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World Water Congress
International Water Resources Association (IWRA)

Strategy for evaluating groundwater resource quantity under freeze/thaw in mountainous areas

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Water for All
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第18届
世界水资源大会
水与万物：
人与自然和谐共生

Content

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- Method for calculating groundwater resource quantity
- Division of calculation units and calculation periods
- Calculation of groundwater resource quantity

Method for calculating groundwater resource quantity

- **Difficulties and challenges in calculating groundwater resources in freeze-thaw mountainous areas in three aspects:**
  - The heterogeneity of groundwater spatial distribution
  - Effect of freeze-thaw process on time allocation of groundwater resources
  - The degree of hydrogeological work is low

- **Previous research method**
  - **Groundwater Calculation Unit (GCU):** according to the lithologic characteristics (mainly based on the idea of a groundwater water-bearing system)
  - **Groundwater Calculation Period (GCP):** one hydrological year is usually used as the basic period
  - **Calculation method:** groundwater discharge

- **Problem:**
  - A groundwater water-bearing system may span multiple groundwater flow systems, and can not reflect the difference in groundwater spatial distribution.
  - The commonly used period division method neglects the effect of seasonal freeze/thaw on the temporal variation of groundwater resource quantity in mountainous areas.

Method for calculating groundwater resource quantity

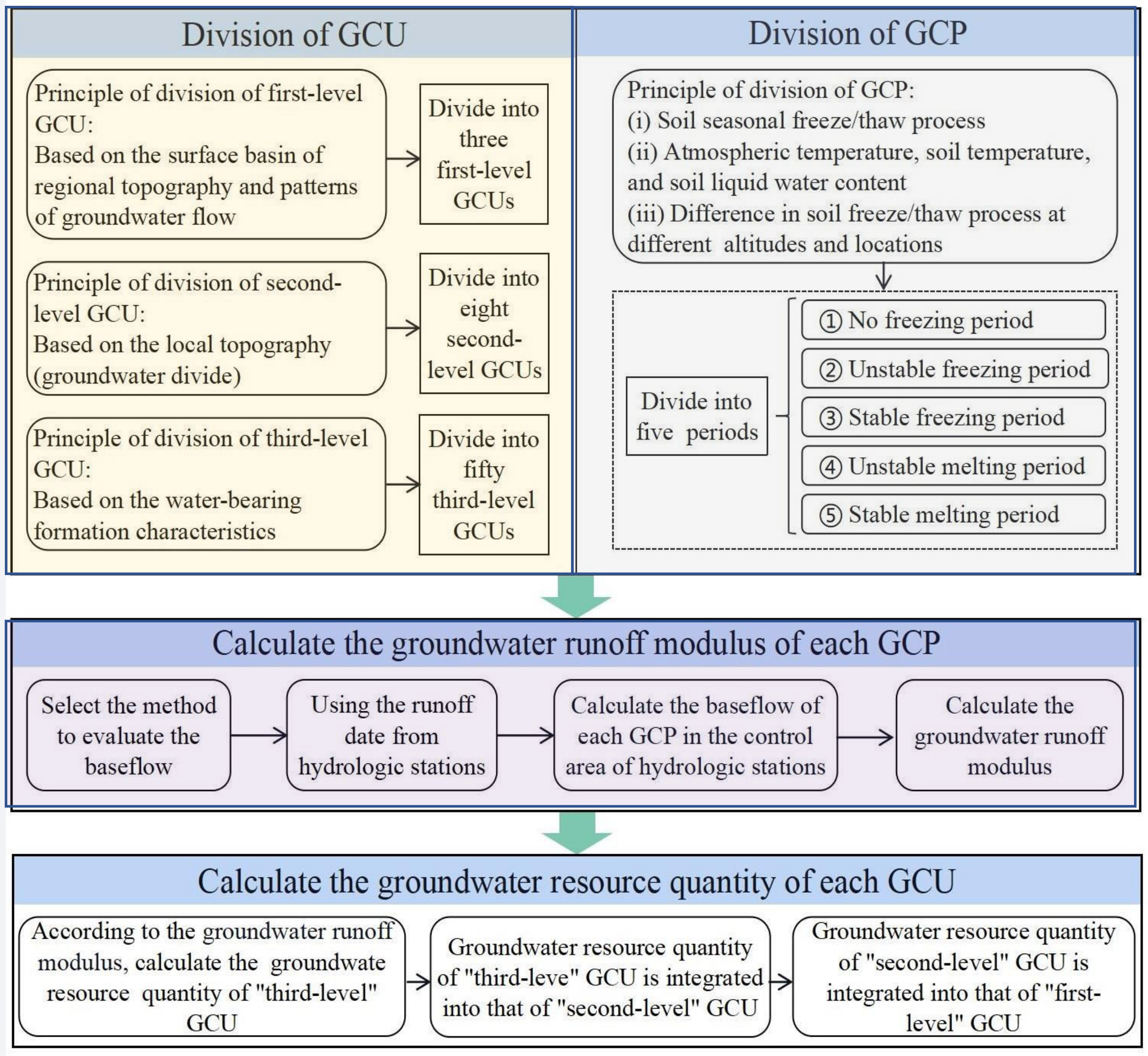
Method of this study

- **Calculation units(GCU)：** Based on the concept of the groundwater flow system along with hydrogeological unit characteristics
- **Calculation periods(GCP)：** It was conducted on the basis of the influence of the soil freeze/thaw process on the temporal distribution of groundwater resource quantity.

