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The role of geospatial techniques on the evaluation of soil salinity – worldwide review

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Abstract

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Soil is an essential part of ecosystem acting as a sustainer, provider, regulator, and cultural asset within the context of ecosystem services. World-wide soil salinity is a serious issue with far-reaching consequences for crop production, ecosystem wellness, and land destruction. Classical literature reviews fall short of addressing the transdisciplinary character of this topic. In response, the paper uses bibliometrics analysis to supply important perspectives into the present state of soil salinity research. This study aimed to identify existing challenges and notable research gaps through an extensive review of publications spanning the past twenty-three years. The analysis, based on 1428 publications indexed in Scopus, comprehensively examines publication trends, types, influential authors, affiliated institutions. We also identify key sponsors, co-authorship and keyword networks. Key research topics encompass soil salinity, remote sensing, mapping techniques, and satellite imagery. Over time, the volume of publications in this field has consistently increased, with research articles being the predominant format. Through this analysis, three major research directions concerning soil salinity processes are identified, offering valuable insights for future investigations. The trajectory of this scientific field in the coming years should prioritize fostering collaboration among researchers and harnessing the potential of remote sensing technologies to comprehensively advance our understanding of soil salinity.

Keywords: soil salinity; bibliometrics analyses; Scopus; modeling; geospatial techniques; monitoring

Introduction

Soil, a crucial and limited resource, fulfills various important functions both within the natural environment and anthropogenic factors (Jumaniyazov et al., 2023). It holds societal, biological, economic, cultural, and spiritual importance, acting as a sustainer, provider, regulator, and cultural asset within the context of ecosystem services (Xie et al., 2020). Soils primarily support plant growth, but they are also essential for retaining and circulating water and carbon. (Jezierski and Kabala, 2021). Inefficient use of soil resources can result in land degradation, including soil salinization as one of its consequences (Khasanov et al., 2021).

If the current trend of land degradation continues, it will worsen the global food supply issue, as highlighted by Abdel Kawy and Ali (2012). Soil salinization can also be caused by

factors such as drought, geological materials, and the use of low-quality irrigation water, leading to an increase in mineral salt content in the soil, as mentioned by Abbas (2023). Soil is classified as saline when its electrical conductivity (EC) at 25°C exceeds 4 dS/m, as defined by Bakr and Ali (2019). Soil salinity depletes resource foundations by reducing soil quality. It can result from environmental factors or from misuse and poor management, reaching a level that compromises the soil's ability to sustain its self-regulating capacity (Hassani et al., 2021; Makhkamova et al., 2022). Soil salinity emerges as a pressing issue with far-reaching implications for agricultural productivity, environmental contamination, and the degradation of vast land areas worldwide (Adeeb and Al-Timimi, 2021). Irrigated agriculture is a main reason for secondary salinization of lands which negatively impacts on every phase of plant development especially germination, vegetative growth and reproductive development (Shrivastava and Kumar, 2015). It presents a significant environmental challenge, negatively impacting crop growth, yield, and overall soil health, as described by Abbas (2023). The economic repercussions are considerable, with an estimated annual cost of around US$ 27.3 billion linked to salt-induced soil degradation in irrigated regions globally, as reported by Bakr and Ali (2019). Soil salinity is not confined to particular regions; it is widespread in arid and semi-arid areas too, as noted by Abdelfattah et al. (2009) and Abou Samra and Ali (2018).

Estimates of salt-affected lands worldwide vary among sources, but commonly, it's suggested that they cover approximately 1 billion hectares, accounting for roughly 7% of the Earth's continental surface (Abuzaid et al., 2023). These affected areas are distributed across at least 100 countries, with significant hotspots in Egypt, Iran, China, the USA, Mexico, Brazil, and numerous countries in Central and Western Asia, as is emphasized by Suleymanov et al. (2023). According to recent research, the regions most severely damaged by salinity are Australia, North and Central Asia, and South America, with 357, 211 and 129 million hectares affected, respectively, as noted by Chele et al. (2021). Regrettably, this issue is projected to exacerbate at an annual rate of approximately 10% due to climate-related factors, including reduced precipitation and rising temperatures (Farahmand and Sadeghi, 2020). It is also predicted that salinity will affect more than half of the world's arable land by the year 2050, as is mentioned by Al-Ali et al. (2021).

Given the factors indicated previously, many scholars and explorers are now increasingly motivated to analyze and assess soil salinity on a worldwide scale. Mai et al. (2013) conducted a remote sensing investigation to monitor soil salinity in the Weigan River-Kuqa Delta Oasis, Duan et al. (2022) concentrated on investigating salinity fluctuations in the exposed seafloor of the Aral Sea, Bai et al. (2016) studied soil alkalinity and salinity on the Songnen Plain in Northeast China, Ammari et al. (2013) investigated soil salinity fluctuations in the Jordan Valley. Latest researches have revealed an increasing interest in the use of remote sensing (RS) satellite images for monitoring agricultural operations, replacing traditional ground-based data gathering methods in Central Asia, as highlighted by Gerts et al. (2020).

Worldwide review using bibliometrics analysis offers valuable methods and tools for studying research publications. It offers a statistical approach to evaluate and detect trends within the literature, aiding in a more structured synthesis and organization of research materials, as outlined by Costa et al. (2023). Performance analysis and scientific mapping are the most widely used methods in bibliometrics research (Chalgynbayeva et al., 2023; Juliev et al., 2024; Juliev et al., 2024; Jumaniyazov et al., 2023; Kannazarova et al., 2024; Mamasolieva et al., 2024; Kannazarova et al., 2024; Khasanov et al., 2021; Abdikairov et al., 2024). In scholarly works, several studies have employed bibliometric analyses to delve into different research themes. For example, there has been considerable attention given to research centered on marginal lands, as exemplified by Jumaniyazov et al. (2023). Moreover, there has been notable interest in geospatial analyses and the utilization of artificial intelligence in agriculture, as elaborated by Karmaoui et al. (2023). Research regarding root harvester machines has also been undertaken, as is evidenced by Xaliqulov et al. (2023).

The aim of this worldwide review was to evaluate scientific production trend and its type as well as most productive authors and academic institutions on soil salinity. Moreover, this study determined both funding sources and analyzed co-authorship and keywords strongly connected with abovementioned research. Furthermore, the study sought to gain new perspectives on soil salinization by analyzing publications from the last two decades.

Material and Methods

Data collection

In this review article, bibliometrics and literature analyses were utilized to explore the worldwide scope of research on soil salinization. This investigation involved querying the keyword "soil salinity" in the reputable bibliographic database, Scopus, covering the period from 2000 to 2023. The analysis was conducted on October 6, 2023, and included a total of 1428 articles that had been published.

