Influence index analysis of inland waterway ports along the Yangtze River

Yanjie Zhou, Liping Luo, Qian Qian Zhao* and Haonan Chen

School of Management,
Zhengzhou University,
Zhengzhou – 450001, China
Email: ieyjzhou@zzu.edu.cn
Email: l3283357998@gs.zzu.edu.cn
Email: qianqianzhao@zzu.edu.cn
Email: chenhn95zz@foxmail.com
*Corresponding author

Zehao Qian

School of Management,
Zhengzhou University,
Zhengzhou – 450001, China
Email: qianzehao@stu.zzu.edu.cn
and
Department of Nature Sciences,
Durham University, UK

Songle Leng

Shanghai Zhenhua Heavy Industries Company Limited (ZPMC),
Shanghai – 200125, China
Email: lengsongle@zpmc.com

Abstract: The port performance index is an essential parameter for evaluating the performance of container ports and port selection. Many previous studies have investigated the methods of port performance index for seaports and focused on annual data analysis. Inland waterway ports located along the inland waterway have different functions compared with seaports that cannot use the previous method adopted for seaports to calculate the inland port influence index. To make a comprehensive analysis, this paper considers multiple years' worth of factors, including the facility of inland ports, urban economic and traffic factors. This paper introduces a group entropy weight method to evaluate the inland port influence index considering the multiple year data. A visualisation tool integrated with the group entropy weight method is developed to analyse the port performance index automatically. Twenty-seven inland waterway ports along the Yangtze River are considered as a case study for analysing their influence index. The management insights of the dynamic change of inland waterway port ranks are also discussed.
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Keywords: port performance index; Yangtze River; inland waterway ports; port ranking.

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Biographical notes: Yanjie Zhou received his PhD from the Department of Industrial Engineering at Pusan National University in 2020 and BS and MS in Computer Science and Computer Applied Technology from the Zhengzhou University in 2012 and 2015, respectively. He is currently an Associate Professor with the School of Management at Zhengzhou University. He focuses on solving real-world optimisation problems by using artificial intelligence techniques.

Liping Luo received her Bachelor's in Logistics Management from the Henan University of Economics and Law in 2022, where she is currently pursuing her Master's degree at the School of Management of Zhengzhou University. Her research interests include logistics and supply chain.

Qian Qian Zhao received her BSc, MSc and PhD in Industrial Engineering from the Pusan National University, South Korea, in 2013, 2015, and 2020, respectively. Since 2020, she has been an Assistant Professor at the Zhengzhou University, China. Her research interests include algorithm design, maintenance optimisation, and cost analysis.

Haonan Chen received his Bachelor's in Management of Logitcis from the Zhengzhou University in 2021, and a Master's in Juris from Hunan University in 2024. His research interests include route optimisation and port research.

Zehao Qian received his BEng in Industrial Engineering from Zhengzhou University, China, in 2023, and currently pursuing his MSc in Data Science (Social Analytics) at the Durham University, UK. His research interests include machine learning, data visualisation, and quantitative research methods.

Songle Leng received his Bachelor's in Electronic Science and Technology from the Hohai University in 2012. Currently, he works in the Shanghai Zhenhua Heavy Industries Co., Ltd. (ZPMC). His research interests include automated container terminal operation system.

1 Introduction

Inland ports, also called inland waterway ports, are container ports on an inland waterway. Inland ports are essential in connecting the hinterland logistics and distribution hub inland from seaports (Liu et al., 2024; Zhou and Kim, 2020a, 2020b). The principal partners of inland ports are seaports and railroad companies, and the primary function of inland ports is to help the partners distribute their retail cargo. More operations and actors of inland ports are discussed by Rodrigue et al. (2010).

An inland port has many benefits:

1 Inland port could reduce highway congestion near the urban port area.

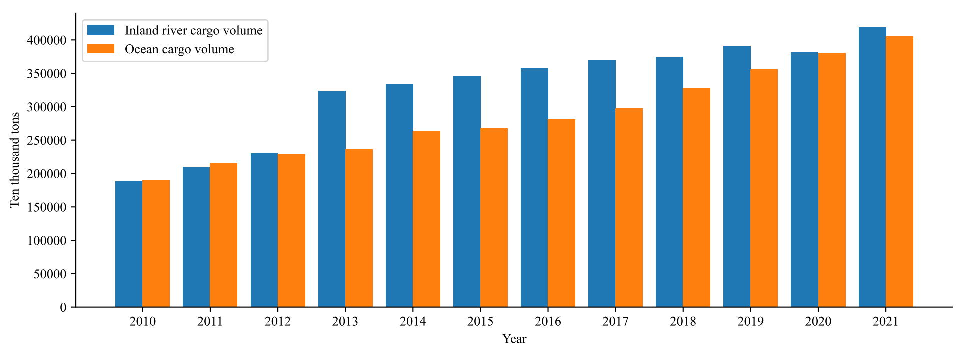
2 Inland port transportation is more environmentally friendly than highway transportation.

3 Inland port transportation could create more jobs to help economic development. Waterway shipping is cheaper than highway transportation and railway transportation. An inland port is an alternative method for drayage.

4 Cargoes transported via inland waterways directly to overseas countries could reduce the shipping time compared to traditional transportation methods.

Figure 1 shows China's inland river cargo volume and ocean cargo volume from 2010 to 2021. The data source of Figure 1 is provided by the National Bureau of Statistics of China[1]. From Figure 1, we can find that inland river cargo volume is greater than the ocean cargo volume in recent years.

Figure 1 Inland river cargo volume and ocean cargo volume in China from 2010 to 2021 (see online version for colours)



Even though many agencies, such as Word Bank Group[2], have released port performance indexes. It is still ambiguous and non-transparent for port operators to know the calculation methods. Additionally, unlike port ranking according to container cargo throughput[3], inland port performance index calculation is very complex. The port influence index analysis belongs to multi-criteria decision making (Lang et al., 2021; Marques et al., 2022; Yang et al., 2017; Dong et al., 2018; Li et al., 2022) and has been studied by many previous studies. However, most of the previous studies focused on the seaports. Different from seaports, inland ports have many different functionalities. The inland port influence index analysis can not be done by directly adopting the previous methods used for seaports. Besides, previous studies focused on port ranking analysis using a single annual data set. For example, Kim (2016) used the statistical data of 2014 to calculate and compare the port competitiveness of Shanghai Port and Busan Port in detail from the aspects of port throughput and port infrastructure. Peng et al. (2018) designed a comprehensive evaluation CCPE model to measure the competitiveness of ports from 18 factors such as conditions, capacity, and efficiency. Based on the data from 2017, they evaluated the competitiveness of 99 ports in 51 countries along the Maritime Silk Road using the model. Wan et al. (2018) adopted the analytic hierarchy process to calculate the weight of each index and used the evidence reasoning method to summarise the evaluation results of each index. Then, through the comparative analysis of China's five major ports in 2013, the evaluation model is further demonstrated.

This paper aims to propose a novel model that can fairly calculate the performance of inland ports. Through a comprehensive analysis of factors affecting inland ports' performance, this paper systematically evaluates the ranking of inland ports and provides a scientific basis for port management, policy making, and operational practices. And, this paper constructs a factor system of inland ports, which considers various factors, including facilities of inland port-related parameters, urban economic development-related parameters, and urban regional traffic-related parameters. Additionally, this paper reveals the changing trends in port ranking through multi-data analysis of factors. Finally, this paper proposes targeted policy recommendations to promote the development of the efficient operation of inland ports.

The remainder of this study is organised as follows. The previous studies are summarised in Section 2. Section 3 introduces the Yangtze River container port system. Methodologies for calculating the influence index of inland waterway ports are introduced in Section 4. Section 5 presents a case study. Finally, the conclusions are given in Section 6.

2 Literature review

Seaports and inland waterway ports are large transportation hubs for handling goods and passenger ships, promoting trade and commerce. The main difference between seaports and inland waterway ports is their location. Seaports are located along the coast and handle ocean-going vessels, while inland waterway ports are located within inland waterways and handle inland river transportation. In addition, river waterways typically are shallower compared to seaports. The deeper water means that ships with higher tonnage can navigate and berth, so the logistics transportation capacity and economic driving capacity of seaports will naturally be stronger. There are many layout styles of seaports, such as shore-side, jetty-side, and isolated pier-side. However, river ports are generally shore-side due to the influence of terrain. Inland ports are less affected by tides, whereas seaports are greatly affected by ocean tides.

Performance evaluation is a way to compare the rank of container ports. The previous studies on port performance evaluation, influence index analysis, and port ranking are summarised as follows.

2.1 Seaport ranking

In terms of evaluation methods, many studies have proposed various methods to assess seaport performance. For example, Lee and Kim (2006) used the factor analysis method to evaluate the performance of the Asian port distriparks. Hanson et al. (2011) gave a first estimate of the exposure of the world's large port cities and presented a global ranking of port cities. Elzarka and Elgazzar (2014) adopted the fuzzy AHP approach to build a model for calculating the green port performance index for sustainable ports in Egypt. There have been many studies on the index system for evaluating port influence. Asgari et al. (2015) investigated the sustainable port performance considering the environmental and economic factors by using a multi-criteria decision making approach. Wei et al. (2018) adopted a basic logistical gravity model exploring the logistical connections between dry ports, seaports, cross-border inland ports, and hub and feeder ports. Molavi et al. (2020) introduced a framework for building a port index for the smart port. Duan et al. (2017) studied the evaluation index system of green ports considering the economy, society, and environment simultaneously. Scholars also studied the competitiveness of seaports in different regions, exploring the characteristics, advantages, and disadvantages of seaports in different regions. The preparation of a smart port factor and calculation of a ranking for the Spanish port system was studied by González et al. (2020). Nayak et al. (2022) developed a unified port performance index to measure port performance considering cargo categories and the multi-dimensional nature of port performance factors. Seguí et al. (2016) conducted a survey on the environmental performance of European inland ports.

2.2 Inland port ranking

Inter-port competition is a common phenomenon in container port selection (Hoyle and Charlier, 1995; Zhou and Kim, 2020a, 2020b). Knowing the performance of container ports will help the shippers select container ports for berthing their container vessels. Even though there is also existing competition between inland waterway ports. The inland waterway port spatial relationship will affect the relationship of the inland waterway port. Wu and Lee (2022) found that the relationship between inland ports along the Yangtze River is complimentary.

Inland port development is closely related to the local economy, marginal capacity investment, and government policy (Zheng et al., 2021). Yangtze River port system is the largest inland port system in China. Veenstra and Notteboom (2011) analysed the concentration of the Yangtze River container port system. Ye et al. (2020) analysed the relative efficiency of China's Yangtze River port system.

