Study on Change of Small Area Land Water Reserves Based on GRACE-FO Satellite

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Keywords: Water Resource, Small Area Land Water Reserves, GRACE-FO, Satellite Gravity, Precipitation; Chongqing.

Abstract: In order to monitor the changes of water resources in small regions, taking Chongqing as an example, the temporal and spatial changes of groundwater reserves in the region are studied by using GRACE-FO gravity satellite data, and the data are processed by Gaussian smoothing, and analyzed in combination with precipitation data and terrain. The results show that the land water reserves in Chongqing all show obvious seasonal changes, showing an upward trend of 1.2mm/mon in summer and autumn, and a downward trend of - 0.9mm/mon in winter and spring; From 2002 to 2022, the change of equivalent water height of land water reserves in Chongqing shows an upward trend, with a change trend of 0.8mm/a. There is a negative correlation between land water reserves and precipitation in Chongqing, with a correlation coefficient of -0.76. The northeast mountainous area with high altitude in Chongqing has a high frequency of rainfall, and the monthly precipitation has little difference. The precipitation in other areas is seasonal; The land water reserves in Chongqing are also related to the topography and population density. The water reserves in the mountainous areas in the north and southeast are high, and the water reserves in the densely populated areas in the southwest are low; The retrieved land water reserves of Chongqing are in good agreement with the county spatial distribution data of groundwater resources in 2015. Based on GRACE-FO satellite, the changes of land water reserves in small areas can be better retrieved.

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1 INTRODUCTION

Water is the origin of all life on the earth and the basis for human survival. With the rapid economic development and climate change, water resources are rapidly consumed. Even though China's freshwater resources are in the forefront of the world, due to the large population base, the per capita water resources are below the world average (LIU et al.,2017). Therefore, studying the change of water resources is of great significance to our survival and sustainable development (Vorosmarty et al.,2000). Quantitative research on the change of land water reserves is helpful to better study regional drought, flood disasters and changes in groundwater resources (Hu X et al.,2006). For traditional water resource observation, hydrometeorology requires multiple monitoring points or monitoring networks, which is difficult to maintain after construction. Due to the impact of topography and other conditions, the observation can only cover local spatial scales, and cannot provide enough spatio-temporal observation to accurately describe the changes in land water storage. In March 2002, the National Aeronautics and Space Administration of the United States (NASA) and the German Aerospace Center launched GRACE gravity satellite, which had been out of service until its crash in 2017. The successor satellite, GRACE-FO, was launched in 2018, providing a new means for retrieving changes in land water reserves (Tapley B D et al.,2004 and Wahr J et al.,2004). Many scholars at home and abroad use GRACE satellite data to recover high-precision earth gravity field information and the research shows that the quality change of the earth's surface and interior is often related to the change of land water reserves in a short time scale (Chen Kun et al.,2018). Therefore, the change of land water reserves can be retrieved from GRACE satellite gravity data.

In recent years, the work of using GRACE/GRACE-FO satellite time-varying gravity observation to study the changes of land water and groundwater reserves has also been carried out. Mohamed et al. Luo et al. Hu et al. preliminarily analyzed the seasonal change of water reserves in

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Many relevant studies should added in this sentence.the Yangtze River basin using the early GRACE observation data; Yang Yuande and others calculated the change of global water reserves by using the time-varying data of GRACE, and further discussed the change of water reserves in Amazon River, Yangtze River and other basins; Xiong Jinghua et al. used GRACE gravity field model to invert the temporal and spatial variation characteristics of land water reserve anomaly in the Pearl River basin from 2002 to 2017 in 2021; Meng Ying et al. explored the change trend of land water reserve anomaly (TWSA) in China's ten major basins and its correlation with temperature, precipitation and water use in 2021; Ni Shengnan et al. discussed the seasonal and interannual variation characteristics of water reserves in the Yangtze River and Yellow River basins for many years in 2014. At the same time, by monitoring the drought in the Yellow River basin from 2002 to 2003, they proved the ability of GRACE satellite in monitoring drought events.

Due to the problem of resolution of GRACE satellite data, previous studies have often analyzed the water reserves in large regions, and few literatures have analyzed the changes of land water reserves in small regions. In this paper, the gravity field model data and GRACE data of GRACE-FO satellite released recently are used to process the data with Gaussian smoothing, and the relationship between groundwater reserves and precipitation, topography and population density is studied by combining precipitation data and terrain analysis; The characteristics of seasonal and interannual variation are analyzed; Compared with the known water reserve data, the reliability of inversion results is verified.

