Visual Analysis of Remote Sensing Monitoring of Soil Salinization

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Abstract Soil salinization seriously restricts the development of agricultural production, the sustainable use of land resources, and the stability of the ecological environment. In order to objectively reveal the research status of soil salinization, CiteSpace software was used to conduct data mining and quantitative analysis on research papers on soil salinization from 2008 to 2023 in China National Knowledge Infrastructure (CNKI) and Web of science databases. The data sources were transformed into visual graphs by reproducing clustering statistics from aspects such as publication volume, authors, keywords, and publishing institutions. In addition, this paper also combined the actual needs and cutting-edge hotspots in relevant research in China, and proposed and analyzed the limitations and future development trends of soil salinity monitoring research in China. This has important practical significance for comprehensively grasping the current research status of salinization, further clarifying and sorting out the research ideas of salinization monitoring, enriching the remote sensing monitoring methods of saline soil, and solving the actual problems of soil salinization in China.

Key words Soil salinization; Trend research; Remote sensing monitoring; Bibliometric analysis; CiteSpace

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Soil salinization refers to the accumulation of soluble salt in soil due to natural factors such as climate, hydrology, and topography, or human destruction and fragile ecological environment, which leads to soil quality degradation and the formation of saline alkali soil. Soil salinization is a common problem faced by countries all over the world, and it is also one of the main causes of soil desertification and land degradation[1]. It has seriously restricted the production and development of agricultural industry, the sustainable utilization of land resources and the security and stability of ecological environment. Saline soil is a general term for all types of soil negatively affected by saline alkali composition. The unique physical, chemical and biological characteristics of saline soil have many negative effects. These include the reduction of soil fertility and productivity, the reduction of crop yield and harvest, the waste of agricultural resources, the instability of the ecological environment and other secondary hazards[2].

At present, the total area of saline alkali land in the world is 1.1×10^9 hm^2, which is widely distributed in more than 100 countries and regions around the world, and the area of global saline alkali land is increasing year by year. At present, the total area of saline alkali land in China is 3.69×10^7 hm^2, accounting for 4.88% of the total available land area in China[3]. It is mainly distributed in arid and semi-arid areas with arid climate, less rainfall, large soil evaporation, high groundwater level and more soluble salts, as well as coastal areas[4]. At present, the research direction in China has gradually changed from the prevention of soil salinization to how to improve the accuracy and improvement of soil salt monitoring.

In recent years, with the rise of remote sensing monitoring, the research based on remote sensing monitoring of saline alkali land has made many achievements. For example, Zou Jie *et al.* used GPR low-frequency antenna to monitor salt migration in saline soil of drip irrigation cotton field[5]; Dai Yunhao *et al.* extracted and analyzed soil salinization information in Alar reclamation area based on spectral index modeling[6]; Han Wenting *et al.* studied on estimation of soil salt content in farmland based on feature selection and machine learning algorithm[7]. Strengthening the management and utilization of salinized soil, monitoring and identifying accurate salinization information, and mastering the salinization level of regional cultivated land have been important goals for scientists to study and overcome.

In recent years, scholars at home and abroad have carried out a lot of work in remote sensing monitoring of saline alkali soil, which has effectively promoted the development of remote sensing monitoring of saline alkali soil. With the help of CiteSpace software, this paper visually analyzed the research status, research hotspots and development trends at home and abroad, so as to provide a scientific basis for the construction and improvement of remote sensing monitoring system of saline alkali in China.

1 Data sources and research methods

1.1 Data sources The data used in this paper were from CNKI and Web of science database. In CNKI, the search topic of "salt monitoring" was selected through the advanced search function, and the search period was set between 2008 and 2023. Among

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them, "remote sensing" was selected as the secondary theme. After filtering it, 63 valid papers were obtained. In the Web of science database, "salinity monitoring" was selected as the search topic, and the search period was set between 2008 and 2023. Among them, "remote sensing" was selected as the secondary theme, and 914 valid papers were obtained. 200 papers in different years were randomly selected for analysis.

1.2 Research methods CiteSpace was used to analyze data, and it was first necessary to establish a local copy of the literature database. Then, the data were imported into CiteSpace software, and the analysis parameters were set, such as time range, literature type, keywords, *etc.* CiteSpace converted the data into nodes and edges, which were visually displayed on the screen. The analysis results included many aspects, such as co-occurrence analysis, hot spot analysis, spatio-temporal evolution analysis and co-occurrence analysis of authors.