From the above research, most of the previous research at home and abroad has focused on the seaports and ports in developed coastal cities as the research subjects. The research on seaports has been relatively mature, and the seaports performance has been extensively studied and evaluated from different aspects and different evaluation methods. The research on inland ports has also involved some essential aspects. However, compared with seaports, research on inland ports is relatively scarce. Previous studies mainly focused on the study in annual years and have not provided a comprehensive evaluation method for inland ports with multi-year data. This paper introduces a group entropy weight method (GEWM) to evaluate the inland port influence index considering the multiple years' data.

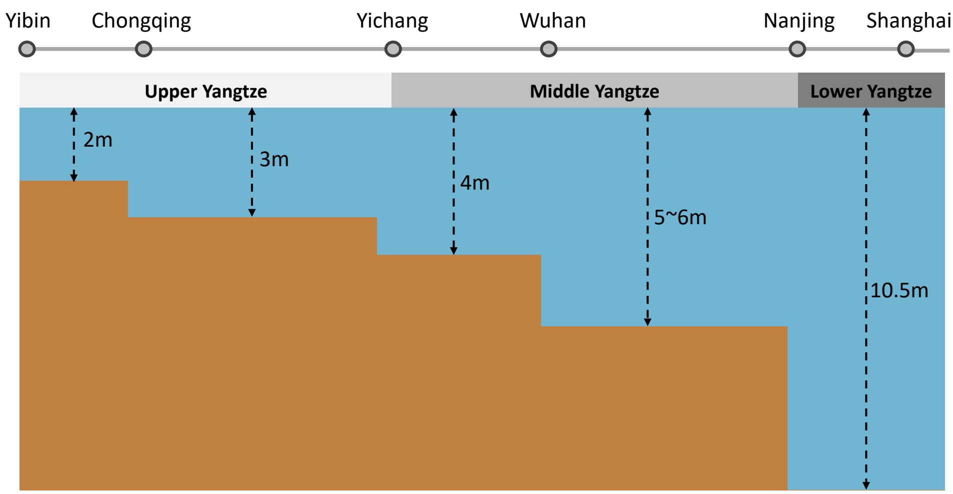
3 Yangtze River container port system

In this section, an overview of the Yangtze River is introduced. The navigation system of the Yangtze River, the Yangtze River inland container system, river and sea transports on the Yangtze River are presented.

3.1 Navigation system of Yangtze River

The Yangtze River is 6,393 kilometres long, and about 2,800 kilometres are navigable by cargo vessels. The Yangtze is open to navigation all year round. The Yangtze River can be divided into three parts: the upstream part from the source of the Yangtze River to Yichang, the midstream part from Yichang to Nanjing, and the downstream part from Nanjing to Shanghai. Chongqing, Wuhan, Nanjing, and Shanghai are the four major cities along the Yangtze River. The Yangtze River is a golden waterway with the largest cargo volume in the world and a major transportation artery connecting the three economic zones of the southwest, central, and east China. Figure 2 shows the navigation of the Yangtze River.

Figure 2 Navigation of Yangtze River (see online version for colours)



3.2 Yangtze River inland container system

The Yangtze River is characterised by a combination of large and small container ports. There are nearly 50 inland ports, such as Chongqing Port, Yichang Port, Wuhan Port, Huangshi Port, Jiujiang Port, Anqing Port, and Wuhu Port along the Yangtze River. The Yangtze River container shipping business started in the 1970s, evolving from a single domestic shipping line to multiple internal shipping lines and multiple international shipping lines. The container type is unified from the domestic 5-ton container to the international standard container (TEU); the mode of transport has evolved from pusher to self-propelled ship. The Yangtze River container transportation system plays an essential role in the Chinese international transportation system. For instance, in 2019, the container throughput of inland ports along the Yangtze River reached 21.66 million TEU, an increase of 4.7% compared with the previous year. The containerised cargo throughput reached 4.398 billion tons, an increase of 0.9% compared with the year earlier. The throughput of goods for international trade reached 429 million tons, an increase of 5.7% compared with the previous year.

3.3 River and sea transports in Yangtze River

The opening of international shipping routes of Yangtze River ports can provide direct, punctual, convenient, and fast shipping services for import and export enterprises in the Yangtze River Delta and Southeast Asia countries, besides a lot of time and considerable logistics costs can also be saved, especially during the epidemic period, cross-regional highway transportation faced challenges. Yangtze River ports can give full play to their advantages and actively open container liner routes to effectively reduce the impact of the epidemic on enterprise logistics and ensure the smooth operation of industrial and supply chains.

4 Methodology

In this section, the factors that affect the influence of inland ports are discussed. Based on these factors, this paper develops two models for calculating the influence of inland ports.

4.1 Factors selection

Deng and Hu (2016) selected 12 factors of the port comprehensive evaluation index system from five impact factors of the port economy. Di and Lei (2016) concluded that the port comprehensive evaluation index system is the port economy, urban economic development level, regional traffic conditions information level, which are refined into second-level factors. Jiang and Pingyu (2013) divided the evaluation index into first-level factors and second-level factors according to the port influence index system and the port city support index system. Gao et al. (2018) uses six factors (port size, port location, hinterland economy, port costs, operations management and growth potential) that are divided into 18 sub-criteria to evaluate port competitive. Kuang and Chen (2007) established four port overall competitiveness index system including the port turnover capacity, work ability and so on.

The influencing factors need to be investigated to evaluate the influence of inland waterway ports. This paper classifies the factors into three classifications, including the factors from facilities of the inland port, factors from urban economic development, and factors from urban regional traffic, which are shown in Table 1. The following sections introduce the details of these factors.

4.1.1 Facilities of inland waterway port

The berth is an essential facility for the container port where the vessel is to be moored. Container vessels load and unload their cargoes by using query cranes. The port operator decides on berth allocation to determine the locations of berthing for each vessel. If the container port has more berths, containers' turnaround time will be shorter. Hence, the number of port berths is essential in evaluating the performance of inland waterway ports. Another factor is the throughput of an inland waterway port. Unlike seaports, many inland waterway ports usually need to handle non-containerised bulk cargoes. A critical function of the inland waterway port is feeder service, which means that many bulk cargoes must be handled. This paper divides the cargo throughput into two categories: bulk cargo throughput and container cargo throughput. Besides, investment is also an essential factor.

Table 1 The port influence evaluation index system

Classification	*Factor*	*Unit*
Facilities of inland port	Bulk throughput (BT)	million ton
	Container throughput (CT)	ten thousand TEU
	Number of port berths (NPB)	
	Port investment level (PIL)	
Urban economic development	Gross domestic product (GDP)	hundred million RMB
	Per capita gross national product (PC-GNP)	hundred million RMB
	Local fiscal revenue (LFR)	hundred million RMB
	Fixed asset investment (FAI)	hundred million RMB
	The proportion of tertiary industry in GDP (PTI-GDP)	%
	Total retail sales of social consumer goods (TRSSCG)	hundred million US dollar
	Urbanisation rate (UR)	%
Urban regional traffic	Highway mileage (HM)	km
	Total amount of post telecommunication services (TAPTS)	

4.1.2 Urban economic development

An inland waterway port development is highly dependent on the urban economic development (Hall and Jacobs, 2012; Fujita and Mori, 1996; Miller, 2017). The urban refers to the city where the inland waterway port is located. Usually, the urban is considered the logistics hub for providing/attracting cargo from/to the inland waterway port. In this paper, the urban economic development factors, including gross domestic product, per capita gross national product, local fiscal revenue, fixed asset investment, the proportion of tertiary industry in GDP, total retail sales of social consumer goods, and urbanisation rate, are considered.

4.1.3 Urban regional traffic

An inland waterway port-hinterland transport network links intermodal facilities and railway network to the inland waterway port (Pettit and Beresford, 2009; Behdani et al., 2020; Witte et al., 2019). In this paper, an inland waterway port's urban regional traffic refers to the highway mileage and the total amount of post-telecommunication services.

4.2 Entropy weight method

Common evaluation methods include fuzzy comprehensive evaluation (FCE), grey relational analysis (GRA), analytic hierarchy process (AHP), entropy weight method (EWM), principal component analysis (PCA), TOPSIS, data envelopment analysis (DEA), etc. A number of previous papers have used these methods. For example, Song and Yeo (2004) used the framework of AHP to analyse the competitiveness of China's container ports from outsiders' perspectives and provided managerial and strategic implications. To gain a clearer understanding of the competitive dynamics in this rapidly developing region, Nguyen and Woo (2022) adopted the TOPSIS method and k-means cluster analysis to evaluate the competitiveness of the top container ports in Southeast Asia. Kammoun and Abdennadher (2022) used data envelopment analysis window analysis to evaluate the technical efficiency of sample container ports, and then used principal component analysis to explain the competitiveness of ports. da Cruz et al. (2013) used AHP to conduct an empirical study on the key factors of stakeholders. There are subjective and objective evaluation methods. Among them, objective evaluation methods have the advantage of reducing the interference of subjective factors and improving the objectivity and credibility of evaluation results. When selecting the factors in this paper, we are not considered to reduce the dimension of data. Therefore we chose the entropy weight method in this study. The EWM determines factors' weights of based on the degree of variation in their values. As an objective weighting method, it has wide applicability and is not influenced by subjective factors. The weights calculated by this method are highly accurate. Additionally, the method allows for appropriate adjustment of the determined weights, which demonstrates its high adaptability to different needs and situations. Therefore, we choose the EWM in this study.

The EWM is a popular method for determining the objective weight according to the magnitude of factors' variability, which has been used in many industry areas (Zou et al., 2006; Zhao et al., 2018). EWM also has been used for seaport analysis (Kim, 2016; Görçün, 2021; Gök-Kısa et al., 2021; Chen, 2020).

Before introducing the details of the EWM, the notations used in this paper are presented. I denotes the set of inland waterway ports and $|I| = m$. n represents the total number of factors. The value of the factor is annual data. i and j are the indices of inland waterway ports and factors, respectively. x_{ij} denotes the value of factor j for inland waterway port i for an arbitrary annual data. The step by step of EWM used is presented in Appendix D.

4.3 *Average entropy weight method*

In this paper, various factors are considered for calculating the influence index. These factors will change with time variation. For example, GDP will change dynamically year by year. The previous subsection introduced the process for calculating the annual rank of inland waterway ports for annual factors.