2 OVERVIEW OF THE STUDY AREA

Chongqing is located in the southwest of China, between 105 ° 11 '- 110 ° 11' east longitude and 28 ° 10 '- 32 ° 13' north latitude. It is the largest economic center in the upper reaches of the Yangtze River and an important land and water transportation hub in southwest China. Its landform is composed of river valleys, basins, hills and mountains, with high mountains and deep valleys, crisscross ravines, mountainous areas accounting for 76%, hills accounting for 22%, and flat river valleys accounting for only 2%, with an altitude of 73m~2796m, as shown in Figure 1. With a total area of 82400 square kilometers and a permanent population of 32124300, Chongqing is rainy in summer and autumn and dry in spring and winter. The climate of Chongqing is subtropical monsoon humid climate. It is hot in summer and warm in winter, humid and overcast, with high temperature, long rainy season, less frost and snow, more overcast days and high humidity. The northeast of Chongqing is Daba Mountain, the southeast is Wushan Mountain, Dalou Mountain and other mountains, the middle is mainly low mountains and hills, and the main rivers are Yangtze River, Jialing River, Wujiang River, Fujiang River, Qijiang River, Daning River, Apeng River, Youshui River, etc. The main stream of the Yangtze River runs across the whole territory from west to east, with a length of 665 kilometers, crossing the three anticlines of Wushan Mountain, forming the famous Qutang Gorge, Wuxia Gorge and Xiling Gorge in Hubei, namely the world-famous Three Gorges of the Yangtze River.

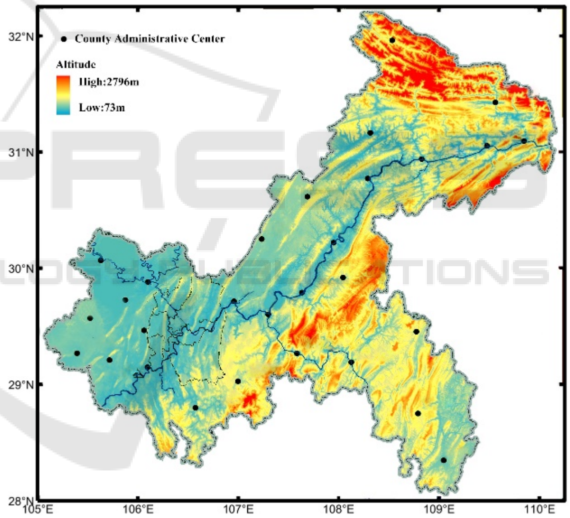

Figure 1: Overview of the study area.

3 DATA AND METHODS

3.1 Data Sources

The satellite gravity data in this paper adopts the RL06 gravity field model (CSR GRACE/GRACE-FO RL06 Mason Solutions (version 02)) of GRACE-FO satellite Level 2 released by the Space Research Center (CSR) of the University of Texas. The highest order is 30, and the resolution of the Mason RL06 data is 0.25 ° × 0.25 °, once a month.

As of June 14, 2022, Mascon RL06 results based on GRACE-FO data have been updated to March 2022. From April 2002 to March 2020, there are 206 periods of data in total (some data are missing).

The historical precipitation data of Chongqing comes from the monthly precipitation data of Chongqing from 1951 to 2021 given by NOAA (National Oceanic and Atmospheric Administration of the United States).

The data of groundwater resources in Chongqing in 2015 comes from the national science and technology basic conditions platform - national earth system science data sharing platform - southwest mountain data resource point (http://www.geodata.cn).

The population data of all districts and counties in Chongqing by the end of 2020 are from Chongqing Statistical Yearbook issued by Chongqing Municipal Bureau of Statistics in 2021.