2 Results and analysis

2.1 Trend analysis of literature quantity Fig. 1 showed the statistics of the number of publications of relevant research literatures in the field of remote sensing monitoring of salinization in CNKI and WOS database from 2008 to 2023. The amount of literature published can represent the attention of the academic community to this field to a certain extent, and its change trend reflects the development speed and degree of this field[8].

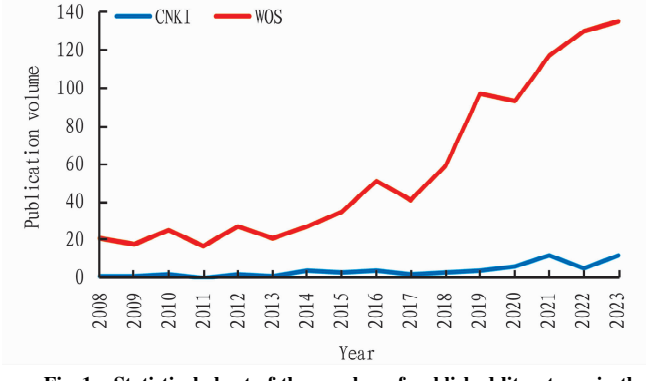

Fig. 1 Statistical chart of the number of published literatures in the field of remote sensing monitoring of salinization in CNKI and WOS database from 2008 to 2023

As can be seen from Fig. 1, the research in the field of remote sensing monitoring of salinization can be divided into three periods, and the nodes were 2008, 2014 and 2019 respectively.

The first period (2008 – 2014): the papers in CNKI and WOS database were in a small and slow growth stage, the research in the field of remote sensing monitoring of salinization was still in its infancy, and the monitoring of soil salt was still in the field survey stage[9].

The second period (2014 – 2019): vigorous development in the field of remote sensing monitoring of salinization was in this period, which was characterized by a steady increase in the number of documents issued each year and a rapid growth. This showed that remote sensing monitoring of salinization was gradually concerned, valued and developed by scholars at home and abroad.

The third period (2019 – 2023): since 2019, although the number of papers in CNKI and WOS database was large, the growth was slower than the previous stage, and even in 2022, the papers in CNKI showed a negative growth trend. Combined with the social environment at home and abroad at that time, it may be due to the difficulty of field sampling caused by the new crown epidemic and the lack of data to verify the experimental conclusion.

With the passage of time, the method of salinization monitoring has gradually changed from field exploration to remote sensing monitoring, and the focus is on remote sensing monitoring. It reflects the progress of science and technology, and remote sensing monitoring is more convenient and accurate than traditional exploration.

2.2 Analysis of core authors and cooperation Fig. 2 showed the co-occurrence network map of main authors in the research field of remote sensing monitoring of salinization in CNKI from 2008 to 2023. It can be seen from Fig. 2 that few authors have published papers in the literature studied. From the perspective of the collaborative relationship between authors, there was less cross cooperation among the authors centered on Guan Yao, and there was little correlation between other authors. These key words provided a strong basis for us to understand the soil salt monitoring methods at home and abroad. It can be concluded that in recent years, articles on "remote sensing" in CNKI database and WOS database have occupied the mainstream and become the research focus of researchers.

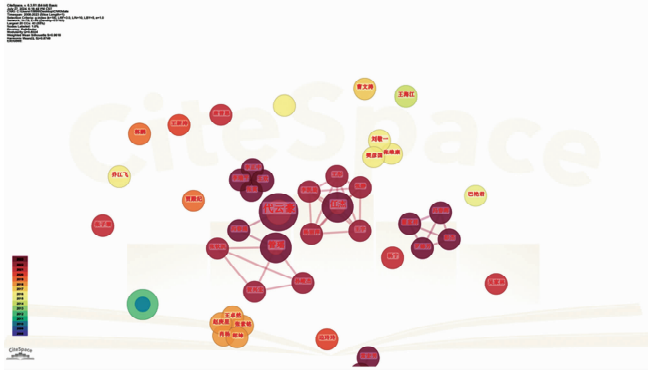

Fig. 2 Co-occurrence network atlas of main authors in the field of remote sensing monitoring of salinization in CNKI from 2008 to 2023

Fig. 3 showed the co-occurrence network map of major authors in the field of remote sensing monitoring of salinization in WOS from 2008 to 2023. It can be seen from Fig. 3 that in the literature studied, the cooperation among authors was more frequent, which was different from the situation in CNKI.

