

# Enlightenment from ancient Chinese urban and rural stormwater management practices

Che Wu, Mengxi Qiao and Sisi Wang

## ABSTRACT

Hundreds of years ago, the ancient Chinese implemented several outstanding projects to cope with the changing climate and violent floods. Some of these projects are still in use today. These projects evolved from the experience and knowledge accumulated through the long coexistence of people with nature. The concepts behind these ancient stormwater management practices, such as low-impact development and sustainable drainage systems, are similar to the technology applied in modern stormwater management. This paper presents the cases of the Hani Terrace in Yunnan and the Fushou drainage system of Ganzhou in Jiangxi. The ancient Chinese knowledge behind these cases is seen in the design concepts and the features of these projects. These features help us to understand better their applications in the contemporary environment. In today's more complex environment, integrating traditional and advanced philosophy with modern technologies is extremely useful in building urban and rural stormwater management systems in China.

**Key words** | ancient wisdom, Fushou drainage, Hani Terrace, modern stormwater management

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## INTRODUCTION

There is an old Chinese saying, 'The water can bear the boat and can swallow it too.' This proverb means that different attitudes toward the water could lead to benefits or consequences. Today, rapid urbanization and inappropriate site developments cause adverse effects, such as floods, water shortage, and pollution. To address these issues, new concepts and technologies in stormwater management, such as low-impact development (LID) and green stormwater infrastructure (GSI), sustainable urban drainage systems (SUDS), etc., are widely applied in several developed countries. The main objectives of these concepts are the reduction of impervious surfaces, the retention of runoff onsite, the promotion of infiltration and evapotranspiration, the full use of rainwater to attenuate the adverse effects of site development, and the maintenance of sustainable water supply in watersheds (Butler & Parkinson 1997; Chang 2010).

In fact, the ancient people of China had a comprehensive understanding of stormwater management and the water environment. They implemented a number of projects that have stood the test of time. The ideas contained in these

projects are similar to modern ones. Two typical cases are selected in this article. One is the Hani Terrace (rice paddy fields) on the steep mountains. The other is the Fushou drainage system in Ganzhou city. Analysis and discussion on their hydrology, geography, structures, design ideas and operational principles in this paper, would provide useful insights for people to understand the real meanings of the concepts and practices.

## METHODS AND MATERIALS

The methods of this study include site surveys, local data collection, Google map search, and literature review. The obtained data help in the thorough understanding of the local geography, history, layout and structure of the ancient methods applied in China. To account for the different time background and site conditions, the two cases are compared with the modern stormwater management practices. The basic information of sites is as follows.

## Study region 1

Hani Terrace is located in Yuanyang, the south of Yunnan province (see Figure 1(a)), which is near the mountain, Ailao. The area is a low-latitude plateau with a subtropical monsoon climate. The vertical climate in the area is prominent (Cui et al. 2008). The river valley is located below at 1,200 m, while the low mountainous area is located between 1,200 and 1,700 m. The average annual rainfall is 1,407 mm. Rainfall is concentrated during a period of 5–10 months, which accounts for 76.5% of the annual precipitation. The water surface evaporation level is 1,080 mm (Li et al. 2010). The mountain slope is steep and ranges from 15 to 75%.

## Study region 2

Fushou drainage system of Ganzhou in Jiangxi province (see Figure 1(a)) sits between the Zhang and Gong rivers, where the average annual rainfall is 1,588 mm during the wet season. Rainfall is concentrated during a period of 4–6 months, which accounts for 44% of the annual precipitation. The name of the Fushou drainage was derived from shapes resembling the Chinese ancient characters (seal character) *Fu* and *Shou* (see Figure 1(b)). The *Fu* ditch was approximately 11.6 km, while the *Shou* ditch was 1 km. The catchment area was about 40 ha.

## ANALYSIS AND DISCUSSION

### Hani Terrace and the LID concept

In February 2010, the southern areas of China suffered an extreme drought. However, the 1,300-year-old Hani Terrace was less vulnerable to drought, and still had steady water supply from the mountain to support the villagers and to

nourish the vegetation. This beneficial condition depended on the unique local environment, function of the terrace and ancient wisdom.