3.2 Research Method

3.2.1 Mason Method

In this paper, Mason method is used to divide the study area into regular grids. Based on the same quality change of each grid data, the functional relationship between point quality change and observation value in the grid area is established, and the impact of quality change in different regions on gravity field change is separated, so that the surface quality change can be inversely obtained. For the elastic earth model, Wahr et al. proposed in 1998 that the change of spherical harmonic coefficient of gravitational potential and the change of load on the earth's surface (Wahr J et al.,1998), as shown in equation (1),

$$\Delta\sigma(\theta,\phi)=\frac{a\rho_{ave}}{3}\sum_{l=0}^{L}\sum_{m=0}^{l}\frac{2l+1}{1+k_l}\times \left[\Delta C_{lm}\cos m\phi+\Delta S_{lm}\sin m\phi\right]P_{lm}(\cos\theta) \tag{1}$$

Where, a is the average radius of the earth, ρ_{ave} is the average density of the earth, $P_{lm}(\cos\theta)$ is a fully normalized associated Legendre polynomial, l、m is respectively the order and number of spherical harmonic expansion, L is the maximum order of spherical harmonic coefficient expansion, k_l is the Leff number of the Lth order load, θ、ϕ is respectively the complementary latitude and longitude, ΔC_{lm} and ΔS_{lm} is the normalized variation of gravitational potential coefficient, which is often used to express the surface quality anomaly in the form of equivalent water height (EWT). Therefore, GRACE gravity satellite can be used to retrieve the changes of land water reserves.

3.2.2 Gaussian Smoothing Method

Gaussian smoothing is an image smoothing filter, which uses normal distribution to calculate the transformation of each pixel in the image. (Guo J Y et al.,2010). The definition on the 2D plane is

$$G(u,v)=\frac{1}{2\pi\sigma^2}e^{-(u^2+v^2)/(2\sigma^2)} \tag{2}$$

Where, (u,v) is the coordinate of the relative center point and σ is the standard deviation. The template coefficient of the Gaussian filter can be obtained by discretizing the Gaussian function. In this paper, because the Mason data of GRACE-FO has a resolution of 0.25 °×0.25 ° grid, Gaussian smoothing can better refine the equivalent water height distribution of land water reserves, especially for the junction area of the grid.

4 RESULTS AND ANALYSIS

4.1 Analysis of the Temporal and Spatial Characteristics of Land Water Reserves in Chongqing

In this paper, the data of the RL06 gravity field model (CSR GRACE/GRACE-FO RL06 Mason Solutions (version 02)) of GRACE-FO satellite Level 2 are processed by MATLAB. Based on the land water reserve data of the past three years, the equivalent water height of Chongqing's monthly average land water reserves is obtained by month average, as shown in Figure 2. After fitting, it can be seen that the land water reserves reached the peak in December, increased gradually in July December, and decreased gradually in January June. Then the land water reserves from July to June of the next year follow the normal distribution, and its axis of symmetry is in December. Through linear fitting, the change trend of equivalent water height of Chongqing's land water reserves from July to December is 1.2mm/mon, and from January to June is -0.9mm/mon. Figure 3 shows the monthly variation of equivalent water height of land water reserves in Chongqing from 2002 to 2022. After linear fitting, it is found that the overall trend is upward, with a variation trend of 0.8mm/a.

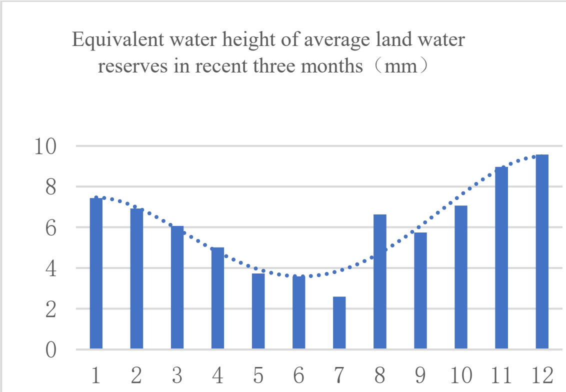

Figure 2: Equivalent water height of monthly average land water reserves in Chongqing

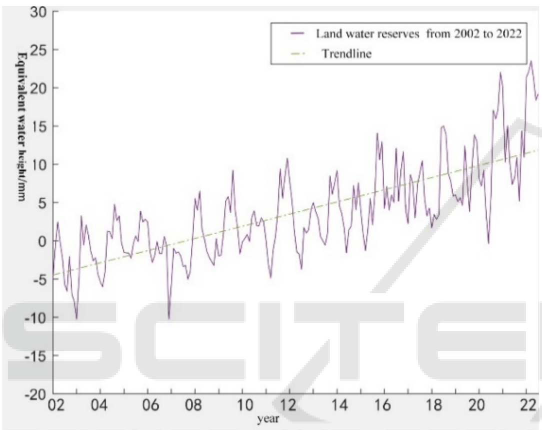

Figure 3: Equivalent water height of land water reserves in Chongqing in recent 20 years.

