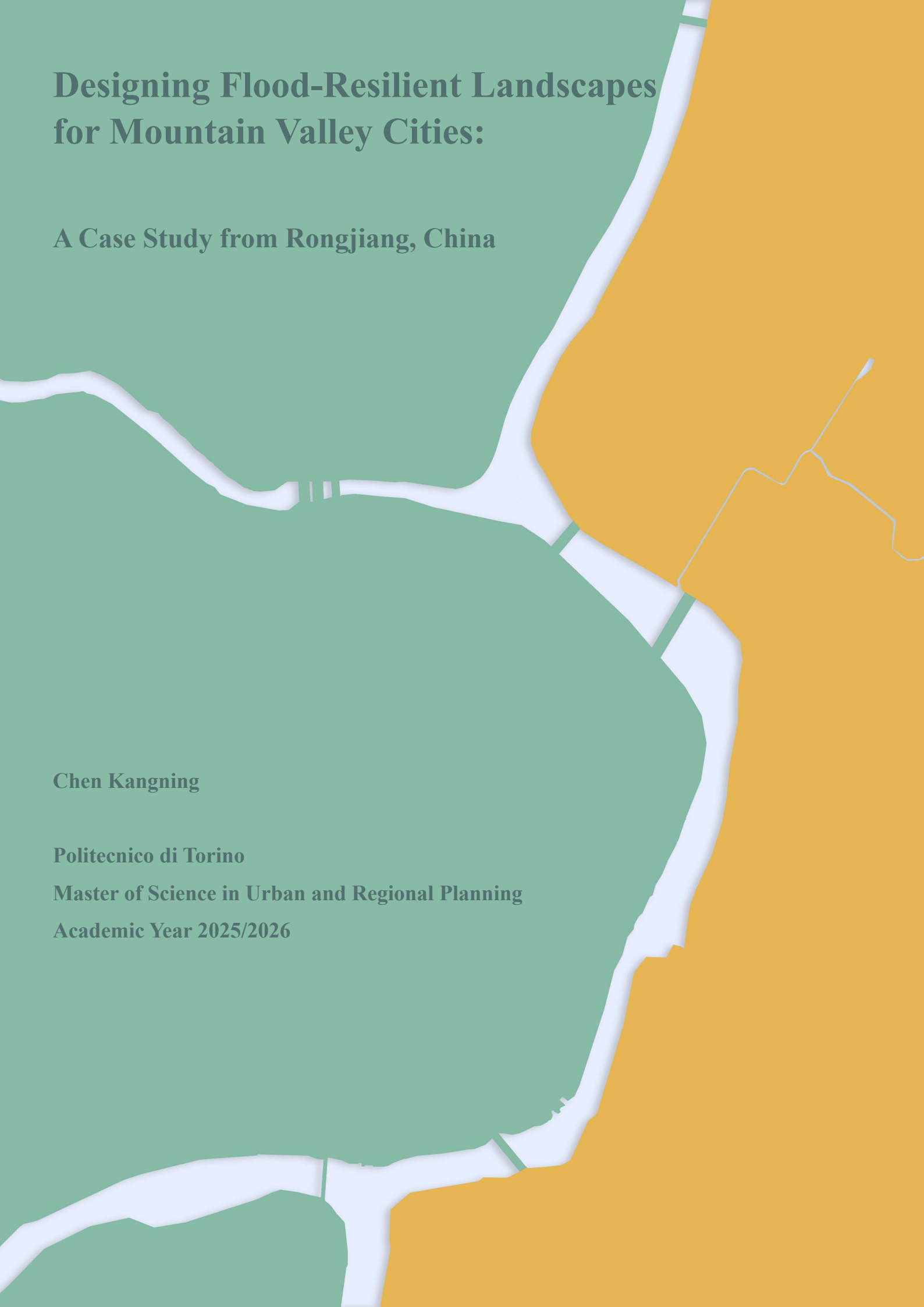
Designing Flood-Resilient Landscapes for Mountain Valley Cities:

A Case Study from Rongjiang, China



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Abstract

Against the backdrop of global climate change, extreme flood events are occurring with increasing frequency and intensity worldwide. In mountain valley regions, steep topography, rapid runoff concentration, and limited flood storage capacity allow intense rainfall to develop rapidly into destructive flash floods. Although mountainous and hilly areas account for approximately 70% of China's land area, existing research and planning practices have primarily focused on lowland floodplain cities. Consequently, relatively limited attention has been given to flood adaptation in mountain valley cities, where pluvial flooding and river flooding frequently occur simultaneously.

Rongjiang County, located in Guizhou Province, China, was selected as a representative case study because it is a typical mountain valley city situated at the confluence of the Duliu, Zhaihao, and Pingyong rivers. In June 2025, two extreme flood events within a single week inundated more than 80% of the urban area, exposing the limitations of conventional engineering-based flood management under increasingly severe climate conditions.

This study proposes an integrated landscape planning framework for flood adaptation in mountain valley cities through the case study of Rongjiang. The research combines hydrological analysis, GIS-based spatial analysis, planning assessment, and landscape planning to identify the key drivers of flood vulnerability and evaluate existing planning conditions. Based on these analyses, a multi-scale planning strategy is developed that integrates Blue-Green Infrastructure, adaptive riverfront landscapes, multifunctional floodable public spaces, and urban stormwater management within a coordinated spatial planning framework.

Rather than replacing conventional flood-control infrastructure, the proposed framework complements engineering measures with landscape-based adaptation to improve urban resilience, ecological connectivity, and public space quality. The study provides a context-specific landscape planning framework for mountain valley cities, offering transferable planning principles for flood adaptation in similar mountainous regions of China and elsewhere.

Keywords: *Mountain Valley Cities; Flood Adaptation; Flood Resilience; Blue-Green Infrastructure; Landscape Planning.*

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During the three years of study in Italy, I learned valuable knowledge and new perspectives in the field of urban and landscape planning, which provided a important foundation for the writing of this paper. The experience of living and studying in a foreign country not only broadened my horizons, but also taught me to deal with various challenges with a more independent and open mind.

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For me, the process of completing this thesis is not only a journey of academic exploration, but also a process of personal growth. It taught me patience and perseverance, and also helped me learn to face uncertainty and loneliness with a more calm and brave attitude. With the end of this chapter, I am not only grateful for the academic knowledge I have learned, but also deeply pleased with the self I have shaped during this journey.

Declaration of the generative AI:

During the preparation of this work the authors used Generative AI tools exclusively for editorial support, such as grammar correction, translations, paraphrasing suggestions, or improving readability.

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Introduction

Research Background

Climate change has fundamentally altered global hydrological patterns, leading to increasingly frequent, intense, and widespread flood events worldwide. According to the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report, heavy precipitation events and flood hazards are expected to become more common across most regions of the world as global warming intensifies (IPCC, 2023). Floods have become one of the most significant natural hazards affecting human settlements, infrastructure, and ecosystems worldwide, posing increasing challenges to urban safety, economic development, and climate adaptation (IPCC, 2023; UNDRR, 2024).

Despite these global trends, flood research and management have traditionally focused on large river floodplains and low-lying delta regions, resulting in relatively limited attention being given to mountainous areas. This research gap is particularly evident in China, where mountainous and hilly terrains account for nearly 70% of the national land area (Cao et al., 2022). Over the past decade, more than two-thirds of flood-related fatalities in China have occurred along small and medium-sized rivers in mountainous regions (Cao et al., 2022; Sun, 2023).

Mountain valley cities face unique flood challenges. Steep slopes generate rapid runoff concentration within minutes or hours following intense rainfall events. Narrow valleys limit natural flood storage capacity and force floodwaters into confined river channels, resulting in high flow velocities and elevated flood risks. At the same time, the limited flat land suitable for urban development is often concentrated within valley bottoms, which are also the areas most vulnerable to flooding. This creates an inherent conflict between urban development and hydrological processes (Benavides-Muñoz & Román-Aguilar, 2025; Liu et al., 2026; Cao et al., 2022).

Southwestern China, particularly Guizhou Province, represents a typical example of these challenges. Characterized by karst landforms, dense river networks, and numerous settlements located within narrow valleys, the region is highly susceptible to flash floods and mountain flood disasters (Wei et al., 2024; Wu & Gong, 2026; Ding, 2022). As extreme weather events become increasingly frequent and intense under climate change, flood disasters are no longer regarded as isolated events but rather as a “new normal” (Yuan et al., 2026). Consequently, conventional flood-control approaches that rely primarily on grey infrastructure are becoming increasingly insufficient. There is an urgent need to develop more adaptive and integrated strategies that combine engineering measures with ecological and landscape-based approaches (Oral et al., 2020; Zhang, 2026).

Rongjiang County, located in southeastern Guizhou Province at the confluence of the Duliu River, Pingyong River, and Zhaihao River, exemplifies the vulnerability of mountain valley cities to flooding (Han, 2001; Yuan et al., 2026). In June 2025, the county experienced two severe flood events within a single week. Approximately 80% of the urban area was inundated, more than 51,000 residents were displaced, and direct economic losses reached 1.35 billion RMB. Hydrological records from the Shihuichang Station documented a peak discharge of 11,400 m^3/s and a water level of 256.71 m, both the highest values recorded since 1958 and exceeding the local flood-control standard by 5.21 m (Yuan et al., 2026; Guizhou Provincial Hydrology Bureau, 2025). This disaster exposed the limitations of conventional engineering-based flood management in addressing the complex flood risks faced by mountain valley cities. Current flood management in Rongjiang remains largely engineering-oriented, relying on

levees, river regulation works, pumping stations, reservoirs, and drainage infrastructure (Han, 2001; Rongjiang County Government, 2025–2026; Wu, 2026). Although these measures improve hydraulic protection, they contribute relatively little to ecological restoration, multifunctional public space, or long-term urban resilience.

Landscape-based strategies, however, offer the potential to accommodate flood dynamics while simultaneously generating ecological and social co-benefits (Oral et al., 2020; Palazzo, 2019). Against this background, this study takes Rongjiang County as a representative mountain valley city to explore how flood-resilient urban landscape strategies can be developed under the constraints of complex flood processes and limited developable land. By integrating blue-green infrastructure, adaptive riverfront design, flood-responsive public spaces, and spatial planning principles, the research aims to establish a transferable framework for enhancing flood resilience, ecological performance, and urban livability in flood-prone mountain valley cities.

Research Problems

Although significant investments have been made in flood-control infrastructure, flood management in many mountain valley cities in China remains largely dominated by conventional engineering approaches. Structural measures such as levees, reservoirs, river channelization, pumping stations, and drainage systems are widely implemented to reduce flood risks (Zhang, 2026; Liu et al., 2026; Li, 2026). While these interventions improve flood protection standards, they primarily focus on hydraulic efficiency and flood conveyance. Moreover, many county towns located in China's mountainous river valleys have significantly lower levels of urban and economic development than those in lowland regions. In many cases, urban infrastructure and drainage systems remain outdated and have not kept pace with contemporary planning and climate adaptation requirements (Cao et al., 2022; Sun, 2023).

Consequently, flood management in these cities has historically prioritised engineering protection over ecological adaptation, spatial planning, and long-term urban resilience.

Rongjiang County reflects many of these challenges. Following the severe flood events of 2025, the local government initiated the Rongjiang County Urban Flood Control Capacity Enhancement Project, which includes levee reinforcement, river regulation works, drainage upgrades, pumping stations, and upstream flood-control facilities (Rongjiang County Government, 2025–2026). Although these measures strengthen the city's capacity to resist flooding, they remain predominantly engineering-oriented and therefore make only a limited contribution to ecological restoration, multifunctional flood storage, and long-term urban adaptation (Wu, 2026).

More importantly, the June 2025 flood exposed not only the physical limitations of conventional grey infrastructure but also the institutional and planning deficiencies that contribute to flood vulnerability in mountain valley cities. In Rongjiang, the Territorial Spatial Plan (2021–2035) identifies resilience as a strategic objective, yet these ambitions remain largely untranslated into binding land-use regulations and effective planning instruments (Rongjiang County People's Government, 2023). Flood-control projects are implemented largely as independent engineering interventions rather than as spatial planning instruments capable of guiding long-term urban adaptation (Rongjiang County Government, 2025). This disconnect between planning objectives, planning instruments, and engineering implementation—rather than the physical limitations of flood-control infrastructure alone—constitutes the central challenge addressed in this research.

Urban expansion and changing land-use patterns have further increased flood vulnerability. Extensive impervious surfaces, fragmented green spaces, poor connectivity between urban open spaces, and the ageing drainage system in the historic old town collectively contribute to severe pluvial flooding during extreme rainfall events (Zhang et al., 2023; Sun, 2023; Wu & Gong, 2026). Moreover, the interaction between river flooding and drainage system failure creates compound flood risks that cannot be adequately addressed by conventional engineering measures alone (Liu et al., 2026). When river levels exceed the elevation of drainage outfalls, stormwater cannot be discharged efficiently, resulting in prolonged inundation in low-lying urban areas. These conditions demonstrate that flood vulnerability in Rongjiang is determined not only by hydrological processes but also by the spatial organisation of urban development (Sun, 2023; Wu & Gong, 2026).

The riverfront areas, which serve as the city's first line of defence against flooding, currently lack adaptive flood-management strategies. Existing riverside spaces are often disconnected from the broader urban blue-green infrastructure network and are unable to perform multiple functions such as temporary flood storage, ecological restoration, stormwater management, and public recreation (Oral et al., 2020; Palazzo, 2019; Yu et al., 2015). Consequently, the riverfront currently functions primarily as a flood-defence corridor rather than as adaptive landscape infrastructure capable of integrating flood adaptation, ecological restoration, and public space.

More fundamentally, the limitations of flood management in Rongjiang are institutional as well as physical. The Territorial Spatial Plan (2021–2035) recognises resilience as a strategic planning objective and establishes flood risk control lines. However, these strategic ambitions have not been translated into effective planning instruments capable of guiding land-use decisions. There is no risk-based zoning, no development intensity control differentiated by flood hazard, and no binding mechanism for allocating blue-green infrastructure within flood-prone areas. Meanwhile, the flood-control enhancement project initiated after the 2025 disaster operates largely as an independent engineering intervention rather than as the implementation of a pre-existing spatial strategy (Rongjiang County Government, 2025–2026). This disconnect between planning objectives, planning instruments, and engineering implementation represents the institutional dimension of flood vulnerability that this research seeks to address.

The key challenge is therefore not simply to improve flood-control infrastructure, but to develop an integrated flood adaptation framework capable of linking spatial planning, flood governance, engineering measures, and landscape design. Such an approach should combine blue-green infrastructure, adaptive riverfront landscapes, and multifunctional public spaces to reduce flood risk while simultaneously improving ecological performance, urban resilience, and public space quality (Oral et al., 2020).

These research gaps lead to the central research question of this study: How can integrated urban flood adaptation strategies be developed for mountain valley cities by combining spatial planning, blue-green infrastructure, and adaptive landscape design to address both river flooding and pluvial flooding while enhancing ecological and social resilience?

Research Aim and Objectives

The aim of this study is to develop an integrated urban flood adaptation framework for mountain valley cities by combining spatial planning, blue-green infrastructure, adaptive riverfront landscapes, and multifunctional public spaces. Using Rongjiang County as a case study, the research seeks to enhance flood resilience by addressing the combined impacts of river flooding and pluvial flooding while improving ecological performance, urban livability, and long-term climate adaptability.

To achieve this aim, the study pursues the following objectives:

Objective 1, To investigate the flood characteristics and hydrological mechanisms of mountain valley cities, with particular attention to the interaction between river flooding, mountain runoff, and pluvial flooding.

Objective 2, To analyse the spatial characteristics, flood vulnerability, and existing planning and flood management conditions of Rongjiang County through hydrological, environmental, and urban spatial analyses.

Objective 3, To critically evaluate the limitations of the existing planning framework, governance structure, and engineering-based flood management system, and to identify opportunities for integrated blue-green infrastructure interventions.

Objective 4, To develop an integrated spatial planning framework for urban flood adaptation that combines flood storage, stormwater management, ecological restoration, and adaptive riverfront planning across multiple spatial scales.

Objective 5, To propose a landscape-based urban flood adaptation strategy for Rongjiang, integrating resilient riverfront landscapes, blue-green infrastructure networks, and multifunctional flood-adaptive public spaces.

Research Methodology

This study adopts a sequential mixed-method approach, and this approach integrates hydrological analysis, spatial analysis, planning and governance assessment, and landscape design together; the research was carried out under the conceptual framework formed by the literature review and comparative case studies, first, the study used published hydrological records, remote sensing data, and GIS-based spatial analysis to examine the hydrological characteristics and spatial distribution of flood vulnerability in Rongjiang, then, the study evaluated the existing spatial planning, flood-control measures, and governance mechanisms in order to identify current planning conditions and adaptation opportunities; on the basis of these findings, the study further translated the planning principles established in the conceptual framework into multi-scale landscape strategies, and these strategies include city-scale Blue-Green Infrastructure, adaptive river corridors, and site-specific flood-responsive interventions. (See Part II for the detailed research methodology.)

PART I - FLOODS AND URBAN MOUNTAIN CONTEXTS: THEORETICAL FRAMEWORK

01

Urban Flood Management: Evolving Visions and Approaches

1.1 From Flood Control to Flood Resilience

Flooding has long been one of the most significant natural hazards affecting urban areas (IPCC, 2023; UNDRR, 2024). Traditionally, flood management has relied on engineering-based approaches aimed at controlling water through structural measures such as levees, floodwalls, dams, pumping stations, and drainage networks. These grey infrastructure systems were designed to reduce flood probability by increasing hydraulic capacity and preventing floodwaters from entering urban areas. For decades, this resistance-oriented approach formed the dominant paradigm of flood risk management and played an important role in protecting rapidly urbanising cities (Godschalk, 2003; Ahern, 2011).

However, the effectiveness of conventional flood control has increasingly been challenged by climate change and rapid urbanisation (IPCC, 2023; Meerow et al., 2016). More frequent and intense rainfall events, together with expanding impervious surfaces, have increased both the frequency and severity of urban flooding. Many existing flood protection systems were designed according to historical hydrological records and predefined return periods, making them less capable of coping with unprecedented or compound flood events. Moreover, grey infrastructure often simplifies natural hydrological processes by rapidly conveying stormwater downstream, reducing infiltration, disconnecting rivers from floodplains, and transferring flood risks rather than reducing them (Ahern, 2011; Yin et al., 2021). These limitations have prompted a fundamental reconsideration of how cities should coexist with water (Ahern, 2011; Becker & Walz, 2025). Against this background, flood management has gradually shifted from a philosophy of flood resistance towards one of flood adaptation and resilience (Ahern, 2011; Davoudi, 2021). Rather than attempting to eliminate flooding completely, resilience-based approaches recognise flooding as an inevitable process that should be anticipated, accommodated, and managed. This conceptual transition reflects a broader change in disaster risk management, where uncertainty and future climate variability are incorporated into planning and design instead of relying solely on engineered protection.

The concept of resilience was first introduced by Holling (1973), who defined ecological resilience as the capacity of a system to absorb disturbances while maintaining its essential structures and functions. Since then, resilience has been widely adopted in urban planning, disaster risk reduction, and climate adaptation. In the context of flood management, urban flood resilience refers to the ability of cities not only to resist flood impacts, but also to maintain critical urban functions during flood events, recover efficiently afterwards, and adapt continuously to future environmental changes. Compared with traditional flood protection, resilience emphasises flexibility, redundancy, learning, and adaptive capacity rather than absolute safety (Godschalk, 2003; Meerow et al., 2016; Lister, 2015).

This conceptual evolution has significantly influenced contemporary urban planning and landscape architecture. Flood adaptation is no longer understood solely as a hydraulic engineering problem but increasingly as a spatial planning issue that requires integrating ecological processes into the urban environment (Ahern, 2011; Palazzo, 2019). Public spaces, parks, river corridors, streets, and open spaces are therefore expected to perform multiple functions, serving everyday recreational and ecological purposes while temporarily accommodating floodwater during extreme events (Palazzo, 2019; Wu et al., 2026). Instead of treating water as an external threat, resilient planning seeks to incorporate hydrological processes into the spatial structure of cities.

Consequently, a series of landscape-based approaches have emerged over the past two decades, including Blue-Green Infrastructure (BGI), Nature-based Solutions (NbS), Sustainable Drainage Systems (SuDS), and China's Sponge City programme (Fletcher et al., 2015; Chan et al., 2018; Oral et al., 2020; Yin et al., 2021). Although these approaches differ in terminology and implementation, they share a common objective: enhancing urban resilience by working with natural processes rather than relying exclusively on engineered flood control. Through stormwater retention, infiltration, detention, ecological restoration, and multifunctional public spaces, these approaches attempt to reduce flood risk while simultaneously improving biodiversity, environmental quality, and urban liveability (Fletcher et al., 2015; Oral et al., 2020).

Nevertheless, recent studies have also highlighted that resilience should not be interpreted as replacing conventional flood defence. Landscape-based measures are highly effective in reducing runoff, delaying peak discharge, and mitigating frequent or moderate flood events, but their effectiveness decreases under extreme floods with long return periods. Increasing evidence therefore suggests that resilient flood management requires a hybrid strategy in which blue-green infrastructure complements, rather than substitutes for, conventional engineering measures (Oral et al., 2020; Benavides-Muñoz & Román-Aguilar, 2025). Such integration is particularly important in environments where flood dynamics are rapid and highly unpredictable.

These challenges are especially evident in mountain valley cities. Compared with lowland or coastal cities, mountain catchments are characterised by steep topography, rapid runoff concentration, confined river corridors, and limited flood storage capacity. Under these conditions, flood management cannot rely solely on either traditional engineering or distributed green infrastructure. Instead, adaptive spatial planning is required to coordinate hydraulic infrastructure, ecological systems, and urban development within a comprehensive resilience framework (Sun, 2023; Benavides-Muñoz & Román-Aguilar, 2025; Cao et al., 2022).

Therefore, this study adopts flood resilience as its overarching theoretical perspective. Rather than seeking to eliminate flood hazards entirely, it investigates how landscape-based planning and Blue-Green Infrastructure can complement existing flood-control infrastructure to enhance the adaptive capacity of mountain valley cities. This resilience perspective provides the conceptual foundation for the subsequent analysis of mountain flood characteristics, international planning approaches, and the development of a flood-adaptive landscape framework for Rongjiang County.

1.1.1 BGI and NBs for Urban Flood Resilience

Blue-Green Infrastructure (BGI) and Nature-based Solutions (NBs) have emerged as influential approaches for enhancing urban flood resilience in response to climate change and rapid urbanisation (Fletcher et al., 2015; Oral et al., 2020). Both concepts reflect a fundamental transition from conventional engineering-based flood control towards planning and design strategies that work with natural hydrological processes rather than attempting to eliminate flooding entirely (Ahern, 2011; Becker & Walz, 2025). Instead of rapidly conveying stormwater through underground drainage systems, these approaches seek to restore elements of the natural water cycle by promoting infiltration, detention, retention, evapotranspiration, and controlled discharge (Fletcher et al., 2015; Oral et al., 2020). Consequently, they have become central components of contemporary climate adaptation and resilient urban planning.

Although closely related, the two concepts differ in scope and application. Nature-based Solutions represent an overarching framework encompassing interventions inspired by or supported by natural processes to address environmental and societal challenges, including flood risk reduction, biodiversity conservation, climate adaptation, and ecosystem restoration (Oral et al., 2020). Blue-Green Infrastructure provides the spatial and planning expression of these principles within urban environments. Rather than referring to individual green facilities, BGI emphasises interconnected networks of blue and green spaces—including rivers, wetlands, parks, green corridors, rain gardens, bioswales, permeable pavements, and green roofs—that collectively perform hydrological, ecological, and social functions (Chan et al., 2018). This network-based perspective distinguishes BGI from isolated engineering interventions and highlights its role in integrating water management with urban spatial structure.

Within the Chinese context, the Sponge City programme can be regarded as the national planning framework for implementing BGI and NBs principles at the urban scale. Through strategies including infiltration, detention, storage, purification, reuse, and controlled drainage, the programme seeks to restore urban hydrological processes while improving ecological quality, water security, and urban liveability (Yu et al., 2015; Li et al., 2017; Yin et al., 2021). Although NBs, BGI, and Sponge City originate from different institutional and geographical contexts, they share a common philosophy: urban water should be managed by working with natural hydrological processes rather than relying exclusively on structural flood-control measures (Fletcher et al., 2015; Chan et al., 2018; Oral et al., 2020).

A growing body of research demonstrates that Blue-Green Infrastructure contributes to urban flood resilience through multiple hydrological, ecological, spatial, and social functions (Fletcher et al., 2015; Oral et al., 2020). Hydrologically, BGI reduces surface runoff by increasing infiltration, temporarily storing stormwater, delaying runoff concentration, and attenuating peak discharge. Numerous studies have shown that green roofs, rain gardens, permeable pavements, wetlands, and urban green spaces effectively reduce runoff volumes during frequent and moderate rainfall events while enhancing groundwater recharge and alleviating pressure on conventional drainage systems (Fletcher et al., 2015; Yin et al., 2021; Oral et al., 2020). By restoring components of the natural hydrological cycle, BGI improves the capacity of urban systems to respond to rainfall variability under changing climatic conditions.

Beyond stormwater regulation, BGI delivers a wide range of ecological and environmental co-benefits. Green corridors, wetlands, and vegetated open spaces improve water quality through natural filtration, enhance biodiversity by increasing habitat connectivity, mitigate urban heat island effects, and strengthen ecosystem resilience (Ahern, 2011; Oral et al., 2020). These multiple ecosystem services have become an important justification for incorporating blue-green infrastructure into climate adaptation strategies rather than treating flood management solely as a hydraulic engineering issue.

From a spatial planning perspective, BGI promotes a more integrated approach to urban water management by linking drainage infrastructure, ecological restoration, public space, and land-use planning within a unified framework (Ahern, 2011; Palazzo, 2019). Rather than functioning as isolated technical facilities, blue-green elements become part of the urban landscape, performing multiple functions simultaneously. Parks, waterfronts, streets, and open spaces can accommodate recreational activities under normal conditions while serving as temporary flood storage and stormwater conveyance during extreme rainfall events (Palazzo, 2019; Wu et al., 2026). Such multifunctionality represents one of the defining characteristics of landscape-based flood adaptation and reflects the increasing convergence of urban planning, landscape architecture, and water management.

Consequently, BGI has evolved from a stormwater management technique into an important planning strategy for climate adaptation and resilient urban development. International approaches such as Sustainable Drainage Systems (SuDS) in the United Kingdom, Water Sensitive Urban Design (WSUD) in Australia, and China's Sponge City programme all incorporate blue-green infrastructure as a key mechanism for integrating ecological processes into urban development (Fletcher et al., 2015; Li et al., 2017; Chan et al., 2018). Despite differences in governance systems and technical standards, these approaches share the objective of creating multifunctional landscapes capable of reducing flood risk while simultaneously improving environmental quality and urban liveability (Oral et al., 2020).

Despite its considerable advantages, the literature increasingly recognises that Blue-Green Infrastructure is not a universal solution for flood management. While numerous studies confirm its effectiveness in reducing runoff and mitigating flooding during frequent and moderate rainfall events, evidence consistently indicates that its performance declines as rainfall intensity and runoff volumes exceed the storage capacity of distributed green infrastructure (Oral et al., 2020). Research from Chinese Sponge City pilot projects demonstrates that although green infrastructure can substantially reduce runoff under ordinary storm conditions, its effectiveness decreases significantly during extreme flood events (Chikhi et al., 2023; Wu et al., 2026). Consequently, BGI alone cannot provide sufficient protection against large-scale flooding, particularly where flood magnitudes exceed the design capacity of infiltration and detention facilities.

Implementation also faces a range of institutional and practical challenges. Urban land scarcity

frequently limits opportunities for large-scale deployment of Blue-Green Infrastructure, especially in densely developed areas. Long-term maintenance requirements can further constrain the sustained performance of decentralised stormwater facilities (Yin et al., 2021). At the planning and governance level, fragmented responsibilities, inconsistent implementation mechanisms, and competing urban-development priorities can further limit the integration of BGI into urban planning (Qian and Lyu, 2026). These challenges indicate that the effectiveness of BGI depends not only on technical design but also on coordinated planning, supportive governance, and long-term management.
These limitations are particularly significant in mountain valley cities. Compared with lowland cities, narrow valley floors provide limited space for stormwater detention and ecological restoration, while steep topography generates rapid runoff concentration and short flood response times that may exceed the capacity of conventional BGI measures (Sun, 2023; Benavides-Muñoz & Román-Aguilar, 2025). Under these conditions, landscape-based interventions alone cannot accommodate the large flood volumes associated with flash floods. Instead, blue-green infrastructure should be understood as a complementary spatial strategy that works alongside conventional flood-control engineering. Its primary contribution lies in slowing runoff, increasing infiltration where feasible, creating adaptable flood storage spaces, improving ecological connectivity, and enhancing the multifunctionality of public landscapes (Sun, 2023; Oral et al., 2020).

From this perspective, flood resilience is achieved not through the replacement of grey infrastructure by green infrastructure, but through their integration within a comprehensive planning framework. Structural flood-control measures remain essential for reducing flood hazards associated with extreme events, while blue-green infrastructure enhances the adaptive capacity of urban landscapes by improving ecological performance, spatial flexibility, and everyday urban liveability (Becker & Walz, 2025; Oral et al., 2020). This hybrid approach is particularly relevant for mountain valley cities, where effective flood adaptation requires balancing engineering protection with landscape-based resilience.
The literature therefore suggests that the principal value of Blue-Green Infrastructure lies not in replacing conventional flood defences, but in strengthening the capacity of cities to coexist with water through adaptive planning, multifunctional landscapes, and integrated water management (Ahern, 2011; Palazzo, 2019; Oral et al., 2020). These findings provide the theoretical basis for the comparative review of international planning approaches presented in the following section.

