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# Assessing China's salt lake resources R&D based on bibliometrics analysis

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**Abstract** The aim of this article is to assess China's R&D position and status on salt lake resources with a method combining bibliometrics with social network analysis. Patent data about the mining and usage of salt lake resources harvested from the SciFinder database and ranging from 1991 to 2010 is analyzed in this paper. The results show that there has been a rapid growth in patent publications regarding salt lake resources in the last 20 years, both at home and abroad. This is especially true with regard to the extraction and application of magnesium and potassium. China's R&D in this field is worthy of attention, because China owns considerable salt lake reserves. The status of R&D groups in China is assessed via network analysis, through both Ucinet software and NetDraw software. We use separate records from the China Academic Journal Network Publishing Database (CAJD) and the Science Citation Index Expanded (SCIE), covering the time span from 2001 to 2010. A collaboration network is established, and its structure and attributes are analyzed with a view to assessing the R&D groups in this field. Results from these analysis demonstrated that China stands in a disadvantaged position in the implementation of related research and technology; several research groups have been formed to explore the mining of salt lake resources; Collaboration is mostly still confined to the domestic scene; cross-national collaboration has not yet started to grow. Finally, proposals are put forward for the formulation of an R&D strategy and for cultivating R&D groups.

**Keywords** Salt lake resource R&D · Bibliometrics · Co-authorship · Social network analysis · Cohesion · Centrality

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## Introduction

Over the past 20 years, much attention has focused on the research and development of the rich resources in salt lakes (Kilic and Kilic 2005; Kesler et al. 2012). Salt lakes are typically defined as a body of salty water with a salinity concentration of more than 3.5 % (the average salinity of sea water) (Zheng and Qi 2006). In addition to well-known table salt (namely sodium chloride), salt lakes can also provide gypsum, sodium sulfate, magnesium salts, basic compounds and so on. Some salt lakes (not all) can also provide rare metallic minerals, such as lithium, boron, potassium, cesium, rubidium, strontium and bromine, as well as non-metallic minerals, which are widely used in the fields of chemical industry, agriculture, light industry, metallurgy, and the architecture and pharmaceutical industries.

China is one of the few countries which own modern, developed salt lakes. These salt lakes are mainly found in the provinces of Qinghai, Xinjiang, Tibet and Inner Mongolia. China's salt lakes enjoy a reputation for having large quantity of abundant resources and rich rare elements (Ma 2009). Huge amounts of both liquid and solid mineral reserves of potassium, lithium, magnesium and sodium are found in these salt lakes.

China's R&D in this field is worthy of attention, so based on Bibliometrics Analysis, we want to assese the R&D position and status. We introduced social network analysis into traditional bibliometrics, because social network analysis is good at researching and mapping relationships between individuals.

Over the past decade, there has been an explosion of interest in network research across both the physical and social sciences. For social scientists, the theory of networks has been a gold mine, yielding explanations for social phenomena in a wide variety of disciplines, from psychology to economics (Borgatti et al. 2009).

To date, the means of applying network analysis to assese the salt lake resources R&D of China has remained elusive.

Patent data are usually being used to evaluate R&D competitiveness of organization, while journal articles are used to research collaboration between individuals.

Firstly, based on bibliometrics methods, we reviewed the international patent records harvested from SciFinder. In so doing, we explored the international salt lake R&D posture. In addition, we ranked China's position in international salt lake R&D.

Secondly, by virtue of a social network analysis technique, we closely analyzed R&D groups involved in the field of salt lake resource mining in China. We used the China Academic Journal Network Publishing Database (CAJD) and the Science Citation Index Expanded (SCIE), during the period from 2001 to 2010. A topological structure diagram of a collaboration network was created, in order to reflect the overall state of R&D groups both visually and effectively. The hierarchical structures and collaboration of the various R&D groups are displayed, and the research leaders and collaboration intermediaries of the groups are discovered.

Through mapping the R&D groups linked by individuals' collaboration, we want to explain the position of China's R&D at international scene by R&D groups' structure, number and size. Then find a way to strengthen China's R&D in this field.

Finally, suggestions are put forward for supporting the decisions of and cultivating the R&D groups in China.

# Data and measures

## Data

SciFinder is a product of the American Chemical Society (ACS), which posts the patents of chemical, biochemical and chemical engineering interests from 63 patent authorities around the world. The patent records from nine major patent offices worldwide which meet CAS selection criteria are available online in SciFinder within 2 days of a patent being issued. The patents are also fully indexed by CAS scientists in $<27$ days from the date of issue. Therefore, international patent documents relating to salt lake resources R&D, covering the 20-year timespan from 1991 to 2010, were collected from the SciFinder database. Then, the patent issuance quantity, field's distribution and quantity and type of patent assignees over the past 20 years, both at home and abroad, were analyzed.

