Groundwater resources in karst area in Southern China and sustainable utilization pattern

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Abstract: Occurrence conditions of groundwater in southern karst area are complicated. The water-bearing media in the karst have multiplicity, and the groundwater is hosted in holes, gaps, seams, pipes and caves. The karst water shows heterogeneity where fast and slow flow coexist, and the Darcy and non-Darcy flow coexist, and the liquid flow, the gas flow and solid flow coexist. The evaluation and investigation indicates that the mineable resource of karst groundwater is about 53.44 billion m^3/y, and the current exploitation quantity is merely 6.565 billion m^3/year. The exploitation and utilization potential is gigantic. In the region there are altogether 2 763 karst subterranean rivers with a total length of 12 687 km. The dry season runoff volume equals to 47 billion m^3/year. At present the exploitation is only 10%. Four effective utilization models of karst groundwater resources have been put forward. (1) The karst hills-depression zone formed the surface-underground united reservoir. By digging tunnels, water diversion irrigation and generating electricity, the ecological economy is developed. (2) In the deep-cut peak cluster depression area, by using the high-part Epikarst spring and constructing the regulation and storage water tank, the stereo ecological agriculture is developed. (3) In the karst peak forest plain and hilly-gully area, the pump-type underground regulating reservoir is constructed and the water-saving ecological agriculture is strengthened. (4) In the fault basin region with the surrounding groundwater runoff belting beam backwater, the water resources are jointly controlled to develop a fruit crop base within the basin.

Keywords: Karst area; Subterranean river; Water resources; Sustainable utilization

Introduction

In Yunnan, Guizhou, Guangxi, Hunan, Hubei, Chongqing, Sichuan, Guangdong *etc.*, the distribution area of karst is 520 000 km^2 (YUAN Dao-xian, 2014). Influenced by the specific geographic conditions of karst, global climate change and human engineering activities (CHEN Meng-xiong, 2003; ZHANG Zhi-gan, 2006; YUAN Dao-xian and CAO Jian-hua, 2008), draughts and water scarcity (ZHANG Zhi-gan *et al.* 2005) turned out to be a daunting task. The water-lacking population is as large as 17 million, amounting to 12% of the total. There are nearly 6 666 667 hm^2 of draught-stricken farmland, amounting to 10% of the total cultivated area. It has restrained social economic development (WANG Ming-zhang *et al.* 2015; CAO Jian-hua *et al.* 2005).

From 2003 to 2015, by conducting a comprehensive survey of hydrogeology and environmental geology and the development, utilization and demonstration of groundwater, a total of 780 000 km^2 of 1/250 000 hydrogeology survey was conducted. The 1/50 000 hydrogeology survey studied an area of 250 000 km^2, detected 60 000 points of comprehensive physical detection, 60 000 m of karst caving detection and 58 000 m drilling of hydrogeology.

First, the occurrence conditions of karst groundwater were determined. The karst water-bearing media have multiplicity, and the ground-

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water is stored in holes, cracks, seams, pipes and caves. The karst water flow has heterogeneity, where the fast flow and the slow flow coexist (CHEN Hong-feng *et al.* 2015), the Darcy flow and non-Darcy flow coexist, and the gas phase flow and the solid phase flow coexist. The karst groundwater is classified into three types including the groundwater pipe system, the corrosion hole system and the fractured water-bearing medium system. The water flow exchange rule among different types and various sizes and systems was studied to support the fair development and exploitation of karst water resources. Second, the distribution conditions of karst groundwater were understood and an assessment of mineable exploitation was made. Third, the main environmental and geographical problems were ascertained in the working area. The karst area was confronted with severe drought and water scarcity, while the water and soil loss led to karst stony desertification. Owing to the poor regulation and storage capacity, blockage in karst pipelines and the lack of depression discharge and monsoon waterlogging also manifested themselves. Fourth, four karst groundwater effective exploitation and usage models have been put forward for demonstration and poverty alleviation including forming reservoir with cave-blocking, tank building and water storage, water pumping and regulation and beaming backwater.