1.1.2 Sponge Cities, SuDS and Hydraulic Invariance

As urban flood management has shifted from structural flood control towards resilience-based adaptation, different countries have developed planning approaches that integrate hydrological processes with spatial planning. Although these approaches were established under different environmental, institutional, and climatic conditions, they provide valuable experience for enhancing urban flood resilience. Rather than relying solely on engineering solutions, they increasingly emphasise multifunctional landscapes, distributed stormwater management, and planning-led flood adaptation (Ahern, 2011; Oral et al., 2020). This section reviews three representative approaches—Italian Hydraulic Invariance, China's Sponge City programme, and British Sustainable Drainage Systems (SuDS)—to identify transferable planning principles that can inform flood adaptation in mountain valley cities.

Sponge City: Landscape-Based Urban Water Management

China's Sponge City programme represents one of the world's most comprehensive national initiatives for integrating Blue-Green Infrastructure into urban planning. Introduced in response to increasing urban flooding, water pollution, ecological degradation, and rapid urbanisation, the programme encourages cities to function like "sponges" by absorbing, storing, infiltrating, purifying, reusing, and gradually releasing rainwater through landscape-based interventions (Yu et al., 2015; Chan et al., 2018). Rather than rapidly conveying stormwater through conventional underground drainage systems, Sponge City promotes the restoration of natural hydrological processes by integrating ecological infrastructure into urban development (Chan et al., 2018).
A defining characteristic of the Sponge City programme is its integration of stormwater management into urban spatial planning rather than treating drainage as a purely engineering issue. Parks, wetlands, green corridors, waterfronts, streets, public open spaces, and ecological corridors are designed to perform multiple functions simultaneously, combining flood regulation with ecological restoration, environmental improvement, biodiversity conservation, and public recreation (Yu et al., 2015; Chan et al., 2018). This multifunctional planning philosophy reflects a significant transition from conventional engineering-based flood control towards landscape-led urban water management, where blue-green infrastructure becomes an integral component of urban spatial structure rather than an isolated technical facility (Chan et al., 2018; Palazzo, 2019; Oral et al., 2020).
Beyond its physical interventions, Sponge City also represents an important policy innovation in China's urban development. Rather than introducing individual engineering projects, the programme seeks to mainstream stormwater management into planning policy, urban renewal, land development, and ecological restoration. Recent studies show that Sponge City has gradually evolved from a pilot-based engineering programme into a broader planning framework influencing urban governance, land-use planning, and climate adaptation across Chinese cities (Ma et al., 2023; Qian & Lyu, 2026). This planning-oriented transition demonstrates the increasing integration of flood resilience with sustainable urban development.

The programme has demonstrated considerable benefits in reducing surface runoff, improving water quality, enhancing groundwater recharge, increasing urban biodiversity, and improving the quality of public open space (Oral et al., 2020; Chan et al., 2018). More importantly, it has strengthened collaboration between landscape architecture, ecological restoration, urban planning, and water management, illustrating how flood adaptation can be incorporated into everyday urban environments rather than being treated solely as specialised hydraulic infrastructure (Chan et al., 2018; Palazzo, 2019).

Nevertheless, recent research has also identified important limitations. Most Sponge City measures are primarily designed to manage urban stormwater runoff and frequent waterlogging rather than independently provide protection against extreme flood events. Their effectiveness can decline when rainfall intensity and runoff volumes exceed the capacity of distributed green infrastructure, indicating that landscape-based measures should be integrated with conventional drainage and flood-control infrastructure rather than treated as a complete substitute for structural protection (Yin et al., 2021; Chikhi et al., 2023). Furthermore, Sponge City implementation faces practical and institutional challenges, including limited land availability in densely developed urban areas, long-term operation and maintenance requirements, insufficient or inconsistent technical standards, and difficulties in coordinating implementation across different planning and management responsibilities (Li et al., 2017; Yin et al., 2021; Qian and Lyu, 2026). These limitations demonstrate that the effectiveness of Sponge City depends not only on the performance of individual landscape interventions, but also on their integration with wider flood-management systems and long-term planning and governance mechanisms.

For mountain valley cities, the Sponge City programme provides valuable planning concepts—including multifunctional public spaces, integrated blue-green networks, ecological stormwater management, and planning-led flood adaptation—but these principles require modification to accommodate rapid runoff concentration, confined valley floors, limited developable land, and high-energy flash floods (Benavides-Muñoz & Román-Aguilar, 2025; Liu et al., 2026). Consequently, Sponge City should be regarded as a complementary planning strategy that enhances urban resilience while operating alongside conventional flood-control infrastructure rather than replacing it (Oral et al., 2020).

Sustainable Drainage Systems: Distributed Stormwater Management

The United Kingdom has developed Sustainable Drainage Systems (SuDS) as an integrated approach to urban stormwater management that seeks to replicate natural hydrological processes within urban environments. Unlike conventional drainage systems, which are designed to rapidly convey stormwater through underground pipe networks, SuDS manages runoff as close as possible to its source by promoting infiltration, detention, storage, evapotranspiration, and controlled discharge (Fletcher et al., 2015; Woods Ballard et al., 2015). The approach incorporates a wide range of landscape-based measures—including permeable pavements, swales, detention basins, wetlands, rain gardens, and green roofs that collectively reduce runoff volumes, improve water quality, enhance biodiversity, and provide recreational and ecological benefits (Woods Ballard et al., 2015; Oral et al., 2020).

One of the defining characteristics of SuDS is the concept of the management train, whereby stormwater is progressively managed through a sequence of interventions operating at multiple spatial scales, from source control and site-level detention to neighbourhood-scale storage and regional drainage. Rather than relying on a single engineering facility, runoff management is distributed throughout the urban landscape, increasing system redundancy, flexibility, and resilience (Woods Ballard et al., 2015). Equally important is the principle of multifunctionality, whereby drainage infrastructure simultaneously contributes to biodiversity enhancement, public open space, climate adaptation, and environmental quality (Palazzo, 2019; Oral et al., 2020).

From a planning perspective, SuDS demonstrates the importance of integrating drainage considerations into land-use planning and development control. Rather than treating stormwater management as an isolated engineering discipline, SuDS encourages collaboration between planners, landscape architects, engineers, ecologists, and environmental managers throughout the planning and design process (Woods Ballard et al., 2015; House of Commons Library, 2026). This interdisciplinary planning philosophy has become one of the defining characteristics of sustainable urban water management and has influenced planning practice well beyond the United Kingdom (Fletcher et al., 2015).

Despite these advantages, SuDS was primarily developed for temperate lowland environments where pluvial flooding is the dominant hazard and rainfall characteristics are comparatively moderate. Its distributed drainage philosophy assumes sufficient land for decentralised stormwater facilities, relatively gentle topography, and predictable runoff behaviour. These assumptions become less applicable in mountain valley cities, where steep terrain, narrow valley floors, limited developable land, and rapid runoff concentration constrain opportunities for infiltration and distributed storage (Benavides-Muñoz & Román-Aguilar, 2025; Liu et al., 2026).

Nevertheless, the planning concepts underlying SuDS—including source control, distributed stormwater management, multifunctional landscape design, and planning-led water management—remain highly transferable. Rather than directly replicating individual technical measures, mountain valley cities can adapt these principles to strengthen the integration between spatial planning, ecological restoration, landscape design, and flood management, thereby improving urban resilience under complex hydrological conditions.

Hydraulic Invariance: Integrating Runoff Control into Spatial Planning

Italy has developed a distinctive planning approach to urban stormwater management based on the principle of hydraulic invariance (invarianza idraulica). The central principle is that post-development runoff discharged from an urban site should not exceed the runoff generated under pre-development conditions. Rather than relying primarily on downstream flood-control infrastructure, hydraulic invariance seeks to reduce flood risk by regulating runoff generation at its source through land-use planning and development control (Regione Lombardia, 2017; Regione Lombardia, 2025).

A defining characteristic of the Italian approach is its integration into the statutory planning system. In the Lombardy Region, developers are required to demonstrate that new developments maintain pre-development runoff conditions through measures such as infiltration, detention, retention, rainwater harvesting, or controlled discharge before planning permission can be granted (Regione Lombardia, 2017). Consequently, hydrological performance becomes a mandatory planning requirement rather than a separate engineering consideration undertaken after development has been approved. The updated regional regulations further strengthen

the application of Nature-based Solutions and Sustainable Drainage Systems as preferred approaches for achieving hydraulic invariance while simultaneously enhancing biodiversity, environmental quality, and climate resilience (Regione Lombardia, 2025).

From a spatial planning perspective, the Italian approach demonstrates how hydrological objectives can be embedded within land-use planning and development management from the earliest stages of urban development. Rather than treating flood mitigation as a post-development engineering intervention, runoff control becomes a planning principle that influences site layout, development intensity, landscape design, and surface permeability before construction begins. This represents an important transition from reactive flood protection towards preventive and planning-led flood adaptation (Ahern, 2011; Davoudi, 2021).

The Italian experience also illustrates the value of integrating engineering requirements with landscape planning. Instead of prescribing only hydraulic structures, the regulations encourage the use of vegetated detention areas, infiltration systems, permeable surfaces, and other blue-green infrastructure measures capable of regulating runoff while improving ecological performance and public space quality (Oral et al., 2020; Regione Lombardia, 2025). This integrated planning philosophy has become an important reference for climate adaptation and sustainable urban development in Europe.

However, hydraulic invariance was primarily developed for lowland catchments where pluvial flooding is the dominant hazard and runoff processes are comparatively predictable. Its technical standards assume relatively gentle terrain, sufficient space for infiltration and detention facilities, and less extreme runoff concentration than is typically observed in mountainous environments. Consequently, although its planning philosophy is highly transferable, its engineering standards and calculation methods cannot be directly applied to mountain valley cities characterised by steep slopes, confined river corridors, rapid runoff concentration, and flash flooding (Benavides-Muñoz & Román-Aguilar, 2025; Liu et al., 2026).

For mountain valley cities such as Rongjiang, the principal lesson is therefore not the direct application of hydraulic invariance calculations, but the integration of hydrological regulation into statutory spatial planning. By embedding runoff control within planning policies, land-use allocation, and landscape design, flood adaptation can be considered proactively during urban development rather than retrospectively through engineering interventions alone. This planning-led philosophy provides an important reference for developing integrated flood adaptation strategies in mountain valley cities.

Although Italian Hydraulic Invariance, China's Sponge City programme, and British Sustainable Drainage Systems were developed under different environmental, institutional, and governance contexts, they share several fundamental planning principles. All three approaches emphasise planning-led flood adaptation, the integration of hydrological processes into urban development, and the multifunctional use of landscapes as essential components of flood-management infrastructure (Ahern, 2011; Oral et al., 2020). Rather than relying exclusively on conventional engineering measures, they promote a proactive planning approach in which runoff regulation, ecological restoration, public space, and land-use planning are considered simultaneously throughout the urban development process.

Despite these common principles, mountain valley cities present a substantially different hydrological context. Compared with lowland cities, they are characterised by steep catchments, rapid runoff concentration, confined river corridors, limited flood storage capacity, and the frequent interaction of river flooding and pluvial flooding (Benavides-Muñoz & Román-Aguilar, 2025; Liu et al., 2026; Sun, 2023). Consequently, planning approaches developed for lowland environments cannot be transferred directly without modification.

For mountain valley cities such as Rongjiang, the principal value of international experience therefore lies not in replicating specific engineering standards or technical measures, but in adapting their underlying planning principles. These include integrating hydrological regulation into statutory planning, establishing multifunctional blue-green infrastructure networks, promoting distributed stormwater management where spatially feasible, and embedding flood resilience within land-use planning and landscape design (Regione Lombardia, 2025; Qian and Lyu, 2026). At the same time, these planning strategies must operate alongside conventional flood-control infrastructure capable of responding to the rapid runoff concentration and severe flood processes associated with complex mountainous terrain.

Accordingly, this study adopts these transferable planning principles as the conceptual basis for developing an integrated flood adaptation framework tailored to the geographical, hydrological, and planning conditions of Rongjiang. Rather than directly transferring existing international models, the proposed framework adapts their core planning concepts to the distinctive environmental constraints and flood characteristics of mountain valley cities.

02

Mountain Valley Cities: Flood Features and Challenges

2.1 Hidrogeological Features of Urban Mountain Contexts

Flood processes in mountain valley cities differ fundamentally from those in lowland and coastal urban areas. While floods in plains generally develop gradually, spread across broad floodplains, and remain relatively stable over time, mountain floods are characterised by rapid onset, high flow velocity, confined river corridors, and strong geomorphological impacts (Benavides-Muñoz & Román-Aguilar, 2025; Liu et al., 2026). These distinctive hydrological characteristics significantly influence urban development patterns and require flood adaptation strategies that differ fundamentally from those developed for lowland cities.

The first defining characteristic is rapid runoff concentration. Mountain catchments typically have steep slopes, short river networks, and limited opportunities for natural water storage. During intense rainfall events, precipitation is rapidly converted into surface runoff and conveyed downstream within a short period of time. Consequently, river water levels may rise dramatically within only a few hours, leaving limited time for flood forecasting, emergency response, or evacuation (Liu et al., 2026; Wei et al., 2024). Compared with lowland rivers, where flood peaks often develop over one or several days, mountain floods exhibit much shorter concentration times and greater uncertainty (Ding, 2022; Cao et al., 2022). From a planning perspective, this limited response time highlights the importance of spatial preparedness, including pre-planned evacuation routes, emergency shelters, and flood-compatible public spaces, rather than relying solely on forecasting and emergency engineering measures (Tang, 2025).

A second characteristic is the high flow velocity and erosive power of mountain floods. Steep river gradients generate fast-flowing water capable of transporting sediment, woody debris, and even large boulders. Flood damage is therefore not only caused by inundation depth but also by hydraulic force, bank erosion, channel instability, and debris impacts (Wei et al., 2024; Ding, 2022). Conventional flood management strategies that focus primarily on water depth may underestimate these hazards. Consequently, landscape design in mountain valleys must consider river dynamics, bank stability, vegetation resilience, and structural resistance in addition to flood storage capacity (Li, 2026).

The third characteristic is the limited availability of flood storage space. Unlike lowland cities, where extensive floodplains can accommodate excess floodwater, mountain valley cities are typically located on narrow valley floors confined by surrounding mountains. These limited flat areas are also the most suitable locations for urban development, resulting in a direct spatial conflict between urban expansion and natural flood processes (Benavides-Muñoz & Román-Aguilar, 2025; Liu et al., 2026). As cities continue to grow within constrained valleys, buildings, transport infrastructure, and public facilities increasingly occupy areas that historically functioned as natural flood conveyance and storage corridors. Consequently, flood adaptation cannot rely on horizontal expansion of floodplains but instead requires more compact and multifunctional spatial strategies, such as multi-level riverbanks, floodable parks, elevated public spaces, and adaptable waterfront landscapes (Palazzo, 2019).

A further challenge is the compound interaction between river flooding and pluvial flooding. In mountain valley cities, external flooding from rivers frequently coincides with internal flooding generated by intense local rainfall. During high river stages, drainage outfalls become submerged, reducing the efficiency of urban drainage systems and preventing stormwater from being discharged into rivers. At the same time, steep surrounding slopes rapidly generate surface runoff that converges towards the valley floor through streets and urban drainage networks. These simultaneous processes create compound flooding, where river overflow and pluvial flooding reinforce one another and substantially increase flood risk (Sun, 2023; Liu et al., 2026). This interaction suggests that river management and urban stormwater management should not be treated as independent systems but as interconnected components of a single urban hydrological network.

These characteristics are particularly relevant in China, where mountainous and hilly terrain occupies approximately 70% of the national territory and supports numerous rapidly urbanising settlements located along narrow river valleys (Cao et al., 2022). In southwestern provinces such as Guizhou, intense seasonal rainfall, complex topography, and dense river networks further amplify the occurrence of flash floods (Zhang, 2026). Although national policies such as the Sponge City programme have significantly advanced urban stormwater management (Chan et al., 2018; Qian & Lyu, 2026), many existing planning and design principles have been developed primarily for lowland cities experiencing relatively slow flood dynamics. Their direct application to mountain valley environments therefore remains limited.

Overall, the literature indicates that mountain valley flooding is not simply a more severe version of lowland flooding but represents a fundamentally different hydrological and spatial condition. The combination of rapid runoff concentration, confined urban development, high-energy flood flows, and compound flood mechanisms requires adaptation strategies that integrate flood management with spatial planning, landscape design, and ecological restoration (Benavides-Muñoz & Román-Aguilar, 2025; Oral et al., 2020). Rather than replicating approaches developed for lowland cities, flood resilience in mountain valley contexts should be based on planning frameworks that acknowledge local topography, river dynamics, and the limited capacity for conventional flood storage (Benavides-Muñoz & Román-Aguilar, 2025; Palazzo, 2019).

These observations provide the physical basis for the following sections of this chapter, which examine how Blue-Green Infrastructure, Nature-based Solutions, and international planning approaches may be adapted to support resilient flood management in mountain valley cities.

2.2 Comparative Case Studies of Flood Adaptation in Mountain Valley Cities

While the international planning approaches discussed in the previous section provide valuable theoretical guidance, their application in mountain valley cities requires further consideration of steep topography, rapid runoff concentration, confined urban development, and short flood-response times. To better understand how these conditions influence flood adaptation in practice, this section examines three representative Chinese cases that illustrate complementary dimensions of mountain flood resilience.

The selected cases are Dongchuan District in Yunnan Province, the Jiayu River Basin in Henan Province, and the central urban area of Chongqing. They are not treated as directly replicable design models. Instead, they are analysed through a common framework comprising five dimensions: the physical flood context, the principal risk management approach, the spatial or institutional mechanisms involved, the limitations of the approach, and its potential relevance to Rongjiang.

Together, the cases demonstrate that mountain flood resilience cannot be achieved through a single intervention. Instead, it requires the integration of terrain-sensitive spatial planning, catchment-scale runoff management, multi-level drainage and storage systems, and coordinated spatial strategies across river corridors, urban districts, and local catchments. The comparison further highlights the importance of adapting flood-management measures to local topography, hydrological processes, and existing urban conditions rather than applying standardised solutions.

2.2.1 Dongchuan District, Yunnan: Terrain-Sensitive Spatial Resilience Planning

Dongchuan District is located in the mountainous region of Yunnan Province, where steep terrain, constrained developable land, and exposure to multiple natural hazards create significant challenges for urban development and disaster-risk management (Chen et al., 2020). As in many mountain cities, urban functions and infrastructure are concentrated within relatively limited areas suitable for construction, while differences in topography, accessibility, and hazard exposure produce substantial spatial variations in disaster risk. These characteristics make the relationship between terrain, urban development, and emergency spatial planning particularly important in Dongchuan (Chen et al., 2020; Li et al., 2026).

A key contribution of the Dongchuan case is the integration of disaster-risk assessment with the spatial planning of emergency facilities. Using Dongchuan District as a case study, Chen et al. (2020) examined the optimisation of fixed emergency shelter locations based on spatial differences in disaster risk. Rather than considering shelter provision solely in terms of service coverage or population distribution, the study demonstrates the importance of incorporating risk conditions into the spatial allocation of emergency facilities. This approach is particularly relevant to mountain cities, where topographical constraints, uneven accessibility, and concentrated development can substantially influence the effectiveness of evacuation and emergency-response systems (Chen et al., 2020; Li et al., 2026).

From a broader resilience perspective, the Dongchuan case illustrates how hazard and risk assessment can be translated into spatial planning decisions rather than remaining solely as analytical

representations of vulnerability. Resilience-oriented planning emphasises that urban systems should respond to spatially differentiated environmental conditions and maintain critical functions during disturbance (Ahern, 2011; Meerow et al., 2016). In mountain cities, this means that areas with different levels of exposure, accessibility, and adaptive capacity should not necessarily perform the same urban functions. Relatively safer and more accessible locations can support emergency shelters, evacuation destinations, and critical facilities, while highly exposed areas may require more restrictive development strategies or flood-compatible uses (Li et al., 2026). In this sense, terrain and risk assessment can provide an important spatial basis for differentiated planning rather than serving only as background information for hazard analysis.

The Dongchuan case therefore supports a terrain-sensitive approach in which spatial differences in disaster risk are incorporated into the organisation of urban functions and emergency infrastructure. This principle is particularly important where steep terrain limits alternative evacuation routes and concentrates movement within a small number of streets and corridors. Research on mountain-city evacuation further demonstrates that elevation differences and street configuration can significantly affect evacuation efficiency, reinforcing the need to coordinate shelter locations, evacuation routes, and urban spatial structure (Tang, 2025). Such an approach is consistent with adaptive planning principles that seek to accommodate environmental uncertainty through spatial differentiation and flexible urban functions rather than relying exclusively on uniform engineering protection (Ahern, 2011; Palazzo, 2019).

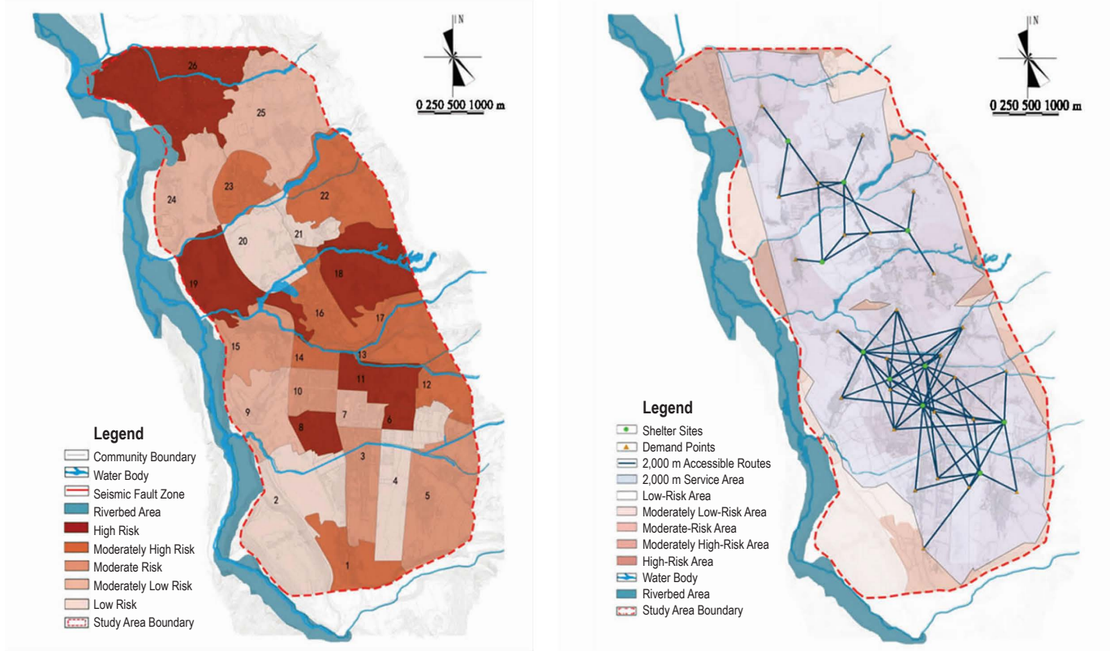


Figure 1. *Comprehensive disaster-risk assessment and optimisation of emergency shelter locations in Dongchuan District. Source: Chen et al. (2020).*

However, the Dongchuan approach also has limitations when transferred to flood adaptation. Risk-based optimisation of emergency shelters primarily addresses the spatial organisation of evacuation and emergency response; it does not in itself determine how floodwater should be intercepted, conveyed, stored, or accommodated within the urban landscape. Nor does it replace hydrological analysis, engineering assessment, or site-specific landscape design. Its principal value for flood-resilient planning therefore lies in demonstrating how spatial risk information can inform the allocation of urban functions and emergency resources, while additional hydrological and landscape analyses remain necessary to determine appropriate flood-adaptation interventions.

For Rongjiang, the principal transferable lesson is that terrain and flood-risk analysis should directly inform spatial planning decisions. Similar to Dongchuan, Rongjiang is strongly constrained by mountainous terrain, while its urban development, transport infrastructure, and public facilities are concentrated within the limited valley floor. The analyses in Chapter 4 further demonstrate that flood exposure is particularly concentrated along the river corridors and within low-lying parts of the Old Town. Consequently, elevation and flood-risk information should be used not only to identify vulnerable areas but also to guide the location of evacuation routes, refuge spaces, emergency facilities, flood-compatible public spaces, and differentiated land-use strategies. The Dongchuan case therefore provides a methodological reference for translating spatial risk assessment into planning decisions (Chen et al., 2020), while Rongjiang extends this principle through the integration of flood-risk analysis with Blue-Green Infrastructure, adaptive river corridors, and landscape-based flood accommodation.

2.2.2 Jiayu River Basin, Henan: Catchment-Based and Functionally Differentiated Flood Management

The Jiayu River Basin provides a second perspective by shifting attention from the individual urban site to the broader watershed. Following the extreme rainfall event that affected Zhengzhou in 2021, hydrological analysis and spatial assessment were undertaken to examine how terrain, land use, river morphology, and drainage conditions influenced the spatial distribution of flood intensity across the basin (Zhang et al., 2023). Unlike conventional urban flood studies that focus primarily on inundated urban districts, the Jiayu case highlights the importance of understanding flood generation and transmission across the entire catchment.

The analysis demonstrated that terrain and hydrological connectivity play a decisive role in flood generation. Steep upstream slopes accelerate the conversion of rainfall into surface runoff, while the structure of the drainage network rapidly transfers runoff towards downstream urban areas (Zhang et al., 2023). Consequently, downstream flood intensity is not determined solely by local rainfall or land use but represents the cumulative effect of upstream runoff production, midstream flow conveyance, river-channel conditions, and the limited drainage capacity of urbanised lower reaches (Zhang et al., 2023; Liu et al., 2026).

This finding challenges flood-management approaches that concentrate interventions exclusively within inundated urban areas. In mountain catchments, downstream flood risk is partly generated outside the administrative or design boundary of the city itself. Although local drainage improvements may alleviate urban waterlogging during moderate rainfall events, they cannot fully compensate for the rapid arrival of large upstream flood volumes during extreme storms. Consequently, flood adaptation should be considered at the catchment scale rather than being confined to individual urban sites (Zhang et al., 2023; Benavides-Muñoz & Román-Aguilar, 2025).

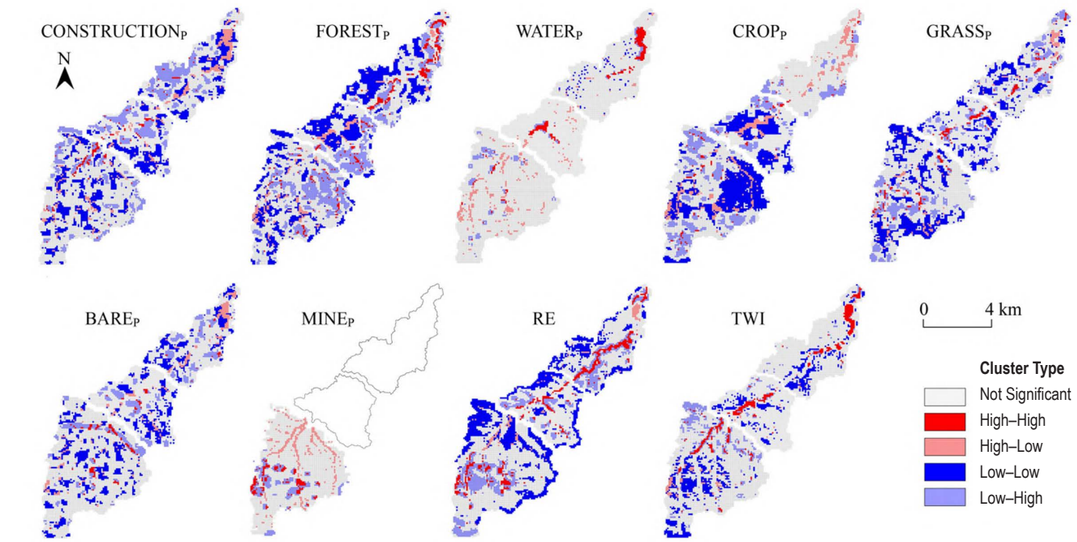


Figure 2. *Local spatial correlations between flood inundation intensity and landscape characteristics in the Jiayu River Basin. Source: Zhang et al. (2023).*

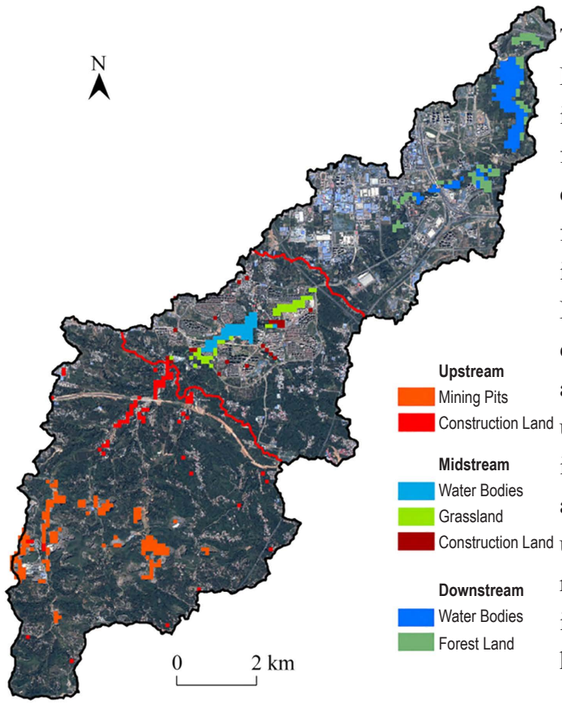


Figure 3. *Green infrastructure planning for differentiated upstream, midstream, and downstream zones in the Jiayu River Basin. Source: Zhang et al. (2023).*

The planning strategy proposed for the Jiayu River Basin therefore differentiates the watershed into upstream, midstream, and downstream functional zones. Upstream areas prioritise ecological conservation, soil and water retention, forest protection, and temporary runoff storage in order to reduce and delay runoff generation. Midstream areas focus on flow attenuation, ecological connectivity, channel restoration, and controlled flood conveyance. Downstream urban areas emphasise flood corridors, drainage improvement, protection of critical infrastructure, and temporary flood storage integrated within the urban landscape (Zhang et al., 2023). Rather than representing isolated engineering measures, these interventions function collectively as a connected hydrological system.