Bibliometric and performance analysis

To fulfill the research aims, three subject areas were chosen from the Scopus database during the designated timeframe, and the pertinent data was exported to a CSV file. To generate co-authorship and co-occurrence networks, we utilized VOS viewer 1.6.19 software, which was developed by van Eck and Waltman at Leiden University in the Netherlands, as is outlined in the research of Perianes-Rodriguez et al. (2016). We utilized Microsoft Excel 2021 to explore and analyze the data provided in this phase due to its versatility. Following this, we identified details such as publication years, journal titles, author names, countries, publication formats, citation counts per article, citation counts per journal, and the distribution of publications across subject cluster names. Our analysis involved employing various tools and formats, including CSV files, Microsoft Excel 2021, Research Information System file format, VOS viewer developed by VanEck and Waltman (2023), and Map charts online platform.

Figure 1 in the paper illustrates the flow of our research methodology and the methods employed in this study.

Results

Analyses of scientific output

Over the last twenty-three years, the number of published documents addressing soil salinity has reflected its global significance. An estimated total of 1428 papers have been published on soil salinity between 2000 and 2023. The current publication trend from Figure 2 can be categorized into two stages based on the increasing trajectory: 2000–2009 and 2010–2023. The first stage witnessed a minimum of 6 papers published, while the second stage saw 41 papers pub-

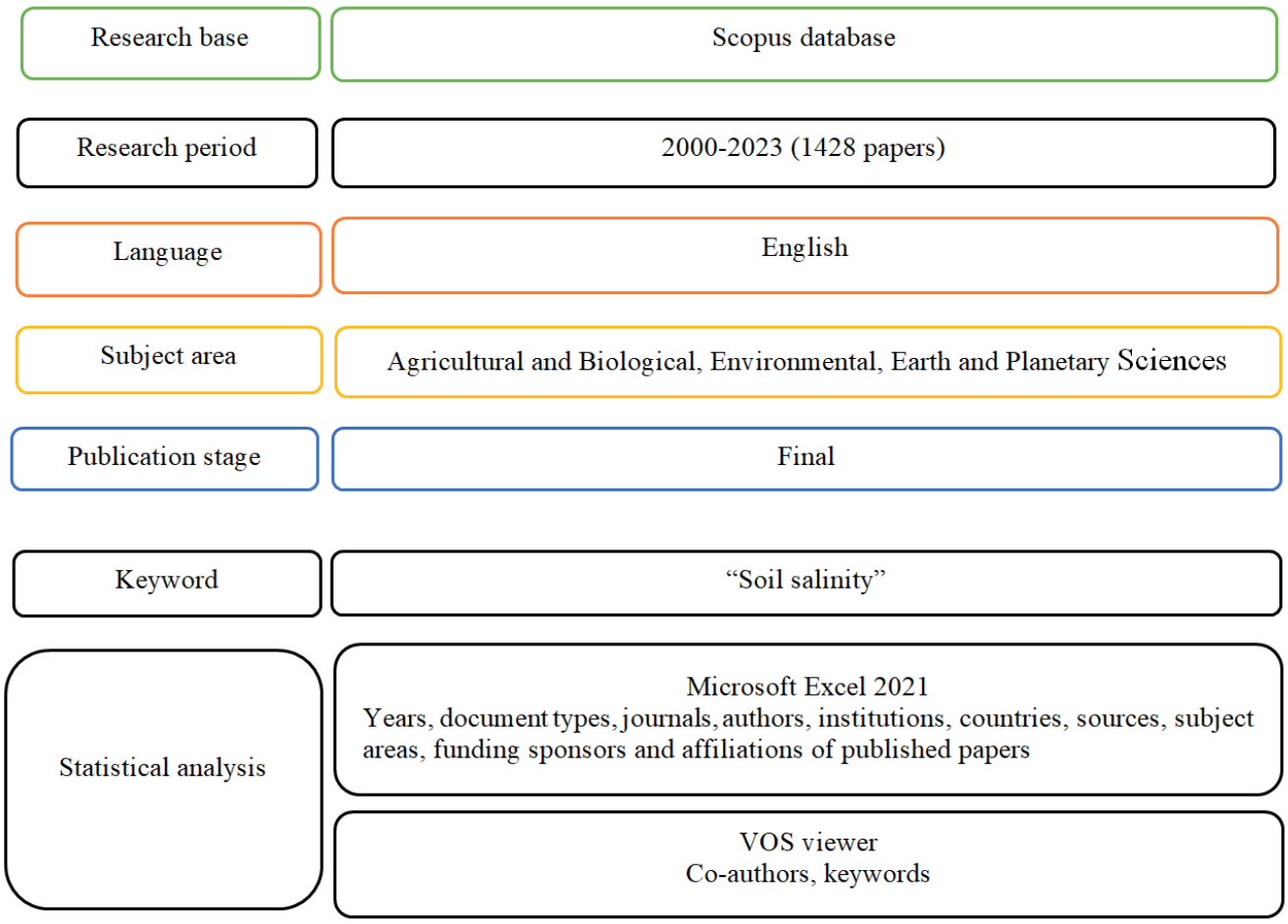


Fig. 1. Methodology flowchart for the research
Source: Authors' own elaboration

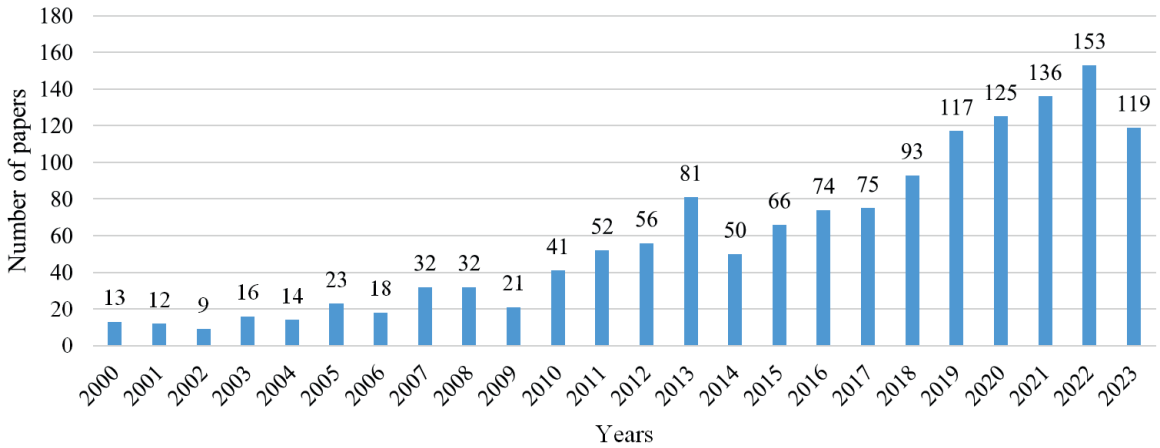


Fig. 2. Annual scientific papers production on soil salinity
Source: Authors' own elaboration

lished, respectively. From 2000 to 2009, there were 190 publications, with the peak occurring in 2007 and 2008, with 32 articles each. Although the publication trend grew from 2010 to 2013, there was a drop in 2014 with only 50 published papers. However, from 2014 to 2022, there was a significant surge in publication trends, rising from 50 to 153 articles, respectively. Notably, the peak in publications over the last two decades was in 2022, accounting for nearly 11% of the total publications. This data clearly underscores the escalating interest of the global academic community in soil salinity research, recognizing it as a critical global challenge with profound implications for sustainable development.