As mentioned in the previous subsection, given an annual history data of the factors, we can adapt the EWM to calculate the influence index of each inland waterway port. Let T denote the set of the year, and X^t denote the factor matrix in year t. X is the set of all the factor matrix and $X = \{X^1, X^2, \ldots, X^t\}$. The definition of X^t shows in equation (1).

$$X^t = \begin{bmatrix} x_{11}^t & x_{12}^t & \cdots & x_{1n}^t \\ x_{21}^t & x_{22}^t & \cdots & x_{2n}^t \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1}^t & x_{m2}^t & \cdots & x_{mn}^t \end{bmatrix} \tag{1}$$

For given X^t, we can obtain the influence index $Rank_i^t$ of inland waterway port i by using the EWM. After calculating all the influence index $Rank_i^t$ for each $t \in T$, we can calculate the average value of the influence index $Rank_i^A$ by using the equation defined in the following. This process of calculating the $Rank_i^A$ is called the average entropy weight method (AEWM).

$$Rank_i^A = \frac{\sum_{t=1}^{|T|} Rank_i^t}{|T|} \tag{2}$$

4.4 GEWM

To make a comprehensive influence index analysis considering all the historical factor data, group decision making needs to be made. The group decision making method used in this paper was proposed by Yue (2017). In this paper, the group decision making method is named the GEWM. Steps 1 to 4 of the GEWM are similar to the EWM, which is presented as follows.

After obtaining the matrix X^t, the normalisation is conducted by using equation (3).

$$\bar{x}_{ij}^t = \frac{x_{ij}^t - \min\left(X_i^t\right)}{\max\left(X_i^t\right) - \min\left(X_i^t\right)}, \tag{3}$$

where $\min\left(X_i^t\right)$ denotes the minimum element in the vector X_i^t and $\max\left(X_i^t\right)$ represents the maximum element in the vector X_i^t, respectively.

After the normalisation operation of X^t, a normalised matrix $\bar{X}^t$ is obtained, which shows in equation (4).

$$\bar{X}^t = \begin{bmatrix} \bar{x}_{11}^t & \bar{x}_{12}^t & \cdots & \bar{x}_{1n}^t \\ \bar{x}_{21}^t & \bar{x}_{22}^t & \cdots & \bar{x}_{2n}^t \\ \vdots & \vdots & \ddots & \vdots \\ \bar{x}_{m1}^t & \bar{x}_{m2}^t & \cdots & \bar{x}_{mn}^t \end{bmatrix} \tag{4}$$

Then the ratio of index value of the factor j of the inland waterway port i in year t is p_{ij}^t, which is defined as follow.

$$p_{ij}^t = \frac{\bar{x}_{ij}^t}{\sum_{j=1}^{n} \bar{x}_{ij}^t} \tag{5}$$

The information entropy of the factor j in year t is denoted as e_j^t.

$$e_j^t = -\frac{1}{\ln m} \sum_{i=1}^{m} p_{ij}^t \ln p_{ij}^t \tag{6}$$

When $p_{ij}^t \to 0$, the function of ln() is out of domain. This paper assumes that when $\lim_{p_{ij}^t \to 0} p_{ij}^t \ln p_{ij}^t = 0$ is hold.

Then the entropy weight of the factor j in year t can be expressed in equation (7).

$$w_j^t = \frac{1 - e_j^t}{n - \sum e_j^t} (j = 1, 2, \ldots, n) \tag{7}$$

Step 5: Weight normalised matrix

After obtaining the weight of entropy and the ratio of each factor, the weight normalised matrix can be expressed as follows.

$$\bar{w}^t = \begin{bmatrix} \bar{w}_{11}^t & \bar{w}_{12}^t & \cdots & \bar{w}_{1n}^t \\ \bar{w}_{21}^t & \bar{w}_{22}^t & \cdots & \bar{w}_{2n}^t \\ \vdots & \vdots & \ddots & \vdots \\ \bar{w}_{m1}^t & \bar{w}_{m2}^t & \cdots & \bar{w}_{mn}^t \end{bmatrix} = \begin{bmatrix} w_1^t p_{11}^t & w_2^t p_{12}^t & \cdots & w_n^t p_{1n}^t \\ w_1^t p_{21}^t & w_2^t p_{22}^t & \cdots & w_n^t p_{2n}^t \\ \vdots & \vdots & \ddots & \vdots \\ w_1^t p_{m1}^t & w_2^t p_{m2}^t & \cdots & w_n^t p_{mn}^t \end{bmatrix} \tag{8}$$

$\bar{w}_{ij}^t$ is an element in matrix $\bar{w}^t$ and $\bar{w}_{ij}^t = w_j^t p_{ij}^t$.

Step 6: Weight matrix transformation

H_i represents the weight matrix of inland waterway port i for all year. H_i is $|T| * n$ matrix, which is defined as follow.

$$H_i = \left(h_{tj}^i\right)_{|T|*n} = \begin{bmatrix} \bar{w}_{i1}^1 & \bar{w}_{i2}^1 & \cdots & \bar{w}_{in}^1 \\ \bar{w}_{i1}^2 & \bar{w}_{i2}^2 & \cdots & \bar{w}_{in}^2 \\ \vdots & \vdots & \ddots & \vdots \\ \bar{w}_{i1}^{|T|} & \bar{w}_{i2}^{|T|} & \cdots & \bar{w}_{in}^{|T|} \end{bmatrix} \tag{9}$$

h_{ij}^+ and h_{ij}^- represent the maximum and minimum element h_{tj}^i for all $i \in I$, respectively. h_{ij}^+ and h_{ij}^- are defined in equations (10) and (11), respectively.

$$h_{tj}^+ = \max_{i \in I} \left\{h_{tj}^i\right\} \tag{10}$$

$$h_{tj}^- = \min_{i \in I} \left\{h_{tj}^i\right\} \tag{11}$$

By using h_{ij}^+ and h_{ij}^-, two matrix H_+ and H_- are defined in equations (12) and (13), respectively.

$$H_+ = \begin{bmatrix} h_{11}^+ & h_{12}^+ & \cdots & h_{1n}^+ \\ h_{21}^+ & h_{22}^+ & \cdots & h_{2n}^+ \\ \vdots & \vdots & \ddots & \vdots \\ h_{|T|1}^+ & h_{|T|2}^+ & \cdots & h_{|T|n}^+ \end{bmatrix} \tag{12}$$

$$H_- = \begin{bmatrix} h_{11}^- & h_{12}^- & \cdots & h_{1n}^- \\ h_{21}^- & h_{22}^- & \cdots & h_{2n}^- \\ \vdots & \vdots & \ddots & \vdots \\ h_{|T|1}^- & h_{|T|2}^- & \cdots & h_{|T|n}^- \end{bmatrix} \tag{13}$$

Step 7: Weight matrix projection

$\text{NProj}_Y(X)$, which was introduced by Yue (2017), means that the projection of matrix X onto Y. The definition of $\text{NProj}_Y(X)$ shows in equation (14).

$$\text{NProj}_Y(X) = \frac{\min\left\{|XY|, |X|^2, |Y|^2\right\}}{\max\left\{|XY|, |X|^2, |Y|^2\right\} + \left|XY - |X|^2\right|} \tag{14}$$

where X and Y are two matrices with the same dimension $(m * n)$. $XY = \sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij}y_{ij}$, the $x_{ij} \in X$ and $y_{ij} \in Y$. $|X|^2 = \sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij}x_{ij}$ and $|Y|^2 = \sum_{i=1}^{m}\sum_{j=1}^{n} y_{ij}y_{ij}$.

$$\text{NProj}_{H_+}(H_i) = \frac{\min\left\{|H_+H_i|, |H_+|^2, |H_i|^2\right\}}{\max\left\{|H_+H_i|, |H_+|^2, |H_i|^2\right\} + \left|H_+H_i - |H_+|^2\right|} \tag{15}$$

$$\text{NProj}_{H_-}(H_i) = \frac{\min\left\{|H_-H_i|, |H_-|^2, |H_i|^2\right\}}{\max\left\{|H_-H_i|, |H_-|^2, |H_i|^2\right\} + \left|H_-H_i - |H_-|^2\right|} \tag{16}$$

Step 8: Influence index

By using the projection operation defined in equations (15) and (16), the influence of inland waterway port i is expressed in equation (17).

$$Rank_i^G = \frac{\text{NProj}_{H_+}(H_i)}{\text{NProj}_{H_+}(H_i) + \text{NProj}_{H_-}(H_i)} \tag{17}$$

5 A case study

In this section, a case study is conducted by using four years of practical data, including all the factors presented in the previous section, for analysing the influence index of the 27 inland waterway ports along the Yangtze River. The following subsections show the details of the analysis and comparison of the EWM, AEWM, and GEWM.

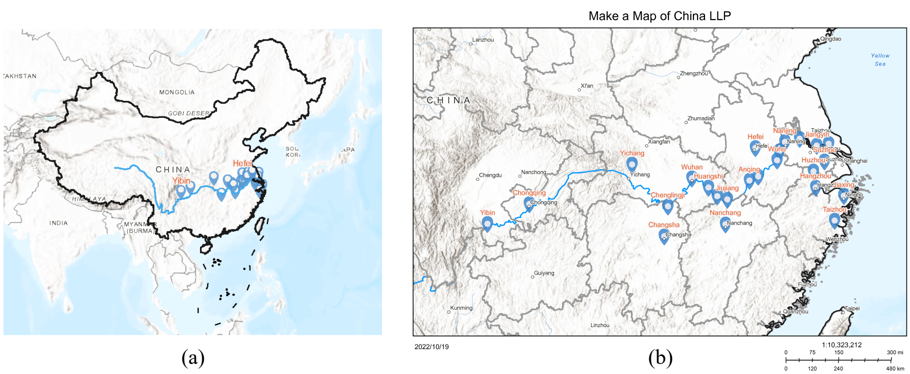
5.1 Parameter setting

This subsection presents the selected inland waterway ports used in the case study and introduces the values of the factors for the selected inland waterway ports.

5.1.1 Inland waterway port selection

To make a comprehensive analysis of the inland waterway ports along the Yangtze River, This paper selected 27 inland waterway ports along the Yangtze River as the candidate inland waterway ports for influence index analysis. These 27 inland waterway ports are Yibin, Luzhou, Chongqing, Yichang, Jinzhou Yueyang, Changsha, Wuhan, Huanggang, Huangshi, Jiujiang, Nanchang, Anqing, Tongling, Chizhou, Hefei, Ma on shan, Wuhu, Nanjing, Zhenjiang, Taizhou, Jiangyin, Nantong, Suzhou, Huzhou, Jiaxing, and Hangzhou inland waterway ports. These 27 inland waterway ports include all the major inland waterway ports along the Yangtze River. The overview of the locations for the selected inland waterway ports is shown in Figure 3(a). Figure 3(b) shows the zoom-in of the overview of locations in Figure 3(a). From Figure 3, we can find that most of the inland waterway ports are located along the middle and lower Yangtze River.