The value of this approach lies in the functional relationship between spatial zones. Upstream retention reduces runoff generation, midstream corridors regulate and safely convey floodwater, while downstream landscapes accommodate residual floodwater and protect essential urban functions. Consequently, flood resilience emerges from the coordinated interaction of retention, attenuation, conveyance, storage, and controlled discharge rather than from any individual intervention (Oral et al., 2020). This systems-based perspective represents an important shift from project-oriented flood management towards integrated watershed planning.

The Jiayu case further demonstrates that the function of Blue-Green Infrastructure depends upon its position within the catchment. An upstream wetland or forested retention area primarily reduces runoff generation, whereas a downstream floodable park temporarily stores floodwater that has already entered the urban area. Likewise, vegetated swales and bioretention systems may effectively manage local stormwater runoff but cannot independently accommodate high-energy river flooding associated with mountain catchments. Consequently, the allocation of Blue-Green Infrastructure should respond to hydrological processes and catchment position rather than applying standardised design solutions throughout the watershed.

Despite these advantages, the Jiayu approach also has limitations. Hydrological models inevitably simplify real flood processes and depend upon the availability and quality of rainfall, topographic, drainage, and land-use data. Moreover, watershed-scale planning can be difficult to implement where upstream and downstream areas are governed by different administrative authorities. Ecological measures can reduce or delay runoff but cannot eliminate flood hazards during exceptional rainfall events. Consequently, catchment planning should complement rather than replace conventional structural flood-protection measures (Zhang, 2026).

For Rongjiang, the Jiayu case provides an important theoretical basis for linking upstream watershed management with downstream urban adaptation. Flood risk in Rongjiang is influenced by runoff from the Duliu, Zhaihao, and Pingyong river systems, with flood hazards intensifying at their confluence (Yuan et al., 2026). Consequently, the urban planning boundary should not be regarded as a hydrologically independent area. Even where detailed interventions cannot be proposed across the entire regional catchment, the planning framework should recognise upstream retention, tributary management, river-reach differentiation, and downstream flood accommodation as interconnected components of a single flood-adaptation system.

This principle also supports the proposed differentiation between Rongjiang's new town and old town. The new town river corridor may prioritise runoff interception, continuous Blue-Green Infrastructure, strengthened riverbanks, and stepped waterfronts, whereas the downstream old town requires greater emphasis on flood storage, wetland restoration, controlled inundation, and emergency evacuation. Rather than representing separate planning strategies, these interventions function together as complementary components within an integrated catchment-scale flood adaptation framework.

2.2.3 Chongqing: Multi-Level Spatial Planning for Mountain Urban Flood Adaptation

The central urban area of Chongqing provides a third perspective on flood adaptation in mountain valley cities by examining how urban flood resilience depends on the spatial organisation of drainage and storage systems rather than solely on the hydraulic capacity of individual drainage facilities. As one of China's most representative mountainous cities, Chongqing is characterised by steep terrain, fragmented catchments, rapid runoff concentration, and intense seasonal rainfall. These characteristics create complex interactions between topography, urban development, and stormwater processes, making conventional drainage-based flood management increasingly insufficient under extreme rainfall conditions (Sun, 2023).

Unlike the Dongchuan and Jiayu cases, which focus respectively on terrain-sensitive resilience assessment and catchment-scale runoff management, the Chongqing case emphasises the importance of organising drainage and storage functions across multiple spatial scales. Through an analysis of cascading failures within the urban major drainage system, the study demonstrates that flood risk is strongly influenced by the spatial configuration and connectivity of drainage corridors, detention spaces, natural waterways, and urban open spaces rather than by the hydraulic capacity of isolated engineering facilities alone (Sun, 2023). The findings further indicate that simply increasing the density of drainage infrastructure or strengthening local connectivity does not necessarily reduce flood risk. Without considering the broader spatial organisation of runoff pathways, additional infrastructure may even accelerate runoff concentration and increase the likelihood of cascading system failures (Sun, 2023).

Based on these findings, the study proposes a hierarchical spatial planning framework operating across three complementary levels: watershed-scale drainage and storage patterns, sub-catchment-scale runoff organisation, and local engineering interventions (Sun, 2023). Rather than relying exclusively on conventional drainage upgrades, this framework integrates natural drainage pathways, flood storage spaces, blue-green infrastructure, and targeted engineering measures into a coordinated spatial system that responds to mountainous terrain. Consequently, landscape structure and spatial organisation become fundamental components of flood resilience rather than simply supporting engineering infrastructure (Palazzo, 2019; Oral et al., 2020).

An important implication of the Chongqing case is that flood adaptation should be organised as an integrated spatial network rather than as a collection of independent engineering projects (Sun, 2023). Natural topography should guide the identification of primary flood conveyance corridors, temporary flood storage areas, ecological corridors, and emergency open spaces instead of being overridden by fragmented urban expansion. At the same time, different planning scales should perform complementary functions: watershed planning manages runoff generation and regional drainage, river corridors regulate flood conveyance, neighbourhoods accommodate local stormwater, and public spaces provide temporary flood storage while maintaining everyday social and ecological functions.

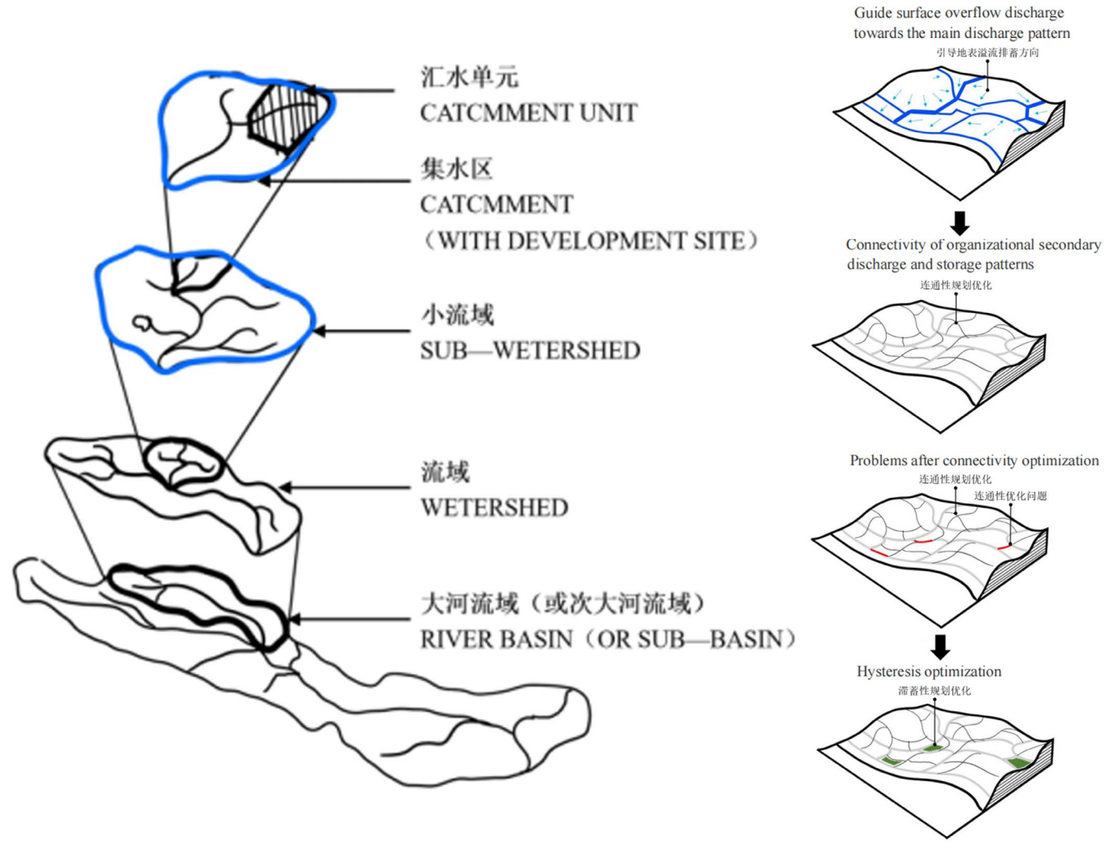


Figure 4. *Multi-scale drainage and catchment organisation in mountainous urban areas. Source: Sun (2023).*

This multi-level planning philosophy is particularly applicable to mountain valley cities because flood processes operate simultaneously across multiple spatial scales (Liu et al., 2026). Runoff generated in upstream catchments rapidly affects downstream river corridors, while local stormwater drainage interacts continuously with river flooding within densely developed valley floors (Benavides-Muñoz & Román-Aguilar, 2025; Liu et al., 2026). Effective flood adaptation therefore depends upon coordination among watershed management, river corridor planning, urban drainage systems, and landscape design rather than the optimisation of any single component.

For Rongjiang, the Chongqing case provides several transferable planning principles. First, drainage and flood storage should be organised as an integrated blue-green spatial network rather than as isolated engineering facilities. Second, natural topography should guide the identification of primary flood conveyance corridors and temporary flood storage spaces. Third, flood adaptation should be coordinated across multiple spatial scales—from the regional watershed and river corridor to neighbourhoods and individual public spaces—allowing different landscape elements to function collectively as a coherent flood adaptation system. Finally, landscape-based planning should complement rather than replace conventional engineering infrastructure, combining Blue-Green Infrastructure with targeted drainage improvements where necessary.

Together, the Dongchuan, Jiayu River Basin, and Chongqing case studies demonstrate that effective flood adaptation in mountain valley cities cannot be achieved through a single intervention. Rather than promoting standardised engineering solutions, the three cases illustrate complementary planning perspectives that collectively strengthen urban flood resilience. Dongchuan highlights the importance of terrain-sensitive spatial planning by demonstrating how spatial differences in disaster risk can inform the allocation of emergency facilities. The Jiayu River Basin emphasises catchment-scale runoff management and the functional relationship between upstream and downstream hydrological processes. Chongqing focuses on the spatial organisation of drainage and storage systems across multiple planning scales, demonstrating how landscape structure and hydrological connectivity influence urban flood resilience. Collectively, these cases suggest that effective flood adaptation depends on integrating terrain-sensitive planning, catchment-scale management, and multi-level spatial organisation within a coherent planning framework. Several transferable planning principles emerge from the comparison:

First, topography should function as the fundamental spatial framework for flood adaptation. All three cases demonstrate that terrain is not merely a physical constraint but the primary determinant of runoff pathways, flood conveyance, development suitability, and the allocation of flood-adaptive land uses. In Rongjiang, elevation, slope, valley morphology, and river confluences should therefore guide land-use intensity, river corridor protection, flood accommodation spaces, evacuation planning, and the spatial organisation of Blue-Green Infrastructure (Benavides-Muñoz & Román-Aguilar, 2025; Ding, 2022).

Second, flood adaptation should be organised at the catchment scale. Both the Jiayu River Basin and Chongqing demonstrate that urban flooding cannot be understood independently of upstream hydrological processes. Effective flood adaptation therefore requires coordinated planning across the entire watershed, recognising the functional relationships between upstream runoff generation, tributary catchments, river corridors, and downstream flood conveyance (Zhang et al., 2023; Sun, 2023; Li et al., 2026). For Rongjiang, this principle supports integrated planning across the Duliu, Zhaihao, and Pingyong river systems rather than treating individual river reaches as isolated planning units (Yuan et al., 2026).

Third, flood management should operate through a hierarchical multi-scale spatial system. The Chongqing case demonstrates that flood resilience depends on coordinating runoff generation, drainage, storage, and conveyance across watershed, sub-catchment, neighbourhood, and site scales rather than relying on isolated engineering interventions. This hierarchical organisation provides an important reference for Rongjiang, where flood adaptation should combine river-scale flood corridors, neighbourhood-scale Blue-Green Infrastructure, and site-scale landscape interventions within an integrated planning framework (Sun, 2023).

Fourth, planning strategies should respond to local spatial conditions rather than applying uniform solutions. All three cases emphasise that different topographical conditions, catchments, river reaches, and urban environments require differentiated planning responses. Flood adaptation should therefore be based on local flood characteristics and spatial functions rather than applying standardised engineering or landscape measures throughout the city. This principle directly supports the proposed planning framework for Rongjiang, in which the Old Town, New Town, river corridors, and surrounding mountain areas adopt different flood adaptation strategies according to their physical characteristics, hydrological functions, and levels of flood exposure.

Fifth, landscape-based adaptation should complement rather than replace conventional engineering infrastructure. None of the three cases suggests that landscape interventions alone can eliminate flood risk in mountainous environments. Instead, flood resilience depends on integrating structural protection, catchment management, distributed Blue-Green Infrastructure, river corridor restoration, and multifunctional public open spaces within a coordinated planning framework. Engineering infrastructure provides essential protection against high-magnitude flood events, while landscape-based strategies enhance ecological performance, spatial flexibility, and the adaptive capacity of urban environments. This hybrid planning approach provides the conceptual basis for balancing engineering safety with ecological restoration and urban liveability in mountain valley cities (Chan et al., 2018; Qian & Lyu, 2026).

These transferable planning principles provide the conceptual bridge between the literature review presented in this chapter and the planning framework developed in the subsequent chapters. Rather than directly replicating planning models from other mountain cities, this research adapts their underlying principles to the geographical, hydrological, and planning conditions of Rongjiang. Accordingly, terrain-sensitive spatial planning, catchment-based flood management, hierarchical Blue-Green Infrastructure, adaptive river corridor planning, and multifunctional landscape design form the conceptual foundation of the integrated flood adaptation framework proposed in this study. This framework guides the subsequent assessment of flood vulnerability, planning deficiencies, and landscape interventions, ultimately informing the planning and design strategies developed for Rongjiang County.

2.3 Towards a Conceptual Framework for Flood Management in Rongjiang

Building upon the literature review and comparative case studies presented in the previous sections, this study develops an integrated conceptual framework for flood adaptation in mountain valley cities (Figure 5). Rather than proposing a universal model, the framework establishes a planning structure that links the distinctive flood characteristics of mountain valley environments with context-specific planning principles and landscape-based adaptation strategies. It synthesises the theoretical insights derived from flood resilience, Blue-Green Infrastructure, international planning approaches, and mountain valley case studies into a coherent planning framework that guides both the empirical analysis of Rongjiang and the development of the flood adaptation strategy presented in the subsequent chapters.

The framework recognises that the distinctive flood characteristics of mountain valley cities generate multiple forms of spatial vulnerability through the interaction between natural hydrological processes and urban development. Flash flooding, rapid runoff concentration, compound flooding, and confined valley morphology create complex hydrological conditions that differ fundamentally from those of lowland cities. At the same time, low-lying urban development, fragmented Blue-Green Infrastructure, flood-prone river corridors, limited flood storage capacity, and continuing development pressure increase the exposure and vulnerability of urban systems. Rather than considering these physical and urban characteristics separately, the framework conceptualises flood vulnerability as the result of their continuous interaction, thereby providing the basis for integrated planning responses.

Drawing upon the literature review and comparative analysis, the framework identifies six interconnected planning principles that underpin flood adaptation in mountain valley cities: flood resilience, terrain-sensitive spatial planning, catchment-based management, Blue-Green Infrastructure, adaptive planning, and integrated governance. Together, these principles represent a transition from engineering-oriented flood control towards adaptive landscape planning that works with natural hydrological processes while simultaneously supporting ecological restoration, sustainable urban development, and long-term urban resilience (Ahern, 2011; Oral et al., 2020; Palazzo, 2019).

These planning principles are translated into a series of integrated planning strategies operating across multiple spatial scales. At the city scale, planning coordinates watershed processes and establishes an interconnected Blue-Green Infrastructure network capable of supporting flood adaptation across the urban area. At the river-corridor scale, adaptive riverfront planning, ecological restoration, distributed stormwater management, and floodable public spaces improve flood conveyance while creating opportunities for temporary flood storage and multifunctional landscape use. At the neighbourhood and site scales, local landscape interventions—including bioswales, rain gardens, permeable pavements, detention spaces, and multifunctional public open spaces—enhance stormwater retention and improve everyday urban environments. Rather than functioning as isolated interventions, these measures operate collectively as an integrated landscape system that links catchment processes, river dynamics, urban drainage, and public space within a unified planning framework.

The implementation of these planning strategies aims to achieve four interrelated planning outcomes: reducing flood risk, restoring ecological systems, creating adaptive urban landscapes, and enhancing long-term urban resilience. Instead of attempting to eliminate flood hazards entirely, the framework seeks to improve the capacity of mountain valley cities to anticipate, accommodate, respond to, and recover from flood events through the coordinated application of spatial planning, landscape design, Blue-Green Infrastructure, and conventional engineering measures. In this way, engineering infrastructure and landscape-based adaptation are understood as complementary components of an integrated flood management system rather than competing approaches.

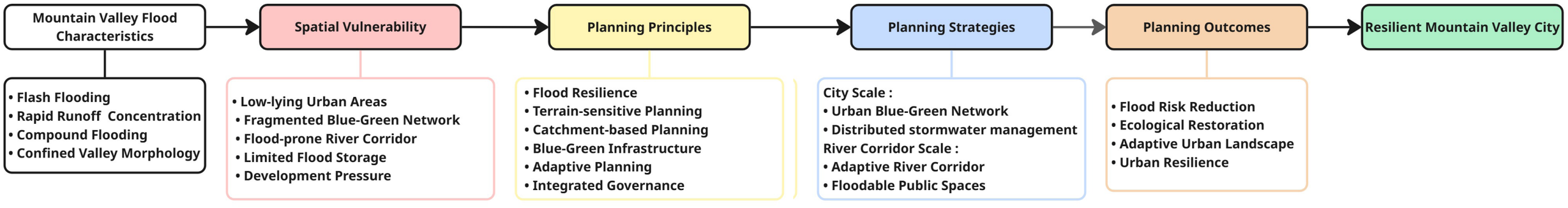


Figure 5. *Conceptual Framework for Flood Adaptation in Mountain Valley Cities. Source: Author.*

PART II - ADDRESSING RONGJIANG CASE STUDY: METHODOLOGICAL FRAMEWORK

03

Research Structure and Phases

This research adopts a sequential mixed-method approach that integrates spatial analysis, planning evaluation, and landscape design to develop a context-specific flood adaptation framework for Rongjiang. Guided by the conceptual framework established in Chapter 2, the methodology combines quantitative analysis of flood characteristics with qualitative assessment of planning and governance before translating the findings into landscape-based planning and design strategies. Rather than developing independent hydrological or hydraulic simulations, the study uses published hydrological information and spatial datasets to support planning analysis and design decision-making. This methodological design reflects the interdisciplinary nature of contemporary flood adaptation research, integrating hydrological analysis with spatial planning and landscape-based resilience (Ahern, 2011; Oral et al., 2020).

The research is organised into six consecutive phases (Figure 2):

The first phase involves data collection, including hydrological records, spatial datasets, satellite imagery, land-use information, and statutory planning documents. These datasets provide the basis for understanding both the physical characteristics of flooding and the existing planning context.

The second phase focuses on flood risk analysis. Published hydrological parameters are combined with GIS-based spatial analysis to examine terrain characteristics, drainage patterns, land use, Blue-Green Infrastructure distribution, and the spatial extent of recent flood events. The purpose of this phase is to identify the hydrological characteristics and spatial vulnerabilities of the study area rather than to undertake detailed hydraulic modelling. Particular attention is given to the interaction between topography, river systems, and urban development, reflecting the distinctive hydrological characteristics of mountain valley cities (Li et al., 2026; Ding, 2022).

The third phase consists of planning and governance evaluation. Through document analysis, planning conformance assessment, and governance mapping, the study evaluates how existing planning policies, land-use regulations, and institutional arrangements address flood resilience. Particular attention is given to identifying the gaps between planning objectives, engineering implementation, and flood management practice. This stage adopts a planning-oriented perspective in which flood adaptation is evaluated not only through engineering performance but also through the effectiveness of spatial planning and governance arrangements (Palazzo, 2019; Ahern, 2011).

The fourth phase develops an integrated planning framework based on the literature review, comparative case studies, and conceptual framework established in Chapter 2. Transferable planning principles are synthesised and adapted to the hydrological, topographical, and urban characteristics of Rongjiang, providing the bridge between the analytical findings and the subsequent planning and landscape design proposals.

The fifth phase develops landscape planning strategies at the city and river-corridor scales. Based on the identified flood characteristics, planning deficiencies, and transferable planning principles, an integrated Blue-Green Infrastructure network, adaptive river corridor strategy, and city-scale flood adaptation framework are proposed to strengthen ecological connectivity and urban flood resilience.

The final phase develops site-specific design proposals. The planning framework is translated into a flood adaptation masterplan together with differentiated landscape design interventions for the Old Town and the New Town. The proposed strategies are subsequently evaluated through a qualitative comparison between their intended planning functions and the flood characteristics identified in the previous analytical phases, thereby assessing the consistency between planning objectives and design outcomes.

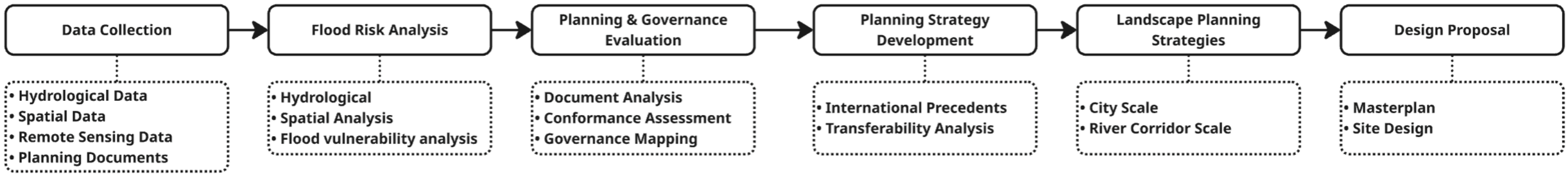


Figure 6. *Research Methodology Framework. Source: Author.*

3.1 Data Collection

To support the flood hazard analysis and planning evaluation, this study collected datasets from multiple authoritative sources, including hydrological records, geospatial datasets, remote sensing imagery, statutory planning documents, and government policy reports. These datasets provide complementary information on flood characteristics, urban spatial conditions, and the existing planning framework. Rather than generating primary hydrological data or undertaking independent hydraulic simulations, this research relies on published datasets, official monitoring records, and statutory planning documents to establish the evidence base for flood analysis, planning assessment, and landscape strategy development. This data-driven approach integrates hydrological information with spatial planning and landscape analysis to support the development of a context-specific flood adaptation framework.

Category	Dataset	Source	Purpose
Hydrological	River discharge, rainfall, flood level	Shihuichang Hydrological Station; Cao (2016); Guizhou Provincial Hydrology Bureau	Flood risk analysis
Remote sensing	Sentinel-1 SAR; Sentinel-2 optical imagery	National Science & Technology Infrastructure of China	Flood inundation mapping
Terrain	DEM	Geospatial Data Cloud	Terrain and drainage analysis
Land use	Land-use/Land-cover	Resource and Environment Science Data Center (RESDC)	Spatial analysis
Infrastructure	Roads, rivers, green space	OpenStreetMap	Urban spatial analysis
Planning	Territorial Spatial Plan (2021–2035)	Rongjiang County Government	Planning evaluation
Policy	Flood Control Plan; Flood Control Project	Government reports	Governance assessment

Table 1. *Principal datasets, data sources, and analytical purposes used in this research. Source: Author's compilation based on the data sources listed in the figure.*

Hydrological and Flood Data

Hydrological information was obtained from published literature, official hydrological reports, and government publications. The principal reference source is the Shihuichang Hydrological Station, the national monitoring station for the Rongjiang urban reach, which provides long-term observations of river discharge, flood level, and rainfall. Additional hydrological information was collected from published research, the Guizhou Provincial Hydrology Bureau, and official government reports to obtain design flood standards, observed flood levels, rainfall records, and other hydrological parameters relevant to flood analysis. Rather than conducting independent hydrological modelling, these published datasets were used to characterise flood magnitude, identify flood frequency, and establish the hydrological basis for subsequent spatial analysis and planning evaluation.

In addition, information relating to the June 2025 flood events was compiled from scientific publications, hydrological bulletins, and official reports. These datasets were used to examine the characteristics of the recent extreme flood events, verify observed flood conditions, and evaluate the performance of existing planning and flood management measures.

Spatial Data

Spatial datasets were collected from open-access geospatial databases and remote sensing platforms to support terrain analysis, flood mapping, and urban spatial assessment. The principal datasets include a Digital Elevation Model (DEM), river network data, land-use and land-cover information, road networks, Blue-Green Infrastructure, and high-resolution satellite imagery.

Remote sensing data from Sentinel-1 Synthetic Aperture Radar (SAR) and Sentinel-2 optical imagery were used to identify flood inundation associated with the June 2025 flood events and to analyse changes in surface water before and after flooding. Together with the DEM, land-use, transportation, and river network datasets, these data provide the basis for analysing terrain characteristics, drainage patterns, runoff pathways, existing Blue-Green Infrastructure, and spatial flood vulnerability within the study area.

To ensure consistency throughout the GIS analysis, all spatial datasets were projected into the WGS 84 / UTM Zone 48N coordinate system before spatial processing and overlay analysis.

Planning and Policy Documents

Planning information was collected from official government websites, statutory planning documents, policy reports, and publicly available planning regulations. The principal documents include the Rongjiang County Territorial Spatial Plan (2021–2035), the Flood Control Plan, the Urban Flood Control Capacity Enhancement Project, relevant water resources planning documents, and associated government policy reports.

These documents provide information on flood management objectives, statutory spatial controls, land-use regulations, implementation mechanisms, and institutional responsibilities. They form the basis for the planning and governance assessment presented in the following section, allowing systematic comparison between declared planning objectives, spatial planning measures, engineering implementation, and existing flood management practices.

3.2 Flood Hazard and Vulnerability Analysis

Flood hazard and vulnerability analysis was undertaken to understand the hydrological characteristics and spatial distribution of flood hazards in Rongjiang. Rather than developing independent hydrological or hydraulic simulations, this study combines published hydrological information with Geographic Information System (GIS)-based spatial analysis and remote sensing interpretation to identify flood-prone areas, drainage patterns, and the interaction between river flooding and pluvial flooding. The objective is not to predict flood inundation through numerical modelling but to provide sufficient hydrological and spatial evidence for planning evaluation and landscape-based flood adaptation. This planning-oriented analytical approach reflects the characteristics of flood adaptation research in mountain valley cities, where hydrological processes are interpreted primarily to support spatial planning and landscape design rather than engineering optimisation (Ding, 2022).

The analytical framework consists of three complementary components: hydrological analysis, spatial analysis, and flood vulnerability analysis (Figure 7). Together, these components establish the physical basis for the subsequent planning and governance assessment.

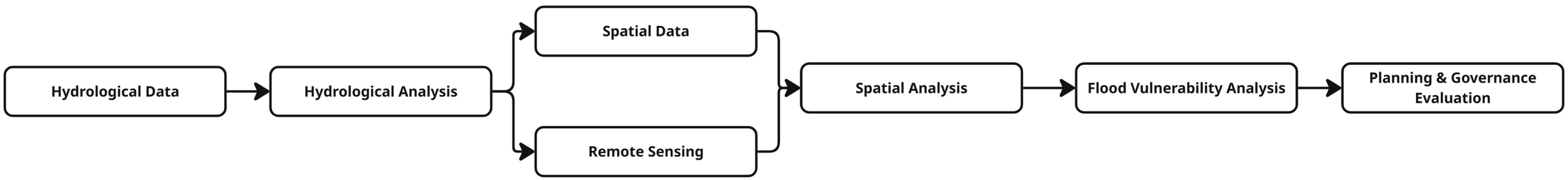


Figure 7. *Flood risk analysis framework. Source: Author.*

Hydrological Analysis

Hydrological analysis was conducted using published hydrological records and official monitoring data to characterise flood magnitude and river behaviour within the study area. River discharge, flood level observations, rainfall records, and design flood standards were collected from published literature, official hydrological reports, the Shihuichang Hydrological Station, and the Guizhou Provincial Hydrology Bureau. These datasets provide the hydrological basis for understanding the frequency, magnitude, and temporal characteristics of flood events affecting Rongjiang.

Rather than constructing new hydrological models, this study adopts existing hydrological information to establish the flood characteristics relevant to planning decisions. Particular attention is given to design flood standards, observed flood events, river discharge characteristics, and the interaction between river flooding and urban flooding. These hydrological characteristics provide the foundation for interpreting flood processes within the spatial analysis and planning evaluation undertaken in the subsequent stages.

Spatial Analysis

Spatial analysis was undertaken using Geographic Information Systems (GIS) to examine the physical characteristics of the study area and identify spatial factors influencing flood vulnerability. Terrain analysis based on the Digital Elevation Model (DEM) was used to investigate elevation, slope, drainage patterns, watershed characteristics, and potential runoff pathways. Land-use data, river networks, transportation systems, existing Blue-Green Infrastructure, and urban development patterns were subsequently integrated to evaluate the relationship between urban development and flood-prone areas.

Remote sensing imagery from Sentinel-1 Synthetic Aperture Radar (SAR) and Sentinel-2 optical imagery was used to identify flood inundation associated with the June 2025 flood events. SAR imagery enabled the delineation of flooded areas during peak inundation, while optical imagery provided additional information on post-flood land-cover conditions and surface water distribution. These datasets were integrated within the GIS environment to identify areas where river flooding and pluvial flooding overlap, thereby supporting the identification of spatial flood vulnerability.

Flood Vulnerability Analysis

The results of the hydrological and spatial analyses were synthesised to identify areas of relatively high flood vulnerability. Rather than producing a quantitative vulnerability index, the analysis adopts a planning-oriented approach that evaluates the interaction between flood hazards and urban spatial characteristics, including topography, land use, drainage conditions, transportation networks, population distribution, and the existing Blue-Green Infrastructure network.