Article types reviewed in the study

After shortlisting the 1428 articles, various analyses were conducted on these retrieved articles. Initially, the articles were categorized into four types: articles, conference papers, reviews, and book chapters, as is illustrated in Figure 3. As expected, the shortlisted publications predominantly comprised research papers (1199), followed by conference papers (143), reviews (43), and book chapters (43). This data indicates that a considerable number of researchers prefer to disseminate their work through journals, particularly research articles, rather than conference proceedings. This preference may stem from a desire to enhance the accessibility and recognition of their research within the scientific community.

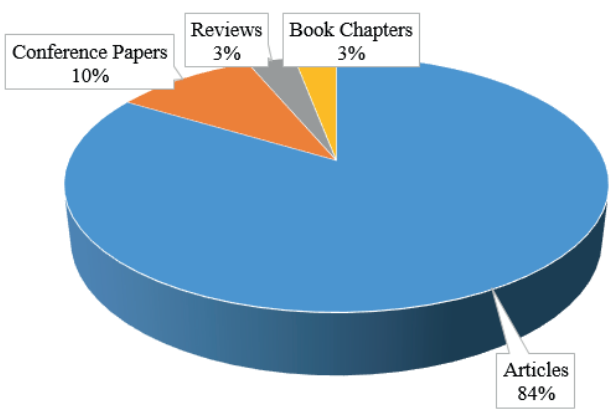


Fig. 3. Publication types on soil salinity
Source: Authors' own elaboration

Top authors on soil salinity

In total, 159 authors from 94 countries worldwide have dedicated their studies to soil salinity between 2000 and 2023. Figure 4 presents a list of the top 10 authors, who have made the most significant contributions to this field based on the number of published papers. Among these prolific authors, Ding, J. and Triantafilis, J., have each contributed 20 research papers, followed by Gorwin, D. L. with 17 publications. Herrero, J., Huang, J., Yang, J., Scudiero, E., Skaggs, T. H., Wu, J., and Yao, R. have authored 12 papers each, while Yao, R. has contributed 11 papers. This global distribution of researchers and scientists focusing on soil salinity highlights the widespread interest in investigating this phenomenon, which is an integral aspect of the broader issue of land degradation.

Contribution of institutions

Evaluation of institutions often considers both the quantity and quality of articles produced by their researchers. In the context of soil salinity research spanning from 2000 to 2023, our findings highlight the notable and productive institutions in this field. As illustrated in Figure 5, a majority of the research on soil salinity originated from the Chinese Academy of Sciences, with 149 records, followed by the Ministry of Education of the People's Republic of China

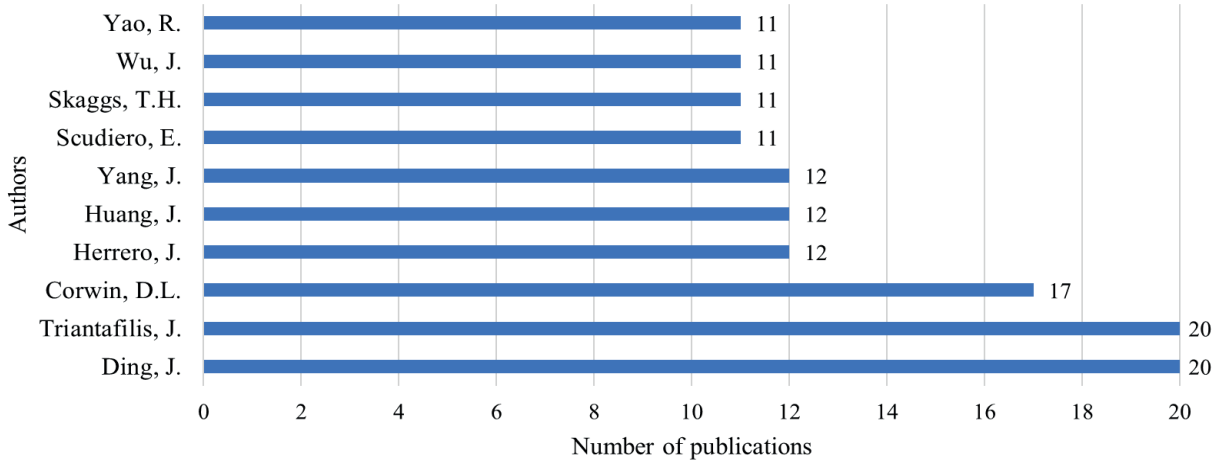


Fig. 4. List of top authors on soil salinity
Source: Authors' own elaboration

and the University of Chinese Academy of Sciences, with 48 and 44 records, respectively. Among the top 15 institutions, nine are based in China, collectively contributing to 75.3% of the total records. This group of leading institutions also encompasses universities, research centers, and institutions from other countries such as Iran, Australia, the USA, the Netherlands, and Uzbekistan, which together account for 24.7% of the total records. Main reasons of soil salinization in these countries include dry climates in Australia (Hassani et al., 2021), poor drainage system in Iran (Singh, 2022)and it is also essential for realizing most of the 'United Nations Sustainable Development Goals (SDGs, irrigation with salt-rich water and inappropriate application of fertilizers in China (Seifi et al., 2020). Additionally, the redirection of main rivers in Central Asia Amu Darya and Syr Darya promoted salinization of agricultural lands in Uzbekistan (Measho et al., 2022). It is evident that Chinese institutions play a prominent and active role, representing three-quarters of the top institutions engaged in soil salinity research. Consequently, documents produced by researchers from these institutions could be considered highly influential.