### The evolution of Hani Terrace

Hani Terrace has gone through three stages of evolution (Gong & Sun 2009). The first stage can be traced back to the Ming Dynasty (AD 1368–1644). Deforestation and incinerated trees were used as fertilizer. When the fertility of the land gradually decreased, the people turned to other forests. The population growth needed more arable land. As the second stage, the arable area was divided into several parts, and the intermittent rotation of crops was implemented to ensure soil fertility. When the Hani nomads migrated from the Tibetan Plateau southward to Yuanyang, the better lands were already occupied; hence, they had to live in the mountains. Influenced by the geography, climate, and the farming habits of Southern China, the Hani built terraces and planted rice on the steep slopes of the lower part of the mountains. But they retained the forest at the top of mountains. This development marked the third stage in the evolution of the area. Ultimately, a four-in-one environmental pattern of combining forests, farmhouses, terraces, and rivers was formed.

### The hydrology of the Hani Terrace

Prior to its development, the Hani land was made up of woodlands with a large forest area characterized by moderate infiltration rate, evaporation, transpiration, and well-drained soil. Thus the hydrology of pre-site is nature and health. According to the research station of the Yunnan Ailao mountain subtropical forest ecosystem, Chinese subtropical forest soils can store 1/3–1/4 of the annual precipitation, or approximately 641–678 t/hm<sup>2</sup>.

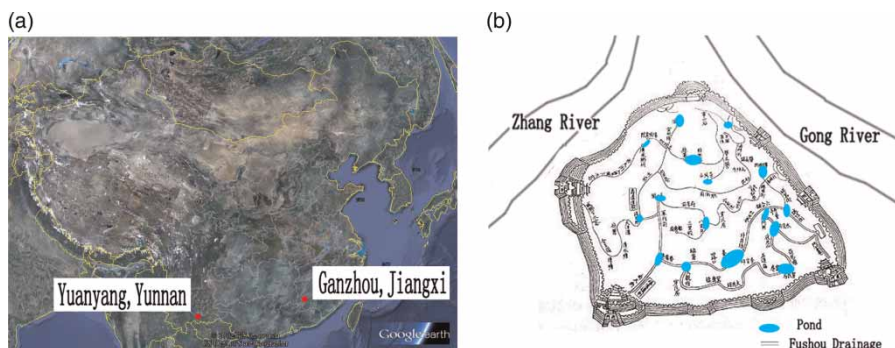


Figure 1 | Location of the study regions. (a) Location of two study regions. (b) Fushou drainage system.

With the construction of the platforms and irrigation ditches, the surface of the Hani area has changed significantly from its natural conditions to the artificial site of cultivation. With regard to post-site hydrology, the terraces are located in a river valley and a lower mountainous region. The region is characterized by high temperature, and a considerably large surface of water that produces more vapor. With cold air at a high altitude, the vapor can be condensed easily and returned to the ground as rainfall. The rainwater is mainly retained in two forms in the different areas. At the top of the mountains, it is easily retained by the forest through interception and evapotranspiration from plants, and the infiltration and storage of soils and roots. The rainwater in the soils and forests with high storage capacity is used to recharge the base flow and groundwater. According to statistical data on Yuanyang, the volume of groundwater resource is about 120 million  $\text{m}^3$  (Rao *et al.* 2009). Even during a drought period, the Hani Terrace can provide adequate water. In the low part of the mountain, through artificial transformation and being soaked in water perennially, the Hani soil becomes heavy clay with lower infiltration rate, which can retain water and nutrients. Thus, most of the rainwater is harvested by the terraces (see Figure 2).

One part of the Hani Terrace, the Mengpin terraces measuring approximately 500  $\text{hm}^2$ , is selected for the estimation of storage capacity. The depth of water is about 0.25–0.3 m. Each level of the terraces has 10–20 cm of

storage height. The retention volume is approximately  $5 \times 10^4 \text{ m}^3$  to  $1 \times 10^5 \text{ m}^3$  for one rainfall event. This structure shows that all the distributed terraces create a sizable retention volume, which utilizes rainwater and reduces the runoff efficiently to maintain the pre-development hydrology. Moreover, the multi-step terraced structure can reduce runoff velocity and protect against erosion and reduce sediment transport.

### Unique productive landscape

Although terraces are distributed throughout the world, hard tillage and maintenance led to the abandonment of a great number of terraces (Wu *et al.* 2003). The Hani Terrace is one of the few reserved areas, which is due to its substantial cycle system. Approximately 200,000 inhabitants live on the mountain area. The water used for their domestic needs comes from the higher forests. Sewage (mainly from washing, toilets, among others) is discharged to the terraces as fertilizer. The wastewater is filtrated, absorbed, precipitated, and degraded by the vegetation, soil, and organisms. Finally, the purified water can overflow into the rivers. Aside from being planted with rice and lotus, the Hani Terraces are used as ponds for fish and field snails by adjusting the height of the spillway during fallow periods. A multipurpose farming of Hani Terrace is integrated with the landscape to form the magnificent scenery (see Figure 2). Now a