In the future scientific research and creation, it is suggested that researchers can increase exchanges and cooperation and share their ideas with each other, which is also conducive to the development of remote sensing monitoring of salinization.

By summarizing the research of a large number of researchers at home and abroad in recent years, it can be found that the research on the classification and extraction of salinity information

using satellite remote sensing data or the retrieval of soil salinity information using multispectral index is further in-depth[10]. At the same time, more and more researchers have begun to pay attention to the integration and application of different observation elements, different scales and different data.

Fig. 3 Co-occurrence network map of main authors in the field of remote sensing monitoring of salinization in WOS database from 2008 to 2023

2.3 Analysis of research hotspots

2.3.1 Keywords co-occurrence analysis. The keywords of literature can reflect the main core content of literature research, and its relevance can explain the internal relationship of knowledge in the subject field to a certain extent[11]. CiteSpace software was used to analyze the keywords of highly relevant literatures in recent years. Fig. 4 showed the keyword co-occurrence analysis of relevant research articles in CNKI database. The analysis showed that the node framework composed of "soil salinity", "remote sensing inversion", "spectral index" and "saline soil" has higher frequency and stronger correlation in the research papers published in CNKI database. Fig. 5 was the keyword co-occurrence analysis chart based on relevant international research articles in the WOS database. The analysis showed that in the WOS database, the node frames of "soil salinity", "model", "spatial distribution", "remote sensing" and "salinization" appeared more frequently and had stronger correlation.

These keywords provide a strong basis for us to understand the soil salt monitoring methods at home and abroad. It can be concluded that in recent years, articles on "remote sensing" in CNKI database and WOS database have occupied the mainstream and become the research focus of researchers.

Based on the above three periods, this paper made an in-depth analysis of Fig. 4 and Fig. 5. ① In the first period, the literature at home and abroad mainly focused on field exploration for salinization monitoring, and there was a small amount of remote sensing monitoring research, which belonged to the stage of theoretical research and practical exploration. Ha Xueping[12] proposed using remote sensing to build a model for long-term monitoring of salinized soil. Wu Jingwei *et al.* [13] compared remote sensing monitoring with traditional monitoring, and concluded that the accuracy of remote sensing monitoring of soil salt was higher, indicating that remote sensing was a useful tool for soil salt detection and soil salt change monitoring. ② In the second period, the literature at home and abroad mainly focused on remote sensing monitoring of soil salinization, which belonged to the period of practical application. Li Jing *et al.* [14-16] used remote sensing to dynamically monitor salinized soil, which greatly improved the efficiency of salinization monitoring. ③ The third period belonged to the period of practice and innovation. The literature was basically the same as that in the previous period, but there were other studies on remote sensing data acquisition. Chen Junying *et al.* [17] used soil salinization monitoring method based on UAV satellite remote sensing upscaling. Hu Jie *et al.* [18] conducted quantitative estimation of soil salinity based on UAV hyperspectral and satellite multispectral images, and new methods based on UAV are gradually emerging.

Through the analysis of the literature information in these three periods, it was found that the center of each period was the improvement of salinization monitoring methods, which was a process from theory to practice, from practice to innovation, and continued to deepen.

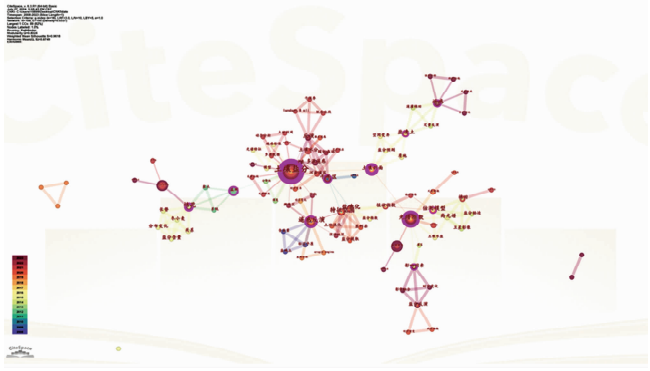

Fig. 4 Keyword co-occurrence analysis chart based on related research articles in CNKI database

