*Research Paper*

# Study on the sustainability of flood control in mountain cities: The Case of Water System Construction in Huizhou Ancient City

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## Abstract

*With the acceleration of urbanization, more and more land is being developed for construction, and suburban areas, mountainous areas, hills and other places have gradually become construction land. However, due to various factors such as historical development problems and modern artificial development, mountain destruction, soil erosion, and ecological imbalance have led to frequent flood disasters in these urban areas. Mountain torrents are characterized by suddenness, high water concentration, large flow, and strong scouring and destructive power. They often cause property losses, interruptions to public utilities, emergency services and transportation, and seriously affect the overall economic situation of a region. Therefore, flood management in mountainous cities is an important issue in modern urban planning.*

*Faced with the crisis of frequent mountain torrents, some ancient Chinese cities, such as Pingliangtai and Chang'an, were able to coexist with water and achieved remarkable achievements in urban construction and water system construction, some of which continue to this day. This paper aims to provide a perspective on the ancient wisdom of preventing and controlling mountain torrents. This study takes the Huizhou area as an example. The Huizhou area is in the southern part of Anhui Province, China, with an area of 13,870 square kilometers. It is mainly hilly and mountainous and is in the area of Jiuhua Mountain and Huangshan Mountain. Due to its unique geographical location, the Huizhou area is a high-risk area for mountain torrents. Huizhou has a history of more than 500 years, with good disaster prevention awareness and historical experience in successfully managing mountain torrents.*

*This paper first uses GIS technology to collect watershed information of more than 100 mountain cities in Huizhou, and compares it with the distribution of these mountain cities to find out the common principles of mountain cities in urban construction and site selection; then through literature review, three typical mountain cities in Huizhou: Hongcun, Jixi, and Chengkan are selected for case analysis, and GIS technology is used again to analyze the water system and water circulation system of these three ancient cities to understand the principles of urban flood control projects; field research is conducted in the three ancient cities to deeply understand the attitude of local people towards rainwater management and the lifestyle of coexisting with floods.*

*According to analysis, the site selection of mountain cities in Huizhou is all above the flood line; the three ancient cities use street networks to become the main flood discharge channels through open channels and culverts to discharge floods to external natural water bodies; at the same time, reservoirs have multiple uses, providing both domestic water and combining with farmland water conservancy.*

*The results of this study propose a modern mountain city flood and rainwater management planning system, covering three dimensions: blocking external water, draining internal water, and regulating rainwater. Blocking external water focuses on the geographical location of the city, scientifically selecting sites, and avoiding urban*

*construction in areas below the flood discharge level; draining internal water should give full play to the multifunctional benefits of flood control projects such as regulating and balancing water systems and reducing flood peaks. Regulating rainwater means organically combining urban water systems with farmland water systems, establishing a recyclable and integrated water circulation system, making full use of water resources, and advocating "multiple uses of water".*

**Keywords**

*Flooding control, Mountain city construction, Water system construction, GIS.*

## 1. Introduction

In recent years, many mountainous cities around the world have suffered major floods. These floods have resulted in loss of life, property damage and long-term environmental damage (Noji and Lee, 2005). Due to their unique topography, mountain cities are more vulnerable to flooding than plains cities. These cities are often located in areas with steep topography and abrupt elevation changes (Weingartner, Barben and Spreafico, 2003). These features increase surface runoff during heavy rains. Water flows faster, and slopes and valleys channel it into powerful floods that damage infrastructure and communities. Landslides and mudslides often follow, exacerbating the damage caused by flooding (Stoffel, Wyżga and Marston, 2016).

Drainage systems and roads in mountainous cities often fail during heavy rains. These systems are unable to handle large amounts of water, leading to infrastructure damage and traffic disruption (Leszek et al., 2024). Topographical constraints also make it difficult to construct large drainage systems. This reduces drainage capacity and leads to frequent flooding in low-lying areas. Floods inundate roads, houses and public facilities, threatening the safety and livelihoods of residents.In 2014, heavy rainfall in Hiroshima Prefecture, Japan, led to widespread flooding and mudslides. The city's mountainous terrain and rugged rivers exacerbate disaster risk. The local government constructed disaster prevention facilities and focused on vegetation restoration to reduce risk.

