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Flood Disaster Risk Assessment Based on DEA Model in Southeast Asia along "The Belt and Road"

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Abstract: The "Belt and Road" initiative proposed by China has received much attention from the international community. Natural disasters along the route have posed considerable challenges to the "Belt and Road" economic construction. Southeast Asia, as the main thoroughfare of the Maritime Silk Road, always suffers from floods. It is necessary to evaluate flood risk to enhance disaster emergency management. Based on the Data Envelopment Analysis (DEA) model, inputs consist of four factors: the number of deaths, victims, frequency of occurrence, and economic losses caused by meteorological disasters. To study the vulnerability to flood disasters in Southeast Asian countries, the four factors caused by flood disasters were taken as outputs, respectively. The relative efficiency values of Laos, Malaysia and Cambodia exceed 0.8. They are most vulnerable to floods. The following four countries, Thailand, Myanmar, Indonesia, and the Philippines, are also vulnerable to flood disasters. The vulnerability of Vietnam is relatively lower than the others. In brief, the risk of flood disasters in Southeast Asia is high. Risk assessment for Southeast Asia is essential to ensure the implementation of the "Belt and Road" initiative.

Keywords: the "Belt and Road"; flood disaster; DEA model; Southeast Asia

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1. Introduction

The "Belt and Road" initiative was first proposed by General Secretary Xi Jinping in September 2013 [1], which included the development strategy of jointly building the "New Silk Road Economic Belt". The strategy calls for cultural exchange and economic cooperation [2]. Since China launched its "Belt and Road" initiative in 2013, it has spanned more than 140 countries [3]. Under the backdrop of a slow global economic recovery, China's "Belt and Road" initiative has become a common cause that contributes to reinforcing trade and overseas investment between countries.

Natural disasters in these regions account for 68.7% of global occurrences [4]. For example, heavy rains resulted in severe damage to Pakistan's infrastructure project. The loss was approximately 0.3 million USD. A rainstorm occurred in the Yangtze River region of China, which lasted for forty days from June 2020 to July 2020. More than 60 million people suffered from the flood disaster. It is necessary to evaluate the risk so that some preparation works can be performed. According to the data observed from the Emergency Events Database, the frequency of floods and flood-affected populations slowly increased between the years 1975 and 2016 [5]. Floods are regarded as one of the most frequently occurring disasters. Seven indices, the analytical hierarchy process (AHP), and *k*-means have been integrated to evaluate the flood disaster in Haikou, China [6]. A framework on the basis of disaster theory was developed to assess the rainstorm disaster in the Yangtze River Delta, China. The top ten indices contributed nearly 75% to the rainstorm risk results [7]. Flood disasters from 1990 to 2015 were assessed in Southeast Asia through TOPSIS and the coefficient of variation method. The results indicated that Southeast Asia, as an essential component of the "Belt and Road" initiative, suffered greatly from the disasters [8]. The trends and the influences of floods in the five regions of Asia have been analyzed from 1990 to 2018. The analysis results have revealed that the trend of flood occurrences was upward [9]. A multi-criteria index was introduced to evaluate flood hazard areas, and the method was used in Greece [10]. A random forest was utilized to assess the regional flood risk in the Dongjiang River Basin of China, where seven risk indices were selected [11]. A flood disaster risk model on the basis of the Choquet integral was established in the Yangtze River Delta region, and the empirical studies implied that risk rankings were the highest in Shanghai City, Jiangsu Province, Zhejiang Province, and Anhui Province [12]. A multi-index evaluation with an information diffusion method was applied to evaluate the risk of flood and drought disasters in the lower and middle reaches of the Yangtze River. The evaluation results have shown that the threat of flooding is more than that of drought [13]. A comprehensive evaluation approach was applied to assess the flood disaster risk in Kelantan, Malaysia, which was more beneficial for the study area [14].

These severe natural disasters in the region along the "Belt and Road" have brought significant challenges to the success of the "Belt and Road" construction. Natural disasters like drought, floods and thunderstorms frequently hit countries along the line. Conducting natural disaster research is significant to disaster prevention and reduction and can reduce disaster damage and social impacts. Particularly, most countries in Southeast Asia along the "Belt and Road" are highly vulnerable to floods. For instance, A. Ahamed et al. established an automated flood monitoring system through a moderate-resolution imaging spectroradiometer to observe the near real-time surface water extent and assess the impact of floods [15]. Naim et al. presented a framing analysis of flood resilience policy in Bangkok, which indicated that the economic growth frame was prevailing [16]. Zou et al. proposed a diffused-interior-outer-set model based on information diffusion theory to analyze the flood disaster risk in China [17]. Nowadays, there is much research on floods, including risk management [18–21], technologies to reduce flood risk [22], disaster vulnerability, and resiliency [23].

