Sponge City Planning and Construction of Small Towns in Subtropical Mountainous Areas of Yunnan Province

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Abstract: Taking Ning’er County, a small town in a subtropical mountain area, as an example, explore a scientific and reasonable sponge city construction plan suitable for small towns. In analyzing the problems of water safety, water resources, water environment, and water ecology in the construction of Ning’er County sponge city, the sponge city construction goals were put forward according to local conditions, and the construction process of the entire process of "source reduction, regional control, and system governance”, Proposed a systematic planning and construction plan for Ning’er County sponge city construction.

1. Introduction

China has entered a stage of rapid development of urbanization since the reform and opening up. The urbanization rate has increased from less than 20% in 1979 to 58.225% in 2017, with an average annual growth rate of nearly 1%. Under the influence of traditional concept, urban development and construction bring about excessive hardening of urban underlying surface, cutting off the natural circulation of water and changing the original matrix and hydrological characteristics [1] of natural ecology. The urban problems brought by urban development mode are becoming increasingly prominent, especially the urban water environment problems such as frequent urban waterlogging, intensified runoff pollution and water shortage. The National New Urbanization Planning (2014-2020) confirms that China’s urbanization needs to enter a new stage of transformation and development focusing on improving quality. Therefore, we must adhere to the new urbanization development, coordinate conflicts between urbanization and environmental resources protection, so as to realize sustainable development.

Since the sponge city with natural accumulation, infiltration and purification was put forward by General Secretary Xi Jinping in December 2013, the sponge city has become one of the hot topics in the city construction [2]. In recent years, China’s small towns have developed rapidly, while at the same time, the water ecological environment has been polluted to a certain extent [3]. In order to actively implement the relevant requirements of new urbanization and water security strategy, vigorously promote the construction of "sponge city" with natural accumulation, natural infiltration and natural purification, save water resources, protect and improve urban ecological environment, explore sponge city construction suitable for small towns, promote ecological civilization construction of Ning’er county, and create a sponge city of Ning’er, the paper puts forward the planning and construction scheme of sponge city of Ning’er, according to the requirements of relevant national standards and technical guidelines.
2. The Overview of Ning’er County

Hani-and-Yi autonomous county in Ning’er (former Pu’er county) is located in the south of Yunnan province and the central part of Pu’er city. It is located in the transition zone of Zhongshan broad valley in the south of Wuliang Mountain of Hengduan Mountain. The mountainous area accounts for 96.77% of the total area of the county, and the geographical area of the whole county is subtropical. The average annual rainfall of Ning’er county is always 1465mm. The rainy season is from May to October, with an average annual precipitation of 5.16 billion cubic meters and an average annual rainfall of 165.3 days. At present, the overall development of the central urban area has strong force, with fast construction, dense urban road network, high building density. The proportion of hardened pavement of underlying surface and roof is high, resulting in large runoff coefficient, shortage of infiltration facilities of urban green space, roof greening, etc., which lead to rapid concentration of rainwater, easy scouring and waterlogging.

3. The Problems

3.1 Water Safety

3.1.1 Urban Flood Control

The central urban area of Ning’er county is high in the north and low in the south. The river system in the urban area mainly includes Xi’er River, Dong’er River, Jinji River, Wenquan River and Xiaodong River, which finally flows into Pu’er River. At present, the flood control standard of Pu’er River is for 10-year return period flood, and the design standard is low, which fails to meet the urban flood control standard. The needs of urban flood control cannot be met due to the small river section and low capacity of flood control. Besides, most of the river banks are not set up water landscape, which is not conducive to the construction of urban landscape.

3.1.2 Drainage and Waterlogging Prevention

At present, with the gradual completion of urban drainage network, waterlogging has been basically solved in the urban area of Ning’er county, with a few low-lying areas still forming a certain amount of water. In addition, the construction standard of urban drainage infrastructure is low and the system is not perfect. At present, the design return period of drainage pipe network in old urban area is generally 1 to 2 years, with the design of one-year return period as the majority and low construction standard. Especially with the development of the city and the expansion of catchment area, some drainage pipes and canals inevitably fail to meet the drainage requirements.

3.1.3 Emergency Management System of Urban Flood Control and Waterlogging Prevention

Ning’er county has formulated A Plan on the Urban Flood Control in Ning’er County, but the mechanism is still not comprehensive. The emergency management system of flood control and waterlogging prevention, the emergency mechanism and the emergency plan are still lack of linkage mechanism. The upstream reservoir cannot be operated to give full play to the role of flood control in a comprehensive and scientific way. Thus, the emergency management system of urban flood control and waterlogging prevention needs to be improved and strengthened.