4.2 Analysis of the Temporal and Spatial Characteristics of Land Water Reserves in Chongqing

Based on the monthly precipitation data of Chongqing from 1951 to 2021 given by NOAA (National Oceanic and Atmospheric Administration of the United States), the distribution of precipitation in Chongqing in the past 70 years is plotted as shown in Figure 4. It can be seen that the precipitation distribution is normal, the peak appears in July, and the precipitation is concentrated in June August. In order to analyze the relationship between Chongqing's land water reserves and precipitation, it is obvious that, compared with the precipitation data, There is a negative correlation between land water reserves and precipitation. Based on the correlation analysis between the monthly equivalent water height retrieved from GRACE land water reserves in Figure 3 and the monthly precipitation data in recent two years, the correlation coefficient is -0.76, and the precipitation in August is significantly lower than that in July and September, which is synchronous with the increase of land water reserves. After the water on the earth is irradiated by the sunlight, it evaporates into water vapor into the air. When the water vapor encounters cold air at high altitude, it condenses into small water droplets and falls from the air, forming precipitation. The reason is that there is a lot of precipitation in summer, indicating that there is a lot of water on the surface evaporating into the air, resulting in less land water reserves. In the dry and rainy winter, due to the temperature, the water evaporation is low, and there is less water vapor in the air, so the land water reserves are large.

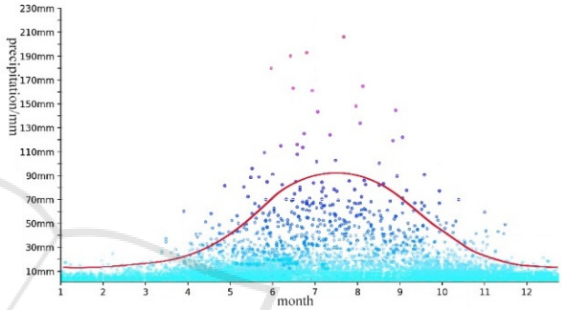

Figure 4: Precipitation statistics of Chongqing in recent 70 years.

Figure 5 shows the spatial distribution map of land water reserves in Chongqing in 2021 by month. From the perspective of space, the seasonal variation of land water reserves in the northeast of Chongqing is not very different, while the land water reserves in other regions of Chongqing are quite different. The water reserves are low in March July and high in October December. From the negative correlation between precipitation and land water reserves, it is known that the precipitation frequency in the northeast of Chongqing is high, and the monthly precipitation is not different, The precipitation in other regions is seasonal, while the northeast is dominated by mountains, indicating that the rainfall frequency is higher in mountain areas with higher altitude, which is consistent with the conclusion that Fang Dexian et al. obtained higher rainfall frequency in mountain areas with high altitude using the rainfall data of the National Meteorological Information Center from 2008 to 2016.

4.3 Relationship Between Land Water Reserves and Population Density

After averaging the equivalent water height data of land water reserves retrieved from the GRACE-FO

