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PRELIMINARY STUDY OF THE ASSESSMENT OF METHODS FOR DISASTER-INDUCING RISKS BY TCs USING SAMPLE EVENTS OF TCs THAT AFFECTED SHANGHAI

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Abstract: Hazard factors, hazard-bear1ing objects, disaster-developing environment, and disaster-preventing capability play key roles in the formation of Tropical Cyclone (TC) disasters. Of all of these, the most important is the intensity of hazard factors (risk sources). In this study, this intensity is uniformly defined by the probability of hazard factors; then a relationship is established between disaster risk intensity and hazard factors. The exceedance probability of various hazard factors, including frequency and timing, scope of wind and rain, and maximum wind and rain of impacting TC cases, are calculated using data from TCs that impacted Shanghai from 1959–2006. The relationship between disaster situation and risk probability of hazard factors is analyzed, and the indices and model of TC disaster assessment are established based on the results. The process maximum wind speed and maximum daily precipitation are very important in TC-related disaster formation in Shanghai. The results of disaster indices coordinate with the results of the assessment model, and both can show the extent of probability of a TC disaster. Tests using TC data in 2007 and 2008 show that disasters caused by TC Krosa (0716) would be more serious than those by TC Wipha (0713), and that TC Fung Wong (0808) would have a weak impact. Real-life situations validate these results.

Key words: TCs; disaster risk; assessment methods

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1 INTRODUCTION

Tropical Cyclones (TC) are, perhaps, the most devastating natural disasters in terms of loss of human life and property. On average, 80 to 100 TCs occur annually all over the world, causing 20 000 deaths and economic losses worth 7 billion U.S. dollars. TCs often produce very strong winds near the surface, causing damage to coastal regions and islands through extreme winds, storm surges, and waves. Vulnerability to TCs is becoming more pronounced because of the fast population growth in tropical and subtropical coastal regions.

As each TC attack causes huge damages, it becomes significant to study the forecasting and assessment of TC disasters. Much work has been done on TC disasters, with research methods focusing on disaster indices[1], classification analysis[2], fuzzy system[3, 4], and others[5-7]. Most of the works, however, are qualitative analyses strongly influenced by the hazard-bearing object; thus, they are unable to reveal how such disasters are induced.

In this paper, a new method based on the exceedance probability of hazard factors is put forward. The basic idea of this method originates in the fact that the intensity of abnormal hazard factors plays a key role in triggering disasters. A strong hazard factor usually surpasses the endurance limits or the present disaster resistance standards of the hazard-bearing object. The stronger the intensity, the greater the disaster risk, especially for extreme events. Hence, the probability of the hazard factor can be regarded as the connection between natural events and disaster risks. The differences among hazard-bearing objects, disaster-developing environment, and disaster-preventing capability can be partially solved by this method. The case tests for Shanghai show that

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Biography: YANG Qiu-zhen, associate professor, mainly undertaking the research on disasters by typhoons.

E-mail for correspondence author: xum@mail.typhoon.gov.cn the method can correctly assess TC disaster risk to some degree.

2 DATA AND METHODS

2.1 *Data*

The TC data used in this study were obtained from the *Tropical Cyclone Yearbook* edited by the Shanghai Typhoon Institute (STI). TC disaster data were obtained from the *Meteorological Yearbook of Shanghai* and the *Yearbook of Shanghai Meteorological Disasters*, both edited by the Shanghai Meteorological Bureau.

All TC disasters are formed in the TC impacting events. The definition of a TC impacting event in Shanghai in this study is given as follows. When at least one station in Shanghai fits one of the following conditions as TC makes landfall or passes nearby, it is defined as one TC-impacting event. In this case, the following conditions should be met: 1) process precipitation$\geq$50 mm; 2) mean wind speed$\geq$13.9 m/s or gust wind speed $\geq$ 17.2 m/s; and 3) process precipitation$\geq$30 mm and mean wind speed$\geq$10.8 m/s or gust wind speed$\geq$13.9 m/s.

2.2 *Methods*

In some literatures, risk is defined as the occurring possibility of a definite event under definite conditions during a definite time period[8-19]. Naturally, this possibility can be described as a stochastic variable. The risk of TC disasters is also denoted as the probability of a TC disaster event, and this probability is connected with the probability of the hazard factors of impacting TCs in this study.