In 2018, Belluno in northern Italy suffered severe flooding following heavy rains. The floods damaged roads and power lines, isolating the community from the outside world and causing significant damage. Large numbers of trees were washed away and sediment clogged the rivers, adding to the environmental damage. 2022 Floods in Pakistan's Swat River basin caused extensive damage. The valley's steep slopes and sparse vegetation allowed the floodwaters to flow rapidly, destroying buildings, infrastructure and farmland. More than a million people were left homeless (UN, 2023).

In summary, flood disasters in mountainous cities have multifaceted impacts, causing widespread and deep-seated damage to infrastructure, residents' lives, and the ecological environment. To address these challenges, mountainous cities urgently need to explore effective flood prevention and management measures to enhance resilience and adaptability in the face of floods. This paper aims to provide a perspective on ancient wisdom in preventing and controlling mountain torrents. Taking Huizhou as an example, we learn from the good disaster prevention awareness and historical experience of successful mountain torrent control and propose a modern mountain city flood and rainwater management planning system.

This paper is organized into five sections. Following this introduction is a literature review that examines theories and models related to flood prevention in mountainous cities, summarizes past experiences, identifies research gaps, and introduces three specific case study cities: Hongcun, Jixi, and Chengkan. The second section details the research methodology, which uses GIS technology to analyze water system data

from hundreds of cities in the Huizhou region and assesses the water systems and circulation of the three ancient cities to understand site selection and flood engineering principles in mountainous areas. The third section presents research findings, including geographic information on topography and rainfall in the Huizhou area and flood risk analysis maps for the case study cities. This is followed by the discussion section, which connects findings to the literature review, elaborates on major discoveries, and proposes recommendations for flood prevention in mountainous cities. The paper concludes with a summary of key points.

## 2. Literature review

### 2.1. Progress in Sustainable Research on Flash Floods in the World

Globally, flood control construction in mountainous cities has received widespread attention from various countries and organizations. As early as 1964, the European Forestry Commission of the United Nations Food and Agriculture Organization (FAO) established a Working Party on Mountain Watershed Management, which regularly hosts the “Mountain Disaster Prevention Conference” in Austria. This conference primarily serves as a forum for European countries to exchange experiences on managing mountainous torrents (European Forestry Commission Working Party, 2023).

In 1885, the Mississippi River Commission in the United States implemented a "levees-only" policy, based on the theory that building levees would force floodwaters to scour the riverbed, deepening the channel sufficiently to carry floodwaters directly to the sea. Proposals for artificial reservoirs, drainage outlets, and spillways were repeatedly rejected. Over the next 40 years, the commission adhered strictly to this policy, refusing to build any artificial drainage outlets and actively closing many of the river’s natural outlets. This “levees-only” approach, which resisted using flood reservoirs, channelization, and retention areas, remained the main flood control policy until the Great Mississippi Flood of 1927. The disaster significantly changed the U.S. government’s perspective on relying solely on levee systems (American Experience, n.d.).

In Asia, Japan introduced a new policy titled “Resilience and Sustainability in River Basin Management through Community Participation.” This policy adopts a comprehensive approach that includes flood prevention, exposure reduction, proper evacuation, response, and recovery. It aims to enhance disaster resilience and sustainability through the collaborative efforts of all stakeholders (Toshio, 2021). In Russia, flood management in mountainous regions focuses on prevention and soil erosion control, emphasizing non-structural engineering measures. This approach advocates the use of biotechnological methods for river management (Perov et al., 2017).

Research on urban flood management in mountainous areas has expanded in recent years. During the Italian Renaissance, Leonardo da Vinci suggested the use of a network of open channels and culverts in streets and alleys to prevent standing water and litter. In modern times, researchers such as Faryad Ebrahimi, Atabak Feizi and Taher Baher Talari (2022) applied advanced tools to study urban flooding. They used SWMM software to identify flood-prone channels and areas in Ardabil, a mountainous city in Iran, while evaluating the use of Low Impact Development (LID) techniques to reduce flooding in cities such as Ardabil.

