

# Research on the Classification of Air-Rail Integrated Hubs in Northwest China Based on Complex Network Theory

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**Abstract:** With the deepening implementation of the “Transportation Power” strategy, air-rail intermodal transport, as a crucial component of the modern comprehensive transportation system, plays a significant role in promoting regional coordinated development. Based on complex network theory, this study focuses on Northwest China, constructing a freight network model comprising 24 air-rail intermodal nodes. It comprehensively evaluates node importance from four dimensions: degree centrality, betweenness centrality, closeness centrality, and eigenvector centrality. Incorporating indicators such as cargo and mail throughput and high-speed rail connection strength, the study applies systematic clustering to classify hub cities into hierarchical levels. The results indicate that the air-rail intermodal network in Northwest China exhibits a four-tier structure: “Core-Regional-Potential-General”. Xi’an and Urumqi are identified as primary core hubs, Lanzhou and Xining as secondary regional hubs, while the remaining cities are categorized as potential hubs or general nodes based on their centrality scores. The findings provide a theoretical basis and practical reference for the planning, construction, and optimal resource allocation of air-rail intermodal hubs in Northwest China.

**Keywords:** Complex Network; Air-rail Intermodal Transport; Comprehensive Hub; Systematic Clustering; Northwest China.

## 1. Introduction

With the launch of China’s new phase of transportation construction and the implementation of the “Transportation Power” and “National Comprehensive Three-Dimensional Transportation Network” planning initiatives, building a modern, high-quality national comprehensive three-dimensional transportation network that is convenient, smooth, cost-effective, green, intensive, intelligent, advanced, safe, and reliable has increasingly become a critical issue requiring urgent resolution, holding significant practical importance. In this process, air-rail intermodal transport has gradually gained attention. It breaks down industry barriers, skillfully integrates the speed of air transport with the extensive coverage of the railway network, and integrates deeply into local economic frameworks, providing an ideal transportation solution for various types of passengers and cargo. Units in Northwest China’s civil aviation sector have also thoroughly implemented the “Strategic Cooperation Agreement on Promoting High-Quality Development of Air-Rail Intermodal Transport” signed by the Civil Aviation Administration and China State Railway Group, as well as the jointly issued “Key Task List for Promoting High-Quality Development of Air-Rail Intermodal Transport (2025-2027)”. They have innovatively developed air-rail intermodal products to meet passenger and cargo transportation demands through high-quality advancements, thereby contributing to the high-quality development of civil aviation and railway services in Northwest China.

China’s Northwest region serves as the core area of the Silk Road Economic Belt and a vital corridor, trade and logistics hub, industrial cooperation platform, and cultural exchange base for countries in Central, South, and West Asia. It boasts prominent strategic importance and significant development potential. In recent years, the Northwest region has continued

to accelerate its development pace; however, it still lags behind the eastern coastal and central regions in certain aspects. Among these, disparities in transportation conditions between the eastern and western parts of China represent one of the key factors contributing to regional economic and social development imbalances. Compared to the relatively mature air-rail intermodal systems in developed regions, the Northwest region still exhibits notable shortcomings in multiple areas, such as an underdeveloped intermodal system and insufficient cargo terminal handling equipment. Against this backdrop, scientifically delineating a multi-level hub network for air-rail intermodal transport in the Northwest region has become a crucial prerequisite for advancing the construction and improvement of multimodal transport infrastructure systems. Rationally defining the hierarchy and functional positioning of air-rail intermodal hub cities will not only enhance cargo distribution and consolidation efficiency but also achieve economies of scale, reduce comprehensive logistics costs, and thereby promote coordinated regional economic development, facilitating the Northwest region’s accelerated integration into the new development paradigm.