If we let ξ be a hazard factor, the probability for the value of ξ to be less than an arbitrary real number x is

$$F(X)=P(\xi\langle x). \tag{1}$$

Then its derivative is

$$f(x)=F'(X). \tag{2}$$

The exceedance probability can be obtained from Eq. (2) as:

$$P(X)=P(\xi\geq x)=1-F(X). \tag{3}$$

Normal information spreading technique is used in the probability calculation, considering that the observational data are limited for TC risk estimation. The method is narrated as follows[20-23].

Set the scope of the values of a hazard factor as

$$U=\{u_1,u_2\cdots,u_n\}, \tag{4}$$

where the values in the set are arranged in a sequence from minimum to maximum.

The information of an observational sample y_j can be distributed to all the points in the U as

$$f(u_i)=\frac{1}{h\sqrt{2\pi}}e^{-\frac{(y-u_i)^2}{2h^2}}, \tag{5}$$

where h is a distribution coefficient and can be calculated from the maximum and minimum values, as well as the sample number of the sample set using the formula

$$h=\begin{cases}1.6987(\mathrm{b}-\mathrm{a})/(\mathrm{m}-1) & 1<\mathrm{m}\leq 5\\ 1.4456(\mathrm{b}-\mathrm{a})/(\mathrm{m}-1) & 6\leq\mathrm{m}\leq 7\\ 1.4230(\mathrm{b}-\mathrm{a})/(\mathrm{m}-1) & 8\leq\mathrm{m}\leq 9\\ 1.4208(\mathrm{b}-\mathrm{a})/(\mathrm{m}-1) & \mathrm{m}\geq 10\end{cases}. \tag{6}$$

If we let

$$C_j=\sum_{i=1}^{n}f_j(u_i), \tag{7}$$

then the normalized information distribution function of the sample y_j can be defined as

$$\mu_{yi}(u_i)=\frac{f_j(u_i)}{C_j}. \tag{8}$$

If we let

$$q(u_i)=\sum_{j=1}^{m}\mu_{yj}(u_i), \tag{9}$$

and

$$Q=\sum_{i=1}^{n}q(u_i), \tag{10}$$

then the frequency of sample points at u_i can be obtained by:

$$p(u_i)=\frac{q(u_i)}{Q}. \tag{11}$$

It can be defined as the estimates of probability at u_i. Therefore, the exceedance probability of one hazard factor with a value no less than u_i is defined as

$$P(u_i)=p(u\geq u_i)=\sum_{k=i}^{n}p(u_k), \tag{12}$$

where $p(u\geq u_i)$ is also regarded as the estimate of risk of hazard factors in this study.

To facilitate the analysis of the relationship between hazard factors and disaster events, disaster information was processed into 0–1 value, which denoted "without disaster" and "with disaster," respectively.

The risk probabilities of the scope and intensity of hazard factors, such as precipitation and wind, were first calculated using Eqs. (4)–(12) in this study. Afterwards, the relationship between these equations and the disaster index was analyzed. The disaster risk was obtained after this analysis, and an assessment model was set up through a regression analysis of the exceedance probability of hazard factors and the 0–1 disaster indices. To display the method clearly, the cases of Shanghai were used as application examples in this study.

3 BASIC FEATURES OF TCs IMPACTING SHANGHAI

There were 165 TCs that impacted Shanghai from 1949–2006, with the yearly mean number being 2.85. The most number of TCs experienced in one year was seven; in some years, no impacting TC was recorded. Shanghai was impacted by at least one TC in 93.1% of the years. The variance coefficient of the yearly impacting TC number is 62.74%.

The seasonal variation of the impacting TCs are presented in Fig. 1. All TC events occurred from May to October, with July, August, and September being the months with the most frequent TCs and the smallest range of yearly variance of impacting TC counts. Of these, May has the largest yearly variance extent of impacting TC counts. August is the highest month in terms of impacting risk, with an exceedance probability of 67.24%; this is followed by September (56.9%) and July (46.55%).

