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Research Article

Assessment of the vulnerability to flooding in industrial areas in Bac Ninh Province

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Abstract: The impact of climate change has become stronger in recent years, climate change has increased hydrometeorological disasters in which flooding is one of the natural disaster risks that have a strong impact on the economy. Bac Ninh province has a lot of industrial zones, thus, the study and assessment of flood damage to Bac Ninh industry is urgent. The study uses Analytical Hierarchy Process (AHP) method to estimate flood damage for industrial areas in Bac Ninh province. This study uses satellite images, land use map and flooded area of Bac Ninh province data to build a matrix to determine the weight of the vulnerability. The study results have calculated the vulnerability weight according to the land use situation, built a vulnerability map for the whole Bac Ninh province and assessment of industrial damage due to flooding for each district of Bac Ninh province.

Keywords: Vulnerability assessment; Industrial flooding; Bac Ninh.

1. Introduction

Flood is one of the natural disasters, regularly threatening people's lives and socio–economic development [1–5]. Flooding has left very heavy consequences, thousands of households were flooded, buildings were destroyed, socio–economic activities were interrupted [6–7]. The process of strong urbanization along with the impact of climate change and the situation of heavy rain causes flooding in urban areas with increasing frequency [8–9]. Inundation affects greatly the management of water drainage. Every the flood events, drainage companies have to work hard to pump and drain water, unclog drains and other response solutions. Annual funding for dredging reservoirs, canals and rainwater regulation, as well as dredging and clearing sewers also costs billions of VND each locality. Flooding also affects wastewater treatment facilities. When it rains heavily, the amount of water flowing to the wastewater treatment plant is greater than the allowed capacity, most factories have to use emergency discharge pipes to the environment, which cannot treat wastewater up to the output standards. Heavy rains make drainage works overloaded, and at the same time make it difficult for managers to find investment solutions to improve the drainage capacity of urban drainage systems. These solutions are often very expensive, and most cannot mobilize private capital, but must use the state budget.

For the assessment of this kind of vulnerability, indicators have proved essential in representing relevant variables and processes involved. Flooding is the result of a variety of factors that include environmental, social, and economic aspects [10]. In recent years, the importance of vulnerability has attracted significant scientific interest, reflecting the need for

a shift to new approaches within risk management [11]. Any approach regarding urban resilience to natural hazards such as coastal flooding should also incorporate features that include the norms, policies, and values that shape cities nowadays [12]. In risk perceptions, the understanding of vulnerability is both broad and subjective.

Bac Ninh is the smallest province in Vietnam, in the Red River Delta and located in the Northern key economic region, Vietnam. In 2019, Bac Ninh is Vietnam's 22nd largest administrative unit in terms of population, sixth in gross domestic product (GRDP), second in GRDP per capita, seventh in growth rate. GRDP growth with 1,378,592 inhabitants. Bac Ninh is one of the provinces affected by inundation caused by heavy rains and storms [13–14].

In this study, a framework for assessing the vulnerability to inundation to industrial urban areas in Bac Ninh Province, the AHP method was selected for this area. Vulnerability is assessed using an interdisciplinary approach based on identification of the socio–economic context, thereby identifying vulnerability patterns and determining exposure to physical threats. Currently, there are two commonly used methods, which are the method of constructing the weighted average (the average value method uses the method [15]; the method of unequal weighting uses the assessment of experts [16]; PCA multivariate statistics and AHP unequal weight method [17]). This study uses the unequal weighted method AHP to assess the flood damage for industrial urban areas in Bac Ninh Province.

2. Materials and Methodology

2.1. Description of study site

Bac Ninh is a province located in the Red River Delta, in the Northern Delta region. The geographical location is in the range from 20°58' to 21°16' north latitude and 105°54' to 106°19' east longitude. The North borders Bac Giang province; the East and Southeast borders with Hai Duong province; To the south, it borders Hung Yen Province; The West borders Hanoi (Figure 1). Rain data at meteorological stations in the region Satellite image of corresponding time of occurrence of heavy rains according to the vulnerability assessment scenarios Current map of land use in Bac Ninh Province.

