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ORIGINAL RESEARCH ARTICLE

Spatial and temporal distribution and utilization of water resources in Guangxi and suggestions for their protection

Shuo Wang, Jianping Qian*, Xiaoyu Pei, Kun Zhang, Xun Zhang
School of Earth Sciences, Guilin University of Technology, Guilin 541004, China. E-mail: jpqian@163.com

ABSTRACT

The spatial distribution characteristics of surface water and underground water resources in Guangxi were discussed. The temporal variation trend of surface water and groundwater resources and the present situation of water resources exploitation and utilization in Guangxi in recent 10 years are analyzed. This paper points out the problems of water pollution in the exploitation and utilization of water resources, and puts forward some suggestions on water resources protection and water pollution control in Guangxi.

Keywords: Water Resources; Development and Utilization; Water Pollution; Water Resources Protection; Guangxi

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1. Introduction

Water is a very important kind of natural resource, an organic part of a country's comprehensive national strength, and one of the most important resources indispensable for human survival and development. China's per capita water resource is only 2,300 m^3, only 1/4 of the world's average level, and China is one of the countries with the most shortage of water resources per capita in the world[1]. Central water conservancy work conference in 2011 put forward to make saving water as the strategic fundamental measures to solve the problem of China's water resources, focus on the strictest water resources management system, speed up to establish three red lines of control and utilization of water resources, controlling efficiency of water use, controlling pollution in water function area. Saving water was carried throughout the economic and social development and the whole process of the masses life and production[2].

Guangxi is located in South China with a land area of 236,700 km^2, including mountains 53.1%, hills 21.7%, plains 22.4% and water 2.8%[3]. The land borders beibu Gulf in the south and faces Southeast Asia. The continental coastline is about 1,595 km. Guangxi has a humid climate and abundant rainfall; the Xijiang River system flows from west to east and the land water network criss-crosses. Guangxi is not only rich in surface water resources, but also abundant in underground water resources; the total and per capita water resources are in a leading position among all provinces in China, and Guangxi is one of the important water sources in the South-to-North Water Diversion Project in China. Therefore, it is of great significance to protect Guangxi water resources.

2. Spatial and temporal distribution of surface water resources in Guangxi

2.1 Spatial distribution characteristics and rules of surface water resources

According to the Water Resources Bulletin of Guangxi Zhuang Autonomous Region in 2016, the total reserve of surface water resources in Guangxi is 217.7 billion m^3[3]. In terms of the amount of surface water resources of the 14 prefecture-level cities in Guangxi District, the total amount of water resources of Guilin is the largest, about 41.9 billion m^3. Hechi City is about 31.5 billion m^3; Liuzhou is about 21 billion m^3; Hezhou is about 16.9 billion m^3; Yulin is about 14.7 billion m^3; Wuzhou is about 13.6 billion m^3; Baise is about 13.1 billion m^3; Nanning is about 12.2 billion m^3; Laibin is about 12.1 billion m^3; Qinzhou is about 11.7 billion m^3; Guigang is about 10.3 billion m^3; Chongzuo is about 8.15 billion m^3; Fangchenggang is about 7.29 billion m^3; Beihai has the smallest total amount of water resources, about 3.4 billion m^3[3].

Guangxi is further divided into Eastern Guangxi according to its geographical location, including Hezhou, Yulin and Wuzhou; Southern Guangxi: Beihai, Fangchenggang, Qinzhou; Western Guangxi: Baise, Chongzuo; Northern Guangxi: Liuzhou, Guilin, Hechi; Central Guangxi: Nanning, Laibin, Guigang. As shown in **Figure 1**, the total water resources in the north of Guangxi reach 94.4 billion m^3, the total water resources in the east of Guangxi reach 45.2 billion m^3, the total water resources in Central Guangxi reach 34.6 billion m^3, the total water resources in Southern Guangxi reach 22.46 billion m^3 and the total water resources in Western Guangxi reach 21.25 billion m^3[3]. It can be seen that the spatial distribution of total surface water resources in Guangxi is uneven, showing a pattern of more in the north and less in the south, more in the east and less in the west[4].