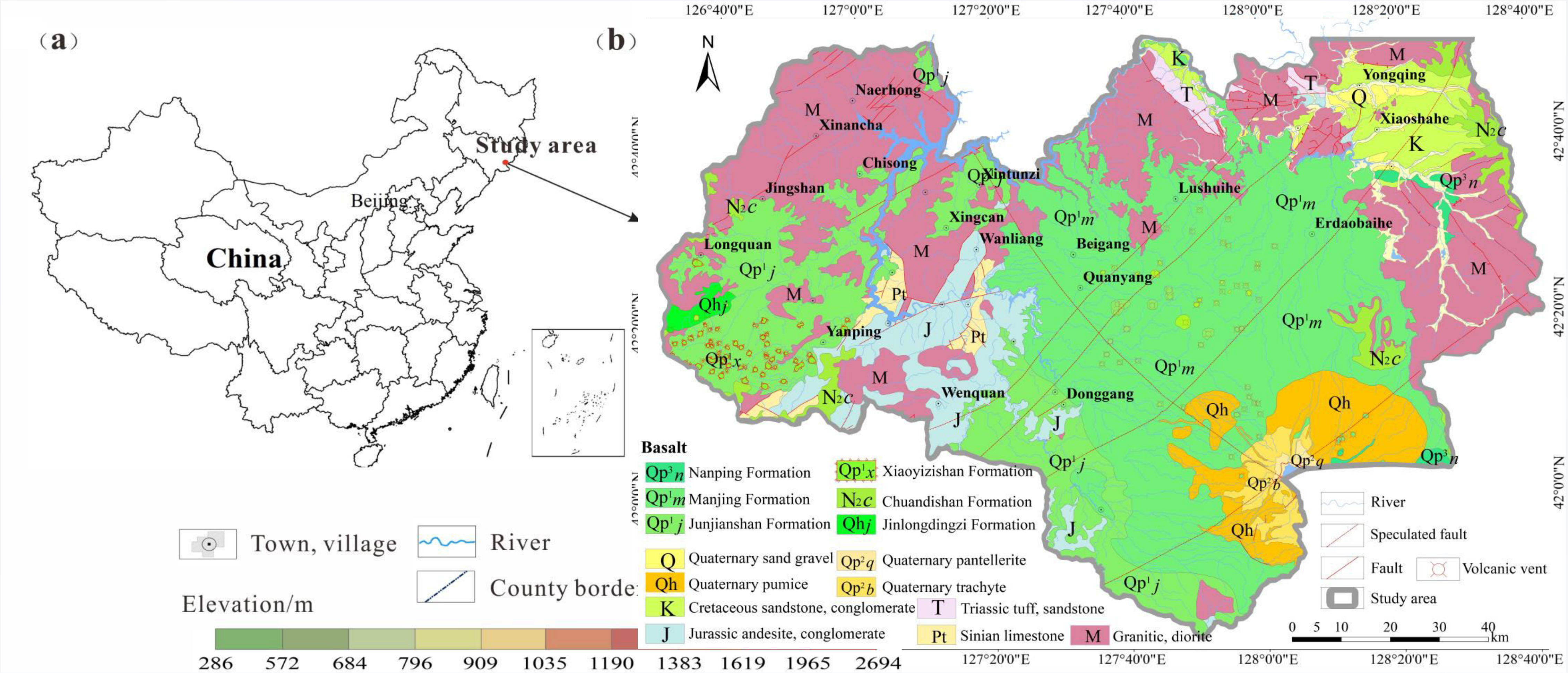
The groundwater flow system is taken as the spatial scale

Take the freeze/thaw period as the time scale

Precise characterization of the spatiotemporal distribution of groundwater resources



Division of calculation units and calculation periods



The Changbai Mountains, located in southeast Jilin Province, China, experience seasonal freeze/thaw process.

The basalt caprock is widely exposed in the study area; it has resulted in the formation of a step-like platform landform, thus forming the volcanic lava low and high platforms.

