Analysis of the influence of stratum on karst development features: Taking Longtan river basin in Youyang County as an example

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Abstract: As the carrier of karst water, the stratum is capable of impacting the water yield property and karst development features, so this paper aims to find out how the stratum characteristics affect the karst water. The study site was Longtan river basin, a typical area of karst topography, located in Youyang County, Chongqing, China. Throng the statistics and analysis of the characteristics of karst water and strata, it was obvious that the thickness of strata has a significant impact on the karst water. In epi-karst, it was demonstrated that as the rock layer thickened, the flow of karst water decreased, but the number of karst springs tended to increase. The influence law was similar in deep layers, that is the relation between the stratum thickness and the average flow could be fitted by a power function, and the stratum thickness and the length of underground river, an exponential one. In addition, the flow-rate of water yielded was likely to drop fairly rapidly while the strata get deeper. Therefore, this paper successfully put forward a method, which can estimate the water resources quantity of karst water as long as the stratum thickness was available and provide a reference for the subsequent evaluation of water-abundance.

Key words: deep karst zone; epi-karst zone; formation thickness; flow rate; length of underground river; Longtan river basin; strata sequence

1. Introduction
Karst water has made an outstanding contribution to water supply around the world with a guarantee of good quality and sufficient quantity in decade years, that has also firmly shored up the economic development [1]. Unfortunately, nowadays the karst water environment is believed to be at huge risk of deterioration result from human disturbance and climate change, normally manifested as drop of water level, sharp cutoff of flow-rate, water degradation etc. [2]. There have been numerous studies that are dedicated to explore the development characteristics and distributing disciplinarian of karst water system, that is considered to be of great help to cope with the problem. Besides, these researches are primarily based on either the field investigation, such as drill hole sampling, tracer experiment and geophysical prospecting, or the establishment of model, mainly including physical model and numerical model. Huang Q B et al. concluded the evolution law of karst water in Liulin spring region [3]. Lin et al. [4] adopted R/S analysis method, Mann-Kendall trend analysis method and wavelet analysis method to investigate the variation law of flow-rate in Xiaonanhai spring on the basis of the flow data from 1971
to 2016. Dong and Shu et al. [5] reported the time-varying characteristics of the attenuation coefficient of underground river flow in typical karst regions of Southwest China after defining the instantaneous attenuation coefficient and nominal attenuation coefficient. In terms of model use, Eisenlohr et al. [6] first proposed to simulate the dispersed flow and the pipe flow according to the hydrodynamic conditions of laminar and turbulent flow in the water-bearing medium. A physical model was set up with dual-media integrated karst pore and pipeline to carry out water flow and solute transport tests [7]. BHS physical model was employed to simulate the attenuation process of spring flow and conversion mechanism of different water source in karst areas [8]. Liu [9] conduct an experiment of Darcy flow and non-Darcy flow at a scale of block mass.

However, we note that most of the studies would actually pay attention to the karst water rather than its carrier, stratum. In fact, the stratum characteristics is a major force impacting water yield property as well as the hydrochemical features, so it is an issue which is exactly worthy to be discussed. Because the stratum characteristic contains many factors, this paper attempt to focus the study on how strata thickness affects the karst water and provide a method to estimate groundwater resource in karst areas, which is helpful to deal with the water shortage problem.

2. Materials and methods
The study area is located on the right bank of the Wujiang river in the west of Youyang county. Within the district, the landform mainly belongs to karst low mountain and karst low-middle mountain of southeast Chongqing and the mountains generally extend in NNE directions, consistent with the terrain structure line (Figure 1). Due to the downcutting of the Wujiang river as well as its tributaries, the terrain fluctuates greatly and a grand karst landscape is developed, which is famous for stone forests, peak cluster depression, sinkholes, caves, underground river etc. and unique to southeast Chongqing. In regard of different causes, geomorphic types can be divided into erosional and denudation structural landform and karst landform, which includes three subcategories: erosional-denudation low mountain structural landform, karst trough dissolution structural landform and peak cluster depression structural landform. It is proved that the outcropped formations are mostly composed of sedimentary rocks, of which Carbonate is the most widespread and thickest, and varies from Triassic to Cambrian except Carboniferous.

![Figure 1. Location, elevation and water system of study area.](image-url)
It is the neotectonic movement in the study area characterized by a series of large-scale, uneven and intermittent rises that has result in the increase of height differences, intense downcutting of surface water, drop of erosion basis and deepening of groundwater table. Meanwhile, under the control of the gentle fold, Carbonate formations are widespread and two large faults with NE and SW trend are formed in the region, through which the precipitation infiltrates into the phreatic zone, and then enters the groundwater system along the favourable karst pipelines such as fissures and underground rivers etc. Therefore, the extremely active karstification has shaped a typical karst landform dominated by the peak cluster depression on the surface, along with the sinkhole and underground river below the surface.