An effective hazard vulnerability assessment is critical for successful disaster preparedness, disaster response, and local reconstruction [24]. In solving this problem, the primary methods can be grouped into four categories: disaster loss data, indicator-based methods, curves, and computer modeling methods, in which the indicator-based approach can more accurately reflect overall flood vulnerability [25]. The Data Envelopment Analysis (DEA) method is considered a "data-oriented" approach for assessing the performance of a set of peer entities called Decision-Making Units (DMUs), which converts multiple inputs into multiple outputs [26]. The DEA method was introduced by Charnes [27] and subsequently developed into various fields, including energy [28], environment [29], health [30], industry [28], sports [31], finance [32], education [33] and natural hazards [34]. However, the application of the DEA method in flood disaster risk assessment, especially along the "Belt and Road", is still at an early stage. In this paper, the vulnerability evaluation uses multidimensional factors, including population, death toll, economy, and frequency. The assessment of flood disasters in Southeast Asia along the "Belt and Road" is developed based on the DEA method, which is simple and feasible, and could have high transferability to other areas or other disasters.

This paper consists of five sections: Section 1—Introduction, Section 2—Dataand Methods. Results and the analysis are presented in Section 3. Discussions are included in Section 4. At last, the conclusions are included in Section 5.

2. Data and Methods

2.1. Data

The statistical data were derived from the Emergency Database (EM-DAT) (https://www.emdat.be/, accessed on 10 July 2022), including the related disaster data of Southeast Asian countries from 2001 to 2018. Considering the lack of data in Brunei, Singapore, and East Timor, only eight countries were selected in Southeast Asia on the Maritime Silk Road as the research object, namely Vietnam, the Philippines, Thailand, Cambodia, Myanmar, Malaysia, Indonesia and Laos. The studied area is shown in Figure 1.

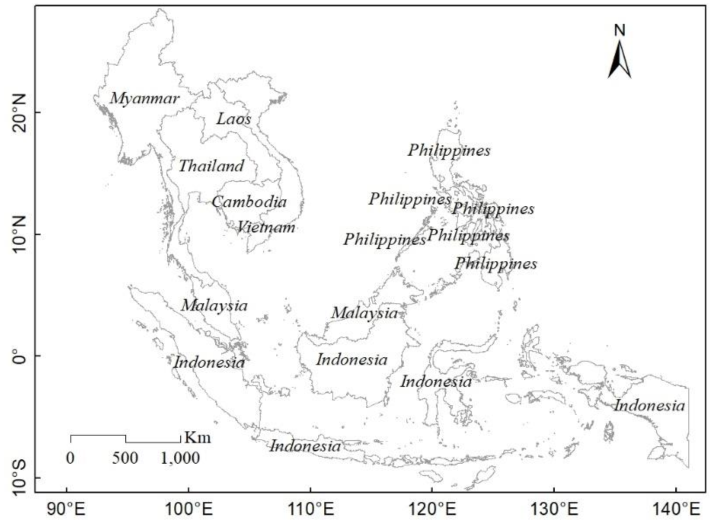


Figure 1. The studied countries.

2.2. Research Methods

The statistical analysis of meteorological disasters in Southeast Asia along the "Belt and Road" from 2001 to 2018 was carried out directly using the death toll, number of victims, number of occurrences, and economic loss. First, the situation of meteorological disasters and floods in Southeast Asia were analyzed, and the distribution and impact of disasters in different countries were further analyzed. Then, flood disaster risk was evaluated based on data envelopment analysis (DEA).

DEA is an efficient evaluation method developed to measure the relative efficiency of different units when inputs and outputs are measured in their natural units. Parameters are not set beforehand in DEA, which only needs to assess the decision-making unit based on the input–output data. It can prevent the interference of subjective factors. The equation of the model is shown as follows:

$$\max\ \left[\theta_k - \varepsilon\left(\sum_{m=1}^{t} s^- + \sum_{n=1}^{r} s^+\right)\right] = v_d(\varepsilon) \tag{1}$$

$$s.t.\begin{cases} \sum_{j=1}^{n} x_{jm} w_j + s_m^- = x_{km} \\ \sum_{j=1}^{n} y_{jn} w_j - s_n^+ = \theta_k y_{kn} \\ w_j \geq 0;\ s_m^- \geq 0;\ s_n^+ \geq 0 \\ \quad j = 1, 2, \cdots n; \\ \quad n = 1, 2, \cdots r; \\ \quad m = 1, 2, \cdots t \end{cases} \tag{2}$$

where x_{jm} represents the value of m_{th} input indicator of j_{th} region; y_{jn} represents the value of n_{th} output indicator of j_{th} region; s_m^- is input slacks; s_n^+ is output slacks; ε is the non-Archimedean infinitesimal; and w_j represents the weight of the indicator. $1/\theta_k$ is the relative efficiency value of the k_{th} decision unit.