3.1.4 Water Supply Security

The urban scale of Ning’er county is developing rapidly. In the long term of planning, the population of the central urban area will reach about 110,000. Dahebian reservoir, Songshan reservoir, Paomuguoqing reservoir and Ximenlongtan reservoir are planned as urban domestic water sources. With the construction of Hezhangtian reservoir, the above two reservoirs will be included in the water supply sources in the future. Although the relevant departments regularly detect the water quality of the water source, there is still a lack of capacity-building for emergency monitoring to deal with sudden water pollution incidents, and thus the safety of water supply cannot be guaranteed to the greatest extent.
3.2 Water Resources

Table 1 Results of analysis of current water supply and demand in Ning’er County

| frequency          | Total water demand (10000m³) | Water supply (10000m³) | Water shortage (10000m³) | Water shortage rate (%) |
|-------------------|------------------------------|------------------------|--------------------------|-------------------------|
| Multi-year average| 3723                         | 3317                   | 407                      | 10.93                   |
| 50%               | 3667                         | 3222                   | 445                      | 12.14                   |
| 75%               | 3888                         | 3068                   | 820                      | 21.09                   |
| 90%               | 4167                         | 2916                   | 1251                     | 30.03                   |
| 95%               | 4335                         | 2892                   | 1443                     | 33.29                   |

It can be seen from the above table that the water supply at different frequencies shows a significant downward trend, which indicates that the water storage project in Ning’er county is insufficient and the regulation and storage capacity is limited. However, the water diversion project has no water to be introduced in the drought year, and cannot adapt to the increase of water use and the changes of the incoming water in the flood and drought years, so the shortage of engineering water is serious.

3.3 Water Environment

3.3.1 The water supply source is polluted without designated protection area of drinking water source, which threatens the safety of drinking water.

3.3.2 The Aggravation of Water Pollution Caused by the Imperfection of Domestic Sewage Collection and Treatment System.

Due to the imperfect construction of sewage collection and treatment system along the Donger River, Xier River, Jinji River, Xiadong River and Wenquan River, most of the water quality monitoring indicators are on the rise in recent years. The main reason is that organic pollution exceeds the standard, such as dissolved oxygen, five-day biochemical oxygen demand, ammonia nitrogen, total phosphorus and anionic surfactant.

3.3.3 Water Quality Deterioration Caused by the Non-Point Source Pollution of Rainwater at Primary Stage

The intercepted combined drainage system is adopted in the old urban area of the central urban area, and part of the initial rainwater in the old urban area enters the sewage treatment plant for treatment. However, due to the low interception ratio (generally 1), a large number of non-point source pollution still enters the urban water body and causes pollution; in addition, in the new area where the rainwater sewage separation system is adopted, the primary rainwater non-point source pollution is not controlled, and a large number of pollutants are entering the urban water body with the initial rainwater, which results in the deteriorated water quality.

3.3.4 Low Recycling Rate of Sewage

At present, there is a sewage treatment plant in Ning’er county, which is located in the southwest of the county. The service range of the sewage treatment plant covers Ning’er county. The short-term designed life is 2015, with 60000 designed service population and 10,000m³/d designed sewage treatment scale; the long-term design life is 2025, with 90000 designed service population and 20,000m³/d sewage treatment scale. CASS process is adopted in the wastewater treatment plant, and the designed effluent quality is grade B. The sewage of sewage treatment plant is directly discharged after treatment, which causes waste of water resources. So, it is urgent for the recycling of wastewater after advanced treatment.
3.4 Water Ecology

The central urban area of Ning’er county mainly includes five rivers: Dong’er River, Xi’er River, Jinji River, Xidong River and Wenquan River. After years of reconstruction, all rivers downtown have been transformed into “rivers with concrete banks and bed”, but the original natural ecosystem characteristics have been greatly changed, and the aquatic ecosystem species are single. Moreover, the water pollution along the river is not complete, resulting in serious water pollution, and the water quality of some river reaches is inferior to Class V. Due to the expansion of the city, the urban area has been highly developed and constructed, with less wetland area. Among them, the natural wetland is dominated by river wetland and beach wetland, and the constructed wetland is mainly composed of ponds. Compared with the natural wetland, the constructed wetland has single biological species, poor anti-interference performance and few wild animals.