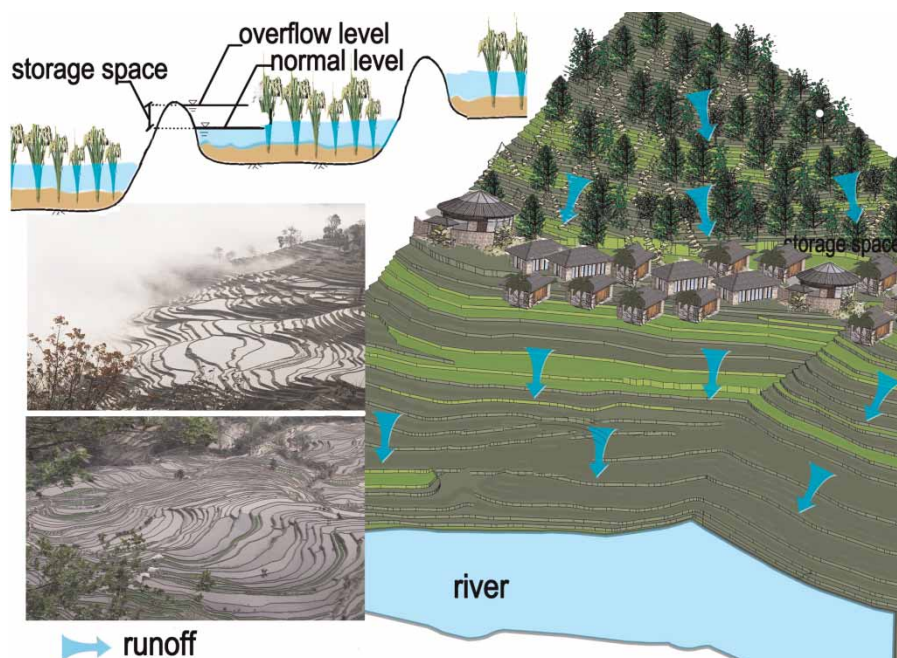


Figure 2 | Diagram of the Hani Terrace (photographs by W. Che).

world-renowned tourist attraction, the area has contributed substantially to the local economy. The local government is now applying for the Hani Terrace to be recognized as a World Cultural Heritage site.

### LID concept behind the Hani Terrace

LID is a site design strategy with a goal of maintaining or replicating the pre-development hydrologic regime through the use of design techniques to create a functionally equivalent hydrologic landscape (USEPA 2000). Hydrologic functions of storage, infiltration, and groundwater recharge, as well as the volume and frequency of discharges are maintained through the use of integrated and distributed micro-scale stormwater retention and detention areas, reduction of impervious surfaces, and the lengthening of flow paths and runoff time (Coffman 2000). The idea and function of Hani Terrace is similar to LID concept. Hani Terrace mainly deals with stormwater by plants and soil of the forest at the top of the mountain and terraces at the low part of mountain, which infiltrate, filter, store, evaporate, and detain runoff close to natural hydrology. And the system protects against erosion, reduces sediment transport and maintains a landscape with aesthetic features, biodiversity, and amenity values. Hence, Hani Terrace is considered an excellent example of an ancient stormwater management system similar to LID in rural areas.

### Integrated drainage and retention pond system of Fushou drainage

In recent years, an increasing number of cities in China have experienced serious floods, which caused huge economic and social losses. Lives were not spared either. However, Ganzhou in Jiangxi province is fortunate. Although its location is an area that is prone to flooding, Ganzhou has experienced few floods because of its integrated drainage and retention pond systems, which were built 900 years ago.

#### Origin of the Fushou drainage

As early as the end of the Tang Dynasty (AD 618–907), Ganzhou has undergone expansion. In the next 200 years, the area suffered frequent floods due to inappropriate urban design and construction. Historically, the highest water levels of the Gong and Zhang rivers have reached 106 and 106.76 m, respectively. A large quantity of stormwater could not be drained into the river by gravity. During the Northern Song Dynasty (AD 960–1127), Yi Liu, the

administrator of the region, planned and rebuilt the streets, implemented zoned districts, and constructed *Fu* and *Shou*, two drainage networks in accordance with the layout and topography of the area.

