Underground karst development characteristics and their influence on exploitation of karst groundwater in Guilin city, Southwest China

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Abstract

Exploitation and utilization of karst groundwater is an effective way of solving the imbalance between supply and demand of water resources in Guilin City, southwestern China. In this study, we carried out a systematic investigation of the underground karst developmental characteristics and their influence on the migration and occurrence of karst groundwater in Guilin city. The results show that the thick limestone formation of D$_g$/r is the most ideal aquifer because it has the highest karst development and the most abundant karst groundwater. The main karst development zone is above 90 m a.s.l., and it accounts for 88.5 % of the karst caves, 11.5 % karst caves are located in the weak karst developed zone of 40-90 m a.s.l, and below 40 m a.s.l., the karst is not developed. Thus, the borehole depth for groundwater extraction is suggested to be approximately 100-120 m owing to the ground-surface elevation of Guilin city being 140-160 m a.s.l. The zone above 120 m a.s.l. is not optimal for karst groundwater exploitation because of its high karst cave filling rate (82.89 %) and low water-filling cavity ratio (16.95-30.08 %), in which the karst groundwater easily connects with surface water therefore an increase of possibility of collapse when extracting groundwater. The zone between 120-90 m a.s.l. could be more optimal for groundwater extraction due to its medium scale of karst caves, relatively low karst cave filling rate (62.07 %), and high water-filling cavity rate (30.43 % -62.10 %) relatively. Meanwhile, a favorable groundwater exploitation and utilization region is located in the eastern study area, which has the highest underground karst development, with the highest percentage of boreholes encountering caverns (80.21 %), linear karst rates (8.58 %), and the lowest karst cave filling rate (65.61 %). This study provides a scientific basis for the exploitation of karst groundwater and construction of a backup emergency water sources for Guilin City.

1. Introduction

Karst regions cover 7–12% of the Earth's continental area, and their aquifers are at least a partial source of drinking water supply to almost a quarter of the world's population (Hartmann et al. 2014; Ford et al. 2007; De et al. 2011; Liang et al. 2018; Parise et al. 2008). The karst area in China, covers an area of 334km$^2$ (1/3 of the national land area) (Ya et al. 2018), and mainly distributes in southwest China, which consists of eight provinces (municipalities), including Guizhou, Yunnan, Sichuan, Chongqing, Hubei, Hunan, Guangdong, and Guangxi (Zhang et al. 1980). Although the region has abundant rainfall and water resources, the subtropical monsoon climate characterized by the rainy season is concentrated in the summer, which contributes to annual unevenness in the distribution of water resources. The dry season leads to water shortages for residents, agricultural production, and industrial production (Lu et al. 2013; Lian et al. 2015; Xia et al. 2003). However, the abundant karst groundwater resources in Southwest China can play significant role in regulating and storing precipitation from the large seasonal differences (Yang et al. 2016; Cao et al. 2017). Thus, drought and water shortages in the dry season can be effectively solved by using abundant karst groundwater resources (Huang et al. 2016; Qin et al. 2017). In addition, because only a very small part of karst groundwater resources has been developed, the utilization and development capacity of karst groundwater resources in southwest China is huge (Xia et al. 1997; Xia et al. 2017). Effectively mitigating drought and water shortage by exploiting karst groundwater resources has increasingly attracted attention from scholars (Huang et al. 2017; Li et al. 2018; Huang et al. 2021).

The Li River is the quintessence of the Guilin landscape and is a major water source for industrial and agricultural production and urban domestic water in Guilin City (Zhao et al. 2018). However, the utilization of water resources in the Li River Basin is not optimistic because of the acute shortage of urban water supply and ecological water requirements for the river landscapes, especially in the dry season. Thus, protecting the beautiful landscape resources of Li River is increasingly becoming arduous (Liu et al. 2014; Fu et al. 2014). There is an urgency of water resource management in Li River Basin hence creating a balance between supply and demand of water resources, which is directly related to the sustainable development of Guilin in the 21st century especially when it comes to the economy and society, innovation (Qin et al. 2012). Karst is well developed in Guilin, contributing to the rich karst groundwater resources, high-quality karst groundwater, convenient exploitation conditions, and a long exploitation history of karst groundwater. According to preliminary statistics, the amount of natural replenishment from precipitation in Guilin city is more than 251 million m$^3$ per year, and the amount of exploitable groundwater resources is more than 98 million m$^3$ per year (Han et al. 2003). Thus, the abundant karst groundwater resources in the Guilin urban area could be used as an alternative water source to support city development (Liang et al. 2014).