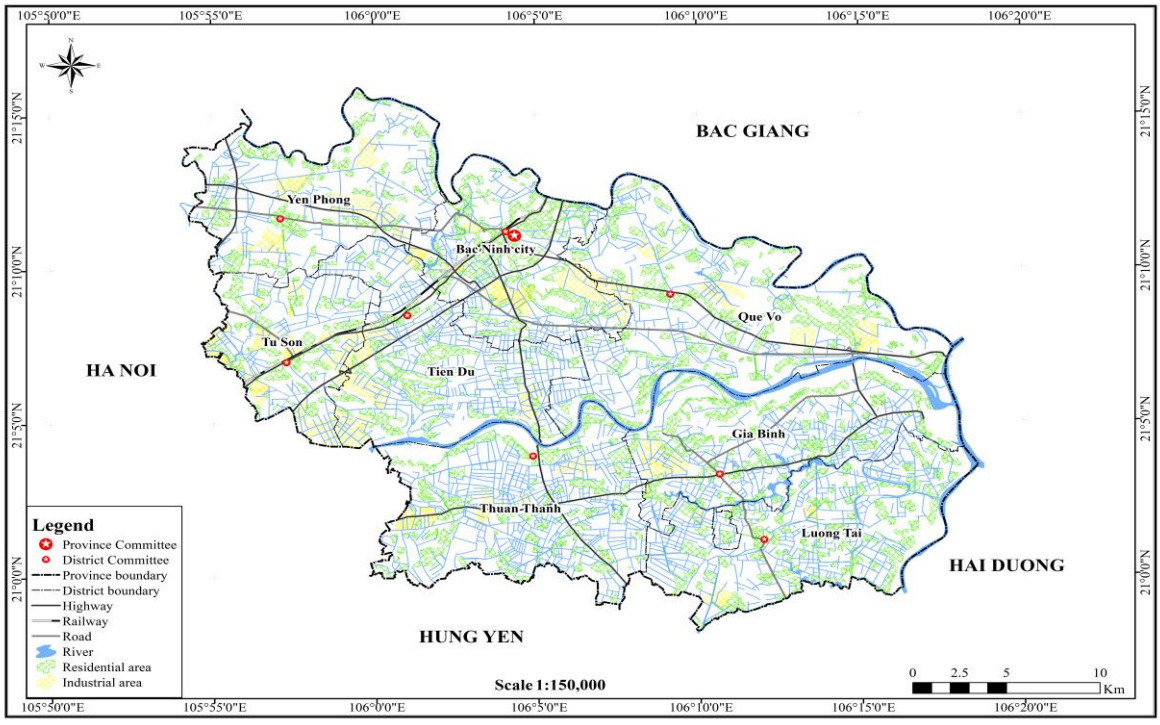


Figure 1. Map of Bac Ninh Province.

2.2. The Analytic Hierarchy Process (AHP)

AHP (Analytical Hierarchy Process) developed by Saaty is a sensitive and practical multi–criteria decision analysis method [18]. The precise presentation of decision problems in a hierarchical structure is the first and possibly the most important step. The hierarchical structure should be constructed so that elements (elements) at the same level have the same magnitude (quantity) and must be related to some or all of the elements at the same level. higher level. In a typical hierarchy, the top level reflects the objective overview (concentration) of the decision problem. The factors influencing the decision are placed at intermediate levels. The lowest level are decision–making options. Accordingly, this form of hierarchy provides a clear and simple view of all the factors influencing the decision and the relationships between them. Once the hierarchy is built, decision makers begin to prioritize the prerequisite decisions that have important correlations among the factors at each level of the hierarchy. Factors at each level are compared in pairs corresponding to their importance in consideration–based decision–making. The comparison is made in the following manner: how important is the relative importance of factor 1 when compared to factor 2 for each particular factor in the higher intermediate level? For each level, starting at the top level of the stratification system and continuing down to the lower levels, a number of square matrices is formed from the results of comparisons between the elements in that level corresponding to an element at the upper intermediate level. Elements are arranged into homogeneous groups according to each layer. The decision maker can express preference between each pair of 2 factors in the following common way: equally (or important, or relevant), moderate priority, high priority, extreme priority period or overriding priority. These preferred descriptors will then be reduced to the form numbers 1, 3, 5, 7 and 9 respectively; where 2, 4, 6, and 8 are intermediate values to satisfy between two consecutive qualitative assessments. The real scope used in AHP allows decision makers to combine subjectivity, experience, and knowledge in an intuitive and natural way [14, 19–21].

The desired outcome is calculated through the matrix's preference vector, which is done by increasing the matrix A with increasing step k. The k increment of matrix A is iterated until the difference in the weights of the vector preference vector for the last two iterations is less than the allowable error of 0.00001. In each iteration, the weights are always normalized so that the sum of the components equals 1. Finally, the maximum characteristic value (k_{max}) of the matrix A is determined. Priority factors are checked for consistency through the consistency ratio (CR), which is the ratio of the random inconsistency index (RI) to the consistency index (CI). CRs below 0.1 are generally considered acceptable but higher values require reconsideration as they are highly inappropriate. The CI coefficients are synthesized from the k_{max} and the order of the matrices (n). RI is a function of n in the relationships between the elements X_1, X_2, …X_n. The questions asked are X_1 is more profitable, more satisfying, contributing more, surpassing, … than X_2, X_3, X_n … X_1, X_2, X_3, …, X_n are factors affecting the object. The questions are very important, they reflect the relationship between the components of one level with the properties of the higher level. Use a rating scale from 1 to 9 as shown in the table below:

Table 1. The classification of Saaty's importance [18].