Division of calculation units and calculation periods

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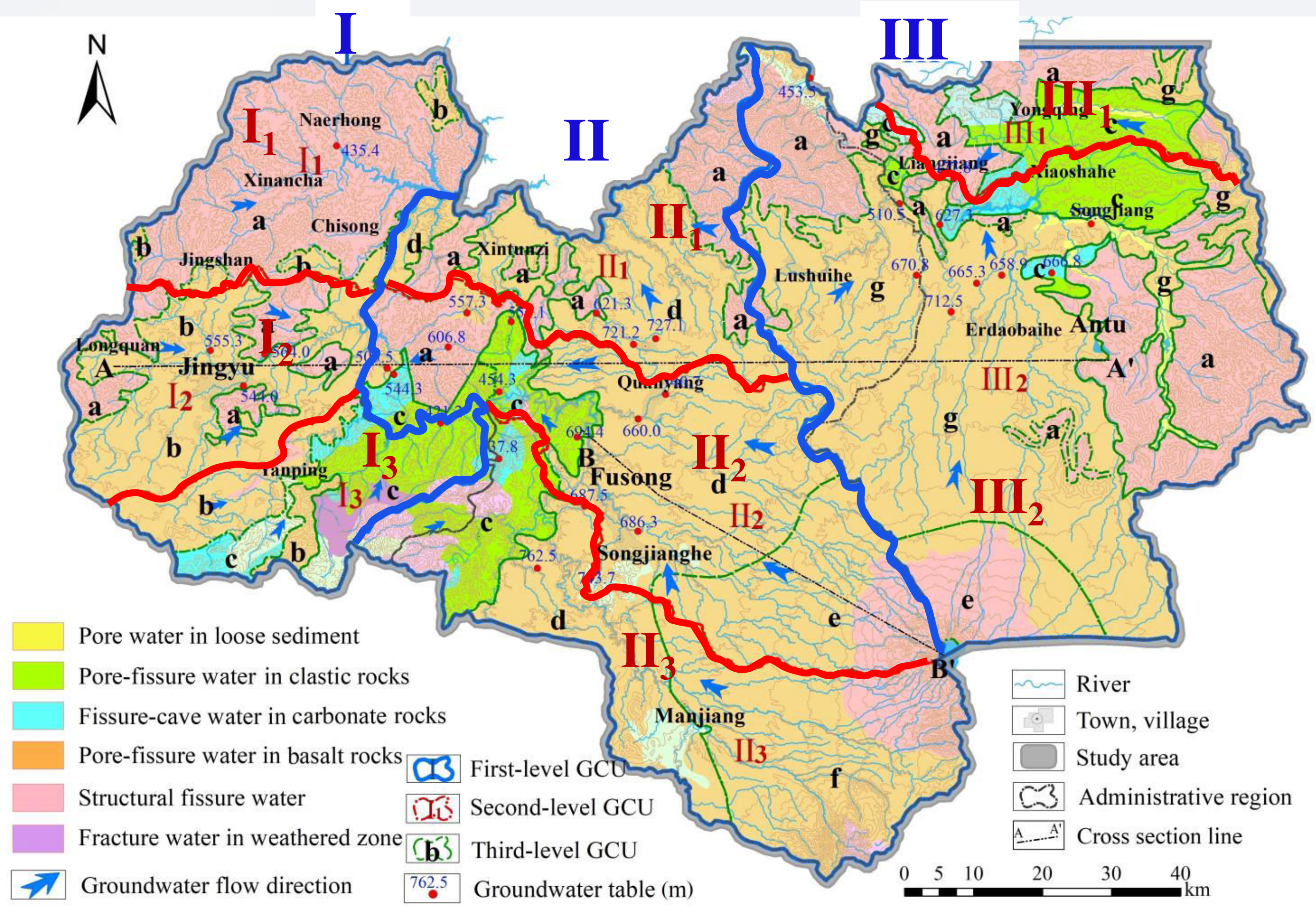
■ Calculation units (GCU)



Division of groundwater resource quantity calculation unit (GCU)

- The controlling effect of surface watershed on groundwater.
- The groundwater watershed is the same as the corresponding surface watershed.