The disaster data of the eight research-object countries in Southeast Asia on the Maritime Silk Road were chosen to conduct flood vulnerability measures. Risk means loss. Four factors are considered in terms of loss, which are the frequency of disasters, victims, death toll, and economic loss. These factors greatly influence the loss associated with flood disasters, and can provide data. Based on the input–output model of natural disaster vulnerability, the exposure and loss are determined as inputs and outputs, as shown in Table 1. The victims factor in this paper is defined as the extent to which a population is susceptible to the loss of production and livelihood due to flood disasters; the death factor refers to the extent to which a population is susceptible to death due to flood disaster; the frequency factor denotes the number of occurrences of flood disasters; the economic loss factor means the extent to which an economic system is susceptible to flood disasters.

Table 1. Input–output metrics.

Factor	Variable of Input	Variable of Output
Frequency	Number of total disasters	Number of flood disasters
Victims	Victims of total disasters	Victims of flood disasters
Death	Death toll of total disasters	Death toll of flood disasters
Economic loss	Economic loss caused by total disasters	Financial loss caused by flood disasters

3. Results and Analysis

3.1. Status of Meteorological Disasters and Floods

The status of meteorological disasters and floods from 2001 to 2018 is shown in Table 2. In the past 18 years, Southeast Asia has had more than 739 disasters, with an average of more than 41 disasters per year. More than 260.959 million people have been affected. The death toll has reached 173,753. (Because of a typhoon in 2008, there were more than 130,000 deaths in Myanmar, which figured into the majority of deaths from meteorological disasters. So, the number of brackets indicates the data after having removed the death toll in Myanmar in 2008.). As a result, the economic losses have exceeded 100 billion dollars. The variable of output of flood disasters in the above statistics is 420, 185.776 million, 28,182, and 71.86 billion dollars, respectively, accounting for 57%, 71%, 80%, 72% of the proportion of total meteorological disasters, respectively, which is shown as Figure 2. It indicates that flood disasters have had a considerable impact on Southeast Asia.

Table 2. Status of meteorological disasters and floods in Southeast Asia.

Disasters	Frequency	Victims/Million	Death Toll	Economic Loss/ Million Dollars
Meteorological disasters	739	260.959	173,753 (35,387)	100,023.176
Floods	420	185.776	28,182	71,860.141

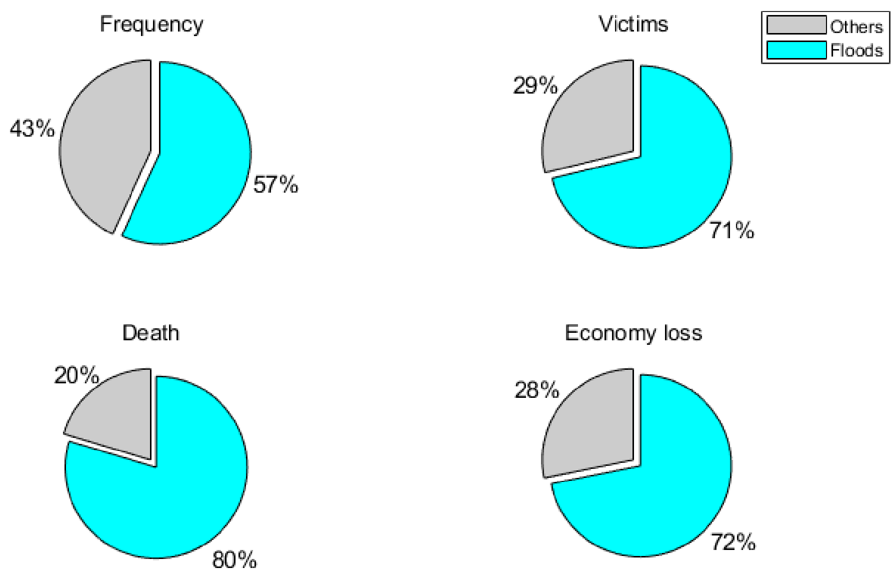


Figure 2. The proportion of floods and other disasters in Southeast Asia.

3.2. Analysis Based on DEA Model

The vulnerability to flood disasters of selected areas is shown in Tables 3–5. The higher the relative efficiency value is, the greater the vulnerability of the regions to floods. That means the comprehensive loss caused by floods to the area is more severe than others in the same situation. The distribution of flood vulnerability in Vietnam, the Philippines, Thailand, Cambodia, Myanmar, Malaysia, Indonesia and Laos are presented in Tables 3–5. The null value indicates no meteorological disaster in the country during the year.

Table 3. Vulnerability to flood disasters in Southeast Asian countries (2001–2006).