Level	Definition	Explanation
1	Equally important	Two activities with equal contributions
3	Moderately important	Experience and judgment have a moderate influence on an activity
5	Relatively important	Experience and judgment have a strong influence on an activitv
7	Very important	A very important activity
9	Extremely important	The highest priority
2, 4, 6, 8	Intermediate level between the above levels	Need a compromise between two levels of perception

Matrix of Expert's Opinion

$$\begin{array}{c} \\ x_1 \\ x_2 \\ \\ x_n \end{array} \begin{array}{c} \begin{array}{cccc} x_1 & x_2 & & x_n \end{array} \\ \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \end{array} \quad (1)$$

where a_{ij} is the rating between the i and j criterion $a_{ij} > 0$, $a_{ij} = 1/a_{ji}$, $a_{ii} = 1$. Choosing w_{ii} be the vector weight of the i factor, w_{ii} is calculated according to the equation 2.

$$w_{ii} = \frac{a_{ii}}{\sum_{i=1}^{n} a_{ni}} \quad (2)$$

AHP multi–criteria method is presented a flowchart of the steps to calculate the damage assessment (Figure 2).

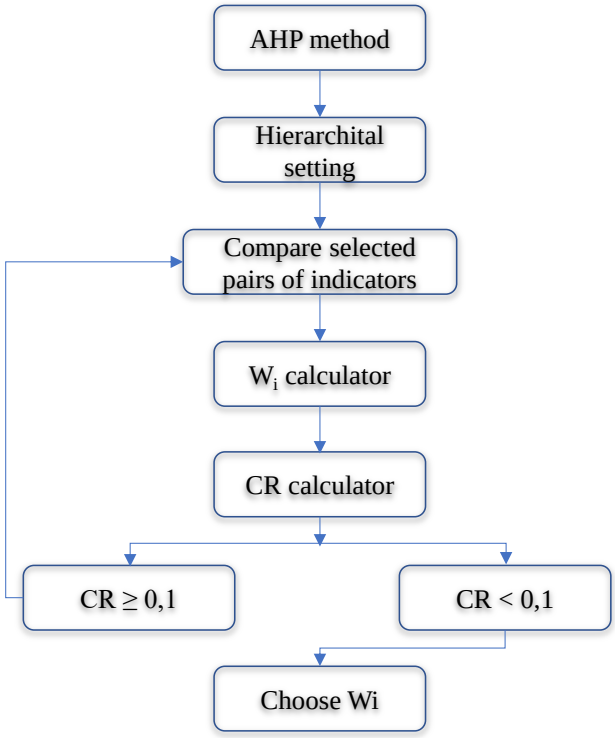


Figure 2. The diagram of multi–criteria method.

3. Results and discussion

3.1. Evaluation of the assessment of vulnerability due to flooding for industrial areas

Using the AHP method, the exposure indices E, susceptibility S and tolerance A of the land use groups in the project area were calculated. In order to be able to classify the vulnerability of land use to inundation, it is necessary to develop a flood risk map of the area. From the flood risk map of the project area, a vulnerable area map will be built based on the superposition of map layers: topographic map layer, current land use map layer and flood map layer. With the data source collected, analyzed and evaluated, the article assesses the extent of inundation vulnerability based on the current state of land use in Bac Ninh province, which is a characteristic factor for both nature and purpose. intended use by humans. Based on the current land use map in 2019 of Bac Ninh province, the article classifies and groups land into 05 types of land, including: land use group for industrial zones, group of traffic

land, group of urban land , group of rural land and group of agricultural land. Rain scenarios are developed corresponding to rain cases according to Decision 18/2021/QD–TTg Regulations on forecasting, warning, communication of natural disasters and disaster risk levels [22], including:

- Scenario 1: Rainfall in 24 hours from 100 mm lasting for 2 days;
- Scenario 2: Rainfall in 24 hours from 100 mm lasting for 4 days;
- Scenario 3: Rainfall in 24 hours from 200 mm lasting for 2 days;
- Scenario 4: Rainfall in 24 hours from 200 mm lasting for 4 days;
- Scenario 5: Rainfall in 24 hours from 500 mm lasting for 1 day;
- Scenario 6: Rainfall in 24 hours from 500 mm lasting for 2 days.