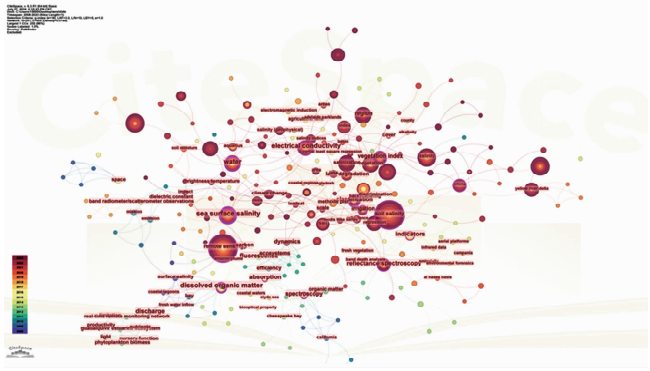

Fig. 5 Keyword co-occurrence analysis chart based on related research articles in WOS database

2.3.2 Keyword clustering analysis. Through the similarity of literature keywords, the literatures in CNKI and WOS database were retrieved. Keyword cluster analysis was performed on the retrieved literatures (Fig. 6 and Fig. 7). Keyword clustering analysis is the process of analyzing keywords extracted from literature into multiple categories composed of similar objects. The higher the ranking of the cluster number, the more keywords the cluster contains. On

the contrary, the more backward the sequence number is, the fewer keywords are included in the cluster. The modular value of clustering index Q ranges from 0 to 1. The higher the value, the better the clustering effect. Generally, when Q is less than 0.3, it indicates that the literature data set structure of the clustering analysis is poor. In Fig. 6, the value of 0.802 4 was obtained by clustering analysis of the literatures in CNKI database. In Fig. 7, a value of 0.785 6 was obtained by clustering the literatures in the WOS database. This shows that the data collected by the Chinese literature database and the international literature database are reliable, and the keyword clustering analysis structure is significant.

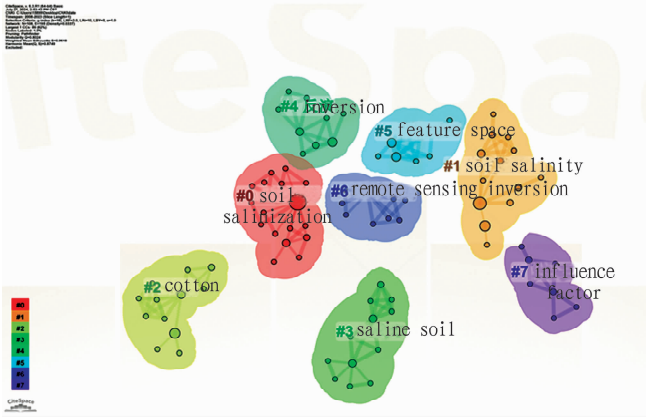

Fig. 6 Keyword clustering mapping based on related literature of soil salt monitoring in CNKI database

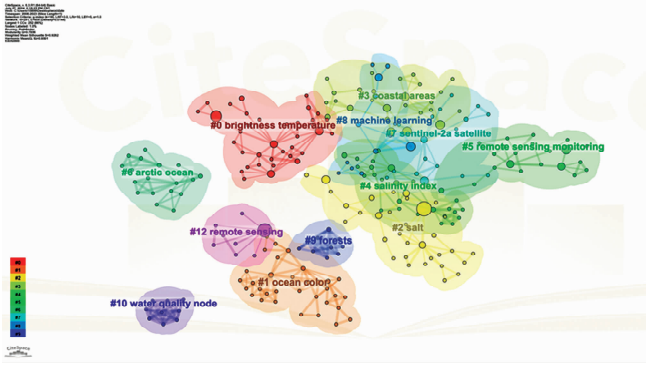

Fig. 7 Keyword clustering mapping based on literature related to soil salinity monitoring in WOS database

The clustering analysis map obtained from the CNKI database had a total of 8 labels, among which the top 6 had 3 related to remote sensing monitoring, namely "feature space", "remote sensing inversion" and "inversion". The clustering analysis map obtained from the WOS database had a total of 12 labels, of which 4 were related to remote sensing, namely remote sensing monitoring, sentinel-2a satellite, machine learning and remote sensing. Based on these methods, researchers have fully utilized advanced remote sensing information technology to promote the development of remote sensing monitoring of salinization.