The China Academic Journal Network Publishing Database (CAJD) is the largest of all China academic journal databases. It covers more than 7900 journals in the fields of science, engineering, agriculture, medicine, and so on. Since most Chinese scholars tend to make their R&D achievements public in their native language, here we take Chinese domestic journal articles into consideration. Then, the domestic journal articles were harvested from those core journals in the CAJD covering the period from 2001 to 2010, using a similar retrieval strategy. International articles were harvested from the Science Citation Index Expanded (SCIE), world famous database covering highest quality, curated, multidisciplinary international articles, covering the same time span and employing the same retrieval strategy. Regarding the records from home and abroad, we ignored any output where their authors and affiliation records were empty. Authors with the same name were identified according to their affiliation. We used social network analysis to separately analyze the collaboration network among scholars at home and abroad. Social networks are constructed of nodes (actors) and links (ties, relations, or edges). Nodes which denote individuals, organizations or information are linked if one or more specific types of relationships (e.g., financial exchange, friendship, trade, or Web links) exist between them. Based on the co-authorships of various scholars' publications, we constructed a co-authors collaboration network. In addition, network attributes are studied.

Data collection report sees Table 1.

## Measures

The British Standards Institution describes bibliometrics as the application of mathematical and statistical methods in the study of the use of documents and publication patterns.

The benefit of analyzing social networks is that it can help people to understand how to share professional knowledge in an efficient way and to evaluate the performance of individuals, groups, or the entire social network.

Our detailed analysis methods are as follows:

For an undirected network composing n actors, the maximum theoretical links are $\frac{n(n-1)}{2}$. If the real links in the network are $m$, then the network density (Liu 2009) is the number of real links divided by the maximum theoretical links, namely $\frac{2m}{n(n-1)}$.

Among the collaboration analysis, structural centrality is the research focus. There are three types of measurements, namely degree centrality, betweenness centrality and closeness centrality. Node A's degree centrality is the number of other nodes connected directly to this node. The degree centrality of node A (i.e., $p_A$) can be defined as follows:

**Table 1** Data collection report

| | Database introduction | Search strategy | Bibliographic field | Results | Search accuracy |
|---|---|---|---|---|---|
| SciFinder | World famous database engaged in chemistry and chemical engineering | Research topic: (“salt lake” or bitter or brine) and (potassium or lithium or magnesium or boron)<br>Document type: patent<br>Publication Year: 1991–2010 | Chemical, biochemical and chemical engineering | 2930 | Recall and precision are satisfied by following the database’ research rules and choosing research keywords carefully |
| CAJD | Covers most comprehensive academic journals in Chinese | su = (盐湖 + 卤水) and su = (锂 + 镁 + 钾 + 硼)<br>Publication Year: 2001–2010* | Science | 747 | |
| SCIE | Covers highest quality, curated, multidisciplinary international articles | ts = (“salt lake*” or bitter* or brine*) and ts = (*magnesium or Mg or *lithium or Li or boro*) and py = (2001–2010)*<br>Countries/territories: (Peoples R China) | Science | 134 (34 are written in Chinese) | |

*Since 2000, R&D on salt lake sources has grown steadily. Therefore, we collected publications from 2001 to 2010 in CAJD and SCIE to research collaboration status of Chinese R&D groups during the rapid growth period

$$C_A(p_A) = \sum_{i=1}^{n} a(p_i, p_A)$$

where $n$ is the number of nodes in the network and a $(p_i, p_A) = 1$ if and only if node i and A (i.e., $p_i$ and $p_A$) are connected; a $(p_i, p_A) = 0$ otherwise (Abbasi et al. 2012).

The more a particular node lies on the shortest path between any pair of nodes, the higher betweenness centrality it has. A node's closeness centrality is the sum of the 'geodesic' distances (the shortest path between any particular pair of nodes in a network) to all other nodes in the network.

Cohesive sub-groups are sets of actors, among who exist intense, direct, close, usual and positive relationships. The above are the foundations of R&D group analysis.

## R&D trend on salt lake resources

### Rapid growth in the past 20 years

From 1991 to 2010, patent issue details on salt lake resources R&D at home and abroad are shown in Fig. 1. Only 61 patents were issued in 1991, after which the number climbed rapidly to 367 in 2010. That figure is 6.6 times the number of patents issued 20 years ago.

In the past 20 years, and especially after the year 2000, the quantity of patents issued in this field has boomed. The slope of the trend line is springing up. Therefore, it can be concluded that more efforts have been made with regard to salt lake resources R&D, and many accomplishments have been made, leading to R&D in this field growing ever more quickly.