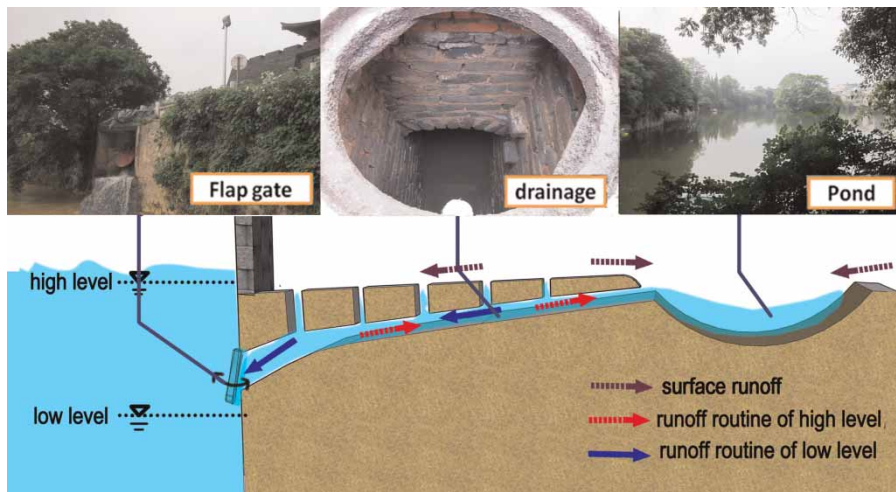
### Integrated drainage and retention pond system

According to the geographical conditions of Ganzhou, both drainage and storage were considered in the design. At the beginning of the rainy season, the water level of the river is below the flap gate at the end of the ditch; hence, the stormwater discharges into the river. To ensure the smooth flow of runoff and to increase the flow rate, the cross-section of the ditch was enlarged to 1.65 m in depth and 1.15 m in width and its slope is 4.25%, which is four times more than the dimensions of regular drainage systems (Huang 2011). Thus, runoff can discharge quickly. During the rainy season, when the water level exceeds the height of the flap gate, the lateral pressure of the water closes the flap gate, which prevents the water from flowing back into the town. The rest of the runoff accumulates in the ditch and flows backward to the ponds that are connected to the drainage system. As the flood recedes, the water level drops below the flap gate, and the excess stormwater in the system then discharges into the rivers (see Figure 3).

The ponds in the system are formed by the micro-landform throughout the old town that would not only collect surface runoff and retain the excess stormwater, but also minimize the pollution. For example, Liwang pond is approximately 5.3 ha, with a storage height of about 1–2 m. The pond can hold  $5.3 \times 10^4$  to  $1.1 \times 10^5 \text{ m}^3$  of rainwater. According to the event mean concentration of pollutants in Chinese cities similar to Ganzhou, the Liwang pond could eliminate chemical oxygen demand ranging from 12 to 24 tons per year, and suspended solids from 9 to 20 tons per year. At the same time, such ponds create more ecological and social benefits. They not only regulate the microclimate and reduce the heat island effect, they also can be used for fish farming, and lotus planting, and provide attractive open space for local residents.

### Sustainability of the Fushou drainage system

SUDS mimic natural drainage processes to reduce the effect on the quality and quantity of runoff from developments and provide amenity and biodiversity benefits (Dickie et al. 2010). Fushou drainage system is an excellent example that combined the drainage and storage, distributed and centralized, underground and ground, grey and green infrastructures.



**Figure 3** | Diagram of the Fushou drainage system (photographs by W. Che and M. X. Qiao).

The ponds in the system are typical measures of SUDS and GSI. They recover the surface water drainage by: storing runoff and releasing it slowly, allowing water to soak into the ground, purifying pollutants. Ponds are also essential green infrastructures providing multifunctional open space and landscape, maintaining biodiversity, and ensuring environmental, social, and economic sustainability. Relying on perfect integration, the stormwater is distributed rationally and the surface runoff conveyance is maintained, while water logging and flooding are prevented in the old town.

The sustainability of Fushou drainage also lies in its design standard, materials and its function, which stands the test of time. Among the existing ditches, the largest is 1 m in width and 1.6 m in depth, while the smallest is 0.6 m in both width and depth. The size of the ditch can meet the needs of a population that is three or four times larger than the current number, about 0.3–0.4 million people (Liao *et al.* 2010). The sustainable materials of the system, such as local traditional stones, black bricks, and trinity mixture, are not easily corroded, are easier to repair and revamp, and are more environmentally friendly than modern ones. Based on these characteristics, the Fushou drainage system still remains beneficial to the current and future generations.

### Enlightenment from ancient wisdom

In ancient times, the people respected and adhered to the processes of nature. Their experiences and the advanced concepts behind these practices are deserving of modern man's attention. Table 1 summarizes the goals, features, means, etc., of ancient stormwater management and

compares them with modern ones, which would provide some enlightenment as follows.