The purpose of the analysis is to identify locations where flood hazards coincide with important urban functions, critical infrastructure, and areas of strategic planning significance. These spatial vulnerabilities provide the basis for the planning and governance assessment presented in the following section and subsequently inform the development of landscape-based flood adaptation strategies for Rongjiang.

The flood hazard and vulnerability analysis therefore establishes the physical evidence base for the planning and governance assessment. By identifying the spatial characteristics, hydrological processes, and urban vulnerabilities associated with flooding, the analysis provides the foundation for developing planning strategies that respond to both river flooding and pluvial flooding within the mountain valley context.

3.3 Planning and Governance Assessment

The planning and governance evaluation examines whether the existing planning system adequately addresses flood resilience in Rongjiang. The evaluation combines qualitative document analysis with planning conformance assessment to examine the consistency between planning objectives, spatial regulations, implementation measures, and institutional responsibilities.

The evaluation focuses on three aspects: planning objectives and statutory policies; spatial planning implementation; governance coordination and institutional arrangements. Rather than assessing planning documents descriptively, the evaluation adopts a planning-oriented perspective to identify inconsistencies between declared resilience objectives and practical implementation. Particular attention is given to the integration of flood risk management into territorial spatial planning, the allocation of blue-green infrastructure, and the coordination between planning authorities and water management agencies. The results of this evaluation are presented in Chapter 4.

3.4 Planning Strategy Development

The planning strategies were developed through the synthesis of the flood hazard and vulnerability analysis, the planning and governance assessment, and the transferable planning principles established in Chapter 2. Rather than replicating individual planning approaches or international case studies, this research adapts their underlying principles to the hydrological, topographical, and urban characteristics of Rongjiang in order to develop a context-specific flood adaptation framework. The strategy development therefore represents the integration of analytical findings with planning theory and landscape-based flood adaptation principles.

The strategy development follows three sequential steps:

First, the spatial constraints and opportunities identified through the flood hazard and vulnerability analysis are translated into planning priorities, establishing the overall direction for flood adaptation.

Second, the planning and governance deficiencies identified through the planning assessment are addressed through an integrated planning framework combining terrain-sensitive spatial planning, catchment-based management, Blue-Green Infrastructure, adaptive river corridor planning, and distributed stormwater management.

Finally, the planning framework is translated into multi-scale planning and landscape design proposals, including a flood adaptation masterplan, a city-scale Blue-Green Infrastructure network, river corridor adaptation strategies, and differentiated landscape design proposals for the Old Town and the New Town.

This process ensures that the proposed planning framework and landscape design respond directly to both the hydrological characteristics and the planning deficiencies identified during the analytical phases. Consequently, the design proposals presented in Chapter 5 are derived systematically from the preceding flood analysis, planning assessment, and conceptual framework rather than representing independent design solutions.

PART III - OPERATIONAL VISIONS FOR
FLOOD RESILIENT MANAGEMENT IN RONGJIANG

04

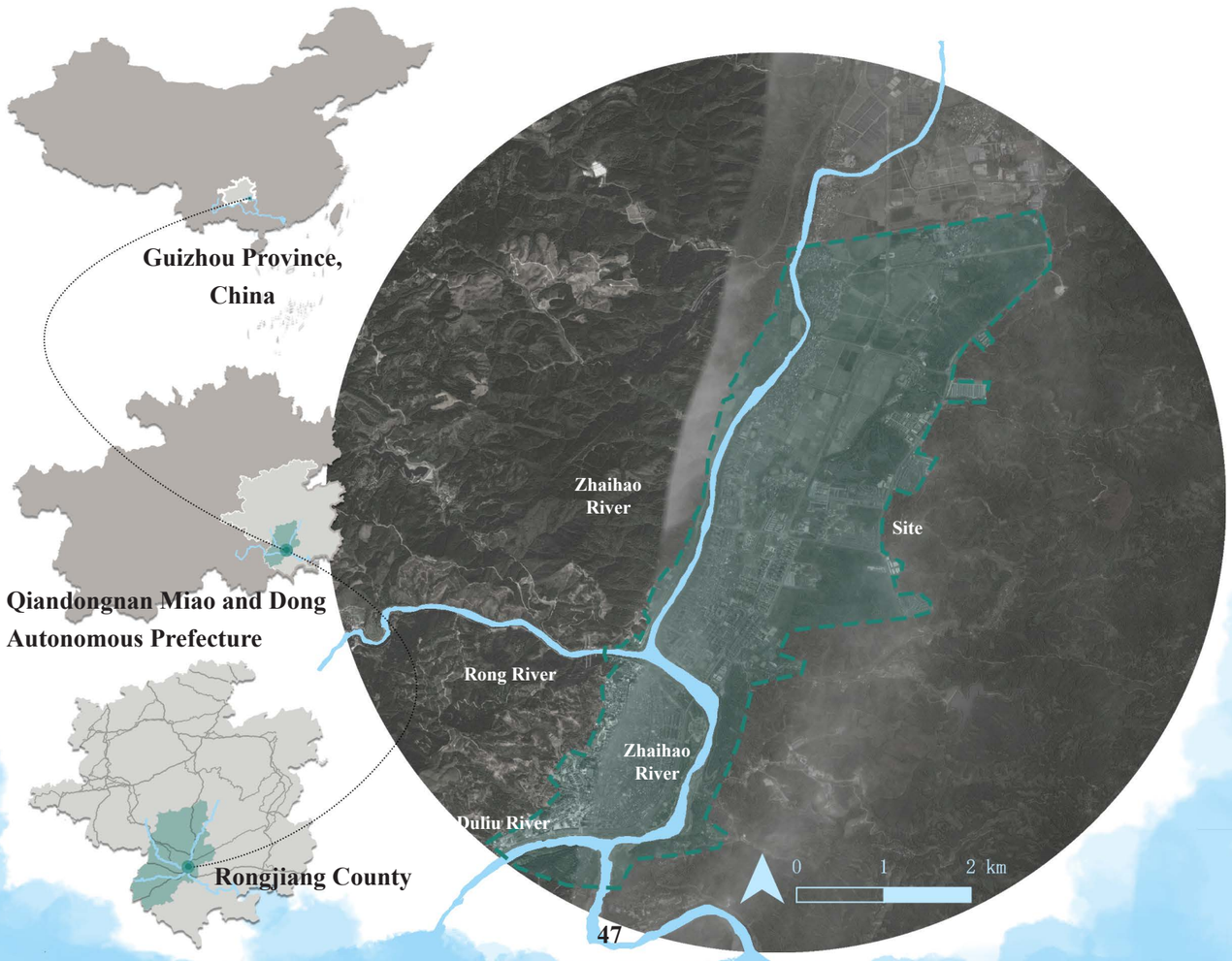
Site Analysis and Planning Assessment

4.1 Site Overview

Rongjiang County is located in the southeastern part of Guizhou Province, China, within the Qiandongnan Miao and Dong Autonomous Prefecture. The county occupies a typical mountain valley setting in Southwest China, where urban development is constrained by steep surrounding mountains and concentrated along narrow river corridors. The county town is situated at the confluence of the Duliu River, Zhaihao River, and Pingyong River, forming a confined valley basin that represents a characteristic mountain valley city (Han, 2001; Liu et al., 2026).

The county has a permanent population of approximately 385,000, of whom more than 83% belong to ethnic minority groups, primarily the Miao and Dong nationalities. Owing to its strategic geographical location, Rongjiang serves as an important transportation node connecting Guizhou Province with Guangxi and the southeastern coastal region of China. In recent years, rapid urbanisation, regional economic development, and the growing influence of the Village Super League (Cun Chao) have accelerated urban expansion, particularly within the northern New Town, increasing development pressure along the valley floor (Rongjiang County People's Government, 2023).

Figure 8. *Location of Rongjiang County and the Study Area. Source: Author's analysis based on google map.*



From a geomorphological perspective, Rongjiang exhibits the defining characteristics of a mountain valley city. The urban area occupies the lowest part of the valley at an elevation of approximately 250–270 m above sea level, while steep mountains enclose the city on both sides. The valley floor provides the only relatively flat land suitable for urban development, resulting in a compact linear urban form extending along the river corridors. However, this geographical setting also places most urban development directly within the natural floodplain, creating an inherent conflict between urban expansion and hydrological processes. Unlike lowland cities, where extensive floodplains provide opportunities for temporary flood storage, Rongjiang's confined valley morphology offers only limited space for flood conveyance and detention, thereby increasing its exposure to flood hazards (Han, 2001; Ding, 2022).

Hydrologically, Rongjiang lies within the upper Pearl River Basin and is characterised by a dense mountain drainage network. The county contains 67 rivers with a combined length exceeding 1,300 km, all of which ultimately converge within the county town. During intense rainfall events, runoff generated from the surrounding mountainous catchments rapidly concentrates into the three principal rivers before entering the urban area. The narrow river channels, together with meandering reaches and multiple confluence zones, substantially restrict flood conveyance capacity and contribute to rapid rises in river water levels during extreme storms. Consequently, flood hazards in Rongjiang are characterised not only by river flooding but also by the interaction between external river floods and internal pluvial flooding (Han, 2001; Yuan et al., 2026).

The vulnerability of this geographical setting was clearly demonstrated during the June 2025 extreme flood events, when two major floods occurred within a single week and inundated more than 80% of the urban area. The events exposed the limitations of conventional flood-control infrastructure under exceptional hydrological conditions and highlighted the challenges of flood adaptation in mountain valley cities. Rather than representing isolated natural disasters, these floods reflected the combined influence of mountainous topography, rapid runoff concentration, river confluences, and intensive urban development within the valley floor (Yuan et al., 2026; Wu, 2026). Consequently, Rongjiang provides a representative case for investigating how landscape planning and Blue-Green Infrastructure can complement conventional engineering measures to strengthen urban flood resilience.

To support the subsequent analysis and planning process, this study distinguishes three nested spatial scales. The hydrological analysis area includes the urban valley, surrounding mountainous catchments, principal river corridors, and upstream flood-control infrastructure, and is used to explain the generation and transmission of flood hazards. The planning area covers the built-up county town together with the river corridors and urban spaces where the integrated flood adaptation framework is developed. Within this planning area, a detailed design area is selected to demonstrate the spatial implementation of representative riverfront adaptation measures and landscape design interventions. These nested boundaries therefore serve different analytical and planning purposes and should not be interpreted as equivalent design extents.

The following section examines the hydrological characteristics and flood processes that underpin flood vulnerability in Rongjiang, providing the physical basis for the subsequent spatial analysis and planning assessment.

4.2 Physical and Flood Context

4.2.1 Mountain Valley Hydrological Characteristics

Rongjiang exhibits the typical hydrological characteristics of mountain valley cities, where flood behaviour is strongly influenced by topography, river morphology, and catchment hydrology. Unlike relatively flat urban catchments, the surrounding mountainous terrain promotes rapid runoff concentration during intense rainfall events, while the confined valley floor limits the space available for flood conveyance and temporary storage. These conditions can result in rapid water-level rise, short flood-response times, and highly dynamic flood processes, which are characteristic of rainstorm and flood hazards in complex mountainous terrain (Han, 2001; Ding, 2022; Wei et al., 2024; Li et al., 2026).

Rongjiang is located at the confluence of the Duliu, Zhaihao, and Pingyong Rivers, where runoff from multiple catchments converges in a narrow urban valley. During extreme rainfall, constrained river sections and urban encroachment restrict flood conveyance, causing floodwater to concentrate within the urban corridor (Han, 2001).a relatively narrow urban corridor (Han, 2001). space available for flood conveyance and may contribute to rapid increases in river level during high-discharge events. Together, the three-river confluence and the spatial constraints of the valley create a hydrological setting in which floodwater becomes concentrated within a relatively narrow urban corridor (Han, 2001).

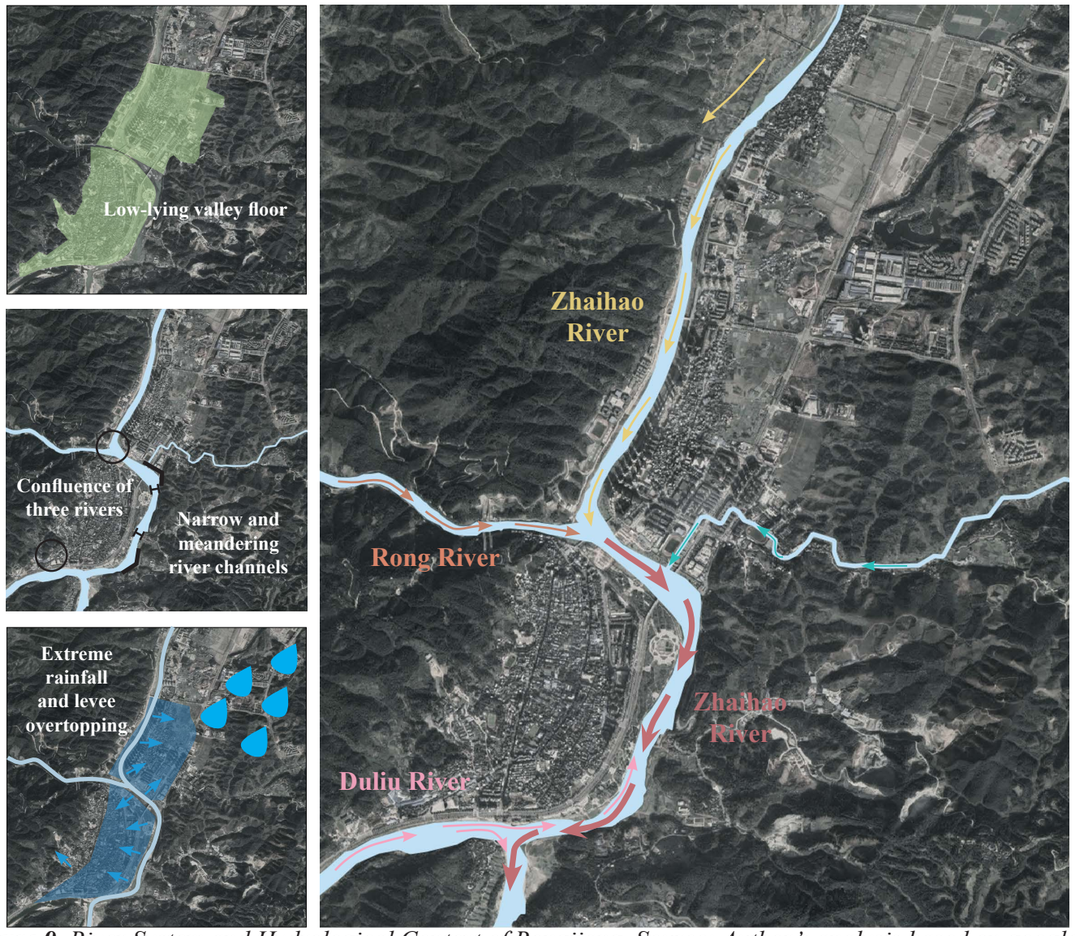


Figure 9. *River System and Hydrological Context of Rongjiang. Source: Author's analysis based on google map.*

Flooding in Rongjiang is further complicated by the interaction between river flooding and locally generated surface runoff. During periods of high river stage, elevated river levels can constrain the effective discharge of urban drainage, while intense rainfall simultaneously generates rapid runoff from the surrounding mountain slopes. This runoff is conveyed towards the valley floor through natural flow paths, streets, and drainage channels, where it interacts with runoff generated within the densely developed urban area and, during severe events, with river flooding. The resulting flood conditions therefore reflect the interaction of fluvial and pluvial processes within a confined mountain-valley setting rather than a single source of flooding (Han, 2001; Ding, 2022; Sun, 2023; Li et al., 2026).

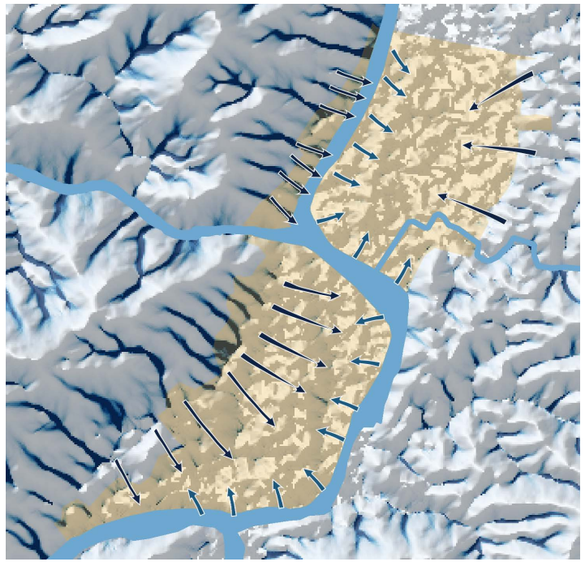


Figure 10. *Mountain Runoff in Rongjiang. Source: Author's analysis based on Geospatial Data Cloud.*

Mountain runoff from surrounding mountains rapidly enters the urban area through roads and low-lying corridors.

These hydrological characteristics indicate that flood adaptation in Rongjiang requires more than reliance on conventional structural flood-control infrastructure alone. River engineering and other structural measures remain essential for managing major river floods, but they need to be complemented by spatial and landscape interventions that manage runoff before it reaches the river system, provide opportunities for temporary flood accommodation where space permits, and adapt urban development to the hydrological constraints of the valley. An integrated approach combining river management, urban stormwater management, Blue-Green Infrastructure, and spatial planning is therefore particularly relevant to the conditions of mountain valley cities (Ahern, 2011; Palazzo, 2019). These characteristics provide the hydrological context for the flood-event analysis presented in the following section and establish the physical basis for the subsequent assessment of urban vulnerability and planning conditions.



Figure 11. *Drainage Patterns in Rongjiang. Source: Redrawn by the author based on google map.*

The urban area is dominated by extensive impervious surfaces, limiting rainwater infiltration and increasing surface runoff during heavy rainfall events.

4.2.2 The June 2025 Flood Event

The hydrological characteristics described above were clearly manifested during the two extreme flood events that affected Rongjiang on 24 and 28 June 2025. The floods caused extensive inundation across the county town, with more than 80% of the urban area affected. At Shihuichang Hydrological Station, the peak discharge on 24 June reached approximately 11,400 m³/s, exceeding the estimated 100-year design discharge of 11,200 m³/s, while the second event also exceeded the 30-year design standard (Cao, 2016; Guizhou Provincial Hydrology Bureau, 2025; Yuan et al., 2026). Table 2 summarises the principal hydrological characteristics of the two events.

The spatial distribution of inundation further reflected the influence of Rongjiang's mountain-valley morphology and urban structure. Severe flooding occurred along the principal river corridors and extended into densely developed low-lying areas, affecting residential neighbourhoods, transport corridors, commercial areas, and public facilities. The observed inundation pattern demonstrates how extreme river discharge combined with the concentration of urban development within the confined valley floor to produce widespread flood exposure (Yuan et al., 2026).

Parameter	Value	Notes
First flood peak discharge	11,400 m³/s	Highest recorded since 1958
Second flood peak discharge	8,000 m³/s	Forecasted at 8,360 m³/s
Peak water level	256.71 m	5.21 m above assurance level (251.50 m)
Cumulative rainfall (18–24 June)	>600 mm	Max point rainfall: 434 mm at Pingyang Station
Inundated urban area	Approx. 80%	Maximum flood depth >2 m
Emergency relocated population	41574	By 18:00, June 28
Direct economic losses	>1 billion RMB	Approximately USD 140 million

Table 2. *Key hydrological characteristics of the June 2025 flood event. Sources: Yuan et al. (2026), Guizhou Provincial Hydrology Bureau (2025), Cao (2016).*

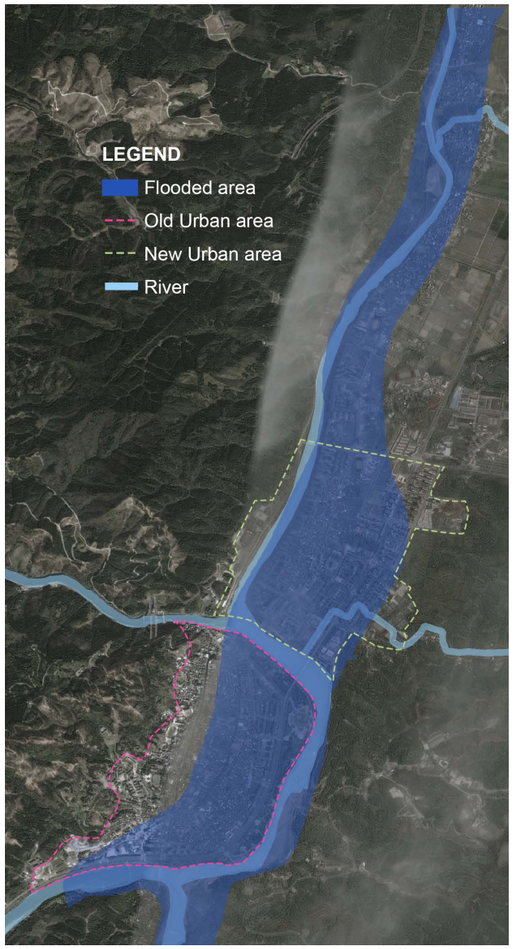


Figure 12. *Flood Inundation Extent of the June 2025 Flood Event.*
Sources: Adapted by the author from Yuan et al. (2026).

The June 2025 floods exposed the limitations of the existing flood-management system under extreme hydrological conditions. When river discharge exceeded established design conditions, the concentration of development within the valley floor and the interaction between river flooding, local runoff, and urban drainage increased the vulnerability of the urban area. Flood risk in Rongjiang therefore cannot be addressed solely through river engineering but requires consideration of the wider relationship between hydrology, urban development, and available flood-compatible space.

The events provide an important empirical basis for the planning and spatial analyses developed in the following sections. In particular, they demonstrate the need to address residual flood risk beyond conventional design standards, providing the hydrological basis for the hierarchical flood adaptation framework developed in Chapter 5.

4.2.3 Implications for Flood Adaptation

The hydrological analysis demonstrates that flood adaptation in Rongjiang requires an approach extending beyond conventional structural flood protection. Upstream reservoirs, river engineering, levees, drainage systems, and pumping stations remain essential for reducing flood risk, particularly during major river floods (Han, 2001). However, the June 2025 events demonstrate that structural measures cannot completely eliminate residual flood risk when extreme hydrological conditions exceed established design capacities (Yuan et al., 2026). Flood adaptation should therefore complement structural protection with measures that increase the capacity of urban systems to accommodate and recover from flooding (Ahern, 2011; Palazzo, 2019).

The interaction of rapid mountain runoff, confined river corridors, and local pluvial flooding further supports a hybrid approach combining engineering protection with landscape-based adaptation. Distributed Blue-Green Infrastructure can intercept, retain, and infiltrate stormwater close to its source, while adaptive river corridors and multifunctional floodable spaces can provide additional opportunities for temporary flood accommodation (Fletcher et al., 2015; Oral et al., 2020). However, the limited availability of open land within Rongjiang's narrow valley floor constrains opportunities for large-scale landscape storage (Han, 2001). Landscape-based measures should therefore complement, rather than replace, conventional flood-control infrastructure.

These findings provide the hydrological basis for the planning and governance assessment developed later in this chapter and establish the physical context for the strategies proposed in Chapter 5. In particular, the relationship between structural protection, distributed Blue-Green Infrastructure, and flood-compatible open space informs the hierarchical flood adaptation framework developed for Rongjiang.

4.2.4 River Dynamics and Flood Vulnerability

River Dynamics

The river dynamics of Rongjiang are strongly influenced by its mountain valley morphology and the convergence of the three principal rivers. As floodwater generated from upstream catchments enters the confined valley, flow becomes concentrated within the river corridor before passing through the urban area. The limited width of the valley floor, together with meandering river sections and locally constrained channels, restricts the space available for flood conveyance and contributes to rapid water-level changes during extreme rainfall events (Ding, 2022; Wei et al., 2024).

River conditions vary considerably along different sections of the urban corridor. In the northern New Town, the Zhaihao River passes through a relatively confined corridor with limited adjacent floodplain space, restricting opportunities for lateral flood accommodation. By contrast, the historic Old Town is located around the wider confluence of the Duliu, Zhaihao, and Pingyong Rivers, where flows from multiple upstream catchments converge. These differences in river morphology create contrasting spatial conditions for flood conveyance and accommodation between the two urban districts. The surrounding mountainous catchments further intensify these processes. During heavy rainfall, runoff from hillslopes rapidly converges towards the valley floor through topographically controlled drainage pathways, increasing both river discharge and surface runoff entering the urban area. Flood conditions therefore reflect the combined influence of river processes and rapid runoff concentration within the mountainous catchment (Ding, 2022; Li et al., 2026).

Spatial Distribution of Flood Vulnerability

Spatial analysis combining flood inundation mapping, topography, land use, and urban infrastructure reveals a distinct pattern of flood vulnerability across the study area. The highest levels of flood exposure are concentrated within the low-lying valley floor, particularly around the three-river confluence and adjacent riverside districts. These areas experienced extensive inundation during the June 2025 flood events and contain a high concentration of residential neighbourhoods, commercial activities, and public facilities (Yuan et al., 2026). Differences between the historic Old Town and the northern New Town are also evident. The Old Town is characterised by high building density, limited public open space, and narrow streets, reducing the spatial capacity available for flood adaptation. In contrast, although the New Town contains comparatively larger open spaces and wider streets, substantial recent development remains located within flood-prone areas adjacent to the river corridor. Consequently, vulnerability in the New Town is primarily associated with flood exposure, whereas vulnerability in the Old Town is further intensified by its dense urban morphology and limited adaptive space. The overlay of flood extent with urban infrastructure further indicates that several principal roads, public facilities, and riverside open spaces are located within areas affected by flooding. This spatial coincidence demonstrates that flood impacts extend beyond individual residential areas and can disrupt the functioning and connectivity of the broader urban system during extreme events.

Synthesis of Flood Risk Characteristics

The spatial analyses indicate that flood vulnerability in Rongjiang results from the interaction of physical and urban factors rather than from a single hydrological process. Mountain runoff, river dynamics, confined valley morphology, urban expansion, and the concentration of development within low-lying areas collectively shape the observed pattern of flood vulnerability. Three characteristics are particularly evident. First, flood exposure is concentrated within the narrow valley floor, where urban development is also most intensive. Second, river flooding interacts with locally generated surface runoff during extreme rainfall, increasing flood pressure within the confined urban area. Third, differences in urban morphology between the historic Old Town and the northern New Town create contrasting patterns of vulnerability and different capacities for spatial adaptation. These findings provide the analytical basis for evaluating the adequacy of the existing planning framework in the following section and establish the spatial rationale for the differentiated flood adaptation strategies developed in Chapter 5.

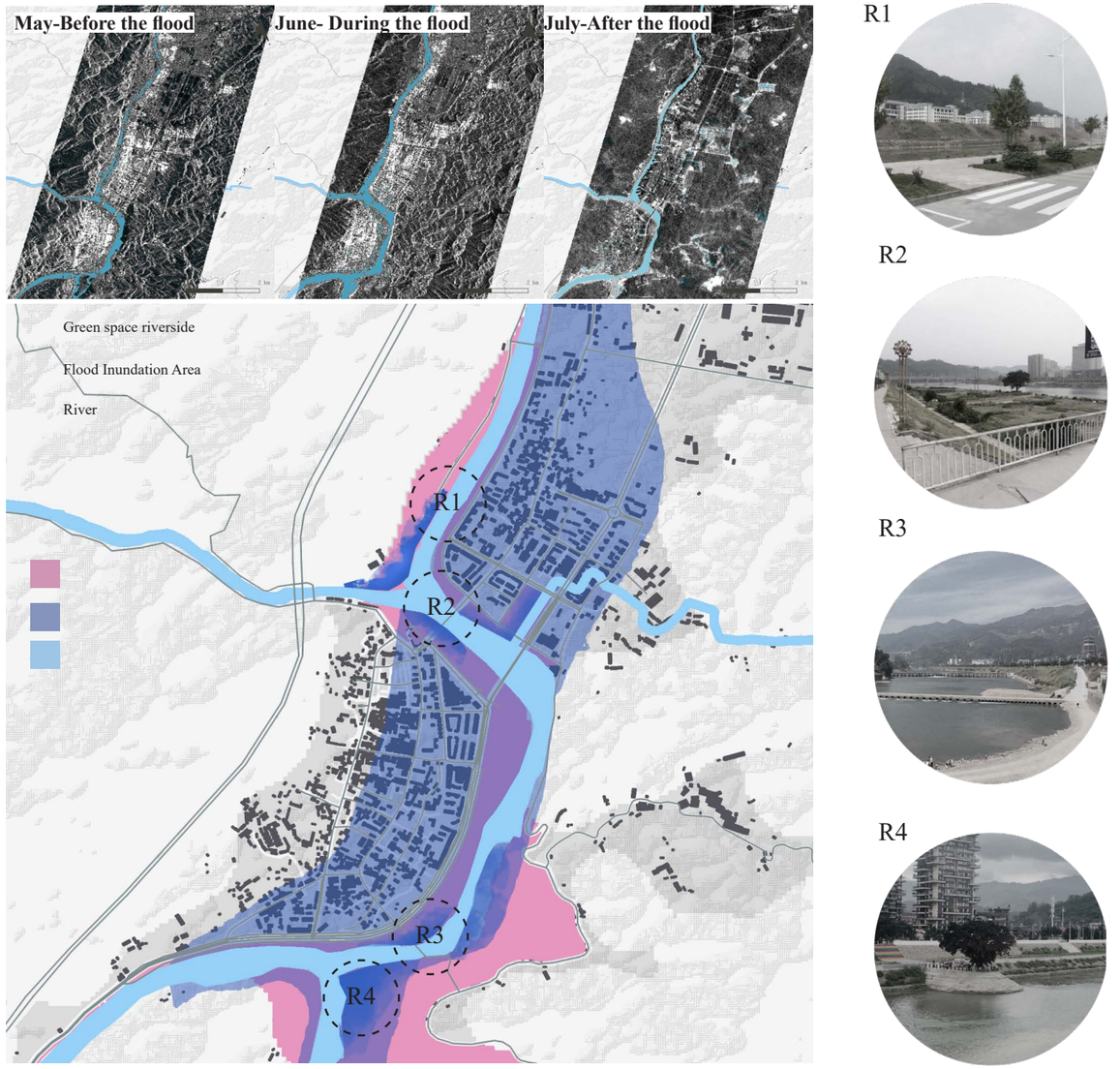


Figure 13. *River Dynamics and Flood Vulnerability in Rongjiang. Sources: Author's analysis based on Sentinel-1 SAR; Sentinel-2 optical imagery.*

4.2.5 Urban Structure

Historical Urban Development

Rongjiang's historical development was strongly influenced by the valley topography and river system. The earliest town settlement formed around the confluence of the Duliu River, Zhaigao River, and Pingyong River in the southern part of the county; this area had relatively flat terrain and convenient water transport, which supported commercial activities and administrative functions, and it gradually developed into the historic old town (Guzhou), showing characteristics of compact urban blocks, narrow streets, and high-density mixed development. Because the developable land on the valley floor was limited, historical urban growth mainly extended eastward and westward along the river corridors rather than expanding toward the surrounding mountains, forming a spatial pattern in which natural landforms and human settlement interacted closely.