4. Main Objectives of Planning and Construction

In order to solve the problems of water security, water resources and water environment in Ning’er, improve the urban disaster prevention ability, protect and improve the urban ecological environment, we should formulate the task objectives of the engineering technical scheme to solve the problem of waterlogging area, including the annual runoff control rate, runoff pollutant control rate and other sponge urban indicators, as well as drainage and waterlogging prevention indicators such as design return period, waterlogging standard, water depth, ponding time, etc. [4], according to the problem of waterlogging in the county and the needs of future development. The construction objectives of sponge city in Ning’er county are shown in Tab.2.

| classification | item index | current situation | recent goals (2022) | Long-term goal (2030) |
|----------------|------------|-------------------|---------------------|----------------------|
| Water ecology  | 1          | Annual runoff control rate | 34                 | 80%                  | 80%                  |
|                | 2          | Urban heat island effect | —                  | relief               | Significant relief   |
|                | 3          | Green area rate      | 35.08%             | 37.35%               | 42.19%               |
| Water Environment | 7       | Surface water environmental quality | Inferior Class V | River: meet the surface water standard III–IV Lakes and reservoires: meet the standards of surface water II–III |
|                | 8          | Urban non-point source pollution control (calculated by SS) | —                   | ≥32%                 | ≥32%                 |
| Water resources | 9          | Wastewater recycling | —                  | 20%                  | 20%                  |
|                | 10         | Rainwater utilization | —                  | 10%                  | 10%                  |
|                | 11         | Leakage rate of water supply network | —                   | ≤15%                 | ≤12%                 |
| Water safety   | 12         | Waterlogging prevention standards | —                   | 20 years             | 20 years             |
|                | 13         | Flood control standard | —                  | Once in 30 years     | Once in 30 years     |
|                | 14         | The return period of urban drainage pipe design | 1 ~ 5 years | 2 ~ 5years | 2 ~ 5years |
| System construction and implementation | 16         | Planning and construction management control system | —                   | Establish management systems and mechanisms for the planning (land transfer, two certificates and one book) and construction (construction |
5. Planning and Construction Scheme

5.1 Construction Division and Control Index of Sponge City
Sponge city is not only a systematic project to solve urban water security, environment, ecology and resources as a whole but a complex system with multiple objectives, systems and means [5]. The purpose of the project is to prevent the damage to the urban ecological system, such as the construction of the natural river, the sponge and the natural lake. The measures to achieve these control objectives usually need to combine with urban construction and relevant specifications, and adopt low impact rainwater facilities that are adapted to local conditions and conform to technical specifications, such as green roofs, shallow grass ditches, tree pools, rainwater tanks, storage facilities, etc. These facilities are suitable for different sites, and achieve their respective functions through water storage. Their essence is to provide interception or storage capacity to achieve the interception, runoff infiltration, retention, regulation and storage of rainwater runoff pollution. Therefore, the sponge city in Ning’er county needs to be constructed in different areas. According to The Revised Overall Plan of Ning’er County (2015-2030), the total planning area of the central urban area of Ning’er county reaches 29.15km², forming a functional structure of “one center, two belts and four groups”. According to the natural ecological spatial layout, land suitability and planning and construction sequence of Ning’er county, the construction of sponge city is proposed. It is divided into the following six areas: the northern ecological residential group, the old city commercial center, the central public service group, the Jinji business logistics group, the Southern new city group and the Pu’er mountain outdoor leisure zone.
5.2 Construction of Rainwater Source Control Engineering System

Development strategy of sponge city construction in China: through urban planning and construction management and control, starting from “source emission reduction, process control, system governance”, comprehensive use of “infiltration, stagnation, storage, purification, utilization, discharge” and other technical measures, coordinate water quantity and water quality, ecology and security, distribution and concentration, green and gray, landscape and function, shore and under shore, ground and underground, etc. to control urban rainwater runoff and minimize the damage to the original natural hydrological characteristics and water ecological environment caused by urban development and construction [1]. Based on the technical route of sponge city construction in Ning’er county, reasonable technical measures are adopted according to different engineering types to achieve the goal of stormwater runoff control in each rainwater management area.

5.2.1. A Project of Roof Rainwater Runoff Control and Recycling

The buildings in Ning’er county adopt inclined roofs, and the domestic hot water of residents generally uses solar energy. The roofs are basically occupied by solar energy facilities and roof water tanks, so there is no available space. Therefore, the planning and construction scheme chooses to give up the green roof of residential areas, and only consider the green roofs of some public buildings in the urban area. After accounting, the proportion of public buildings using green roofs is about 10%. The roof area of Ninger county is 7.29km², and the green roof area is 0.04km².

5.2.2. Stormwater Runoff Control Project on Hard Land

The hard land area of public area in Ning’er county is 5.28 km². This part of hard land area runoff control uses permeable pavement, permeable parking lot and square, ecological tree pool, rainwater garden, sunken grass planting ditch and storage facilities for rainwater runoff control. The permeable pavement, permeable parking lot and square are estimated by 30% - 80% of the hard land area according to the different land use types; the ecological tree pool, rainwater garden and sunken grass planting ditch are estimated as 1%, 2% and 4% of the hard land area, and the planned hard ground permeable pavement
area is 2.64 km².

