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Lightning Hazard Assessment in Hainan Island Based on Hierarchical Analysis Model

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Abstract: According to the lightning monitoring data of Hainan Province from 2011 to 2020,eight cities in Hainan Province were selected as the evaluation units.Combined with the statistics of population, lightning weather, economic characteristics and land area of each city, the population density, GDP value, thunderstorm days, illiteracy level and lightning frequency (density) of each city were selected as risk assessment indicators, and the evaluation model was established by AHP. Get the weight of each index and calculate the lightning risk disaster index of each city according to the numerical value of each index of each city. After consulting relevant materials, it is found that the construction of communication base stations will also induce lightning disaster accidents, and the evaluation results of each city will also be affected by the number of communication base stations in the region, so the correctness of the results also indicates the rationality of the evaluation method.

Keywords: Analytic hierarchy, Lightning disaster, Hazard assessment, Hainan.

1. Introduction

Lightning has an irresistible effect as a natural disaster. We can not avoid it, but can use science and technology to predict its location and intensity, so as to minimize the loss of people's lives and property, so the risk assessment of lightning disaster is particularly important. According to the local climate differences between east and west, south and north China, from the Cai Zhongzhou, Hu Yana, the research status of [1], jinxin using GIS lightning disaster risk zoning maps generated the xining region, using kriging interpolation method, natural breakpoint method and other methods to realize the meteorological data, social development, geographic information, lightning disaster data spatial matching, form the visual disaster distribution database. Hu Haibo et al. [2] completed the risk estimation of lightning disasters in Beijing based on the AHP model. It is also found that the lightning disaster in Beijing is not only related to the spatial distribution of natural lightning, but also related to the vulnerability of the underlying surface and the distribution of disaster bearing bodies. Yuan Xiangling et al. [3] established a risk assessment grade standard according to the general method of unified dimension of catastrophology, taking into account the difference in weight of each index, and divided the risk grades of lightning disasters in cities of Heilongjiang Province. However, according to the research report of Li Jiaki [4] and Sun Liudi [5], it is not difficult to find that the number of communication base stations in the region directly affects the generation of lightning disasters, and the education level of the population will also affect the losses caused by disasters.

Hainan Province, located at the southern tip of the country, is one of the country's largest tourist cities. In this paper, the population density, GDP value, thunderstorm days, population education level and lightning frequency (density) of each city in Hainan Island from 2011 to 2020 were selected as indicators, and the analytic hierarchy process (AHP) was used to establish a risk assessment model, obtain the weight of each index, and divide the risk level of each city. Finally, the results are compared with the number of communication base stations in each city to verify the accuracy of the results.

2. Data Source

The data used in this paper include: 1) Annual average thunderstorm days of each city from 1958 to 2007,this data comes from Daokebaba, a thunderstorm day in each city and county of Hainan Province; 2) The level of illiteracy in each municipality, derived from the seventh national census; 3) Permanent population and land area of each city, which are all from the seventh National Census and the Red and Black Population database; 4) The annual average number of thunderstorm days is from the statistical yearbook of each city in Hainan Province; 5)The number of 5G communication base stations in each region of Hainan Island, which is obtained from the 2021 government Work report of each city.

3. Index Analysis

The indicators used in this paper include: thunderstorm days, population density, economic (GDP) value, lightning disaster frequency (density), population education level. Number of thunderstorm days (L, unit: d), which can be obtained directly through the query; Population density (R, unit: person square kilometer), calculated by the formula R=N/S, N is the number of permanent residents of the seventh census in 2020 (unit: person), and S is the corresponding land area of the region (unit: square kilometer). The average economic (GDP) value of each district (G, unit: 100 million yuan) is divided by the total annual GDP of the region (duration = 10(years)); Lightning disaster assessment rate (density) (P, unit: d/m), the calculation formula is P=L/S, L is the average number of thunderstorms in the area, S is the corresponding area of land; The degree of illiteracy (C) was calculated as C=[(number of illiterate persons aged 15 and above) /N] × 100%.