	Vulnerability					
Country	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Vietnam	0.682	0.421	0.563	0.398	0.175	0.274
The Philippines	0.597	0.401	0.460	0.986	0.716	0.617
Thailand	0.792	0.726	0.716	0.469	0.301	1.000
Cambodia	1.000	0.655		1.000	1.000	1.000
Myanmar	1.000	1.000		0.220	0.278	0.529
Malaysia	1.000	0.100	1.000	0.564	1.000	0.965
Indonesia	0.675	0.637	0.753	0.140	0.486	0.617
Laos	1.000	1.000				

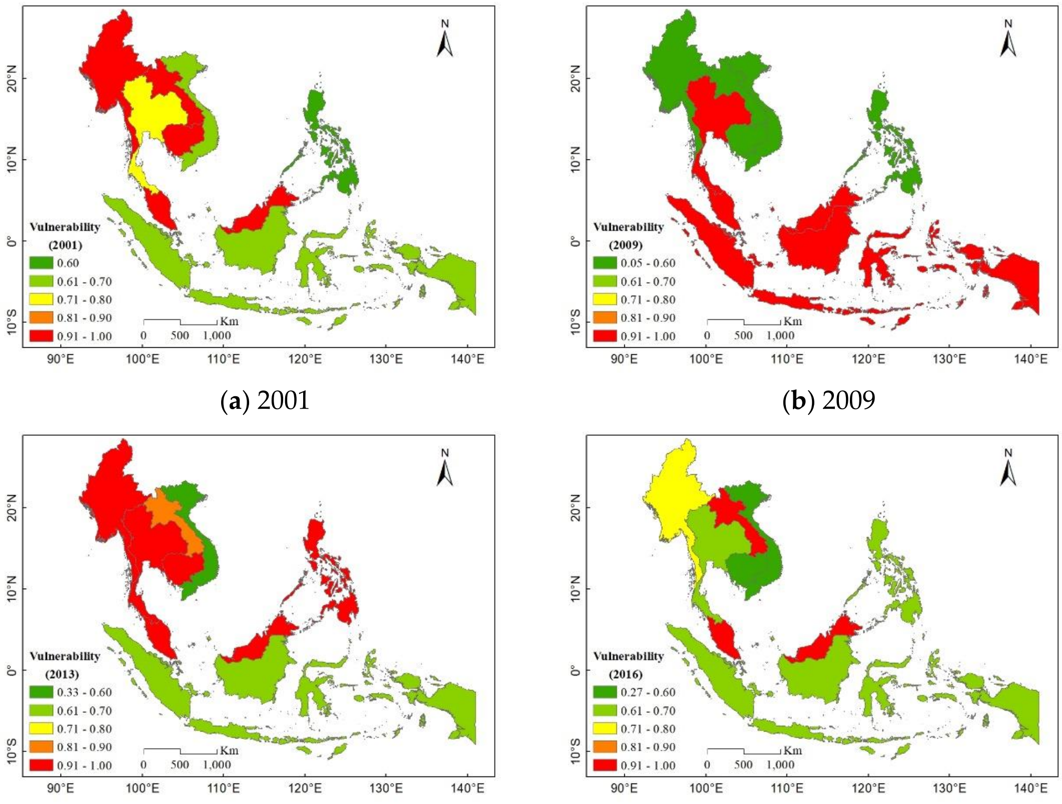
Table 4. Vulnerability to flood disasters in Southeast Asian countries (2007–2012).

	Vulnerability					
Country	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Vietnam	0.628	0.291	0.129	0.785	1.000	0.529
The Philippines	0.715	0.528	0.584	0.231	0.476	0.642
Thailand	0.983	0.495	1.000	1.000	1.000	0.783
Cambodia	0.954		0.050	1.000	1.000	1.000
Myanmar	1.000	0.075	0.100	0.038	1.000	1.000
Malaysia	0.795	1.000	1.000		0.998	
Indonesia	0.696	0.918	1.000	0.916	1.000	0.631
Laos		1.000	0.381		1.000	

Table 5. Vulnerability to flood disasters in Southeast Asian countries (2013–2018).

	Vulnerability					
Country	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Vietnam	0.332	1.000	0.016	0.301	0.444	0.013
The Philippines	1.000	0.848	0.545	0.645	0.410	0.136
Thailand	1.000	0.505	0.220	0.649	0.663	
Cambodia	0.993	1.000	0.777	0.267		1.000
Myanmar	1.000	1.000	0.461	0.706	0.999	1.000
Malaysia	0.914	0.448	1.000	1.000	1.000	1.000
Indonesia	0.688	0.573	0.456	0.628	0.562	0.405
Laos	0.847	1.000	0.954	0.997	0.306	1.000

The vulnerability to flood disasters of the eight countries in 2001, 2009, 2013, and 2016 is presented in Figure 3. Overall, the vulnerability to flood disasters of Cambodia, Malaysia, Laos and Myanmar are higher than the others. When relative efficiency values of Cambodia, Malaysia, Laos and Myanmar exceed 0.8, the frequency of floods is 11, 12, 8 and 9, respectively. Moreover, the frequency of values reaching 1 is 9, 7, 6 and 8, respectively. It is worth noting that the number of meteorological disaster records in these four countries is 15, 16, 11 and 17, respectively. The rate of relative efficiency value exceeding 0.8 is more than 0.5, which explains why the vulnerability to flood disasters in Cambodia, Malaysia, Laos, and Myanmar is very high. For example, the catastrophic floods in many Southeast Asian countries in July 2018 caused severe impacts on countries such as Cambodia and Laos, and the corresponding flood disasters have a value of 1.