Many studies conducted in the 1990s and the 2000s focused on the formation and control factors of karst landforms (Tang et al. 2002; Tang et al. 2000; Waltham. 2008), hydrochemical characteristics of karst groundwater (Tang et al. 2002), and formation mechanism of karst collapse in the central urban area of Guilin (Yuan et al. 1990; Liu et al. 2008; Huang et al. 2015). These researches have provided scientific support for the exploitation of landscape resources, protection of groundwater, and prevention and control of karst collapse (Guo et al. 2015; Yu et al. 2015). However, because Karst aquifers have complex characteristics such as high heterogeneity, large voids, high flow velocities up to several hundreds of m/h (Michel. 2005), few studies research on the distribution characteristics of Karst aquifer and the occurrence mechanism of karst groundwater in Guilin City (Michel. 2005; Wu et al. 2019), which seriously restricts the exploitation and utilization of abundant karst groundwater. This study, first, based on adequate karst data revealed by borehole, the differences in the percentage of boreholes encountering caverns, the linear karst rates, the karst development elevations, and the karst cave filling rate in the eastern, northwestern, and southwestern regions of the Guilin urban area are systematically investigated. Second, combined with stratigraphic lithology and groundwater runoff conditions, the controlling factors of significant differences in karst development in different regions were systematically analyzed. Finally, the favorable exploitation area of karst groundwater and the suitable depth of groundwater extraction by drill holes in Guilin City were defined. The results of this study will provide scientific support for the exploitation of karst groundwater and the construction of backup emergency water sources in Guilin City, which is helpful in solving the imbalance of water supply and demand in the Li River Basin, improving water supply capacity, and enhancing water supply security.

2. Study Area

Guilin City, in the northeastern part of the Guangxi Zhuang autonomos region, is a north-south karst basin located in the middle of the northern end of the Guilin-Yangshuo karst basin. The Li River flows from north to south through the middle of the Guilin Basin and becomes the main river with tributaries,
including the Taohua River in the northwest and the Liangfeng River in the southwest (Fig. 1). The surface water resources of the Li River are abundant, with an average annual flow of 138 m³/s, as observed at the Guilin hydrologic station. Guilin City is located in a subtropical humid monsoon climate zone, which is dominated by the East Asian monsoon and is characterized by four distinct seasons with long summers and short winters, abundant rainfall, sufficient sunlight, and abundant heat. The average annual precipitation and mean annual temperature in Guilin City are 1,886 mm and 18.9 °C, respectively. The rainy season occurs from March to August, accounting for 75–77% of the total rainfall, while the dry season occurs from September to February.

Guilin City is a karst catchment basin spreading from the north to south, and groundwater mainly converges from the east and west sides to the river valley terraces, and the peak cluster karst and depressions on both sides are the main recharge areas that receive atmospheric precipitation. The low and gentle central karst plain is not only the main runoff area of groundwater but also receives recharge from atmospheric precipitation and a large amount of surface water (Yang et al. 2019). The river valley terrace in the middle of the basin is the concentrated discharge area of groundwater. The exposed surface of carbonate rocks on both sides is widely distributed, underground karst is strongly developed, and atmospheric precipitation is abundantly, leading to abundant groundwater resources with smooth drainage condition, rapid circulation, and a strong self-purification ability. Guilin has a water storage structure in the form of a karst basin, which mainly contains bedrock fissure water, carbonate karst water, and pore phreatic water in the loose layer (Fig. 1). Karst water mainly occurs in the carbonate rocks of the middle and upper Devonian and lower Carboniferous strata. According to the lithologic combination and occurrence medium of karst groundwater, karst groundwater can be divided into three subtypes: fissure-cavern water in pure carbonate rocks, cavern-fissure water in carbonate rocks intercalated with clastic rocks, and fissure-karst water in clastic rocks intercalated with carbonate rocks (Fig. 1).

The geological structure around Guilin is characterized by a north-south synclinorium, which is slightly arc-shaped. The synclinorium contains a 3,000 m thick carbonate rock sequence (limestone and dolomitic limestone), from the upper and middle Devonian to the lower Carboniferous. On both flanks of the synclinorium, there are non-carbonate strata (sandstone, quartzose sandstone, siltstone, shale, and flysch deposits) from the Cambrian to the lower Middle Devonian (Yuan et al. 1990).