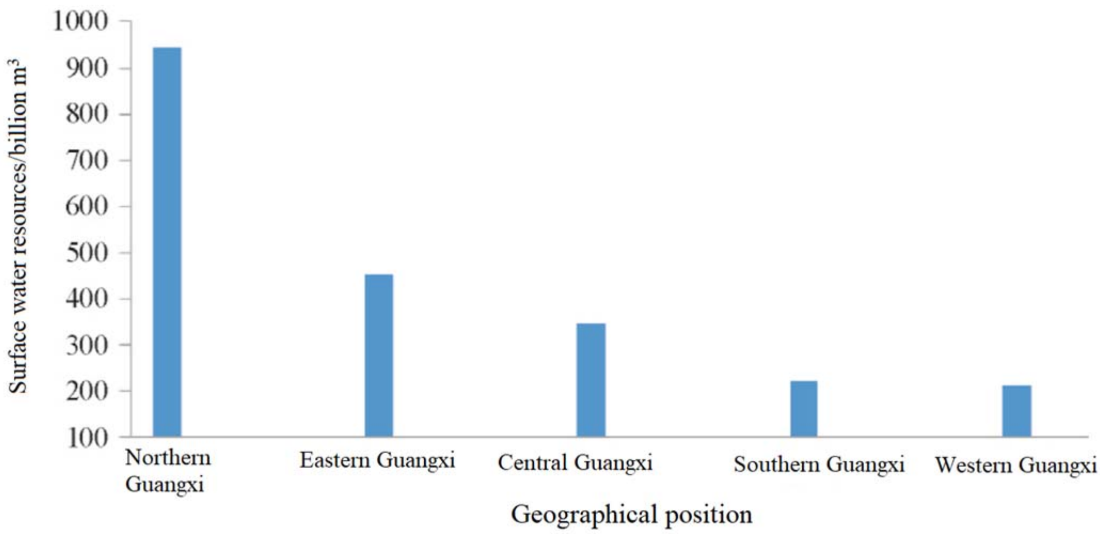

Figure 1. Distribution of surface water resources in Guangxi.

2.2 Temporal distribution characteristics and rules of surface water resources

As can be seen from **Figure 2**, surface water resources in Guangxi have been on the rise in the past 10 years, with an average annual resource amount of 200.58 billion m^3. The total water resources in 2009, 2010, 2011 and 2014 were lower than the average, while the total water resources in other years were higher than the average. The surface water resources of Guangxi was the least in 2011 with 135 billion m^3, and it was the most in 2015 with 243.2 billion m^3[5]. Therefore, the temporal distribution of surface water resources is also uneven.

Another characteristic of the distribution of surface water resources is that the change of surface water resources is basically the same as that of total precipitation, and the surface water resources are relatively abundant in years with abundant precipitation, and vice versa. The correlation analysis between the amount of surface water resources and the rainfall data from 2008 to 2016 was conducted[3–12], and the correlation coefficient between the two was 0.973, greater than the critical value of 0.764 (α = 0.01), indicating a significant correlation between the two.

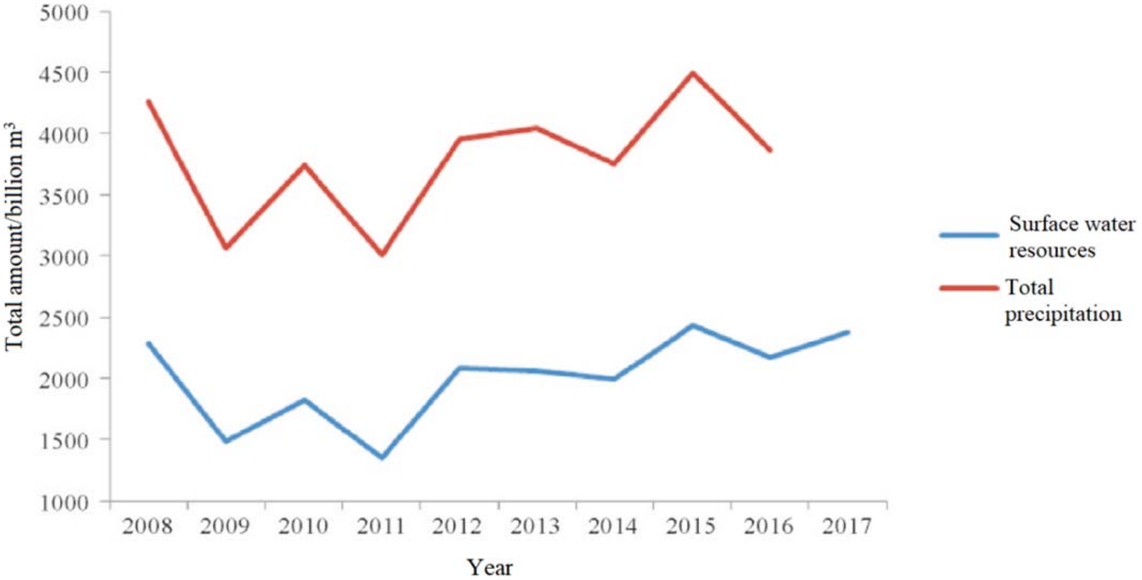

Figure 2. Annual distribution curve of surface water resources and precipitation in Guangxi.