1 Mineable utilization potential of karst groundwater resources

Through the survey and research, the karst groundwater resources distribution were ascertained and the assessment of mineable utilization potential was conducted. Southwest karst area is endowed with abundant groundwater resources with the total groundwater resource volume of 162.057 billion m^3. The mineable utilization volume amounts to 53.44 billion m^3/year and current exploitation quantity is 6.565 billion m^3/year with an exploitation degree of 12.28%. The development and utilization potential of karst groundwater is large, as much as 46.875 billion m^3/year (Table 1, Fig. 1). The surplus mineable utilization volume of provinces (autonomous regions, municipality) are respectively 4.69 billion m^3/year in Yunnan, 9.666 billion m^3/year in Guizhou, 14.828 billion m^3/year in Guangxi, 5.433 billion m^3/year in Hunan, 3.742 billion m^3/year in Hubei, 882 million m^3/year in Chongqing, 6.147 billion m^3/year in Sichuan and 1.487 billion m^3/year in Guangdong .

Table 1 The groundwater resources in Southern Karst Area

Province (autonomous region, municipality)	Total resources (100 million m³/year)	Mineable resources volume (100 million m³/year)	Current development and utilization volume (100 million m³/year)	The surplus mineable utilization volume (100 million m³/year)
Yunnan	215.82	57.39	10.49	46.90
Guizhou	206.12	112.75	16.09	96.66
Guangxi	464.80	162.57	14.29	148.28
Hunan	269.33	62.83	8.50	54.33
Hubei	98.77	46.78	9.36	37.42
Chongqing	53.31	10.56	1.74	8.82
Sichuan	261.22	63.62	2.15	61.47
Guangdong	51.20	17.90	3.03	14.87
Total	1 620.57	534.40	65.65	468.75

2 Growth characteristics of karst subterranean river

Owing to the intense corrosion effect in carbonatite, atmospheric precipitation and surface water quickly permeated into the ground (ZHU Xue-wen, 2010), the surface drainage is underdeveloped. 2 763 subterranean waters were nurtured underground (YANG Li-zheng, 1985; QIN Xiao-qun *et al.* 2007) with a total length of 12 687 km. The catchment area was around 300 000 km^2 and dry season runoff amounted to 47 billion m^3/year, nearly as much as the runoff volume of the Yellow River (Table 2). Among them, Guangxi Zhuang Autonomous Region, Guizhou Province, Yunnan Province and Hunan Province are the main distribution areas of karst subterranean rivers. The subterranean river extends comparatively long with a large flow.