### 2.2 Progress in Mountain Flood Prevention Research in China

The increased frequency of extreme weather events, the increased risk of flash floods in mountainous areas, and the critical importance of effective flood management to combat climate change and promote sustainable development have attracted great attention from Chinese scholars.

In 2004, Wang Senqiang's book Hongcun Water Veins explored the evolution, structure and human-water relationship of the ancient water system in Hongcun. The village's strategic layout followed natural topography and water flow, improving the environment and demonstrating a harmonious relationship with water.

Modern research has explored innovative approaches to urban flood protection in mountainous areas.2021 Wang Guangpeng and colleagues used Fuzzy Hierarchical Hierarchy Analysis (FAHP) and Geographic Information Systems (GIS) to assess the flood risk of a metro system under subsidence conditions. They found that ground subsidence has a significant effect on the flood risk of the metro. The researchers recommended measures such as raising station entrances, installing waterproof barriers and adding flood gates to reduce future flooding. This study is particularly relevant to the Beijing metro system and provides a theoretical basis for flood risk assessment in other cities.

**2.3 Flood Control in Ancient Chinese Mountain Cities**

Historically, many mountainous cities in China have developed unique water systems to cope with flooding. Cities such as Pinggiantai and Chang'an successfully coexisted with water, and their achievements in urban and water conservation are still relevant today. These historical practices provide valuable lessons for modern urban planning.

In Pinggongdae, the inhabitants built a ‘triple flood defence’ system. They built dykes and flood walls around the city to keep out external floodwaters. In addition, they developed an internal drainage network to channel rainwater away from the city through outfalls. They also raised the foundations of important buildings such as granaries to protect them from flooding (Li, 2023).

In the Huizhou region, ancient mountainous cities demonstrated a deep understanding of flood prevention in their urban design and water systems. These cities followed the principle of ‘building for the land and living by the water’. Historic towns such as Jixi, Hongcun and Chengkan integrated flood control with the living environment. Their innovative water systems reflect a harmonious balance between urban life and flood control (Qi, 2015). Studies of ancient water systems in Huizhou have revealed effective water use, flood control and disaster management strategies.

Previous studies have focused on specific regions, often using computational simulations to analyse flood data for individual cities. However, systematic studies covering multiple cities are rare. Wyoming flood management studies usually emphasise the historical context and multifunctionality of ancient hydraulic systems. Future studies could synthesise the flood control practices of individual cities. This approach will deepen the understanding of historical flood management and provide guidance for planning modern mountain cities.

## 3. Research Methodology

This study adopts a mixed-method approach combining macro-level data analysis and micro-level field investigation, incorporating GIS technology and on-site observations to systematically examine flood prevention practices in Huizhou’s mountainous cities.

- **GIS Data Collection and Watershed Analysis**

The study begins by using GIS technology to collect watershed information from over a hundred mountain cities in the Huizhou region. Through precise spatial mapping and analysis, we positioned and examined the geographical environment and watershed distribution of ancient mountain cities in Huizhou. This data reveals the common principles underlying the geographic placement and water system layout of these cities. GIS technology not only provides detailed data support but also allows for the visualization of urban siting and flood adaptation strategies across different geographical settings, laying a foundation for understanding the overarching characteristics of these mountain cities.

- **Literature Review and Selection of Representative Cases**

Building on previous studies on water systems and flood prevention strategies in Huizhou, a systematic literature review was conducted. From this review, we selected three representative mountain cities—Hongcun, Jixi, and Chengkan—for in-depth analysis. These cities exhibit diverse water system structures and flood control designs within mountainous environments, making them ideal case studies to uncover both the commonalities and differences in flood prevention among mountain cities. Detailed case analysis of these cities provides valuable insights into water system planning in Huizhou, offering practical reference points for other mountainous urban areas.

- **Case Analysis with GIS Technology**

After identifying the three typical mountain cities, we applied GIS technology to conduct detailed analysis of their water and drainage systems. By mapping the distribution of water bodies and the layout of flood control infrastructure in each city, we assessed the level of flood risk and the role of flood prevention facilities within the urban landscape. GIS technology made it possible to visually highlight the effective water management strategies in these cities, providing scientific evidence to support flood prevention design in mountainous urban environments.