5.2.3. Green Space Rainwater Runoff Control Project
Ning’er county has a total planning area of 16.35 km². In order to minimize surface runoff, regulate, store and purify runoff rainwater, concave green space is used as far as possible for rainwater runoff control. According to the goal of stormwater control, the area of concave green space is 8.17 km².

5.3 Construction of Water Ecology and Water Conservation Engineering System

5.3.1. Planning and Construction of Ecological Park
The internal rainwater of community parks and forest parks is filtered by vegetation, and is discharged slowly and infiltrated. It is combined with wetland and rainwater pond to reduce runoff, sediment and purify water quality [6]. From the perspective of constructing ecological space, regulating urban microclimate, retarding rainwater runoff infiltration and promoting water conservation, nine urban parks and two urban parks are planned to be built. The nine parks planned to be reconstructed and expanded are public green ecological spaces for residents to get close to nature, outdoor leisure, cultural fitness and disaster prevention.

5.3.2. Planning and Construction of Comprehensive River Regulation
With the growth of urban population and the expansion of urban area, the existing flood control standards cannot meet the requirements. It is necessary to carry out flood control and ecological comprehensive treatment for Donger River, Xi’er River, Jinji River, Xiadong River and Wenquan River. On the basis of interception and dredging, Riverside vegetation filter buffer zone is constructed to slow down the speed of rainwater runoff, and plants intercept, store and infiltrate rainwater, so as to fully reduce rainwater runoff, purification of water quality, protection of river ecology, improvement of urban microclimate and improvement of urban ecological environment quality.

5.3.3. Water Source Protection Planning and Construction
In order to ensure the safety of urban drinking water source, prevent soil erosion, prevent domestic sewage and rural non-point source pollution from threatening the safety of drinking water, it is necessary to protect the main drinking water sources in Ning’er county. Grade I protection zone: Dahebian reservoir, Songshan reservoir, Paomuguoqing reservoir and Hezhangtian reservoir shall be classified as grade I protection zone, including all water areas below the normal water level line and the land area within 200 meters above the normal water level line, the land area above a certain elevation line, but not exceeding the watershed. Grade II protection area: the water area of all reservoirs outside the boundary of the first grade protection zone; the land area of Dahebian reservoir, Songshan reservoir, Paomuguoqing reservoir and Hezhangtian reservoir is the whole basin of the upper reaches of the reservoir (outside the land area of the first grade protection zone); the quasi protection area is the catchment area beyond the second level protection area.

5.4 Planning and Construction of Drainage Facilities

5.4.1. Projects of Pipe Networks of Rainwater and Sewage and Rainwater Flood Storage and Detention
The construction of sponge city in Ning’er county, through the vertical control of planning, ensures smooth drainage at the source, collects rainwater nearby and discharges into nearby water bodies. Rainwater and sewage form their own systems to ensure that sewage does not enter the rainwater system, and the new area strictly implements the diversion system. According to the construction division of sponge city, the drainage area is reasonably divided into six areas to improve the rainwater and sewage pipe network system. Ning’er county plans to construct a total of 45282 meters of rainwater pipe network DN500–DN2000 and 61425 meters of sewage pipe network DN400–DN600; a sewage lifting pump station of 115m³/h is built in Tianbi road; one rainwater storage tank is built in the county hospital
of traditional Chinese medicine, the county bus passenger station and Jinji area for general regulation and storage, with a volume of 31800m³.

Upgrading and Reconstruction of Sewage Treatment Plant and Regeneration of Water Utilization System

According to the principle of the end treatment of sponge city, the existing sewage treatment plant in Ning’er county was upgraded to meet the first class a standard in The Standards for Pollutant Discharge from Municipal Wastewater Treatment Plants (GB18918-2002). In order to make effective use of water resources, it is planned to carry out advanced treatment on the effluent from the sewage treatment plant, and reuse it for road square, greening and landscape water supply after reaching the standard. Moreover, a new reclaimed water pipe network DN50–DN150 with a total of 32652m will be built.

Through the whole process control of “source emission reduction, partition control and system governance”, the pollutant removal rate of Ning’er county can reach 50%.

6. Conclusion

Located in the subtropical mountainous area of Yunnan province, Ning’er county is a representative in the construction of sponge city in small towns. According to the construction principle of “source emission reduction, partition control and system governance”, the problems of water security, water resources, water environment and water ecology in Ning’er county has been solved in an all-round way, providing constructive experience for the construction of sponge cities in small towns.

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