4. Principles and Steps of Chromatographic Analysis

The analytic hierarchy process (AHP) was proposed by

Professor Saaty, an American operations research scientist. The risk assessment of lightning disaster in Hainan based on hierarchical analysis model is based on the impact of lightning weather only on Hainan, and the appropriate assessment indicators are selected: population density, GDP value of each city, number of thunderstorm days of each city, illiteracy degree of each city, and lightning frequency (density) of each city for risk assessment. The analysis steps are as follows:

(1) Establish a hierarchical analysis model. The model is divided into three layers. The first layer is the target layer (Ray Electrical risk estimation); The second layer is the criterion layer (five indicators of the impact of lightning disaster); The third layer is the plan layer (eight cities in Hainan Province).

Construct the weight judgment matrix (T) of lightning hazard risk assessment index. The judgment matrix represents the comparison between the relative importance of a factor at the previous level and the factors related to it at this level.T = $\begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix}$,where a_{ij} is the importance ratio obtained by comparing factor i with factor j.

Table 1. Scaling and significance of the judgment matrix

scale	connotation
1	Two factors are equally important
3	Factor i is slightly more important than factor j
5	Factor i is more important than factor j
7	Factor i is much more important than factor j
9	Factor i is absolutely more important than factor j
Count backwards	Factor j is compared to factor i

Conformance test. First, with MATLAB, the maximum eigenvalue of the judgment matrix T is calculated λ max and its corresponding eigenvector W, both TW=λmaxW. Then you calculate the consistency index CI, CI = (λ max-n) / (n-1), where n is the order of the judgment matrix; then find the random agreement Sex Index RI, Professor Saaty gives the average random consistency index RI of the judgment matrix of order 1-9 Table; Finally, the random consistency ratio CR is calculated, CR =CI/RI, and it is generally considered judged when CR is <0. 1 The consistency of the broken matrix is acceptable, otherwise the judgment matrix should be properly corrected.

Table 2. RI Table

order	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1. 12	1.24	1.32	1.41	1.45

The building of the model. After normalization of the feature vector W, it is the weight of each index, and the normalized result is set as W '= [A1, A2, A3, A4, A5]. Let X=[x1, x2, x3, X4, X5] be the normalized results of the corresponding five indexes of each area. Therefore, the risk assessment model is:

$$\Omega = A_1X_1 + A_2X_2 + A_3X_3 + A_4X_4 + A_5X_5 = \sum_{i,j=1}^{5} A_iX_i \qquad (1)$$

5. Apply the Model to Reality

5.1. Establish the weight judgment matrix T for risk assessment

Establish the lightning disaster risk assessment and judgment matrix (T) and the weight according to the Saaty scale method Distribution (Table 3).

Table 3. Judgment matrix (T) and weight distribution of lightning hazard risk assessment

T	X1	X2	X3	X4	X5	Weight
X1	1	2	3	5	9	0.4513
X2	1/2	1	2	3	7	0.2712
X3	1/3	1/2	1	2	3	0.1471
X4	1/5	1/3	1/2	1	2	0.0855
X5	1/9	1/7	1/3	1/2	1	0.0449

Note: X 1, X 2, X 3, X 4 and X 5 represent lightning weather density, thunderstorm days, population density, GDP value, and population education level, respectively.

5.2. Conformance test

Using MATLAB software, the maximum eigenvalue λmax=5.0228 of the judgment matrix T is obtained. Lambda

Max corresponding eigenvector W = [0.8130, 0.4885, 0.2650, 0. 1541, 0.0809], the normalization processing after W = '[0.4513, 0.2712, 0. 1471, 0.0855, 0.0449]. Therefore, CI= (λmax-n)/(n- 1)= (5.0228-5) /(5- 1) =0.0057, and since the consistency index RI= 1. 12, the consistency ratio CR=CI/RI=0.0057/ 1. 12=0.0051 < 0. 1, It indicates that the consistency test of judgment matrix T is qualified.