- **Field Investigation**

The author conducted field investigations in Hongcun, Jixi, and Chengkan, focusing on residents' attitudes towards rainwater management and their everyday interactions with water. Information was gathered on how residents respond to flood events, as well as how they manage and utilize rainwater in daily life. This phase of the research, through the perspectives of residents, enriched the study by adding insights on flood management practices rooted in daily habits and cultural identity, making the findings more closely aligned with practical realities.

In summary, this study combines macro-level analysis with micro-level investigation to provide a holistic view of flood prevention in mountainous cities in the Huizhou region. From a technical perspective, we explore the principles behind flood management systems, while from a socio-cultural perspective, we examine residents' flood awareness and practices. This approach highlights the uniqueness of Huizhou's water system and flood protection measures, and provides practical suggestions for improving flood protection strategies in other mountain cities.

## 4. Results and Discussion

An analysis of the ancient mountain city of Huizhou using GIS technology reveals common principles of urban construction and site selection. The analyses focused on urban distribution, slope, topography, water flow and rainfall patterns. A key finding is that many of Huizhou's famous cities and towns were

located at higher elevations to reduce flood risk. This ‘upland siting’ strategy is an important flood prevention measure that allows cities to naturally avoid flood-prone areas (Figures 1 and 2).

The results emphasize the importance of considering the geographical environment scientifically in the initial stages of urban planning. By carefully selecting city locations with a focus on natural defences against floods, the ancient planners of Huizhou managed to mitigate flood risk from the outset. This approach serves as a valuable reference for modern flood prevention in mountainous urban areas, highlighting the role of site elevation and topography as proactive measures against flooding.