3. Materials and methods

Guilin City, bounded by the Li River and Liangfeng River, is divided into eastern, northwestern, and southwestern region (Fig. 1). In this study, we collected the karst data of 273 boreholes from the hydrogeological survey report of Guilin City (Hydrologic Engineering geological Team of Guangxi Zhuang Autonomous Region. 1983), and detailed analyzed the karst development characteristics by mathematical statistics method in these boreholes, including 96, 56, and 121 boreholes distributed in the eastern, northwestern, and southwestern regions, respectively. Table 1 shows the statistical results of the percentage of boreholes encountering caverns and the linear karst rates in the three areas (Table 1). Based on adequate karst data revealed by borehole, the differences in the percentage of boreholes encountering caverns, the linear karst rates, the karst development elevations, and the karst cave filling rate in the eastern, northwestern, and southwestern regions of the Guilin urban area are systematically investigated.

4. Results and discussion

4.1 Characteristics of karst development in boreholes

There was a large difference in the percentage of boreholes encountering caverns and linear karst rates in the eastern, northwestern, and southwestern region (Table 1). The percentage of boreholes encountering caverns and linear karst rates in the eastern region was the highest, followed by those in the northwestern and southwestern regions. Seventy-seven boreholes are encountered karst caves, which meant that 80.21% of boreholes encountering caverns in the eastern region. The total thickness of carbonate rocks exposed by boreholes is 6,880.95 m, where 253 caves generate a total height of 504.35 m and then a linear karst rate of 8.58%. Thirty-three boreholes are encountered karst caves, which meant that 58.93% of boreholes encountering caverns in the northwestern region. The total thickness of carbonate rocks exposed by boreholes is 2,510.38 m, where 89 caves generate a total height of 169.41 m and then a linear karst rate of 6.75%. In the southwestern region, forty-seven boreholes are encountered karst caves, which meant that 38.84% of boreholes encountering caverns. The total thickness of carbonate rocks exposed by boreholes is 3,692.03 m, where 105 caves generate a total height of 147.63 m and then a linear karst rate of 3.99%.

The large difference in underground karst revealed by boreholes in the three regions reflects the control of groundwater dynamic conditions on the development of underground karst (Song et al. 2018). In the eastern region, the recharge area of atmospheric precipitation is large (Fig. 1), the terrain is low and flat, and the area of carbonate rock outcrops is widely distributed, which is conducive to the recharge and collection of groundwater (Qin et al. 2012). In addition, clastic rocks are distributed around Yao Mountain on the northeastern side of the watershed (Fig. 1), which brings a large amount of non-karst water with a low saturation index and high erosivity into the karst area (Ya et al. 2018). This makes karst groundwater has a strong dissolution ability, resulting in the greatest development of underground karst in this area. The northwestern region is located in an interfluvial block composed of the Taohua River and the Li River, while the southwestern region is located in an interfluvial block composed of the Liangfeng River and the Li River. Both regions have a small area of carbonate rocks, indicating a small groundwater recharge and short runoff path, which results in the weak intensity of karst development in the northwestern and southwestern regions being less than that in the eastern region.
Significant differences in the strata lithology caused significant differences in the percentage of boreholes encountering caverns and the linear karst rate. The thick limestones of the D_{3r} and D_{3g} have the highest percentage of boreholes encountering cavern and the linear karst rates, which are 64% and 8.11%, respectively. Followed by the dolomitic limestone of the D_{2d}, the percentages of boreholes encountering caverns and the linear karst rates were 57.80% and 2.46%, respectively. The limestone interbedded with dolomite of C_{1r} and C_{1y} has the lowest rates of 38.33% and 4.85%, respectively (Table 2). Therefore, the percentage of boreholes encountering caverns and the linear karst rates in the D_{3r} and D_{3g} were 1.7 times that of C_{1r} and C_{1y} formations, but 1.1 times and 3.3 times that of D_{2d} formations, which reflects the influence of lithology on karst development. The limestone of D_{3r} and D_{3g} in the study area, represented as thick and medium-thick layers without argillaceous and siliceous layers have high calcite (89.5%) and CaO content (68.6%), low dolomite content (24.82%), acid-insoluble substances (0.61%), and high specific solubility (0.76) (Table 2), which leads to the most developed karst in this stratum. However, compared with limestone of D_{3r} and D_{3g}, the dolomite content (55.24%) of D_{2d} was higher and the calcite content (50.7%) and CaO content (44.3%) were low, resulting in its karst development being inferior to that of limestone of D_{3r} and D_{3g}. C_{1r} and C_{1y} are mainly interbedded limestone and dolomite, as medium-thick layers and thin layers, interlated with argillaceous limestone and siliceous layers, which cause a high content of acid-insoluble substances (7.58%), low specific solubility (0.52), and finally the weakest karst development degree. Therefore, according to the percentage of boreholes encountering caverns and the linear karst rates, D_{3r} and D_{3g} are ideal aquifers for karst groundwater resource exploitation in Guilin city.