(**a**) 2001 (**b**) 2009

(**c**) 2013 (**d**) 2016

Figure 3. The results of DEA in 2001, 2009, 2013, and 2016.

Followed by Thailand, when relative efficiency values are more significant than 0.8, the frequency of floods is 6, and the instances of values reaching 1 is 5. Meanwhile, the number of meteorological disaster records is 17, indicating that the vulnerability to flood disasters in Thailand is also high. For example, in 2011, Thailand suffered a major flood disaster, and 65 out of the 77 cities across the country were affected, causing hundreds of deaths and severe economic losses. Therefore, the flood disaster risk in Thailand cannot be ignored.

Indonesia, the Philippines and Vietnam all recorded 18 meteorological disasters, showing that meteorological disasters occur yearly. When the relative efficiency values are more than 0.8, the frequency of flood disasters is 4, 2 and 2, respectively. Although the frequency of values surpassing 0.8 is small, the number of meteorological disasters is great. Flood disasters occur in most years, with high incidence.

On average, as shown in Figure 4, the average relative efficiency value of flood vulnerability is ranked as Laos > Malaysia > Cambodia > Thailand > Myanmar > Indonesia > the Philippines > Vietnam. The average efficiency values of Laos, Malaysia and Cambodia are all greater than 0.8, which is consistent with the overall level of vulnerability, indicating that they are highly vulnerable countries. Moreover, the number of meteorological records in Laos is 11. Although the times of meteorological disasters and floods in Laos are fewer than that in the other countries, the relative efficiency value of flood disasters is very high, demonstrating that the impact of each occurrence of a flood disaster is enormous. The average efficiency values of Thailand, Myanmar, Indonesia, and the Philippines are 0.724, 0.671, 0.655 and 0.585, respectively. Although the vulnerability to floods for these four countries is not as high as in the previous three countries, each value also exceeds 0.5, indicating that the vulnerability to flood disasters is also high. The average efficiency value of Vietnam is the lowest in the research countries, which is 0.443. However, the frequency of floods in Vietnam is 2, with the relative efficiency value reaching 1. This shows that flood disasters are the only meteorological disasters in some years and that they have reached abnormally significant conditions. However, in general, the vulnerability of Vietnam is relatively stable.

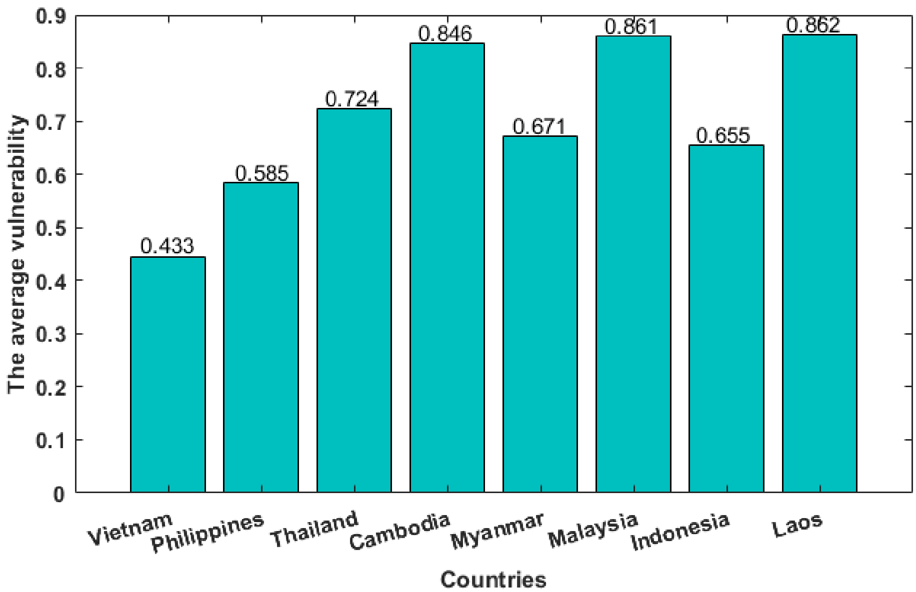


Figure 4. The average vulnerability to flood disasters in Southeast Asian countries.

4. Discussion

The vulnerability to flood disasters in Southeast Asia is generally high. In the 18 years from 2001 to 2018, the frequency of relative efficiency values greater than 0.8 in all countries calculated by the DEA model reached 54, with relative efficiency values reaching 1 as many as 35 times. In the case of a relative efficiency value greater than 0.8, the ratio of values reaching 1 is 65%, which shows that the vulnerability to floods in Southeast Asia is very high.