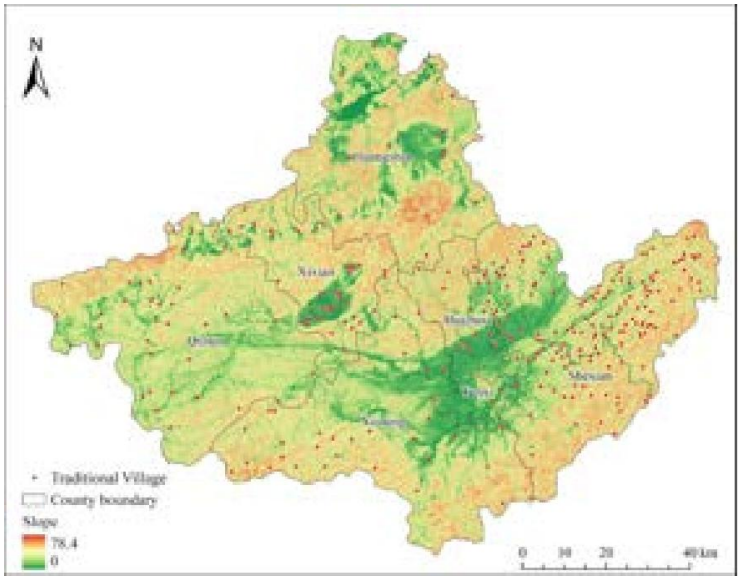


**Figure 1. Huizhou slop map. Source: Author’s work.**

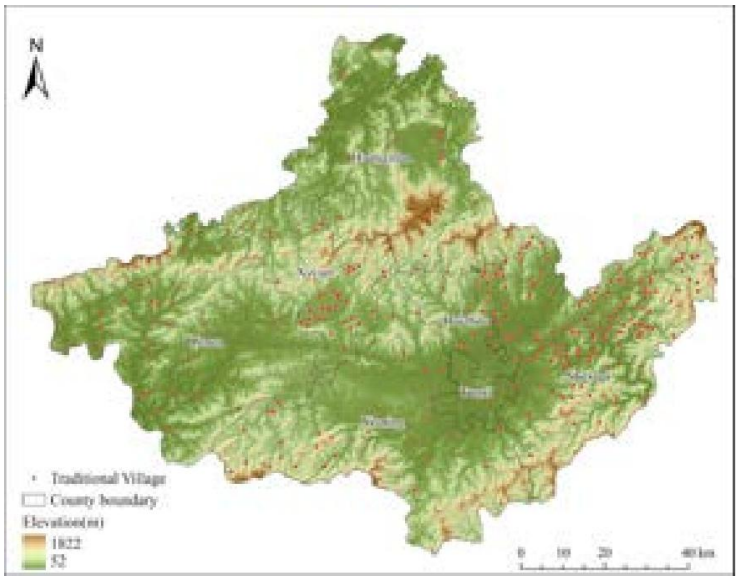


**Figure 2. Huizhou elevation map. Source: Author’s work.**

On the other hand, situating cities on the elevated edges of basins is one of the most common layout strategies in Huizhou's mountainous urban planning (Figures 3 and 4). Located at the confluence of rivers within mountain basins and valleys, this placement provided villages with ample space for growth and development. The relatively flat basin areas offer extensive catchment areas for water, which fosters the

gradual development of rivers that shape the basins and valleys. Over time, these river systems deposit rich and fertile soil layers in the middle and lower reaches, making the land highly suitable for agriculture.

By selecting high ground along the basin edges, ancient Huizhou settlements could avoid the direct impact of floods while preserving flat and fertile basin plains for farming. This strategic placement allowed for a balance between flood protection and agricultural productivity, demonstrating an adaptive approach that leverages both topography and water management to create sustainable mountain cities.

Based on the literature review and analysis, three ancient mountain cities in Huizhou - Hongcun, Jixi and Chengkan - are selected as representative cases of flood control. As examples of Huizhou mountain cities, these ancient cities reflect the wisdom of the ancients and are compatible with the local topography and climate conditions.

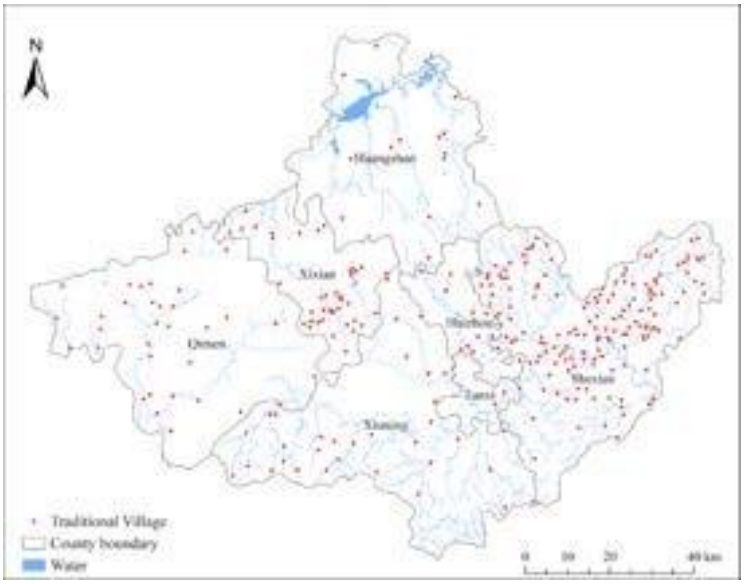


**Figure 3. Huizhou water flow map. Source: Author's work.**

The ecological wisdom of ancient Huizhou is thus demonstrated as these measures not only improve the convenience of residents' daily lives, but also reduce the risk of flooding. They emphasise the sustainable balance between human and natural environments and provide valuable insights into flood resilience in modern mountain urban planning.

A detailed study of three case cities, Hongcun, Jixi and Chengkan, reveals similarities in their urban and water system designs. Each city was built near a river source with upstream water flowing from a deep valley. Huizhou's ancestors often chose to settle in areas surrounded by mountains and streams, usually locating their villages downstream. The complex mountainous terrain created many tributaries that formed a stable network of rivers that supported agriculture and community life. These downstream areas also provided important natural resources (Yang et al., 2022).