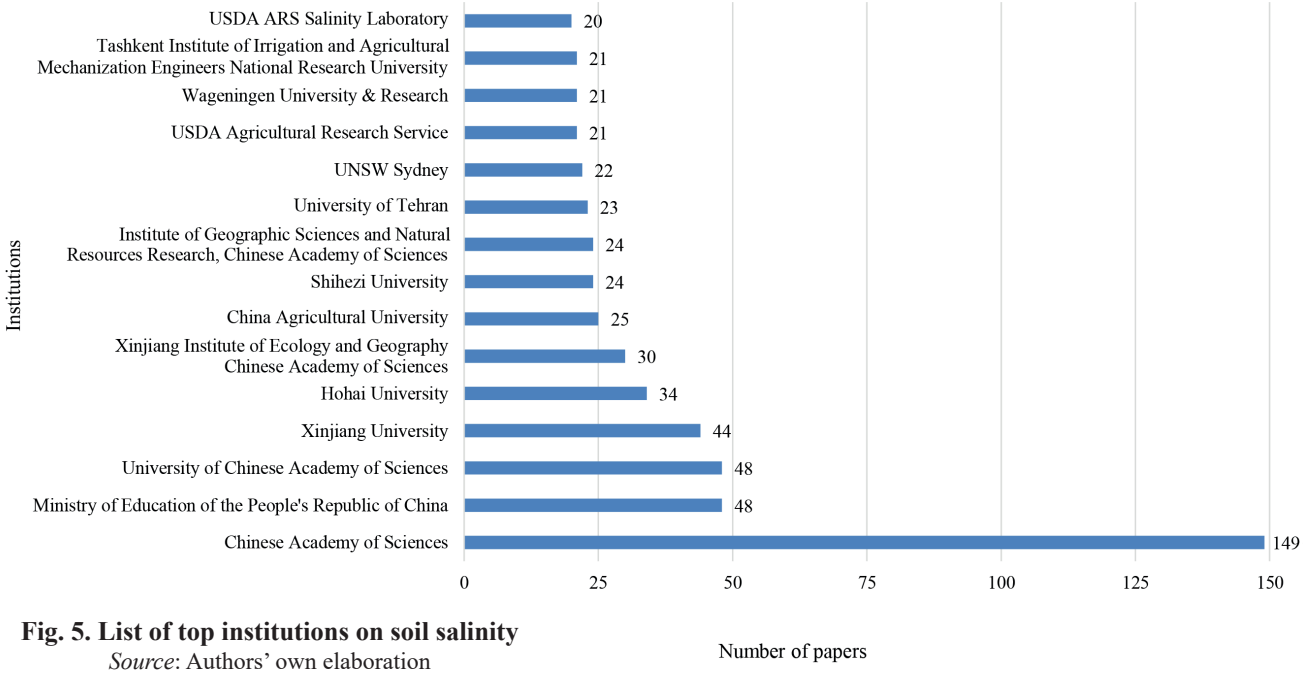


Fig. 5. List of top institutions on soil salinity
Source: Authors' own elaboration

Primary funding sponsors for soil salinity

Research funding supports an extensive range of costs, including labor costs, the purchase of equipment, facility upkeep, as well as information analysis. Figure 6 displays the 14 institutions that published the highest number of articles on soil salinity between 2000 and 2023, collectively representing over 35% of the studies. During this research period, a total of 159 different funding sponsors collaborated to publish 937 papers, contributing to 503 publications. The "National Natural Science Foundation of China" emerged as the predominant sponsor, with a share of 17.5%, followed by the "National Key Research and Development Program of China" at 4.1%. Subsequently, the "Chinese Academy of Sciences" and the "Fundamental Research Funds for the Central Universities" held shares of 2.8% and 1.9%, respectively. Contributions from all other sponsors ranged from 0.7% to 1.12%. Among the 14 funding sponsors identified, nine were based in China, while the remaining five represented the USA, the Russian Federation, Germany, Portugal, and the European Union. These findings underscore the significant role played by various funding sponsors, particularly those from China, in supporting research on soil salinity.

Co-authorships and keywords visualization analyses

This analysis enables us to grasp the evolution and trends guiding the advancement of the thematic domain through its clusters, which depict the primary research topics in this field (Erazo-Mora et al., 2023). Utilizing bibliographic data, VOS viewer devised at Leiden University was employed to generate maps of co-authorship and keyword co-occurrences. As is depicted in Figure 7, the co-authorship analysis identified a network of 4250 authors contributing to research on soil salinity. To emphasize more prolific authors in this field, only those with a minimum of five articles on soil salinity were included in the analysis. The co-authorship network is structured into 12 clusters, with the number of items distributed as follows: cluster 1 (19 items), cluster 2 (17 items), cluster 3 (16 items), cluster 4 (12 items), cluster 5 (11 items), cluster 6 (9 items), cluster 7 (9 items), cluster 8 (6 items), cluster 9 (5 items), cluster 10 (5 items), cluster 11 (5 items), cluster 12 (2 items). These clusters offer insight into the collaborative networks among researchers in the field of soil salinity and the thematic groupings of their work.

This analysis aids in identifying key research areas and collaboration within the discipline. In the keyword map illustrated in Figure 8, scientific publications were categorized into four groups, each denoted by different colors. The analysis identified a total of 8 221 keywords. To refine the analysis and concentrate on more pertinent keywords, generic terms with low relevance values and those with low occurrence rates were excluded. Following this filtering process, 59 keywords remained for further examination. Each keyword is depicted as a node in a network map, with the size of the node corresponding to the relevance of the keyword. This visualiza-

