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Research Article

Visual Analysis of Research Hotspots and Trends of Infectious Disease Prevention and Control at Ports in China

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Abstract

Objective: This study analyzed the current research status, hot topics, evolutionary trajectory, and future trends in the field of infectious disease prevention and control at ports, so as to provide reference for building a strong defense line of public health security at border ports. Methods: Taking the journal literature related to the prevention and control of infectious diseases at ports included in CNKI from 2005 to 2024 as the research object, CiteSpace software was used to conduct visual analysis of research cooperation, keyword clustering, development context and trend. Results: The study found that the annual publication volume of infectious disease prevention and control at ports showed volatility; there are 71 core authors in this field, but a stable core author group has not yet been formed. Customs at all levels are the absolute main force of infectious disease prevention and control at ports research, but the cooperation between publishing institutions is loose, and the participation of scientific research forces such as universities is insufficient. High-frequency and high-central keywords include health quarantine, ports, infectious diseases, monitoring, quarantine, etc., mainly showing 11 clusters. The research hotspots are divided into four major themes: health quarantine capacity building, epidemic analysis and prevention, biological safety at border ports, and risk monitoring and evaluation. The topics such as digital innovation of epidemic prevention and control, core capacity building path of port public health, biosafety risk assessment, and early warning of epidemic input risk have great potential to become the frontier of future research. Conclusion: The academic exchange mechanism in the field of infectious disease prevention and control at ports should be improved, and scientific research cooperation between customs and universities should be strengthen. It is necessary to speed up the deep integration of new generation technology and port epidemic prevention application scenarios, so as to build a public health security barrier at border ports with scientific and technological innovation.

Keywords

Prevention and Control of Infectious Diseases, Port, Epidemic Situation, Risk, Visual Analysis

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1. Introduction

The prevention and control of infectious diseases at ports is a key link in preventing the risk of cross-border transmission of infectious diseases, ensuring people's health and life safety, and maintaining social security and stability. It is an important part of the national public health system and biosafety system [1]. As the first line of defense to safeguard the security of the country, China's border ports strictly adopt quarantine inspection, infectious disease monitoring, emergency response and other prevention and control measures to effectively block the spread of infectious diseases to the country [2]. At present, under the new development pattern of domestic and international dual circulation, with the more convenient and frequent cross-border flow of personnel and trade, the risk of cross-border transmission of infectious diseases is increasing, which makes the prevention and control of infectious diseases at ports face more severe challenges.

The Chinese government attaches great importance to the prevention and control of infectious diseases at ports. The "Healthy China 2030" Plan Outline proposes to establish a port infectious disease prevention and control system for intelligent monitoring and early warning of global infectious disease epidemic information, which provides an action guide for actively preventing imported infectious diseases. However, due to factors such as climate change, pathogen evolution, and expansion of human activities, the outbreak frequency and transmission speed of emerging infectious diseases have increased significantly, which seriously threatens the safety of the country [3]. According to the monthly report on the risk monitoring of infectious diseases at ports issued by the General Administration of Customs of China, ports are paying close attention to the prevalence of 67 cross-border infectious diseases such as yellow fever, dengue fever and monkeypox [4]. At the same time, in order to continuously improve the level of cross-border trade facilitation and improve the efficiency of customs clearance of personnel and goods, border ports have greatly reduced customs clearance time and actively adopted non-infection clearance methods, which puts forward higher requirements for the prevention and control of cross-border transmission of infectious diseases. In addition, there are still some practical shortcomings in public health management at border ports, such as inaccurate risk control, lack of health quarantine professionals, and weak laboratory testing capabilities, which also makes it still a long way to improve the level of prevention and control of infectious diseases at ports [5, 6]. This paper collects the literature on the prevention and control of infectious diseases at ports in China in the past 20 years, and uses visual maps and bibliometric methods to deeply analyze the hotspots in this research field, so as to reveal the evolution trend of infectious disease prevention and control at ports in China, in order to provide reference for further improving the core competence of port public health.

2. Data Sources and Methods

2.1. Data Sources

The data selected for this study was sourced from the China National Knowledge Infrastructure (CNKI) database, with search keywords including port infectious diseases, port epidemics, port health and quarantine, border infectious diseases, frontier infectious diseases, and imported infectious diseases. The time span was set from 2005 to 2024, and all literature was published in academic journals. According to the above search criteria, 1194 relevant research literature were obtained. The advanced search formula is as follows, TS = (‘port infectious diseases’ or ‘port epidemics’ or ‘port health and quarantine’ or ‘border infectious diseases’ or ‘frontier infectious diseases’ or ‘imported infectious diseases’). After excluding news reports, meeting minutes, work briefings, and articles with missing information or irrelevant research content, 960 valid literature were finally obtained as the research sample for this article and exported in "Refworks" format.

2.2. Research Tools and Methods

This paper uses Excel 2013 to count the annual publication of sample literature and draw graphics, and uses Citespace 6.4. R1 to interpret and visualize the research status and evolution trend. The time span of Citespace is set from January 2005 to December 2024, and the time slice is set to 1 year, the threshold Top N is set to 50, and the graph pruning algorithm is set to pathfinder and pruning sliced networks. The clustering algorithm uses log-likelihood ratio, and other parameters are default settings. The node types are set as author, institution, and keyword, respectively. Through analysis of co-occurrence, clustering, and burst emergence, the structure, distribution, and law of infectious disease prevention and control knowledge at ports are explored.