From the rainfall data according to the above scenarios, the article analyzed satellite images taken during the period with equivalent rainfall to determine the flooded area of each land use group corresponding to each rain scenario. Below is the statistics of flooded area of Bac Ninh province according to the rainfall scenarios corresponding to the rain cases according to Decision 18/2021/QD–TTg Regulations on forecasting, warning, communication of natural disasters and risk levels natural disasters, specifically as follows:

Table 1. Area of soil affected by inundation scenario 1 [13].

No	Land use group	Flooded area (km^2)					
		Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
1	Transportation	158.7	305.88	504	523.3	723.1	927.5
2	Industrial zone	79.29	109.89	108.99	123.3	255.35	278.7
3	Urban land use	104.3	124.2	167.2	252.1	458.7	559.3
4	Rural land use	51.84	156.51	188	270.9	576.4	983.2
5	Agricultural land use	1647.18	3738.97	5407.26	5538.01	12897.1	20256.1

Table 1 shows that the agricultural land group in Bac Ninh is the most vulnerable group because the it is mainly used with major food crops such as rice, maize, potatoes and vegetables; When heavy rain occurs, the agricultural land area is flooded causing a decrease in the yield of food crops and vegetables, even the possibility of losing everything. The second vulnerable group of land users is the group of rural land, because at present the rural population still accounts for the majority, when inundation occurs, the rural land group will suffer significant damage. The third group of land users affected by inundation when heavy rains occur is the group of urban land users because the assets of households in urban areas are relatively high and urban inundation can cause delays. production activities in the economic centers of the province. The fourth vulnerable group is land used for industry because this area has equipment and machinery with high investment costs, but industrial parks have high leveling foundation along with standard drainage systems. standard, so it is less affected by flooding. The last vulnerable group is the group of roads and major national highways with the ability to quickly drain water, less affected by heavy rain causing flooding. For each group of land use status, the analysis is carried out according to the percentage of the area affected by inundation and divided into 5 levels: Very low, low, medium, high and very high.

3.2. Assessment of vulnerability due to inundation according to land use groups of Bac Ninh Province

The table assesses the vulnerability of groups of soil on a scale showing the vulnerability of those factors under the impact of inundation. In fact, the vulnerability of different types of land use is not similar. This difference is reflected in the determination of the weight of each factor. Below is the matrix to determine the vulnerability of land use groups calculated by the AHP method.

Table 2. Matrix of determining the impact of vulnerability of groups of land use.

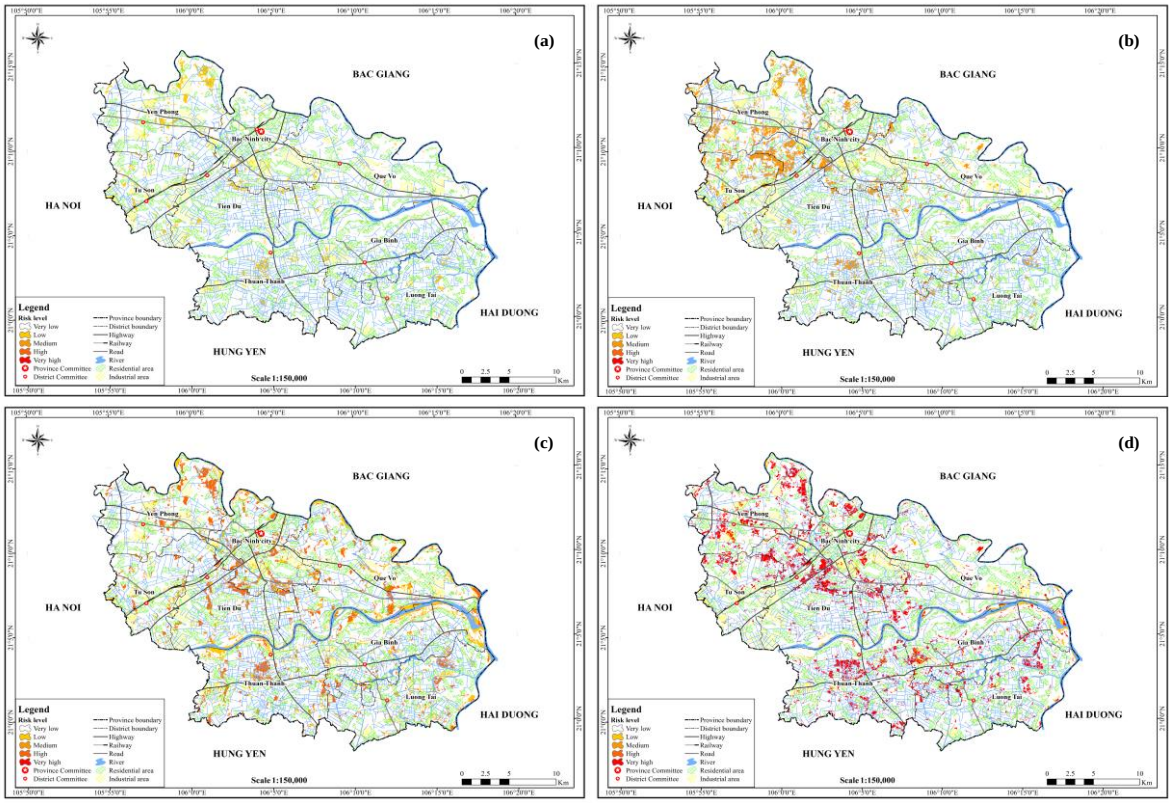
Land use group	Land for transportation	Land for industry	Land for urban use	Land for rural use	Land for agriculture
Land for transportation	1	3	5	7	9
Land for industry	1/3	1	4	5	7
Land for urban use	1/5	1/4	1	3	5
Land for rural use	1/7	1/5	1/3	1	4
Land for agriculture	1/8	1/7	1/5	1/4	1