Figure 3 Twenty-seven inland waterway ports along the Yangtze River, (a) overview of location of the 27 inland waterway ports (b) zoom in on the overview of locations in Figure 3(a) (see online version for colours)



(a) (b)

Source: ArcGIS

5.1.2 Value of the factors for selected inland waterway ports

In this paper, 13 factors, including BT, CT, NPB, PIL, GDP, PC-GNP, LFR, FAI, PTI-GDP, TRSSCG, UR, HM, and TAPTS, are adopted. The details of these factors are already explained in the previous section. The value of these data is released by different departments of the Chinese Government, such as the National Bureau of Statistics of China, the Ministry of Transport of the People's Republic of China, etc. We need to manually collect these data. The details of the data source are shown in Appendix A. We adopted four years of data from 2017 to 2020 on these factors. The values of these factors for each inland waterway port of 2017, 2018, 2019, and 2020 are shown in Appendix C, respectively. To create factor tables with classifications, abbreviations, and sources and then present the descriptive statistics of variables (Nayak et al., 2022), Table 2 shows the average values of these factors for each inland waterway port of four years. Note that the – in these tables represents that the data is not accessible. Suppose data of a factor of an inland port in an arbitrary year is not accessible. In that case, we will adopt accessible data of that factor of a year to replenish the – during the calculating process. You can also download the source data by accessing https://gitee.com/qian_zehao/map-source-version2/tree/master/data.

Table 2 Average value of all the factors for 27 inland waterway port of four years

Port	*BT*	*CT*	*NPB*	*PIL*	*GDP*	*PC-GNP*	*LFR*	*FAI*	*PTI-GDP*	*TRSSCG*	*UR*	*HM*	*TAPTS*
Yibin	0.11	27.07	56.00	2,403.88	52,895.50	168.81	1,657.50	2.66	0.39	961.32	0.50	12,015.83	231.11
Luzhou	0.17	36.61	54.50	1,958.24	46,041.00	156.46	2,199.51	3.07	0.37	948.29	0.50	15,781.29	215.25
Chongqing	1.90	121.01	1,005.25	22,099.12	70,843.25	2,186.77	14,511.32	82.73	0.52	10,973.37	0.67	175,912.00	2,136.70
Yichang	0.61	15.22	218.25	4,074.71	98,973.50	209.06	2,842.69	2.44	0.41	5,770.31	0.62	33,055.09	325.46
Jingzhou	0.36	11.68	129.75	2,319.06	58,396.50	179.28	2,406.40	0.48	0.41	1,408.83	0.56	21,726.36	273.59
Yueyang	1.08	47.38	79.00	3,578.29	64,513.25	148.16	3,099.05	6.06	0.48	1,401.81	0.59	19,810.50	230.29
Changsha	0.17	28.49	124.00	11,043.26	132,325.50	932.60	8,790.12	61.72	0.54	4,608.43	0.81	16,332.00	933.73
Wuhan	1.00	160.81	183.75	14,964.70	133,435.75	1,711.53	6,847.69	110.12	0.58	6,896.82	0.71	15,235.39	1,071.05
Huanggang	0.52	4.67	115.00	2,150.40	34,338.25	145.55	2,340.66	0.53	0.43	1,253.86	0.47	31,675.00	45.40
Huangshi	0.36	5.34	73.25	1,612.34	65,537.25	108.98	1,686.19	1.89	0.39	883.39	0.64	7,556.50	55.61
Jiujiang	1.17	46.18	162.50	2,941.87	59,588.50	275.19	3,157.80	22.58	0.45	993.56	0.57	16,239.00	325.42
Nanchang	0.37	15.93	127.25	5,252.29	89,210.25	459.69	5,961.26	36.25	0.47	2,265.68	0.75	9,020.97	540.11
Anqing	0.29	12.92	72.75	2,118.73	46,818.50	133.20	1,994.90	2.76	0.43	969.37	0.52	21,262.75	56.16
Tongling	0.98	3.27	76.00	960.08	67,610.50	77.62	1,316.69	3.58	0.42	339.76	0.59	4,927.25	62.83
Chizhou	0.78	1.73	84.00	752.50	52,775.75	65.05	834.50	4.10	0.45	298.38	0.54	9,064.55	66.89
Hefei	0.47	29.82	125.00	8,570.48	102,494.00	719.32	7,082.87	33.09	0.54	3,363.37	0.77	19,394.00	738.81
Ma on shan	1.04	19.01	125.75	1,981.55	87,070.50	242.52	2,554.48	25.59	0.44	643.52	0.69	7,405.75	125.21
Wuhu	1.28	88.16	123.00	3,403.27	91,915.25	320.62	3,823.61	28.90	0.45	1,173.29	0.67	11,068.00	238.44
Nanjing	2.50	255.44	213.75	13,438.04	148,979.25	1,489.92	5,923.72	40.36	0.61	6,680.65	0.84	10,482.75	863.59
Zhenjiang	2.44	40.36	213.75	3,977.42	124,450.25	301.11	1,931.31	9.17	0.48	1,114.03	0.72	7,227.25	219.86
Taizhou	2.56	33.29	152.75	4,909.54	107,708.00	362.87	3,986.86	15.65	0.46	1,305.22	0.66	9,978.50	268.14
Jiangyin	2.03	52.79	106.50	3,852.33	228,955.00	251.37	898.64	9.38	0.46	880.98	0.73	2,401.95	89.61
Nantong	2.87	132.42	124.50	9,051.68	119,129.50	613.84	5,547.96	25.95	0.48	3,196.94	0.68	18,603.50	546.19
Suzhou	5.54	607.25	296.50	18,666.69	154,308.75	2,138.22	5,085.71	47.96	0.52	7,422.06	0.77	12,097.75	1,549.72
Huzhou	1.12	46.78	314.00	2,953.12	92,857.00	294.29	2,399.02	13.58	0.47	1,334.78	0.46	8,060.25	343.15
Jiaxing	1.10	20.31	97.00	5,099.74	100,240.75	531.71	2,888.98	32.27	0.44	1,996.10	0.67	8,236.50	541.48
Hangzhou	1.29	7.27	152.00	14,736.61	135,091.50	1,863.06	6,675.85	68.96	0.66	5,939.14	0.78	16,663.25	2,939.51

Table 3 The normalised matrix of the decision matrix of shown in Table 37

	BT	*CT*	*NPB*	*PIL*	*GDP*	*PC-GNP*	*LFR*	*FAI*	*PTI-GDP*	*TRSSCG*	*UR*	*HM*	*TAPTS*
Yibin	0.01	0.06	0.01	0.07	0.06	0.03	0.06	0.00	0.15	0.03	0.18	0.04	0.02
Luzhou	0.05	0.09	0.00	0.06	0.05	0.04	0.08	0.01	0.08	0.03	0.20	0.07	0.01
Chongqing	0.32	0.24	1.00	1.00	0.18	1.00	1.00	1.00	0.54	0.52	0.59	1.00	0.24
Yichang	0.01	0.03	0.19	0.16	0.30	0.07	0.11	0.02	0.08	1.00	0.46	0.17	0.10
Jingzhou	0.05	0.02	0.05	0.08	0.15	0.06	0.09	0.00	0.09	0.06	0.34	0.13	0.09
Yueyang	0.19	0.07	0.03	0.13	0.13	0.04	0.11	0.04	0.41	0.06	0.40	0.10	0.02
Changsha	0.00	0.02	0.07	0.50	0.55	0.34	0.41	0.51	0.54	0.24	0.94	0.09	0.11
Wuhan	0.16	0.23	0.17	0.66	0.50	0.59	0.43	0.95	0.69	0.34	0.13	0.02	0.15
Huanggang	0.10	0.01	0.06	0.07	0.00	0.03	0.09	0.00	0.22	0.05	0.13	0.17	0.01
Huangshi	0.00	0.00	0.04	0.04	0.16	0.02	0.05	0.01	0.07	0.03	0.53	0.04	0.00
Jiujiang	0.18	0.05	0.11	0.10	0.10	0.09	0.12	0.19	0.30	0.04	0.35	0.05	0.10
Nanchang	0.04	0.02	0.06	0.21	0.26	0.16	0.26	0.31	0.34	0.10	0.78	0.00	0.07
Anqing	0.06	0.01	0.04	0.06	0.03	0.03	0.06	0.02	0.25	0.03	0.31	0.10	0.01
Tongling	0.17	0.00	0.03	0.02	0.20	0.01	0.04	0.02	0.00	0.00	0.36	0.02	0.00
Chizhou	0.07	0.00	0.04	0.00	0.07	0.00	0.00	0.04	0.36	0.00	0.19	0.05	0.00
Hefei	0.07	0.04	0.07	0.34	0.32	0.27	0.34	0.29	0.43	0.14	0.80	0.11	0.06
Ma on shan	0.17	0.04	0.11	0.06	0.24	0.08	0.09	0.22	0.18	0.02	0.66	0.04	0.01
Wuhu	0.20	0.12	0.09	0.12	0.27	0.11	0.16	0.26	0.23	0.04	0.59	0.06	0.02
Nanjing	0.39	0.54	0.17	0.60	0.55	0.55	0.33	0.36	0.90	0.29	1.00	0.06	0.08
Zhenjiang	0.23	0.07	0.16	0.16	0.47	0.10	0.12	0.13	0.48	0.04	0.72	0.04	0.01
Taizhou	0.32	0.05	0.10	0.20	0.37	0.13	0.17	0.16	0.49	0.06	0.58	0.05	0.03
Jiangyin	0.25	0.09	0.05	0.15	1.00	0.08	0.03	0.09	0.39	0.03	0.71	0.01	0.01
Nantong	0.38	0.17	0.06	0.39	0.41	0.24	0.25	0.24	0.51	0.14	0.61	0.10	0.05
Suzhou	1.00	1.00	0.23	0.87	0.58	0.84	0.29	0.44	0.62	0.36	0.85	0.07	0.12
Huzhou	0.16	0.06	0.25	0.11	0.29	0.08	0.06	0.10	0.49	0.05	0.00	0.04	0.11
Jiaxing	0.15	0.02	0.05	0.21	0.32	0.17	0.14	0.29	0.37	0.09	0.57	0.04	0.04
Hangzhou	0.17	0.01	0.10	0.67	0.51	0.69	0.31	0.65	1.00	0.30	0.87	0.09	1.00