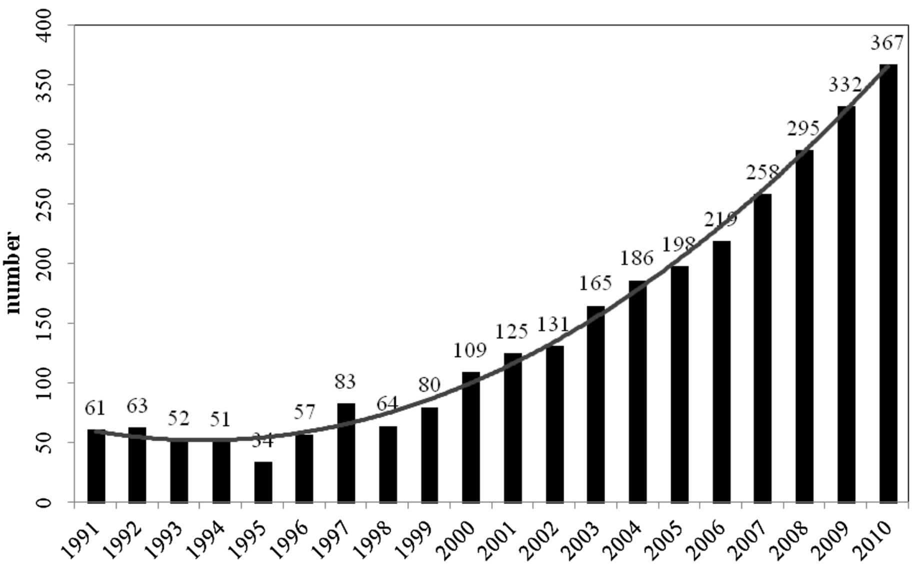


**Fig. 1** Salt Lake Resource R&D Trend, *Note: Application date or priority date should be more reliable for technology trend analysis, because in general there is a delay between an application and a grant. In SciFinder, patent records are analyzed by their publication date. However, I believe our analysis results can still shed light on the development trends in this field

Salt lake resources R&D is driven by the following factors: Firstly, there are affluent chemical resources in salt lakes. These chemicals have great value in terms of their development and utilization potential. They can be widely applied in various agricultural and industrial fields, including potash fertilizer, pharmaceuticals, glass, ceramics, and electronics. Secondly, R&D is driven in terms of finding applications in new energy fields, for example the lithium battery and electric vehicles. In addition, the wide applying of potash fertilizer and the resulting increase in its price has helped bring about an upsurge in salt lake resource development. It is therefore important to assess the state and trend of salt lake resources R&D.

## R&D domains analysis

Patent documents are analyzed by their technology domain, in order to explore the direction of salt lake resources R&D. Salt lake resources R&D domains are distributed between 139 CA (chemical abstract) sections. They concentrate on the following domains: Industrial Inorganic Chemicals Food and Feed Chemistry, Fossil Fuels Derivatives and Related Products, Pharmaceuticals, Electrochemistry, Metals and Alloys, and Waste Treatment and Disposal.

In practical terms, salt lake resources R&D focuses on the enrichment and use of potassium, lithium, magnesium and boron resources. According to those four types of resources, the obtained patent documents are analyzed.