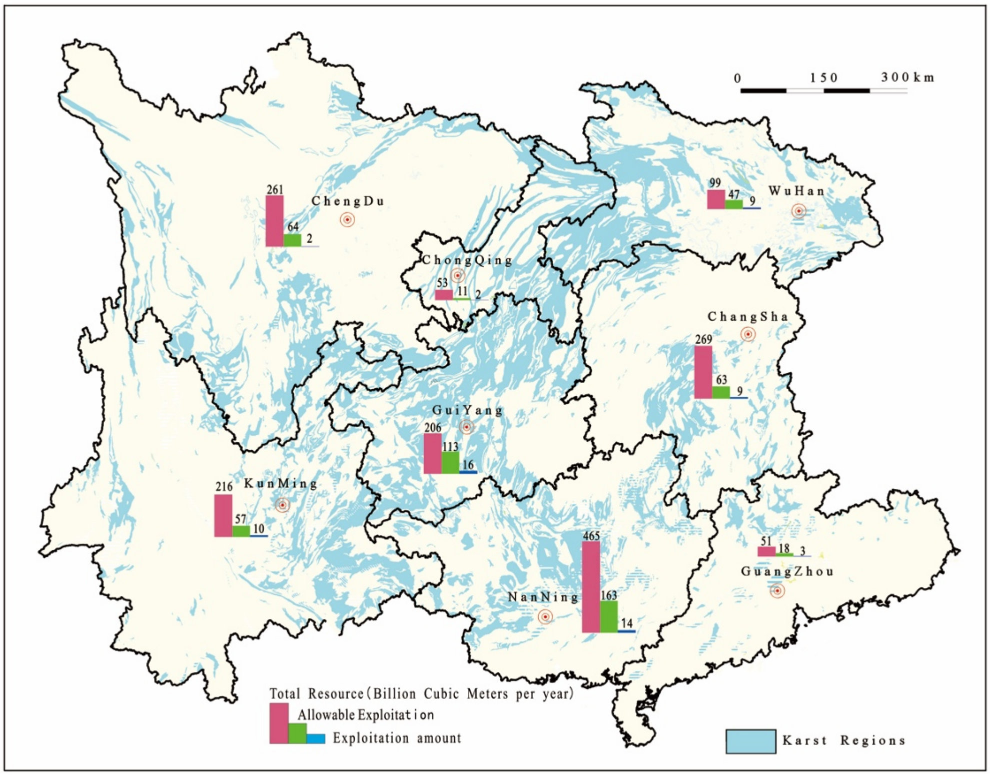

Fig. 1 Distribution of groundwater resources in southern karst area

Table 2 Development of subterranean river in southwest karst area

Province (autonomous region, municipality)	Subterranean river (number)	Length (km)	Dry season runoff (m^3/sec)
Yunnan	266	339.9	386.22
Guizhou	479	3 164.3	236.48
Guangxi	498	4 643.9	239.54
Hunan	798	2 465.3	205.89
Hubei	157	742.3	185.02
Chongqing	250	384.6	58.92
Sichuan	209	488.5	88.32
Guangdong	106	458.4	25.92
Total	2 763	12 687.2	1 426.31

The Red River Basin (Fig. 2), located in the junction of Yunnan, Guizhou and Guangxi , is the most typical subterranean river development area within the region. The catchment area of subterranean river system in Daxiaojing, Guizhou is as large as 1 943 km^2 with an outlet flow rate of 0.35-15.00 m^3/sec. Yunnan Nandong subterranean river system has a catchment area of 1 684 km^2 with an outlet flow rate of 1.50 to 44.30 m^3/sec. The catchment area of Disu subterranean river system in Guangxi is 1 130 km^2 with an outlet flow rate of 4.86 to 54.5 m^3/sec.

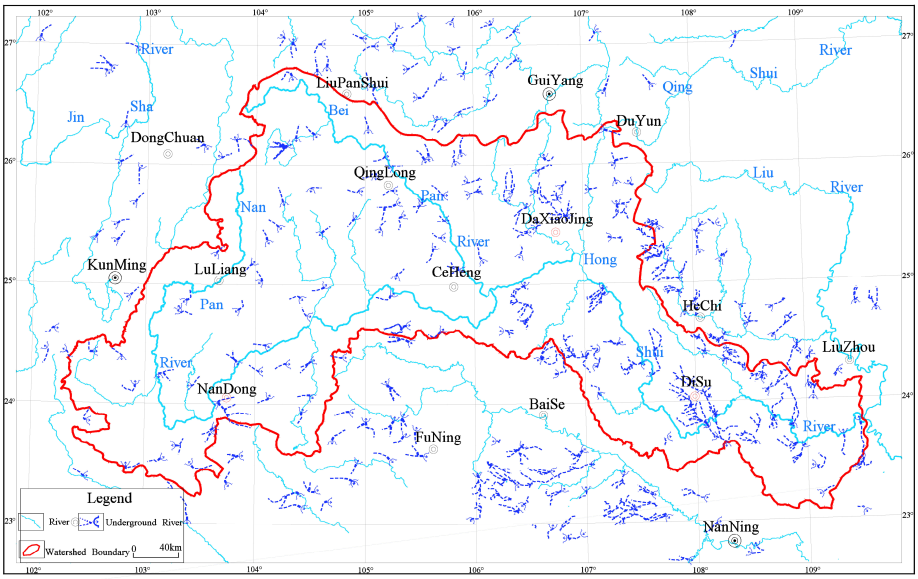

Fig. 2 Distribution map of Red River Basin karst subterranean river

The karst subterranean river is endowed with abundant water and hydroelectric resources. Because they are deeply buried several hundred meters underground (YI Lian-xing *et al.* 2012), on the earth's surface you can only see the outlets and a few sinkholes of subterranean river. Influenced by multiple factors such as strata, the structure, hydrology and landform, the underground distribution structure is complicated with strong lack of homogeneity and complicated water flow law of motion. Therefore, the difficulty of development and utilization increased. So far 270 rivers have been exploited, only accounting for 10% of the total number of subterranean rivers. It is necessary to conduct a further large scale hydrogeology survey and detection on the subterranean water system, utilize conditions as proof and formulate development, utilization and protection plans.