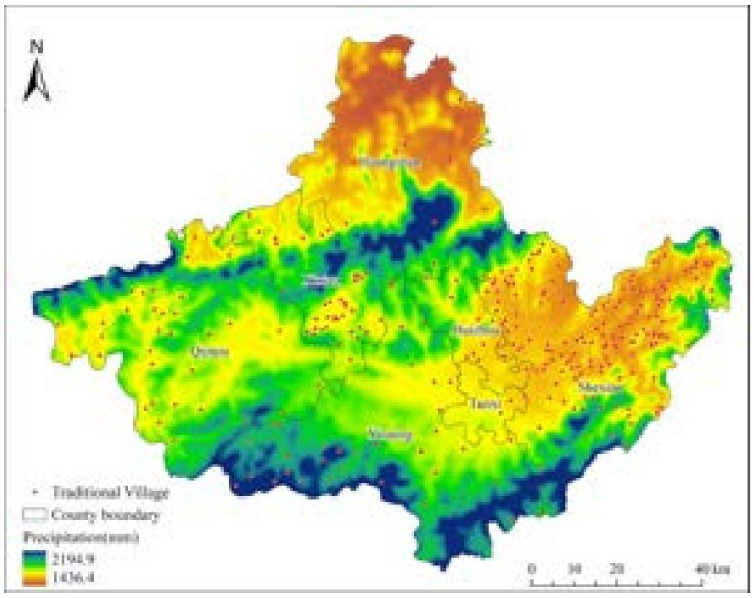


**Figure 4. Huizhou precipitation map. Source: Author's work.**

**Figure 5. Picture of Hongcun, Jixi, Chengkan. Source: Anhui province government, 2019. 'Polar Bears in the Arctic'[Image]. Available： https://www.ah.gov.cn/ [Accessed 13 September 2024].**

Using GIS technology to analyse the flood risk levels of these cities, it was found that the risk levels were generally low to medium (Figures 6, 7 and 8), indicating that the integration of water facilities and drainage systems in the road network in Huizhou area has effectively improved the city's flood resilience. At the same time, these designs also balance the efficient use of water resources with the maintenance of regional water ecosystem stability.

In the Huizhou region, the cities of Hongcun, Jixi, and Chengkan have ingeniously integrated their street networks with flood drainage systems. Through the use of both open and underground channels, they effectively direct excess floodwater to external natural bodies of water (Figure 9), creating an efficient urban drainage network. This street-based drainage system not only meets daily water discharge needs but also allows for rapid diversion during flood events, significantly reducing the risk of urban flooding and waterlogging. Furthermore, the reservoir facilities in these cities serve multiple functions; they not only provide a reserve of potable water but also connect to the surrounding agricultural irrigation systems, ensuring the rational allocation of water resources for agriculture.

