain fragmented with minimal integration of nature-based solutions or sustainable drainage systems, leaving the area highly vulnerable to recurrent flooding. The absence of proactive interventions reveals a critical gap

in the capacity of the city government to respond more comprehensively and structurally requiring a long-term resilience strategy to prevent future disasters. This strategy should encompass enhanced drainage infrastructure, nature-based solutions, flood-resistant building designs, the integration of roads as flood conveyance pathways,

and a robust early warning system to improve urban flood resilience.

In terms of Three-Point Approach (3PA) compliance, B2 does not comply with the extreme domain, as it lacks adequate protective measures against severe flood events, reinforcing the need for a more resilient and adaptive flood management strategy. Similarly, day-to-day water management in public spaces remains insufficient, as the implementation of nature-based solutions (NBS) appears to be minimal.

4.2 Step 2—Vision

This section outlines the envisioned future for Zhengzhou, specifically focusing on the contrasting case studies of B1 and B2, and aligning with the principles of the 3PA’s second step: envisioning an appealing future. This future aims to minimize the damage caused by extreme flood events while simultaneously maximizing the day-to-day benefits for residents, the environment, and the city’s overall functionality, projecting 20 to 100 years ahead. The vision addresses multiple scales (micro/block, meso/city, macro/catchment) and time horizons (short-term: 2035, long-term: 2100-2125). During this step, representatives from local communities were engaged, and experts from academia and the municipality were consulted for input and feedback.

4.2.1 Block-level vision

B1 (New, Low-Density) The vision for district B1 builds upon its existing advantage as a relatively elevated area within a predominantly low-lying downstream region. It aims to evolve into a self-reliant and highly resilient community, capable of withstanding extreme flood events and functioning as a regional resource hub focused on water detention and retention. This resilience extends to critical infrastructure, allowing B1 to independently

sustain essential services, such as energy, potable water, food, accessibility, and communication, for a few days during and after extreme conditions. Public spaces are planned as multifunctional assets, serving as urban water buffers during periods of heavy rainfall and flooding, while simultaneously offering recreational opportunities and ecological benefits during everyday conditions.

Existing structures are adapted to serve as “safe havens”, providing refuge not only for B1 residents but also for those from district communities, further strengthening its role as a regional hub. The integration of ecological features, such as natural islands and green roofs, enhances biodiversity and contributes to overall environmental sustainability, providing additional flood buffering capacity. This vision leverages the area’s predominantly young population and their needs, shaping public spaces to be both functional and aesthetically pleasing. B1 becomes a model of integrated water management, demonstrating how new developments can be designed for both extreme resilience and enhanced daily living. The exploration of innovative infrastructure solutions, such as alternative systems for elevating arterial roads, further exemplifies the forward-thinking approach embedded in this vision (see Fig. 9).

B2 (Old, High-Density) B2’s vision is to serve as a catalyst in transforming traditional grey road infrastructure into a thriving green-blue urban network throughout the city. This transformation will be achieved through a strategy of incremental adaptation, taking small, deliberate steps, and by leveraging opportunities that emerge from ongoing urban renewal and maintenance efforts. Recognizing the limited space and high building density (30% of the area, with only 18% dedicated to urban open spaces), the vision focuses on creatively integrating water management into the existing urban fabric, focusing on conveyance. Streets are reimagined as multifunctional spaces, serving as temporary water networks during periods of high rainfall, effectively conveying stormwater and reducing flood