3 An effective utilization model of karst subterranean water resources

Owing to the complexity of the storage distribution of karst subterranean water, the difficulty of development and utilization increased, leading to a low development and utilization rate of karst underground water resources. Therefore, it failed to satisfy the local water scarcity demand. Several problems concerning the effective development and utilization of the underground water resources in the south remain to be resolved. (1) The heterogeneity of space. The underground water-bearing medium is dominantly karst caves, pipelines and dissolved pores. They are highly heterogenous. The heterogeneity of karst subterranean river is obvious (WANG Zhe *et al.* 2013). The research and detection technology of karst underground water distribution rules need to be strengthened. (2) The seasonality of time distribution. Some of the natural emergence of water spots in the southern karst area is seasonal. The emergence only took place in monsoon season with a gigantic volume. However, during that time, water is not needed, which only brings upon waterlogs. During the dry water scarcity season, the water flow decreased evidently and even was depleted and could not satisfy the demand of water. The water-level amplitude of the karst underground water could reach tens of to several hundred meters while the amplitude variation of water could reach ten to several hundred times. It is an extremely unstable dynamic change (YI Lian-xing *et al.* 2014). Taking the technical means to reasonably adjust water resources in the wet season is a scientific issue that needs to be addressed in the development and utilization of subterranean water. (3) The deep embedment of underground water. Because the shallow part karst passageway was intensely developed, combining with the thin soil layer and few vegetation, the water conservation and regulation capacity in the shallow part was inadequate and the precipitation quickly went to ground. In the southern karst area the surface incision was deep. Except for the peak-forest plain, the groundwater buried depth was usually 50 m deep, and in peek-cluster area the groundwater buried depth was over 300 m deep. It is necessary to retain and regulate groundwater flow in the relatively high alimentation area and runoff area, and to take biological engineering measures to increase the regulation and storage capability of water conservation in the shallow part.

(4) The relevance to ecological economy. In the southern karst area the pedogenesis capability is lacking. Water and soil loss and the development of stony desertification lessened the capability of water conservation in the shallow part. Lack of water, agricultural production mainly depends on the weather and the local people live in impoverishment. The poor background, excessive land reclamation and deforestation further damaged the ecological environment, aggravated water and soil loss and stony desertification, intensified drought and water scarcity and led to the vicious circle of the ecological environment. The development and utilization of water resources must combine with ecological construction and economic development so that they can truly realize sustainable utilization.

Influenced by strong uplifting of the Qinghai-Tibet Plateau, the spacial distribution of carbonate rocks in southern karst area is controlled by strata, structure and landform. They were divided into many little blocks. The karst hydrogeology system is mainly in small scattered distribution. The occurrence and distribution characteristics of the karst groundwater resources are various with large basins as the main characteristics of groundwater resources in the north. They decided the diversity of the form of development and utilization. They should adjust measures to local conditions and offer classified guidance.

3.1 Karst hills-depression area

The cave-blocking in the subterranean river formed a surface-underground joint reservoir. Tunnels were dug for diversion irrigation and electricity generation to develop ecological economy.

This type of area is mainly distributed in Hunan Province, Hubei Province, Guizhou Province, Guangdong Province *etc*. The geomorphic type is dominated by hill depression. The karst subterranean river shaped up multiple-tiered platform from the upstream alimentation area to downstream discharge area. In the high depression of groundwater alimentation area, choose the part of centralized growth in the karst pipeline. The cave-blocking formed the surface underground joint reservoir. In the runoff area the caves were rigged to intercept the subterranean river for water diversion irrigation and electricity generation. In the high mountainous region and steep slopes, optimize the choice of local premium varieties of trees and introduce fast growing species of trees, build ecological forests, timber forests, fuelwood forests and economic forests to restore the ecological environment. The biogas digesters were built to address the issue of fuels, reduce the damage to vegetation and realize the virtuous cycle of ecological economy.

Fig. 3 Dam impoundment project of Jumu Subterranean River, Pingtang County, Guizhou Province

For example, the subterranean river in Jumu, Pingtang County, Guizhou Province, underwent the impoundment and diversion project (Fig. 3). A dam was built at the outlet of the subterranean river in Jumu to contain the underground water. Then an underground reservoir of 630 000 m^3 was formed which raised the water level by 20 meters and a hydropower station was constructed as well. It can solve the problem of drinking water for over 5 000 local people in Tangbian County and 10 000 domestic animals and the water irrigation for 400.2 hm^2 of farm land. It promoted the improvement of crop production. The paddy rice increased production by 900 000 kg/year, oilseed rapes by 88 200 kg/year and the annual economic income reached 1.45 million yuan.