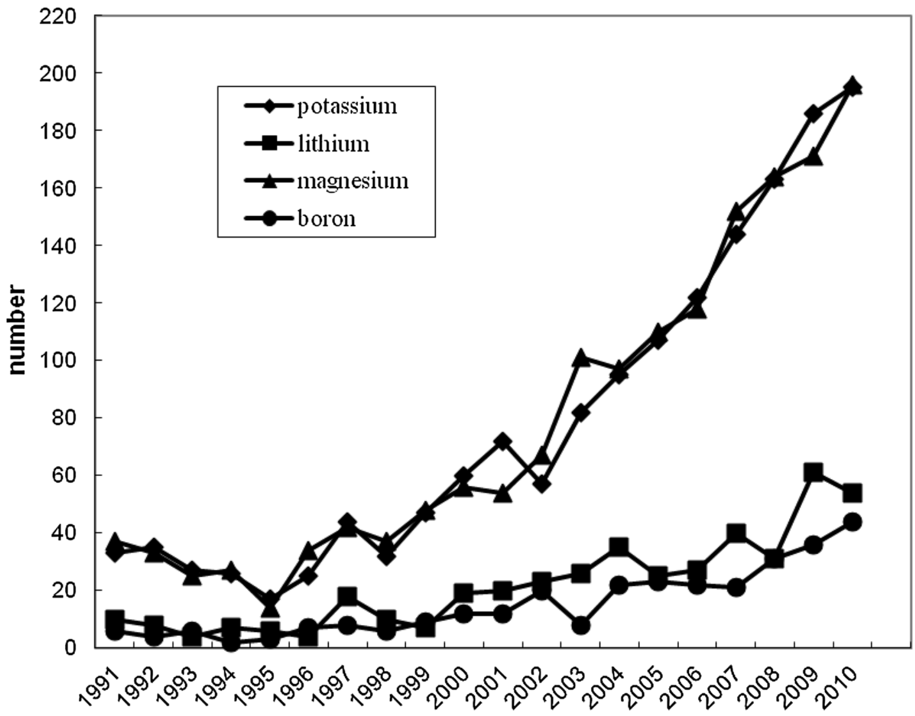


**Fig. 2** R&D Domains of salt lake resources

From 1991 to 2010, salt lake resources R&D evolved into two plates, potassium—magnesium and lithium—boron (see Fig. 2). Generally speaking, the two plates are both experiencing growth, and especially after the year 2000. Since 1998, the quantity of patents issued which relate to potassium–magnesium increased more quickly than those issued with regard to lithium–boron. In 1998, the quantity of patents issued relating to potassium–magnesium was over three times the patents issued which related to lithium–boron. As time goes on, the gap between the two plates is becoming more and more remarkable. It can be demonstrated that the development of new energy forms is pushing the development of salt lake resources R&D.

## Position of China in the R&D of salt lake resources

From 1991 to 2010, a total of only 19 patent assignees were issued more than 10 patents in the whole period. Of those 19, nine of them are from Japan, six are from the USA, and the remainder come from India, China, Germany and France, respectively (see Table 2). The nine Japanese assignees own 113 patents between them, and the six American assignees own 152 patents. Halliburton Energy Services Inc., from the USA, owns 58 patents and ranks in the top position. In comparison, the Qinghai Institute of Salt Lakes Chinese Academy of Sciences owns 27 patents in the field of salt lake resources, and ranks fourth.

From the quantities of both patent assignees and the number of patents issued, we can draw the reasonable conclusion that Japan and the USA have the absolute advantage in this field. Only one Chinese organization is listed in Table 2. Therefore, it is clear that China lags far behind in salt lake resource technology R&D. As far as organization types are

**Table 2** Patent assignees distribution of salt lake resources R&D

| No. | Patent assignee | Country | Number of patents |
|---|---|---|---|
| 1. | Halliburton Energy Services Inc. | USA | 58 |
| 2. | Baker Hughes Incorporated | USA | 39 |
| 3. | Council of Scientific and Industrial Research | India | 27 |
| 4. | Qinghai Institute of Salt Lakes Chinese Academy of Sciences | China | 27 |
| 5. | Kao Corp | Japan | 17 |
| 6. | BASF SE | Germany | 16 |
| 7. | JFE Steel Corp | Japan | 15 |
| 8. | Matsushita Electric Industrial Co Ltd | Japan | 15 |
| 9. | Cargill Incorporated | USA | 13 |
| 10. | Schlumberger Technology Corporation | USA | 13 |
| 11. | Toray Industries Inc | Japan | 12 |
| 12. | BJ Services Company | USA | 11 |
| 13. | Japan Polypro Corp | Japan | 11 |
| 14. | Mitsui Chemicals Inc | Japan | 11 |
| 15. | Nippon Steel Corp | Japan | 11 |
| 16. | Sumitomo Metal Mining Co Ltd | Japan | 11 |
| 17. | MILLC | USA | 18 |
| 18. | Services Petroliers Schlumberger | France | 10 |
| 19. | Sumitomo Chemical Company Limited | Japan | 10 |

concerned, the listed organizations in Table 2 are all enterprises and companies, except for the sole Chinese organization, which is an institute. These figures are also evidence that China stands in a disadvantaged position in the implementation of related research and technology.

## Collaboration status of R&D groups of China

### Establishment of a collaboration network

Since 2000, the quantity of patents issued in the salt lake field has boomed. So in this paper, we pay close attention to the collaboration status of Chinese R&D groups during the rapid growth period from 2001 to 2010. Our aim is to find an appropriate path for China to follow to fully take advantage of its own national salt lake resources.

After data cleaning, the articles collected from the CAJD and SCIE for the period from 2001 to 2010 were separately analyzed via network analysis. We constructed two research collaboration networks of the scholars named in these articles, namely a domestic collaboration network and an international collaboration network. The nodes of the research collaboration network represent scholars. A link between two nodes represents a publication co-authorship relationship between those scholars. It is supposed that each author in the same article made the same contribution to that article. The relationship strength between them is equal. Collaboration frequency between authors is ignored (Yuan and Wang 2010). We are only concerned with whether or not the authors are linked to each other by co-authorship. We then assign 1 to the element in the collaboration adjacency matrix (an $n$ by $n$ matrix A, where n is the number of scholars); otherwise, the element is 0. Based on this method, we built two collaboration network matrixes for domestic and international co-authorship networks.