5.3. Establishment of Evaluation Index Data Table of Hainan Region (Table 4)

Table 4. Data sheet of eight cities in Hainan Province

City name	Number of thunderstorm days (L,unit :d	density of population(R,unit:Man/ square kilometre)	The average economy (GDP) count Value(G,unit:100million yuan)	Lightning hazard frequency(P,unit:d/Square kilometre)	Population illiteracy level(C,unit:%)
HAIKOU	108.0	918.936	1231.525	0.035	1.51
SANYA	60.5	536.906	487.637	0.031	1.66
CHENGMAI	126.6	225.9	249.49	0.061	3.59
DANZHOU	113.6	256.362	493.911	0.033	6.44
QIONGHAI	86.3	308.911	214.82	0.05	1.84
WENCHANG	91.3	228.158	192.74	0.037	2.48
WANNING	70.0	293.680	179.85	0.037	2.75
WUZHISHAN	103.8	97.35	25.14	0.091	2.98

5.3.1. The normalization formula

The normalization formula is:

$$x^* = (x - x_{\min})/(x_{\max} - x_{\min})$$

5.4. Normize the data above (Table 5)

Table 5. Normalized Index data sheet

City name	Number of thunderstom days (L,unit:d)	Density of population(R,unit:Man/square kilometre)	The average economy(GDP) count Value (G,unit:100million yuan)	Lightning hazard frequency (P,unit:d/square kilometre)	Population illiteracy level (C,unit:%)
HAIKOU	0.85	1.00	1.00	0.38	0.23
SANYA	0.48	0.58	0.40	0.34	0.26
CHENGMAI	1.00	0.25	0.20	0.67	0.56
DANZHOU	0.90	0.28	0.40	0.32	1.00
QIONGHAI	0.68	0.34	0.17	0.55	0.29
WENCHANG	0.72	0.25	0.16	0.41	0.39
WANNING	0.55	0.32	0.15	0.41	0.43
WUZHISAHN	0.82	0.11	0.02	1.00	0.46

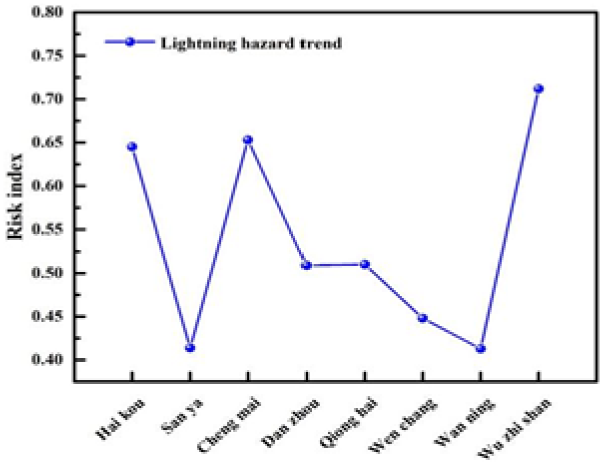
5.5. According to Model (1), the risk coefficient of each city is calculated (Table 6)

By multiplying the value of each city's normalized evaluation index with the weight of each evaluation index, the result is the call risk index of the city.(Table 6)

Table 6. Lightning hazard assessment results in Hainan Province

City	HAI KOU	SA NY A	CHEN GMAI	DANZ HOU	QION GHIA	WENC HANG	WAN NING	WUZHI SHAN
Hazard Rate	0.645	0.414	0.653	0.509	0.510	0.448	0.413	0.712

5.5.1. Draw a line chart of the lightning hazard.(chart 1)



It can be seen from the table that the lightning hazard in Sanya of Hainan Island is smaller, and the lightning hazard in Wuzhishan area is the largest.Plug the data into Origin, draw a scatter plot, and connect the dots to form a broken line.Then, the increase or decrease of the hazard index can be expressed by the rise or fall of the broken line. The statistical chart of the broken line can not only reflect the quantity, but also reflect the increase or decrease trend of the quantity change.The picture clearly shows that there is a big difference between Haikou and Sanya. Located in the northern and southern end of Hainan Province, Haikou is at high risk of lightning hazard, while Sanya is relatively safe.In addition, it is found that the lightning hazard in Wuzhishan area is the most serious, which is close to the high risk standard. But its surrounding cities such as Sanya and Wanning are relatively low.