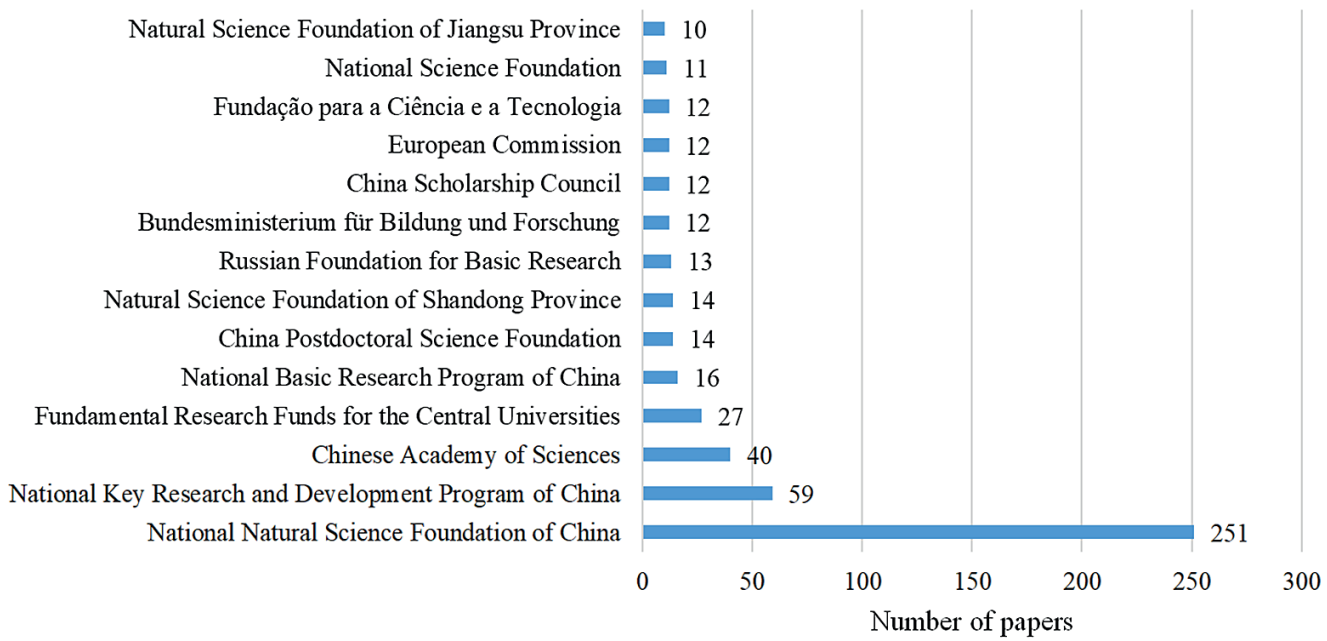


Fig. 6. Most funding sponsors on soil salinity

Source: Authors' own elaboration

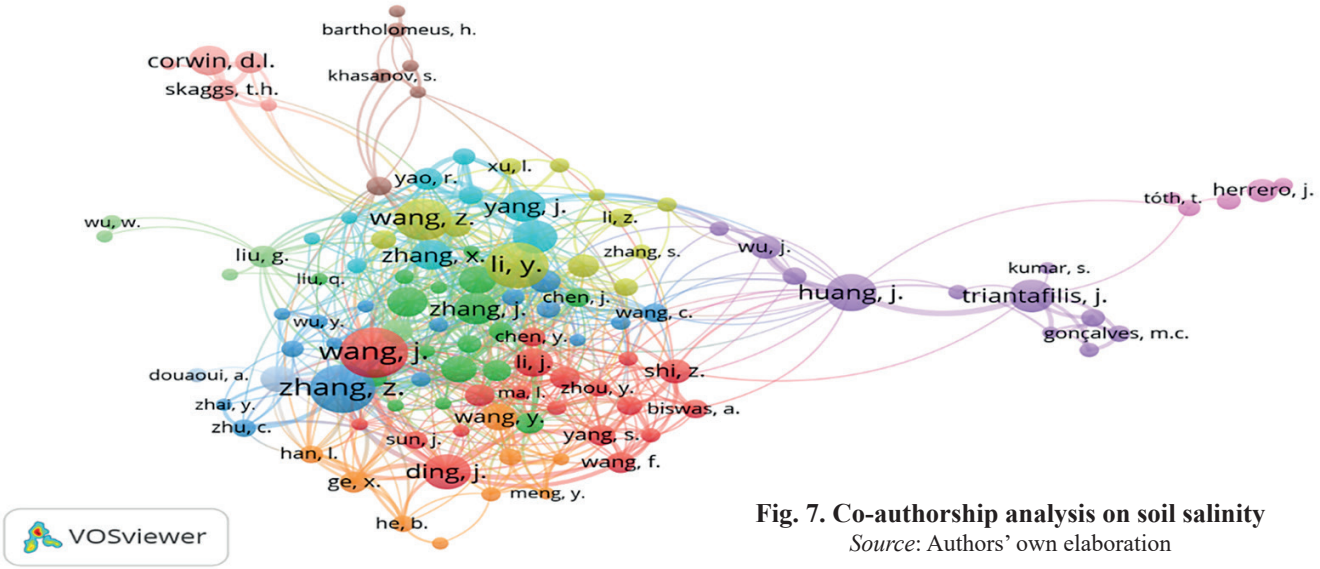


Fig. 7. Co-authorship analysis on soil salinity
Source: Authors' own elaboration

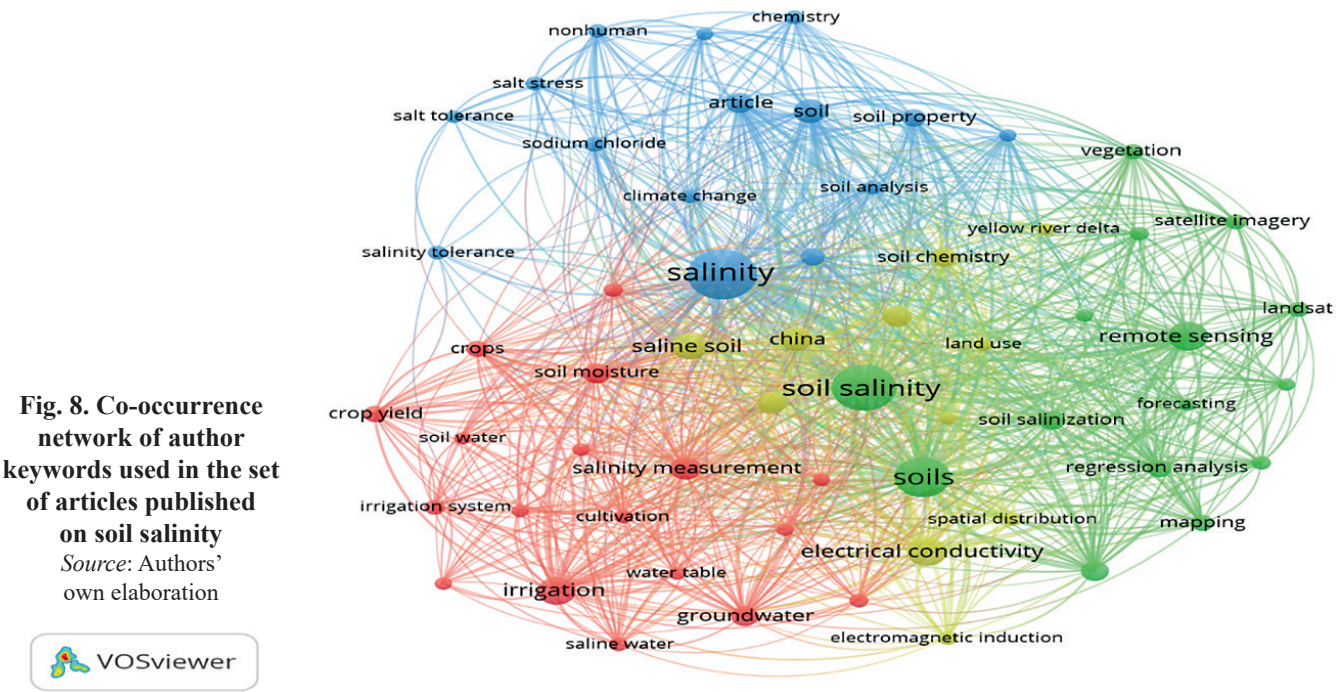


Fig. 8. Co-occurrence network of author keywords used in the set of articles published on soil salinity
Source: Authors' own elaboration

tion enhances comprehension of the relationships and patterns among keywords in soil salinity research, emphasizing the most pertinent and frequently co-occurring terms.