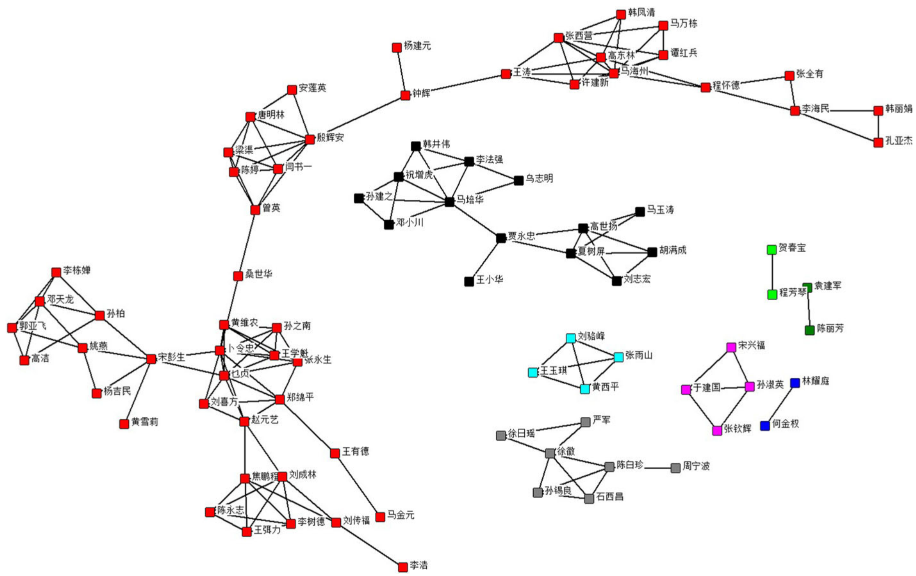


**Fig. 3** Visualization of a domestic collaboration network based on CAJD

## Network attributes analysis

After preparing the network matrix, we used UCINET (Borgatti et al. 2002) as a tool for visualizing the collaboration networks and identifying the network attributes in the field of salt lake resources R&D in China.

### *Visualization of collaboration networks*

*Collaboration network based on CAJD* For domestic journal articles from the **CAJD**, we selected the core authors who published more than three articles (≥4), and there are 91 nodes (see Fig. 3).

The collaboration network in the field of salt lake resources R&D is an undirected network, and there exist six isolated nodes (deleted in Fig. 3, so there are actually only 85 nodes). In a perfect connected network only, each pair of nodes are linked by certain relationships in order to communicate. As a result, information and knowledge flow and are shared among the whole network. Therefore, the collaboration network we built is not a perfect connected network, because some of the authors did not collaborate within the set of authors having four papers or more.

The entire network is composed of 14 subgroups, including six single nodes. Their type and structure are shown in Table 3.

Although we only take core authors into consideration, there are still six isolated nodes. To explain clearly, these six authors did not collaborate within the set of authors having four papers or more. This single-node type subgroup occupies over 42 % of the different types of subgroups. There are three double-node subgroups and five multi-node subgroups. These figures show that groups of differing size and scale have been formed to research the field of salt lake mining in China. The largest subgroup is composed of 50 nodes and therefore occupies nearly 55 % of all nodes in the entire network. The second largest subgroup is composed of fourteen authors. The research of these eight sub-groups should be the backbone of and force behind salt lake mining in China. These groups may play an important role in the field.

**Table 3** Type and structure of subgroups

| Subgroup type | Quantity | Percentage (%) number of node/total nodes |
|---|---|---|
| Single node | 6 | 6.6 |
| Double node | 3 | 6.6 |
| Multi-node | | |
| 4 | 2 | 8.8 |
| 7 | 1 | 7.7 |
| 14 | 1 | 15.4 |
| 50 | 1 | 54.9 |
| Total | | |
| 91 | 14 | 100 |

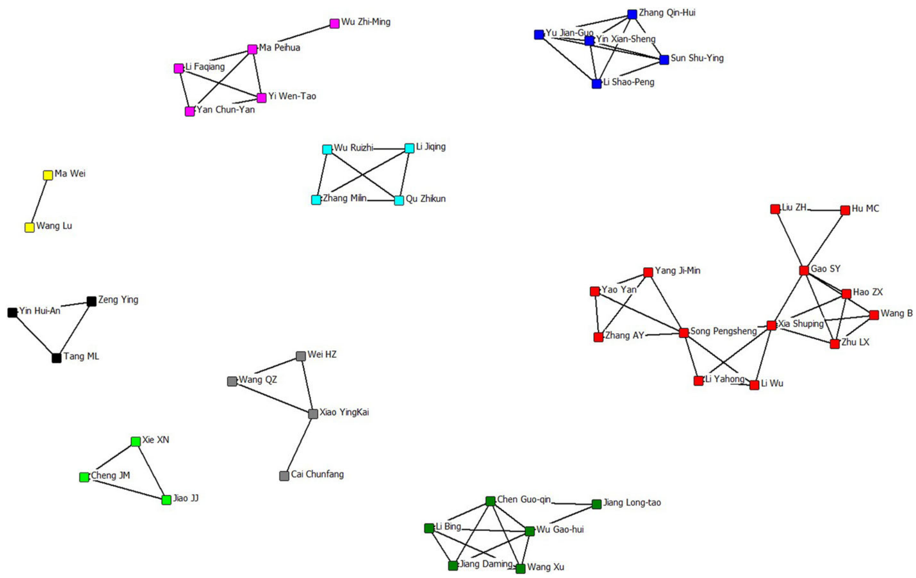


**Fig. 4** Visualization of a domestic collaboration network based on SCIE

*A collaboration network based on SCIE* For international publications from SCIE, we selected authors who published more than one article ($>1$), and there are 53 nodes (see Fig. 4).