2.3. Data Sorting

Due to the adjustment of the State Council of China, the entry-exit inspection and quarantine management responsibilities and teams were assigned to the customs as a whole in 2018. Therefore, a large area of changes occurred in the belonging institution of the same researchers, such as Jiangsu entry-exit inspection and quarantine bureau assigned to Nanjing customs. In order to maintain the continuity and objectivity of the analysis of the research institution, this article combines the entry-exit inspection and quarantine bureau in the research institution with the corresponding customs.

3. Results

3.1. Time Series Analysis of the Number of Publications

The annual number of published papers is one of the basic indicators reflecting the degree of academic attention to research topics, reflecting the changing trend of research heat in this field. In this paper, 960 valid literatures from 2005 to 2024 are statistically analyzed, and the annual distribution of the number of publications is shown in Figure 1. Based on the analysis of relevant literature and the data in Figure 1, it can be found that the number of publications in the field of infectious disease prevention and control at ports shows the characteristics of fluctuating changes, and there are four local peaks of publications.

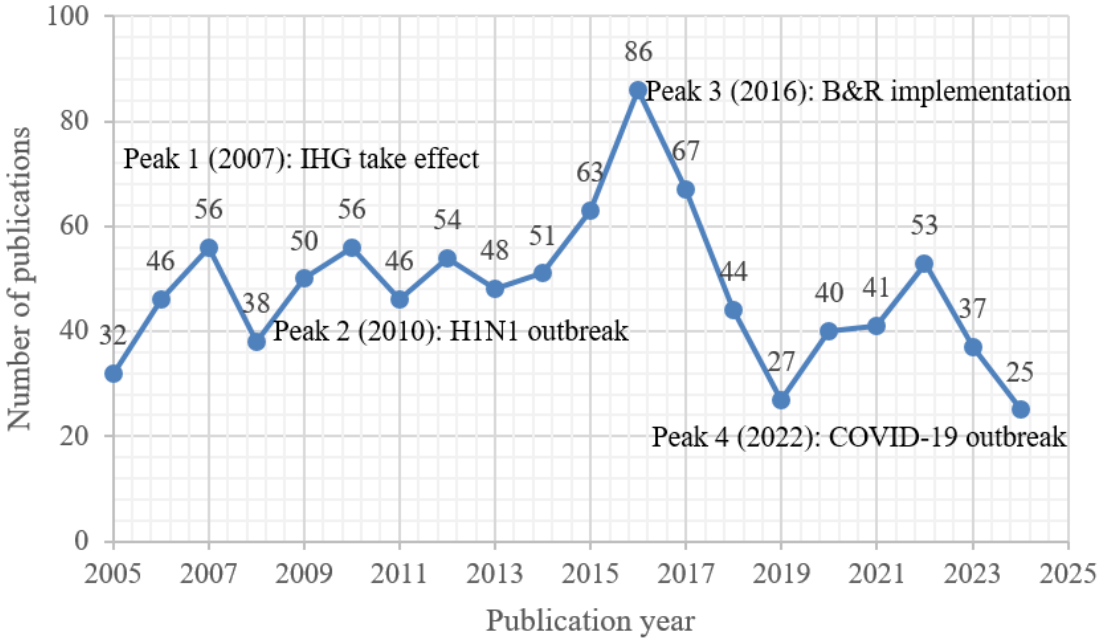

Figure 1. *The trend of infectious disease research publications at ports from 2005 to 2024.*

Specifically, in 2007, the Chinese government made a statement that the "International Health Regulations (2005)"(IHG) was applicable to the whole territory of China, which led scholars to strengthen the research on the construction of port public health capacity under the new policy framework. The number of publications in 2007 was 56, forming the first peak. From 2009 to 2010, H1N1 influenza broke out globally, which posed a serious challenge to the prevention and control of cross-border transmission of influenza at ports. The research on the prevention and control of Hemagglutinin 1 Neuraminidase 1 (H1N1) at ports attracted the interest of researchers. The number of annual publications increased significantly, and a second peak was formed in 2010. In 2015, the "Vision and Actions for Jointly Building the Silk Road Economic Belt and the 21st Century Maritime Silk Road" was officially released. African countries actively responded to "The Belt and Road"(B&R), and the economic and trade exchanges between the two sides were closer. However, due to the restrictions of health conditions in Africa, people infected with epidemic diseases are frequently found in African inbound people, which makes the port health and quarantine work face greater pressure. Therefore, a large number of literatures on the prevention and control of cross-border transmission of high-incidence infectious diseases in Africa have emerged, such as yellow fever, Ebola and hemorrhagic fever. The monitoring of infectious diseases among migrant workers in Africa has become a research hotspot. In 2016, the number of publications reached 86, the most in the past two decades, forming the third peak. Since the outbreak of the new coronavirus epidemic, the customs, as the first line of defense to safeguard the security of the country, has assumed the important responsibility of preventing the import of the epidemic. The research on the prevention and control of the Coronavirus Disease 2019 (COVID-19) at the port has become the focus of scholars' attention. Relevant papers have increased year by year in the following three years. In 2022, the number of publications reached 53, forming the fourth peak. In general, the research upsurge in the field of infectious disease prevention and control at ports is highly related to the release of major national policies and the outbreak of global epidemics, indicating that the research in this field has both theoretical and practical characteristics.