The surface rivers in the area are divided into four river drainage area systems. In the Xijiang river system of Pearl River basin, there are mainly Hongshui River, Qianjiang, Xunjiang, Yujiang, Liujiang and Guijiang River and He River, whose watershed area accounts for 85.8% of the total area of Guangxi; the Dongting Lake system of the Yangtze River basin is mainly composed of the upper reaches of Xiangjiang River and Zishui River, whose basin area accounts for 3.5% of the total area of Guangxi; Baidu River belongs the red River system, which only accounts for 0.7% of the total area of Guangxi. The coastal rivers of South Guangxi and the river sources of Western Guangdong, which belong to the coastal basins of South China, account for about 10% of the total area of Guangxi[1].

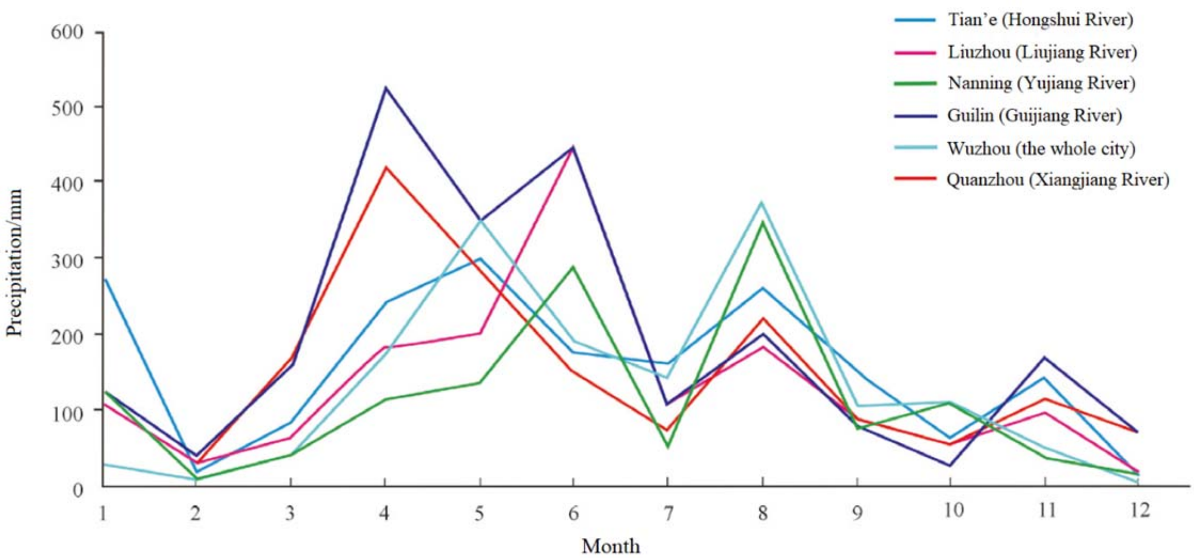

Figure 3. Comparison of monthly precipitation in major rivers in 2016.

Figure 3 shows that the amount of surface water resources in the same year also keeps changing. The water resource reserves are the largest in April and the smallest in October. Therefore, April to June can be divided as the wet season, the surface water resources are relatively sufficient, October to December can be divided as the dry season, and the surface water resources are relatively scarce.

3. Spatial and temporal distribution of groundwater resources in Guangxi

3.1 Spatial distribution characteristics and rules of groundwater resources

According to the water resources bulletin of Guangxi Zhuang Autonomous Region in 2016, the total reserves of groundwater resources in Guangxi are 52.9 billion m^3. According to the statistics of city as units, the total amount of groundwater resources of the 14 prefecty-level cities in Guangxi Zhuang Autonomous Region is ranked as follows. The total value of water resources in Guilin is the largest, about 9.81 billion m^3; Hechi is about 6.39 billion m^3; Liuzhou is about 4.58 billion m^3; Yulin is about 4.55 billion m^3; Baise is about 4.44 billion m^3; Hezhou is about 4.02 billion m^3; Nanning is about 3.59 billion m^3; Qinzhou is about 2.86 billion m^3; Laibin is about 2.57 billion m^3; Wuzhou is about 2.47 billion m^3; Guigang is about 2.34 billion m^3; Chongzuo is about 2.34 billion m^3; Fangchenggang is about 1.89 billion m^3; the North Sea has the smallest total water resources, about 1.09 billion m^3[3].