Table 4 The matrix of p_{ij}

	BT	*CT*	*NPB*	*PIL*	*GDP*	*PC-GNP*	*LFR*	*FAI*	*PTI-GDP*	*TRSSCG*	*UR*	*HM*	*TAPTS*
Yibin	0.00	0.02	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01
Luzhou	0.01	0.03	0.00	0.01	0.01	0.01	0.02	0.00	0.01	0.01	0.01	0.03	0.00
Chongqing	0.06	0.08	0.30	0.14	0.02	0.17	0.19	0.16	0.05	0.13	0.04	0.36	0.10
Yichang	0.00	0.01	0.06	0.02	0.04	0.01	0.02	0.00	0.01	0.24	0.03	0.06	0.04
Jingzhou	0.01	0.01	0.02	0.01	0.02	0.01	0.02	0.00	0.01	0.02	0.02	0.05	0.04
Yueyang	0.04	0.02	0.01	0.02	0.02	0.01	0.02	0.01	0.04	0.01	0.03	0.03	0.01
Changsha	0.00	0.01	0.02	0.07	0.07	0.06	0.08	0.08	0.05	0.06	0.07	0.03	0.04
Wuhan	0.03	0.07	0.05	0.09	0.06	0.10	0.08	0.15	0.07	0.08	0.01	0.01	0.06
Huanggang	0.02	0.00	0.02	0.01	0.00	0.00	0.02	0.00	0.02	0.01	0.01	0.06	0.00
Huangshi	0.00	0.00	0.01	0.01	0.02	0.00	0.01	0.00	0.01	0.01	0.04	0.01	0.00
Jiujiang	0.04	0.02	0.03	0.01	0.01	0.02	0.02	0.03	0.03	0.01	0.03	0.02	0.04
Nanchang	0.01	0.01	0.02	0.03	0.03	0.03	0.05	0.05	0.03	0.02	0.06	0.00	0.03
Anqing	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.02	0.01	0.02	0.04	0.00
Tongling	0.04	0.00	0.01	0.00	0.02	0.00	0.01	0.00	0.00	0.00	0.03	0.01	0.00
Chizhou	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.03	0.00	0.01	0.02	0.00
Hefei	0.02	0.01	0.02	0.05	0.04	0.05	0.06	0.05	0.04	0.03	0.06	0.04	0.03
Ma on shan	0.04	0.01	0.03	0.01	0.03	0.01	0.02	0.03	0.02	0.00	0.05	0.01	0.00
Wuhu	0.04	0.04	0.03	0.02	0.03	0.02	0.03	0.04	0.02	0.01	0.04	0.02	0.01
Nanjing	0.08	0.18	0.05	0.09	0.07	0.09	0.06	0.06	0.09	0.07	0.07	0.02	0.03
Zhenjiang	0.05	0.02	0.05	0.02	0.06	0.02	0.02	0.02	0.05	0.01	0.05	0.01	0.01
Taizhou	0.06	0.02	0.03	0.03	0.05	0.02	0.03	0.02	0.05	0.01	0.04	0.02	0.01
Jiangyin	0.05	0.03	0.01	0.02	0.12	0.01	0.01	0.01	0.04	0.01	0.05	0.00	0.00
Nantong	0.08	0.06	0.02	0.06	0.05	0.04	0.05	0.04	0.05	0.04	0.04	0.04	0.02
Suzhou	0.20	0.33	0.07	0.12	0.07	0.14	0.06	0.07	0.06	0.09	0.06	0.02	0.05
Huzhou	0.03	0.02	0.08	0.02	0.04	0.01	0.01	0.02	0.05	0.01	0.00	0.01	0.05
Jiaxing	0.03	0.01	0.01	0.03	0.04	0.03	0.03	0.05	0.04	0.02	0.04	0.02	0.02
Hangzhou	0.03	0.00	0.03	0.09	0.06	0.12	0.06	0.10	0.10	0.07	0.06	0.03	0.41

5.2 Analysis of the EWM

In this section, we will use the factors of 2017 as an example to demonstrate the process of the EWM. The step by step of calculation of the EWM shows as follows:

Step 1 The source data shown in Table 37 is the initial decision matrix.

Step 2 By using the source data shown in Table 37, the normalised matrix can be calculated. After normalising the decision matrix shown in Table 37, the normalised matrix is obtained, which shows in Table 3.

Step 3 p_{ij} can be calculated by using the normalised matrix shown in Table 3. The matrix of p_{ij} shows in Table 4. By using the p_{ij}, e_j can be easily calculated. The value of e_j for each factor shows in Table 5.

Table 5 The value of e_j for each factor

Factors	*BT*	*CT*	*NPB*	*PIL*	*GDP*	*PC-GNP*	*LFR*
e_j	0.86	0.72	0.83	0.86	0.92	0.81	0.88
Factors	*FAI*	*PTI-GDP*	*TRSSCG*	*UR*	*HM*	*TAPTS*	
e_j	0.82	0.93	0.79	0.95	0.79	0.70	

Step 4 By using the value of e_j, the value of w_j for each factor can be easily obtained, which shows in Table 6.

Table 6 The value of w_j for each factor

Factors	*BT*	*CT*	*NPB*	*PIL*	*GDP*	*PC-GNP*	*LFR*
w_j	0.06	0.13	0.08	0.07	0.04	0.09	0.06
Factors	*FAI*	*PTI-GDP*	*TRSSCG*	*UR*	*HM*	*TAPTS*	
w_j	0.08	0.03	0.10	0.02	0.10	0.14	

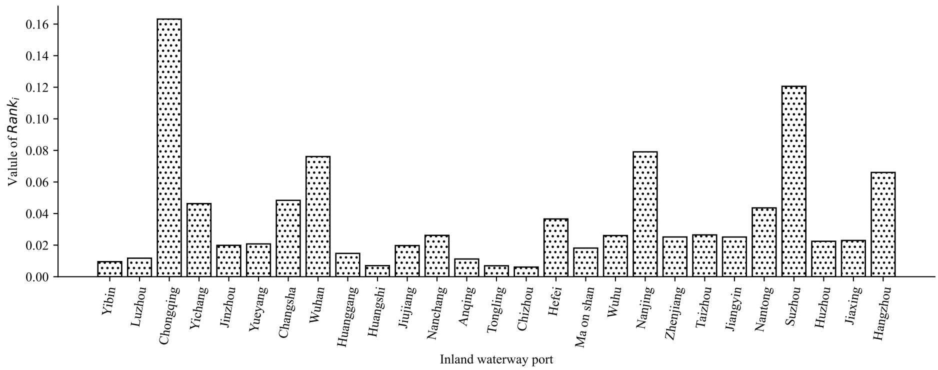
Step 5 After obtaining the value of w_j for each factor, the weight normalised matrix can be obtained, which shows in Table 7.

Step 6 Finally, the influence index $Rank_i$ can be obtained. Figure 4 shows the ranking of inland waterway ports along the Yangtze River in 2017. From Figure 4, we can easily find the ranks of these inland waterway ports. Chongqing inland waterway port ranks first place. Suzhou inland waterway port ranks second, and Nanjing inland waterway port ranks third.

Table 7 Weight normalised matrix

	BT	*CT*	*NPB*	*PIL*	*GDP*	*PC-GNP*	*LFR*	*FAI*	*PTI-GDP*	*TRSSCG*	*UR*	*HM*	*TAPTS*
Yibin	0.00015	0.00266	0.00021	0.00062	0.00028	0.00051	0.00064	0.00001	0.00046	0.00077	0.00030	0.00140	0.00089
Luzhou	0.00067	0.00390	0.00000	0.00054	0.00025	0.00056	0.00087	0.00012	0.00026	0.00074	0.00033	0.00268	0.00031
Chongqing	0.00409	0.01021	0.02413	0.00947	0.00085	0.01519	0.01095	0.01313	0.00165	0.01225	0.00097	0.03611	0.01372
Yichang	0.00015	0.00113	0.00453	0.00147	0.00142	0.00106	0.00122	0.00029	0.00023	0.02350	0.00076	0.00627	0.00607
Jingzhou	0.00060	0.00069	0.00131	0.00073	0.00068	0.00088	0.00099	0.00000	0.00029	0.00145	0.00056	0.00463	0.00538
Yueyang	0.00245	0.00297	0.00073	0.00126	0.00062	0.00061	0.00126	0.00058	0.00125	0.00130	0.00066	0.00346	0.00098
Changsha	0.00000	0.00097	0.00176	0.00475	0.00260	0.00511	0.00449	0.00675	0.00165	0.00553	0.00155	0.00319	0.00616
Wuhan	0.00200	0.00976	0.00421	0.00628	0.00234	0.00900	0.00469	0.01244	0.00209	0.00803	0.00021	0.00085	0.00897
Huanggang	0.00129	0.00034	0.00156	0.00066	0.00000	0.00043	0.00096	0.00002	0.00067	0.00122	0.00021	0.00616	0.00041
Huangshi	0.00001	0.00011	0.00096	0.00041	0.00076	0.00032	0.00054	0.00017	0.00020	0.00075	0.00088	0.00127	0.00021
Jiujiang	0.00237	0.00233	0.00275	0.00097	0.00048	0.00137	0.00132	0.00253	0.00092	0.00084	0.00058	0.00196	0.00607
Nanchang	0.00056	0.00086	0.00147	0.00198	0.00123	0.00245	0.00288	0.00408	0.00103	0.00238	0.00129	0.00000	0.00381
Anqing	0.00071	0.00049	0.00108	0.00055	0.00016	0.00039	0.00067	0.00021	0.00075	0.00079	0.00052	0.00375	0.00045
Tongling	0.00224	0.00021	0.00083	0.00015	0.00092	0.00009	0.00041	0.00031	0.00000	0.00007	0.00060	0.00077	0.00001
Chizhou	0.00088	0.00000	0.00099	0.00000	0.00033	0.00000	0.00000	0.00047	0.00108	0.00000	0.00032	0.00163	0.00001
Hefei	0.00096	0.00149	0.00179	0.00321	0.00150	0.00410	0.00369	0.00387	0.00131	0.00319	0.00131	0.00387	0.00362
Ma on shan	0.00222	0.00173	0.00275	0.00055	0.00114	0.00125	0.00101	0.00291	0.00055	0.00036	0.00108	0.00133	0.00035
Wuhu	0.00261	0.00499	0.00208	0.00118	0.00129	0.00171	0.00172	0.00344	0.00071	0.00088	0.00097	0.00215	0.00102
Nanjing	0.00498	0.02294	0.00421	0.00568	0.00257	0.00838	0.00360	0.00471	0.00274	0.00689	0.00165	0.00216	0.00436
Zhenjiang	0.00295	0.00303	0.00375	0.00156	0.00223	0.00152	0.00130	0.00171	0.00146	0.00104	0.00118	0.00135	0.00072
Taizhou	0.00408	0.00229	0.00245	0.00192	0.00173	0.00194	0.00190	0.00205	0.00148	0.00130	0.00096	0.00186	0.00178
Jiangyin	0.00326	0.00383	0.00117	0.00144	0.00470	0.00118	0.00029	0.00119	0.00118	0.00079	0.00117	0.00031	0.00050
Nantong	0.00491	0.00722	0.00147	0.00373	0.00191	0.00365	0.00278	0.00310	0.00155	0.00338	0.00101	0.00371	0.00263
Suzhou	0.01289	0.04264	0.00561	0.00825	0.00271	0.01280	0.00322	0.00579	0.00187	0.00843	0.00140	0.00244	0.00666
Huzhou	0.00211	0.00247	0.00611	0.00100	0.00136	0.00120	0.00067	0.00132	0.00150	0.00121	0.00000	0.00146	0.00642
Jiaxing	0.00188	0.00072	0.00115	0.00195	0.00151	0.00263	0.00150	0.00383	0.00113	0.00202	0.00095	0.00150	0.00227
Hangzhou	0.00214	0.00039	0.00240	0.00632	0.00237	0.01043	0.00337	0.00851	0.00304	0.00703	0.00143	0.00322	0.05792