3.2. Research Collaboration Analysis

3.2.1. Analysis of Research Authors

Through the analysis of the graph spectrum of the research author cooperation network, it can not only identify the leading figures and core authors in the research field, but also reveal the structure of the collaboration network, so as to provide support for further promoting academic exchanges and cooperation. The Citespace analysis tool was used to draw the co-occurrence map of the research authors, as shown in Figure 2.

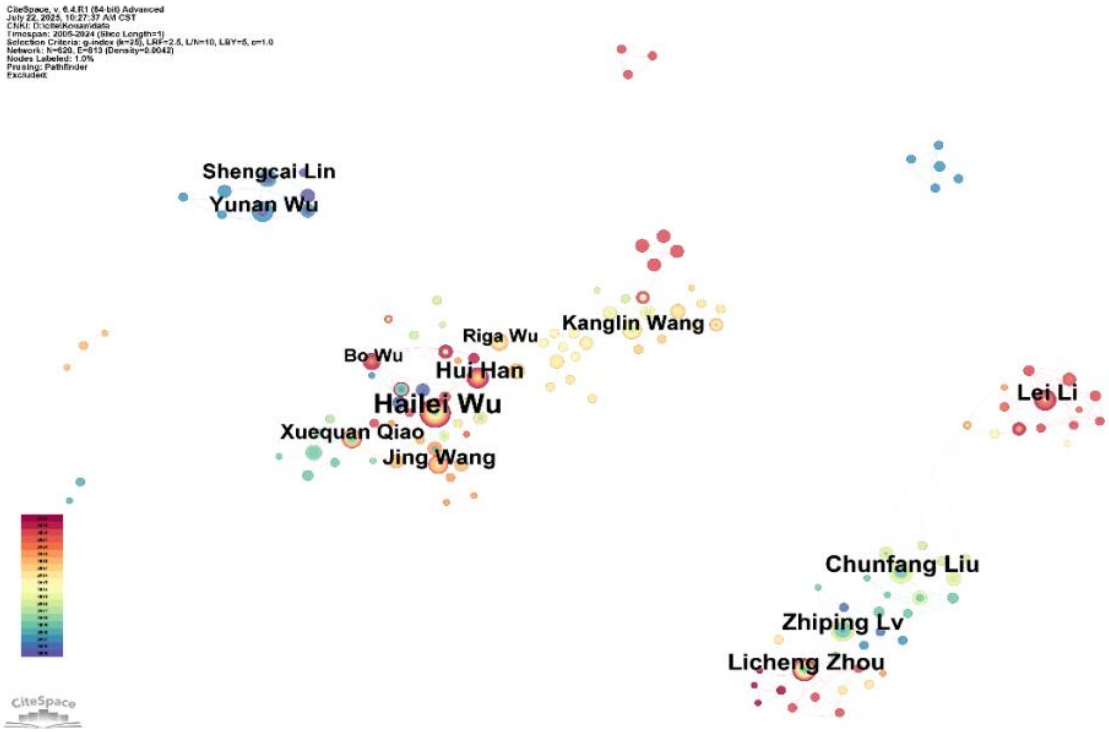

Figure 2. *Collaborative Network Graph of Literature Authors.*

In this map, Wu Hailei of Nanjing Customs has the largest node, ranking first with 22 articles. In addition, six authors published more than 10 articles, including Zhiping Lv (13), Chunfang Liu (13), Lei Li (12), Yunan Wu (11), Hui Han (11), Licheng Zhou (11). At present, the largest cooperation network had been formed with Haili Wu and Hui Han as the core. Local collaborative networks centered around Zhiping Lv, Chunfang Liu, Licheng Zhou, Lei Li, and Yunan Wu were formed. In addition, there are some smaller research teams with relatively weak cooperation and influence, and their network structure has not been demonstrated. It is worth mentioning that there is almost no connection between the collaboration networks, which indicates that the current research is mainly limited to the internal collaboration of a few teams, and there is very little horizontal cooperation between teams.

According to Price's law, this paper further analyzes the core author group through the number of articles published, where N is the number of articles published by any author, Nmax is the number of articles published by the highest-yielding author, and when $N \geq 0.749\sqrt{N_{\max}}$ established, the corresponding author is the core author [7]. Because of Nmax=22, it can be determined that the authors with more than 4 articles are the core authors in this field, with a total of 71 people and a total of 419 articles. However, the total number of papers written by the core authors has not reached 50% of the total number of papers in this field, which indicates that the core author group of the current domestic research on the prevention and control of infectious diseases at ports has not yet formed stably [8]. There are 620 nodes and 813 connections in the figure, and the network density is 0.0042. This also shows that in the past 20 years, there are a large number of scholars in related fields, but the cooperative relationship generally shows the characteristics of overall dispersion and partial concentration, and the academic connection between different scientific research teams needs to be strengthened.