Through keyword clustering analysis of literature in the field of remote sensing monitoring of salinization in CNKI and WOS databases, it can be concluded that: ① the clustering analysis results of literature keywords in CNKI and WOS databases were basically consistent, indicating that Chinese scholars have conducted comprehensive research in the field of remote sensing monitoring of salinization; ② remote sensing technology is one of the main directions for future research on soil salinization monitoring.

2.4 Study area With the intensification of global warming, the problem of soil salinization in middle and low latitudes will become more and more obvious, especially in China, the United States, Hungary and Australia. The problem of soil salinization in North and East Africa, South America, the Middle East, Central Asia and other regions will become more serious. Global soil salinization hotspots include many Central and West Asian countries, as well as Pakistan, China, the United States, India, Argentina and Sudan. The three main saline alkali areas on earth are the Songnen Plain in China, Victoria in Australia and California in the United States.

China is rich in saline soil resources and has a vast territory. For the study of saline soil in China, many types need to be considered, including coastal saline soil in the eastern low plain, soda saline soil in the Northeast Songnen Plain, oasis saline soil in Xinjiang, muddy saline soil in Hebei plain irrigation area, tidal saline soil in the Huang Huai Hai Plain, alkaline saline soil in the Hexi Corridor, acid sulfate saline soil in the southern coastal area, saline soil in extreme arid areas in Qinghai and Xinjiang.

Saline soil in China is mainly distributed in the arid and semi-arid areas in the north, of which the area of saline alkali cultivated land is 7.6 million hm^2, accounting for 6% of the cultivated land area, which is widely distributed in coastal and inland areas. A large part of this saline alkali land is still undeveloped as reserve land.

Outside China, research fields included the Aral Sea in Central Asia, the Nile River Basin in East Africa, the Mediterranean coast of Europe (affected by factors such as groundwater exploitation and sea-level rise), Western Australia, *etc.*, which were consistent with the most influential countries.

2.5 Evolution of phased research hotspots Fig. 8 showed the prominent keywords in the field of remote sensing monitoring of salinization in CNKI from 2008 to 2023. By utilizing the software's burst detection function and setting a threshold of 0.2, 13 burst words were obtained. Compared to traditional high-frequency keyword analysis, emergent primary secondary analysis is more suitable for exploring emerging trends and hot topics in disciplinary development. The results showed that the research hotspots in this field in recent years have evolved into "remote sensing inversion", "unmanned aerial vehicles", "soil moisture", "Hetao irrigation area", "canopy temperature", and "inversion".

Fig. 9 showed the prominent keywords in the field of remote sensing monitoring of salinization in the WOS database from 2008 to 2023. By utilizing the software's burst detection function and setting a threshold of 0.2, 16 burst words were obtained. The results showed that the research hotspots in this field in recent years have evolved into "electrical conductivity", "sea surface salinity", "salt affected soils", and "electromagnetic induction".

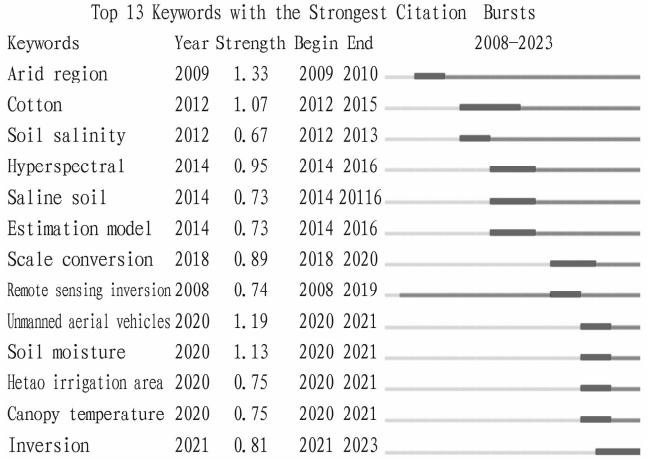

Fig. 8 Key words emerging in the field of remote sensing monitoring of salinization in CNKI from 2008 to 2023