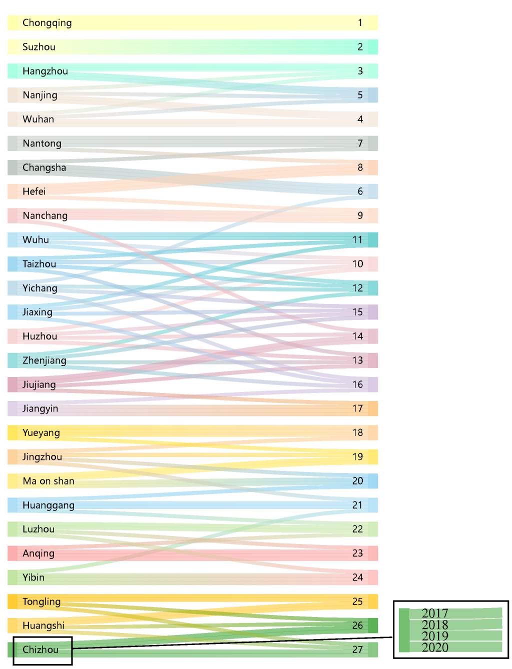
Figure 4 The ranking inland waterway ports along the Yangtze River of 2017



5.3 Analysis of the AEWM

The above described contents show the step-by-step details of the EWM for calculating the influence index of the inland waterway ports of 2017. Using the EWM, the influence index of the inland waterway ports in 2018, 2019, and 2020 can also be obtained. Figure 5 shows the influence index of the inland waterway ports in 2017, 2018, 2019, and 2020.

Figure 5 The ranking of inland waterway ports along the Yangtze River from 2017 to 2020 (see online version for colours)



From Figure 5, we can find that the top-ranked and bottom-ranked inland waterway ports are very stable in terms of their ranking from 2017 to 2020. However, the middle-ranked inland waterway ports fluctuated significantly. This phenomenon is fascinating. The top-ranked inland waterway ports have the dominating position, and it is difficult to change the ranks of the top-ranked inland waterway ports.

Figure 6 The ranking inland waterway ports along Yangtze River by using the AEWM (see online version for colours)

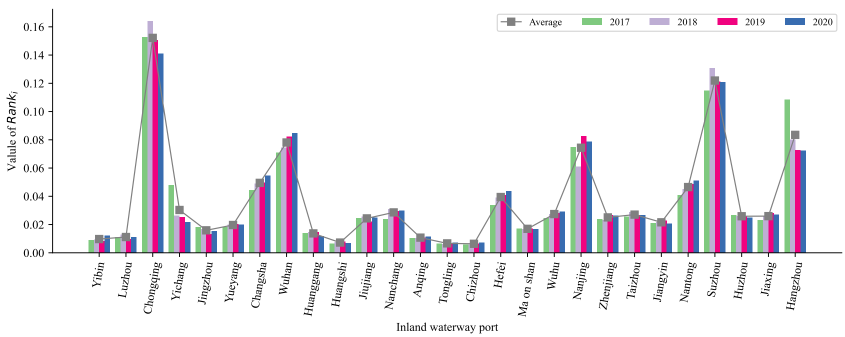


Figure 6 shows the ranking of inland waterway ports along the Yangtze River by using the AEWM.

5.4 *Analysis of the GEWM*

Steps 1–5 are similar to the EWM, which has been discussed in the previous subsection. In this subsection, we will start from step 6 to discuss the GEWM.

Step 6 Weight matrix transformation H_i is calculated in step 6. For each inland waterway port, we can obtain a $t * n$ matrix. In this case study, $t = 2017$, 2018, 2019, and 2020. n is the total number of factors. Table 8 shows an example of the weight matrix transformation H_i with $i =$ Yibin.

Table 8 The weight matrix transformation H_i with $i =$ Yibin

		BT	*CT*	*NPB*	*PIL*	*GDP*	*PC-GNP*	*LFR*
Year	2017	0.000152	0.002658	0.000208	0.000625	0.000281	0.000513	0.000636
	2018	0.000001	0.003068	0.000003	0.000801	0.000450	0.000640	0.000665
	2019	0.000001	0.001459	0.000260	0.000820	0.000483	0.000722	0.000539
	2020	0.000001	0.000776	0.000413	0.000937	0.000450	0.000914	0.000625
		FAI	*PTI-GDP*	*TRSSCG*	*UR*	*HM*	*TAPTS*	
Year	2017	0.000013	0.000459	0.000769	0.000298	0.001397	0.000886	
	2018	0.000014	0.000401	0.000869	0.000275	0.001176	0.001177	
	2019	0.000505	0.000000	0.000900	0.000230	0.001230	0.001269	
	2020	0.000595	0.000000	0.000923	0.000216	0.004425	0.001774	

Table 9 shows the matrix of H_+.

Table 9 The matrix of H_+

		BT	*CT*	*NPB*	*PIL*	*GDP*	*PC-GNP*	*LFR*
Year	2017	0.012894	0.042642	0.024128	0.009474	0.004695	0.015188	0.010949
	2018	0.011283	0.052189	0.027133	0.009462	0.004982	0.014583	0.016899
	2019	0.009651	0.044135	0.026381	0.010537	0.004879	0.013892	0.012027
	2020	0.011093	0.040483	0.021458	0.011683	0.003458	0.015948	0.005884
		FAI	*PTI-GDP*	*TRSSCG*	*UR*	*HM*	*TAPTS*	
Year	2017	0.013128	0.003036	0.023498	0.001650	0.036113	0.057924	
	2018	0.014362	0.002065	0.013120	0.001918	0.038055	0.026758	
	2019	0.015775	0.003108	0.013698	0.002606	0.040341	0.016226	
	2020	0.013439	0.003593	0.015575	0.002203	0.034745	0.016202	

Table 10 shows the matrix of H_-.

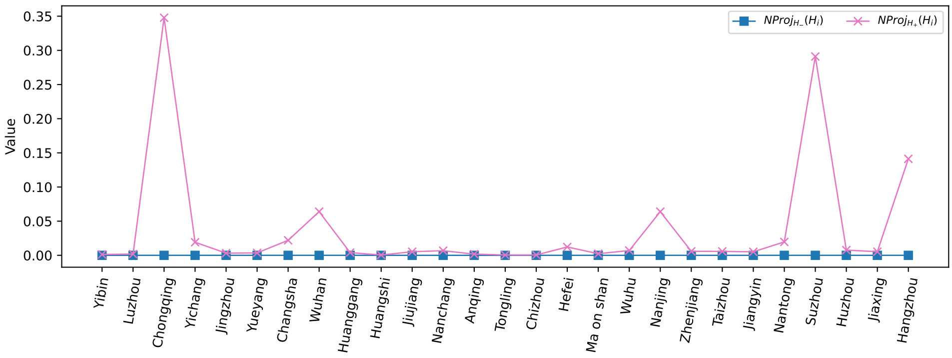
Table 10 The matrix of H_-

		BT	*CT*	*NPB*	*PIL*	*GDP*	*PC-GNP*	*LFR*
Year	2017	0.000001	0.000004	0.000002	0.000001	0.000000	0.000002	0.000001
	2018	0.000001	0.000005	0.000003	0.000001	0.000000	0.000001	0.000002
	2019	0.000001	0.000004	0.000003	0.000001	0.000000	0.000001	0.000001
	2020	0.000001	0.000004	0.000002	0.000001	0.000000	0.000002	0.000001
		FAI	*PTI-GDP*	*TRSSCG*	*UR*	*HM*	*TAPTS*	
Year	2017	0.000001	0.000000	0.000002	0.000000	0.000004	0.000006	
	2018	0.000001	0.000000	0.000001	0.000000	0.000004	0.000003	
	2019	0.000002	0.000000	0.000001	0.000000	0.000004	0.000002	
	2020	0.000001	0.000000	0.000002	0.000000	0.000003	0.000002	

Step 7 Weight matrix projection can be calculated by using the matrix of H_+, H_- and H_i shown in step 6. Weight matrix projection of the $\text{NProj}_{H_+}(H_i)$ and $\text{NProj}_{H_-}(H_i)$ shown in Figure 7. From Figure 7, we can find that the large value of the $\text{NProj}_{H_+}(H_i)$ of an inland waterway port will have a higher rank.

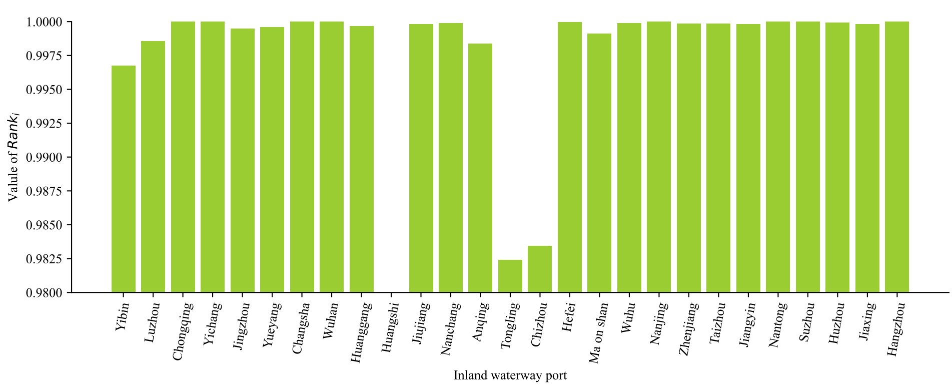
Step 8 By using the $\text{NProj}_{H_+}(H_i)$ and $\text{NProj}_{H_-}(H_i)$, the influence index of each inland waterway port can be calculated. Figure 8 shows the ranking of inland waterway ports by using the GEWM. From Figure 8, we can easily find the ranks of these inland waterway ports. Chongqing inland waterway port ranks first place. Suzhou inland waterway port ranks second, and Wuhan inland waterway port ranks third.