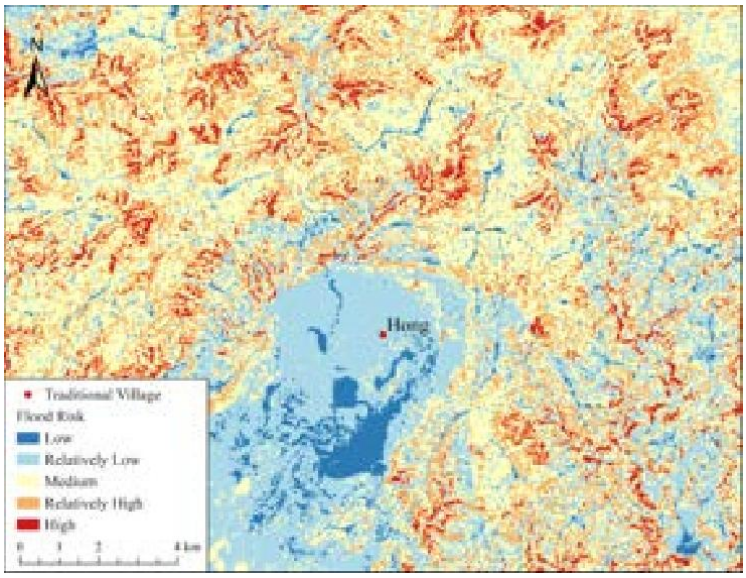


**Figure 6. Hongcun Flood Risk map. Source: Author's work.**

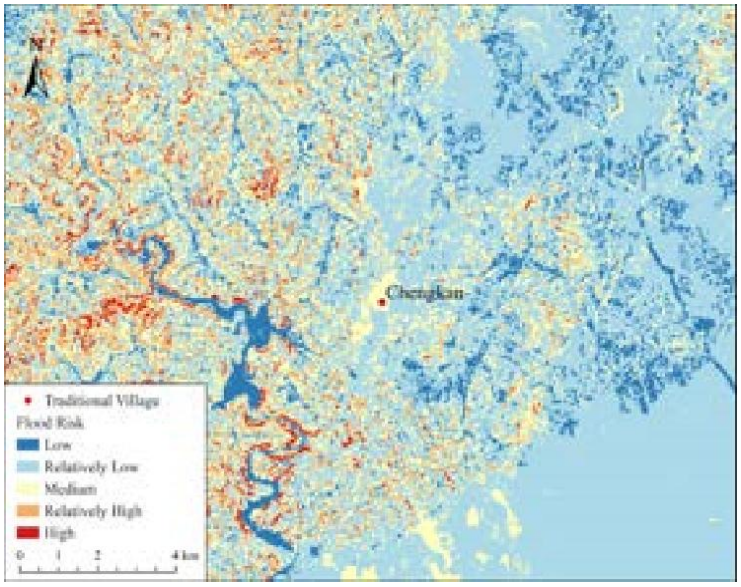


**Figure 7. Chengkan Flood Risk map. Source: Author's work.**

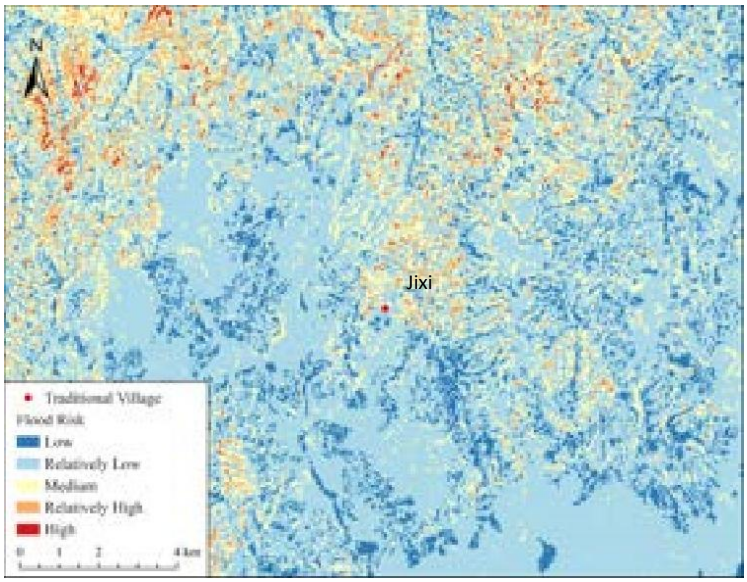


**Figure 8. Jixi Flood Risk map. Source: Author's work.**

**Figure 9. Rainwater management. Source: Li (2013:53) .**

## 5. Conclusion

The aim of this study is to investigate modern stormwater management systems for sustainable mountain cities, focusing on three key aspects: 'external water retention, internal drainage, and stormwater storage and regulation'. This approach aims to address the unique flooding challenges faced by mountain cities.

First, external water storage emphasises the integration of urban geography with hydrological conditions. Cities should be sited to avoid areas of high flood risk, such as areas below the flood discharge level. This proactive approach helps to reduce the threat of flooding and ensure safer urban development.

Secondly, internal drainage management focuses on maximising the use of existing flood protection infrastructure. Flood levels are reduced to protect urban safety by optimising the regulatory balance of the water system. Peak flood pressures are reduced through multi-layered drainage networks and overflow channels.

Finally, the rainwater storage and conditioning component includes collection, storage, conditioning and multiple uses. It contributes to the reduction of urban flooding, improves the management of rainwater resources and promotes water recycling and ecological sustainability.

In summary, the combination of the three water systems management will greatly improve the flood resilience of mountainous cities. It will reduce the disaster risks associated with extreme rainfall events and provide an efficient, green, and sustainable pathway for water environment governance in these

areas, thereby offering robust support for ecological safety and improving living conditions in mountainous urban environments.

## 6. References

American Experience (no date) The Mississippi River Commission and the Army Corps of Engineers. Available at: https://www.pbs.org/wgbh/americanexperience/features/flood-control/ (Accessed: 22 October 2024).