As shown in **Figure 4**, the total amount of groundwater resources in Northern Guangxi reaches 20.78 billion m^3. The total water resources of Eastern Guangxi are 11.04 billion m^3, Central Guangxi 8.5 billion m^3, Western Guangxi 6.78 billion m^3 and Southern Guangxi 5.84 billion m^3. It can be seen that, consistent with the distribution characteristics of surface water, the spatial distribution of total groundwater resources in Guangxi also presents a pattern of more in the north and less in the south, more in the east and less in the west[4].

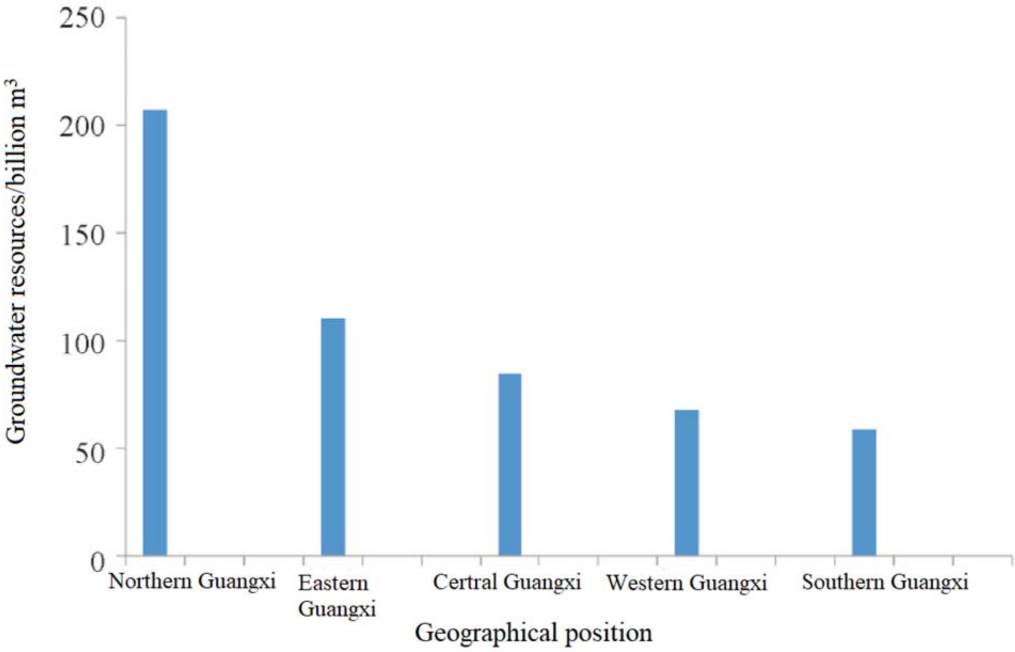

Figure 4. Spatial distribution of groundwater resources in Guangxi.

3.2 Temporal distribution characteristics and rules of groundwater resources

As shown in **Figure 5**, groundwater resources in Guangxi have generally shown an upward trend in the past 10 years, which is attributed on the one hand to the increase of precipitation in recent years, and on the other hand to the government's enhanced protection of water resources. The annual average resource volume of Guangxi is about 42.82 billion m^3. The total groundwater resources in 2009, 2010, 2011 and 2014 were lower than average, and the total groundwater resources in other years were higher than average value. The groundwater resources in Guangxi are at least 25.68 billion m^3 in

2009[7] and at most 58.7 billion m^3 in 2012[9]. Therefore, the temporal distribution of groundwater resources is also uneven.

The data of groundwater resources, rainfall and surface water resources from 2008 to 2016 are used for correlation analysis, and the results are shown in **Table 1**. The correlation coefficient between groundwater resources and surface water resources is 0.846, greater than the critical value of 0.764 (α = 0.01), indicating a significant correlation between the two. The correlation coefficient between groundwater and rainfall is 0.798, greater than the critical value of 0.764 (α = 0.01), indicating a significant correlation between the two. However, it is less than the correlation coefficient of 0.846 between groundwater resources and surface water resources, indicating that groundwater resources are more important to recharge from surface water.