Discussion

Geospatial techniques based on soil salinity assessment

The findings of the study clearly demonstrate that geospatial technologies for detecting and mapping soil salinity have experienced notable advancement over the past two decades. Petsetidi and Kargas (2023) emphasize soil salinity monitoring has shifted towards employing sophisticated modeling approaches and advanced technological tools to precisely measure soil salinity levels and evaluate its severity on a global scale. Satellite remote sensing methods have emerged as a pivotal tool in this context, providing extensive detection capabilities and high acquisition efficiency. These techniques facilitate the gathering of spectral data on land

salinization at regular intervals, as is underscored by Jiang et al. (2023). In recent times, satellite-based remote sensing has been extensively embraced as a potent approach for identifying and mapping extensive soil salinity, as is noted by Scudiero et al. (2017). Moreover, the advancement of predictive models that incorporate remotely sensed soil salt data alongside ground monitoring has minimized the requirement for extensive ground validation data, consequently resulting in reduced monitoring expenses, as is noted by Sahbeni et al. (2023). In order to attain more accurate outcomes and gauge soil salinity distribution, diverse methodologies associated with remote sensing technology are utilized to collect soil salinity data. Table 1 showcases some frequently encountered keywords in the titles of papers pertaining to salinity monitoring, emphasizing the fundamental aspects and methodologies employed in this domain.

Mapping and monitoring

According to the literature review, soil salinity mapping and monitoring represent a substantial portion of research outcomes, making up 17.5% of the overall published papers. This category consists of 19 distinct sections, comprising a total of 251 research articles. The predominant theme within this field is "soil salinity mapping", which is prominently highlighted in the titles of 37 research papers. This topic primarily revolves around the utilization of remote sensing techniques and Geographic Information Systems (GIS), employing various methods and approaches. These comprise partial least-square regression (Sarkar et al., 2023), analyses of spectral indexes (Barreto et al., 2023), and machine learning algorithms (Li et al., 2023; Wang et al., 2021). Moreover, researchers have utilized platforms like Google Earth Engine (Aksoy et al., 2022), and data sources such as SAR Sentinel-data (Hoa et al., 2019; Morgan et al., 2018; Taghadosi et al., 2019) and Landsat data (Al-Ali et al., 2019; Sahbeni, 2021) to advance soil salinity mapping.

The topic of "soil salinity assessment" is another notable area, identified in the titles of 29 papers. This theme primarily depends on traditional methods for evaluating soil salinity, such as focused soil sampling utilizing electromagnetic technology (Amezketa Lizarraga, 2007; Azabdaftari and Sunar, 2016; Farzamian et al., 2018), as well as measurements involving saturated paste and mass soil (Kargas et al., 2018). Throughout the research period, "soil salinity dynamics" emerged as a frequently examined subject, featuring in the titles of 19 published papers. Researchers investigated soil salinity dynamics under various conditions, including the effects of drip irrigation (Jiang et al., 2023; Mai et al., 2013)

Table 1. List of top encountered topics in soil salinity papers

11	Mapping and monitoring			Remote sensing data types and approaches		3	Modelling techniques	
#№	Topics	Publications	№	Topics	Publications	№	Topics	Publications
1	Soil salinity mapping	37	1	Sentinel	35	1	Machine learning	28
2	Soil salinity assessment	29	2	Remote sensing	34	2	Modelling	20
3	Soil salinity dynamic	19	3	Landsat	29	3	Algorithm	19
4	Soli salinity gradient	14	4	Imagery	22	4	Climate change	13
5	Soil salinity management	14	5	GIS	12			
6	Soil salinity stress	14	6	OLI data	9			
7	Soil salinity level	14	7	Satellite image	9			
8	Soil salinity change	13	8	Remote sensing technique	8			
9	Soil salinity monitoring	13	9	Arid landscape	6			
10	Soil salinity prediction	13	10	Spatial prediction	6			
11	Soil salinity estimation	11	11	Hyperspectral data	5			
12	Soil salinity condition	11	12	Unmanned aerial vehicle	5			
13	Soil salinity control	8						
14	Soil salinity detection	8						
15	Soil salinity distribution	7						
16	Soil salinity inversion	7						
17	Soil salinity risk	7						
18	Soil salinity variation	6						
19	Soil salinity effect	6						

Source: Authors' own elaboration

and its response to climate change (Bannari and Al-Ali, 2020; Halder et al., 2022). Moreover, categories like "soil salinity gradient," "soil salinity management," "soil salinity stress" and "soil salinity level" each incorporate 14 published articles. Additionally, subjects such as "soil salinity change", "soil salinity monitoring" and "soil salinity prediction" were covered in 13 papers. Researchers delved into diverse facets of soil salinity, including its effects on plant growth (Zhang et al., 2021), management with drip irrigation (Sun et al., 2012), the influence of plant growth on soil salinity stress (Shilev, 2020; Zafar-ul-Hye et al., 2019) and the application of remote sensing data for soil salinity level identification (Aslanov et al., 2021; Djuraev et al., 2021).

Moreover, changes in soil salinity were noted in connection with the management of groundwater levels (Liu et al., 2023) and its response to climate change (Kawser et al., 2022; Khamidov et al., 2022). Soil salinity monitoring and prediction were conducted using remote sensing data (Jiang et al., 2023; Kaplan et al., 2023). Furthermore, numerous areas such as soil salinity calculation, condition assessment, control measures, detection techniques, distribution patterns, inversion processes, risk evaluations, and variation analyses were examined through the use of remote sensing data (Alqasemi et al., 2021; Chen et al., 2021; Davis et al., 2019; Ge et al., 2022; Kazemi Garajeh et al., 2022; Park and Harmon, 2008; Romanov and Khvostov, 2019; Tan et al., 2023). In summary, the review underscores that soil salinity mapping and assessment, employing various estimation approaches, are predominantly conducted through the application of remote sensing data. Gao et al. (2023) promoted accuracy mapping of salinization in agricultural lands would enhance sustainable long-term land management. Gopalakrishnan and Kumar (2020) described that most national and international strategies had centered on soil protection using soil salinity mapping.