There exist eight isolated nodes which have been deleted in Fig. 4, so there are actually 45 nodes in total in this collaboration network. The entire network is composed of 17 subgroups, including eight single nodes. Their type and structure are shown in Table 4.

The eight isolated nodes did not build a co-author relationship with others. The scale of these sub-groups, excluding the isolated nodes, is evenly distributed. The number of three-node, four-node and five-node subgroups is two, and the number of double-node, six-node and thirteen-node subgroups is one. Compared to a network based on the CAJD, the scale

**Table 4** Type and structure of subgroups

| Subgroup type | Quantity | Percentage (%) number of nodes/total nodes |
|---|---|---|
| Single node | 8 | 15.2 |
| Double node | 1 | 3.8 |
| Multi-node | | |
| 3 | 2 | 11.4 |
| 4 | 2 | 15.0 |
| 5 | 2 | 18.8 |
| 6 | 1 | 11.3 |
| 13 | 1 | 24.5 |
| Total | | |
| 53 | 17 | 100 |

of the largest subgroup is sharply reduced, from 50 to 13. This subgroup only contains 24.5 % of the total nodes. From this viewpoint, it is apparent that international research groups are emerging in this field.

Generally speaking, collaboration networks based on the CAJD and SCIE show that, in China several research groups have been formed to explore the mining of salt lake resources. The scale of subgroups from native language publications (CAJD) is much larger than that from international publications (SCIE). Collaboration is mostly still confined to the domestic scene; cross-national collaboration has not yet started to grow.

## Cohesion analysis

Cohesion is used to characterize the closeness of inter-relationships in the network. Cohesion includes several indexes, including density, distance-based cohesion and so on. The value of density ranges from 0 to 1. When the density is approaching 1, the network relationship is close, while when the density approaches 0, the relationship is loose. Larger distance-based cohesion indicates greater cohesiveness.

The cohesion analysis results are shown in Table 5. The density of a collaboration network, based on CAJD, is 0.1336, which is slightly greater than that of a collaboration network based on SCIE, which is 0.1205. The average distance of the former is 5.039. The latter is much shorter, at 1.697, while the former's distance-based cohesion is 0.106, greater than the latter's at 0.070. Therefore, a collaboration network based on CAJD has greater cohesiveness than a collaboration network based on SCIE. Among those networks based on CAJD, there is a relative close relationship, which is helpful with regard to the sharing and communication of knowledge.

## Centrality analysis

Closeness centrality is only applied to a perfect connected network. Our collaboration network does not meet this requirement, so only degree centrality (Figs. 5, 6; Table 6) and betweenness centrality (Figs. 7, 8; Table 7) are analyzed in the following.

The node size in the distribution figure is positively related to the degree centrality. The maximum degree of a collaboration network based on CAJD is 58; the minimum is 0, and the mean is 12.022. Conversely, the maximum degree of a collaboration network based on SCIE is 20; the minimum is 0, and the mean is 6.264. The former has a bigger degree than that of the latter.

For both figures, nodes with a larger degree tend to be found in larger sub-groups. That is because, in the larger groups, nodes have a higher probability of building a collaboration

**Table 5** Cohesion of collaboration networks

| | Collaboration network based on CAJD | Collaboration network based on SCIE |
|---|---|---|
| Network scale (number of node) | 91 | 53 |
| Density | 0.1336 | 0.1205 |
| Average distance | 5.039 | 1.697 |
| Distance-based cohesion | 0.106 | 0.070 |