3.2.2. Research Institution Analysis

The co-occurrence map of research institutions can intuitively show the scientific research strength and cooperation and exchange relationship in the field of infectious disease prevention and control at ports. In the main interface of Citespace, the node type is set as an institution, which can visually analyze the publication of research institutions and

the cooperative relationship between institutions, as shown in Figure 3. In the figure, a total of 361 nodes and 307 connections are generated. The network density is 0.0047, and the cooperation between institutions is generally loose. There are also several cooperation networks between some institutions, but the cooperative research is mainly limited to the internal customs system, such as the Guangdong regional cooperation with Shenzhen customs and Guangzhou customs as the main body, and the Jiangsu regional cooperation with Nanjing customs as the main body. From the perspective of the type of publishing institutions, customs are the absolute main force in the research of infectious disease prevention and control at ports, and some scientific research institutes also have important contributions to the research in this field. However, as one of the important forces of scientific research, universities have a serious lack of participation in the research in this field in China. The analysis of the publishing institutions shows that the current research cooperation is mainly concentrated within the customs system or within the region, and the joint research across regions and industries is relatively insufficient.

Figure 3. *Collaborative co-occurrence map of research institutions.*

3.3. Research Hotspots Analysis

3.3.1. Keyword Co-occurrence Analysis

Keywords are highly concise to the theme of the literature. Through keyword co-occurrence analysis, the internal relationship between theoretical research can be revealed, and then research hotspots in a certain field can be identified. The node type in Citespace is selected as the keyword, and the software is run to obtain the keyword co-occurrence map. There are 425 network nodes, 988 connections, and the network density is 0.011, as shown in Figure 4. The size of the node in the figure is proportional to the word frequency of the keyword. The deeper the color of the connection line and the shorter the distance, the closer the relationship between the nodes. The color of the node circle is compared with the chromaticity bar in the lower left corner, indicating the year in which the keyword appears. Intermediary centrality is a measure of the importance of keyword nodes as intermediaries in the co-occurrence network, reflecting the control of nodes on information flow and knowledge dissemination. When it is greater than or equal to 0.1, it is identified as a key node. The initial year indicates the year in which the keyword first appears in the research time span.

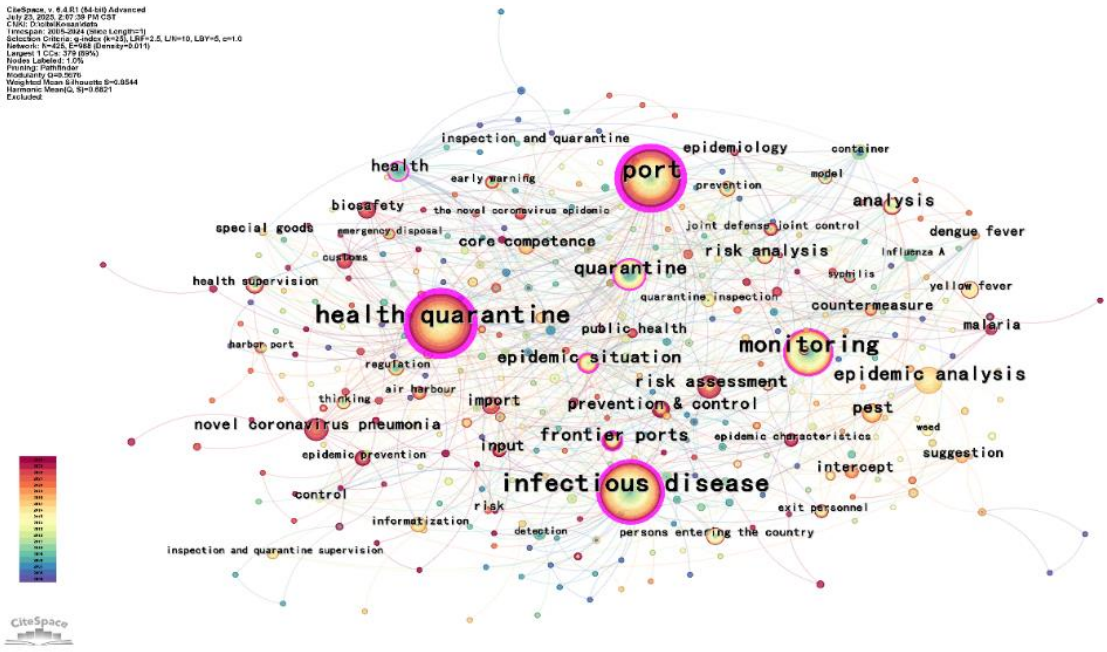

Figure 4. *Keyword co-occurrence graph.*

The statistical results showed that the keywords with the highest frequency were infectious diseases (190), health quarantine (184), port (179), monitoring (116), quarantine (49), epidemic analysis (43), frontier ports (38), etc. Among them, the centrality of health quarantine (0.48), port (0.42), infectious disease (0.29), monitoring (0.16), quarantine (0.13) and frontier ports (0.10) are greater than 0.1, which are the key nodes in the co-occurrence map, as shown in Table 1. The high-frequency and high-center keywords in the table are the core terms in the field of port infectious disease prevention and control, and together with other nodes constitute hot topics in this research field. It can be seen that the keyword frequency is related to the centrality, and the key nodes with high centrality are the top-ranked high-frequency words. At the same time, the frequency of keywords is not strictly positively correlated with the value of centrality. For example, the centrality of infectious diseases with the highest frequency is significantly lower than that of health quarantine with lower frequency. From the year when the keywords first appeared, the prevention and control of infectious diseases at ports has always been the focus of theoretical research. Seven of the top ten high-frequency keywords appeared in 2005, that is, the initial year of the research span. The new coronavirus pneumonia appeared in 2020, that is, after the outbreak of the epidemic, and the initial year was the latest.