### Table 1

<table>
<thead>
<tr>
<th>Partition</th>
<th>Drilling holes (pieces)</th>
<th>boreholes with karst caves (pieces)</th>
<th>percentage of boreholes encountering caverns (%)</th>
<th>Total of karst caves (pieces)</th>
<th>The total thickness of the karst layer (m)</th>
<th>Total height of caves (m)</th>
<th>Linear karst rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>East</td>
<td>96</td>
<td>77</td>
<td>80.21</td>
<td>253</td>
<td>5880.95</td>
<td>504.35</td>
<td>8.58</td>
</tr>
<tr>
<td>Northwest</td>
<td>56</td>
<td>33</td>
<td>58.93</td>
<td>89</td>
<td>2510.38</td>
<td>169.41</td>
<td>6.75</td>
</tr>
<tr>
<td>Southwest</td>
<td>121</td>
<td>47</td>
<td>38.84</td>
<td>105</td>
<td>3692.03</td>
<td>147.63</td>
<td>3.99</td>
</tr>
<tr>
<td>Total</td>
<td>273</td>
<td>157</td>
<td>57.51</td>
<td>447</td>
<td>12083.36</td>
<td>821.39</td>
<td>6.8</td>
</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>Layer</th>
<th>Drilling holes (pieces)</th>
<th>Encountering cavern holes (pieces)</th>
<th>the percentage of boreholes encountering caverns (%)</th>
<th>Total of karst caves (pieces)</th>
<th>The total thickness of the karst layer (m)</th>
<th>Total height of caves (m)</th>
<th>Linear karst rate (%)</th>
<th>calcite (%)</th>
<th>Dolomite (%)</th>
<th>CaO (%)</th>
<th>acid-insoluble substances (%)</th>
<th>specific solubility (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D_{3r} and D_{3g}</td>
<td>175</td>
<td>112</td>
<td>64%</td>
<td>348</td>
<td>8544.31</td>
<td>692.92</td>
<td>8.11</td>
<td>89.5</td>
<td>24.82</td>
<td>68.6</td>
<td>0.61</td>
<td>0.76</td>
</tr>
<tr>
<td>D_{2d}</td>
<td>38</td>
<td>22</td>
<td>57.9</td>
<td>44</td>
<td>1809.58</td>
<td>44.56</td>
<td>2.46</td>
<td>50.7</td>
<td>55.24</td>
<td>44.3</td>
<td>0.94</td>
<td>0.64</td>
</tr>
<tr>
<td>C_{1r} and C_{1d}</td>
<td>60</td>
<td>23</td>
<td>38.3</td>
<td>55</td>
<td>1729.47</td>
<td>83.91</td>
<td>4.85</td>
<td>70.5</td>
<td>30.43</td>
<td>51.2</td>
<td>7.58</td>
<td>0.52</td>
</tr>
</tbody>
</table>

#### 4.2 Elevation of karst development

Figure 2 shows that 396 of 447 exposed karst caves by boreholes are distributed above 90 m a.s.l., accounting for 88.5% of the total karst caves. Fifty-one caves appeared at the elevation of 90 – 40 m, accounting for only 11.4% of the total, indicating that the development of underground caves has obvious zonation. There are 253 underground karst caves in the eastern region, with 228 developed at the elevation of 150 – 90 m, accounting for 90.01% of the total number of karst caves. Only 25 appear at the elevation of 90 – 50 m, accounting for 9.99% of the total. There were 89 karst caves in the northwestern region, including 76 developed at the elevations of 150 – 90 m, accounting for 85.39% of the total karst caves, and only 13 appeared at an elevation of 90 – 40 m, accounting for 14.60% of the total. There are 105 underground karst caves in the southwestern region, including 92 developed at an elevation of 170 – 90 m, accounting for 87.60% of the total karst caves, and only 13 are developed at an elevation of 90 – 60 m, accounting for 12.40% of the total (Fig. 2). Therefore, the karst development in the study area can be divided into three depths: a karst strong development zone above 90m, a weak karst development zone of 40–90 m, and an extremely weak karst development zone below 40 m (Fig. 3).