As shown in Table 6, among the eight countries, the average vulnerability to floods in Laos is the highest, reaching 0.862. Compared with its 11 meteorological disaster records, the instances of flood relative efficiency values outstripping 0.8 are 8, and the instances of values reaching 1 are 7. It should be stated that although the number of meteorological disasters in Laos is smaller than in the other seven countries, the vulnerability index of flood disasters is not low. The average relative efficiency value of flood vulnerability in Malaysia ranks second. From the vulnerability to flood disasters over the past 18 years, its frequency of flood relative efficiency values exceeding 0.8 is 12, with 16 records of meteorological disasters. In addition, the instances of flood relative efficiency values reaching 1 in Laos are 7. The above three frequencies in Cambodia are 11, 15, and 9, respectively. Although the relative efficiency value of Cambodia has reached 1 more times than Malaysia, it has been found that Malaysia's relative efficiency values of greater than 0.8 are equivalent to or greater than 0.9. This indicates that the considerable relative efficiency value is in a higher range. Thailand, Myanmar, Indonesia, and the Philippines have average relative efficiency values between 0.5 and 0.8, of which Thailand ranks first at 0.724, followed by Myanmar and Indonesia at 0.671 and 0.655, respectively.

Table 6. Analysis results in Southeast Asia.

Country	Relative Efficiency Value		Average Relative Efficiency	Number of Meteorological Disasters
	More Than 0.8	Reach 1		
Laos	8	7	0.862	11
Malaysia	12	7	0.861	16
Cambodia	11	9	0.846	15
Thailand	6	5	0.724	17
Myanmar	9	8	0.671	17
Indonesia	4	2	0.655	18
The Philippines	2	1	0.585	18
Vietnam	2	2	0.433	18

On the whole, the frequency of relative efficiency values in Myanmar greater than 0.8 is 9, while the instances of relative efficiency values reaching 1 are 8. Furthermore, there are 17 records of meteorological disasters. The vulnerability to floods is high for more than half of the year, but it was lower than in Thailand because in some years, such as 2009 and 2010, the relative efficiency values were 0.1 and 0.038, respectively. This means that flood disasters have small impacts or do not occur in some years. There were 18 instances of meteorological disasters in Indonesia, the Philippines and Vietnam. From this, it can be noted that meteorological disasters occur every year. Among the research regions, the average relative efficiency value was less than 0.5 only in Vietnam.

The selected regions have been divided into three categories based on the above analysis of vulnerability to flood disasters. The first echelon of vulnerability includes Laos, Malaysia and Cambodia representing the high disaster vulnerability, respectively. Thailand, Myanmar, Indonesia, and the Philippines are the countries in the second echelon with a medium–high rating. Meanwhile, only one region in the third tier, namely Vietnam, reflects a medium flood disaster vulnerability.

5. Conclusions

Based on historical data, eight countries in the Southeast Asia of the 21st Century Maritime Silk Road were used as the research object, and the DEA model is used for evaluating the vulnerability to flood disasters in Vietnam, the Philippines, Thailand, Cambodia, Myanmar, Malaysia, Indonesia and Laos over the 18 years between 2001 and 2018. The results have indicated that the vulnerability to floods in Southeast Asia is at a high level, and there is a slight difference in the spatial distribution of flood hazard risk. Among these countries, the vulnerability to flood disasters of Laos, Malaysia and Cambodia is the most, and the average relative efficiency value is greater than 0.8, which fully indicates that Laos, Malaysia and Cambodia are highly vulnerable countries. Furthermore, the average relative efficiency value of Myanmar, Indonesia, and the Philippines is between 0.5 and 0.8, which can be classified as countries with medium–high flood vulnerability. The average efficiency value of Vietnam reaches 0.433, which is half that of the top three countries and ranks at the bottom out of the 8 countries listed. However, the number of flood disasters in Vietnam with a relative efficiency value of 1 is 2. It is also impossible to ignore the risk pressure of flood disasters, so it could possibly be defined as a country with medium flood vulnerability.

We consider that flood disaster has become the main obstacle to the sustainable development of the "Belt and Road". Therefore, public meteorological services should be further provided in various forms to maximize the coverage of information regarding disasters in order to keep the public informed. Combined with our research, recommendations are given in the following paragraphs.

Southeast Asia is a tropical rainforest climate and a tropical monsoon climate. It is a hot, humid climate and is susceptible to floods, heavy rains and typhoons. When carrying out economic construction, choose a higher terrain to prevent flooding.