Fig. 9 Long-term vision proposal for B1: regional hub

risk in a cost-effective manner, where road infrastructure deliberately functions as part of a drainage network. Critical infrastructure and buildings are elevated where possible and feasible, either through retrofitting existing structures or incorporating raised platforms in new constructions, protecting essential services and reducing damage from floodwaters in particular in the lowest parts of B2. Green infrastructure, including rain gardens, bioswales, and green roofs, is strategically integrated in small pockets, to improve infiltration, reduce runoff, and provide localized amenity benefits. Existing sports fields are optimized to function as “sponge” underground storage areas, significantly increasing water retention capacity during exceedance and extreme events. The vision also includes the renaturalization of existing canals and the creation of sponge parks, expanding floodplains and providing valuable green spaces for the community, particularly beneficial for the area’s predominantly elderly population. Community education and emergency response planning are integral components of this vision, fostering a culture of preparedness and resilience. This vision for B2 acknowledges the challenges of

retrofitting an older, dense urban area but emphasizes the potential for significant improvements through a combination of strategic interventions and community engagement, transforming a vulnerable area into a more resilient and liveable district. The pre-existent dike from Shang Dynasty, is part of the long-term vision, diverting the upstream flow (see Fig. 10).

4.2.2 Meso-scale (city-catchment) vision

By 2035 A fully functional Sponge City, successfully realizing the formal goal of Sponge City Construction (SCC), hinges on the effective implementation of 3PSPa across numerous future Sponge City projects. As these projects gradually interconnect through an expanding network of green-blue infrastructure, a resilient urban water management system emerges. A key guiding principle is to maximize water retention in upstream areas while integrating adaptive measures in lower-lying regions to effectively manage excess water. Over time,

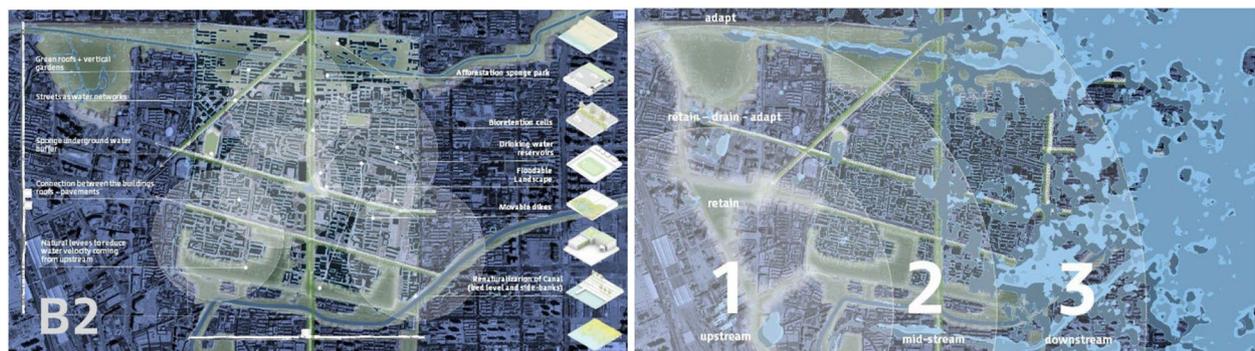


Fig. 10 Long-term vision of B2: from the district scale to upscaling the NBS to the surroundings



Fig. 11 Long-term vision of B2: from the district scale to upscaling the NBS to the surroundings

a network of urban green drainage corridors naturally takes shape as roads, gutters, and drainage systems are strategically designed within urban renewal efforts to enhance stormwater management (see Fig. 11).

4.2.3 Macro-scale (catchment) vision

By 2125 At the Macro-scale (catchment level), the city is envisioned to be fully integrated in a major ecological corridor, with restoration of connections between the green and blue fragments. The vision embraces the catchment acting as a “sponge”, applying three key strategies:

- Retain: Implementing water retention strategies upstream, such as wetland forests and headwater drainage management.
- Slow: Employing measures to slow water flow mid-stream, including floodplain wetland restoration and riparian woodland establishment.
- Adapt: Adapting to water downstream through managed realignment, amphibious infrastructure, and other strategies to accommodate floodwaters (see Fig. 12).

4.3 Step 3—Short-term interventions

This section details the proposed interventions for areas B1 and B2, distinguishing clearly between short-term, readily implementable actions (Step 3), and pathway required to achieve the envisioned future (Step 4). As previously noted, Step 4 involves detailed research, planning and stakeholder engagement, placing it beyond the scope of the current study.