- Topography
- lithology
- Geological structure

3 first-level GCUs
8 second-level GCUs
50 third-level GCUs

Division of calculation units and calculation periods

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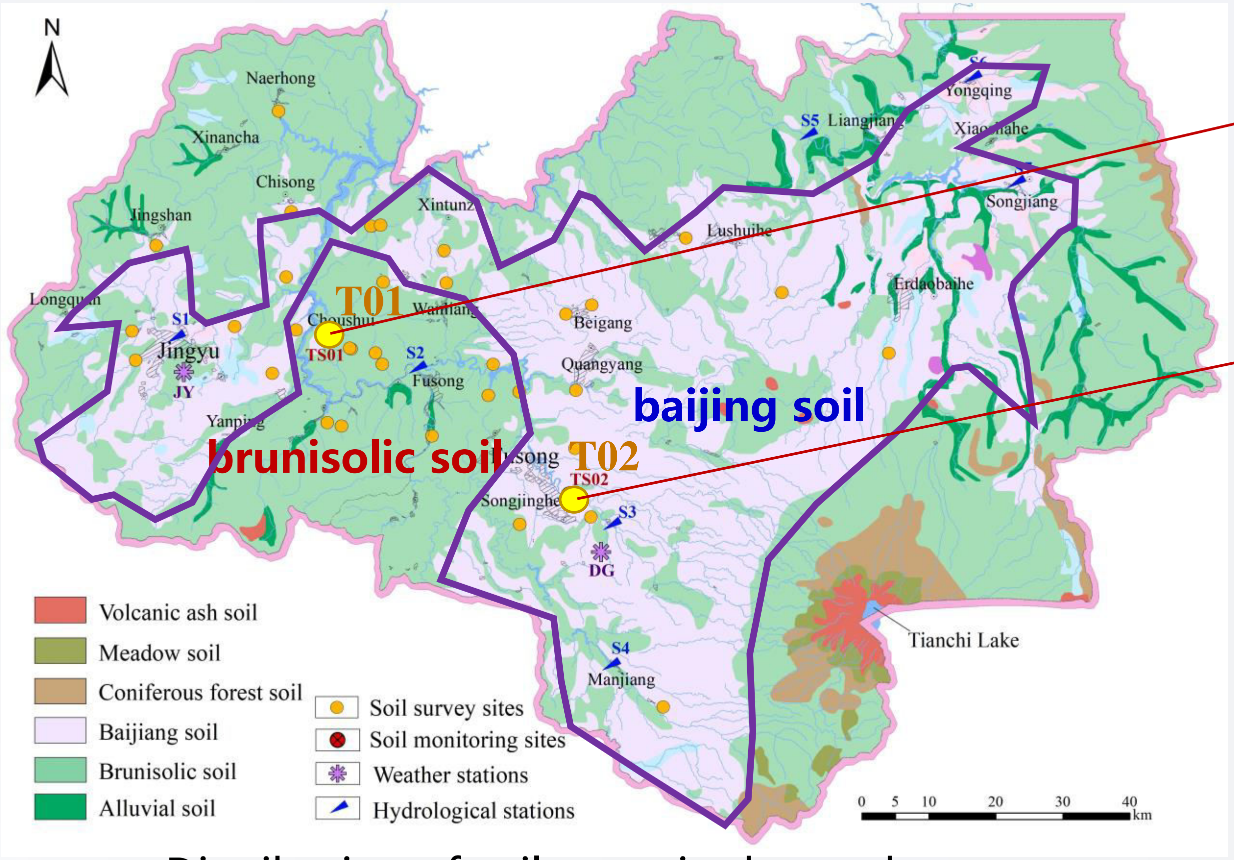
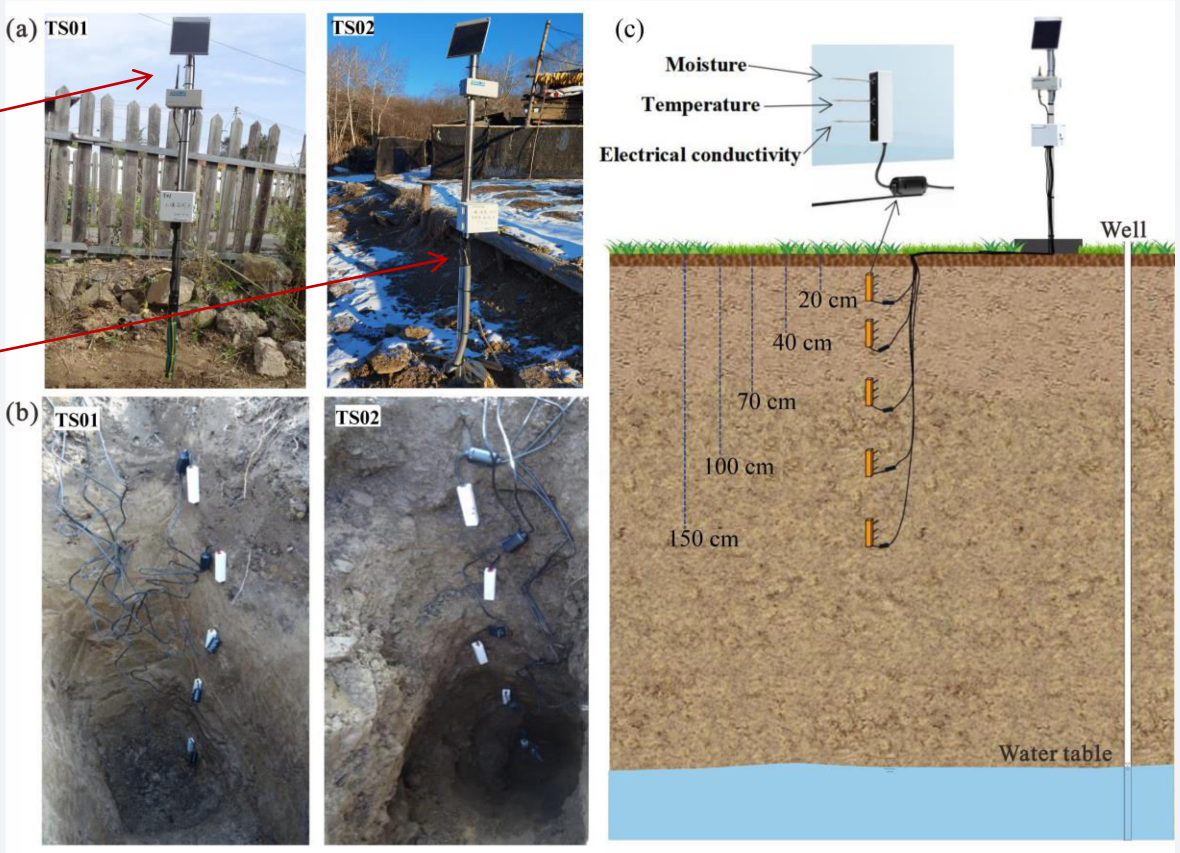
■ **Calculation periods (GCP)** was conducted on the basis of the influence of the soil freeze/thaw