Further development of predictive monitoring technology is essential for preventing and mitigating flood disasters. The first is to improve the monitoring accuracy of hydrometeorological satellites and enhance the satellite monitoring capability. The second is to improve the monitoring capability of surface hydrological stations, especially the rapid transmission and analysis capabilities. The third is to deal with the scientific scheduling model of floods, scheduling scheme generation, and scheduling services. Currently, the flood control implementation system is still not perfect. Therefore, actively carry out international cooperation on disaster prevention and reduction. The adjacent countries along the "Belt and Road" often have similar natural disasters, which provide a basis for establishing a cooperation mechanism for disaster prevention and relief. In the face of catastrophe risk, an individual country has limited ability to take losses. Thus, establishing a national cooperation mechanism for disaster prevention and reduction can improve the efficiency of disaster relief and achieve resource sharing and risk sharing.

Although the climatic and hydraulic models perform well on large-scale events, they are sometimes inferior in forecasting small-scale events. This lack of awareness is typically the main reason people may not take extreme flood events seriously, which may lead to overconfidence and inadequate preparation, and consequently to high fatality. In subsequent analyses, we will focus on small-scale events to conduct profound research, as there are many types of natural disasters along the "Belt and Road" besides floods, such as earthquakes, which cause massive damage to local populations, and therefore also deserve attention.

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References

1. Song, A.Y.; Fabinyi, M. China's 21st century maritime silk road: Challenges and opportunities to coastal livelihoods in ASEAN countries. *Marine Policy* **2022**, *136*, 104923. [CrossRef]
2. Yu, L.; Peng, C.; Regmi, A.D.; Murray, V.; Pasuto, A.; Titti, G.; Shafique, M.; Priyadarshana, D.G.T. An international program on Silk Road Disaster Risk Reduction–a Belt and Road initiative (2016–2020). *J. Mt. Sci.* **2018**, *15*, 1383–1396. [CrossRef]
3. Chai, D.; Wang, M.; Liu, K. Driving factors of natural disasters in belt and road countries. *Int. J. Disaster Risk Reduct.* **2020**, *51*, 101774. [CrossRef]
4. Wang, Q.; Liu, K.; Wang, M.; Koks, E.E. A River Flood and Earthquake Risk Assessment of Railway Assets along the Belt and Road. *Int. J. Disaster Risk Sci.* **2021**, *12*, 553–567. [CrossRef]
5. Hu, P.; Zhang, Q.; Shi, P.; Chen, B.; Fang, J. Flood-induced mortality across the globe: Spatiotemporal pattern and influencing factors. *Sci. Total Environ.* **2018**, *643*, 171–182. [CrossRef] [PubMed]
6. Xu, H.; Ma, C.; Lian, J.; Xu, K.; Chaima, E. Urban flooding risk assessment based on an integrated k-means cluster algorithm and improved entropy weight method in the region of Haikou, China. *J. Hydrol.* **2018**, *563*, 975–986. [CrossRef]