The statistics of karst water and strata in the study area showed that there were in total 5 underground rivers and 61 karst springs, three of which were large karst springs in deep layers and 58 of which were epi-karst springs in shallow layers, mainly belonging to O2b, ∈ 3m, ∈ 3g, and ∈ 2g. In addition, the flow of underground rivers, large karst springs and epi-karst springs ranged 108 ~ 2980 L·s⁻¹, 12.5 ~ 38 L·s⁻¹ and 0.02 ~ 5.89 L·s⁻¹ respectively. Because a great deal of previous studies have clearly delineated the relationship between the attitude of stratum and karst development features, this paper intended to lay emphasis on the analysis of influence of stratum characteristics, especially the thickness and sequence, on the karst water development, which is supposed to benefit the follow-up studies on the spatial characteristic and distributing rule of karst water in other regions.

3. Results and discussion

3.1. The influence of stratum thickness on karst development in shallow layers

The epi-karst zone plays an important role in regulating and storing karst water that is one of the most significant processes of the hydrologic cycle [10]. Therefore, to find out the distribution law of the epi-karst water is helpful to boost the storage capacity of the karst water system and advance the reasonable utilization of karst water. The epi-karst zone is affected by a series of factors, such as vegetation cover, precipitation, features of the stratum, etc. which is fairly complicated [11]. Then, just like some previous studies have focused the work on the relationship between the emergence of karst spring and the rock properties [12], this study is set to just explore how the stratum thickness, that can reflect the rock composition and the content of water-soluble minerals in a sense, influence the epi-karst water.

![Figure 2. Distribution of epi-karst spring in different strata.](image)

As is well known, the epi-karst zone has much easier access to the precipitation recharge, which makes the epi-karst water system particularly developed. Meanwhile it is either the weak carbonate karst zone or the non-soluble layer under the epi-karst water that brings about the stagnation and storage of the precipitation. The number and average flow-rate of the karst spring in different strata in the study
area were calculated, shown as Figure 2. We can see that there were 58 epi-karst springs totally with the average flow-rate ranging from 0.02 to 5.89 L·s⁻¹ and they were mainly distributed in Cambrian strata, among which \( \in 2p \) had the most because it mainly consisted of dolomite limestone and lime dolostone interbedded with a small mass of dolomite, all belonging to carbonate rock and are more soluble. Additionally, the stratum was relatively thick, between 338~400m, which could mitigate the infiltration and erosion of karst water but was likely to create more impediments at the same time, and this is why it had a well-developed karst system but a relatively smaller flow.

Afterwards, we analyzed and illustrated the relationship between the average thickness of the strata and the corresponding average flow-rate, as shown in Figure 3. The result indicated the thickness of the stratum tended to deviate from the average flow-rate, that is, the thicker the stratum was, the smaller the average flow-rate would be. Further, correlation analysis showed that the negative correlation trend was present in any stratum, which was summarized in Table 1.

![Figure 3. Thickness and flow rate of different strata in epi-karst zone.](image)

| Correlation analysis                      | Value         |
|------------------------------------------|---------------|
| Pearson correlation                      | -.337         |
| Significance test (bilateral)            | .009          |
| Sum of the square and the cross product  | -3492.437     |
| Covariance                               | -60.214       |
| N                                        | 59            |

Based on all above analysis, it became evident that with the increase of stratum thickness, the flow-rate of epi-karst water was inclined to decrease but the number of karst springs tended to increase. Combined with the field investigation, it can be seen that the stratum was used to being loaded with more impurities when the thickness of it became larger, that could result in forming a relative water-resisting stratum that was bound to hinder the development of karst system and made the flow-rate decrease. However, epi-karst spring were more likely to emerge if the fissures in rocks and strata thickness increased, which could account for increase of the number of karst springs in some strata. Besides, it was pointed out that the stratum thickness was also a key factor impacting the epi-karst development, in addition to rock formations.

3.2. The influence of stratum thickness on karst development in deep layers

Karst water in the deep formation is quite stable in large quantity and good quality, so it has been one of the most primary groundwater-supply sources across the word. Its water-storing medium is used to
be large fissure, sinkhole and underground river, that tend to result in a large flow but a poor shortage. A number of studies have attempted to investigate how the karst water transfers between the water-storing mediums by setting up hydrological models. Sun and Shu et al. [12] calculated the flow recession curve of spring water discharge on the basis of fissure-pipeline medium physic-chemical model. Teng and Wang et al. [13] reported the fissure-pipeline medium physical network model could be set up if the various fractures were generalized into regular two-dimensional round holes, and the dimensionality of fissure flows was reduced into multiple linear channel flows. These models were capable of reflecting the flow characteristics of karst water, but ignored the different water storage capacity of strata, so to analysis the relationship between karst water flow and the properties of the strata ought to be of great benefit to establish the karst water system hydrological model.