Synthesize data from the table of the level of damage caused by inundation with the accessing matrix, build a table to evaluate the level of vulnerability under the influence of inundation for different land use groups.

Table 3. Summary table of inundation vulnerability for land use group.

Land use group	Land for transportation	Land for industry	Land for urban use	Land for rural use	Land for agriculture
Extremely low	< 0.2	< 0.4	< 0.1	< 0.08	< 0.05
Low	0.2–0.4	0.4–0.6	0.1–0.2	0.08–0.15	0.05–0.15
Average	0.4–0.6	0.6–0.75	0.2–0.4	0.15–0.25	0.15–0.25
High	0.6–0.8	0.75–0.85	0.4–0.6	0.25–0.4	0.25–0.35
Extremely high	> 0.8	> 0.95	> 0.6	>0.4	> 0.35
Weight	0.03	0.05	0.17	0.30	0.45
Vulnerable degree	**Extremely low**	**Low**	**Average**	**High**	**Extremely high**

The groups of vulnerable land use types are determined through the establishment of a matrix to compare the correlation between factors and calculate the weight of each factor. After decentralizing and calculating the weights corresponding to the vulnerability of different types of land use, the article has built a vulnerability map of inundation for Bac Ninh Province according to scenarios corresponding to rain cases. Figures 3a–3f is these maps of flood vulnerability and a detailed assessment of flood damage to urban industrial areas in Bac Ninh province.