4.3.1 B1

For B1, a two-tiered approach is proposed, differentiating between immediate, self-contained actions and a more comprehensive, long-term strategy. The short-term interventions focus primarily on achieving a few days self-reliance for the island during extreme flood events. These represent incremental adjustments and address urgent needs related to essential services. This system incorporates both a semi-centralized storage facility (a large, natural square) and decentralized storage at the building level. Concurrently, the main access road to the island will be designed for temporary elevation during extreme flood events, ensuring continued connectivity with the rest of the city (see Fig. 13). The existing subway station entrance will be elevated by +0.30 m to protect this critical infrastructure. Furthermore, energy distribution systems will be flood-proofed by locating essential components above the flood protection level, specifically from the second pavement upwards. Finally, amphibious



Fig. 12 Long-term vision of B2: from the district scale to upscaling the NBS to the surroundings

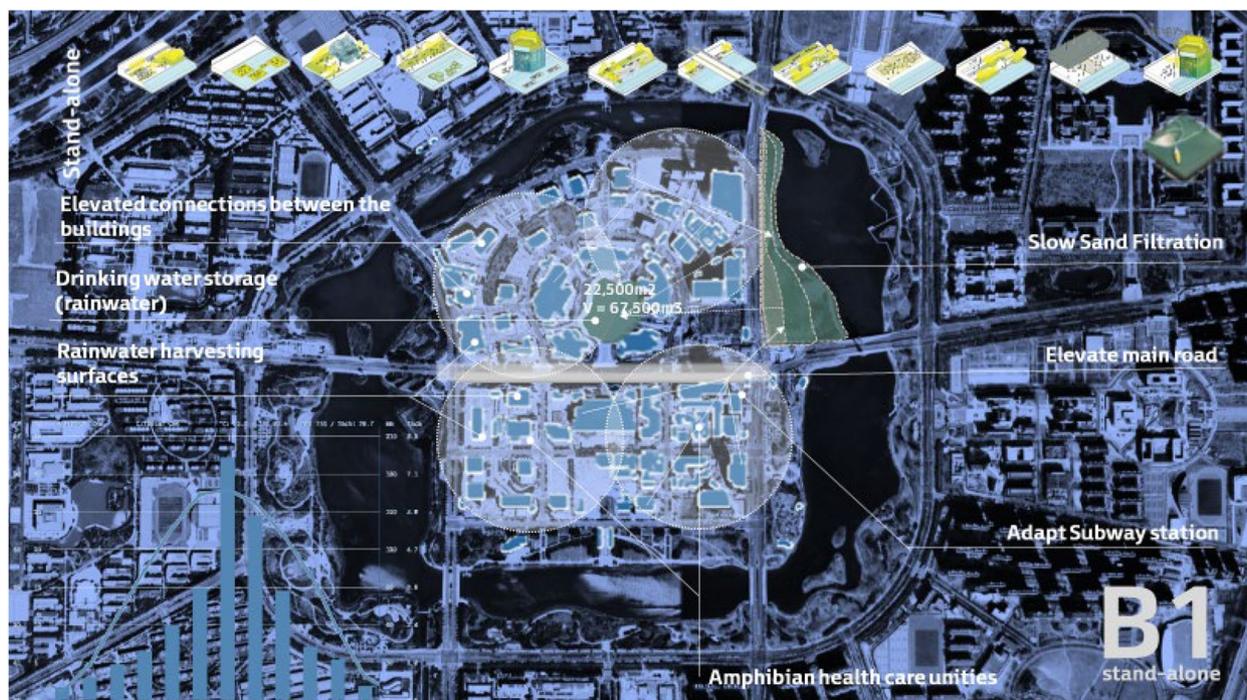


Fig. 13 Stand alone schematic proposal for B1, masterplan and axonometric cross-section

mobile health units, including medical drones and food delivery capabilities, will be deployed to ensure access to essential health services and supplies within a 250-m radius of every household.