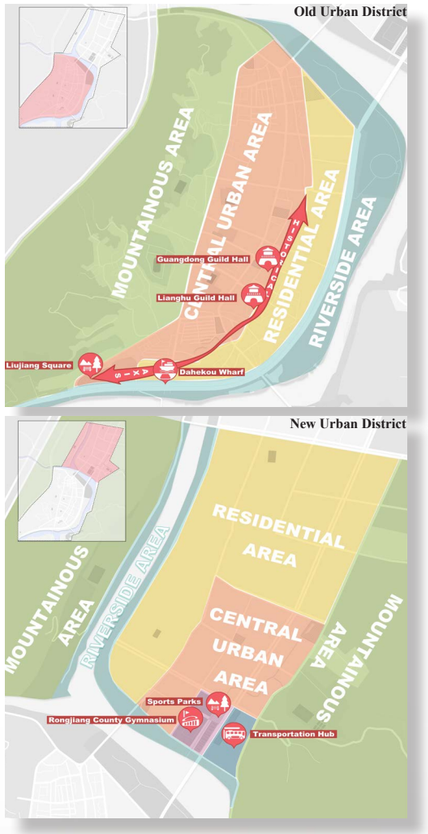


Figure 14. *Spatial Structure of the Old Town and New Town in Rongjiang. Sources: Author.*

Rapid urbanisation over the past two decades has significantly changed Rongjiang's spatial structure. The historic core remains concentrated in the southern old town, while after the implementation of the 2009 master plan, major development shifted to the northern new town.

The new town has wider roads, newer residential areas, public facilities, and larger development plots, with more modern planning standards. However, the overall urban form is still constrained by the narrow valley floor: development is distributed along both banks of the Zhaigao River, connected by a small number of bridges, forming a compact but spatially fragmented pattern. High-density residential areas, commercial centres, schools, and public facilities are concentrated in the low-lying valley floor, while the surrounding hillsides remain largely undeveloped. Urban expansion has been driven mainly by topography rather than flood risk, and the scarcity of developable land has pushed population and facilities toward flood-prone areas, making the current urban structure reflect both the constraints of the valley topography and the long-term accumulation of development within the floodplain. Under these conditions, Rongjiang presents a dual-centre structure in which the dense historic old town in the south and the rapidly expanding new town in the north coexist, and the two are mainly connected through the river corridor. The connectivity of different parts of the city depends not only on the road network, but also on the spatial relationships among rivers, bridges, and topography. Traffic and activity corridors are concentrated on the valley floor, forming a highly ordered urban fabric, but this also limits the spatial flexibility of future urban expansion. There are clear differences between the old town and the new town in terms of morphological characteristics and flood vulnerability, and these spatial differences provide the basis for the zoning planning and landscape strategies in Chapter 5; they will be further developed in the subsequent analysis of land use, blue-green infrastructure, and flood vulnerability.



Figure 15. *Spatial Distribution of Major Urban Landmarks in Rongjiang. Sources: Author.*

4.2.6 Land Use and Green Open Spaces

Land Use Pattern

The current land-use pattern of Rongjiang reflects the strong influence of its mountain valley setting. Urban development is concentrated almost entirely on the narrow valley floor, while the surrounding hillsides remain predominantly covered by forests and agricultural land. As a result, the urban area forms a compact development corridor confined by topography and closely associated with the three river systems (Rongjiang County People's Government, 2023).

Within the built-up area, land uses are characterised by a clear spatial differentiation between the historic Old Town and the northern New Town. The Old Town contains a dense mixture of residential, commercial, and public functions organised within a compact street network, whereas the New Town accommodates larger residential neighbourhoods, educational facilities, sports venues, and administrative buildings. Public services and commercial activities are primarily concentrated within the central valley floor, where accessibility is highest but flood exposure is also greatest .

The distribution of urban functions indicates that a substantial proportion of residential areas, public facilities, transportation infrastructure, and commercial activities are located adjacent to the river corridors and other low-lying areas. Consequently, flood events affect not only residential neighbourhoods but also critical urban functions, increasing the potential for widespread disruption during extreme rainfall events.

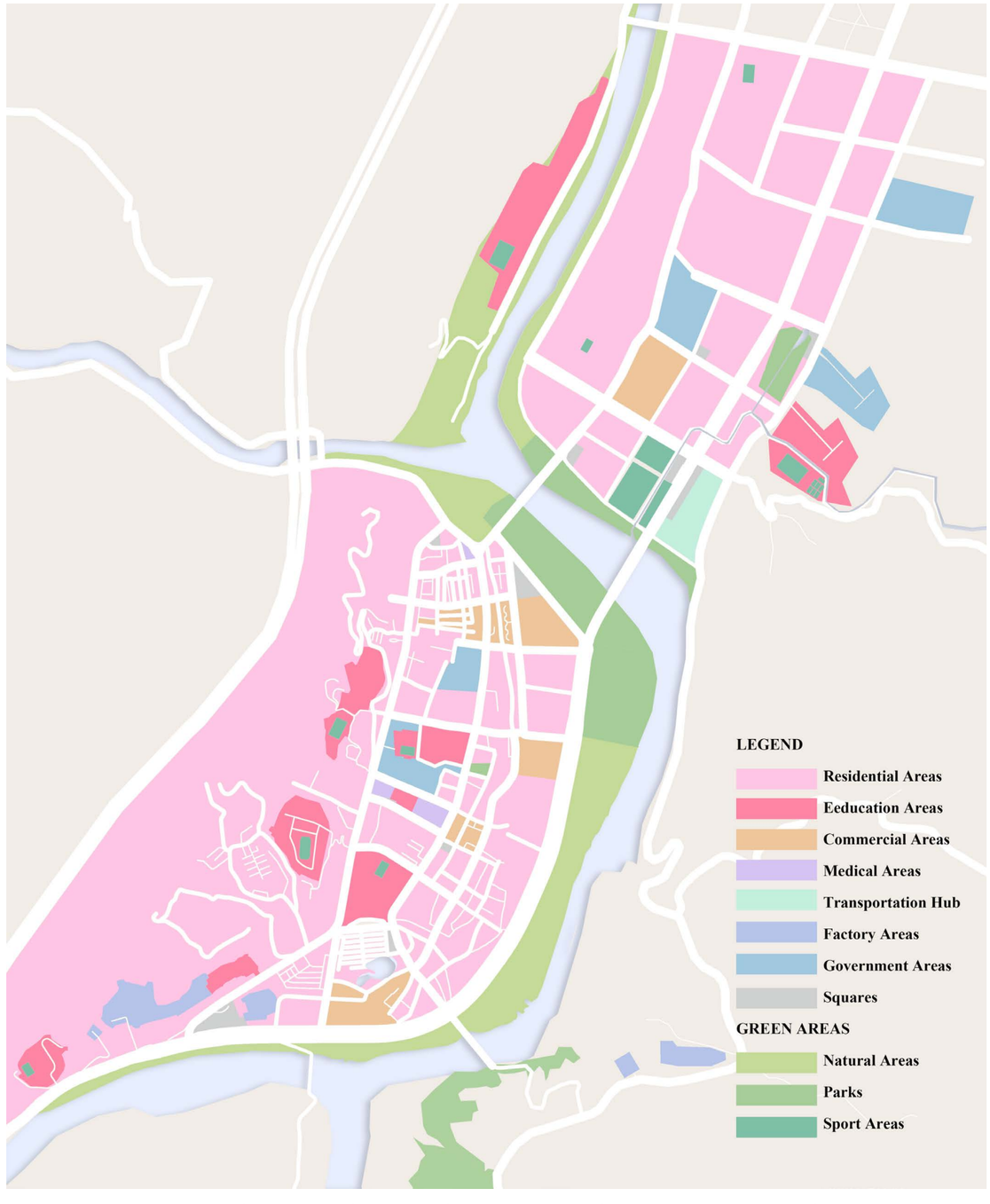


Figure 16. *Land-Use Distribution in the Rongjiang Urban Area. Sources: Author.*

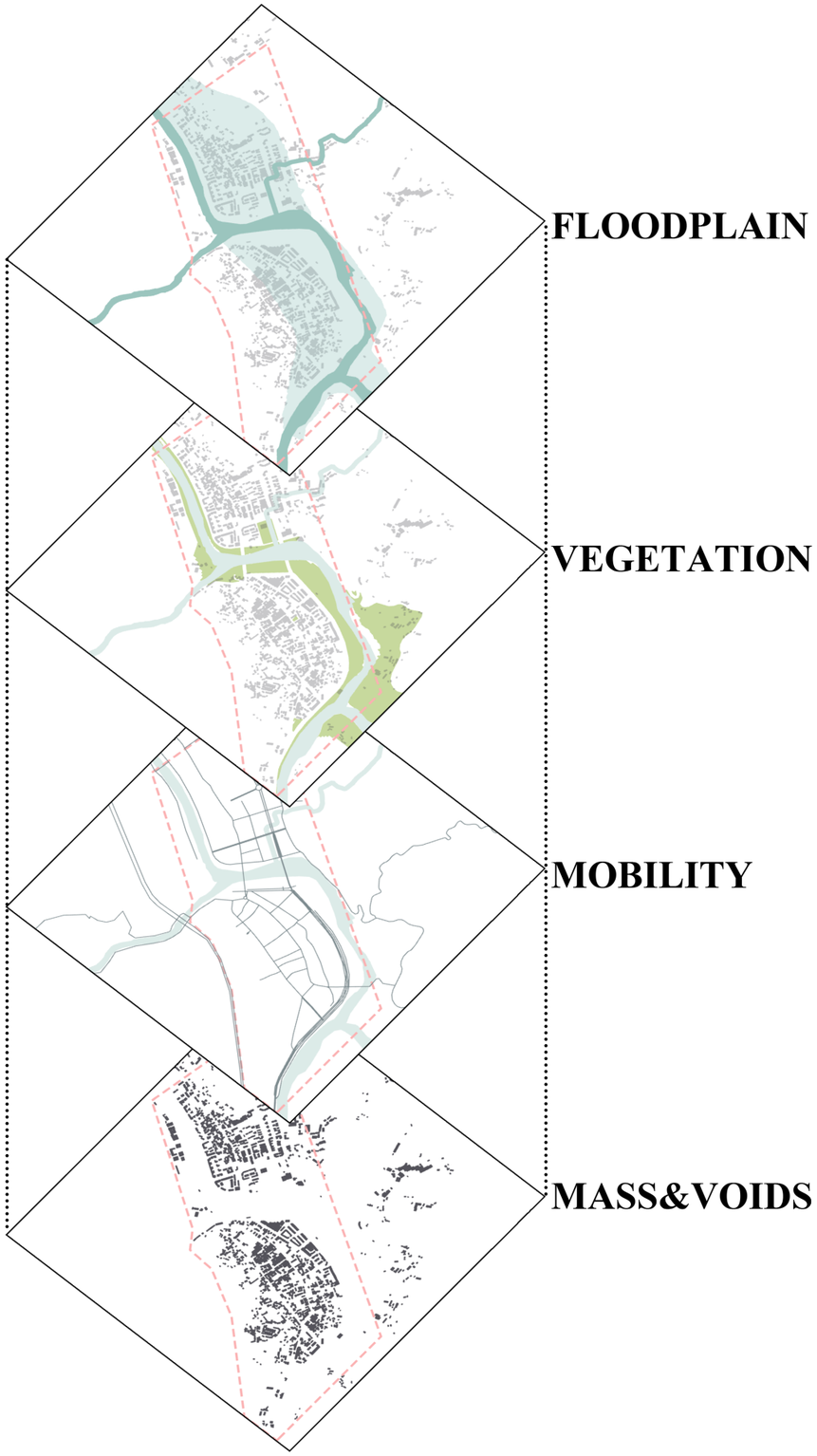


Figure 17. *Spatial Structure Analysis of Rongjiang Urban Area. Sources: Author.*

Existing Green Open Spaces

The existing green infrastructure system is characterised by an uneven spatial distribution and limited connectivity. Green spaces are primarily concentrated along riverbanks, neighbourhood parks, roadside planting strips, and scattered public open spaces, while large continuous urban parks are relatively scarce. Although the surrounding mountains provide extensive natural vegetation, these ecological resources remain largely disconnected from the internal urban green space system.

Differences between the Old Town and the New Town are particularly evident. In the historic Old Town, high building density and limited open space restrict the availability of green infrastructure. Riverside spaces are generally narrow and fragmented, while internal neighbourhoods contain relatively few public green areas. As a result, opportunities for stormwater infiltration and temporary surface storage are limited.

By comparison, the northern New Town contains wider roads, larger public open spaces, school campuses, and sports facilities, creating comparatively better conditions for integrating green infrastructure. Nevertheless, these green spaces currently function primarily as recreational and ornamental landscapes rather than as components of an interconnected ecological network. Connections between riverside parks, street greenery, public open spaces, and surrounding natural landscapes remain weak.

Overall, the existing green infrastructure exhibits a fragmented spatial pattern. Although individual green spaces are distributed throughout the urban area, they do not currently operate as an integrated system capable of supporting ecological connectivity or improving the hydrological performance of the urban landscape. These characteristics establish the spatial basis for the flood vulnerability assessment and the Blue-Green Infrastructure planning strategies developed in the following sections.



Figure 18. *Existing Green Infrastructure Network in Rongjiang. Sources: Author.*

4.2.7 Mobility Analysis

Road Network and Urban Mobility

The mobility network of Rongjiang has developed in close response to the constraints imposed by its mountain valley landscape. Owing to the limited width of the valley floor, the primary road system extends predominantly along the river corridors, forming a linear transportation structure that connects the historic Old Town with the northern New Town. Several bridges across the Zhaihao River provide the principal east–west connections, while the surrounding mountains restrict opportunities for alternative transport routes (Rongjiang County People's Government, 2023).

Distinct differences can be observed between the two urban districts. The historic Old Town is characterised by a dense street network composed of narrow roads and compact urban blocks that evolved gradually through historical development. This fine-grained street pattern supports local accessibility and pedestrian movement but offers limited capacity for future road expansion. By contrast, the northern New Town follows a more regular street layout established under the 2009 Urban Master Plan, with wider roads, larger intersections, and improved vehicular accessibility that reflect contemporary planning standards (Han, 2001; Rongjiang County People's Government, 2023).

Although the overall transportation system functions effectively under normal conditions, the urban structure remains strongly dependent on a limited number of primary roads and bridge crossings. Consequently, mobility throughout the county town is concentrated within several key transport corridors that traverse the valley floor and connect the two urban districts.

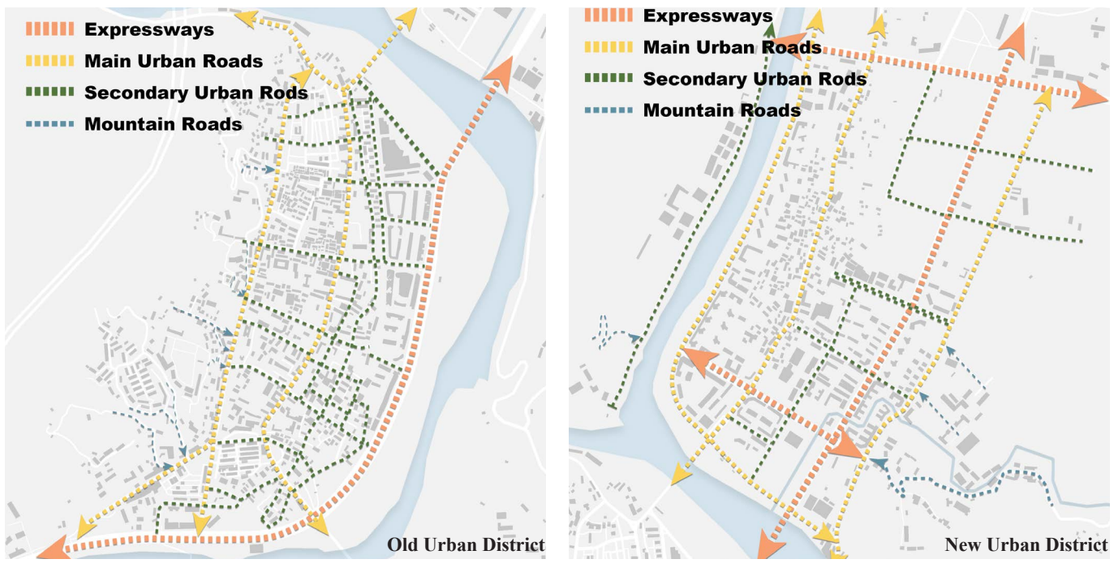


Figure 19. *Urban Mobility Network in Rongjiang. Sources: Author.*

4.3 Planning and Governance Assessment

4.3.1 Planning Objectives: Declared Goals and Spatial Ambitions

The Rongjiang County Territorial Spatial Plan (2021–2035) was approved by the Guizhou Provincial Government in June 2025 (Rongjiang County People's Government, 2023). As the county's highest statutory spatial planning document, it establishes three legally binding spatial control lines: the permanent basic farmland protection line, the ecological protection red line, and the urban development boundary. Together, these instruments constitute the principal legal framework governing future land development and spatial growth.

Within this framework, the plan explicitly recognises flood resilience as a strategic planning objective. It proposes to delineate flood risk control lines and water body protection lines, optimise the systematic allocation of Blue-Green Infrastructure and open spaces, improve disaster prevention infrastructure, and enhance territorial spatial resilience. These objectives reflect China's broader transition towards climate adaptation, disaster risk reduction, and resilience-oriented spatial planning within the Territorial Spatial Planning Reform (Rongjiang County People's Government, 2023).

However, the existence of planning objectives does not necessarily imply the existence of effective planning instruments. Planning objectives express strategic ambitions, whereas planning instruments determine how these ambitions are translated into legally enforceable spatial regulations and development decisions. A critical examination of the Rongjiang Territorial Spatial Plan reveals that this translation mechanism remains weak.

Although the plan identifies flood risk control lines, it does not specify corresponding land-use restrictions, development intensity controls, mandatory flood-adaptive design standards, or designated flood storage areas within these zones. Likewise, while the plan promotes the establishment of a Blue-Green Infrastructure network, it neither identifies specific ecological corridors nor defines implementation priorities or performance requirements. Consequently, resilience remains primarily a strategic planning vision rather than a binding spatial planning instrument.

This limitation is particularly significant in Rongjiang's mountain valley context. The county seat is located almost entirely on the narrow valley floor where developable land coincides with areas exposed to the highest flood risk. At the same time, the plan promotes industrial development and continued tourism expansion associated with the rapid growth of the Village Super League (Cun Chao). Although both economic growth and flood resilience are recognised as planning objectives, the planning framework provides no explicit mechanism for balancing these competing priorities (Rongjiang County People's Government, 2023).

The result is therefore a structural contradiction: the areas with the greatest development potential are simultaneously those with the greatest flood exposure, yet the planning system lacks regulatory instruments capable of reconciling these competing objectives.

4.3.2 Planning Instruments: Formal Completeness and Procedural Fragmentation

From an institutional perspective, Rongjiang possesses a relatively complete planning instrument system. The Territorial Spatial Plan provides the strategic framework, while the Detailed Control Plan, currently under revision, is intended to translate strategic objectives into plot-level regulations through land-use zoning, development intensity controls, building setbacks, and infrastructure requirements. The county's Flood Control Plan establishes engineering standards and flood protection levels, while the Water Project Planning Consent procedure requires engineering projects to demonstrate compliance with higher-level river basin planning before implementation (Rongjiang County Government, 2025–2026).

Taken individually, these instruments appear comprehensive. Collectively, however, they function as largely independent procedures rather than as an integrated planning system. The most significant weakness lies in the missing transmission mechanism between strategic planning and implementation. Until the Detailed Control Plan is formally adopted, the flood risk control lines identified in the Territorial Spatial Plan cannot be translated into legally enforceable development controls at the parcel level. Similarly, the Water Project Planning Consent procedure evaluates compliance with basin-level flood management requirements but does not require engineering projects to demonstrate consistency with the spatial resilience objectives established in the Territorial Spatial Plan.

Consequently, planning instruments function primarily as procedural approval mechanisms rather than substantive instruments for flood adaptation. Compliance is assessed through administrative procedures, whereas spatial integration between land-use planning, flood risk management, and Blue-Green Infrastructure remains largely absent within the existing planning framework.

4.3.3 Governance and Implementation Gaps

The limitations of the planning framework are reinforced by a fragmented governance structure. Responsibility for flood management is distributed among several government departments with limited institutional integration.

The Natural Resources Bureau is responsible for territorial spatial planning and land-use regulation. The Water Resources Bureau manages hydrological monitoring, river engineering, and flood forecasting. The Emergency Management Bureau coordinates disaster response, while water-related administrative enforcement has been transferred to the Comprehensive Law Enforcement Bureau. Although each institution has clearly defined responsibilities, no single organisation is responsible for ensuring that planning objectives are translated into engineering decisions or that flood resilience is addressed through an integrated spatial governance framework.

This fragmentation is particularly evident in the implementation of the Rongjiang County Urban Flood Control Capacity Enhancement Project, which includes river regulation works, levee construction, drainage upgrades, pumping stations, and flood-diversion infrastructure (Rongjiang County Government, 2024).

Beyond the urban engineering works, the regional flood-control strategy also incorporates a series of upstream reservoir projects, including the Hongyan, Dingwei, and Zhongcheng reservoirs, which are intended to attenuate flood peaks before floodwaters enter the confined urban valley. Together with river regulation, levees, pumping stations, and drainage improvements, these projects constitute a multi-layer engineering system operating at the catchment scale. Nevertheless, upstream regulation primarily reduces flood peaks at the catchment scale and cannot completely eliminate flood risk within the county town, particularly when extreme river flooding coincides with intense local rainfall, pluvial flooding, and the limited floodplain capacity of the mountain valley (Wu, 2026).

Procedurally, the project complies with the Territorial Spatial Planning approval process. Substantively, however, its design decisions—including levee alignments, tunnel locations, pumping station siting, and the coordination of upstream engineering works—are determined primarily through hydraulic engineering criteria rather than spatial planning objectives.The existing and planned flood-management framework therefore consists of several complementary layers, ranging from catchment-scale flood regulation to urban drainage and river engineering. However, coordination between these different levels of flood management remains limited. Catchment-scale engineering, river regulation, and urban planning continue to be implemented largely through separate institutional and technical processes rather than as an integrated flood-adaptation system.

The implementation gap can therefore be understood through four interconnected factors. First, the transmission mechanism from flood risk control lines to engineering siting remains absent because the Detailed Control Plan has not yet operationalised these strategic objectives. Second, engineering approval procedures evaluate procedural compliance rather than substantive planning integration. Third, engineering optimisation continues to dominate decision-making, with structural flood protection remaining the preferred response even where more integrated spatial alternatives have previously been identified. Finally, institutional responsibilities remain fragmented, preventing any single authority from coordinating planning, engineering, ecological restoration, and urban development within a unified flood adaptation framework.

The principal challenge of flood resilience in Rongjiang is therefore not the absence of planning objectives, but the absence of planning instruments capable of translating those objectives into spatial decisions. Existing planning documents recognise resilience as a strategic priority, yet the mechanisms required to implement these ambitions through land-use regulation, development control, and engineering coordination remain insufficient.

This institutional disconnection provides the central justification for the planning strategy proposed in this study. Rather than replacing conventional engineering infrastructure, the proposed Blue-Green Infrastructure framework is conceived as a spatial framework for reconnecting planning objectives with engineering implementation. By integrating adaptive riverfronts, multifunctional public spaces, ecological corridors, and flood-responsive urban landscapes within a coherent spatial framework, the proposed strategy seeks to bridge the existing gap between territorial planning and flood management while strengthening the long-term resilience of mountain valley cities. The planning framework developed in Chapter 5 is intended to provide this missing spatial integration by linking flood risk management, Blue-Green Infrastructure, and adaptive landscape planning within a unified planning strategy.

4.4 Problem Identification

The preceding analyses demonstrate that flood vulnerability in Rongjiang is not solely the result of extreme hydrological conditions but also reflects the interaction between urban development, spatial structure, land-use patterns, and planning implementation. Although the existing planning framework recognises the importance of flood resilience, the spatial analyses presented in this chapter reveal several critical issues that continue to constrain effective flood adaptation. These issues provide the analytical basis for the planning strategies developed in Chapter 5.

4.4.1 High Exposure of Urban Development within the Valley Floor

The concentration of residential neighbourhoods, public facilities, commercial centres, and transportation infrastructure within the limited valley floor has substantially increased urban exposure to flooding. Historical urban growth and recent expansion have both followed the relatively flat land adjacent to the river corridors, resulting in a spatial overlap between areas of intensive development and areas of highest flood hazard. Consequently, flood risk is closely associated with the long-term pattern of urban development rather than with individual flood events alone.

4.4.2 Fragmented System of Green Spaces

Existing green spaces are unevenly distributed and remain largely disconnected from one another. Although riverside parks, neighbourhood green spaces, and surrounding natural landscapes are present, they do not function as an integrated Blue-Green Infrastructure system capable of supporting ecological connectivity or improving urban hydrological performance. The fragmented spatial structure limits opportunities for distributed stormwater management and reduces landscape adaptability during flood events.

4.4.3 Engineering-Dominated Riverfronts

Flood management along the river corridors continues to rely primarily on conventional engineering infrastructure, including embankments and channel modification. While these measures provide essential flood protection, they also reduce the interaction between urban space and natural river processes. Opportunities to integrate flood adaptation with ecological restoration and multifunctional public space remain limited, particularly within the densely developed sections of the riverfront.

4.4.4 Lack of Integrated Stormwater Management

The existing drainage system remains largely dependent on conventional pipe drainage and engineered channels, while natural runoff pathways from the surrounding hillslopes are insufficiently integrated into the urban landscape. Surface runoff is rapidly conveyed towards low-lying urban areas, where limited infiltration and temporary storage increase the likelihood of pluvial flooding during extreme rainfall events.

4.4.5 Gaps between Planning Objectives and Spatial Implementation

According to the planning assessment, the Rongjiang County Territorial Spatial Plan (2021–2035) has recognised flood resilience as a strategic objective; since the Plan is still within its implementation period, these objectives are gradually being turned into spatial planning controls, Blue-Green Infrastructure networks, and coordinated implementation mechanisms. At the current stage, however, there are still opportunities to further strengthen the integration of flood resilience objectives with spatial planning and implementation across different scales, and in particular, stronger coordination between catchment-scale flood regulation, river engineering, urban land-use planning, and distributed Blue-Green Infrastructure could help to progressively implement a more integrated multi-scale flood adaptation framework (Guizhou Provincial Government, 2025).

Together, these five issues indicate that improving flood resilience in Rongjiang requires more than enhancing conventional flood-control infrastructure alone. Future flood adaptation should strengthen the spatial integration between urban development, river systems, Blue-Green Infrastructure, and planning implementation. Based on these identified issues, Chapter 5 develops an integrated landscape planning framework that combines flood adaptation, Blue-Green Infrastructure, and spatial planning to improve the resilience of mountain valley cities.

05

Flood Adaptation Strategy and Design Proposal

5.1 Design Vision and Planning Objectives

This study uses the design vision “Adapting to Floods Rather than Controlling Floods”; this vision comes from Yu et al. (2015), who argue that human activities and urban development should be adapted to natural water processes instead of making water adapt to human needs. This vision recognises that flooding is an inherent characteristic of mountain valley cities rather than a hazard that can be completely eliminated through engineering infrastructure alone (Ahern, 2011). The June 2025 flood showed that even substantial structural flood-control measures may be exceeded in extreme events, which highlights the need for a more adaptive approach to flood management.

Instead of trying to completely prevent flooding, this study suggests that floodwater should be accommodated by spatial planning and landscape design wherever appropriate. Public spaces continue to work as parks, waterfronts, streets, and recreational areas under normal conditions. When river levels are high or rainfall is extreme, selected spaces are designed to temporarily hold floodwater; this reduces pressure on the urban flood-management system and keeps their ecological and social functions after flooding has receded. This approach treats floodwater as a dynamic natural process that can be integrated into the urban landscape rather than excluded from it (Ahern, 2011; Chan et al., 2018).

The planning and governance assessment in Chapter 4 shows that flood resilience in Rongjiang depends on multiple layers of flood management working together; based on this, the proposed strategy recognises this dependence. Before floodwaters reach the urban area, upstream reservoirs and catchment-scale flood regulation reduce flood peaks; river engineering, levees, pumping stations, and drainage infrastructure provide structural protection and flood conveyance; landscape planning and Blue-Green Infrastructure address residual flood risk by temporary flood storage, stormwater management, ecological restoration, and adaptive public spaces within the built-up area. Rather than replacing conventional engineering infrastructure, the proposed planning framework complements the existing flood-management system by integrating grey and blue-green infrastructure across multiple spatial scales (Ahern, 2011; Chan et al., 2018).