Karst development is controlled by the base level of groundwater discharge (Wang et al. 2022). Groundwater alternates rapidly, and the karst develops strongly above the base level of groundwater discharge (Ahmed et al. 2013). While below the base level of groundwater discharge, the alternating speed of groundwater is slow, and the development of karst is weak (Bi et al. 1999). According to previous studies (Yuan et al. 1990), the ancient channel of the original Li River in Guilin city was approximately 47–50 m deeper than the current river valley (145 m a.s.l.), therefore, the elevation of 90 m a.s.l. is the ancient base level of groundwater discharge in the Li River Basin (Fig. 4). Therefore, controlled by the ancient base level of groundwater discharge, the hydraulic gradient above 90 m a.s.l. is large, the groundwater flow rate is fast, and the dissolution and erosion of groundwater is quite strong, resulting in
strong karst development above 90 m a.s.l.. Below 90 m, the groundwater moves to the bottom of the Li River in the form of a reverse siphon, the groundwater runoff path is long, and the circulation depth is large. Therefore, the dissolution of the groundwater is weaker than that of the groundwater above the base discharge level in the form of phreatic movement, resulting in weaker karst development below 90 m a.s.l.

### 4.3 Filling characteristics of underground karst caves

The filling rate of boreholes in the study area is high (Table 3). There were 157 holes encountering karst caves, and 133 holes were filled, thus the filling rate of holes was 84.71%. The northwestern region has the highest filling rate, with 33 boreholes encountering karst caves, and 32 were filled (a filling rate of 96.97%). Subsequently, the eastern region, has 77 boreholes, encountering karst caves, of which 63 were filled, hence a filling rate of 81.22%. The Southwestern region has the lowest filling rate, with 47 boreholes encountering karst caves, of which were filled, with a filling rate of 80.85%.

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>East</td>
<td>77</td>
<td>63</td>
<td>81.22</td>
<td>253</td>
<td>137</td>
<td>54.15</td>
<td>29</td>
<td>11.46</td>
<td>87</td>
<td>34.39</td>
</tr>
<tr>
<td>Northwest</td>
<td>33</td>
<td>32</td>
<td>96.97</td>
<td>89</td>
<td>66</td>
<td>74.16</td>
<td>17</td>
<td>19.1</td>
<td>6</td>
<td>6.74</td>
</tr>
<tr>
<td>Southwest</td>
<td>47</td>
<td>38</td>
<td>80.85</td>
<td>105</td>
<td>76</td>
<td>72.38</td>
<td>4</td>
<td>3.81</td>
<td>25</td>
<td>23.81</td>
</tr>
<tr>
<td>Total</td>
<td>157</td>
<td>133</td>
<td>84.71</td>
<td>447</td>
<td>279</td>
<td>62.42</td>
<td>50</td>
<td>11.19</td>
<td>118</td>
<td>26.39</td>
</tr>
</tbody>
</table>

The filling rate of underground karst caves was also high. Among the 447 caves, 329 caves are filled or semi-filled with a filling rate of 73.61%. The filling rate in the northwestern region was the highest (93.26%), followed by the southwestern (76.19%) and eastern (65.61%) regions (Table 3). It can be concluded that the filling rate of karst caves decreases with increasing depth (Fig. 5). There were 263 karst caves with an elevation of more than 120 m a.s.l., 218 of which were filled and semi-filled, with a filling rate of 82.89%. There were 145 karst caves at the elevations between 120 and 90 m, 90 of which were filled and semi-filled with a filling rate of 62.07%. There were 39 karst caves at an elevation of 90 – 40 m, 19 were filled and semi-filled, with a filling rate of 48.72% (Table 3).