4.3.2 B2

For B2, the interventions are driven by the constraints of a densely populated, older urban area with limited space. The primary focus is on utilizing streets as temporary water networks, a cost-effective approach to manage stormwater runoff, particularly in areas where installing new flood conveyance canals is unfeasible. This strategy enhances daily runoff management, provides conveyance capacity during exceedance events, and serves as an emergency drainage system during extreme rainfall. Where possible, buildings and critical infrastructure will be elevated, either through retrofitting or incorporating raised platforms in new constructions. This includes suspending energy distribution systems to protect them from floodwaters. Green infrastructure, such as rain gardens, bioswales, and green roofs, will be implemented in available spaces, however small, to enhance rainwater absorption, retention, and filtration. Existing sports fields will be optimized to function as “sponge” underground storage facilities, increasing their capacity to hold water during exceedance and extreme events (see Fig. 14).

4.4 Step 4—Preliminary pathways

The pathways outlined here represent preliminary actions for phased implementation, beginning with short-term, readily achievable actions and progressing towards transformative, long-term interventions. These preliminary pathways require further detailed study, validation, and extensive stakeholder engagement to ensure their feasibility and acceptance.

For B1, the envisioned “Regional Hub” builds upon initial interventions, positioning the area as a critical resource for the broader region. Preliminary long-term actions include creating community “safe havens” (to enhance preparedness/recovery), expanding green infrastructure along the lake, enhancing biodiversity through natural islands, implementing green roofs, and installing visual flood markers. Additionally, innovative road elevation solutions are proposed for further exploration.

For B2, the preliminary long-term pathway emphasizes continued incremental adaptation aligned with ongoing urban renewal. Proposed measures include the renaturalization of canals and creation of floodable landscapes, leveraging existing dikes to divert upstream flow and reduce downstream impacts, introducing amphibious health units, promoting building-level flood-proofing, and strengthening community education and emergency preparedness. The exploration of temporary, ephemeral solutions is also



Fig. 14 Proposed B2 under day-to-day, and extreme situation (top); B2 photocollage using the Shang Dynasty Levee as a dike to divert the flow from upstream during extreme rainfall, and underground water reservoir (bottom)

recommended. Potential spatial conflicts are considered through integrated and multifunctional design solutions.

Both pathways for B1 and B2 are interconnected with broader meso-scale (city-level) and macro-scale (catchment-level) strategies. Interventions in B1 and B2 may serve as catalysts for the city-wide adoption and integration of Sponge City principles by 2035, while the catchment-level vision extends towards achieving comprehensive, long-term resilience by 2050 or even beyond.

5 Conclusions and reflection

The catastrophic 2021 flood in Zhengzhou exposed critical vulnerabilities in the city’s flood resilience. This study applied the Three-Point Sponge Policy Approach (3PSPa) to assess Zhengzhou’s response and identify pathways for enhancing flood resilience. We examined two contrasting urban areas of Zhengzhou which were affected by the 2021 flood: B1, a newly developed low-density area, and B2, a high-density historical core. B1 exemplifies planned adaptation, where proactive flood resilience measures, including nature-based solutions and multifunctional urban spaces, can be integrated from the outset. In contrast, B2 requires an opportunistic approach, leveraging incremental urban renewal and maintenance activities to retrofit blue-green-grey infrastructure into a dense and constrained urban fabric.

This distinction highlights the necessity of balancing planned adaptation with adaptive, opportunistic planning, ensuring both long-term resilience and

immediate risk reduction. A key insight from this study is the importance of spatial and temporal integration in flood resilience planning. While short-term interventions, such as street-level water networks in B2, address immediate risks, they must be embedded within a long-term vision, such as the 2035 goal of achieving a fully functional Sponge City and beyond that time horizon of integrating Zhengzhou into a major ecological corridor.

The preliminary hydraulic model relied on open-source datasets, including rainfall records from the 20 July 2021 extreme rainfall event, SRTM Plus ground elevation data at 30 m resolution, and initial estimates of runoff coefficients. The limited availability and accessibility of field data reduced the reliability of the model outputs. However, the information gathered through the interviews enabled us to confirm the areas that experienced the most severe flooding.