So, the proposed design strategy follows four related objectives:

1.To reduce flood exposure through integrated spatial planning;

2.To establish a connected Blue-Green Infrastructure network that enhances stormwater management and ecological connectivity;

3.To create adaptive riverfronts and multifunctional floodable public spaces that accommodate periodic inundation;

4.To strengthen the long-term resilience of Rongjiang through the coordinated integration of engineering infrastructure, landscape planning, and governance.

These objectives give the conceptual base for the flood adaptation framework and planning strategies that are developed in the next sections.

5.2 Flood Adaptation Framework for Different Return Periods

5.2.1 Hydrological Basis for Flood Adaptation

The selection of appropriate flood adaptation strategies requires a clear understanding of the magnitude and frequency of flood events. In mountain valley cities, where limited floodplain space and rapid runoff concentration significantly constrain flood management, planning measures should be matched to different levels of flood hazard rather than relying on a single design standard (Liu et al., 2026; Cao et al., 2022). Consequently, this study adopts a return period-based framework to establish the hydrological basis for subsequent planning and landscape interventions.

The hydrological reference adopted in this research is based on the design flood analysis conducted for the Shihuichang Hydrological Station, located immediately upstream of Rongjiang County (Cao, 2016).estimated the design peak discharges using long-term hydrological observations and Pearson Type III frequency analysis, following the procedures specified in the Guizhou Storm Flood Calculation Practical Handbook (Wang, 1983). The resulting design discharges range from approximately 6,100 m³/s for the 10-year return period to 11,200 m³/s for the 100-year return period (Cao, 2016). These values provide the hydrological reference adopted in this study for interpreting different levels of flood hazard in the Rongjiang urban area.

The June 2025 flood provides an important benchmark for evaluating the adequacy of existing design standards. According to Yuan et al. (2026), the observed peak discharge at the Shihuichang Hydrological Station reached approximately 11,400 m³/s, with a corresponding peak water level of 256.71 m, exceeding the published 100-year design discharge of 11,200 m³/s (Cao, 2016; Yuan et al., 2026). More than 80% of the urban area was inundated (Yuan et al., 2026), demonstrating the exceptional magnitude of the event and the limitations of relying on a single engineering design threshold under extreme flood conditions.

This comparison illustrates that return periods should not be interpreted as fixed thresholds separating safe and unsafe conditions. Rather, they provide a probabilistic representation of flood magnitude and frequency, while their application to long-term planning should also recognise the increasing uncertainty associated with non-stationary hydrological conditions (Milly et al., 2008). Within the framework developed in this study, frequent floods with relatively low peak discharges are associated primarily with stormwater management and runoff reduction, while moderate floods require additional temporary flood storage and adaptive public spaces. Extremely rare events, such as the June 2025 flood, may exceed the practical capacity of landscape-based measures alone and therefore require structural flood protection to operate together with emergency management and landscape-based adaptation.

Rather than attempting to eliminate flood risk entirely, the planning framework proposed in this study recognises that different flood magnitudes require different combinations of engineering and landscape-based measures. The return period analysis therefore serves as the hydrological foundation for developing a hierarchical flood adaptation framework that integrates Blue-Green Infrastructure, floodable landscapes, and conventional flood-control infrastructure according to the scale of flood hazard.

Return Period	Frequency P (%)	Peak Discharge (m³/s)	Design Context
10-year	10	6100	Urban drainage reference
20-year	5	7400	Recently completed flood protection standard
30-year	3.33	8200	County Spatial Plan standard
50-year	2	9300	Long-term planning target
100-year	1	11200	Check flood reference
2025 observed		11400	June 24, 2025 measured peak

Table 3. *Design Peak Discharges for Different Return Periods at Shihuichang Hydrological Station. Source: Cao (2016) and Yuan et al. (2026).*

5.2.2 Hierarchical Flood Adaptation Framework

Flood risk in mountain valley cities cannot be effectively addressed through a single flood-control measure or engineering standard. As demonstrated in the preceding hydrological analysis, flood events vary considerably in magnitude, frequency, and spatial extent, requiring planning responses that are proportional to the level of hazard. Instead of pursuing complete flood exclusion, contemporary flood adaptation increasingly adopts a hierarchical approach in which different measures operate collaboratively under different flood conditions. This approach improves urban resilience by combining routine stormwater management, temporary flood storage, and structural flood protection within an integrated planning framework.

For frequent and low-intensity rainfall events, priority should be given to reducing surface runoff before it enters the drainage system. Distributed Blue-Green Infrastructure (BGI), including rain gardens, bioswales, permeable pavements, green streets, and small detention facilities, can increase infiltration, delay runoff concentration, and reduce pressure on the urban drainage network (Fletcher et al., 2015; Chan et al., 2018). In mountain valley cities, where impervious surfaces are concentrated within narrow valley floors and runoff rapidly converges from surrounding hillsides, these distributed measures are particularly important for mitigating pluvial flooding caused by short-duration rainfall.

As flood magnitude increases beyond the capacity of conventional drainage systems, planning objectives shift from runoff reduction to temporary flood storage. Rather than preventing flooding entirely, selected public open spaces can be designed to accommodate temporary inundation while maintaining their recreational and ecological functions during normal conditions. Floodable parks, waterfront green spaces, sports fields, wetlands, and multifunctional open spaces can therefore function as controlled storage areas during flood events, reducing local flood impacts and temporarily accommodating floodwater (Ahern, 2011; Chan et al., 2018). This adaptive approach recognises flooding as a natural hydrological process and incorporates it into urban spatial planning instead of relying exclusively on flood exclusion.

For extreme flood events with very low probabilities of occurrence, landscape-based measures alone cannot provide adequate protection. Conventional grey infrastructure, including levees, floodwalls, pumping stations, and river training works, remains essential for protecting densely developed urban areas and critical infrastructure. However, these structural measures should not operate independently. Instead, they should be coordinated with BGI networks, floodable landscapes, emergency evacuation systems, and land-use planning to establish multiple layers of flood defence. Such integration enhances overall system resilience while reducing dependence on continuously increasing engineering standards.

Based on these principles, this study proposes a hierarchical flood adaptation framework consisting of three complementary planning responses (Table 4). The first layer focuses on distributed BGI for managing frequent rainfall and reducing urban runoff. The second layer employs multifunctional floodable landscapes to temporarily retain floodwater during moderate and severe flood events. The third layer relies on conventional engineering infrastructure and emergency management to reduce residual risks associated with extreme floods that exceed the adaptive capacity of landscape-based measures. Rather than replacing engineering infrastructure, the proposed framework integrates grey and Blue-Green systems to achieve a more flexible and resilient approach to flood adaptation in mountain valley cities.

Return Period	Peak Discharge (m³/s)	Flood Characteristics	Recommended Planning Response
10-year	6100	Frequent rainfall and minor flooding	Distributed Blue-Green Infrastructure (rain gardens, permeable pavement, bioswales, infiltration facilities)
20-year	7400	Moderate urban flooding	Neighbourhood stormwater detention and local drainage improvements
30-year	8200	Design flood corresponding to the current protection standard	Conventional flood-control infrastructure combined with urban drainage
50-year	9300	Major flood with widespread inundation	Floodable public spaces and temporary flood storage
100-year	11200	Extreme flood event	Integrated grey infrastructure and adaptive floodplain management
2025 observed	11400	Exceeded published 100-year discharge	Resilience evaluation for events beyond the design standard

Table 4. *Design Flood Discharges and Recommended Planning Responses. Sources: Author's compilation based on Cao (2016) and Yuan et al. (2026).*

5.2.3 Estimation of Flood Volume

To evaluate the contribution of the proposed landscape-based flood adaptation measures, it is first necessary to estimate the flood volume associated with the design flood event. Unlike peak discharge, which represents the maximum instantaneous flow rate, flood volume reflects the total quantity of water passing through the river during a flood event. This parameter provides an appropriate benchmark for assessing the storage capacity of floodable landscapes and Blue-Green Infrastructure (BGI).

At present, the available published information on the June 2025 Rongjiang flood reports the observed peak discharge and maximum flood level but does not provide the complete flood hydrograph or corresponding event flood volume (Yuan et al., 2026). Consequently, a simplified planning-level estimation is adopted in this study to provide an order-of-magnitude reference for the subsequent storage-capacity evaluation.

The total flood volume is estimated using the following equation:

$$V = Q_{mean} \times T$$

where V is the flood volume (m^3), Qmean is the mean discharge during the flood event (m^3/s), and T is the flood duration (s).

Because no measured hydrograph is available, the mean discharge is approximated by

$$Q_{mean} = \varphi Q_{max}$$

where Qmax is the observed peak discharge (m^3/s) and φ is a coefficient representing the ratio between mean discharge and peak discharge.

Because no complete flood hydrograph is available for the June 2025 flood event, a value of $\varphi = 0.4$ is adopted as a planning-level assumption, together with an assumed effective flood duration of 24 hours (86,400 s). Based on the observed peak discharge of 11,400 m^3/s, the estimated flood volume is calculated as

$$Q_{mean} = 0.4 \times 11400 = 4560 m^3/s$$

$$V = 4560 \times 86400$$

$$V \approx 3.94 \times 10^8 \ m^3$$

or approximately 394 million cubic metres.

It should be emphasised that this calculation is intended to provide an order-of-magnitude benchmark for planning analysis rather than to reproduce the actual flood hydrograph. The estimated flood volume is subsequently used as the reference for evaluating the storage capacity of the proposed floodable landscapes and Blue-Green Infrastructure network in the following section.

5.2.4 Evaluation of Flood Storage Capacity

In the preceding section, the scenario flood volume was estimated to be approximately 3.94×10^8 m^3, and this value provides an order-of-magnitude benchmark against which the storage capacity of the proposed floodable spaces and Blue-Green Infrastructure can be evaluated; this comparison is intended to assess the relative contribution of landscape-based measures within the broader flood-management framework and, importantly, to clarify both their potential and their limitations.

Before estimating storage capacity, the spatial allocation of the proposed floodable spaces was evaluated with the 12 m Digital Elevation Model (DEM); low-lying areas along the river corridor, relatively flat valley-floor terrain, and locations with direct spatial connections to the river system were identified as suitable areas for temporary flood storage. Consequently, floodplain wetlands, floodable parks, green corridors, and urban storage areas were preferentially located within these naturally flood-prone zones, while distributed BGI elements, including bioswales, vegetated swales, bioretention tree trenches, community sunken plazas, and rain garden parks, were allocated according to urban street networks, public open spaces, and mountain-foot runoff pathways. This terrain-based allocation allows the proposed flood-storage system to respond to the topographic characteristics of the mountain valley while making use of the limited urban land available for landscape-based adaptation.

A planning-level volumetric approach was used to estimate the storage capacity of the proposed floodable spaces; in this approach, the design area of each typology was multiplied by its specified effective storage depth. The selected storage depths were based on terrain conditions from the 12 m DEM and on the intended hydraulic function of each landscape typology. The space types include floodplain wetlands, floodable parks, floodplains, green corridors, urban storage areas, bioswales, bioretention tree trenches, vegetated swales, community sunken plazas, and rain garden parks. River-scale floodplain wetlands and floodplains were assigned temporary storage depths of about 1.0–1.5 m, while floodable parks and green corridors were assigned depths of 0.5–1.0 m. Street-scale BGI and node-scale retention facilities were designed for shallower storage depths ranging from 0.15–0.40 m. These facilities primarily support runoff interception, temporary detention, infiltration, and local stormwater management, consistent with the source-control and distributed stormwater-management principles discussed in the LID, SuDS, and Sponge City literature (Fletcher et al., 2015; Chan et al., 2018). These depths are treated as planning and design parameters rather than values derived from detailed hydraulic simulation.

Scale	Category	Area (ha)	Storage Capacity (m³)	Length (km)	Share of Total Storage (%)
River	Floodplain Wetland	9.15	109,754		94.9%
	Floodable Park	39.47	315,749		
	Floodplain	19.2	287,932		
	Green Corridor	15.92	79,621		
	Urban Storage	13.19	41,424		
Street	Bioswale	3.83	11,503	9.15	
	Bioretention Tree Trench	7.52	15,042	50.14	3.7%
	Vegetated Swale	1.51	6,344	5.33	
Node	Community Sunken Plaza	2.64	7,065		1.7%
	Rain Garden Park	3.32	8,312		
Total		115.76	878,975	64.62	100%

Table 5. *Estimated Flood Storage Capacity of Proposed Floodable Spaces and Blue-Green Infrastructure. Source: Author's calculations.*

Note: Storage capacities were calculated by multiplying the design area of each typology by its effective storage depth. For linear BGI elements (bioswales, bioretention tree trenches, and vegetated swales), storage capacity was estimated from the calculated plan area derived from feature length and design width. River-scale storage depths were estimated according to the elevation difference between existing terrain and proposed flood storage levels derived from DEM analysis, whereas storage depths for street- and node-scale BGI were determined from the proposed landscape design profiles.

The estimated storage capacities for each typology are summarised in Table 5. The proposed system provides an estimated total temporary storage capacity of about 8.79×10^5 m³, or about 879,000 m³. River-scale interventions, including floodplain wetlands, floodable parks, floodplains, green corridors, and urban storage areas, provide most of this capacity, contributing about 94.6% of the total storage volume; street-scale BGI, including bioswales, bioretention tree trenches, and vegetated swales, contributes about 3.7%, while node-scale retention facilities, including community sunken plazas and rain garden parks, contribute about 1.7%. This distribution reflects the spatial characteristics of Rongjiang's mountain valley setting, where the narrow urban corridor provides limited opportunities for distributed storage, whereas the river corridor and adjacent floodplains offer substantially greater capacity for temporary flood retention.

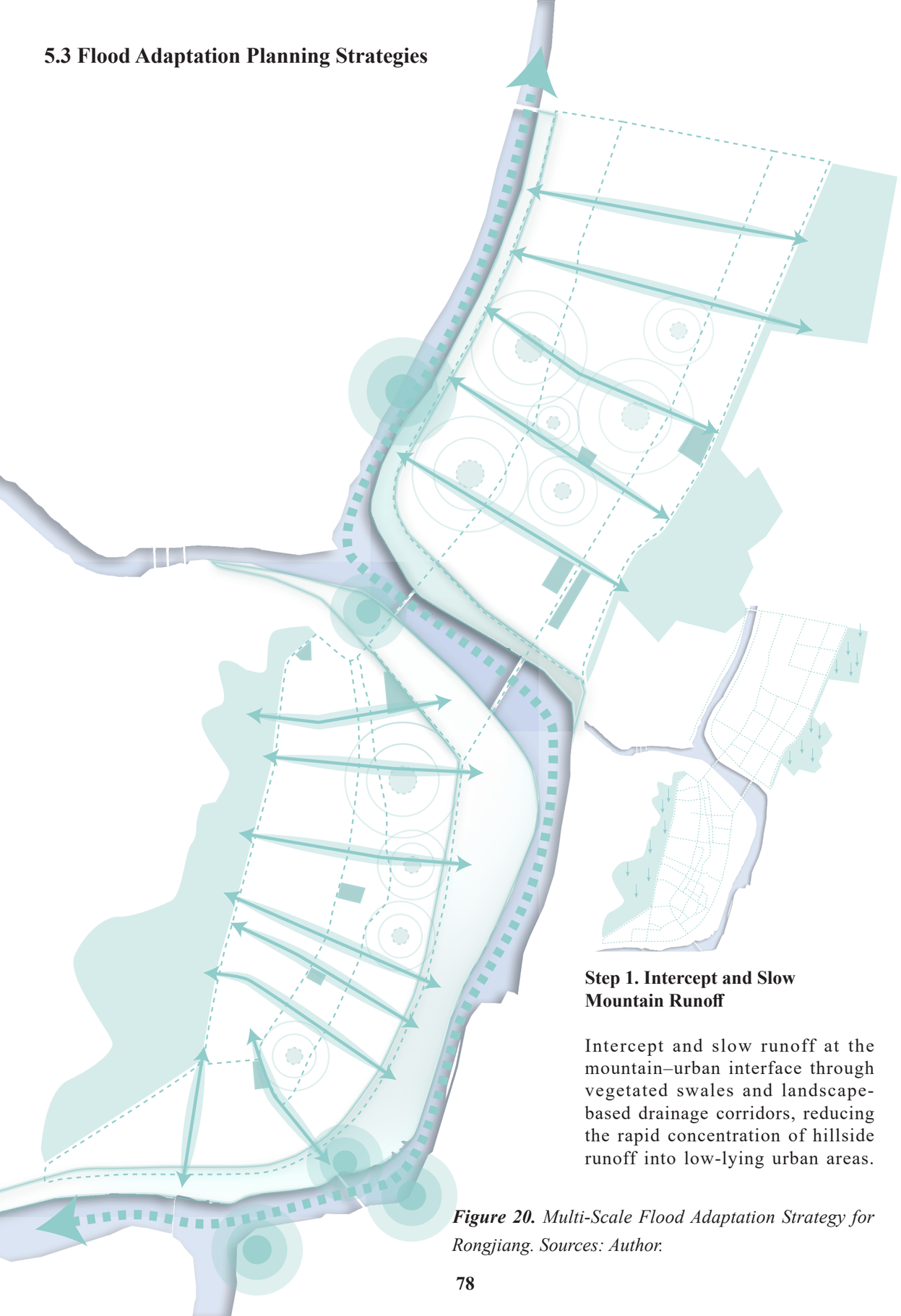
Comparing the estimated storage capacity with the scenario flood volume gives an indication of the relative scale of landscape-based storage within the overall flood-management system. The total estimated storage capacity of the proposed system (8.79×10^5 m³) is equivalent to approximately 0.22% of the scenario flood volume (3.94×10^8 m³); this relatively small proportion should not be interpreted as a direct measure of the effectiveness of the proposed strategy. Rather than replacing large-scale grey infrastructure such as levees, upstream reservoirs, or flood-diversion infrastructure, the proposed BGI and floodable landscape system is intended to complement structural measures by providing distributed detention, restoring floodplain functions, and increasing the adaptive capacity of the urban landscape (Ahern, 2011; Chan et al., 2018).

For frequent rainfall events, distributed BGI can intercept runoff, promote infiltration, delay runoff concentration, and reduce pressure on the urban drainage system (Fletcher et al., 2015). When flood magnitude increases, floodable parks, green corridors, wetlands, and urban storage areas provide additional space for temporary inundation and controlled accommodation of floodwater. During extreme flood events, however, the available landscape storage is insufficient to contain the total flood volume, and these spaces should therefore be understood as one component of a broader flood-management system rather than as a substitute for structural protection (Chan et al., 2018). Their role is consequently not to eliminate extreme flooding, but to provide additional spatial capacity and flexibility within a multi-layered flood adaptation system, consistent with a safe-to-fail resilience approach (Ahern, 2011).

The evaluation also highlights the importance of the river corridor as the main location for landscape-based flood storage within the constrained valley floor; the concentration of storage capacity within river-scale typologies reflects the geomorphological characteristics of Rongjiang, because the limited width of the valley restricts opportunities for distributed storage within the built-up area, while the river corridor and adjacent low-lying land provide substantially greater opportunities for temporary inundation. These findings support giving priority to riverine floodable landscapes within the proposed strategy, complemented by distributed BGI in streets, neighbourhoods, and public open spaces where spatial conditions permit.

Several limitations should be acknowledged. The storage-capacity estimates assume that the proposed floodable spaces can reach their specified design storage depths; in reality, effective storage utilisation depends on flood timing, local topography, hydraulic connectivity, river water levels, inlet and outlet conditions, and the sequence in which individual storage areas are inundated. The calculations do not simulate the filling and emptying processes of individual storage areas, nor do they account for hydraulic interactions between adjacent flood-storage spaces or operational flood-management rules; consequently, the values presented here should be interpreted as potential planning-level storage capacities rather than effective storage volumes derived from hydraulic simulation.

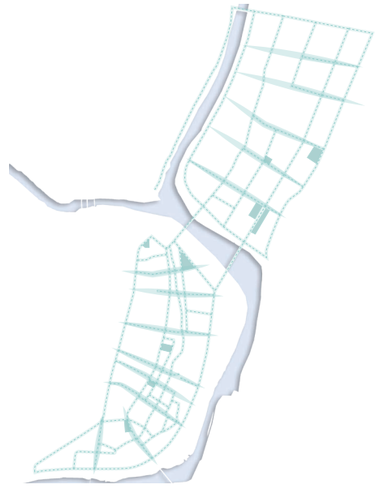
Despite these limitations, the analysis provides a clear quantitative assessment of the scale of landscape-based flood storage within the broader flood-management framework. While the proposed floodable spaces and BGI cannot replace conventional flood-control infrastructure, they introduce an additional layer of adaptive capacity by providing temporary storage, strengthening ecological connectivity, supporting multifunctional public spaces, and improving the flexibility of the urban landscape (Ahern, 2011). Their contribution therefore lies not only in the volume of water that can potentially be accommodated, but also in the way flood adaptation is integrated with spatial planning, ecological restoration, and everyday urban functions.



Step 1. Intercept and Slow Mountain Runoff

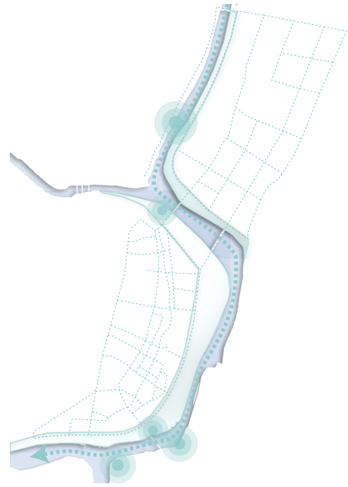
Intercept and slow runoff at the mountain–urban interface through vegetated swales and landscape-based drainage corridors, reducing the rapid concentration of hillside runoff into low-lying urban areas.

Figure 20. *Multi-Scale Flood Adaptation Strategy for Rongjiang. Sources: Author.*



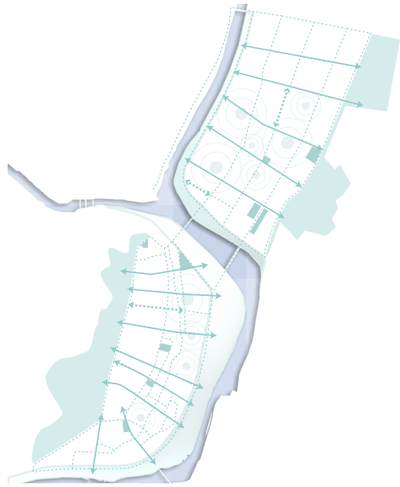
Step 2. Retrofit Urban Streets and Parks

Transform urban streets, parks, and public spaces into a distributed Blue-Green Infrastructure network incorporating bioretention streets, bioswales, rain gardens, sunken plazas, and floodable streets. These interventions retain and infiltrate stormwater during ordinary rainfall while providing temporary storage and controlled surface conveyance during heavier rainfall events.



Step 3. Establish an Adaptive River Corridor

Transform selected riverfront areas into adaptive flood landscapes, including green corridors, floodplain wetlands, floodable parks, and floodplains. These spaces accommodate seasonal and extreme flooding while supporting ecological restoration, recreation, and everyday public use.



Step 4. Establish an Integrated Blue-Green Network

Connect mountain runoff pathways, urban Blue-Green Infrastructure, floodable streets, public open spaces, and adaptive river corridors into a continuous mountain–city–river network. The system coordinates runoff interception, retention, infiltration, controlled conveyance, and flood accommodation across multiple spatial scales.

5.3.1 Flood Adaptation Masterplan

The proposed Flood Adaptation Masterplan translates the planning vision and hierarchical flood adaptation framework established in the previous sections into a spatial response to the key challenges identified in Chapter 4. In particular, the masterplan addresses five interconnected problems: the concentration of urban development within the flood-prone valley floor, the fragmentation of existing green infrastructure, the engineering-dominated character of the riverfront, the lack of integrated stormwater management, and the gap between strategic planning objectives and spatial implementation. Rather than responding to these challenges through isolated interventions, the masterplan establishes an integrated flood adaptation system in which mountain runoff pathways, urban Blue-Green Infrastructure, river corridors, public open spaces, and existing flood-control infrastructure perform complementary functions across multiple spatial scales. The spatial structure of the masterplan follows the topographical and hydrological conditions of Rongjiang. Runoff generated on the surrounding mountain slopes is intercepted and slowed at the mountain–urban interface through vegetated swales before entering the densely developed valley floor. Within the urban area, continuous bioretention tree trenches, bioswales, rain gardens, and other distributed Blue-Green Infrastructure retain and infiltrate stormwater where spatial conditions permit, while floodable streets provide controlled surface conveyance and temporary accommodation when local retention capacity is exceeded. These elements connect urban runoff pathways with flood-compatible public spaces and the river corridor, creating a continuous mountain–city–river system. This spatial organisation directly responds to the fragmented green infrastructure and disconnected stormwater management identified in Chapter 4.

Within this system (Figure 21), the river corridor forms the primary spatial structure for flood adaptation. Rather than functioning solely as an engineered flood-conveyance boundary, different riverfront sections are assigned complementary ecological, hydrological, and public-space functions according to their spatial conditions. Green corridors (R1) strengthen riparian continuity and ecological connectivity; floodplain wetlands (R2) combine ecological restoration with temporary water storage; floodable parks (R3) provide recreational space under normal conditions while accommodating periodic inundation; and floodplains (R4) preserve larger areas for natural flood accommodation. Existing structural flood-control measures remain essential where hydraulic protection is required. The proposed river strategy therefore complements, rather than replaces, conventional engineering infrastructure and responds directly to the engineering-dominated riverfront condition identified in Chapter 4. The masterplan (Figure 21) also differentiates adaptation measures according to the contrasting spatial conditions of the Old Town and New Town. In the Old Town, high development density and limited available land restrict opportunities for large-scale distributed Blue-Green Infrastructure. The strategy therefore makes greater use of existing streets, public spaces, and the adjacent river corridor, introducing floodable streets, rain gardens, sunken plazas, and flood-compatible riverfront landscapes where space permits. In the New Town, wider streets, larger development parcels, public facilities, and available open spaces provide greater opportunities for distributed stormwater management. Continuous bioretention tree trenches, bioswales, vegetated swales, rain gardens, and floodable streets are integrated into the urban fabric to intercept, retain, infiltrate, and convey runoff before it accumulates in low-lying areas. Existing football fields and other large open spaces are incorporated into the wider blue-green network as multifunctional open-space nodes rather than treated as isolated recreational facilities. At the city scale, these interventions establish a multi-layer flood adaptation system rather than a single line of defence. Existing and planned engineering infrastructure provides essential protection against major river floods, while the river corridor provides flood conveyance and flood-compatible open space. Distributed Blue-Green Infrastructure manages local runoff within the urban fabric, floodable streets provide controlled surface pathways during heavier rainfall, and adaptable public spaces provide additional temporary accommodation. The masterplan therefore assigns different flood-management functions to different spatial components according to topography, development intensity, available space, and their relationship with the river system. This differentiated structure responds to the high concentration of urban development within the flood-prone valley floor by increasing adaptive capacity within the limited spaces available rather than assuming that flood exposure can be eliminated entirely. Importantly, the masterplan also provides a spatial response to the planning–implementation gap identified in Chapter 4. The proposed river adaptation zones, Blue-Green Infrastructure network, floodable streets, multifunctional open-space nodes, and differentiated Old Town and New Town strategies translate broad resilience objectives into identifiable spatial interventions. The masterplan is therefore intended not only as a landscape design proposal, but as a spatial framework that can inform subsequent river-corridor planning, detailed control planning, public-space retrofitting, and site-specific landscape design. The institutional and regulatory mechanisms required to support this translation are further developed in the Planning Recommendations section.



Figure 21. *Flood Adaptation Masterplan for Rongjiang.*
Sources: Author.