Anhui province government, 2019. Picture of Hongcun, Jixi, Chengkan. [Image]. Available：https://www.ah.gov.cn/ [Accessed 13 September 2024].

Ebrahimi, F., Feizi, A. and Talari, T.B.(2022)'Investigation of the Potential Threat of Urban Flood at Mountainous Areas through Low Impact Development Techniques (Case Study: Ardabil City)', *Journal of Hydraulic Structures*,8(2), pp. 52-67.

European Forestry Commission Working Party (2023) Working Party on the Management of Mountain Watersheds. Available at: https://www.fao.org/forestry-fao/37705/en/ (Accessed: 20 October 2024).

Leszek, G., Bogusława, B.Z. and Wojciech, Z. (2024) 'Flash Floods Hazard to the Settlement Network versus Land Use Planning (Lublin Upland, East Poland)', *Applied Sciences (Switzerland),* 14(18), pp. 1-23.

Li, P.Y. (2023) The earliest known pottery drainage system in China was unearthed at the Pingliangtai ancient city site, dating back about 4,000 years. Available at: https://www.chinanews.com.cn/cul/2023/08-15/10061281.shtml (Accessed: 20 October 2024).

Li, T.J. (2013) 'Ancient Study on water system construction and flood control design in Huizhou villages and towns', Master thesis. Hefei University of Technology, p. 53.

Noji, E.K., Lee, C.Y. (2005) 'Disaster Preparedness' in Frumkin, H.(ed.) *Environmental health: from global to local*. 1st edn. San Francisco: Jossey-Bass, pp. 745–780.

Perov, V., Chernomorets, S., Budarina, O., Savernyuk, E. and Leontyeva, T.(2017)'Debris flow hazards for mountain regions of Russia: regional features and key events', *Natural Hazards*, 88, pp. 199-235.

Qi, M.N. (2015) 'Enlightenment of water resource utilization in traditional Huizhou villages on modern residential planning', *City Construction*, 5(10), p.1.

Stoffel, M., Wyżga, B., Marston, R.A. (2016) 'Floods in mountain environments: A synthesis', *Geomorphology*,272, pp.1-9.

Toshio, K. (2021) 'Evolution of Japan's flood control planning and policy in response to climate change risks and social changes', *Water policy,* 23 (S1), pp.77–84.

Tullos, D., Byron, E., Galloway,G., Obeysekera, J., Prakash, O. and Sun, Y.H. (2016) 'Review of challenges of and practices for sustainable management of mountain flood hazards', *Natural Hazards*, 83, pp. 1763-1797.

United Nations（2023） Guterres: Pakistan floods a 'litmus test' for climate justice. Available at: https://news.un.org/zh/story/2023/09/1122342 (Accessed: 26 October 2024).

Wang, G.P., Liu, Y., Hu, Z.Y., Zhang, G.M., Liu, J.F., Lv, Y.L., Yu, G., Huang, X.C., Zhang, Q.Y., Liu, L.Y.(2021) 'Flood Risk Assessment of Subway Systems in Metropolitan Areas under Land Subsidence Scenario: A Case Study of Beijing', *Remote Sensing,* 13(4), pp. 1-33.

Wang, S.Q. (2005) *Water vein Hongcun*. Nanjing: Jiangsu Fine Arts Publishing House.

Weingartner, R., Barben, M., Spreafico., M. (2003) 'Floods in mountain areas—an overview based on examples from Switzerland', *Journal of Hydrology*, 282(1-4), pp. 10-24.

Wu, Q.Z. (1995) *Research on Flood Control in Ancient Chinese Cities*. Beijing: China Architecture & Building Press.

Yang, M., Chen, D.K., Shi, L.Y., He, J., Liu, L.Y., Shang, X.Q. (2022) 'How do construct a sponge city that can improve residents' satisfaction? Evidence from a suburb of Huizhou City, China', *Ecological Indicators,* 142, pp.1-17.

Zhao, G., Pang,B., Xu, Z.X., Yue, J.J. and Tu, T.B.(2018)'Mapping flood susceptibility in mountainous areas on a national scale in China', *Science of The Total Environment*, 615, pp.1133-1142.