Currently, scholars both domestically and internationally have conducted multi-faceted research on the construction and classification of air-rail intermodal network hubs. In developed countries such as those in Europe and America, the development of air-rail intermodal networks is relatively mature, with substantial practical experience accumulated. Early theoretical research primarily focused on the location and layout of intermodal hubs. For instance, Arnold et al. [1] proposed integer programming models and heuristic algorithms, providing a methodological basis for hub location in rail and road transport nodes. Vasconcelos et al. [2] studied the hub location problem in uncapacitated transportation networks under decentralized management systems. Alumur et al. [3] explored hub classification issues from the perspective of multimodal transport networks, constructing a

network model incorporating multiple transportation modes based on actual data from Turkey. Reza et al. [4] proposed a hub classification method by developing mathematical models and verified its broad applicability. In contrast, domestic research has mainly focused on predicting the scale of multimodal transport hubs and their influencing factors. For example, Zhang et al. [5] analyzed problems in the logistics system and their influencing factors, constructing an evaluation index system and classifying central cities, with a case study on 12 key cities in the Yangtze River Delta region. Li [6], drawing on domestic and international hub classification methods and standards, developed a classification system for external hubs based on Suzhou's transportation characteristics and urban development plans, providing a reference for domestic comprehensive transportation hub research; Liu et al. [7] proposed a classification method and planning layout ideas for comprehensive passenger transport hubs.

A comprehensive analysis of existing research reveals that international studies on multimodal transport hubs predominantly focus on micro-level aspects, such as hub location, layout optimization, and optimal transport path selection. In contrast, domestic research has primarily concentrated on economically developed regions, with systematic studies on the hierarchical classification of multimodal transport network hubs in Western China remaining relatively scarce. Although the Medium and Long-Term Plan for the Comprehensive Transport Network designates 42 national comprehensive transport hubs, the hierarchical classification of regional and local hubs remains insufficient. It should be noted that national comprehensive transport hubs are typically defined at the city level. Depending on their scale, spatial structure, and transport network characteristics, each hub city may host one or multiple physical comprehensive transport hub facilities. The concept of a "comprehensive transport hub" is broad in scope, potentially referring to a province, a city, or even a specific station within a city, encompassing both passenger and freight functions. The air-rail intermodal network hubs examined in this study specifically refer to freight hubs equipped with both railway and air transport capabilities. The research emphasizes the macro-level construction of a hierarchical hub system for the air-rail intermodal network in Northwest China, aiming to provide a foundation for the subsequent layout and positioning of multimodal transport facilities. Given the inherent complexity of air-rail intermodal networks, this paper employs complex network theory to model the air-rail freight intermodal network in Northwest China and conducts an empirical analysis of its basic topological properties. Furthermore, by establishing an evaluation index system for air-rail freight transfer nodes, cities with high hub importance are identified. Subsequently, systematic clustering analysis is applied to clarify the hierarchical classification of hubs, with the objective of providing decision-making references for the planning, construction, and investment in transport facilities in these hub cities.

## 2. Overview of the Study Area

Currently, air-rail intermodal transport in Northwest China is breaking through the traditional boundaries of geography and transport modes, demonstrating distinct regional characteristics and innovative vitality. Among them, Xinjiang, leveraging its unique geographical advantages, is focused on building an international cross-border intermodal hub. By

operating the nation's first "Railway + Aviation" cross-border freight train and actively exploring "Single-Consignment Note" services, it has not only reduced the transit time of international supply chains by over 15% but also established a new, efficient logistics paradigm characterized by "one-time entrustment, one set of documents, and one-time settlement." Simultaneously, Shaanxi, centered around Xi'an, is concentrating on domestic distribution and the deep integration of airport and dry port operations. Building upon the synergistic advantages of the China-Europe Railway Express assembly center and Xi'an Xianyang International Airport, it has significantly shortened regional commuting times and, empowered by intelligent transport systems, is driving a comprehensive improvement in regional logistics network efficiency. As a crucial pivot in the Northwest land corridor, Gansu is actively promoting the air-rail connection between Lanzhou International Land Port and Zhongchuan International Airport, aiming to build a logistics transfer hub for Central and South Asia. Qinghai, relying on the coordination between Xining Caojiapu Airport and the Qinghai-Tibet Railway, is expanding transport channels for plateau-specific products and exploring green intermodal models that meet ecological conservation requirements. Ningxia, utilizing the synergy between Yinchuan Hedong Airport and the Baotou-Lanzhou Railway, is promoting the development of regional cold chain and e-commerce logistics, strengthening its transfer function for North China and the Silk Road Economic Belt.