According to the development elevation of karst caves, the underground karst caves in the study area mainly developed between 150 and 40 m a.s.l.. Given that the ground-surface elevation of the Guilin urban area is 140–160 m a.s.l., the borehole depth for groundwater extraction is suggested to be approximately 100–120 m. The karst caves above 120 m a.s.l are large in scale, densely distributed, and mostly extended in the shape of a grid, but the filling rate is as high as 82.89%, most of which are filled with clay, sand, or gravel, while the space rate of water filling is only 16.95–30.08% (Table 4). In addition, this section of the karst groundwater easily amalgamates with surface water, hence low water quality, and easily collapses during water intake; therefore, it is not the main groundwater extraction section. The number of karst caves at 120 – 90 m was large, the scale of karst caves was medium, the filling rate was relatively low (62.07%), and the water-filling cavity rate (30.43%-62.1%) was high. Meanwhile, the karst fissure in this section is also well-developed, and the drilling hole is easily exposing the karst cave and fractures (Bi et al. 1999); therefore, it is the main groundwater extraction section and exploitation object. The karst cave at 90 – 40 m is small scale, and is not as large as the water storage space of karst cave at 120 – 90 m. This karst cave, however, is rarely filled with mud, sand, and clay (the filling rate is 48.72%). A well can also be formed when a drill hole encounters cave or fissure.

<table>
<thead>
<tr>
<th>Karst cave segment</th>
<th>Elevation (m)</th>
<th>East</th>
<th>Emptiness (pieces)</th>
<th>Void rate (%)</th>
<th>Northwest</th>
<th>Emptiness (pieces)</th>
<th>Void rate (%)</th>
<th>Southwest</th>
<th>Emptiness (pieces)</th>
<th>Void rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The first segment</td>
<td>150 – 120</td>
<td>133</td>
<td>40</td>
<td>30.08</td>
<td>59</td>
<td>10</td>
<td>16.95</td>
<td>57</td>
<td>15</td>
<td>26.32</td>
</tr>
<tr>
<td>The second segment</td>
<td>120 – 90</td>
<td>95</td>
<td>39</td>
<td>62.1</td>
<td>19</td>
<td>9</td>
<td>47.37</td>
<td>23</td>
<td>6</td>
<td>30.43</td>
</tr>
<tr>
<td>The third segment</td>
<td>90 – 40</td>
<td>25</td>
<td>19</td>
<td>76</td>
<td>11</td>
<td>4</td>
<td>36.37</td>
<td>11</td>
<td>5</td>
<td>45.45</td>
</tr>
</tbody>
</table>

### 5. Conclusion

The underground karst in the Guilin urban area is well developed, and the percentage of boreholes encountering caverns and the linear karst rates are high; however, there are obvious differences among the eastern, northwestern, and southwestern regions. The eastern region has a large recharge area of atmospheric precipitation with low and flat topography, which is conducive to the recharge and collection of groundwater, resulting in a high percentage of boreholes encountering caverns and linear karst rates, low cave filling rates, and stronger karst development than in the northwestern and southwestern regions. Moreover, there are significant differences in karst development in different strata, in which D3r and D3g have pure lithology, thick stratum, and the...
most developed karst, followed by Dd and C, therefore, the conditions for the development and utilization of groundwater in the eastern region are more favorable, where the karst of the thick limestone aquifers of D3 and D3g is the most developed, and karst groundwater is the most abundant, which is the most ideal aquifer for karst groundwater exploitation.

The surface elevation of the peak-forest karst plain area in Guilin is 140–160 m a.s.l. Controlled by the ancient channel of the original Li River, underground karst caves are mainly developed above 90 m a.s.l., with weak karst development at 40–90 m and no karst caves below 40 m a.s.l. Therefore, karst groundwater mainly exists above 40 m a.s.l., and the drillhole depth for groundwater extraction should be 100–120 m. The filling rate of the karst cave above 120 m a.s.l. was high, water-filling cavity rate was low, and karst groundwater was not abundant. In addition, karst groundwater at above 120 m a.s.l. caves are easily connected to surface water, and leading to karst collapse when taking water. Therefore, karst caves above 120 m a.s.l. are not optimal for groundwater development and utilization. The 120–90 m section is the optimal exploitation section of karst groundwater in the Guilin city because of the large number of karst caves at a medium scale, relatively low filling rate, and high water-filling cavity rate.

Declarations

Author contributions
All authors contributed to the study conception and design. Pu is responsible for research methods, experimental design, data collection, processing and analysis, and writing papers, Huang is responsible for the planning, design and implementation of the entire study. Guarantee the completeness and accuracy of the study. Provide economic and technical support, Li. Zou. Liao, and Zhao participated in the research design, method selection, etc., assisted in data collection, processing and analysis, and provided experimental equipment, technology, and paper writing suggestions; Wu. Luo. and Jiao provided suggestions for paper writing. The first draft of the manuscript was written by Pu. and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Conflict of interest
The authors have no relevant financial or non-financial interests to disclose.

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