Table 1. *Keyword frequency and intermediary centrality statistics of relevant literature on infectious diseases at Chinese ports from 2025 to 2024.*

No.	keyword	frequency	centrality	year
1	infectious disease	190	0.29	2005
2	health quarantine	184	0.48	2005
3	port	179	0.42	2005
4	monitoring	116	0.16	2005
5	quarantine	49	0.13	2005
6	epidemic analysis	43	0.07	2007
7	frontier ports	38	0.10	2005
8	risk assessment	31	0.08	2006
9	epidemic situation	28	0.10	2005

No.	keyword	frequency	centrality	year
10	pest	28	0.06	2010
11	analysis	28	0.07	2008
12	risk analysis	26	0.06	2005
13	prevention & control	24	0.04	2007
14	health	23	0.10	2005
15	core competence	22	0.03	2010
16	import	22	0.04	2015
17	novel coronavirus pneumonia	20	0.05	2020
18	countermeasure	18	0.09	2005
19	intercept	17	0.09	2010
20	public health	15	0.03	2006

3.3.2. Keyword Cluster Analysis

By extracting structured knowledge from text data, clustering analysis can group keywords with semantic relevance or similar topics into the same category, and visually show the research direction in the academic field. In Citespace, the logarithmic likelihood ratio algorithm (LLR) is used to perform keyword clustering analysis on literature data, and a visual map is obtained as shown in Figure 5. The results show that the Modularity Q = 0.5676 > 0.3 (critical value), indicating that the network structure is significant and the clustering effect is obvious. The Weighted Mean Silhouette S=0.8544>0.7, indicating that the keywords in the category have high similarity, good clustering consistency, and have practical reference significance [9]. Through cluster analysis of the sample literature, a total of 11 clusters were obtained. #0~10 represents the number of clusters. The smaller the number, the larger the cluster and the more documents it contains. According to the clustering results, the research hotspots in the field of port infectious disease prevention and control in Chinese academic journal database from 2005 to 2024 are further summarized, which can be divided into the following four research topics.

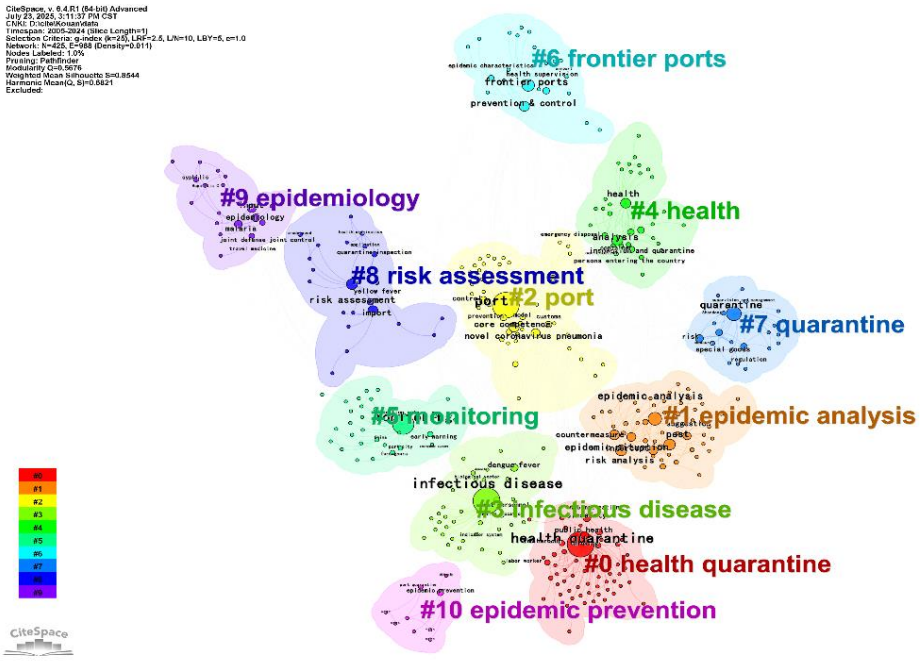

Figure 5. Keyword clustering graph of infectious disease prevention and control at ports.