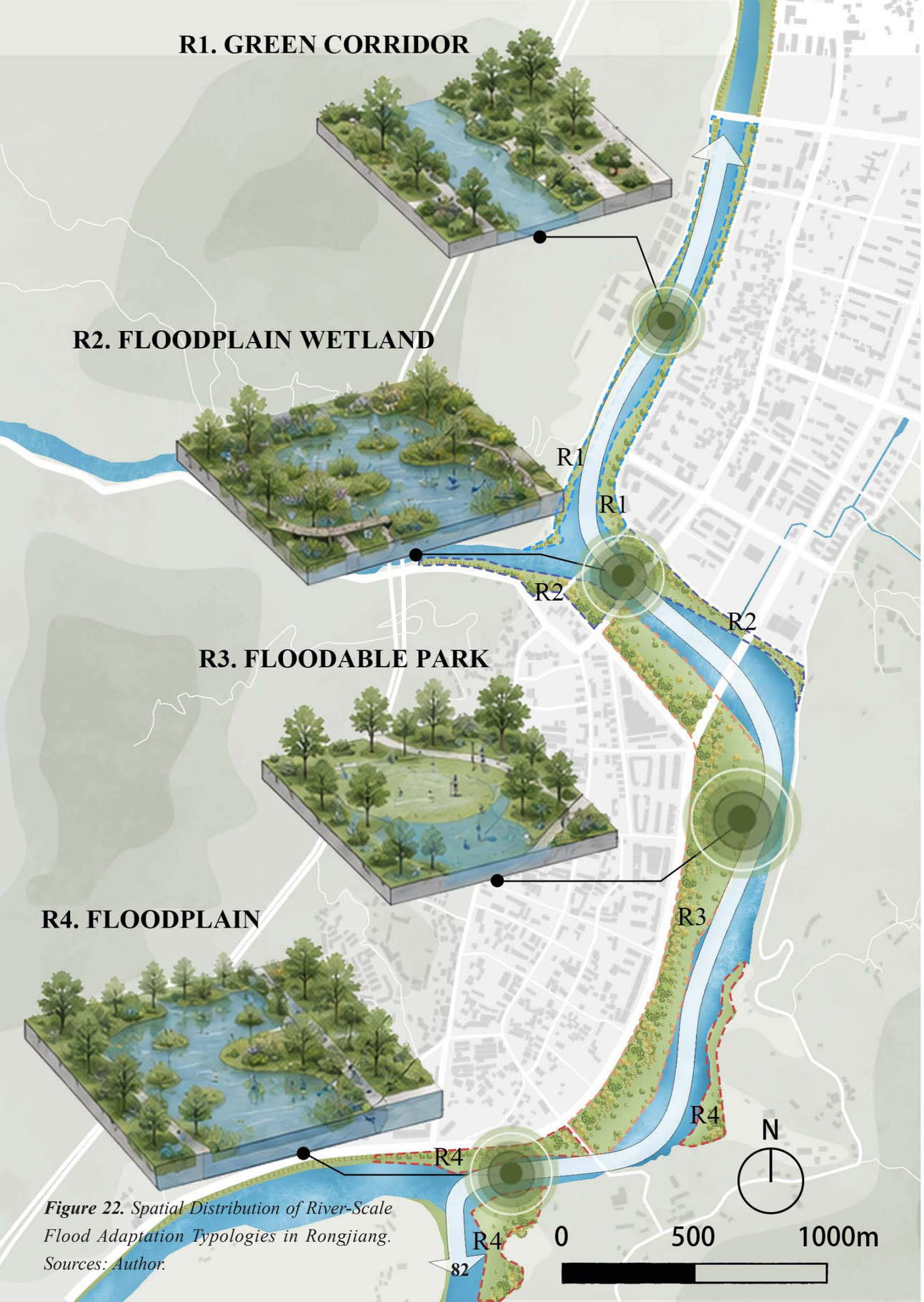


Figure 22. Spatial Distribution of River-Scale Flood Adaptation Typologies in Rongjiang. Sources: Author.

5.4 River-Scale Flood Adaptation Strategy

The river corridor forms the primary spatial structure of the proposed flood adaptation strategy and provides a direct response to the high flood exposure and engineering-dominated riverfront conditions identified in Chapter 4. Rongjiang's development is concentrated along the narrow valley floor and around the confluence of the Duliu, Zhaihao, and Pingyong Rivers, where urban areas are closely exposed to river flooding. Rather than treating the riverfront solely as a rigid flood-defence boundary, the proposed strategy establishes a multifunctional river corridor in which existing structural protection is complemented by flood-compatible landscapes, ecological restoration, and public open space. The strategy adopts a reach-based approach according to variations in river morphology (Figure 22), available floodplain space, surrounding development intensity, and existing riverfront conditions. Four principal river landscape typologies are introduced along different reaches: Green Corridor (R1), Floodplain Wetland (R2), Floodable Park (R3), and Floodplain (R4). These typologies are not applied uniformly along the river. Instead, each responds to the spatial and hydrological characteristics of its location and performs a different combination of flood-management, ecological, and public-space functions.

The Green Corridor (R1) is primarily applied to relatively confined river sections where the proximity of urban development and limited riverfront width restrict opportunities for extensive flood accommodation. In these locations, existing structural flood protection remains important, while riparian vegetation and continuous riverside green space strengthen ecological connectivity and improve the environmental quality of the river edge. The Green Corridor therefore functions principally as an ecological and spatial connection within the wider Blue-Green Infrastructure rather than as a major flood-storage area.

R1. Green Corridor Section: Ecological Connection and Flood-Compatible River Edge

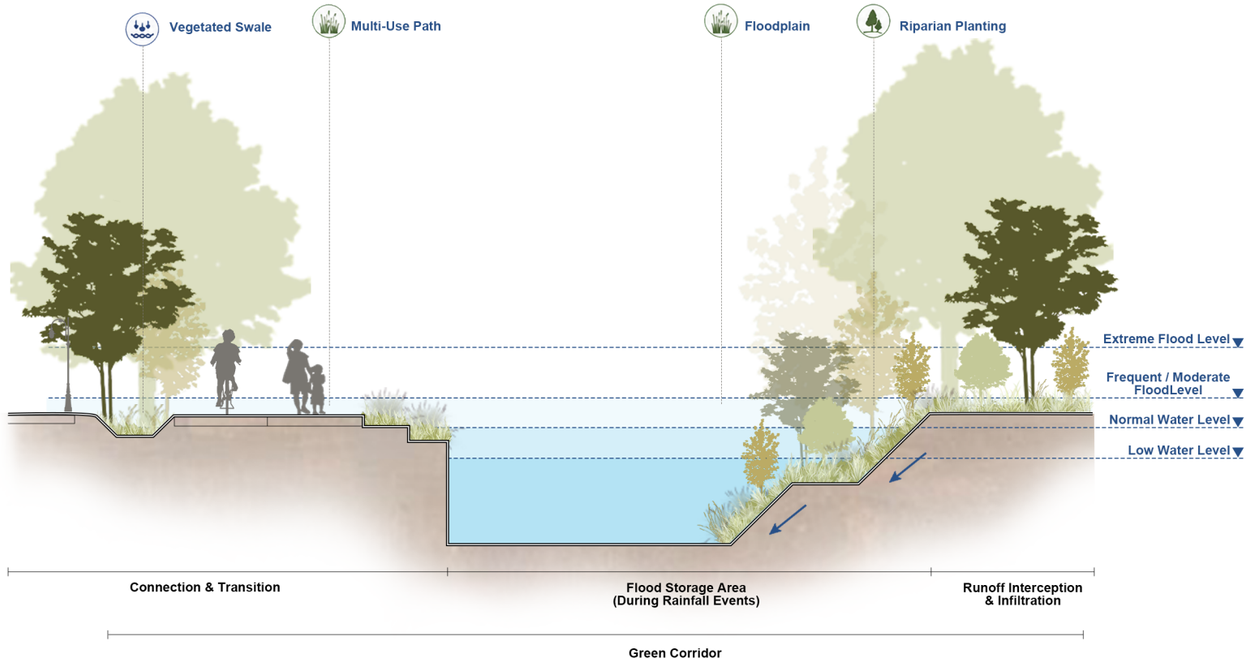


Figure 23. *Green Corridor Flood Adaptation Section. Sources: Author.*

The Floodplain Wetland (R2) is introduced around wider and hydrologically significant river sections, particularly near the confluence where greater space is available between the river and surrounding development. Wetland vegetation, shallow depressions, and flood-tolerant landscapes allow these areas to accommodate periodic fluctuations in water level while providing habitat restoration and water-related ecological functions. The wetland therefore creates a transitional landscape between the active river channel and the urban edge, increasing the capacity of the river corridor to accommodate water without requiring intensive urban reconstruction.

R2. Floodplain Wetland Section: Ecological Restoration and Temporary Water Storage

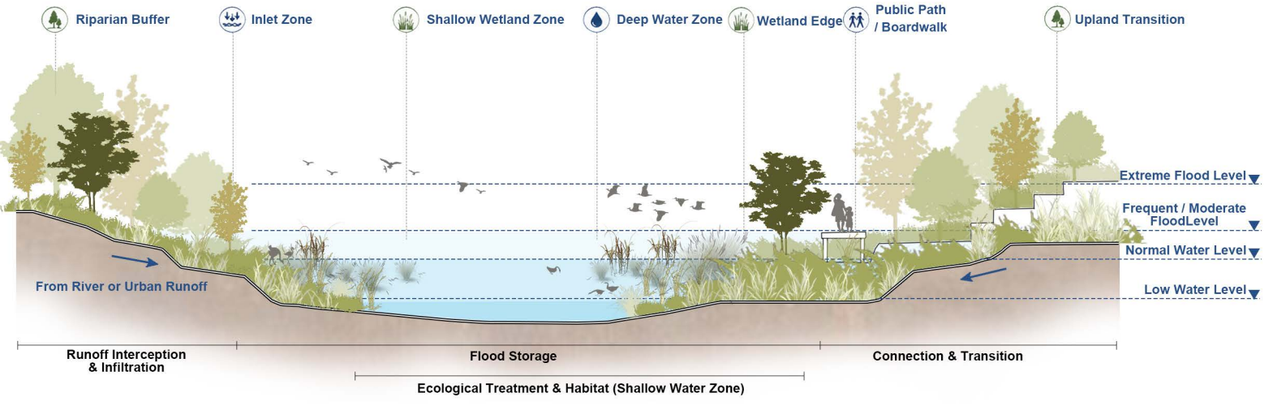


Figure 24. *Floodplain Wetland Flood Adaptation Section. Sources: Author.*

The Floodable Park (R3) is located along the wider riverfront adjacent to the Old Town, where available open space provides an opportunity to combine flood adaptation with everyday recreational use. Under normal conditions, the area functions as accessible riverside public space. During higher river levels, lower portions of the park are designed to tolerate temporary inundation, while higher areas and circulation routes remain less frequently affected. In this way, recreational open space becomes part of the flood adaptation system without losing its everyday social function.

R3. Floodable Park Section: Seasonal Flood Accommodation and Multifunctional Public Space

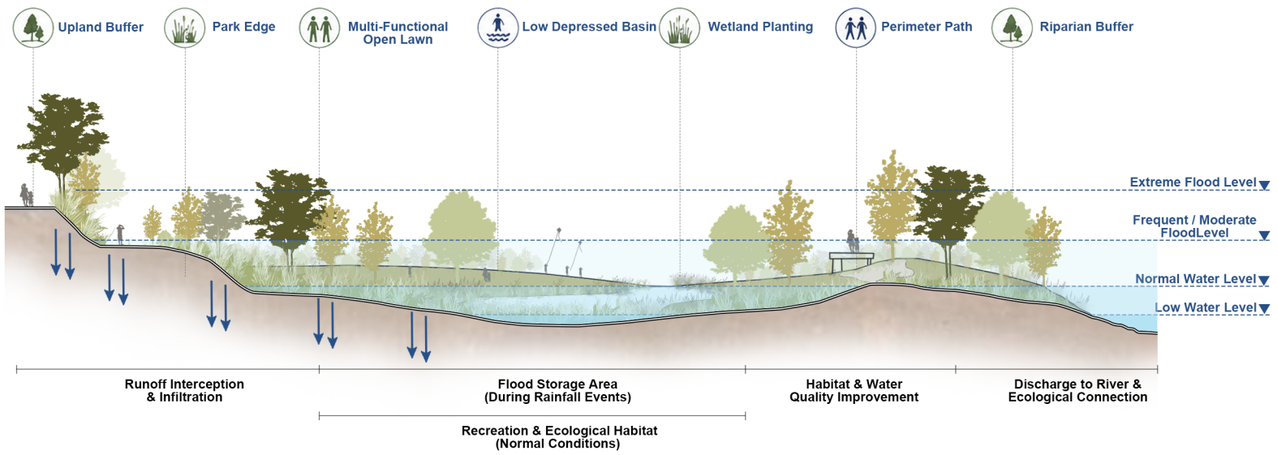


Figure 25. *Floodable Park Flood Adaptation Section. Sources: Author.*

The Floodplain (R4) is concentrated within the broader downstream river reaches and confluence areas where existing open land provides the greatest opportunity for accommodating river flooding. Compared with the more intensively programmed Floodable Park, these areas retain a more natural and flood-compatible landscape character. Their primary role is to preserve space for periodic inundation, maintain the hydraulic and ecological continuity of the river corridor, and avoid further intensive development within areas naturally exposed to flooding.

R4. Floodplain Section: Natural Flood Accommodation and Riparian Habitat

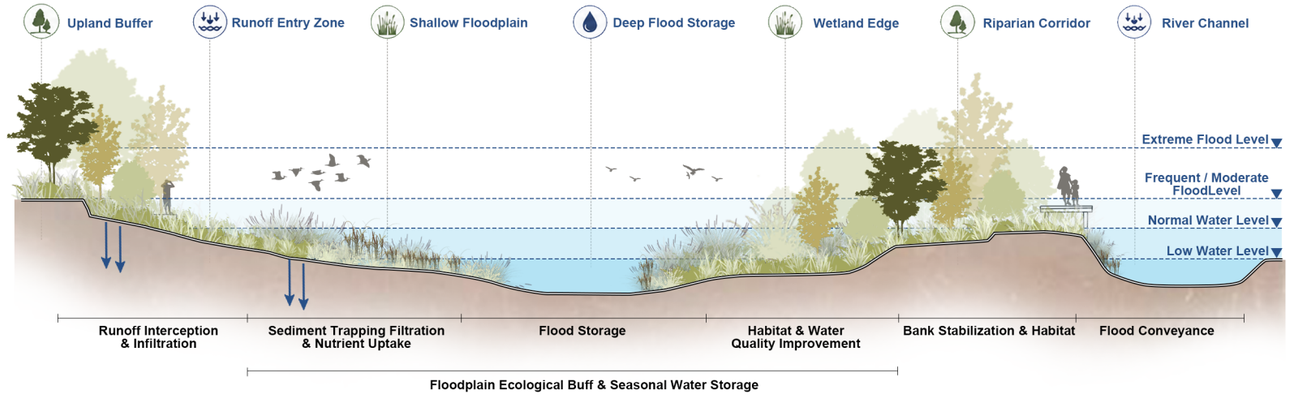


Figure 26. *Floodplain Flood Adaptation Section. Sources: Author.*

Together, the four river landscape typologies establish a differentiated sequence of flood adaptation spaces rather than a uniform treatment of the entire waterfront. More spatially constrained reaches retain a stronger relationship with existing structural flood protection, while wider riverfront areas progressively provide greater opportunities for ecological restoration, public use, and controlled flood accommodation. This approach directly addresses the engineering-dominated riverfront condition identified in Chapter 4 by expanding the role of the river corridor beyond flood conveyance and defence, while recognising that landscape-based measures cannot replace structural protection in high-risk and spatially constrained locations.

At the city scale, these river landscapes also form the ecological and hydrological backbone of the proposed Blue-Green Flood Adaptation Network. The river corridor receives runoff managed through the distributed urban BGI system, connects major blue-green nodes, and provides the final spatial interface between urban stormwater management and the natural river system. The river-scale strategy therefore establishes the foundation for the differentiated Old Town and New Town flood adaptation systems developed in the following sections.

5.5 Blue-Green Flood Adaptation Network

5.5.1 Differentiated Flood Adaptation Strategy for the Old Town and New Town

The spatial analyses in Chapter 4 reveal contrasting patterns of flood vulnerability and adaptation capacity between the historic Old Town and the northern New Town. While the Old Town is characterised by high development density, limited open space, and restricted opportunities for large-scale landscape intervention, the New Town provides wider streets, larger development parcels, and more available open spaces. The flood adaptation strategy therefore adopts differentiated spatial responses rather than applying a uniform Blue-Green Infrastructure model across the entire urban area.

Southern Old Town Strategy: Adaptive Flood Accommodation and Public-Space Retrofit

The southern Old Town is characterised by high development density, limited open space, and substantial flood exposure. Because opportunities for large-scale distributed Blue-Green Infrastructure are constrained, the strategy focuses on retrofitting existing streets and public spaces while strengthening their connection with the river corridor. Floodable streets provide controlled surface conveyance, while rain gardens, sunken plazas, and flood-compatible riverfront spaces provide distributed retention and temporary flood accommodation. Rather than requiring extensive reconstruction of the existing urban fabric, these interventions use available public spaces to increase local adaptive capacity within the spatial constraints of the historic district.

Northern New Town Strategy: Blue-Green Infrastructure-Based Flood Management

Compared with the Old Town, the northern New Town contains wider streets, larger development parcels, and more available open spaces, providing greater opportunities for distributed stormwater management. Continuous bioretention tree trenches, bioswales, vegetated swales, rain gardens, and floodable streets are integrated into the urban fabric to intercept, retain, infiltrate, and convey runoff before it accumulates in low-lying areas. Together, these interventions establish a connected Blue-Green Infrastructure network between the mountain–urban interface and the river corridor. This distributed structure makes use of the greater spatial capacity of the New Town to manage runoff closer to where it is generated before excess water reaches the river system.

The Old Town and New Town therefore adopt differentiated but interconnected flood adaptation strategies according to their contrasting spatial conditions. In the dense Old Town, adaptation focuses on retrofitting existing streets, public spaces, and riverfront landscapes to provide controlled conveyance and temporary flood accommodation. In the New Town, wider streets and larger open spaces support a more extensive distributed Blue-Green Infrastructure network for runoff interception, retention, infiltration, and conveyance. Despite these differences, both systems connect mountain runoff pathways, urban Blue-Green Infrastructure, and river corridors, forming an integrated mountain–city–river flood adaptation framework.



Figure 27. *Differentiated Flood Adaptation Strategy for the Old Town and New Town. Sources: Author.*

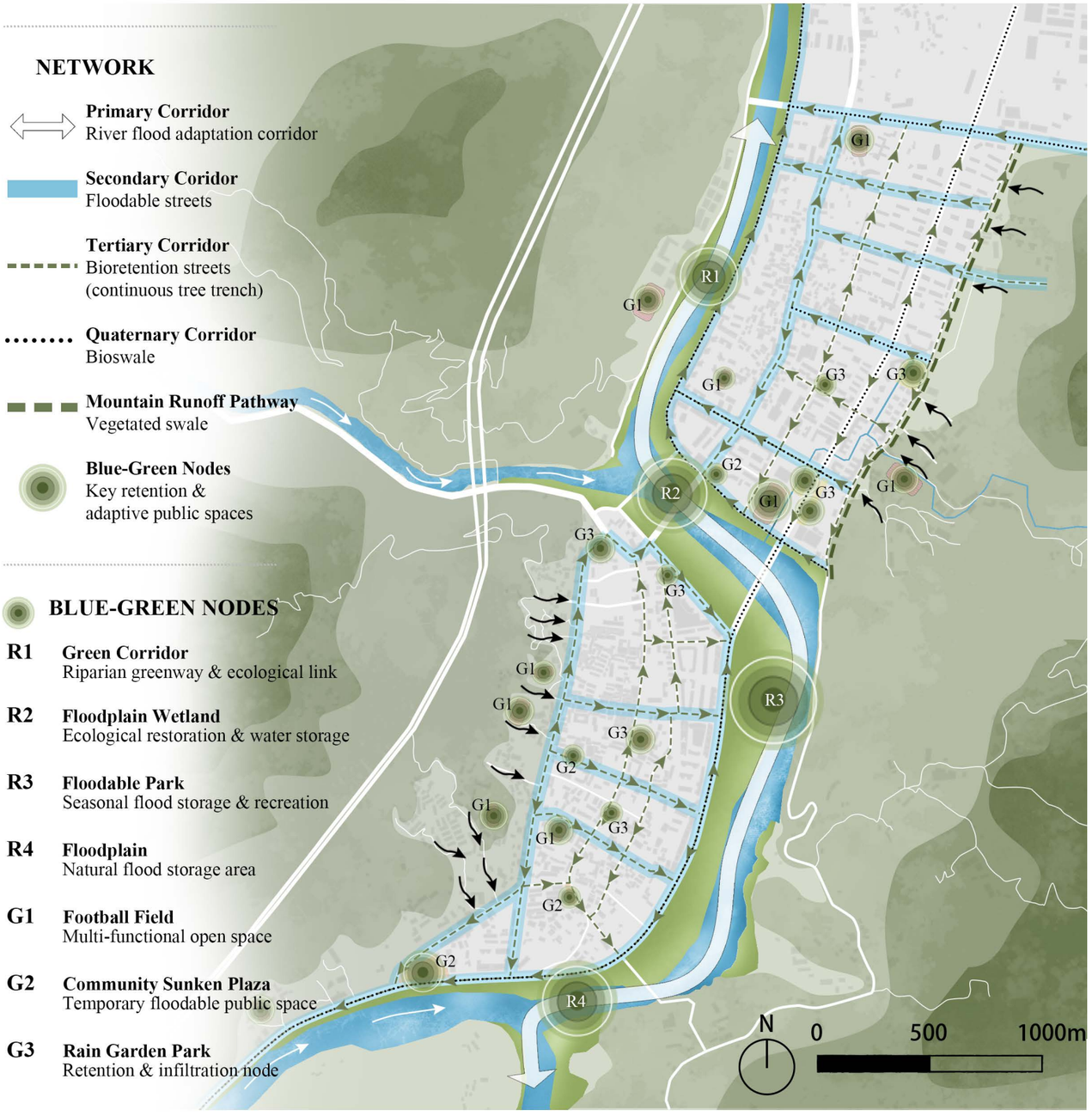


Figure 28. *Blue-Green Flood Adaptation Network and Runoff Management System for Rongjiang. Sources: Author.*

5.5.2 Integrated Blue-Green Infrastructure

Building upon the differentiated strategies for the Old Town and New Town, the proposed Blue-Green Infrastructure connects individual flood-adaptation measures into an integrated mountain–city–river system. Rather than treating bioswales, floodable streets, rain gardens, wetlands, and riverfront landscapes as isolated interventions, the network organises them according to their position within the urban hydrological process. Its primary objective is to intercept runoff from the surrounding mountains, retain and infiltrate stormwater within the urban fabric, convey excess runoff through designated surface pathways, and ultimately accommodate floodwater within adaptive river corridors and flood-compatible open spaces. The network is organised through a spatial hierarchy that assigns different hydrological functions to different landscape components. The river corridors form the primary flood-adaptation corridor, providing the principal structure for flood conveyance, ecological continuity, and flood accommodation. Floodable streets form secondary corridors, connecting urban catchments and public spaces with the river system while providing controlled surface conveyance during intense rainfall. Continuous bioretention tree trenches form tertiary corridors, retaining and infiltrating runoff along urban streets, while bioswales operate as smaller-scale quaternary corridors that collect and manage runoff closer to its source. At the mountain–urban interface, vegetated swales form runoff interception pathways, slowing runoff descending from surrounding slopes before it enters the built-up area. Together, these corridors establish a connected drainage and landscape structure across the valley floor.

A series of Blue-Green spaces complements this corridor network by providing additional retention, flood accommodation, ecological, and public-space functions. Along the river system, green corridors (R1) strengthen riparian ecological continuity, floodplain wetlands (R2) provide ecological restoration and temporary water storage, floodable parks (R3) combine seasonal flood storage with recreational use, while floodplains (R4) preserve larger areas for natural flood accommodation. Within the urban fabric, existing football fields (G1) are incorporated as multifunctional open spaces, community sunken plazas (G2) provide temporary floodable public spaces, and rain garden parks (G3) provide distributed retention and infiltration. The combination of linear corridors and spatial nodes allows runoff to be managed progressively rather than concentrated immediately within conventional drainage infrastructure.

Hydrologically, the network operates through a sequential process of interception, retention, conveyance, and accommodation. Mountain runoff is first intercepted and slowed at the mountain–urban interface. Within the urban area, distributed Blue-Green Infrastructure retains and infiltrates stormwater where local spatial and soil conditions permit. When rainfall exceeds local retention capacity, excess runoff is conveyed through floodable streets and connected open spaces towards the river system. River corridors, floodplains, wetlands, and floodable parks then provide larger-scale flood accommodation and adaptive landscape capacity. This sequence does not replace the conventional drainage and flood-control system, but supplements it by distributing stormwater management across multiple spatial components before excess water reaches the river. The proposed network therefore performs multiple functions beyond stormwater management alone.

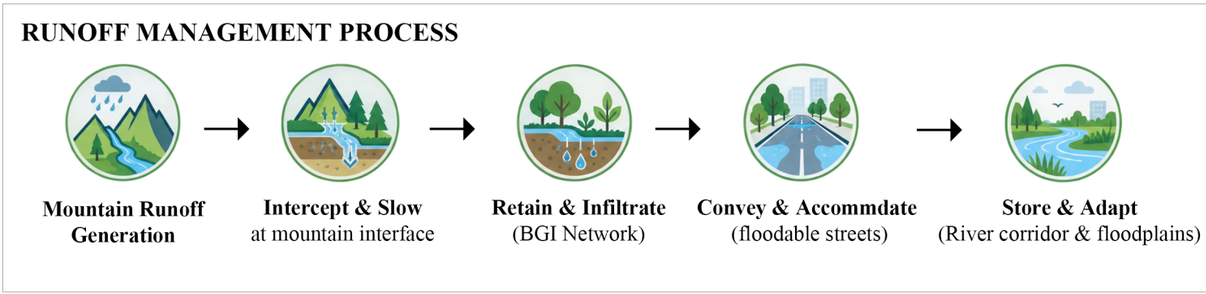


Figure 29. *Runoff Management Process from Mountain Catchments to River Corridors. Sources: Author.*

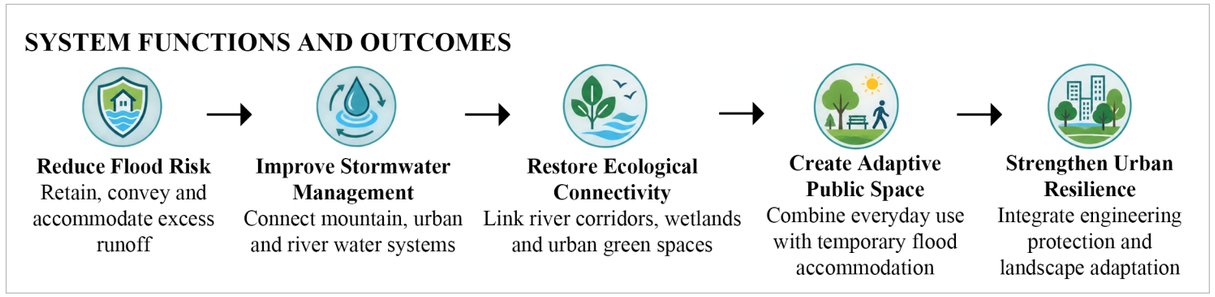


Figure 30. *System Functions and Expected Outcomes of the Flood Adaptation Framework. Sources: Author.*

By reconnecting fragmented green spaces, streets, public open spaces, mountain runoff pathways, and riverfront landscapes, it strengthens ecological connectivity while increasing the capacity of the urban landscape to accommodate water. At the same time, multifunctional public spaces retain their recreational and social functions under normal conditions while providing temporary flood-management functions during extreme events. Together with existing and planned engineering infrastructure, the integrated Blue-Green Infrastructure provides a complementary landscape-based layer of flood adaptation and translates the resilience objectives identified in the planning assessment into a continuous spatial system.

5.6 Old Town Flood Adaptation System

The Old Town represents one of the most spatially constrained and flood-exposed parts of Rongjiang. As identified in Chapter 4, dense development occupies much of the low-lying valley floor, while limited open space, fragmented green infrastructure, rapid runoff from the surrounding mountain slopes, and the engineering-dominated riverfront restrict opportunities for large-scale flood adaptation. These conditions require a strategy that works primarily through the retrofit of the existing urban fabric rather than extensive spatial reconstruction. The proposed Old Town Flood Adaptation System therefore follows a Convey–Accommodate–Store–Discharge approach, combining controlled surface drainage with flood-compatible public spaces and adaptive riverfront landscapes. Runoff management begins at the mountain–urban interface. Surface runoff descending from the western slopes is intercepted and directed towards selected streets that form part of the proposed flood conveyance network. Rather than relying exclusively on the conventional underground drainage system, these streets are designed as floodable streets capable of temporarily conveying excess surface runoff during intense rainfall events. This establishes a visible and continuous drainage structure between the mountain edge, the urban neighbourhoods, and the river corridor, responding directly to the disconnected stormwater pathways identified in Chapter 4. Within the dense urban fabric, existing streets and available public spaces are selectively retrofitted to provide temporary runoff accommodation. Community sunken plazas, rain gardens, and other small blue-green nodes are positioned along the drainage network to retain part of the runoff and reduce the amount of water immediately transferred downstream (Figure 33).

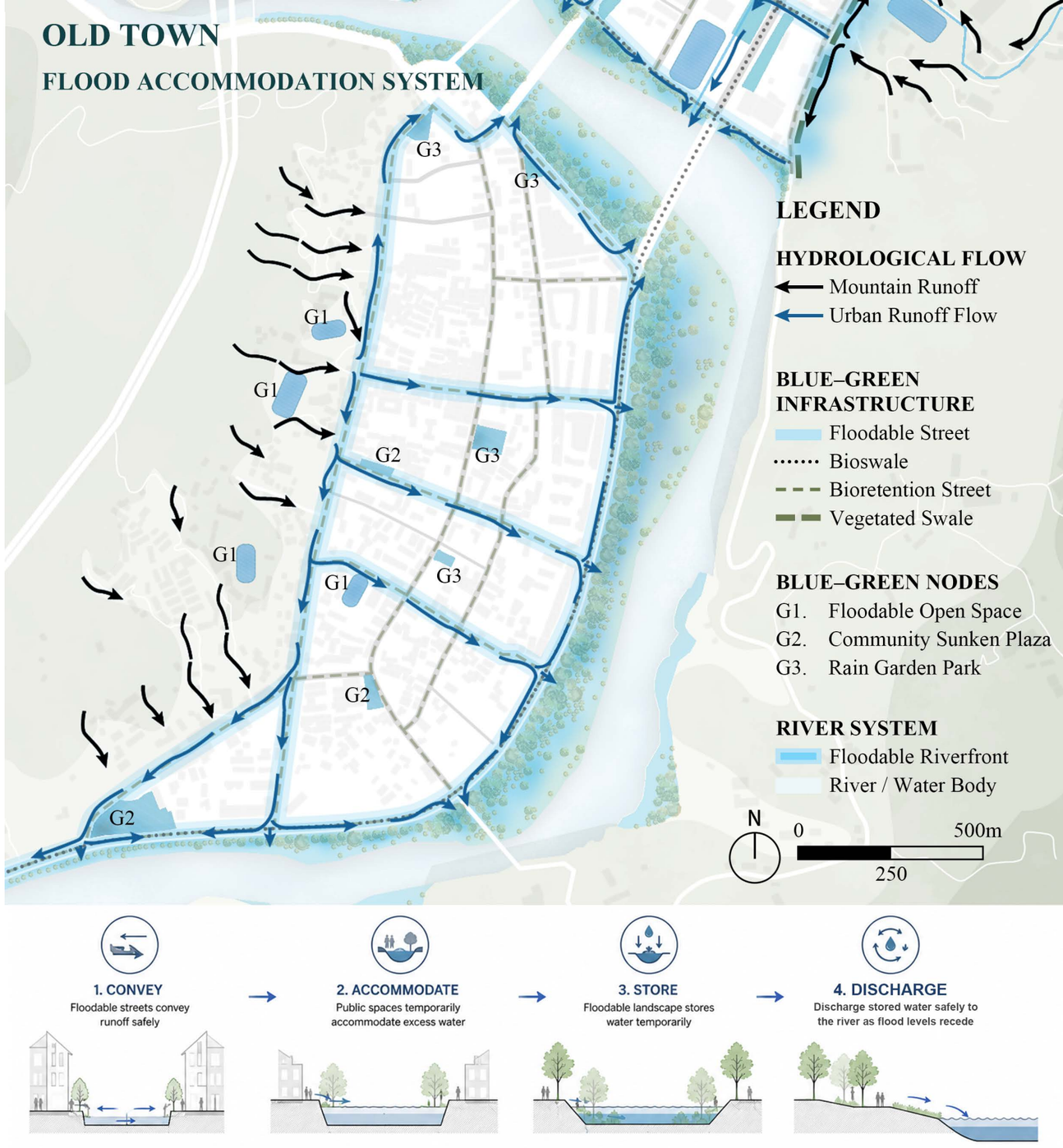


Figure 31. *Old Town Flood Accommodation System and Blue-Green Infrastructure Strategy. Sources: Author.*

Because available land within the Old Town is limited, these interventions are not intended to provide large-scale flood storage independently. Instead, they operate as distributed intermediate spaces within a wider system, supporting local retention and controlled conveyance while maintaining their everyday functions as community and public spaces.