6. Results and Analysis

6.1. Classification of hazard classes

According to the assessment criteria given by experts, the lightning hazard is divided into four grades(Table7)

Table 7. Grade standard for lightning hazard assessment in Hainan Island area

Risk division	[0,0.25)	[0.25,0.5)	[0.5,0.75)	[0.75, 1]
risk grade	low risk	Medium risk	High risk	Very high risk

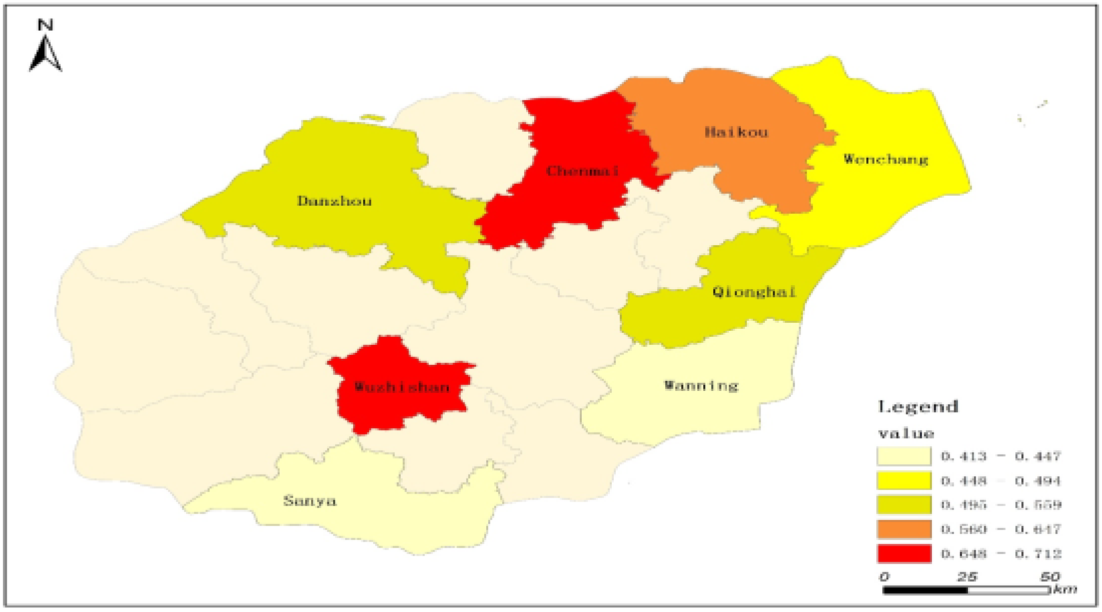
6.2. Divide each city hazard level

Then the lightning hazard index calculated by each city corresponds to the hazard level.(Table 8)

Table 8. Classification of lightning hazard grade in Hainan Island

City	HAI KO U	SAN YA	CHEN GMAI	DAN ZHO U	QION GHAI	WENC HANG	WAN NING	WUZHI SHAN
Result	High risk	Medium risk	High risk	High risk	High risk	Medium risk	Medium risk	High risk

6.2.1. Draw a thermal map of lightning hazard in Hainan Province.(chart 2)



The map of Hainan Province is divided into each section, and the eight cities selected are the eight representative cities of Hainan Province (the most populous and the most developed economy). The greater the lightning hazard, the more red, the lower the more yellow. And the rest of the city is mostly mountainous, sparsely populated, lightning hazard is very low, so all use light yellow instead. The results show that the overall risk of lightning disaster in Hainan Island is high, and the average of lightning hazard in Hainan Island is close to high risk. The central area of Hainan Island is more serious, and the eastern and western areas are less harmful. The reason may be that the central region is more densely populated, while the eastern and western regions are less densely populated and economically backward.

In addition, next, the number of 5G communication base stations in each city is counted, and its value is compared with the lightning hazard value in each city to observe whether the communication base stations have an absolute impact on the lightning hazard degree.