First, health quarantine capacity building. Entry and exit health quarantine is one of the core duties of the Chinese customs. By taking relevant quarantine measures, it can avoid social panic or economic losses caused by disease input. Promoting the steady improvement of health quarantine capacity is not only the practical need to ensure the safety of the country, but also the focus of theoretical research. From the clustering map, it can be found that #0 health quarantine, #4 health, and #7 quarantine are all studies mainly focused on the theme of health quarantine capacity building. According to the keywords in the cluster, it can be further subdivided into three main research directions. The first is the research on the health quarantine management mechanism represented by key words such as core competence, laws, countermeasures and suggestions. For example, on the basis of the analysis of the relevant systems of epidemic prevention and control at ports, Zhongge Shao proposed countermeasures and suggestions to further improve the core competence of public health at ports [10]. The second is the study of health quarantine objects represented by keywords such as entry personnel, special goods and containers. With the increasing convenience of foreign trade and transportation, the import and export business and cross-border personnel flow continue to increase, and different entry-exit objects such as containers, laborers, and passengers have different characteristics of disease transmission, so it is necessary to take targeted measures to ensure effective health quarantine [11, 12]. The third is the research on health quarantine work represented by key words such as health treatment, inspection and quarantine, and emergency disposal. Port health quarantine is rich in connotation. According to the needs of infectious disease prevention and control, it is composed of multiple processes. It is important to seriously deal with the risk of infectious disease input in every health quarantine link [13].

Second, epidemic analysis and prevention. In view of the arduous situation of infectious disease prevention and control at ports, it is one of the hot spots in theoretical research to continuously improve the ability of epidemic analysis and prevention and control at ports. The #1 epidemic analysis, #3 infectious diseases, # 9 epidemiology, #10 epidemic prevention in the cluster map are mainly focused on the theme of epidemic analysis and prevention. Further analysis of the keywords in the cluster, it is found that the research topic covered three main research directions. The first is to focus on the study of epidemic pathogens at ports, involving keywords such as novel coronavirus, influenza A, and dengue fever. Strengthening the control of infectious disease sources is the key to the prevention and control of epidemics at ports. Targeted research on the characteristics of pathogens such as different viruses and bacteria, and taking precise countermeasures are conducive to the management of epidemic prevention and control sources, thereby improving the ability to respond to infectious diseases [14, 15]. The second is the research on the information technology of epidemic prevention and control driven by the construction of smart customs. The keywords involved include: big data, information system, digitization, etc. The construction of smart customs is a key way to realize the modernization of customs governance system, and provides important technical support for blocking the cross-border spread of the epidemic. In order to make up for the shortcomings of traditional quarantine methods that cannot meet the early identification and response of infectious diseases, making full use of intelligent new technologies such as big data, artificial intelligence, and robots to promote digital technology-enabled port epidemic prevention and control has become a broad consensus in academia and port work practice [16, 17]. The third is to study the countermeasures and suggestions for epidemic prevention and control. The key words involved include: health education, multi-disease prevention, control, countermeasures, etc. The practical significance of epidemic analysis is to put forward targeted and operable countermeasures and suggestions according to the bottleneck problems existing in the current epidemic prevention and control, so as to help the level of port infection prevention and control continue to improve. Strengthening the publicity and education of medical science for outbound personnel, increasing the training of health quarantine personnel, and strengthening epidemic monitoring and early warning are important ways to solidly promote the prevention of multiple diseases at ports and further strengthen the epidemic prevention line at ports [18, 19].

Third, biosecurity at frontier ports. Maintaining biosafety at frontier ports is an inevitable requirement for implementing the overall national security concept and an important cornerstone for improving the public health system. Strengthening the prevention and control of biosafety risks is closely related to the prevention of cross-border transmission of infectious diseases at ports. It has long attracted much attention. In particular, the revision and implementation of the "Biosafety Law of the People's Republic of China" in April 2024 further highlights the key role of biosafety in safeguarding people's lives and health and responding to the challenges of globalization. The #2 port and #6 frontier port in the cluster map are all focused on the research on the theme of biosafety at frontier ports, and can be further subdivided into two main research directions [20]. On the one hand, it is a macro-policy research on maintaining port biosafety, involving keywords including: public health, biosafety, etc. For example, on the basis of a comprehensive analysis of the current situation of biosafety system and prevention and control capacity at domestic ports, Jianguo Xu put forward suggestions on accelerating the construction of overseas infectious disease sentinels and actively participating in international public health cooperation. On the other hand, it is a study on the micro-level response measures to the potential risks at the port, involving keywords including: prevention and control, dynamic management, ballast water, etc. Customs maintenance of port biosafety work is diverse and complex. In addition to the need

to pay attention to the flow of people, there are potential risks in the daily contact objects such as ballast water, vectors, animals and plants in the entry and exit means of transportation and goods, which need to take the initiative to prevent [21, 22].

Fourth, risk monitoring and assessment. In order to avoid the serious impact of the outbreak and spread of infectious diseases on the society, it has become a hot topic of academic research to promote the transformation of the focus of port infectious disease prevention and control from post-processing to pre-assessment and early warning, so as to achieve early identification, early detection and early disposal. The #5 monitoring and #8 risk assessment in the cluster map are mainly focused on the theme of risk monitoring and assessment, and could be divided into two main research directions. On the one hand, it is a dynamic monitoring study on the input risk of infectious diseases, including the keywords of epidemic trend, detection rate and so on. Based on the analysis of the epidemic characteristics, clinical manifestations and laboratory diagnosis of emerging infectious diseases in the world, the existing research put forward the types of infectious diseases that need to be monitored at ports. At the same time, through the monitoring and analysis of the epidemic situation of Human Immunodeficiency Virus (HIV), viral hepatitis, tuberculosis and other infectious diseases, the key population and weak links of infectious disease monitoring are revealed, which is helpful to improve the accuracy of infectious disease prevention and control at ports [23, 24]. On the other hand, it is the risk assessment mechanism of cross-border transmission of infectious diseases, including risk assessment, index system, container index and so on. The identification and assessment of infectious disease input risk is a key link in port health and quarantine work. By using epidemiological theory, risk management theory, probability and statistical model and other theoretical methods, on the basis of constructing risk assessment index system and expert consultation, assessment of port infectious disease information and accurate screening of imported risks can provide decision support for the prevention and control of major emerging infectious diseases abroad and the protection of public health safety at ports of large international activities [25, 26].