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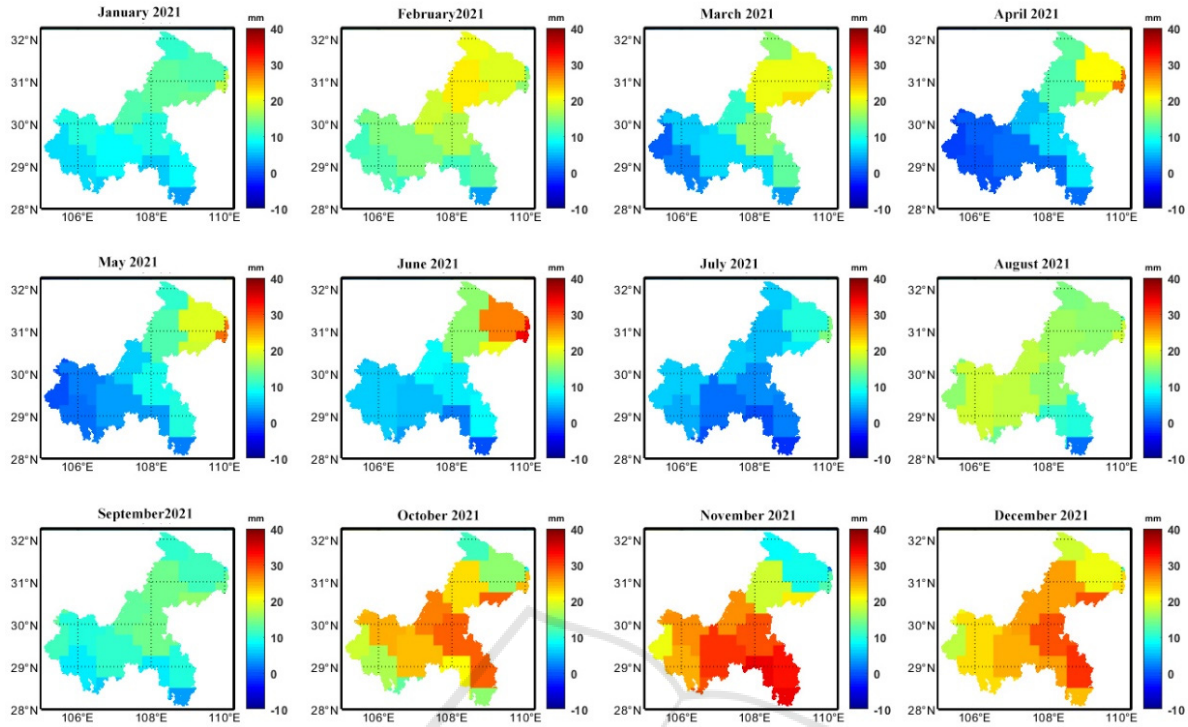

Figure 5: Land water reserves of Chongqing in 2021

gravity satellite data of Chongqing in the last two years, the distribution of land water reserves in Chongqing is obtained. Since the resolution of GRACE-FO gravity satellite data is 0.25 ° × 0.25 ° grid distribution. After smoothing the grid data with the Gaussian smoothing method, the distribution of land water reserves in Chongqing is shown in Figure 6.

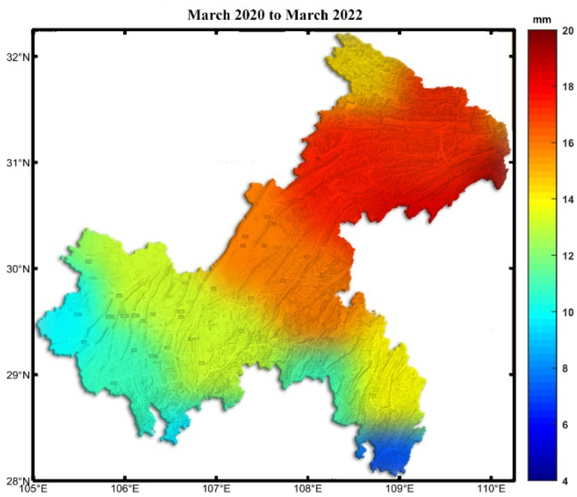

Figure 6: Average equivalent water height of land water reserves in Chongqing.

The population density distribution map of Chongqing is shown in Figure 7. It can be seen from Figure 1 and Figure 7 that the southeast and northeast regions are mainly mountainous regions with high altitude, and the middle regions are mainly hilly regions, The terrain is relatively low, and the population distribution is related to this. It is concentrated in the middle of the lower terrain and distributed along the Yangtze River basin. Chongqing has more land water reserves in the northeast and southeast, while the land water reserves in the central and western regions are less. Therefore, it can be seen that due to the impact of human activities, the land water reserves have had a certain impact, and the densely populated areas have less water reserves.