7. Deng, M.; Li, Z.; Tao, F. Rainstorm Disaster Risk Assessment and Influence Factors Analysis in the Yangtze River Delta, China. *Int. J. Environ. Res. Public Health* **2022**, *19*, 9497. [CrossRef]
8. An, Y.; Tan, X.; Gu, B.; Zhu, K. Flood risk assessment using the CV-TOPSIS method for the Belt and Road Initiative: An empirical study of Southeast Asia. *Ecosyst. Health Sustain.* **2020**, *6*, 1765703. [CrossRef]
9. Kimuli, J.B.; Di, B.; Zhang, R.; Wu, S.; Li, J.; Yin, W. A multisource trend analysis of floods in Asia-Pacific 1990–2018: Implications for climate change in sustainable development goals. *Int. J. Disaster Risk Reduct.* **2021**, *59*, 102237. [CrossRef]
10. Kazakis, N.; Kougias, I.; Patsialis, T. Assessment of flood hazard areas at a regional scale using an index-based approach and Analytical Hierarchy Process: Application in Rhodope–Evros region, Greece. *Sci. Total Environ.* **2015**, *538*, 555–563. [CrossRef]
11. Wang, Z.; Lai, C.; Chen, X.; Yang, B.; Zhao, S.; Bai, X. Flood hazard risk assessment model based on random forest. *J. Hydrol.* **2015**, *527*, 1130–1141. [CrossRef]
12. Sun, R.; Gong, Z.; Guo, W.; Shah, A.A.; Wu, J.; Xu, H. Flood disaster risk assessment of and countermeasures toward Yangtze River Delta by considering index interaction. *Nat. Hazards* **2022**, *112*, 475–500. [CrossRef]
13. Liu, Y.; You, M.; Zhu, J.; Wang, F.; Ran, R. Integrated risk assessment for agricultural drought and flood disasters based on entropy information diffusion theory in the middle and lower reaches of the Yangtze River, China. *Int. J. Disaster Risk Reduct.* **2019**, *38*, 101194. [CrossRef]
14. Jiang, W.; Deng, L.; Chen, L.; Wu, J.; Li, J. Risk assessment and validation of flood disaster based on fuzzy mathematics. *Prog. Nat. Sci.* **2009**, *19*, 1419–1425. [CrossRef]
15. Ahamed, A.; Bolten, J.D. A MODIS-based automated flood monitoring system for southeast asia. *Int. J. Appl. Earth Obs. Geoinf.* **2017**, *61*, 104–117. [CrossRef]
16. Laeni, N.; van den Brink, M.; Arts, J. Is Bangkok becoming more resilient to flooding? A framing analysis of Bangkok's flood resilience policy combining insights from both insiders and outsiders. *Cities* **2019**, *90*, 157–167. [CrossRef]
17. Zou, Q.; Zhou, J.; Zhou, C.; Guo, J.; Deng, W.; Yang, M.; Liao, L. Fuzzy risk analysis of flood disasters based on diffused-interior-outer-set model. *Expert Syst. Appl.* **2012**, *39*, 6213–6220. [CrossRef]
18. Zhao, J.; Jin, J.; Xu, J.; Guo, Q.; Hang, Q.; Chen, Y. Risk assessment of flood disaster and forewarning model at different spatial-temporal scales. *Theor. Appl. Climatol.* **2017**, *132*, 791–808. [CrossRef]
19. Plate, E.J. Flood risk and flood management. *J. Hydrol.* **2005**, *267*, 2–11. [CrossRef]
20. Feng, L.; Mao, Z.; Zhao, X. Risk Analysis of Meteorological Factor Based on Information Diffusion Theory. In Proceedings of the 2010 International Conference on Intelligent Computation Technology and Automation, Changsha, China, 11–12 May 2010; pp. 214–216.
21. Li, Q.; Zhou, J.; Liu, D.; Jiang, X. Research on flood risk analysis and evaluation method based on variable fuzzy sets and information diffusion. *Saf. Sci.* **2012**, *50*, 1275–1283. [CrossRef]
22. McCallum, I.; Liu, W.; See, L.; Mechler, R.; Keating, A.; Hochrainer-Stigler, S.; Mochizuki, J.; Fritz, S.; Dugar, S.; Arestegui, M.; et al. Technologies to Support Community Flood Disaster Risk Reduction. *Int. J. Disaster Risk Sci.* **2016**, *7*, 198–204. [CrossRef]
23. Kim, H.; Marcouiller, D.W. Considering disaster vulnerability and resiliency: The case of hurricane effects on tourism-based economies. *Ann. Reg. Sci.* **2015**, *54*, 945–971. [CrossRef]
24. Du, Y.; Ding, Y.; Li, Z.; Cao, G. The role of hazard vulnerability assessments in disaster preparedness and prevention in China. *Mil. Med. Res.* **2015**, *2*, 27. [CrossRef]
25. Nasiri, H.; Mohd Yusof, M.J.; Mohammad Ali, T.A. An overview to flood vulnerability assessment methods. *Sustain. Water Resour. Manag.* **2016**, *2*, 331–336. [CrossRef]
26. Cooper, W.W.; Seiford, L.M.; Zhu, J. Data Envelopment Analysis: History, Models, and Interpretations. In *Handbook on Data Envelopment Analysis*; Springer: Boston, MA, USA, 2011; pp. 1–39. Available online: https://link.springer.com/chapter/10.1007/978-1-4419-6151-8_1 (accessed on 10 July 2022).
27. Charnes, A. Measuring the efficiency of decision making units. *Eur. J. Oper. Res.* **1978**, *2*, 429–444. [CrossRef]
28. Arocena, P. Cost and quality gains from diversification and vertical integration in the electricity industry: A DEA approach. *Energy Econ.* **2008**, *30*, 39–58. [CrossRef]
29. Zhou, P.; Poh, K.L.; Ang, B.W. A non-radial DEA approach to measuring environmental performance. *Eur. J. Oper. Res.* **2007**, *178*, 1–9. [CrossRef]
30. Kohl, S.; Schoenfelder, J.; Fügener, A.; Brunner, J.O. The use of Data Envelopment Analysis (DEA) in healthcare with a focus on hospitals. *Health Care Manag. Sci.* **2018**, *22*, 245–286. [CrossRef]
31. Sexton, T.R.; Lewis, H.F. Two-Stage DEA: An Application to Major League Baseball. *J. Product. Anal.* **2003**, *19*, 227–249. [CrossRef]
32. Camanho, A.S.; Dyson, R.G. Cost efficiency measurement with price uncertainty: A DEA application to bank branch assessments. *Eur. J. Oper. Res.* **2005**, *161*, 432–446. [CrossRef]
33. Nazarko, J.; Šaparauskas, J. Application of DEA method in efficiency evaluation of public higher education institutions. *Technol. Econ. Dev. Econ.* **2014**, *20*, 25–44. [CrossRef]
34. Huang, D.; Zhang, R.; Huo, Z.; Mao, F.; Zheng, W. An assessment of multidimensional flood vulnerability at the provincial scale in China based on the DEA method. *Nat. Hazards* **2012**, *64*, 1575–1586. [CrossRef]