Distribution of soil types in the study area



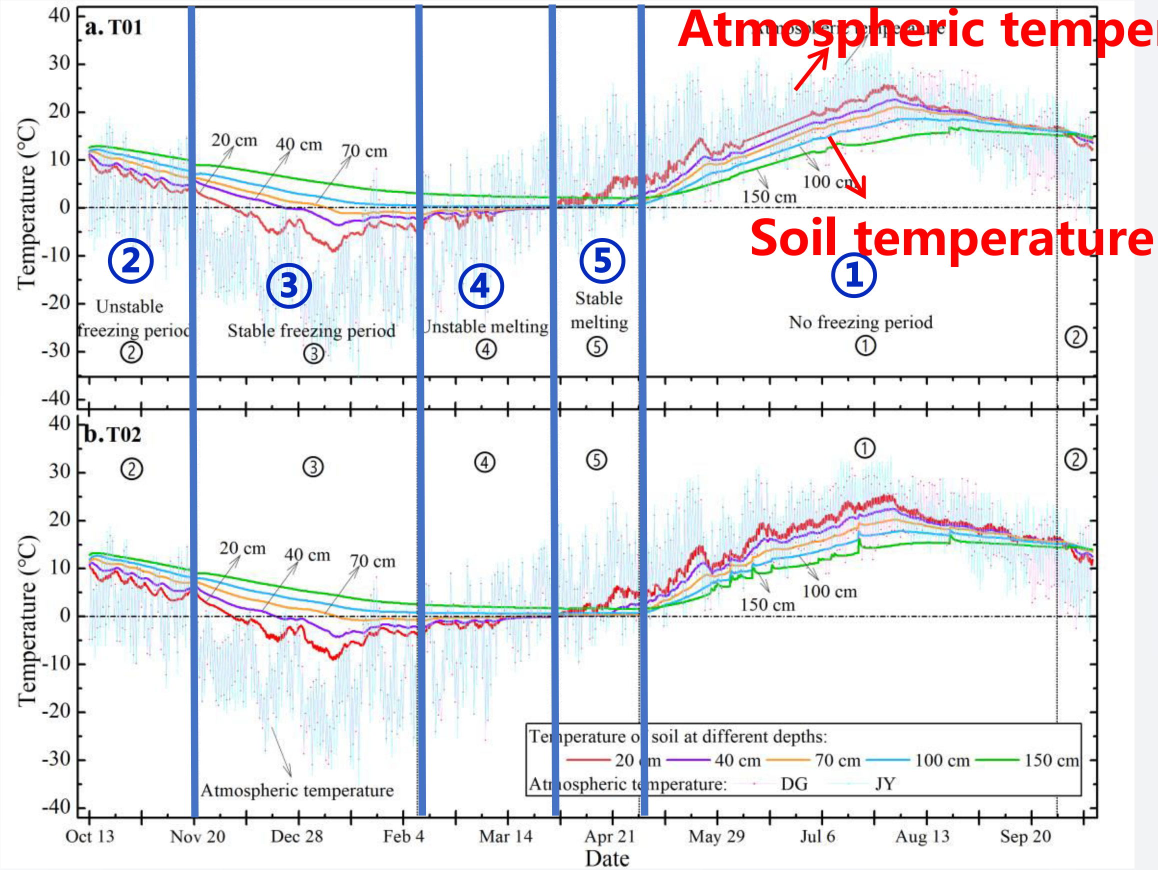
To obtain real-time soil temperature and liquid water content data for describing the freeze/thaw process of soil

⇨

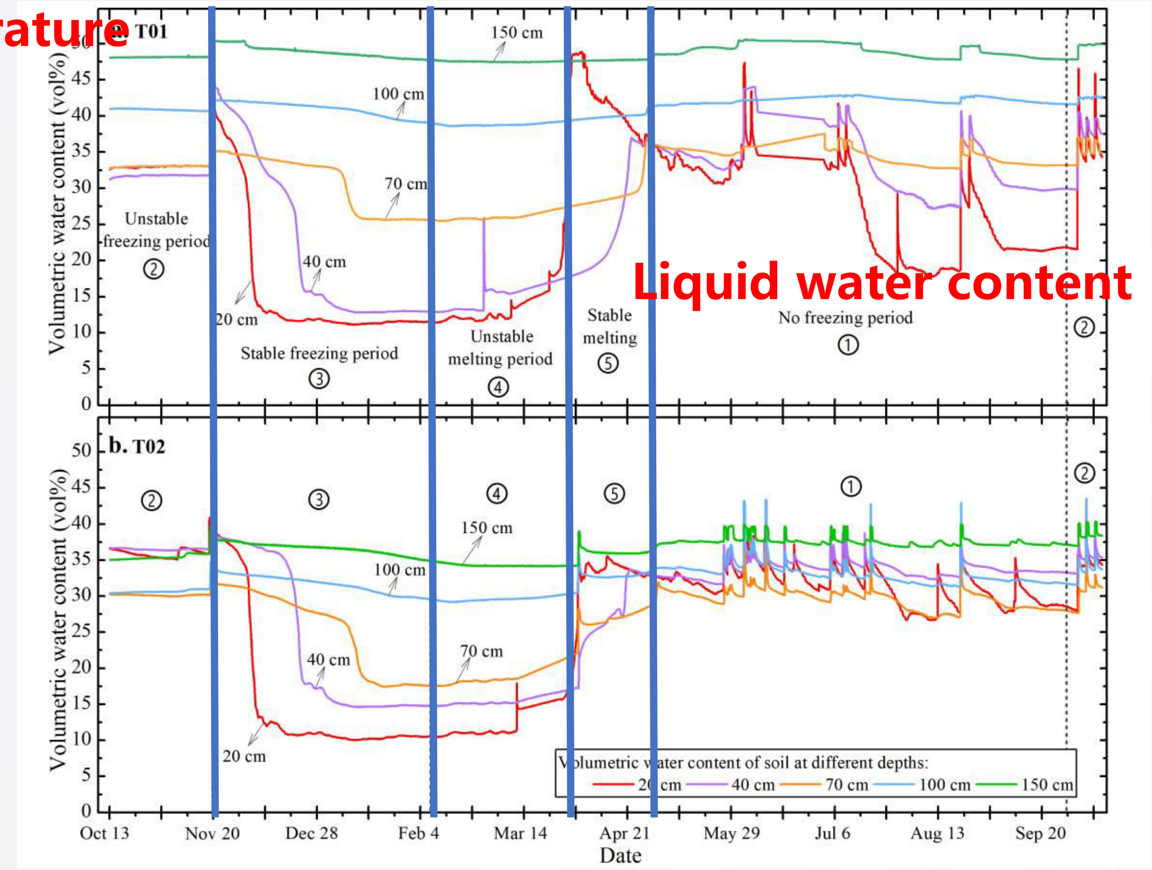
Two real-time soil monitors were deployed in the field. The monitoring depths were set at 20, 40, 70, 100, and 150 cm.