Remote sensing data types and approaches

Over the years, remote sensing technology has progressively supplanted traditional methods due to its superior efficiency in monitoring soil salinity across large areas from a single location. Sahbeni et al. (2023) confirmed that the combination of remote sensing data with robust analytical tools has demonstrated significant potential in salinization mapping. The utilization of various remote sensing data with diverse geographical and temporal resolutions has paved the way for qualitative research methods on soil properties (Mohamed et al., 2023). The literature on soil salinity assessment involving remote sensing data can be categorized into 13 sections, encompassing a total of 180 papers, constituting 12.6% of the total published articles. Each section represents the type of remote sensing data mentioned in the paper titles.

The most frequently encountered topic is "Sentinel," found in 35 paper titles. Researchers have applied Sentinel data for soil salinity prediction (Yang and Guo, 2019), mapping and monitoring (Al-Gaadi et al., 2021; Wang et al., 2019), and estimation (Mukhamediev et al., 2023). "Remote sensing" is another prominent theme, with 34 published articles, employed by researchers like Haq et al. (2023) for spatial mapping of soil salinity, Shahrayini and Noroozi (2022) for modeling soil salinity and alkalinity, and Jingwei et al. (2008) for monitoring changes in soil salinity. The "Landsat" topic includes a total of 29 published articles and has been used for purposes such as mapping (Gharsallah et al., 2022), monitoring (Golabkesh et al., 2021), and detecting soil salinity (Alamdar et al., 2023). The "Imagery" topic includes 22 published papers, focusing mainly on satellite data types such as Landsat, Sentinel, and Gaofen-2 (Yang et al., 2023).

Other topics that have been explored by researchers in this context include "GIS" (Abdullaev et al., 2023), "OLI data" (Bannari and Al-Ali, 2020), "satellite image" (Golabkesh et al., 2021), "remote sensing technique" (Abuzaid et al., 2023), "arid landscape" (Al-Ali et al., 2021), "spatial prediction" (Ma et al., 2023), "hyperspectral data" (Avliyakulov et al., 2020), and "Unmanned aerial vehicle" (Hu et al., 2019). As is pointed out by Mohamed et al. (2023), recent research has successfully mapped and monitored soil salinity using free optical remote sensing data, including Landsat, SPOT, ASTER, RapidEye, IKONOS, QuickBird, and Sentinel-2. Among these, Sentinel-2, with a spatial resolution of 10 meter and revisit duration of 5 days, is particularly well-suited for soil salinity monitoring, outperforming MODIS (500 meters) and Landsat (30 meters) in this regard. However, Cui et al. (2023) emphasizes the advantages of unmanned aerial vehicle (UAV) remote sensing, which includes low operating costs, high monitoring efficiency, and minimal interference with field operations, in contrast to the limitations of satellite remote sensing, such as susceptibility to weather conditions, extended revisit cycles, and lower temporal and spatial resolution.

The literature analysis indicates that salinized soils exhibit distinct spectral reflectance values compared to non-saline soils, with soil spectrum reflectance values increasing with higher soil salinity levels. Tan et al. (2023) suggests that salinity indices, including the Soil Salinity Index, Normalized Differential Salinity Index (NDSI), and Salinity Index (SI 1-5) are effective methods for assessing and monitoring soil salinity on a large scale. These indices provide a solid theoretical foundation for studying soil salinity trends. Recent advancements have been made in estimating and mapping soil salinity by integrating multiple spectral salinity indices.

Modeling techniques

Continuous monitoring and prediction of soil salinity distribution are essential for effective management and mitigation of its adverse effects. Traditional methods are often labor-intensive and costly, making remote sensing an appealing alternative (Zhao et al., 2023). Remote sensing data is employed to assess soil salinity using salinity indices, which are typically derived by combining multiple spectral bands to train machine learning algorithms. Several machine-learning models are available for soil salinity estimation, including Artificial Neural Network (ANN) (Noureddine et al., 2019), Decision Tree (DT) (Elnaggar and Noller, 2010), Random Forest (RF) (Suleymanov et al., 2023), Support Vector Machine (SVM) (Nurmemet et al., 2018), Partial Least Squares Regression (PLSR) (Nawar et al., 2014), Multi Linear Regression (MLR) (Li et al., 2019), Deep Learning (DL) (Kazemi Garajeh et al., 2022), and Convolutional Neural Network (CNN) (Sirpa-Poma et al., 2023). The results of the research indicate that the section related to modeling techniques for soil salinity assessment can be divided into four primary topics, with varying numbers of publications. These topics include "machine learning" (28 publications), "modeling" (20 publications), "algorithm" (19 publications), and "climate change" (13 publications). Researchers such as Vermeulen and Van Niekerk (2017) and Xiao et al. (2023) have demonstrated the prediction of soil salinity parameters using machine learning models. Chang et al. (2019) illustrated the modeling of long-term soil salinity dynamics, while Jiang et al. (2023) and Wang et al. (2020) compared multiple algorithms for monitoring and predicting soil salinity. Corwin (2021) evaluated the impact of climate change on soil salinity levels and developed proximal sensors and remote imagery methodologies for assessing sa-

Table 2. The main funding directions of NCFS

№	2019	Projects	2020	Projects	2021	Projects
1	General Program	18995	General Program	19357	General Program	19420
2	Key Program	743	Key Program	737	Key Program	740
3	Major Program	46	Major Program	45	Major Program	52
4	Major Research Plan	526	Major Research Plan	460	Major Research Plan	388
5	International (Regional) Joint Research Program	428	International (Regional) Joint Research Program	368	International (Regional) Joint Research Program	322
6	Young Scientists Fund	17966	Young Scientists Fund	18276	Young Scientists Fund	21072
7	Fund for Less Developed Regions	2960	Fund for Less Developed Regions	3177	Excellent Young Scientists Fund	645
8	Excellent Young Scientists Fund	625	Excellent Young Scientists Fund	625	National Science Fund for Distinguished Young Scholars	341
9	National Science Fund for Distinguished Young Scholars	296	National Science Fund for Distinguished Young Scholars	298	Science Fund for Creative Research Groups	42
10	Science Fund for Creative Research Groups	45	Science Fund for Creative Research Groups	37	Fund for Less Developed Regions	3337
11	Joint Research Fund for Overseas Chinese Scholars in Hong Kong and Macao	23	Programs for Joint Funds	1084	Programs for Joint Funds	911
12	Programs for Joint Funds	925	Special Fund for Research on National Research Instrument	88	Special Fund for Research on National Research Instrument	73
13	Special Fund for Research on National Research Instrument	85	Basic Science Center Program	13	Basic Science Center Program	17
14	Basic Science Center Program	13	Special Fund for Emergency Programs	521	Special Fund for Emergency Programs	759
15	Special Fund for Emergency Programs	715	Tianyuan Fund for Mathematics	120	Tianyuan Fund for Mathematics	133
16	Tianyuan Fund for Mathematics	89	Research Fund for International Young Scientists	146	Research Fund for International Young Scientists	256
17	Research Fund for International Young Scientists	161	International (Regional) Personnel Exchange Program	501	International (Regional) Personnel Exchange Program	301
18	International (Regional) Personnel Exchange Program	551				

Source: Authors' own elaboration

linity at multiple scales. To identify the optimal approach for salinity modeling, a literature analysis was conducted, revealing that in China, Iran, and Algeria, Random Forest (RF) and Support Vector Machine (SVM) were found to be the most effective models for predicting soil salinity. They are widely applied machine learning algorithms for analyzing land cover focusing on soil salinity and vegetation (Adugna et al., 2022). Support Vector Machine (SVM) is a sophisticated controlled learning method with a fundamental premise is to turn the input data into a multidimensional space via the kernel technique while Random Forest (RF) algorithm is an effective solution applicable to classification and regression issues applying a technique known as "bagging" or bootstrap aggregating to produce a group of either regression or classification trees (Lachaud et al., 2023).