Most of the karst water in the deep formation is in form of underground river and karst spring, and its interaction with the surface water is far less than that of epi-karst spring, which makes the statistical analysis method employed for shallow layer no longer applicable. Table 2 shows the identifying information of all underground rivers and karst springs within the research area.

Table 2. Information of underground rivers and karst springs in the study area.

| Karst water type     | Number | Stratum | Length of underground river (m) | Depth to water table (m) | Outlet flow (L·s⁻¹) | Average flow (L·s⁻¹) |
|----------------------|--------|---------|---------------------------------|-------------------------|---------------------|----------------------|
| Underground river    | S06    | ₁h      | 2                               | 50~150                  | 80                  | 2980                 | 1530                 |
|                      | S14    | ₁m      | 4                               | 100~200                 | 20                  | 520                  | 270                  |
|                      | S55    | ₂p      | 12                              | >200                    | 6                   | 108                  | 57                   |
|                      | S56    | ₁m      | 6                               | 50~200                  | 9                   | 145                  | 77                   |
|                      | S57, S58 | ₁g    | 15                              | >200                    | 13                  | 300                  | 156.5                |
| Large karst spring   | S13    | ₁g      | /                               | /                       | /                   | /                    | 17.2                 |
|                      | S24    | ₂p      | /                               | /                       | /                   | /                    | 38                   |
|                      | S54    | ₂g      | /                               | /                       | /                   | /                    | 12.5                 |

It was clear from Table 2 that the underground river mainly developed in Cambrian rock formations, such as ₁m, ₂p and ₁g, and the number of the three was the same. Addition to Cambrian, there was a single one present in Ordovician, but the flow of which was the largest. Based on the analysis, we aimed to find out how the strata influence the characteristics of karst water in deep layers. Figure 4 illustrated an evident negative correlation between the thickness of stratum and average flow of karst water, in accordance with what it was in shallow layers, that was the greater the thickness, the smaller the flow rate.

Figure 4. Thickness and flow rate of different strata in deep layers.
Moreover, the discharge and length of the 5 underground rivers were available through field survey (Table 1), and then the scatter plot graph was worked out to investigate the relationship between the length of the underground rivers and the thicknesses of strata. (Figure 5)

![Figure 5. Relation between the stratum thickness and length of underground river in deep layers.](image)

Based on the nonlinear regression analysis of Figure 5, it was revealed that when the thickness of the stratum increased, the underground river grew longer, but the average flow rate dropped, that was exactly similar to the relationship between the stratum thickness and the number of karst springs as well as the flow rate in the shallow layers. So, in a way, we can infer that the more developed fissures could account for the longer underground river, which indicated it was more likely to generate the underground river under the same dissolution. The relationship between the thickness of the stratum and the length and the average flow-rate of the underground river can be expressed as the following equations:

$$Q = 685896H^{-1.528}$$
$$L = 1.4517e^{0.0058H}$$

Where Q is the average flow-rate of the underground river; L is the length of the underground river; H is the thickness of the stratum.

Although only one impact factor, that was thickness, has been taken to analyze how the stratum affect the karst development in deep layers, but it certainly can help to estimate the quantity of karst water resources in the study area, which has a great reference value for the follow-up underground water resources survey.

4. Conclusion

We have concentrated our efforts on investigating the impacts of stratum thickness on karst development, and our findings indicated that if the stratum thickness increased, the number of karst springs tended to increase but the flow-rate of epi-karst water tended to reduce in shallow layers in study area. Meanwhile, a generally similar response was observed in deep layers, that was, with the increase of stratum thickness, the length of the underground river increased at an exponential function and the average flow-rate decreased at a power function. Besides, the flow-rate of karst water were likely to rapidly decline as the strata go deeper. It's no doubt that our findings provide an approach for estimating the flow-rate of karst water in and out of the stratum preliminarily according to stratum thickness, especially if the age of the stratum can be determined. It is noted that the study area is seriously short of water but the karst water system is well developed, so our conclusion will have certain significance to the local hydrogeological survey and groundwater exploitation and utilization. In addition, the karst development is also affected by many other factors, such as formation occurrence, and we argue that this issue deserves more attention in the follow-up researches.
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