Division of calculation units and calculation periods

■ Calculation periods (GCP)



soil temperature at different depths



soil liquid water content at different depths

Five GCPs were defined

- ① **No freezing period**
- ② **Unstable freezing period**
- ③ **Stable freezing period**
- ④ **Unstable melting period**
- ⑤ **Stable melting period**

Calculation of groundwater resource quantity

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The present field survey and previous studies in the study area have confirmed that the groundwater in the Changbai Mountains is primarily discharged into surface water rivers in the form of baseflow.

This lays a foundation for the estimation of groundwater resource quantity using the baseflow separation method in this study.

➢ Baseflow —the dual-parameter filtering method (DFM)

$$Q_b(i) = \frac{(1-BFI_{max})\alpha Q_b(i-1) + (1-\alpha)BFI_{max}Q(i)}{1-\alpha BFI_{max}}$$

where α represents the recession index, BFI_{max} represents the maximum baseflow index, i represents the time step, $Q_b(i)$ represents the baseflow at the i^{th} moment (m^3/s), and $Q(i)$ represents the total runoff (m^3/s). Lastly, Q_b represents the corresponding total baseflow amount of each hydrologic station (S1–S7) in the control area.

Hydrographic station

7 hydrologic stations:

daily runoff data from 2006-2016

Calculation of groundwater resource quantity

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Hydrologic station	F_{hydr}(km²)	The groundwater typein third-level GCUs	Partition Code	GRM($10^4 m^3/T \cdot km^2$)				
				Nofreezing period	Unstable freezing period	Stable freezing period	Unstable melting period	Stable melting period
S7	1357	Bedrock fissure water	a	4.09	1.10	0.42	0.11	0.75
S1	457	Jingyu Basalt fissure water	b	6.48	1.70	2.15	0.80	1.05
S6	283	Clastic rock pore-fissure water	c	6.50	1.06	0.42	0.15	0.69
S2-S3-S4	3890	Fusong Basalt fissure water	d	6.70	0.74	1.28	0.84	0.91
S3	253	Songjianghe Basalt fissure water	e	10.73	3.20	4.44	1.74	1.56
S4	582	Manjiang Basalt fissure water	f	9.93	2.00	2.84	1.13	1.34
S5-S6-S7	6892	Antu Basalt fissure water	g	7.27	0.64	0.63	0.31	1.36

➢ Groundwater runoff modulus (GRM) method

$$GRM_{third\text{-}level} = Q_b(\mathrm{T})/F_{\mathrm{hydr}}$$

$$Q_{\mathrm{g},third\text{-}level} = F_{third\text{-}level} \cdot GRM_{third\text{-}level}$$

where Q_b(T) represents the baseflow of each GCP (m³/T), $GRM_{third\text{-}level}$ represents the groundwater runoff modulus in the third-level GCU ($m^3/T \cdot km^2$), F_{hydr} represents the control area of the hydrologic station (km²), $Q_{g,third\text{-}level}$ represents the groundwater resource quantity of the third-level GCU at each GCP (m³/T), $F_{third\text{-}level}$ represents the area of the third-level GCU (km²), and T represents the number of days of the GCP.

- **On this basis, the groundwater runoff modulus (GRM) of the watershed is calculated. For watersheds without hydrologic station control, the analogy watershed which has hydrologic station, were determined by comparing the topographic and hydrogeological conditions. Then, the groundwater resource quantity in the watershed without hydrologic station control is calculated.**