The riverfront provides the principal flood-accommodation and storage component of the Old Town system. Existing open areas along the river are reorganised as floodable parks and floodplain landscapes, creating a gradual transition between the dense urban fabric and the river. Under normal conditions, these areas function as accessible green and recreational spaces. During more frequent or moderate flood events, lower riverfront areas can be temporarily inundated, while during larger events additional flood-compatible areas provide supplementary accommodation for rising river water and urban runoff. Higher-level routes and urban spaces remain outside the primary floodable landscape wherever possible, maintaining circulation and access as water levels fluctuate. This spatial arrangement establishes a sequential relationship between the mountain, urban fabric, and river corridor. Rather than attempting to retain all runoff within the densely developed Old Town, excess water is progressively conveyed through floodable streets, temporarily accommodated within distributed public spaces, stored within flood-compatible riverfront landscapes, and ultimately returned to the river system. The strategy therefore responds to the physical constraints of the historic district by assigning different hydrological functions to different parts of the existing urban landscape. At the same time, the Old Town strategy addresses the broader problems identified in Chapter 4. Retrofitting streets and public spaces introduces distributed stormwater functions into an area with limited green infrastructure; connecting these interventions to the river corridor transforms previously fragmented landscape elements into a continuous flood adaptation system; and converting selected riverfront spaces into flood-compatible landscapes reduces dependence on an exclusively engineering-dominated waterfront. Existing structural flood-control infrastructure remains necessary for protection against major river floods, but it is complemented by landscape spaces capable of accommodating water under less extreme conditions. Overall, the Old Town Flood Adaptation System does not seek to reconstruct the dense historic district as a sponge-city landscape. Instead, it establishes a context-specific adaptation model based on controlled conveyance, temporary accommodation, riverfront storage, and adaptive public-space retrofit. Through the coordinated sequence of Convey–Accommodate–Store–Discharge, the strategy translates the flood vulnerabilities identified in Chapter 4 into a spatially explicit system that works with the limited land availability, existing urban structure, and riverfront conditions of Rongjiang's Old Town.

5.7 New Town Flood Adaptation System

The New Town presents a different spatial condition from the densely developed Old Town. Although it is also located within the flood-prone valley floor, its wider street network, larger development parcels, lower building density, and greater availability of public and open spaces provide more opportunities for distributed stormwater management. At the same time, as identified in Chapter 4, runoff descending rapidly from the surrounding mountain slopes, fragmented green infrastructure, and the limited integration between surface drainage and urban open spaces increase the potential for stormwater accumulation in low-lying areas. The proposed New Town Flood



Figure 32. *New Town Flood Accommodation System and Blue-Green Infrastructure Strategy. Sources: Author.*

Adaptation System therefore adopts an Intercept–Retain–Infiltrate–Convey–Discharge approach, using a distributed Blue-Green Infrastructure network to manage runoff progressively from the mountain–urban interface to the river corridor. The first layer of the system focuses on intercepting mountain runoff before it enters the urban fabric. Along the eastern mountain–urban interface, vegetated swales are positioned parallel to the urban edge to intercept and slow runoff descending from the surrounding slopes. Rather than allowing concentrated surface flow to enter streets and neighbourhoods directly, these linear landscape elements provide an initial buffer where runoff

can be slowed, partially retained, and redirected towards the urban drainage network. This responds directly to the rapid runoff concentration associated with Rongjiang's mountain valley topography and establishes the mountain–urban interface as the first line of landscape-based stormwater management. After entering the urban area, runoff is managed through a distributed network of bioretention streets, bioswales, rain gardens, and flood-compatible open spaces. Bioretention tree trenches are integrated along selected streets to retain runoff close to its source and increase infiltration within the urban fabric, while bioswales provide additional linear retention and conveyance along major drainage routes. Rain garden parks and smaller landscape nodes supplement these linear systems

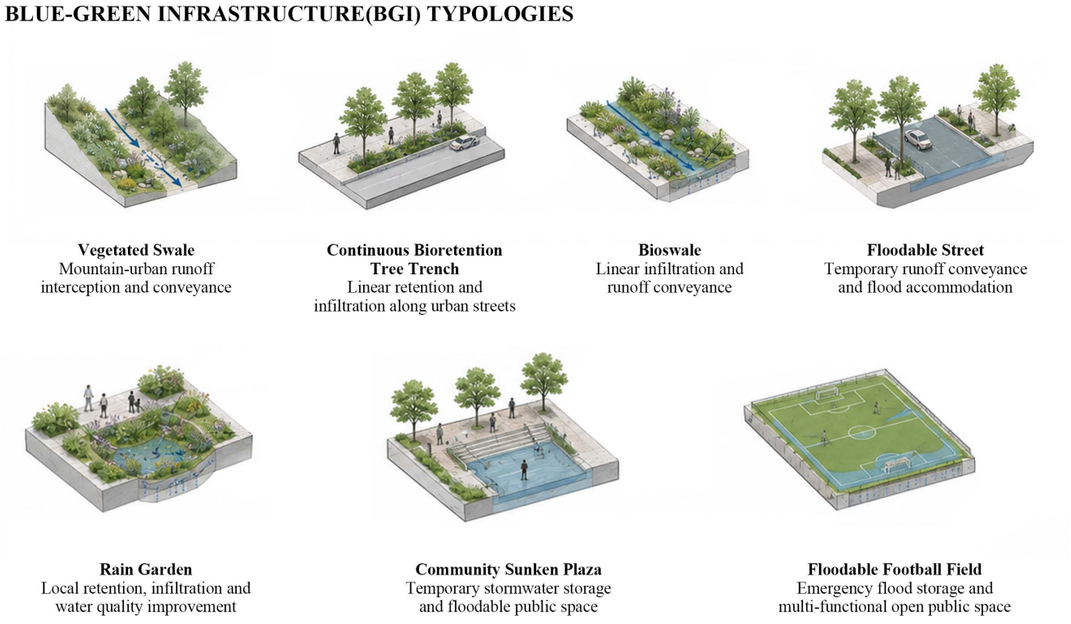


Figure 33. *Blue-Green Infrastructure Typologies for Urban Flood Adaptation in the Old Town and New Town. Sources: Author.*

by providing localised retention and infiltration capacity. Together, these interventions transform previously fragmented green spaces and streets into an interconnected Blue-Green Infrastructure, directly responding to the fragmented green infrastructure and lack of integrated stormwater management identified in Chapter 4. Public open spaces provide a further layer of temporary storage within this distributed system. Rain garden parks, community sunken plazas, and floodable football fields are designed to perform everyday recreational and community functions under normal conditions while providing additional stormwater accommodation during intense rainfall. Rain gardens retain and infiltrate frequent runoff at a local scale; sunken plazas temporarily accommodate excess water when the capacity of surrounding streets and bioretention facilities is exceeded; and floodable football fields provide larger emergency storage areas during more severe rainfall events. The use of existing and proposed public spaces for temporary water storage increases stormwater capacity without requiring land to be reserved exclusively for flood-control purposes.

When rainfall exceeds the retention and infiltration capacity of the distributed BGI system, floodable streets provide controlled surface conveyance towards the river corridor. The proposed street network therefore performs not only a mobility function but also a hydrological function. Selected streets follow the topographical direction of runoff and connect mountain-edge interception facilities, neighbourhood-scale BGI, public open spaces, and the riverfront. Excess runoff can consequently move through predetermined surface pathways rather than accumulating unpredictably within low-lying neighbourhoods. This creates a continuous hydrological connection between individual BGI facilities and the larger river system. At the downstream end of the system, excess runoff is discharged into the river corridor through designated flood-compatible riverfront landscapes. The riverfront therefore operates as the receiving component of the distributed network, connecting neighbourhood-scale stormwater management with the wider flood adaptation system established in the masterplan. During normal and moderate rainfall events, the distributed BGI network reduces and delays runoff before discharge; during more intense events, floodable streets and open spaces provide additional conveyance and temporary accommodation before excess water reaches the river. These landscape measures complement rather than replace the existing drainage and flood-control infrastructure, which remains necessary during extreme events. The New Town system therefore establishes a continuous hydrological sequence from mountain to city to river. Runoff is first intercepted at the mountain urban interface, then retained and infiltrated through vegetated and bioretention infrastructure, conveyed through flood-compatible streets when local capacity is exceeded, and finally discharged into the river corridor. Different Blue-Green Infrastructure typologies are assigned specific roles within this sequence according to their spatial location and available capacity, allowing individual interventions to operate as components of a coordinated runoff-management network rather than as isolated landscape elements. Overall, the New Town Flood Adaptation System responds to the problems identified in Chapter 4 by transforming streets, green spaces, public facilities, and the mountain–urban interface into a distributed stormwater-management structure. In contrast to the Convey–Accommodate–Store–Discharge strategy adopted in the spatially constrained Old Town, the greater availability of streets and open spaces in the New Town enables a more decentralised Intercept–Retain–Infiltrate–Convey–Discharge system. Together, the two approaches demonstrate how flood adaptation can be differentiated according to urban morphology while remaining connected through the city-wide Blue-Green Flood Adaptation Network.

5.8 Adaptive Flood Mechanism

This study conceives the proposed flood adaptation strategy as a dynamic and multi-layered system that responds progressively as hydrological conditions become more severe; the strategy does not rely on a single line of defence, but different spatial components perform complementary functions, which range from runoff interception and infiltration under ordinary rainfall conditions to temporary flood accommodation and structural protection during more severe events. Therefore, the return-period categories used in this section represent planning scenarios for organising adaptive responses, not precise hydraulic activation thresholds; within this framework, distributed Blue-Green Infrastructure (BGI), flood-compatible public spaces, riverfront landscapes, and conventional flood-control infrastructure operate at different spatial scales and assume different roles as flood severity increases.

5.8.1 Normal Conditions

Under normal conditions, the proposed flood-adaptive spaces primarily perform ecological, recreational, and public-space functions. Riverfront green corridors, floodplain wetlands, floodable parks, and floodplains contribute to ecological connectivity and everyday access to the waterfront, while neighbourhood-scale facilities such as rain garden parks, community sunken plazas, and floodable open spaces support daily recreation and community activities. Street-scale BGI, including bioswales, bioretention tree trenches, and vegetated swales, forms part of the everyday streetscape while maintaining the capacity to manage small volumes of runoff.

Hydrological functions remain largely integrated into these everyday landscape uses. Infiltration, evapotranspiration, interception, and soil-water storage reduce runoff generation and delay its movement towards the drainage and river systems. Flood adaptation is therefore embedded within the normal functioning of the urban landscape rather than activated only during flood emergencies.

5.8.2 Frequent Rainfall Events (Planning Scenario: up to approximately a 10-Year Return Period)

During frequent rainfall events, distributed BGI becomes the principal landscape-based component of the adaptation system. At the mountain urban interface, vegetated swales intercept and slow runoff descending from surrounding slopes. Within the urban fabric, bioswales and bioretention tree trenches retain, infiltrate, and convey runoff from streets and adjacent impermeable surfaces, while rain gardens and community sunken plazas provide additional local detention capacity.

The response differs according to urban morphology. In the New Town, the wider street network and larger open spaces enable runoff to be managed through a more distributed intercept–retain–infiltrate–convey–discharge sequence. In the denser Old Town, where infiltration and storage opportunities are more constrained, selected streets and public spaces primarily support controlled conveyance and temporary accommodation. At this stage, the principal objective is to manage rainfall close to its source and reduce pressure on the conventional drainage system before extensive riverfront flood accommodation becomes necessary.

5.8.3 Moderate Flood Events (Planning Scenario: approximately 10–50-Year Return Period)

As rainfall intensity, surface runoff, and river levels increase, the role of the adaptation system progressively shifts from distributed runoff management towards temporary flood accommodation. Street-scale BGI continues to intercept and delay local runoff, but excess water is increasingly conveyed through designated flood-compatible routes towards larger storage and accommodation spaces.

Riverfront landscapes, including floodable parks, floodplain wetlands, floodplains; and selected green corridors, provide additional space in which water can be temporarily accommodated. Lower and more flood-tolerant areas are allowed to inundate before higher value and more intensively developed urban areas. In the Old Town, this process follows a convey–accommodate–store–return sequence, using floodable streets, public spaces, and adaptive riverfront landscapes to manage excess water within the limited available space. In the New Town, distributed BGI and floodable streets continue to regulate runoff before excess water reaches the river corridor.

The purpose of this intermediate response is therefore not to prevent all inundation, but to influence where water is allowed to accumulate and how it moves through the urban landscape. Temporary flooding is preferentially directed towards spaces designed to tolerate inundation and recover after the event, thereby reducing exposure within more vulnerable residential and public service areas.

5.8.4 Extreme Flood Events (Planning Scenario: greater than approximately a 50-Year Return Period)

During extreme events, landscape-based measures alone cannot provide sufficient protection against the magnitude of river flooding experienced in Rongjiang. Conventional flood-control infrastructure, including levees, upstream reservoirs, diversion infrastructure, pumping stations; and urban drainage systems, therefore remains essential. The proposed landscape system is conceived as a complementary layer rather than a substitute for these structural measures.

Under such conditions, floodplains, wetlands, floodable parks, streets, and other designated flood-compatible spaces continue to provide supplementary accommodation and controlled pathways for excess water. Their contribution should not be interpreted as sufficient to store the total flood volume; instead, their role is to provide additional spatial flexibility, reduce uncontrolled surface water accumulation, maintain designated movement and evacuation routes where possible, and limit exposure by directing inundation towards predetermined flood-compatible areas.

The objective under extreme conditions consequently shifts from runoff reduction and local detention towards damage limitation, controlled accommodation, and safe urban response. This distinction is particularly important for Rongjiang, where the magnitude of extreme mountain-valley floods exceeds the capacity that can realistically be provided by urban landscape interventions alone. The adaptive landscape therefore operates together with catchment-scale regulation and structural flood protection as part of a multi-layer flood-management system.

5.8.5 Post-Flood Recovery

Following flood recession, the system enters a recovery phase in which temporarily inundated landscapes return progressively to their everyday functions. Floodplain wetlands and vegetated riverfront areas support ecological recovery, while floodable parks, plazas, streets, and other public spaces are designed with flood tolerant planting, robust surfaces, and recoverable landscape elements to facilitate cleaning, maintenance, and reopening after inundation.

Distributed BGI also contributes to post-event recovery by retaining sediments and filtering pollutants carried by surface runoff, although maintenance and sediment removal may be required following major events. The recovery capacity of individual spaces therefore forms part of their flood-adaptation function rather than being treated as a separate consideration after flooding occurs.

Taken together, the five scenarios demonstrate that the proposed strategy does not assign a single flood-control function to each landscape element. Instead, the role of the landscape changes progressively with hydrological conditions: everyday use and infiltration under normal conditions; distributed retention during frequent rainfall; controlled conveyance and accommodation during moderate flooding; complementary protection and damage limitation during extreme events; and ecological and functional recovery following flood recession. This adaptive sequence provides the operational logic linking the city-wide masterplan, the differentiated Old Town and New Town strategies, and the individual BGI typologies proposed in this chapter.

5.9 Planning Recommendations

The proposed flood adaptation strategy has implications beyond the physical design of individual riverfronts, streets, and public spaces. As identified in Chapter 4, the principal planning challenge in Rongjiang is not the absence of flood-resilience objectives, but the limited capacity of the existing planning system to translate these objectives into spatial regulations, development controls, and coordinated implementation. The Territorial Spatial Plan already recognises flood resilience, Blue-Green open space, and flood risk control as strategic priorities, yet these objectives remain weakly connected to detailed planning and engineering decisions. This reflects a broader challenge in urban flood resilience, where effective adaptation requires flood risk to be integrated into spatial planning and urban development rather than addressed solely through defensive infrastructure (Ahern, 2011). Based on the spatial strategies developed in this chapter, four planning recommendations are therefore proposed to strengthen the transition from strategic resilience objectives to implementable flood-adaptation measures.

5.9.1 Integrate Flood Adaptation into Statutory Spatial Planning

Flood adaptation should be incorporated into statutory spatial planning as a fundamental determinant of land-use allocation and urban development rather than treated primarily as a subsequent engineering response. Resilience-oriented planning increasingly emphasises the capacity of urban systems to adapt to changing environmental conditions and accommodate disturbance rather than relying exclusively on resistance-based approaches (Ahern, 2011; Meerow et al., 2016). In mountain valley cities such as Rongjiang, where developable land is concentrated on the same narrow valley floor that is exposed to flooding, future development decisions should therefore explicitly consider the relationship between flood risk, topography, and development intensity.

Flood risk control lines identified in the Territorial Spatial Plan should be associated with differentiated spatial regulations. River corridors, floodplains, wetlands, and other flood-compatible open spaces should be protected from incompatible development, while development intensity and permitted land uses within flood-prone areas should reflect their levels of exposure and required flood-management functions. Such an approach is consistent with the broader transition from conventional flood defence towards adaptive spatial planning (Ahern, 2011), in which land use and multifunctional landscapes form part of the flood-management system. In this way, flood-prone land would no longer be treated simply as developable land subject to engineering protection, but as part of the spatial infrastructure required for long-term urban resilience. This would translate the strategic resilience objectives identified in Chapter 4 into a more explicit spatial framework for future urban growth.

5.9.2 Translate Flood-Resilience Objectives into Detailed Planning Controls

The effectiveness of flood-adaptation planning ultimately depends on its translation from strategic objectives into implementable regulations. The ongoing revision of Rongjiang's Detailed Control Plan provides an important opportunity to incorporate the proposed Blue-Green Flood Adaptation Network into plot and street level planning controls.

Key components identified in the masterplan, including riverfront flood-accommodation areas, floodable parks, floodplain wetlands, mountain urban runoff interception corridors, floodable streets, bioswales, vegetated swales, bioretention tree trenches, rain gardens, and multifunctional floodable public spaces, should be reflected in detailed planning through appropriate land-use designation, development setbacks, open space requirements, and stormwater management provisions. The integration of such measures into urban planning is consistent with the multifunctional character of contemporary stormwater management, in which runoff management is increasingly combined with water-quality, ecological, amenity, and recreational objectives rather than treated solely as a conventional drainage function (Fletcher et al., 2015). New development and major urban renewal projects should also be required to demonstrate how runoff is intercepted, retained, conveyed, accommodated, or safely discharged within the wider urban drainage and river system.

Such measures would establish a clearer transmission mechanism between the Territorial Spatial Plan, the Detailed Control Plan, and individual development projects. The Blue-Green Infrastructure network proposed in this study

could therefore function not only as a landscape-design framework, but also as a spatial reference for translating broad resilience objectives into more specific planning requirements. In this way, the planning framework would move beyond general resilience ambitions towards spatially identifiable and implementable flood-adaptation measures.

5.9.3 Strengthen Coordination between Spatial Planning, Flood Engineering, and Urban Development

The governance assessment in Chapter 4 demonstrates that flood management in Rongjiang currently involves multiple institutions responsible for spatial planning, water management, emergency response, infrastructure, and urban development. Although these responsibilities are individually defined, limited coordination between them can result in flood-control engineering, land-use planning, and landscape interventions being developed through separate technical and administrative processes. More broadly, urban resilience requires coordination across spatial scales, sectors, and governance systems because disturbances rarely correspond to the administrative or technical boundaries of individual institutions.

Future flood-adaptation projects should therefore establish stronger coordination between the Natural Resources Bureau, Water Resources Bureau, Emergency Management Bureau, and other relevant authorities during both planning and implementation. Major flood-control projects should be evaluated not only according to hydraulic and engineering requirements but also according to their compatibility with territorial spatial planning, ecological restoration, public space provision, and the proposed Blue-Green Infrastructure network.

This coordination is particularly important in Rongjiang because flood management operates across multiple spatial scales. Upstream reservoirs and catchment-scale regulation influence flood peaks entering the valley; levees and river engineering manage river flooding within the urban area; distributed BGI manages local runoff; and emergency management systems address residual risk during extreme events. These components should therefore be planned as complementary layers of a single flood-adaptation system rather than as independent projects. Such a multi-scale approach is consistent with resilience thinking that emphasises multifunctionality, redundancy, diversity, and connectivity across multiple scales rather than reliance on a single protective system (Ahern, 2011).

5.9.4 Combine Landscape-Based Adaptation with Conventional Flood Engineering

Landscape-based adaptation should complement rather than replace conventional flood-control infrastructure. The magnitude and rapid concentration of mountain valley floods mean that the storage and infiltration capacity available within the urban landscape is insufficient to manage extreme events independently. Levees, upstream reservoirs, diversion infrastructure, pumping stations, and drainage improvements therefore remain essential components of Rongjiang's flood management system. This complementary relationship is consistent with the broader shift towards adaptive flood management, in which conventional protection is combined with measures that increase the capacity of urban systems to accommodate and recover from flooding (Ahern, 2011; Chan et al., 2018).

The role of Blue-Green Infrastructure is different but complementary. At the mountain–urban interface, vegetated systems can intercept and slow surface runoff; within the urban fabric, distributed BGI can retain, infiltrate, and convey stormwater; and along the river corridor, floodplains, wetlands, floodable parks, and adaptive public spaces can provide additional flood accommodation and spatial flexibility. The multifunctional character of these measures allows stormwater management to be integrated with ecological processes and public space functions (Fletcher et al., 2015). During extreme events, these landscape systems provide supplementary capacity and controlled flood-compatible spaces, while structural infrastructure continues to provide the principal level of protection (Chan et al., 2018).

Future investment should therefore avoid treating grey and Blue-Green infrastructure as competing alternatives. Instead, project evaluation should consider how engineering protection, spatial planning, ecological restoration, and multifunctional landscape infrastructure can be coordinated according to flood magnitude and spatial context. This hybrid approach is particularly relevant to mountain valley cities, where extreme flood hazards require structural protection but limited land availability also demands that flood-management spaces perform multiple ecological and urban functions.

Overall, these recommendations translate the design strategies developed in this chapter into a broader planning and implementation framework. For Rongjiang, improving flood resilience requires not only additional flood-control projects, but also a stronger institutional connection between strategic planning objectives, detailed spatial regulation, engineering investment, and landscape implementation. The proposed Blue-Green Flood Adaptation Network can provide a spatial framework for this integration by identifying where runoff should be intercepted, where water can be retained or accommodated, and how these spaces should connect with the river and existing flood-control infrastructure. In this sense, the principal planning implication of the study is not the replacement of engineering-based flood management, but the establishment of a multi-scale and coordinated planning framework in which spatial planning, landscape adaptation, and conventional flood engineering perform complementary roles.

06

Concluding Remarks: Outcomes, Limitations and Research Perspectives

This study investigated how landscape planning and design can contribute to flood adaptation in mountain valley cities through the case of Rongjiang, Guizhou Province, China. And the study comes from a basic spatial contradiction: the development and construction of mountainous river valley cities is concentrated in narrow and low-lying river valleys, which are also the primary pathways for mountain runoff and river floods; the flood disaster in Rongjiang County in June 2025 showed this contradiction very clearly, and it showed that when extreme flood disasters happen, there are limits to depending only on traditional flood control and drainage infrastructure.

The analysis showed that the vulnerability of floods in the Rongjiang area is not only determined by the hydrographic conditions, but also by its valley topography, the confluence of the three rivers, concentrated urban growth, fragmented green infrastructure, engineering-based waterfront belts, poor integration of rainwater management, and the gap between strategic resilience goals and spatial implementation; these conditions are caused by the combined action of multiple factors. These research findings show that improving flood resilience not only calls for strengthening flood control capabilities, but also rethinking the arrangement and linkage of urban space, river corridors, open spaces, streets and natural hydrological processes.

In response, this study created an integrated landscape planning framework that links structural flood protection, river corridor-adaptation, distributed Blue-Green Infrastructure, and flood-compatible public space across multiple spatial scales; rather than applying a single flood-management solution throughout the city, the framework adapts to differences in topography, flood exposure, development density, and available space. At the river scale, Green Corridors, Floodplain Wetlands, Floodable Parks, and Floodplains create distinct relationships between flood accommodation, ecological restoration, and public use; at the urban scale, these river landscapes are linked with distributed BGI to form a continuous mountain–city–river flood adaptation network. The Old Town and New Town are further handled with different strategies: the dense and highly exposed Old Town focuses on controlled flood conveyance and accommodation within existing public and riverfront spaces, while the New Town uses its wider streets and larger open spaces to intercept, retain, infiltrate, and convey runoff before it reaches low-lying areas and the river system.

The resulting strategy shows that different spatial components should carry out different functions based on flood magnitude rather than trying to hold back all floods through a single line of defence. During frequent rainfall events, distributed BGI, including bioswales, bioretention streets, vegetated swales, and rain gardens, mainly handles runoff near its source through interception, retention, and infiltration; as flood magnitude increases, floodable streets, parks, wetlands, and floodplains provide additional conveyance and temporary accommodation. During extreme events, however, the capacity of these landscape measures is surpassed and structural flood-control infrastructure remains essential, so the proposed landscape system functions as a complementary layer that manages residual risk and creates additional spatial capacity for water rather than as a substitute for engineering protection.

This distinction is backed up by the storage capacity assessment that the study carried out, and the estimated flood volume of the 24 June 2025 event was approximately 3.94×10^8 m³, greatly surpassing the storage that can actually be provided by floodable landscapes within the constrained urban valley floor. This finding is significant because it clarifies the realistic role of landscape-based flood adaptation in Rongjiang, and its worth is not about storing an entire extreme flood, but in reducing and delaying local runoff, temporarily accommodating water in designated spaces, reducing pressure on drainage and flood-control systems, and allowing selected urban landscapes to tolerate inundation without causing the same level of disruption and damage. For a mountain valley city with limited land available for large-scale storage, flood resilience thus depends on the coordinated operation of landscape and engineering systems rather than either approach operating independently.

The study consequently suggests a shift from treating floodwater solely as something to be excluded from the city toward deciding where water should be intercepted, where it can be retained and infiltrated, where it should be safely conveyed, where temporary inundation can be accommodated, and where structural protection must remain the primary defence, and this principle is shown in the design vision of “Living with Floods, Not Fighting Floods.” In this context, living with floods does not mean accepting uncontrolled inundation; instead, it means organising urban space so that different parts of the city can respond appropriately to different hydrological conditions while protecting vulnerable urban functions and maintaining essential structural flood protection.

The importance of this research therefore is not about suggesting a single landscape solution for Rongjiang, but in showing how the particular conditions of a mountain valley city can be turned into a differentiated, multi-scale flood adaptation framework; by connecting the problems identified through hydrological, spatial, and planning analysis directly to river-scale, urban-scale, and site specific interventions, the study gives a planning and design approach in which flood resilience becomes part of the spatial structure of the city rather than remaining primarily an engineering objective. Although developed specifically for Rongjiang, the underlying approach combining terrain-sensitive planning, differentiated river-corridor adaptation, distributed runoff management, flood-compatible public space, and structural protection provides a reference for other mountain valley cities facing similar constraints between rapid runoff concentration, limited flood-storage space, and intensive development within flood prone valley floors.

This study has some limitations that should be acknowledged, because it does not carry out independent hydrological modelling of the proposed interventions, and the flood adaptation framework is based on published hydrological records, official flood information, terrain and spatial analysis, planning documents, and landscape-based storage estimates; therefore, the calculated storage capacities indicate the approximate scale and relative contribution of the proposed landscape interventions rather than their precise hydraulic performance during individual flood events.

Future research could test the proposed spatial framework through two dimensional hydrological modelling, more detailed topographic and infiltration data, and scenario-based simulation of different return period floods; further field investigation and engagement with local communities, planning authorities, and water-management agencies would also help evaluate implementation feasibility, maintenance requirements, and the integration of the proposed landscape strategies into statutory planning.

Despite these limitations, the study demonstrates that landscape planning can provide an important intermediate layer between conventional flood engineering and urban development in mountain valley cities, and for Rongjiang, the central question is therefore not whether floods can be completely prevented, but how the city can create appropriate space for water while maintaining the protection required where flooding cannot safely be accommodated; establishing this relationship between water, landscape, infrastructure, and urban space is the principal contribution of the proposed flood adaptation framework.

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