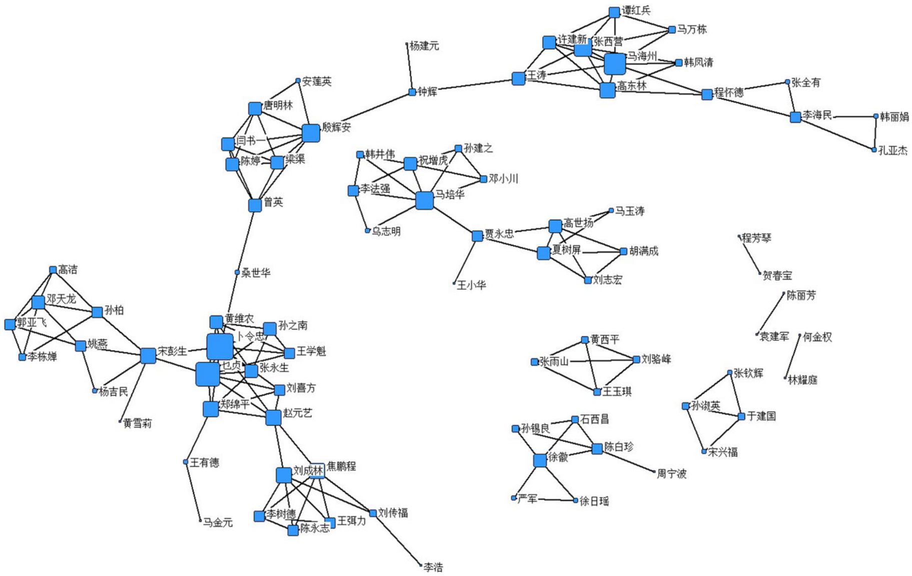


**Fig. 5** Distribution of degree centrality of a collaboration network based on CAJD

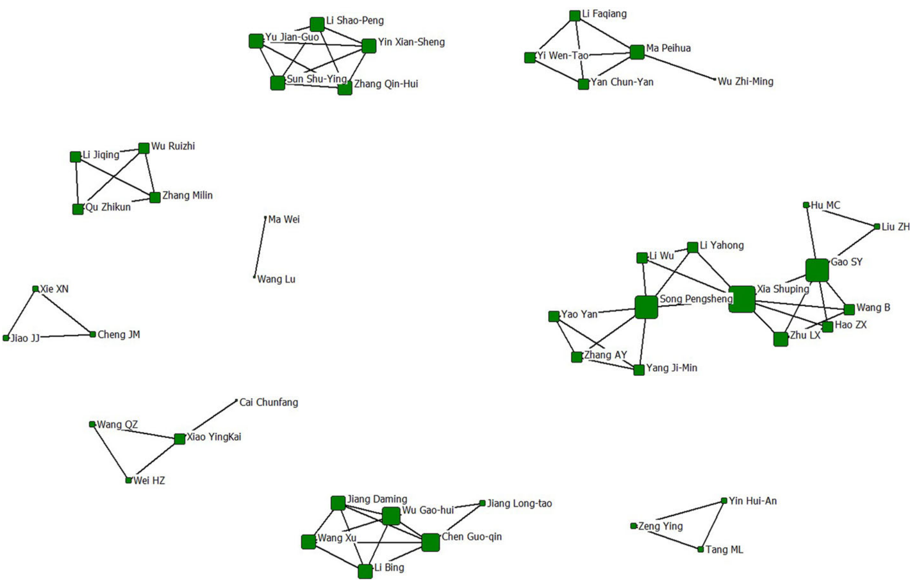


**Fig. 6** Distribution of degree of a collaboration network based on SCIE

with others. In larger groups, a hierarchy degree exists. As far as smaller groups are concerned, degree distribution is relatively even. Researchers with high degree should be the leaders in the research groups (Qiu and Wu 2011), they occupy the upper layer in the pyramid structure.

**Table 6** Result of degree centrality

| | Collaboration network based on CAJD | | Collaboration network based on SCIE | |
|---|---|---|---|---|
| | Degree centrality | | Degree centrality | |
| | Absolute | Normalized | Absolute | Normalized |
| Mean | 12.022 | 0.668 | 6.264 | 1.721 |
| Std Dev | 11.915 | 0.662 | 5.324 | 1.463 |
| Minimum | 0 | 0 | 0 | 0 |
| Maximum | 58 | 3.222 | 20 | 5.495 |