Behind these achievements lies robust policy support from the national to local levels, as well as the core driving force provided by cutting-edge technologies like blockchain and big data in enabling the "Single-Consignment Note" system. However, the further development of air-rail intermodal transport in the Northwest still faces core challenges such as the seamless connectivity of infrastructure, uneven network coverage, and the scalable promotion of business models. This necessitates continued efforts to deepen collaborative mechanisms and optimize the hub-and-spoke network structure to truly unleash the synergistic effects of multimodal transport.

According to administrative boundary data, the study covers 51 airports and 51 cities/districts across 5 provinces and autonomous regions. The distribution, categorized by prefecture-level cities, is shown in Fig. 1.

## 3. Analysis of Air-Rail Intermodal Hub Importance in Northwest China

### 3.1. Preliminary Screening of Hubs in the Northwest Air-Rail Intermodal Network

An air-rail intermodal freight network is a freight transportation framework primarily constructed using aviation and high-speed rail as the main modes of transport. Within this network, hubs undertake core functions such as cross-regional and cross-modal cargo collection, transfer, and distribution, serving as critical facility nodes for achieving efficient intermodal operations. As key nodes in the intermodal network, air-rail intermodal hubs must possess extensive coverage and strong cargo consolidation and distribution capabilities to handle large-scale freight flows. Furthermore, as the network develops, these core hubs will further evolve into critical transfer nodes for extra-regional logistics transportation, promoting the formation of a comprehensive freight hub system. To systematically identify

potential hub sets in Northwest China, this study conducts a preliminary screening of cities that have both airports and high-speed rail stations, based on intermodal transport infrastructure conditions. The results are shown in Table 1. Due to the unique plateau environment of the study area, this paper also defines some cities with stations served by trains prefixed with “C” or “D” as cities possessing “high-speed rail stations”.



Fig 1. Airport distribution map

Table 1. Hub candidate set

Number	Airport	High-speed Rail Station	City
1	Xianyang Airport	Xi'an North Station	Xi'an
2	Chenggu Airport	Hanzhong Station	Hanzhong
3	Nanniwan Airport	Yanan Station	Yanan
4	Zhongchuan Airport	Lanzhou West Station	Lanzhou
5	Mogao Airport	Dunhuang Station	Dunhuang
6	Jiuquan Airport	Jiyuguan South Station	Jiyuguan
7	Qingyang Airport	Qingyang Station	Qingyang
8	Maijishan Airport	Tianshui South Station	Tianshui
9	Ganzhou Airport	Zhangye West Station	Zhangye
10	Chengxian Airport	Longnan Station	Longnan
11	Hedong Airport	Yinchuan Station	Yinchuan
12	Shapotou Airport	Zhongwei South Station	Zhongwei
13	Caojiapu Airport	Xining Station	Xining
14	Golmud Airport	Golmud Station	Golmud
15	Delingha Airport	Delingha Station	Delingha
16	Qilian Airport	Menyuan Station	Haibei
17	Tianshan Airport	Urumqi Station	Urumqi
18	Guhai Airport	Karamay Station	Karamay
19	Jiaohe Airport	Turpan North Station	Turpan
20	Yizhou Airport	Hami Station	Hami
21	Yining Airport	Yining Station	Yining
22	Huayuan Airport	Shawan City Station	Shawan
23	Alashankou Airport	Bole Station	Bole
24	Licheng Airport	Korla Station	Korla

As shown in the table above, due to the vast territory of Qinghai Province and Xinjiang Uygur Autonomous Region, multiple airports have been constructed within some of their administrative divisions. For research purposes, this study

categorizes such airports under the prefecture-level cities they belong to for analysis.

### 3.2. Analysis of Aviation and High-Speed Rail Network

A complex network consists of nodes and edges. In the air-rail intermodal network studied in this paper, each city is regarded as a node, and the transportation routes between cities are regarded as edges. Therefore, the nodes in this study are the 24 cities screened and listed in Table 1, and the transportation routes between these 24 cities constitute the edges.