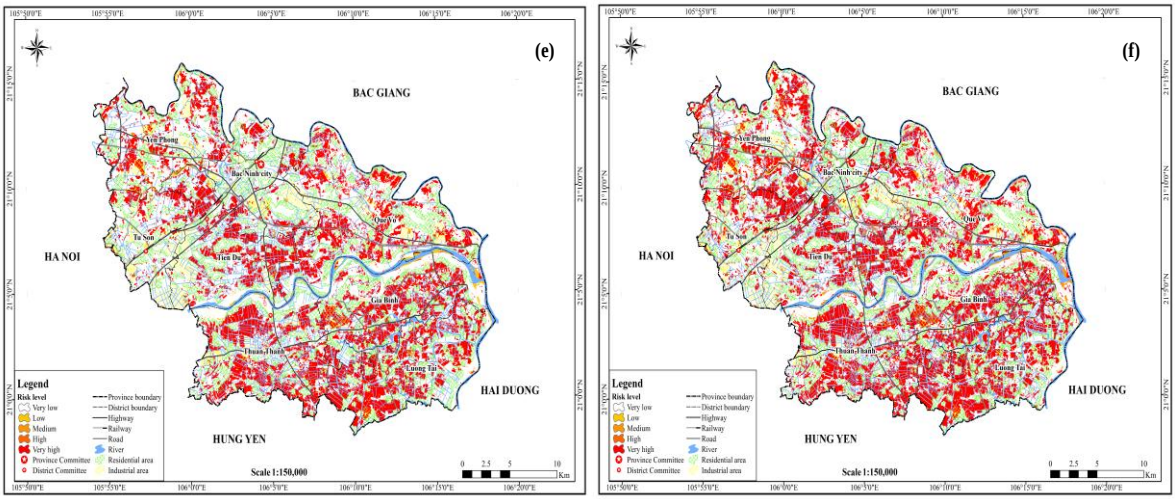
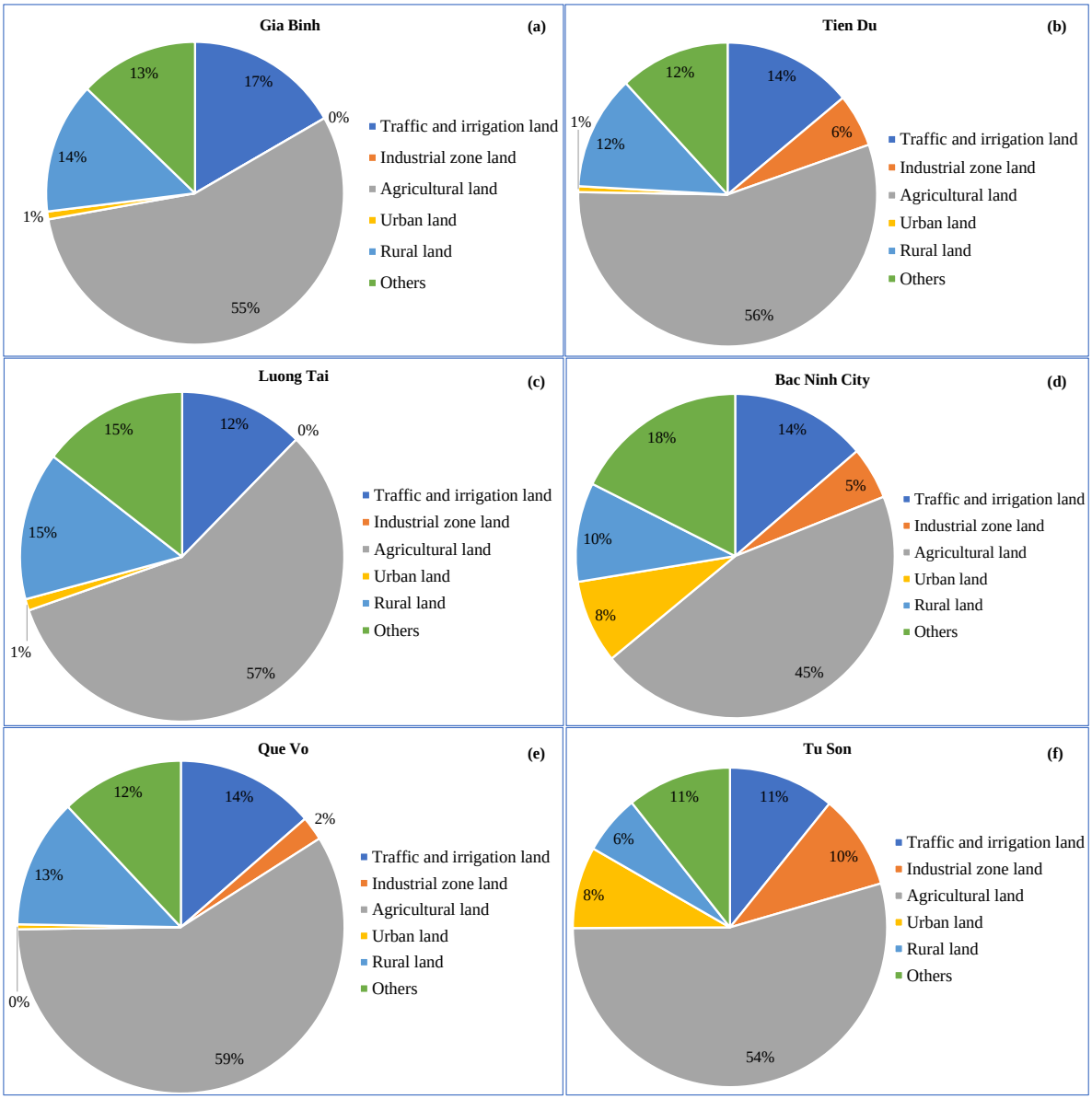


Figure 3. Maps of inundation vulnerability in Bac Ninh province: (a) Scenario 1; (b) Scenario 2; (c) Scenario 3; (d) Scenario 4; (e) Scenario 5; (f) Scenario 6.

The area of industrial parks and urban land in Bac Ninh Province is statistically shown in figures 4a–4h.