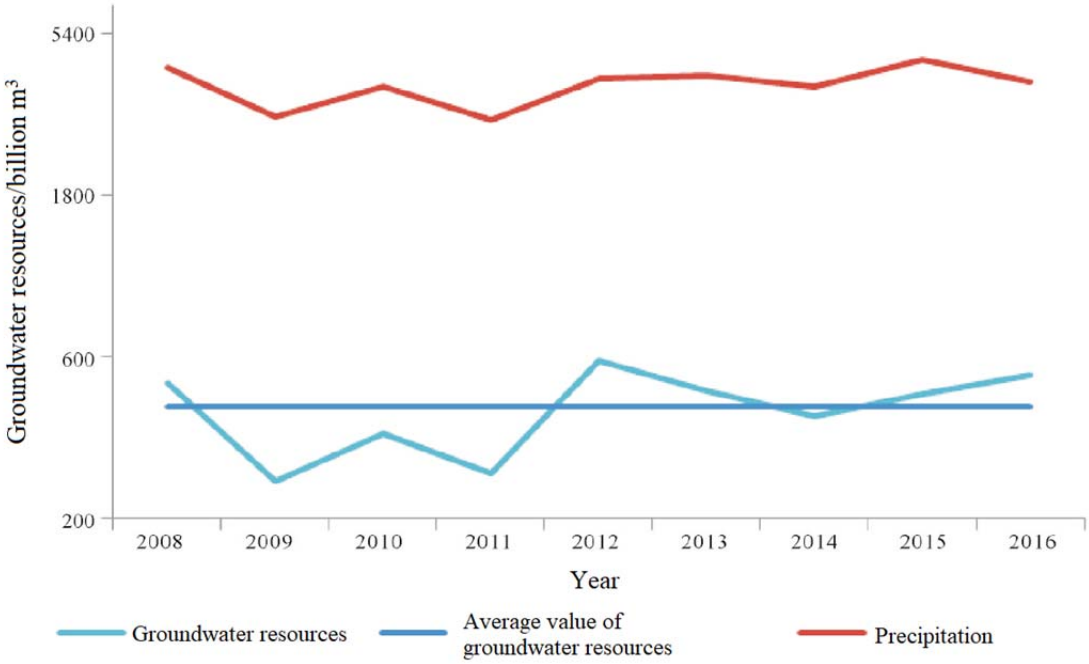

Figure 5. Annual distribution curve of groundwater resources and precipitation in Guangxi.

Table 1. Correlation analysis of groundwater resources with annual precipitation and surface water resources

Item	Precipitation	Surface water resources	Groundwater resources
Precipitation	1		
Surface water resources	0.973	1	
Groundwater resources	0.798	0.846	1

There are four types of groundwater in Guangxi: pore water of loose rock, karst water of carbonate rock, fissure pore water of red clastic rock and fissure water of bedrock. Except Beihai plain area, most areas of Guangxi belong to mountain and hilly area. Karst landform is relatively developed and karst water is distributed in the area most widely. The most widespread, mainly distributed in central, west and northeast Guangxi, north and southeast Guangxi, with an area of about 94,600 km^2. Groundwater recharge source is mainly the infiltration of atmospheric precipitation and mutual recharge with surface water, so the change of groundwater level is also directly related to rainfall. It basically conforms to the division of dry and wet season of surface water, which is divided into wet season from April to June and dry season from October to December.

4. Utilization of water resources in Guangxi

As shown in Figure 6, in the past 10 years, water consumption in Guangxi has generally shown a downward trend, which may be largely due to the improvement of water resource utilization rate and people's awareness of water conservation. The average water consumption over the years is about