Based on historical inter-city flight route data, the connectivity relationships among the 24 airports can be obtained. Using the UCINET network analysis tool, the results are visualized as shown in Fig. 2.

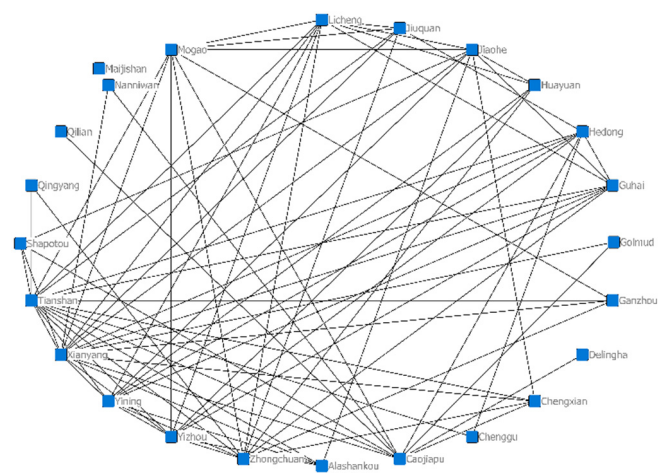


Fig 2. Aviation network among initially screened city nodes

Subsequently, the connectivity relationships of high-speed rail lines among the 24 high-speed rail stations were obtained through statistics from the official 12306 website. Similarly, the UCINET network analysis tool was used for visualization, as shown in Fig. 3.

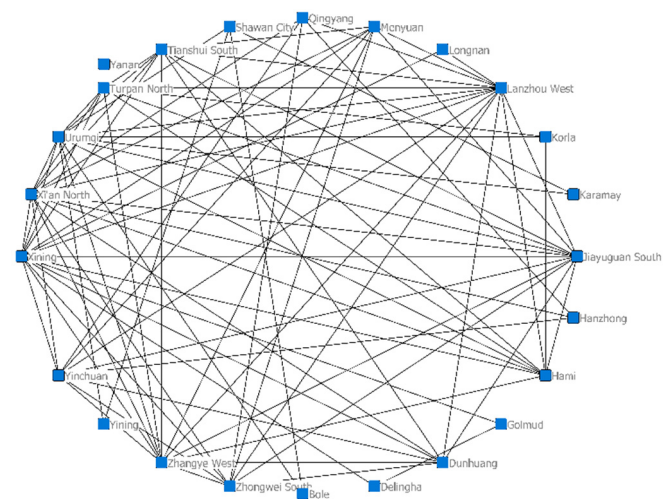


Fig 3. High-speed rail network among initially screened city nodes

Through the analysis of the aviation and high-speed rail networks of the 24 initially screened cities, we found that the traffic flow in the five northwestern provinces exhibits a high degree of “intra-provincial” characteristics. That is, transportation activities are primarily internal cycles, with Qinghai and Xinjiang being particularly notable, while inter-



In matrix form, this is expressed as:

$$\lambda \mathbf{x} = \mathbf{A} \cdot \mathbf{x} \quad (7)$$

Here,  $\mathbf{x}$  is the eigenvector of matrix  $\mathbf{A}$ , and  $\lambda$  is its corresponding eigenvalue. Typically, we take the eigenvector corresponding to the principal eigenvalue (i.e., the largest eigenvalue) as the eigenvector centrality value for each node.

To better align with the research perspective of air cargo, the analysis of the aviation network additionally introduces cargo and mail throughput as a supplementary indicator to

enhance the applicability of the comprehensive evaluation. For the high-speed rail network, due to the difficulty in obtaining freight data, this paper introduces the average daily train frequency as a proxy indicator to more comprehensively measure its hub centrality, reflecting the connection strength and service frequency of nodes within the network. The centrality metrics for the aviation and high-speed rail networks, calculated using UCINET software, are presented in Table 2 and Table 3, respectively.