Figure 7 Weight matrix projection of the $\mathrm{NProj}_{H_+}(H_i)$ and $\mathrm{NProj}_{H_-}(H_i)$ (see online version for colours)



To validate our computational results, we consulted relevant literature on port competitiveness. Among them, Tang et al. (2020) proposed that there are many ports along the Yangtze River system, and the gap between ports is large. The calculated ranking of port competitiveness within the Yangtze River system is as follows: Suzhou Port, Chongqing Port, Wuxi Port, Nanjing Port, Wuhan Port, Xuzhou Port, Hangzhou Port, etc. The ports of top ranking, such as Suzhou Port, Chongqing Port, Nanjing Port, etc. are consistent with the results of our paper. At the same time, it also verifies the rationality of the index system of our paper. Deng et al. (2022) evaluated the port connectivity, results show that ports such as Suzhou Port and Chongqing Port rank higher in connectivity, which is consistent with our paper's results. These studies reflect the rationality of our index system and calculation methods.

Figure 8 The ranking inland waterway ports by using the GEWM (see online version for colours)



From Figure 7, we can find that the value of the $\mathrm{NProj}_{H_-}(H_i)$ is very small. When the gap between $\mathrm{NProj}_{H_-}(H_i)$ and $\mathrm{NProj}_{H_+}(H_i)$ is too large or too small, the value of $Rank_i^G$ will be approximate to 1. That is why most of the values of $Rank_i^G$ shown in Figure 8 are approximated to 1.

5.5 Analysis of the port influence evaluation index system and ranking results

5.5.1 The analysis of index weights

From Table 6, factors such as TAPIS, CT, and TRSSCG ranked in the top three positions in the 2017 port ranking. TAPIS and TRSSCG reflect the economic development level of the hinterland, indicating that the hinterland's economy plays a crucial role in determining inland port ranking. CT is an important factor to assess a port's cargo handling capacity and logistics efficiency, and has an important influence on port ranking. Overall, these three factors significantly influence the improvement of port ranking. Therefore, we can take these factors into account when formulating corresponding development strategies and plans for ports.

5.5.2 The analysis of port ranking

From Figure 4, we can find the ranking of 27 ports is Chongqing Port, Suzhou Port, Hangzhou Port, Nanjing Port, Wuhan Port, Yichang Port, Changsha Port, Nantong Port, Hefei Port, Huzhou Port, Taizhou Port, Wuhu Port, Jiujiang Port, Nanchang Port, Zhenjiang Port, Jiaxing Port, Jiangyin Port, Jingzhou Port, Yueyang Port, Ma on shan Port, Huanggang Port, Luzhou Port, Anqing Port, Yibin Port, Tongling Port, Huangshi Port, Chizhou Port. Chongqing Port and Suzhou Port ranked relatively high, and the upstream ports, such as Luzhou and Yibin ranked relatively low. Chongqing and Suzhou are both cities with strong economic foundations. Therefore, they score highly in factors such as 'urban economic development level' and 'urban regional traffic level'. Additionally, both Chongqing Port and Suzhou Port are major ports along the Yangtze River. However, Luzhou Port and Yibin Port, located in the upstream region of the Yangtze River face limitations like the width of the Yangtze River, water flow conditions, and local economic development levels. Consequently, these ports rank lower. These rankings indicate that ports in the middle and lower reaches of the Yangtze River possess significant development trends and influence.

5.5.3 The analysis of comprehensive ranking

From Figure 5, Chongqing Port and Suzhou Port have consistently ranked in the top two, while Tongling Port, Huangshi Port, and Chizhou Port have always ranked last. The ports in the middle of the ranking have experienced relatively large fluctuations. Chongqing Port and Suzhou Port rank high and have stable economic foundations, geographical advantages, stable market demand and customer base. However, the ports ranked lower may have certain shortcomings in terms of geographical location, infrastructure, market demand, competitive environment, etc., resulting in their lower ranking. Some ports in the middle of the ranking have experienced relatively large fluctuations in different years. For example, the ranking of Jiaxing Port has shown an upward trend because of various factors. Therefore, by analysing ports with relatively large changes in rankings, we can predict the future trends of ports and formulate corresponding strategies. To improve port ranking, ports at the bottom of the ranking need to enhance the value of various factors. For example, ports with lower rankings can cooperate with other ports, such as Luzhou Port and Yibin Port, which can cooperate with Chongqing Port, and Chongqing Port can drive the development of surrounding ports. Additionally, ports can cooperate with local governments and enterprises to jointly promote regional economic development and improve port ranking and competitiveness.

Through the above analysis, we can formulate corresponding port management and development strategies so as to enhance the overall competitiveness and development level of the port.

5.6 Analysis of different projection measures

In the previous section describing the GEWM, equation (14) defines a projection measure. Here, the projection measure defined in equation (14) is named projection measure A. There are also existing other projection methods. In the following, two different projection measures are presented, called projection measures B and C, respectively. The projection measures B and C are proposed by Yue and Jia (2017).

5.6.1 Projection measure B

The following equation defines the projection measure B.

$$\text{NProj}_Y(X) = \frac{XY}{|Y|} \tag{18}$$

By using the above projection measure B, we can formulate the projection of H_- on H_i, which is defined as follow.

$$\text{NProj}_{H_-}(H_i) = \frac{H_i H_-}{|H_-|} \tag{19}$$

The projection of H_+ on H_i is defined as follow.

$$\text{NProj}_{H_+}(H_i) = \frac{H_i H_+}{|H_+|} \tag{20}$$

5.6.2 Projection measure C

The following equation defines the projection measure C.

$$\text{RProj}_Y(X) = \frac{XY}{|Y|^2} \tag{21}$$

By using the above projection measure C, we can formulate the projection of H_- on H_i, which is defined as follow.

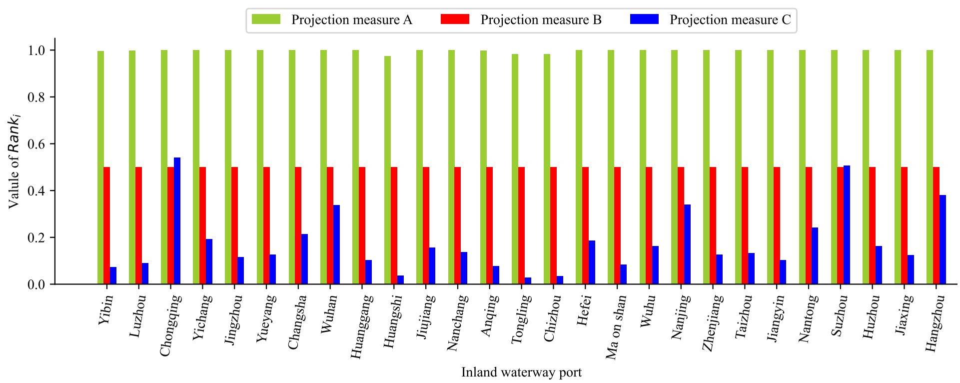
$$\text{NProj}_{H_-}(H_i) = \frac{\text{RProj}_{H_-}(H_i)}{\text{RProj}_{H_-}(H_i) + |1 - \text{RProj}_{H_-}(H_i)|} \tag{22}$$

The projection of H_+ on H_i is defined as follow.

$$\text{NProj}_{H_+}(H_i) = \frac{\text{RProj}_{H_+}(H_i)}{\text{RProj}_{H_+}(H_i) + |1 - \text{RProj}_{H_+}(H_i)|} \tag{23}$$

Figure 9 shows the $Rank_i^G$ with projection measures A, B and C. From Figure 9, we can find that different projection methods will generate different results. The worse case is projection method B. All the value of the $Rank_i^G$ with projection measure B is 0.5. Using projection measure B could not differentiate the ranking of the each inland waterway port. The variance of the $Rank_i^G$ with the projection measure C is the largest among the projection measures A, B and C.

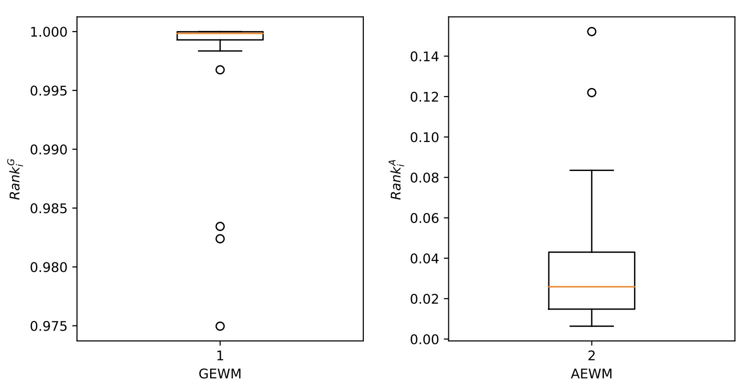
Figure 9 $Rank_i^G$ with projection measure A, B and C (see online version for colours)



5.7 *Comparison of GEWM and AEWM*

In this subsection, the comparison of the GEWM and AEWM is presented. Figure 10 shows the box plot of the $Rank_i^A$ and $Rank_i^G$. From Figure 10, we can find that the distribution of the $Rank_i^G$ is denser than the $Rank_i^A$.