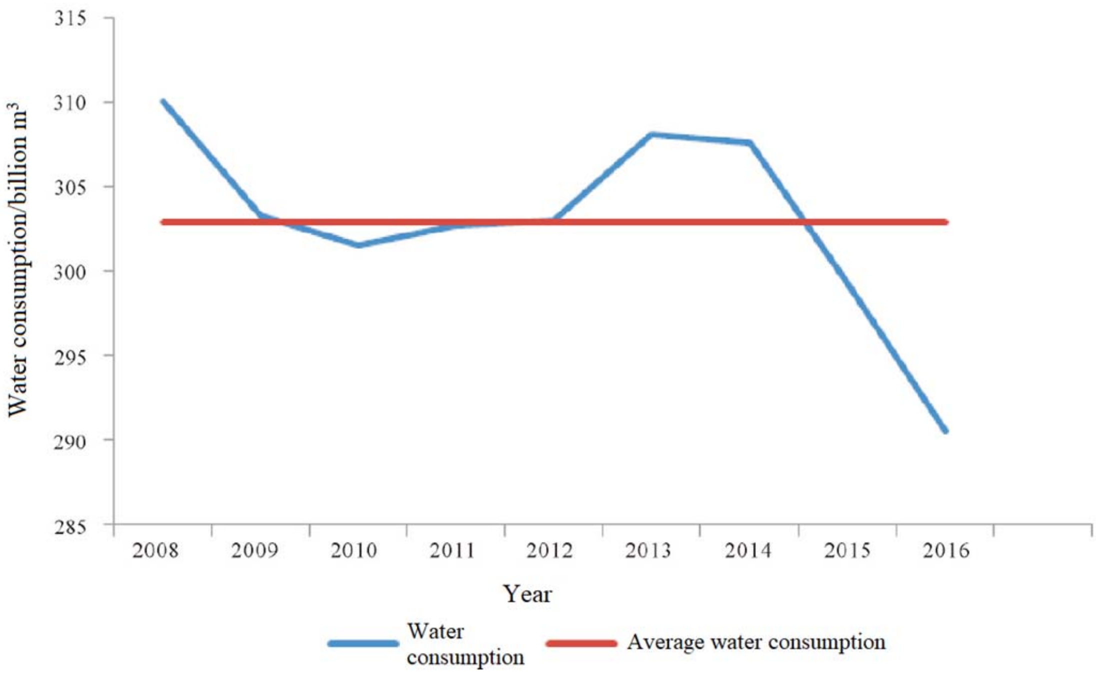

Figure 6. Annual distribution curve of water consumption in Guangxi.

30.29 billion m^3. The water consumption in 2010, 2011, 2015 and 2016 was lower than the average, and the water consumption in other years was higher than the average.

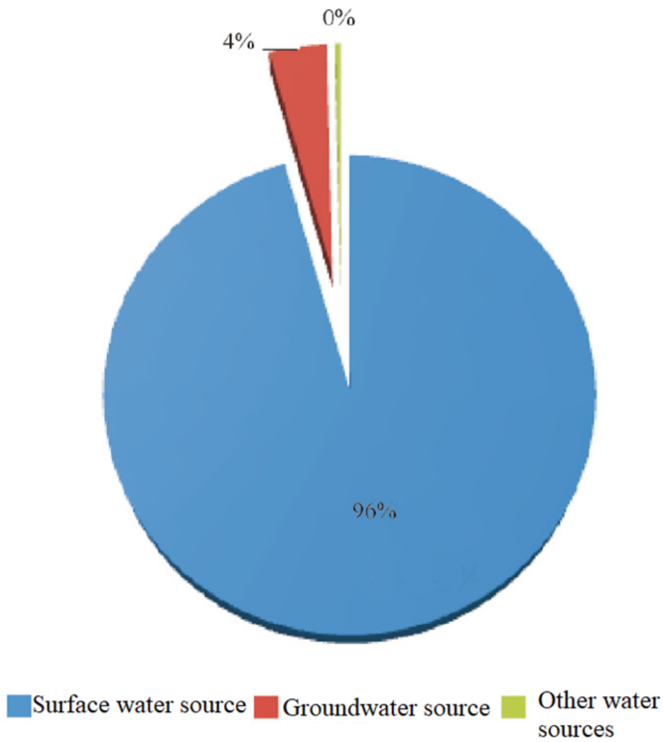

Figure 7. Schematic diagram of water use structure in Guangxi.

As shown in **Figure 7**, water in Guangxi mainly comes from surface water, taking 2016 as an example. In 2016, the total water supply of the region was 29.06 billion m^3, of which 27.80 billion m^3 was supplied by surface water sources, accounting for 95.7% of the total water supply; underground water supply was 1.15 billion m^3, accounting for 3.94% of the total water supply; other water sources supply 110 million m^3, accounting for 0.39% of the total water supply[3].

Water reserves are not fixed, but dynamically cyclical. Water has many uses. According to the *Water Act* of China, water resources can be divided into three types: domestic water, production water and ecological environment water. In this paper, production water is further divided into agricultural and industrial water, so the utilization of water resources is divided into four categories: agriculture, industry, life and ecological use.

As shown in **Figure 8**, agricultural water consumption in Guangxi is the largest, accounting for 68% of the total water consumption. The second is industrial water, accounting for the total water consumption 17%; next comes domestic water, which accounts for 14% of the total; ecological water consumption is the least, accounting for only 1% of total water consumption. The agricultural water consumption in Guangxi is much higher than the national average, while the industrial water consumption is lower than the national average. At the same time, the structure of water consumption in Guangxi is changing constantly, among which the proportion of domestic water consumption increases rapidly.