Calculation of groundwater resource quantity

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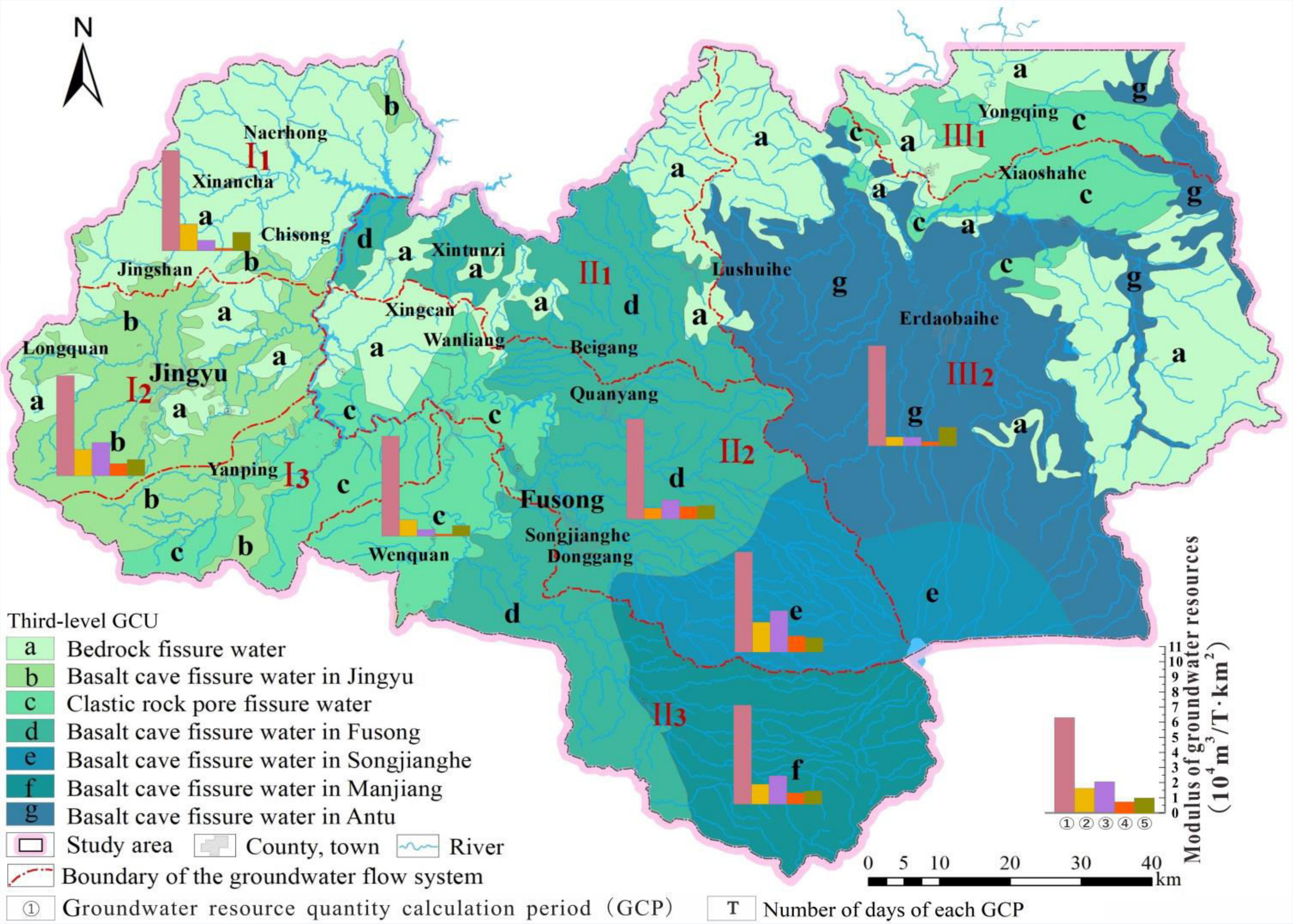
➢ Groundwater runoff modulus in different hydrologic stations



According to the division of the third-level GCUs, the **GRM** of the 50 third-level GCUs was calculated for the five GCPs.

Then, the groundwater resource quantity of the corresponding second-level GCUs was obtained by adding the groundwater resource quantity of all third-level GCUs.

The groundwater resource quantity of the first-level GCUs was determined.