Figure 10 Box plot of the $Rank_i^A$ and $Rank_i^G$ (see online version for colours)



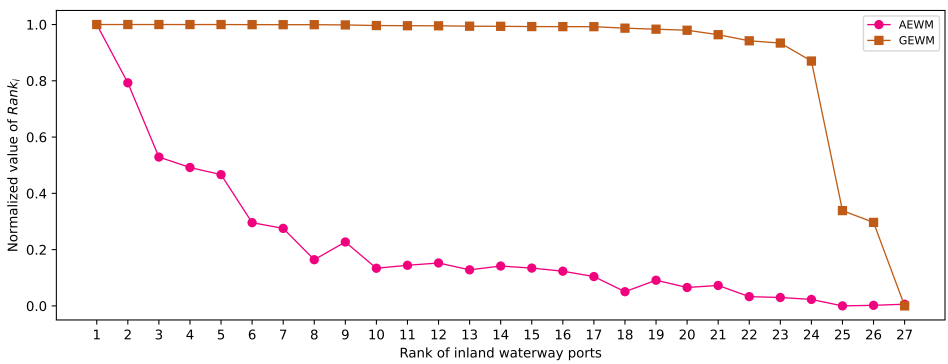
$Rank_i^A$ and $Rank_i^G$ are calculated by using two different methods, and it is difficult to directly compare the value of $Rank_i^A$ and $Rank_i^G$. To compare the value of $Rank_i^A$ and $Rank_i^G$, this paper defines normalised $Rank_i^A$ and $Rank_i^G$ as $NorRank_i^A$ and $NorRank_i^G$, which show as follows, respectively.

$$NorRank_i^A = \frac{Rank_i^A - \min(\{Rank_1^A, \ldots, Rank_m^A\})}{\max(\{Rank_1^A, \ldots, Rank_m^A\}) - \min(\{Rank_1^A, \ldots, Rank_m^A\})} \tag{24}$$

$$NorRank_i^G = \frac{Rank_i^G - \min(\{Rank_1^G, \ldots, Rank_m^G\})}{\max(\{Rank_1^G, \ldots, Rank_m^G\}) - \min(\{Rank_1^G, \ldots, Rank_m^G\})} \tag{25}$$

A larger value of the $NorRank_i^A$ or $NorRank_i^G$ denotes a higher rank. Figure 11 shows the comparison of the $NorRank_i^A$ or $NorRank_i^G$. From Figure 11, we can find that the function of $NorRank_i^A$ decreases more quickly than the function of $NorRank_i^G$ from the first place to the ninth place of the rank. While the function of $NorRank_i^G$ decreases more quickly than the function of $NorRank_i^A$ at the end of the rank.

Figure 11 Comparison of the $NorRank_i^A$ or $NorRank_i^G$ (see online version for colours)



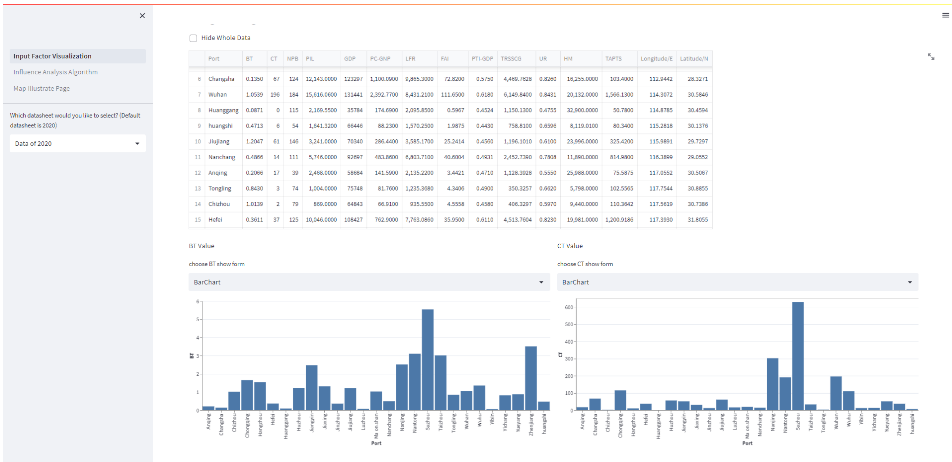
From Figure 11, we can also find that the value of $NorRank_i^A$ gives a lower bound of $NorRank_i$ and the value of $NorRank_i^G$ gives an upper bound of $NorRank_i$, respectively.

5.8 Visualisation tool

Visualisation is an essential tool in business analysis. A good visualisation tool could help decision makers understand business data better. This paper tries to develop a universal visualisation framework to analyse the influence index of inland waterway ports. This universal visualisation framework should be easily extended for analysing the ranking of seaports.

This paper develops a visualisation tool based on the Python package Streamlit, which is both open-source and free. The source code of the developed visualisation tool can be accessed by https://gitee.com/qian_zehao/map-source-version2. For loading the data of the factors, this paper adopts pandas and openpyxl. NumPy is adopted for implementing the EWM, average entropy method, and group entropy method. Figure 12 shows the user interface of the developed visualisation tool.

Figure 12 The screenshot of the user interface of the developed visualisation tool (see online version for colours)



The developed visualisation tool has three major functions, which are summarised as follows:

- Factor loading function: The factor loading function is the primary function of the visualisation tool for rendering the annual factors. The left side shows a table view, which supports uploading an Excel data file for dashboard generation. After loading the factor of inland waterway ports, the location view will present the locations of each inland waterway port. Figure 12 shows the locations of all the inland waterway ports of the case study. Figure 12 shows the user interface of the factor loading function. Each type of factor can be shown in a bar, line, or pie chart.
- Solution generation function: The solution generator could generate the influence index of all the inland waterway ports by using the input data loaded by the factor loading function. The solution generator provides three methods which are discussed in the previous section. After the solution generator generates the solution, the step-by-step solutions could be available, which could make it easier for the reader to understand this paper. The solution generator also supports changing the projection measures of the GEWM. Figure 13 shows an example of the screenshot of the calculation process of each method.
- Solution visualisation function: The solution view displays a 2D and 3D view. The 2D view shows the locations of each inland waterway port, and the 3D view shows the ranking of an inland waterway port for each method. Figure 14 shows the 2D and 3D views of the solutions.

Figure 13 The screenshot of the calculation process of each method (see online version for colours)

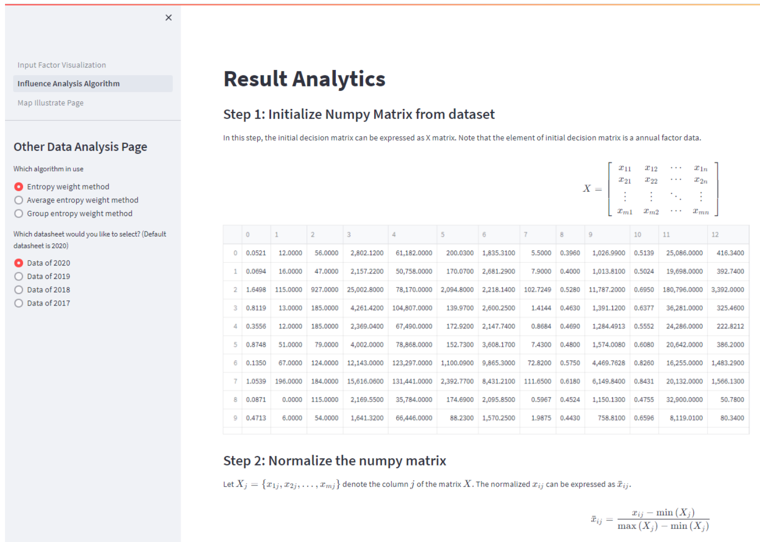
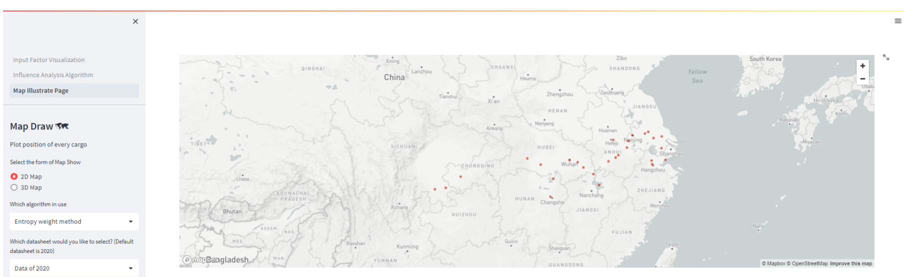
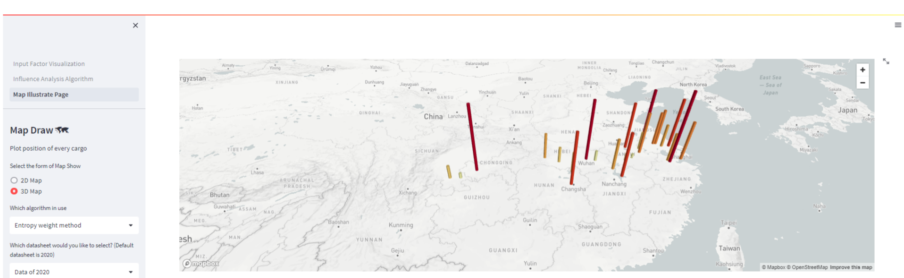


Figure 14 (a) 2D and (b) 3D views of the solutions (see online version for colours)



(a)



(b)

5.9 Managements insights

Port choice is a critical behaviour for shippers (Rezaei et al., 2018) in the maritime industry. Many previous studies have developed many models for port selection, in which the port reputation is one of the essential parameters. This paper developed a GEWM for calculating the inland waterway port influence index, which can be used as a port reputation for calculating port choice behaviours. The developed method and tool can also be easily extended for estimating the influence index of the seaport. Port investment is an essential issue in port economics. Given a specific investment, the port operator usually wants to maximise its influence to attract more cargo. Using the developed tool, the port operator could analyse its investment planning to maximise its influence. The GEWM can also be used for inland waterway ports with expert scoring evaluation.

6 Conclusions

In this study, we evaluated the comprehensive ranking of inland ports along the Yangtze River using the influence index model constructed with the EWM and GEWM and considering the factors of facilities of inland port, urban economic development, and urban regional traffic. This study is a powerful supplement to the existing research on the calculation of port ranking methods and provides a necessary reference for the study of port ranking.

Based on the statistical data of 2017–2022, we use the EWM and GEWM to evaluate the comprehensive ranking of 27 inland ports. The study result shows that different factors have different effects on the port ranking, which can be known from the weight values of each factor. TAPIS, CT, and TRSSCG play an important role in port ranking. At the same time, from the four-year port ranking, it can be known ports ranked near the top (such as Chongqing Port, Suzhou Port, Hangzhou Port) or bottom (such as Tongling Port, Chizhou Port, Huangshi Port) tend to maintain their positions with minimal fluctuation. Chongqing Port has ranked first for four years. However, the middle-ranked inland waterway ports fluctuated significantly.

The advantages of this study compared to existing research include: we introduce a GEWM to evaluate the inland port influence index considering the multiple years' data. We also developed an open-source code visualisation tool integrated with the EWM and GEWM. The developed tool could help researchers analyse the inland waterway port ranking. There are still some shortcomings in this paper. In selecting port influence factors, due to data availability, some factors are not included in the evaluation system, such as ports' operating capacity which are not published or no longer measured. These factors may also influence the ports' ranking.

Further research can focus on the uncertainties of ports' influence factors to predict port operations. Factors affecting port operations may include water level changes, waterway siltation, traffic conditions, political factors, etc. By studying these factors' uncertainty, a more accurate forecast of future port operations can be attained, which holds significant implications for stakeholders such as port managers and shipping companies.

Appendices/Supplementary materials are available on request by emailing the corresponding author or can be obtained under https://ieyjzhou.github.io/.

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Notes

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