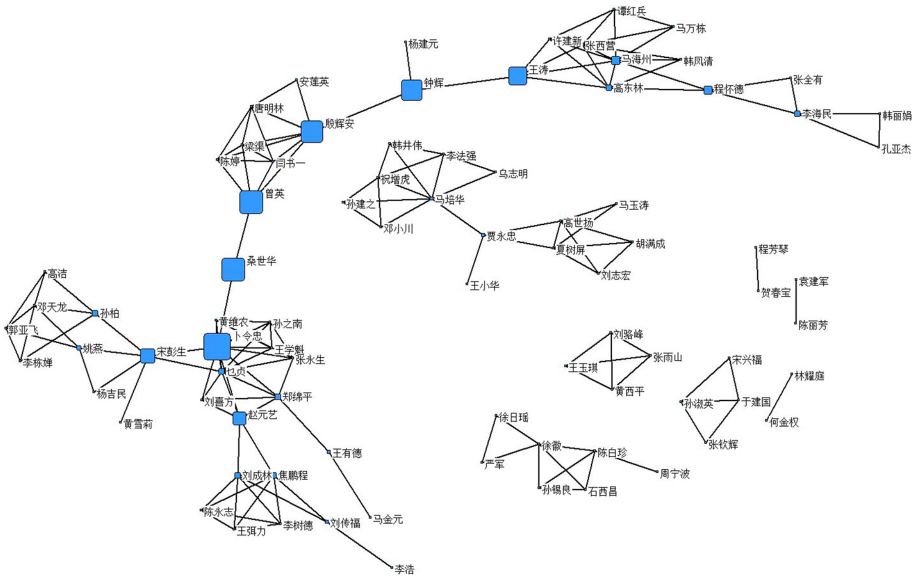


**Fig. 7** Distribution of betweenness centrality of a collaboration network based on CAJD

The maximum betweenness centrality of a collaboration network based on CAJD is 58; the minimum is 0, and the mean is 12.022. On the other hand, the maximum betweenness centrality of a collaboration network based on SCIE is sharply reduced at just 20; the minimum is still 0, and the mean is 6.264. Only three nodes in the network based on SCIE have relatively greater betweenness centrality. Therefore, we can say that a domestic collaboration network has been formed with a collaboration core, while the international collaboration network's collaboration core is still at an embryonic stage of development. Betweenness centrality is an index that shows to what degree an author plays the role of an intermediary. Without those bigger-sized nodes, sub-groups will fracture into even smaller sub-groups containing fewer nodes. The lack of an intermediary should influence the carrying out of cooperation; it goes against the communication of information and sharing of thoughts between different groups of scholars. When the objective is to form a large collaboration network, it is important to strengthen the culture of the intermediary, and thus make trans-university, trans-organization and trans-enterprise collaborative R&D possible.

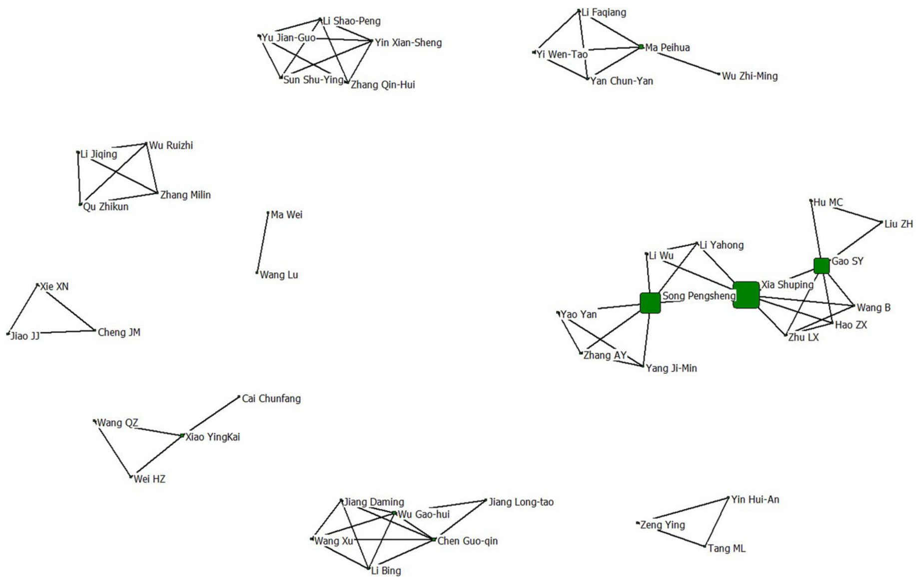


**Fig. 8** Distribution of betweenness centrality of a collaboration network based on SCIE

**Table 7** Result of betweenness centrality

| | Collaboration network based on CAJD | | Collaboration network based on SCIE | |
|---|---|---|---|---|
| | Betweenness centrality | | Betweenness centrality | |
| | Absolute | Normalized | Absolute | Normalized |
| Mean | 12.022 | 0.668 | 6.264 | 1.721 |
| Std Dev | 11.915 | 0.662 | 5.324 | 1.463 |
| Minimum | 0 | 0 | 0 | 0 |
| Maximum | 58 | 3.222 | 20 | 5.495 |

## Conclusions

Based on the quantity of assignees and the number of patents issued, China lags far behind the USA and Japan. This should not be the case, given China's inherent advantage in salt lake resources.

Cohesion and centrality analysis results of collaboration networks based on CAJD and SCIE show that domestic research groups in China are of a larger scale and have a more compact and reasonable structure than the research groups abroad. Research groups are also more competitive at home than they are abroad.

China should make a greater effort to develop its salt lake resource R&D. More supporting policies and greater investment should be invested into the development and application of salt lake resources, and a combined effort from industry, academies and researchers should be encouraged. An R&D platform can be built by the government to support fundamental research and transform research achievements into commercial applications. R&D groups and leaders should be encouraged to improve communication and cooperation, especially abroad. Important fields ought to be made clear and definite. This could be done by establishing demonstration projects. Only through these measures can China realize the comprehensive development and effective, recyclable utilization of its salt lake resources. These measures would also help China and its researchers to own more proprietary intellectual property rights, form R&D fields with Chinese characteristics, and transform the country's resource superiority into a practical technological advantage.

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