### Changing conception to turn 'waste' into treasure

The ancients used stormwater as a resource for agricultural irrigation and water supply. Today, stormwater is a problem or a by-product of urbanization that needs to be discharged as quickly as possible. Guided by that principle, several 'high efficiency infrastructures', such as pipes and concrete tanks, are widely applied. However, these grey infrastructures are not successful in addressing the issues of flooding, water pollution, water shortage and ecology. Thus, the first and most crucial step is to change the misconception. Most rainwater should be as a beneficial resource returned to the earth and stored, infiltrated at source.

### Considering nature in design to maintain a healthy hydrological cycle

The ancient people profoundly understand how to achieve balance in healthy hydrology. Hydrological characteristics are the key factors of the regional water environment, but these factors have been altered by the development in urban and rural areas. To attenuate the adverse impact, the hydrological properties and a solid stormwater management plan should be considered at the beginning of site development. Elements from nature, such as vegetation, topography, geography, waters, and soils, should be utilized to retain and to purify stormwater, and to ensure the quantity and the quality of runoff.

**Table 1** | Comparison of ancient and modern stormwater managements

	Chinese ancient stormwater management		Modern stormwater management	
	Hani Terrace	Fushou drainage	Convention	New
Site location	Rural area, steep mountain	Old town between two rivers		
Goal	Agricultural production, rainwater harvest control of erosion and pollution	Discharge of stormwater and sewerage, control of flood and water logging	Discharge of stormwater and sewerage control of flood and water logging	Healthy watershed and hydrology, control of water quality, volume, peak flow, etc.
Measure	Forests, terraces	Ditches, ponds, flap gate, etc.	Pipe, pumps, concrete tanks, etc.	Rain garden, green roof, grass swale, etc.
Hydrologic function	Storage, filter, evapotranspiration infiltration, etc.	Conveyance, storage, evapotranspiration, sedimentation, etc.	Conveyance, etc.	Storage, filter, evapotranspiration, infiltration, etc.
Feature	Distributed, at source, micro-scale, multifunctional, 'green', etc.	Integrated drainage and storage, 'grey' and 'green', distributed and centralized, etc.	Rapid-drainage 'grey'	Distributed and centralized multifunctional, 'grey' and 'green', micro/macro-scale, etc.
Concepts	Similar to LID and GSI	Similar to SUDS, GSI and conventional		LID, GSI, SUDS, etc.

### Developing a stormwater management system in the local context

The two cases mentioned share a similar concept with modern stormwater management, although the facilities and structures differ. The application of stormwater management techniques to the city and the village may vary in accordance with project specifications, design targets, climate, geography, culture, and social conditions. Moreover, the differences in the form and structure of ancient and modern stormwater management systems indicate that the modern version is not only a combination of several technologies used only in cities, but is also flexible for application to rural areas.

### New era, new challenge

Although the ancient methods can be considered advanced for their time, contemporary stormwater management is more challenging because of the severe conditions, such as fast urbanization, scarce land and water resources, environmental pollution, climate change, and infrastructure complexity. In the Fushou drainage system, for example, urban development has resulted in having 80% of the ponds filled, and heavy eutrophication in the remaining ponds (Feng 1984).

To solve the complex problems, traditional principles and modern technologies, and green and grey infrastructures

need to be integrated. In the past 10 years, a lot of LID or GSI facilities and practical projects have been implemented in many Chinese cities, including schools, green buildings, residential areas, open space and municipal areas, etc. Most metropolitan areas in China, such as Beijing, Shanghai and Guangzhou, etc., are engaged in constructing detention tanks, while a number of cities are conducting application of LID and GSI (Che et al. 2010). Correlative research and demonstration projects have been adopted into a national research plan, i.e. the Major Science and Technology Program for Water Pollution Control and Treatment etc. China is working to strengthen the linkages among urban planning, landscape design, municipal engineering, and environmental engineering. The government, along with scholars, designers, developers, and the public, should face the new challenge of stormwater management and water environment design together.

### CONCLUSION

The Hani Terrace and the Fushou drainage system demonstrate the ancient knowledge of stormwater management and water environment design in recovering natural conditions, utilizing rainwater effectively, controlling floods, and maintaining water environmental health. These concepts are similar to modern stormwater management

approaches. Exploring ancient wisdom and using the ideas of the ancestors could help us to understand modern stormwater management, and to apply the idea and technology to the development of urban and rural stormwater management systems in developing countries under different environmental conditions.

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