**Table 2.** Centrality metrics of the aviation network

Airport	Degree Centrality	Betweenness Centrality	Closeness Centrality	Eigenvector Centrality	Cargo and Mail Throughput
Xianyang Airport	0.69565	0.18996	0.44231	0.50131	1
Chenggu Airport	0.08696	0	0.31944	0.08831	0.00151
Nanniwan Airport	0.08696	0	0.32857	0.08146	0.00138
Zhongchuan Airport	0.47826	0.05174	0.37705	0.3735	0.29611
Mogao Airport	0.3913	0.03486	0.38983	0.35318	0.00587
Jiuquan Airport	0.26087	0.00334	0.35938	0.26914	0.00818
Qingyang Airport	0.08696	0	0.32394	0.0961	0.00102
Maijishan Airport	0	0	0	0	0.00001
Ganzhou Airport	0.17391	0.0011	0.34848	0.18915	0.00129
Chengxian Airport	0.21739	0.01215	0.36508	0.21212	0.00015
Hedong Airport	0.34783	0.03963	0.38333	0.30198	0.15813
Shapotou Airport	0.17391	0.0048	0.35938	0.17144	0.00382
Caojiapu Airport	0.43478	0.19987	0.38983	0.24673	0.12835
Golmud Airport	0.08696	0	0.32857	0.08146	0.00343
Delingha Airport	0.04348	0	0.2875	0.02687	0.00088
Qilian Airport	0.04348	0	0.2875	0.02687	0.00032
Tianshan Airport	0.69565	0.19558	0.44231	0.50894	0.81199
Guhai Airport	0.34783	0.00687	0.37097	0.35296	0.00419
Jiaohe Airport	0.3913	0.02954	0.36508	0.31734	0.00045
Yizhou Airport	0.43478	0.02088	0.38333	0.40455	0.00232
Yining Airport	0.43478	0.02062	0.38333	0.40103	0.02894
Huayuan Airport	0.21739	0.00151	0.32394	0.21006	0.00127
Alashankou Airport	0.26087	0.0017	0.35938	0.2794	0.00091
Licheng Airport	0.47826	0.02382	0.38983	0.43249	0.03207

**Table 3.** Centrality metrics of the high-speed rail network

High-speed Rail Station	Degree Centrality	Betweenness Centrality	Closeness Centrality	Degree Centrality	Connection Strength
Xi'an North Station	0.6087	0.10314	0.42593	0.46213	1
Hanzhong Station	0.13043	0	0.31507	0.09379	0.43243
Yanan Station	0	0	0	0	0.05946
Lanzhou West Station	0.6087	0.08746	0.42593	0.46172	0.41351
Dunhuang Station	0.34783	0.00113	0.35385	0.32145	0.00541
Jiyuguan South	0.52174	0.02481	0.41071	0.4393	0.05405
Qingyang Station	0.21739	0.00343	0.32857	0.16398	0.16216
Tianshui South	0.43478	0.01103	0.39655	0.37997	0.37027
Zhangye West Station	0.52174	0.02481	0.41071	0.4393	0.07027
Longnan Station	0.08696	0	0.31944	0.08916	0.05676
Yinchuan Station	0.43478	0.02546	0.36508	0.3391	0.11622
Zhongwei South	0.3913	0.00741	0.35938	0.33079	0.06757
Xining Station	0.65217	0.21612	0.43396	0.45589	0.15405
Golmud Station	0.08696	0	0.31507	0.04907	0.00541
Delingha Station	0.08696	0	0.31507	0.04907	0.01351
Menyuan Station	0.34783	0.00113	0.35385	0.32145	0.03514
Urumqi Station	0.56522	0.31028	0.41818	0.34575	0.10541
Karamay Station	0.08696	0	0.30667	0.03794	0.01622
Turpan North Station	0.3913	0.01976	0.38983	0.33172	0.05405
Hami Station	0.3913	0.01976	0.38983	0.33172	0.04054
Yining Station	0.08696	0	0.30667	0.03794	0.01622
Shawan City Station	0.17391	0.00593	0.31507	0.04465	0.07568
Bole Station	0.08696	0	0.30667	0.03794	0.01081
Korla Station	0.13043	0	0.31081	0.09806	0.01622