3.2 Deep cut peak cluster depression area made use of the high-part surface karst spring water to construct a regulation and containment water tank to develop a three-dimensional ecological agriculture

This type of area is mainly located in the slopes of Yunnan-guizhou Plateau, Chongqing, Hubei, western Hunan and western Guangxi. The general configuration of the earth's surface features peak cluster depression and deep-cut river valleys. The landform has a deep cut and large altitude difference. It is the most adverse natural environment in southwest karst area (JIANG Zhong-cheng *et al*. 2007). In addition to the hill depression and the bottom of the valley, the buried depth of underground water is usually deeper than 300 m, and unsuitable for the borehole drilling. Because of the torn and broken surface, the farmland was scattered and residents lived in a scattering pattern, unsuitable for a large scale centralized water supply.

Construct a water tank in the epikarst karst spring and accumulate water resources. Build a small hilly pond reservoir on the high depression. Adjust measures to local conditions, disperse water impoundment and catchment, address the issue of sporadic farmland water irrigation and scattered residents drinking water. By constructing the bulkhead dam, plant adaptive tree species and quick growing species of trees conserve water. Plant medicinal materials and fruit trees shape up a three-dimensional ecological agriculture and famous-special and high-quality tree species base. By developing karst landscape resources, the ecological tourism is developed.

For instance, Sanzhiyang Town in Duan County, Guangxi, conducted the Epikarst spring series regulation and storage project (Fig. 4). On the accumulated part of epikarst spring and overland flow, impounding reservoirs are built in a scattered manner. Use drip irrigation technology to provide orchards and medicinal water to form a karst depression economic demonstration zone.

Fig. 4 Epikarst Zone, Sanzhiyang Town, Duan County, Guangxi, regulation and storage water tank and medicinal materials base

3.3 Karst Peak Forest Plain and Hilly-gully Valley. Construct an water-pumping underground regulation reservoir to develop water-conservation ecological agriculture

The type of area is mainly located in the central and northeastern parts of Guangxi and the southern part of Hunan. The main characteristics include a flat terrain, concentrated arable land, shallow burial depth of groundwater, abundant water and solar-heat resources. It is a valuable agricultural base within the karst area (TANG Jian-sheng *et al*. 2007).

By making use of the characteristics of intensive karsification in the shallow layer of peak forest plains, water-bearing capacity and water permeability, in the dry season when crops are in need of water, the water resources of underground karst runoff zone are exploited to form the regulated empty storage capacity. After the monsoon season, the natural precipitation permeates and restores the underground storage capacity. With the application of water-saving and irrigation technology such as sprinkling irrigation, drip irrigation, and portable irrigation, the water utility efficiency was improved. Meanwhile, we should reasonably adjust the agricultural industrial structure to expand the area of economic fruit wood and reduce the planting area of high water consuming crops and construct an ecological economic forest, so as to combine the regulation and storage of water resources with highly efficient planting, highly efficient cultivation and ecological construction.

Through the development of surface karst groundwater and the excavation of more than 30 large diameter wells and drilling well, *e.g.*, the Qiaomei demonstration area of Xiecun Village Litangxie Town, Binyang County of Guangxi, this area has realized the groundwater supply capacity of 4 000 m^3/h, the implementation of water-saving irrigation for hundreds acres, and the establishment of a vegetable-based and efficient agricultural base, with an annual output value of more than 13 million yuan.

This type of area is mainly distributed in Yunnan-Guizhou Plateau, and there are more than 1 440 of this type of area in Yunnan Province alone, with a total area of 24 000 m^2 (WANG Yu *et al*. 2003). The landform is featured with the alternating distribution of rift basins and low mountains, the Tertiary and Quaternary soil covering the basin, and the area is flat providing a major activity area for human life and production.

The surrounding area of the basin is karst groundwater runoff area, with not only the relative concentration of the main subterranean rivers and groundwater runoff belt, but also a seasonal river or spring water exposure, providing precious water resources for development and exploitation. Groundwater is buried deep in dry season, and should be exploited and used by taking certain measures.

At the downstream of subterranean river, a dam was built to raise the groundwater level; at the midstream, holes were made for blocking, so as to draw seasonal spring; at upstream, a regulating reservoir was built to realize joint scheduling of surface water and groundwater; an irrigation canal network was built in the basin for centralized water supply; the tillage was limited on the basin peripheral, reforestation was implemented, and ecological-economic forests were planted; the industrial structure in the basin was rationally adjusted and economic forest fruit and vegetable planting areas were expanded, and efficient farming and processing industries were developed, which contributed to the formation of an efficient agricultural production base featured with planting-production-processing.