3.4. Research Frontier Analysis

Keyword burst refers to the phenomenon that the word frequency of keywords in the literature increases suddenly in a period of time, which reflects the attention of researchers and can be used to analyze the changing rules and frontier development trends of research hotspots in specific fields. Citespace software was used to detect and analyze the keywords in the past two decades, and the top 15 keywords in the field of infectious disease prevention and control at ports were obtained, shown in Figure 6. The burst intensity is positively correlated with the degree of attention, and the burst period is positively correlated with the duration of attention.

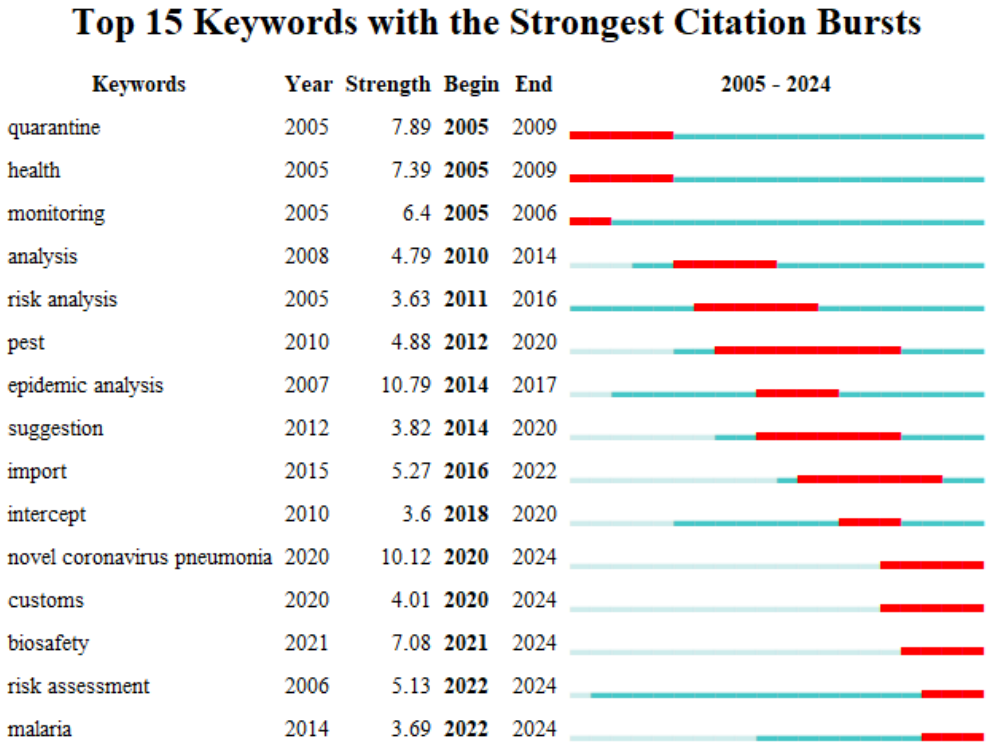

Figure 6. *Keyword burst graph of infectious disease prevention and control at ports.*

From the perspective of burst intensity, the burst intensity of 'epidemic analysis' was the largest, reaching 10.79, followed by 'novel coronavirus pneumonia', 'quarantine', 'health', 'biosafety', 'monitoring', 'import' and 'risk assessment', and the burst intensity all exceeded 5, indicating that epidemic monitoring and prevention, health quarantine, and border biosafety are important topics of concern in the field of infectious disease prevention and control at ports. From the perspective of the emergence period, the keyword 'pest' has the longest duration of burst, reaching 9 years, which indicates that the prevention of vector organisms, pathogens, cargoes carrying pathogens and other risk sources of epidemic input has always been the focus of port infectious disease prevention and control work. From the perspective of the order of burst, the traditional work connotation of port health quarantine, such as 'quarantine', 'health' and 'monitoring', are the focus of scholars' attention earlier. Keywords such as 'biosafety', 'risk assessment', and 'novel coronavirus pneumonia' are still in the burst period, indicating that there is still research hotspot. In the context of the revision and implementation of the 'International Health Regulations', the direction of integration research with hot issues in the current burst period is expected to become a new research hotspot. It is predicted that health and quarantine related policy theory research, epidemic prevention and control digital innovation, public health core capacity building path, biosafety risk assessment, epidemic input risk early warning, etc., have great potential to become the research frontier in the next few years.

4. Discussion

At present, the threat situation of emerging infectious diseases to human health and economic and social development is complex and diverse. The prevention and control of infectious diseases at ports is of great responsibility. In this paper, the bibliometric method is used to visually analyze the relevant literature in the field of infectious disease prevention and control at ports in China in the past 20 years through Citespace software. The research status and hot topics in this field are sorted out, and the change law and development trend of related research are revealed.