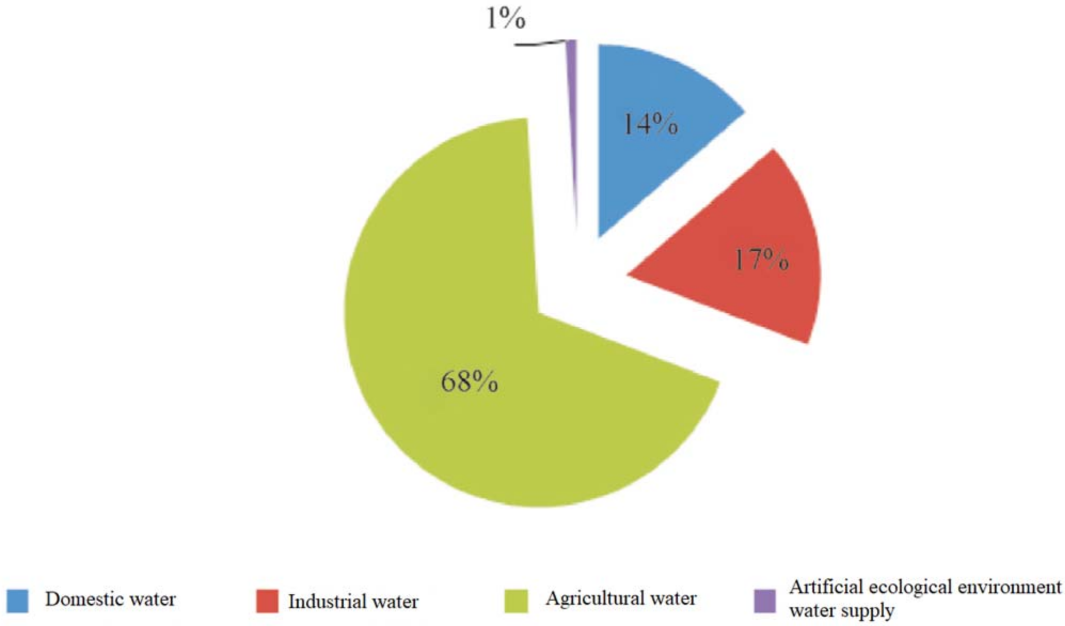

Figure 8. Schematic diagram of Guangxi water supply structure.

5. Water pollution in Guangxi

With the rapid economic development and rapid urbanization and industrialization in Guangxi, the problem of water resources pollution has also came as a result. According to the different pollution sources, Guangxi water resources pollution can be divided into mining pollution, industrial pollution, agricultural pollution and urban pollution.

5.1 Water pollution from mines

Guangxi is rich in mineral resources and known as the hometown of nonferrous metal minerals. Over the years, a large number of tailings and wastewater rich in heavy metals (such as As and Pb) in mining areas have not been well treated and discharged into rivers around the mining area, polluting rivers around the river or farmland[13]. For example, on July 6, 2013, Hejiang River, one of the main tributaries of the Xijiang River, suffered from regional heavy metal pollution, which has seriously affected the drinking water supply of people along the river and caused concern about water consumption in Guangdong Province downstream. The source of the pollution is basically identified as mining enterprises along the Mawei River section of the Hejiang River. In addition, according to data, the mining wastewater discharge in Nandan County is 1,700 t/a, and the amount of harmful substances in the wastewater is 206 t/a lead and 1776 t/a arsenic, which leads to serious pollution of Diaojiang River: the concentration of some heavy metals exceeds the maximum concentration of surface water allowed by nation by 10 times or even 100 times[23]. In addition, a large amount of tailings is deposited on the riverbed, which destroys the aquatic ecosystem of the river and makes fish and shrimp disappear in the middle and upper reaches of the river[14].

5.2 Water pollution from industrial sources

With the development of Western China and the rise of Beibu Gulf Economic Zone as a national development strategy, industrial enterprises and construction projects are gradually increasing, and industrial pollutants are gradually increasing in some areas, causing serious pollution in some river sections. For example, on January 15, 2012, heavy metal cadmium was detected in the Longjiang River section of Yizhou City, Guangxi Province, exceeding the standard of class III of *Surface Water Environmental Quality Standard* by about 80 times, which severely threatened the drinking water safety of residents along the coast and downstream[15]. Some engineering construction, industrial process management and control measures are not in place, but also pose a threat to the water environment. Some established sewage treatment plants have limited scale and low treatment capacity, which cannot meet the needs of local economic development and sewage treatment. As a result, untreated industrial sewage is directly discharged into rivers, causing pollution and damage to water environment and water ecology[16].