Research funding in soil salinity

Research funding is a critical component of scientific research, typically obtained through a competitive process. Securing research funding requires a strong interest in a particular subject, in-depth knowledge of the subject matter, and the ability to identify gaps in existing knowledge (Neema and Chandrashekar, 2021). The results of this review indicate that many research investigations on soil salinity have been sponsored by Chinese foundations. The leading sponsor is the National Natural Science Foundation of China (NSFC), which has funded 251 research projects in this field. NSFC was established on February 14, 1986, and is managed by the Ministry of Science and Technology of China (Liu et al., 2019). Since its establishment, NSFC has implemented a rigorous and objective merit-review system to support basic research, nurture talented researchers, promote international cooperation, and contribute to socioeconomic development. Table 2 provides an overview of the main funding directions of NSFC from 2019 to 2021, along with the number of projects funded (Han et al., 2019, 2020, 2021).

Soil salinization is indeed a global challenge that necessitates international collaboration. This is why we have examined the International (Regional) Joint Research Program of the National Natural Science Foundation of China (NSFC). Figure 9 offers insights into projects related to Earth Sciences. Despite an increase in the number of applications, funding for research in Earth Sciences, including soil salinity, has been on the decline. The issue of soil salinity is a matter of concern for the global scientific community, which underscores the need for research to prevent soil degradation processes on a broader scale.

The Research Fund for International Scientists (RFIS) aims to support outstanding international scholars who conduct research in China under the financing framework of

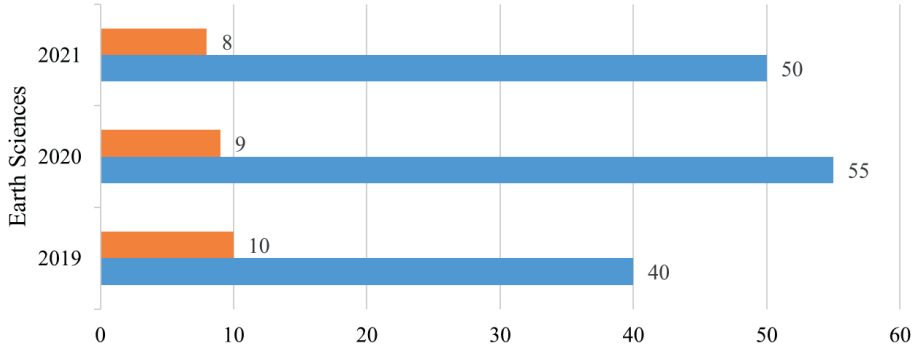


Fig. 9. Funding trend in Earth Sciences
Source: Authors' own elaboration

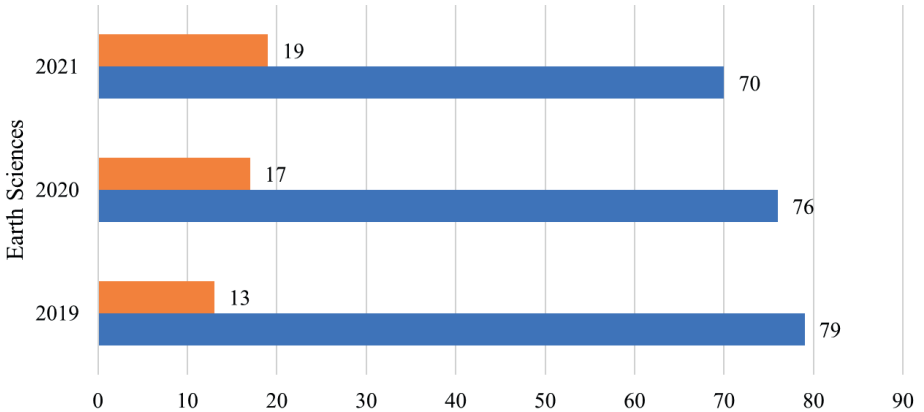


Figure 10. Funding trend in RFIS for Earth Sciences
Source: Authors' own elaboration

China's National Natural Science Foundation. This program is designed to promote long-term and stable academic collaboration and exchange between international and Chinese experts. RFIS is divided into three categories: RFIS-I (International Young Scientists), RFIS-II (International Excellent Young Scientists), and RFIS-III (International Senior Scientists). Furthermore, we have conducted an analysis of the application and funding of RFIS projects specifically in the field of Earth Sciences for the period of 2019–2021, as shown in Figure 10.

Conclusion

In this study, we conducted a comprehensive analysis of 1428 academic papers related to soil salinity published between 2000 and 2023, extracted from the Scopus database in English. Our research has revealed several key characteristics and trends in soil salinity research including scientific production output, where the number of articles on soil salinity has steadily increased over the years, with significant growth observed after 2015. This growth can be categorized into four stages: a low-yield period (2000–2004), a developmental sprout period (2005–2009), a period of growth and advancement (2010–2015), and a highly productive active period (2016–2023). Research articles are the most common publication type, providing valuable insights to a wide audience. The most active 10 authors with contribution to 9.6% of total publications indicated Ding and Triantafilis J. as the most productive researchers. China is mentioned as a leader according to academic institutions activity based on publications on soil salinity topic. From selected 15 institutions, nine are from China, collectively contributing to 75.3% of the total records. Additionally, Chinese funding sponsors dominate the field of soil salinity research, occupying the top seven positions and supporting 45% of total funded publications. The majority of publications are related to agricultural and biological sciences (542 papers), followed by environmental science (400 papers), earth and planetary sciences (243 papers), and other subjects (243 papers). Last but not least moment is co-authorship analysis which identified a network of 4250 authors collaborating in soil salinity research. Moreover, the most frequent keywords include soil salinity, remote sensing, soil, satellite imagery, and electrical conductivity. Cluster analysis suggests that soil salinity mapping and monitoring, particularly using remote sensing data and geographical information systems, will be important research directions in the future.

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