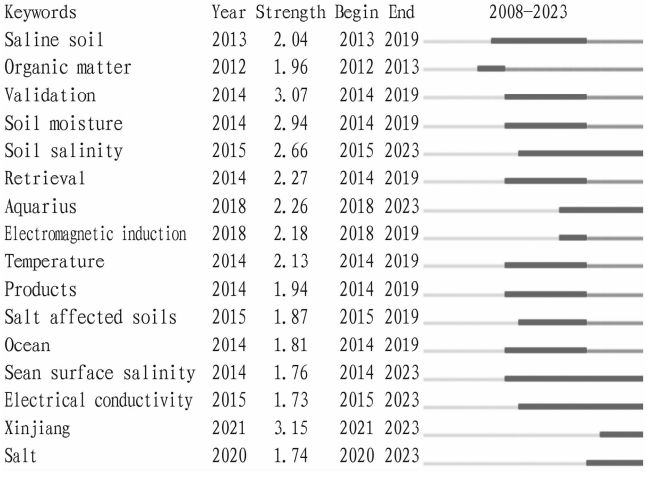

Fig. 9 Emerging keywords in the field of remote sensing monitoring of salinization in the WOS database from 2008 to 2023

As divided into three periods in Section **2.1**, remote sensing monitoring of salinization has gradually gained attention from researchers since 2014, and various hot topics related to remote sensing have gradually appeared in the papers of scholars. Although the number of papers was affected by the COVID-19 epidemic from 2019 to 2023, the hot words of the study remained unchanged.

Although the research hotspot in recent years has mainly focused on remote sensing monitoring of salinization, there were also different directions of research on remote sensing monitoring. In the past, remote sensing monitoring was often conducted on a single scale or by selecting administrative regions as scale indicators. Although the development of large-scale measurement is relatively advanced, there is limited research on the interconversion and related studies between different scales. Factors such as surface variability, complexity of salinization processes, and significant variations in spatial differences in soil salinity at different scales can all lead to significant differences in the correlation of the same variable at different scales.

If analysis is only conducted on a large scale, it may lead to the occlusion of small-scale spatial structural features, making it difficult to conduct in-depth analysis of the structural characteristics of soil spatial differences. At present, there is still a need for further research on the conversion between different scales. Based on Fig. 8 – 9, domestic and foreign researchers have gradually begun to study related issues[19]. For example, Jia Jiangsu *et al.* [20] developed a soil salinity monitoring model based on ground unmanned aerial vehicle (UAV) satellite data collaboration. In order to meet the needs of high-precision and large-scale monitoring, a soil salinity monitoring model that integrates ground, UAV, and satellite data was developed in this paper.

3 Conclusions

Based on CNKI and WOS databases, using CiteSpace software and bibliometric methods, visual quantitative analysis was conducted on existing research results at home and abroad. Using key research personnel, research institutions, and reproducing keywords as entry points, the evolution laws and development trends in the field of salt remote sensing monitoring were explored. And the following conclusion was obtained:

(1) From the changes in the number of publications, although the total number of articles in the field of salinization on CNKI has not increased significantly since 2008, it has generally grown linearly. In the future research process, the quality and quantity of related papers still need to be improved. The number of papers in the WOS database is relatively large, and overall it has shown a linear growth, especially around 2018 when there was a significant increase.

(2) From the perspective of researchers, due to the scarcity of related articles in CNKI, there were also fewer authors, but there were more authors in the WOS database. Except for a small number of authors who have collaborated, there was no collaboration among other authors.

(3) From the perspective of research topics, there was a high degree of overlap in keywords between CNKI and WOS databases, among which keywords such as "soil salinity", "salinity", "hyperspectral", saline soil", "model", "spatial distribution", and "remote sensing" were popular research terms in the field of salinization monitoring. Utilizing high-resolution remote sensing data, exploration and refinement of monitoring applications in different regions is an urgent problem that needs to be solved at this stage.

(4) From the perspective of the evolution path of hotspots, there were differences in the research hotspots of salinization monitoring in different periods. Currently, the focus of research both domestically and internationally is on remote sensing. With the increasingly serious soil salinization in China, it is of great significance to find more efficient, reliable, accurate, and economical monitoring methods for soil salinization.

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