5.3 Water pollution from agricultural sources

As a major producer of grain in China, Guangxi agriculture is its pillar industry, so compared with provinces and cities with developed industry, agricultural water pollution in Guangxi is also a very important source of pollution. Agricultural pollution sources are relatively unitary, and the main sources of pollution are pesticides, fertilizers and feed. For example, the pollution of gully and pond system in the upper reaches of Lijiang River in Northern Guangxi is serious. Among the 2,721 gully and pond water bodies interpreted by remote sensing, 720 are suspected to have been polluted and 1,350 are potentially polluted. The pollution sources causing these water bodies are mainly non-point source pollution in rural settlements[17].

5.4 Water pollution from urban sources

With the expansion of city scale and the increase of population, the discharge of municipal wastewater is increasing. The construction of sewage pipe network lags behind the construction of sewage treatment plant, which greatly affects the effect of sewage collection and treatment, so that sewage treatment plant cannot fully play its role. For example, Nanning was rated as one of the five cities with the most serious water pollution in China in 2016. The main reason is that the sewage discharged by urban factories everywhere and the treatment capacity of municipal sewage treatment plant is limited, which leads to the extremely poor water quality of all rivers in the city, accompanied by fetid odor and red tide. In 2010, Qian *et al.* conducted a study on mercury distribution and pollution in Lijiang River system, which showed that there was mercury pollution to a certain extent in Lijiang River system of Guilin City[18].

6. Suggestions on water resources protection and management

At present, there is a certain gap in the demand and utilization of all kinds of water resources in China, and with the continuous acceleration of urbanization, the water resources shortage will be more and more serious. Therefore, the protection of water resources is urgent. The following suggestions are put forward for the protection of water resources.

(1) The government actively carries out the publicity of water resources protection to enhance the public's awareness of environmental protection. For water resources in the region, the government should make unified planning, rational exploitation and effective utilization, and gradually transit from concentration management to total control management[19]. Improve the monitoring and reward and punishment system for water pollution, strengthen the binding force of law, increase the intensity of punishment, so that violations of laws are punished by law. Expand the team in charge of water resources protection and give full play to the role of the river chief system.

(2) To reduce the discharge of industrial wastewater, economic, political and legal means

can be used simultaneously. To administer, punish and supervise the correction of enterprises that discharge pollutants abnormally. For substances discharged during industrial production, a series of detailed and standardized evaluation standards are formulated, and third-party spot checks are often carried out on assessment reports made by enterprises, and penalties for violations are strengthened, so as to deter other enterprises from violating the environmental bottom line. The site selection of large factories and chemical plants with serious discharge pollution shall be strictly examined and kept away from water sources to avoid pollution to water sources and affect the whole water system.

(3) Standardize the distribution of agriculture, animal husbandry and forestry, strictly control the discharge of chemical fertilizers, pesticides, livestock urine, processing sewage and other pollution sources, so as to control the impact on water resources, and strengthen monitoring with a variety of monitoring means. Do not throw rubbish and pesticide waste bottles into rivers, and control the fertilizer applied to crops quantitatively. Farmers are encouraged to use fewer polluting fertilizers and pesticides, and to use more farm manure. In addition, livestock waste can be specially treated as non-toxic fertilizers. And reasonably irrigate the farmland, improve planting efficiency, learn to farm scientifically, plant first crops requiring less fertilizer.

(4) Reduce the direct discharge of household garbage. One is to classify the recycled garbage; second, waste disposal should be timely to avoid waste accumulation causing pollution to the environment. The distribution of water resources, the collection of water charges, the collection of sewage charges and the collection of funds for pollution control in each region can be effectively unified, so as to realize the steps from local to overall governance, so as to solve the water environment problems in our region[20]. Improve the urban sewage treatment system: in order to control the deterioration of water, enterprises must actively control water pollution, especially the discharge of toxic pollutants must be treated separately or pretreatment. With the adjustment of industrial layout and urban layout and the construction and improvement of urban sewer pipe network, centralized treatment of urban sewage can be gradually realized, so that urban sewage treatment and industrial wastewater treatment can be combined[21]. As for individuals, we should protect water resources in production and life, thus cutoff the behavior of waste and pollution from the root.

(5) To establish water resources protection areas, some natural water sources must be strictly protected. Only suppress from the source of containment, actively handle in the middle, and finally repair serious, can we better solve the problem of water pollution. For the rivers in the area, we should focus on the improvement of the surrounding environment of the river, cleaning up the silt in the river, preventing soil erosion, river accumulation and other problems; for the lakes in the area, water quality monitoring should be strengthened to prevent the occurrence of eutrophication such as water bloom, and trees should be planted around the river to enhance the self-purification capacity of the river itself.

Conflict of interest

The authors declared no conflict of interest.

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