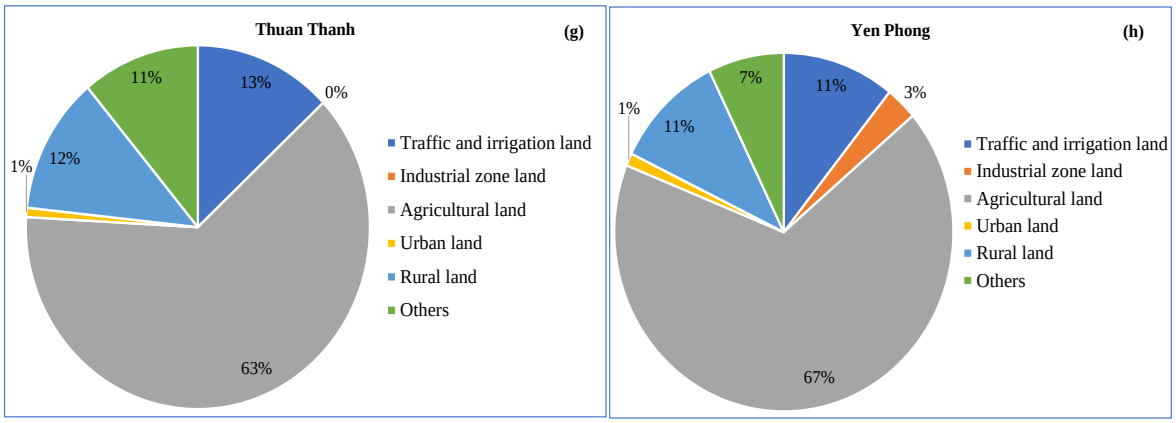


Figure 4. Proportion of urban and industrial land areas: (a) Gia Binh District; (b) Tien Du District; (c) Luong Tai District; (d) Bac Ninh City; (e) Que Vo District; (f) Tu Son District; (g) Thuan Thanh District; (h) Yen Phong District.

Overlapping the weighted layers of vulnerability due to flooding in Bac Ninh province, inundation map in Bac Ninh Province, land use map in Bac Ninh province with statistical charts of the area of damage caused by flooding in urban and industrial areas of districts Bac Ninh Province are presented in Figures 5a–5f.

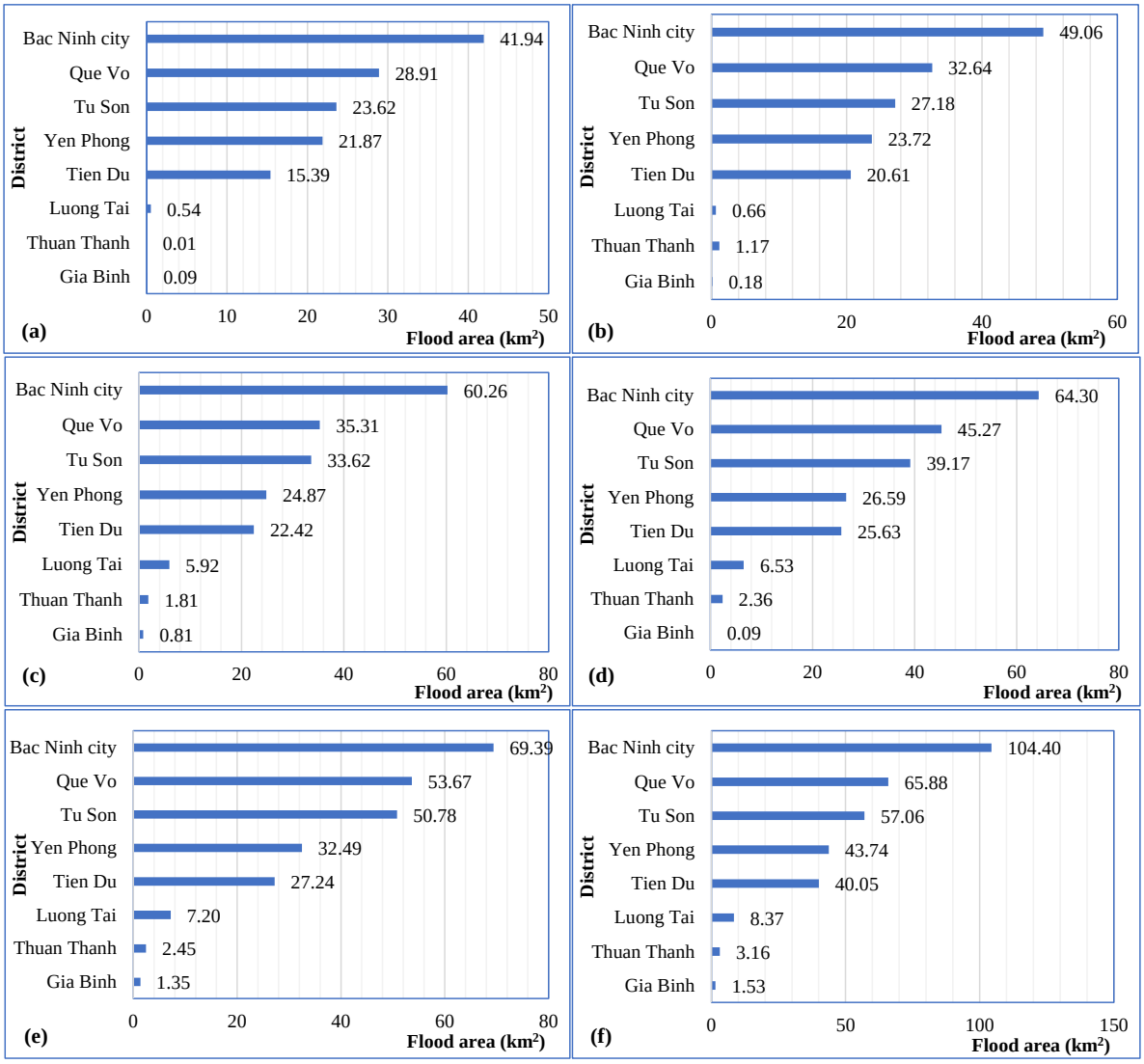


Figure 5. Area affected by flooding in industrial areas: (a) Scenario 1; (b) Scenario 2; (c) Scenario 3; (d) Scenario 4; (e) Scenario 5; (f) Scenario 6.