Factor analysis was conducted using SPSS to determine the weight values of each indicator, subsequently enabling the

calculation of comprehensive evaluation scores for each node. To derive the comprehensive evaluation metrics for the air-rail intermodal network, the respective values from the aviation network and high-speed rail network were processed. Within the air-rail intermodal framework, air and high-speed rail transport are considered equally important. Therefore, a weighted average method was adopted to determine the

comprehensive score of air-rail city nodes. The specific calculation formula is: Comprehensive Score of an Air-Rail City Node = Aviation Comprehensive Score × 50% + High-speed Rail Comprehensive Score × 50%. Based on the aforementioned method, the comprehensive air-rail scores and corresponding rankings for each city were calculated, with the results presented in Table 4.

**Table 4.** Comprehensive score of air-rail city node

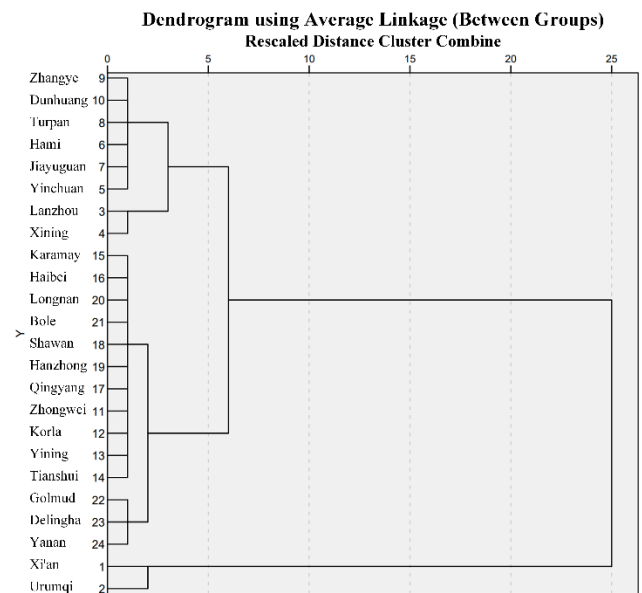
Ranking	City	Total Score	Ranking	City	Total Score
1	Xi'an	0.54479	13	Yining	0.18201
2	Urumqi	0.45605	14	Tianshui	0.17373
3	Lanzhou	0.37562	15	Karamay	0.16288
4	Xining	0.35241	16	Haibei	0.16055
5	Yinchuan	0.2713	17	Qingyang	0.14771
6	Hami	0.26473	18	Shawan	0.14638
7	Jiayuguan	0.26144	19	Hanzhong	0.14551
8	Turpan	0.25109	20	Longnan	0.14461
9	Zhangye	0.24326	21	Bole	0.14377
10	Dunhuang	0.24246	22	Golmud	0.10408
11	Zhongwei	0.20678	23	Delingha	0.09031
12	Korla	0.20396	24	Yanan	0.05326

In the centrality analysis of nodes within the air-rail intermodal network, cities exhibit notably distinct characteristics across different dimensions. Overall, Xi'an, Urumqi, Lanzhou, and Xining demonstrate significantly higher centrality compared to other nodes, indicating their potential to serve as key hubs in constructing the air-rail intermodal network.

#### 4. Hierarchical Cluster Analysis of Air-Rail Intermodal Network Hubs

Hierarchy is one of the fundamental attributes of transportation networks. Within the air-rail intermodal system, the transfer between different transportation modes is often closely related to the hierarchical structure of the network. This inherent hierarchical relationship provides structural support for the coordinated management of multimodal transport. Scientifically and rationally classifying hubs into different hierarchy helps enhance system functionality and improve transport organization efficiency. It is not only a key pathway for optimizing the structure of the air-rail intermodal network but also an effective method for promoting the integrated development of multimodal transport systems.