The analysis results of literature publication showed that the number of annual publications in the field of infectious disease prevention and control at ports appeared fluctuating changes, and there were four peaks of publications, which were closely related to the changes of policy environment and the outbreak of epidemic situation. In terms of research partnerships, there are 71 core authors in this field, but the cumulative number of publications accounts for less than 50%, indicating that the core author group has not yet formed stably. Most of the research authors in this field in China are scattered at all levels of customs. However, in China Customs, the discipline construction is not paid enough attention. Many authors have carried out some theoretical research based on the port work practice they are engaged in. However, due to the lack of theoretical knowledge reserve and the lack of communication and cooperation with other institutions, most authors have not carried out in-depth research or expanded research. This results in most of the authors only having a few articles, and the number of prolific authors is small, which leads to the lack of core author groups. At present, a few research teams have begun to take shape, but research cooperation is mainly limited to within the team and less cooperation between different teams. In the future, it is necessary to further improve the academic exchange promotion mechanism in this field, encourage scientific research teams to carry out horizontal cooperation, and promote the output of more high-quality research results. From the perspective of the issuing agencies, in the past two decades, the customs system has been in an absolute advantage in the field of port infectious disease prevention and control. The agencies with the largest number of documents are Shenzhen Customs, Tianjin Customs, Guangzhou Customs and Nanjing Customs. It can be found that these institutions are located in the economically developed coastal areas, which reflects the problem of uneven geographical distribution of scientific research forces. Compared to inland regions in China, coastal areas such as Guangdong Province, Tianjin City, and Jiangsu Province have more developed economies. There are more inbound and outbound personnel and more frequent foreign trade in economically developed coastal areas, which makes the pressure of port infectious disease prevention and control work in coastal areas greater, and the urgency of carrying out related research is stronger. Therefore, coastal customs have richer paper output than inland customs. Similar to the author's cooperation, the cooperation of the research institutions is also mainly limited to the internal customs system. The participation of colleges and universities in this field is obviously insufficient. The possible reasons mainly include two aspects. On the one hand, the management policies of ports have special characteristics and are generally limited to the internal understanding of various levels of customs, without being open to the public for access. Therefore, it is difficult for universities to obtain internal data of customs and practical situations through open channels. On the other hand, the daily management of customs is highly specialized, and only a few universities in China, such as Shanghai Customs university, pay attention to research in the field of customs management. The focus of discipline construction in most universities is not in this direction. Therefore, the prevention and control of infectious diseases at ports has become an important but easily overlooked research direction by universities. It is suggested to give full play to the role of universities as the technology innovation center, promote interdisciplinary cooperation, and further gather the wisdom to speed up the construction of core public health capabilities at ports [27]. Customs could collaborate with universities, disease control centers, hospitals, and other relevant entities to establish joint

laboratories, recruit more university researchers for joint research, and exerting financial advantages to increase capital donation investment in universities with discipline advantages, thereby enhancing the monitoring and early warning capabilities of infectious diseases at ports.

The results of keyword hotspot analysis showed that infectious diseases, health quarantine, port, monitoring, quarantine were high-frequency and high-center keywords in the field of infectious disease prevention and control at ports. Among the top ten high-frequency keywords in the past 20 years, seven first appeared in the initial year of the research span, indicating that the research in the field of infectious disease prevention and control at ports has strong continuity and stability, but it also reflects the lack of interdisciplinary integration. The combination of new theories, new technologies, new methods and port epidemic prevention practices is not close enough, resulting in the slow emergence of new research hotspots. Actively implementing digital innovation technology is conducive to the improvement of the prevention and control level of infectious diseases at ports, such as AI, robots, big data models, blockchain technology, and the like. From the perspective of keyword clustering map, the hot topics of port infectious disease prevention and control research have formed multiple clusters with significant structure, which are further summarized into four aspects, including health quarantine capacity building, epidemic analysis and prevention, biosecurity at frontier ports, and risk monitoring and assessment. In this study, Citespace knowledge map was used to visually analyze the research authors, publishing institutions, research hotspots, and other aspects of relevant literature in the field of infectious disease prevention and control at ports, so as to reveal the current characteristics, development rules and future trends of this research field. The International Health Regulations and China's revised Biosafety Law (2024) provide important guidelines for the prevention and control of infectious diseases at ports. In order to ensure the biological safety of frontier ports, it is necessary to increase the recruitment of professional talents and the training of professional quarantine skills, expand investment of infrastructure construction at ports, and increase the forefront monitoring points focusing on global epidemic information. In the future, it is necessary to further improve the mechanism of academic exchange in this field, encourage scientific research teams to carry out horizontal cooperation, and promote the output of more high-quality research results. In addition, it is suggested to give full play to the advantages of scientific research in universities and strengthen the cooperation between customs and universities, so as to accelerate the construction of core competence of port public health.

Abbreviations

IHG	International Health Regulations
B&R	The Belt and Road
COVID-19	Coronavirus Disease 2019
H1N1	Hemagglutinin 1 Neuraminidase 1
HIV	Human Immunodeficiency Virus

Author Contributions

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Conflicts of Interest

The authors declare no conflicts of interest.

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