Analysis of the aggregate results from the above graphs shows that:

Scenario 1: The area of industrial urban land damaged by flooding in Bac Ninh is 42 km^2, in Que Vo is 29 km^2, Tu Son is 24 km^2, Yen Phong is 22 km^2, Tien Du is 15.4 km^2, Luong Tai is 0.54 km^2, Thuan Thanh and Gia Binh areas are insignificant.

Scenario 2: The area of industrial urban land damaged by flooding in Bac Ninh is 49 km^2, in Que Vo is 33 km^2, Tu Son is 27 km^2, Yen Phong is 23.7 km^2, Tien Du is 20.6 km^2, Luong Tai is 0.66 km^2, Thuan Thanh is 1.17 km^2 and Gia Binh is 0.18 km^2.

Scenario 3: The area of industrial urban land damaged by flooding in Bac Ninh is 60 km^2, in Que Vo is 35 km^2, Tu Son is 333 km^2, Yen Phong is 25 km^2, Tien Du is 22.4 km^2, Luong Tai is 5.9 km^2, Thuan Thanh is 1.8 km^2 and Gia Binh is 0.8km^2.

Scenario 4: The area of industrial urban land damaged by flooding in Bac Ninh is 64.3 km^2, in Que Vo is 45 km^2, Tu Son is 39 km^2, Yen Phong is 27 km^2, Tien Du is 26 km^2, Luong Tai is 6 km^2, Thuan Thanh is 3 km^2 and Gia Binh is 0.1 km^2.

Scenario 5: The area of industrial urban land damaged by flooding in Bac Ninh is 70 km^2, in Que Vo is 54 km^2, Tu Son is 51 km^2, Yen Phong is 33 km^2, Tien Du is 27 km^2, Luong Tai is 7.2 km^2, Thuan Thanh is 2.5 km^2 and Gia Binh is 1.35 km^2.

Scenario 6: The area of industrial urban land damaged by flooding in Bac Ninh is 104.4 km^2, in Que Vo is 66 km^2, Tu Son is 57 km^2, Yen Phong is 44 km^2, Tien Du is 40 km^2, Luong Tai is 8.4 km^2, Thuan Thanh is 3.16 km^2 and Gia Binh is 1.53 km^2.

4. Conclusion

The study results show that in different rain scenarios, Bac Ninh Province has the most vulnerable industrial areas to flooding, followed by Que Vo district, Tu Son district, Yen Phong district, Tien Du district, Luong Tai district, but Thuan Thanh district and Gia Binh district are least vulnerable to flooding.

It can be seen that the area of urban industrial land in Bac Ninh occupies a relatively low proportion in most districts, only Que Vo, Tu Son and Bac Ninh city have a similar proportion of land used for industrial urban areas. relatively high (Tu Son is 18% and Bac Ninh city is 13%). Combined with the injury map of Bac Ninh province built from the results of the multi–criteria method and overlapping the map, the vulnerability of the industrial area and urban land are 0.05 and 0.17 respectively, which are low and moderate damage. This is appropriate, because the main area in Bac Ninh is still agricultural and rural areas, so when flooding occurs, these are the most vulnerable site. The area of industrial parks and industrial clusters is increasingly being planned to expand in Bac Ninh, although the equipment of industrial parks is of high value, but when it rains heavily, the possibility of damage from rainwater flooding to industrial parks increases, most industrial zones are designed with standard rainwater collection and drainage systems. Statistics show that there much heavy rains causing urban flooding in Bac Ninh, but they do not occur much in the urban area, the water is flooded for a short period of time, so the impact on the city is only moderate.

The limitation of the article is that have no flood data about inundation area and amount of inundation. The study also only assesses the damage caused by flooding to land use group in Bac Ninh province.

Author contribution statement: Author contribution statement: D.Q.T.; Q.T.T.T.; Analyzed and interpreted the data; Materials, analysis tools and data; Calculation, analyzed and interpreted the results: N.V.N., Q.T.T.T.; Wrote the draft manuscript: Q.T.T.T., N.V.N.; Materials, manuscript editing: D.Q.T.

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