The research objective of this paper is to achieve a clear hierarchical classification of air-rail intermodal city nodes. Considering the limited number of research subjects and the need for the hierarchical system construction to possess good interpretability and structural intuitiveness, the hierarchical clustering method was selected for analysis. Also known as systematic clustering, hierarchical clustering naturally generates a dendrogram, reflecting the aggregation process of samples from the micro to macro level, which aligns well with the requirements for constructing hub hierarchies in hub-and-spoke logistics networks. Based on the above analysis, this study utilizes the comprehensive evaluation results of hub node centrality. Taking the preliminarily selected 24 hubs as the research subjects, a systematic cluster analysis was conducted using SPSS software, ultimately yielding the cluster dendrogram shown in Fig. 5.



**Fig 5.** Dendrogram

Based on the clustering results shown in the dendrogram, and considering the comprehensive evaluation of node centrality and regional characteristics, the 24 air-rail intermodal city nodes can be divided into four tiers, establishing a “Core-Regional-Potential-General” hub system. Among them, Xi'an and Urumqi are the first to cluster into one group. They significantly lead in various centrality metrics, possess outstanding cargo and mail throughput capacity, and have extensive network coverage and strong control influence, thus being defined as Core Hubs (Primary Axes). Lanzhou and Xining, serving as provincial hubs, have well-developed air-rail facilities and high connection strength, enabling them to undertake regional collection and distribution and transfer functions, forming Regional Hubs (Secondary Axes). Six cities—Yinchuan, Hami, Jiayuguan, Turpan, Zhangye, and Dunhuang—show strengths in certain centrality metrics and possess certain development potential. However, their overall functionality is still constrained by local conditions, allowing them to be categorized as Potential Hubs and included as alternatives within the regional hub scope. The remaining cities are General Nodes with relatively

weaker centrality, primarily responsible for network coverage and basic services. Overall, this clustering result exhibits clear tiers, aligns with reality, and effectively reflects the functional structure of air-rail intermodal nodes in the Northwest region. To further visually present the spatial distribution characteristics of the hubs, this study utilized ArcGIS to visualize the distribution of hubs within the hub-and-spoke network of the Northwest region's air-rail intermodal system, with the result shown in Fig. 6.

## 5. Conclusion

This study systematically classified the air-rail intermodal hubs in the Northwest region based on complex network theory, utilizing centrality metrics and hierarchical clustering methods. By developing air and high-speed rail network models, we comprehensively evaluated the hub functions of node cities, ultimately establishing a four-tier hub system comprising "Core-Regional-Potential-General" hubs. Xi'an and Urumqi, leveraging their highly concentrated transport resources and strong network control capabilities, emerged as core hubs of the air-rail intermodal network. Lanzhou and Xining function as regional hubs, demonstrating strong collection, distribution, and transfer capabilities. Cities such as Yinchuan and Hami possess certain development potential and can be cultivated as potential hubs, while the remaining cities primarily undertake basic service functions. This classification system not only reveals the structural characteristics of the Northwest region's air-rail intermodal network but also provides scientific support for subsequent hub station layout planning, transport organization optimization, and regional coordinated development. Future research could further incorporate dynamic data such as freight flow and economic linkages to deepen the exploration of the air-rail intermodal network's evolution mechanisms and optimization pathways.

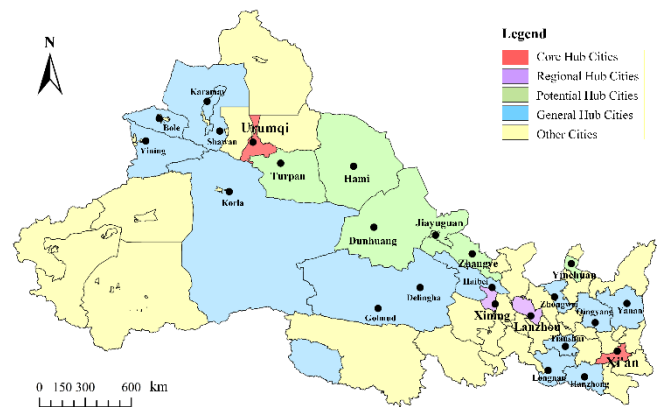


Fig 6. Spatial distribution of clustering results

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