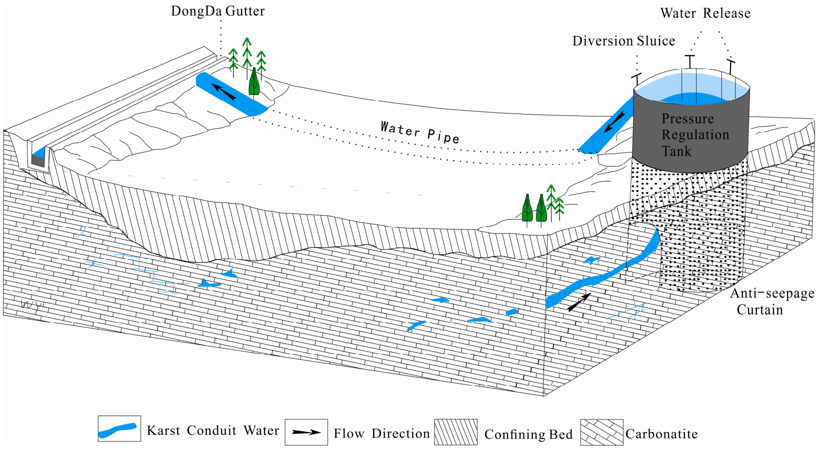

Fig. 5 Pijiazhai karst big spring beam regulator backwater project in Luxi basin of Yunnan Province

Mengzi Basin of Yunnan Province has 24 679 hm^2 of arable land. Due to the problem of agricultural irrigation water, the land suffered from drought and water shortage. Until early 1990s, the food self-sufficiency rate was still less than 50%. Each year, central government needs to deploy 500 million kilograms of food to this area. In 1995, Wulichong Reservoir was built at upstream to realize inter-basin regulation of Nanxihe river surface water and to use natural karst blind valley for flood storage. The reservoir has a capacity of 79.49 million cubic meters, of which 12.1 million cubic meters per year are used for urban water supply, increasing or improving an irrigation area of 8 004 hm^2. Within the basin 6 667 hm^2 of garden of pomegranate and 1 334 hm^2 of vineyards were built. The rice yield per unit within the basin has increased by over 1 500 kg/hm^2, fruit output reached more than 10 million kilograms, and the annual water supply benefits reached 30 million yuan.

Luxi Basin of Yunnan Province, Pijiazhai karst big spring beam regulator backwater project (Fig. 5) was implemented, and a gravity irrigation water diversion project was built. Using the beam seepage and backwater regulating measures, the water level was raised up to 4.4 m and water supply reached 60 000 m^3/day. The project not only solved the drainage problem of 534 hm^2 of arable land at downstream, solved the irrigation water problem for 133 hm^2 of rice, 67 hm^2 of flue-cured tobacco, 1 000 acres of pyrethrum, but also improved the irrigation of 1 668 hm^2 of arable land at eastern edge and living water conditions for 15 000 people. In 2011, a cold-water fish farm was built using beam surge tank, with an annual output value of 100 million yuan.

4 Conclusions

Every year, the southern karst area has a groundwater exploitation potential of 46.875 billion cubic meters, providing water security for the dry karst area. That the karst water-bearing media and the movement of groundwater are complex and that the types of water environment are diverse determine the diverse methods of development and utilization. Effective exploitation mode of karst groundwater is: for karst depression hilly areas, blocking the holes to form surface-underground joint reservoirs and developing ecological economy; for deep cut peak clusters and depression area, constructing flood storage tanks and developing ecological agriculture; for karst peak plains and hilly valleys, constructing underground regulating reservoirs featured with water-pumping and developing water-saving ecological agriculture; for rifted basin area, the surrounding groundwater runoff plugging holes with water to realize joint scheduling and to develop fruit grain base within the basin. The project has explored collaborative ways of the use of water resources together with ecological rehabilitation and economic development: The Jumu subterranean river impoundment engineering in Guizhou has increased food production and income by solving water and electricity problems; In Guangxi, the Three Goats epikarst spring storage project has restored karst depression ecology and formed an ecological economic demonstration zone; The Litang epikarst pumping and regulating project in Guangxi has built a highly efficient agricultural base; the Pijiazhai karst big spring beam regulator backwater project in Yunnan has promoted the development of farming and aquaculture.

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