The pathways presented in this study are preliminary, yet they highlight the need for scalable measures that progress from localized interventions to catchment-level strategies consistent with the “retain, slow, adapt” approach. Developing a fully integrated strategy for Zhengzhou’s flood resilience, however, lies beyond the scope of this paper. Further research and structured engagement with stakeholders will be necessary to refine and validate the proposed measures. This includes a more detailed assessment of required detention and sponge capacity at the block, city, and catchment scales, as well as the development of a more

reliable hydraulic model to evaluate intervention performance under extreme rainfall conditions. Such efforts will require far more detailed datasets, particularly on land elevation and land use.

Despite these limitations, the 3PSPa framework has shown considerable value as a structured, design-oriented methodology that supports the Sponge City Concept. By systematically identifying resilience gaps, exploring future scenarios, and generating context-sensitive solutions, the framework has strong potential to strengthen urban resilience, support integrated water management, and improve the liveability and sustainability of cities facing hydrological stress.

To build on this potential, the 3PSPa approach is currently being tested in collaboration with Chinese authorities through case studies in China and Europe. This work will produce practical guidelines and tools for applying the Three-Point Sponge Policy Approach to enhance resilience to climate change and extreme weather events.

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Authors' contributions

All authors contributed to the conceptualization and writing of this manuscript. Mila Avellar Montezuma, Chris Zevenbergen, and Frans van de Ven were responsible for the development of the methodological framework and case study analysis, providing expertise on urban flood resilience and the Three-Point Sponge Policy Approach. Zihang Ding, William Veerbeek, Gerald Corzo Perez, and Junguo Liu provided important insights and contributed to the overall analysis and discussion. All authors read and approved the final manuscript.

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Data availability

All data generated or analyzed during this study are included in this published article.

Declarations

Competing interests

Chris Zevenbergen serves on Advisory Board for Urban Lifeline and was not involved in the editorial review, or the decision to publish this article. The authors declare that there are no other competing interests.