6.3. Number of communication base stations and compared with the hazard index.(Table 9)

Table 9. Total number of communication base stations owned in each region

City	HAIKOU	SANYA	CHENGMAI	DANZHOU	QIONGHAI	WENCHANG	WANNING	WUZHISHAN
base station	4100	1487	305	312	524	190	130	15

6.3.1. Comparison results analysis chart.(chart 3)

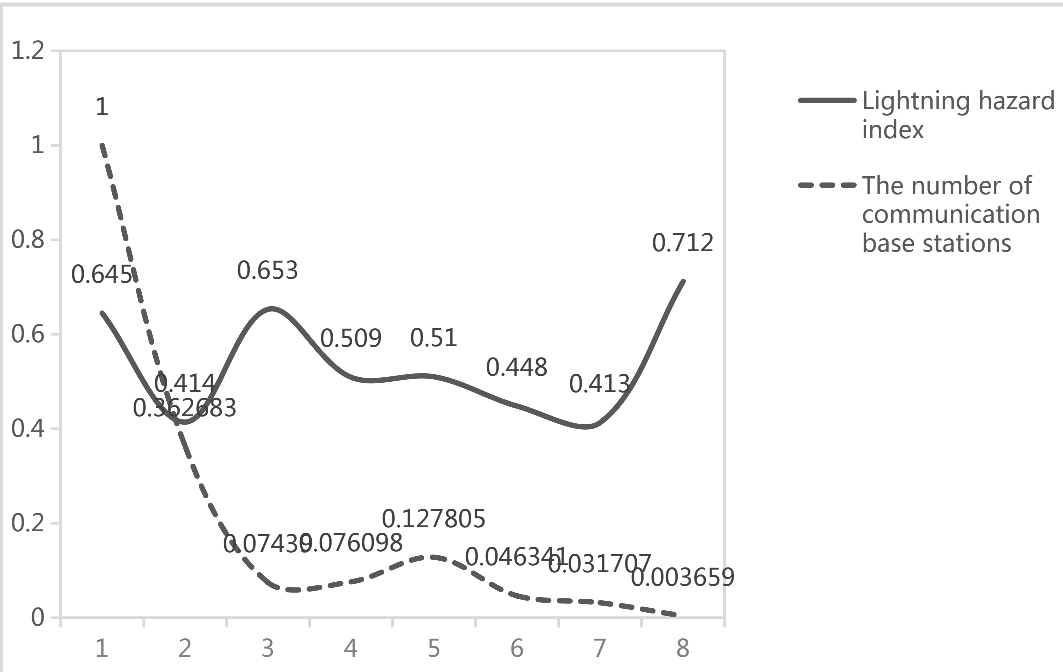


Figure 1. Comparison of the proportion of communication base stations and lightning hazard index in various regions of Hainan Island.

It is found that the number of communication base stations in a certain area is not directly proportional to the magnitude of the lightning hazard in the area, which means that the number of communication base stations is not the most important factor affecting the lightning disaster. It is not comprehensive only from the number of communication base stations, which should be combined with the land area of the region, the density of communication base stations, and the density of population in the region.Therefore, the number of communication base stations will not directly lead to the increase of lightning hazard index, so the lightning hazard index of each city is not necessarily proportional to the number of communication base stations in each city.

7. Conclusion

Population density, GDP value, thunderstorm days, thunderstorm density and illiteracy rate were selected in this paper. The analysis found a higher proportion of thunderstorm days, which is also consistent with other results.

(2) Apply GIS technology to risk assessment. The results show that the lightning hazard in Haikou, Chengmai, Wuzhishan and other cities in Hainan Island is relatively high, reaching the high risk level, while the lightning hazard in Sanya, Wenchang, Wanning and other areas is low, all at the medium risk level.

(3) The study found that the average lightning risk in Hainan is higher than in most Chinese cities, mainly because Hainan is surrounded by the ocean and has a tropical monsoon climate that is wet and rainy all year round.

(4) In future research, more evaluation indicators can be used to improve the accuracy of evaluation. In addition, every city should match better lightning protection facilities.

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