Calculation of groundwater resource quantity

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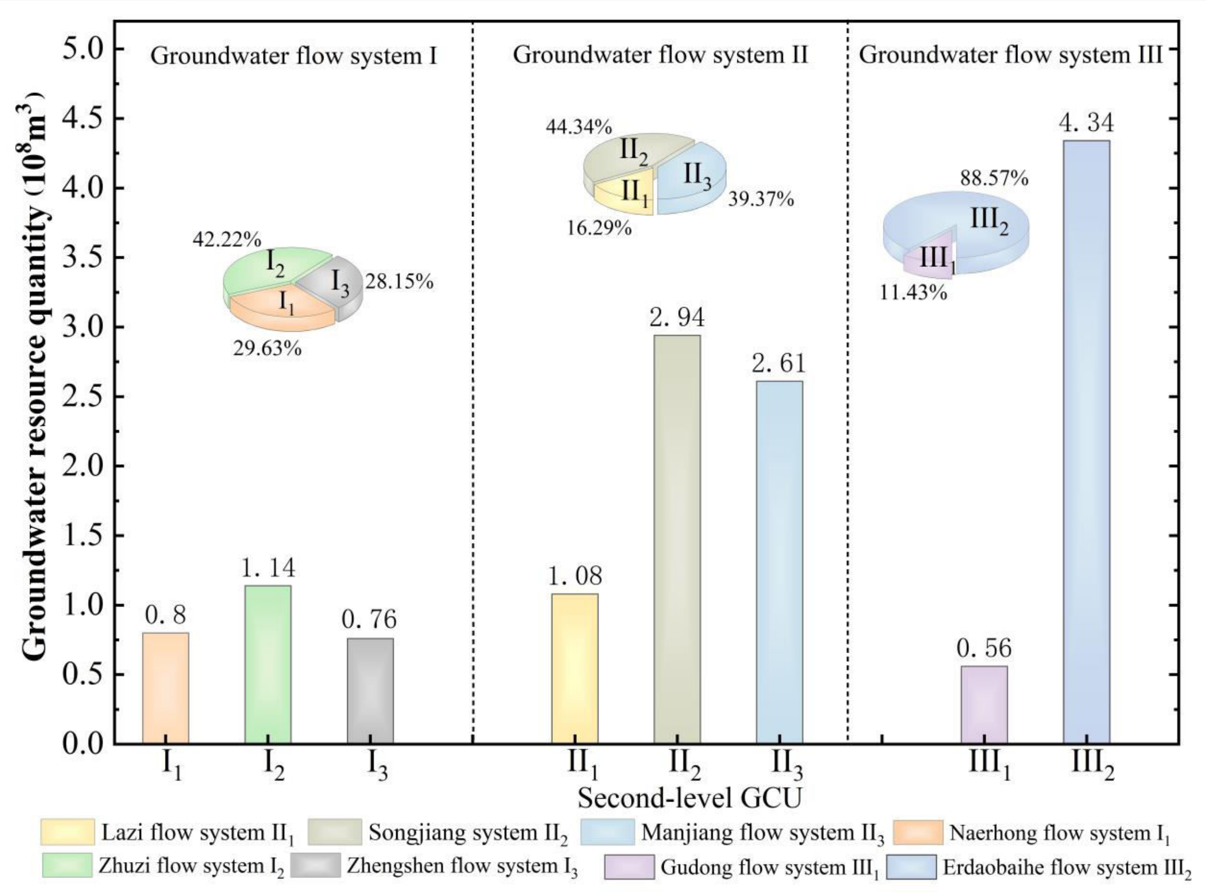
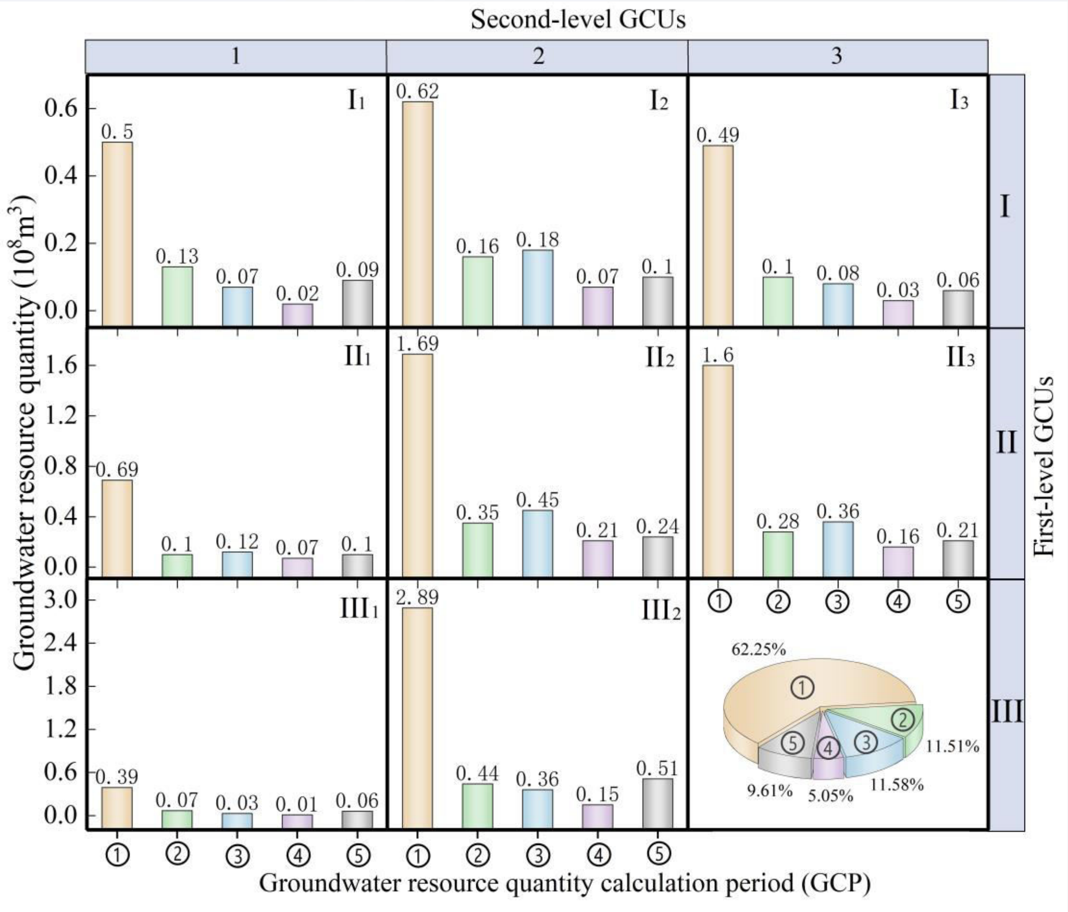
➢ Groundwater resource quantity was $14.24 \times 10^8\ m^3/a$



Spatial distribution of groundwater resource quantity in eight second-level groundwater resource quantity calculation unit (GCU)



Temporal distribution characteristics of groundwater resource quantity in different second-level groundwater resource quantity calculation unit (GCU)

Conclusion

- This study demonstrated that the GCU' s division strategy, based on the groundwater flow system theory, can better express the complexity of hydrogeological conditions in mountainous areas.
- It is necessary to consider the effect of freeze/thaw processes while calculating groundwater resource quantity in mountainous areas. The division of multiple GCPs can effectively express the impact of the freeze/thaw process on groundwater resource quantity.
- Based on the calculation results of total groundwater resource quantity of different GCUs and GCPs and combined with the daily groundwater resource quantity in the different GCUs of the study area, the spatial and temporal distribution map of groundwater resource quantity was developed. The map provides a new basis for planning the exploitation of groundwater resource at different regions and periods of the study area.

Seasonal freeze/thaw mountains are distributed worldwide. The complex terrain and geological conditions of mountainous areas, and the influence of freeze/thaw cycles, make the accurate calculation of groundwater resource quantity in these areas difficult. Considering the Changbai Mountain area of China as an example, this study proposed a new strategy to deal with the calculation of groundwater resource quantity in seasonal freeze/thaw mountainous areas. Our findings can be used as a reference for evaluating groundwater resource quantity in other seasonal freeze/thaw mountainous areas.

THANK YOU FOR LISTENING !

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