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References

- IPCC (2021) Summary for policymakers. In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press
- Department of Economic and Social Affairs Population Division (DESAPD) (2018) World urbanization prospects: the 2018 revision. <https://population.un.org>. Accessed 15 November 2020
- Si Seneviratne, X Zhang, M Adnan, W Badi, C Dereczynski, A Di Luca, S Ghosh, I Iskandar, J Kossin, S Lewis, F Otto, I Pinto, M Satoh, SM Vicente-Serrano, M Wehner, and B Zhou (2021) Weather and climate extreme events in a changing climate. In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*
- Xiaona Guo, Jie Cheng, Chenglong Yin, Qiang Li, Ruishan Chen, Jiayi Fang (2023) The extraordinary Zhengzhou flood of 7/20, 2021: how extreme weather and human response compounding to the disaster. *Cities*, Volume 134, 2023, 104168. ISSN 0264–2751. <https://doi.org/10.1016/j.cities.2022.104168>
- Zevenbergen C, Fu D, Pathirana A (2018) Transitioning to sponge cities: challenges and opportunities to address urban water problems in China. *Water* 10(9):1230. <https://doi.org/10.3390/w10091230>
- Avellar Montezuma M (2023) Minimizing risks and maximizing benefits: 3PA and design integration for day-to-day, design, exceedance and extreme flood events. MSc thesis. Institute for Water Education IHE Delft
- Ka Shun Chan F, A Griffiths J, Higgitt, Shuyang Xu D, Zhu F, Tang Y, Xu Y, R Thorne C (2018) "Sponge City" in China—a breakthrough of planning and flood risk management in the urban context. *Land Use Policy*, ISSN 0264–8377. <https://doi.org/10.1016/j.landusepol.2018.03.005>
- Fratini CF, Geldof GD, Kluck J, Mikkelsen PS (2012) Three points approach (3PA) for urban flood risk management: a tool to support climate change adaptation through transdisciplinary and multifunctionality. *Urban Water J* 9(5):317–331. <https://doi.org/10.1080/1573062X.2012.668913>
- Balbi M, Lallemand D, Lim TN, Hamel P, Schmitt R, Win S (2021) Nature-based solutions for flood risk reduction: a probabilistic modeling framework. *One Earth* 4(9):1310–1321
- Berger A, and Guzmón AN (2018) Design for urban stormwater wetlands. MIT Norman B. Levental Center for Advanced Urbanism
- Gersonius B, Ashley R, Salinas-Rodríguez R, Rijke J, Radhakrishnan M, and Zevenbergen C (2016) Flood resilience in water sensitive cities: guidance for enhancing flood resilience in the context of an Australian water sensitive city. *Socio-Technical Flood Resilience in Water Sensitive Cities – Adaptation across spatial and temporal scales*. Cooperative Research Centre for Water Sensitive Cities
- Thorne CR, Lawson EC, Ozawa C, Hamlin SL, Smith LA (2018) Overcoming uncertainty and barriers to adoption of blue-green infrastructure for urban flood risk management. *J Flood Risk Manag* 11(S2):S960–S971
- Lerer S, Righetti F, Rozario T, Mikkelsen P (2017) Integrated hydrological model-based assessment of stormwater management scenarios in Copenhagen's first climate resilient neighbourhood using the three point approach. *Water* 9:883. <https://doi.org/10.3390/w9110883>
- Gan N, and Yeung J (2021) Record-breaking rains devastated central China, but there is little talk of climate change. CNN. Accessed 23 July 2021
- Ministry of Infrastructure and Environment Affairs, and Ministry of Economic (2009) National water plan (2016–2021). <https://www.government.nl/documents/policy-notes/2015/12/14/national-water-plan-2016-2021>
- General Office of MoHURD (2024) Notice of the General Office of the Ministry of Housing and Urban-Rural Development on soliciting public opinions on the national standard "Code for Urban Wastewater and Stormwater Engineering Planning"(partially revised draft for soliciting public opinions). https://www.mohurd.gov.cn/gongkai/zc/wjk/art/2024/art_17339_777759.html. Accessed 15 Jan 2025
- China-Europe Water Platform (2022) Policy guidance on China-Europe cooperation on Sponge Cities. <https://www.cewp.eu/sites/default/files/2023-01/CEWP%20PolGuidSpongeCities.pdf>

18. van de Ven FHM, Zevenbergen C, Avellar Montezuma M, Ding Z, Veerbeek W, Chen S (2024) The three-points sponge policy approach: toward an enhanced multi-level resilience strategy. *Front Water* 6:1361058. <https://doi.org/10.3389/frwa.2024.1361058>
19. Geldof DG, and Kluck J (2008) The Three Points Approach. Proceedings of 11th ICUD - international conference on urban drainage. 31 August–5 September, Deventer, the Netherlands : Tauw B.V. . English translation by Woutera Translations, Nijmegen
20. Geldof DG (2005) Coping with complexity in integrated water management. On the road to interactive implementation, Deventer, the Netherlands : Tauw B.V. . English translation by Woutera Translations, Nijmegen
21. Randall M, Jensen MB, van de Ven F, Zevenbergen C, Körber JH, Sun Z, Zhang S (2025) The three points approach (3PA) applied to two Chinese and four European cities for knowledge exchange on stormwater challenges and strategies. *Urban Water Journal*, 22(5), 526–536. <https://doi.org/10.1080/1573062X.2025.2490490>
22. Zevenbergen C (2021) Towards a performance-based approach for Sponge Cities [Presentation]. Presented at the China-Europe Water Platform Workshop, online, Accessed 15 March 2021
23. Wong THF, Brown RR (2009) The water sensitive city: principles for practice. *Water Sci Technol* 60(3):673–682. <https://doi.org/10.2166/wst.2009.436>
24. Cai E, Bi Q, Lu J, Hou H (2022) The spatiotemporal characteristics and rationality of emerging megacity urban expansion: a case study of Zhengzhou in Central China. *Front Environ Sci* 10:860814. <https://doi.org/10.3389/fenvs.2022.860814>

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