4.4 Verification of Land Water Reserves Retrieved by GRACE-FO Satellite

Figure 8 shows the amount of groundwater resources in Chongqing in 2015. The data comes from the National Science and Technology Infrastructure Platform - National Earth System Science Data Sharing Platform - Southwest Mountain Data Resource Point. As shown in Figure 6, Chongqing's

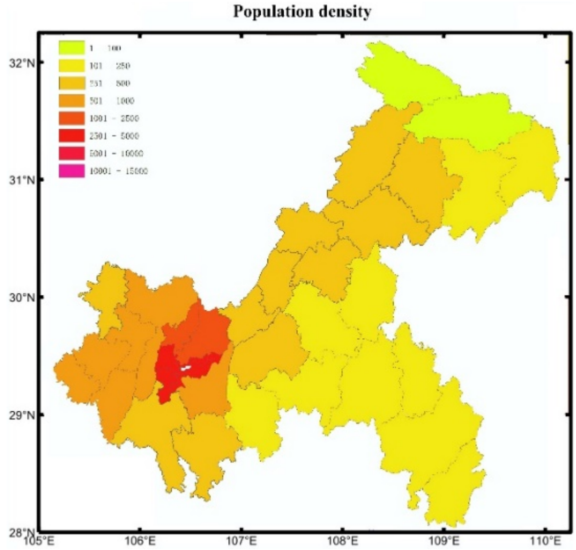

Figure 7: Population density distribution map of Chongqing in 2020.

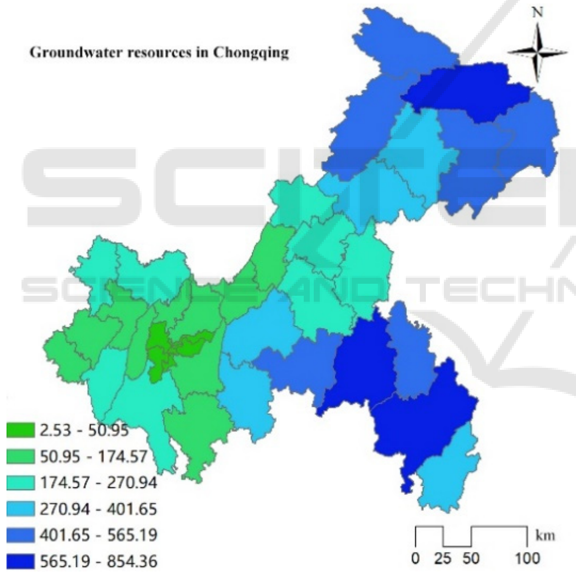

Figure 8: Population density distribution map of Chongqing in 2020.

land water reserves in recent two years are more in the northeast and southeast, while the land water reserves in the central and western regions are less, consistent with the data of known conclusions, It shows that GRACE-FO gravity satellite can well reverse the land water reserve data, and has certain reliability.

5 CONCLUSIONS

In this paper, Chongqing is taken as the research area. Based on GRACE-FO gravity satellite data, the land water reserve changes of Chongqing from 2002 to 2022 are retrieved. The temporal and spatial characteristics of land water reserve changes in Chongqing are analyzed. The relationship between land water reserves and precipitation is analyzed by combining Chongqing precipitation data, and the relationship between land water reserves and population density is analyzed by combining Chongqing population data. The following conclusions are obtained:

Using the RL06 gravity field model data of GRACE-FO satellite Level 2 to retrieve the land water reserves data of Chongqing in recent three years, the land water reserves show obvious seasonal changes, reaching the peak in December, increasing gradually from July to December, and decreasing gradually from January to June. Through linear fitting, the change trend of equivalent water height of Chongqing's land water reserves from July to December is 1.2mm/mon, and from January to June is -0.9mm/mon. The monthly variation of equivalent water height of land water reserves in Chongqing from 2002 to 2022 shows a rising trend after linear fitting, with a variation trend of 0.8mm/a.

There is a negative correlation between land water reserves and precipitation in Chongqing, with a correlation coefficient of -0.76. The precipitation frequency in the northeast of Chongqing is high, with little difference in monthly rainfall. The precipitation in other regions is seasonal, while the northeast is dominated by mountains, indicating that the rainfall frequency in mountainous areas with higher altitude is high.

The land water reserves in Chongqing are also related to the terrain and population density. The water reserves in the north and southeast mountain areas are high. Due to the impact of human activities, the water reserves in densely populated areas in the southwest are low.

The land water reserves of Chongqing are more in the northeast and southeast, while the land water reserves in the central and western regions are less. The comparison with the county spatial distribution data of groundwater resources in 2015 shows that the GRACE-FO gravity satellite can better reflect the land water reserves data of small regions, with certain reliability and wider use value.

It is suggested to strengthen the research on the refined algorithm of gravity data model in small areas in the follow-up work

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