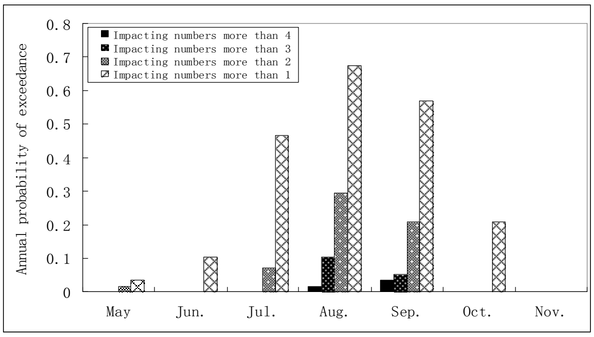

Fig. 1. Monthly distribution of the risk of number of impacting TCs in Shanghai

The duration of the impacting TC events was from 1 to 5 days. The frequencies of 1-, 2-, 3-, 4-, and 5-day events were 63.03%, 23.03%, 9.09%, 4.24% and 0.61%, respectively. As shown in relevant statistics of spatial scope of the impacting TC events, 30% of the events covered all the stations, 41.1% covered over 80% of the stations, and 31% events covered less than 20% of the stations.

For the process precipitation, 27.9% of the TC impacting events were greater than 100 mm and 14.7% of the extreme daily precipitations were greater than 100 mm. In terms of maximum extreme wind, 16.3% of the stations are no less than 17.2 m/s, while 35.7% of them were no less than 20.8 m/s in terms of extreme wind gustiness.

4 DISASTER RISKS OF TC AND THE ASSESSMENT MODEL

Given that most of the meteorological stations started their observations in 1959, data from 1959–2006 were used in this study to guarantee the match of the station number and the integration of meteorological and disaster data. There were 113 impacting TCs in Shanghai during the statistical period, and 45.13% of these resulted in disasters. The climatology of the impacting TCs and TC disasters is shown in Fig. 2. The impacting counts and the disaster counts change in phase on the seasonal scale, with a correlation coefficient of 0.9247. The TC disaster events peaked in August and the second pentad in September. The rate of disaster is the highest from September 11 to 30, during which over 70% of the impacting TCs brought disasters to Shanghai. The rate of the disaster is greater than 50% in August, while no disaster occurred in May and on October 11–31.

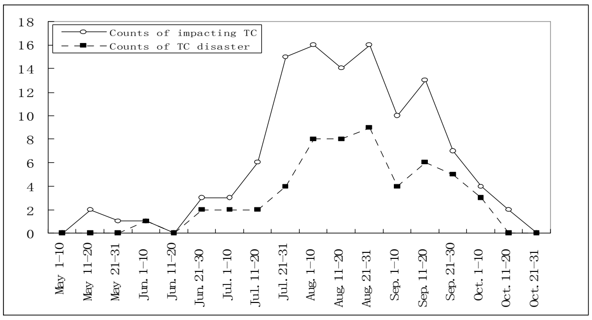

Fig. 2. Seasonal variation of the impacting TC counts and TC disaster counts in Shanghai

Thirteen indices of rain and wind were investigated. The correlation coefficients of their exceedance probabilities and disaster indices are listed in Table 1. All of the correlation coefficients passed the 99% significance test.

The exceedance probability of the normalized index of the extreme value of gust wind among all the stations is denoted as X_1, and the exceedance probability of the normalized index of the maximum station daily precipitation is denoted as X_2. The correlation coefficient for X_1 and X_2 is 0.0153, which is not on a 99% significance level. The regression equation of disaster risk was set up using these two independent variables as

$$Y = 1.2396 - 0.8723X_1 - 0.6223X_2 . \quad (13)$$

The multiple correlation coefficient of the equation is 0.8313, and the standard error is 0.3638, $F = 50.2983 \gg F_{a0.01}$. The fitting effect of the equation is listed in Table 2.

After an analysis of the fitting results, the threshold was set at 0.4 with Y^* to judge no appearance of disasters. According to the model, there were 61 instances of “no disaster” in contrast to 53 incidents of “no disaster” in reality, constituting 8 false reports of “no disaster” on the part of the model. In addition, there were 19 instances of “no disaster” when $Y^* \leq 0.1$ according to the model, and there were 19 instances of “no disaster” in reality, showing no errors on the part of the model.

Table 1. Correlation of probability of hazard factors and disaster index

Exceedance probabilities for	R	F
Count of impacting stations	-0.4636	30.3840
Count of stations with process precipitation ≥ 100 mm	-0.2627	8.2259
Count of stations with daily precipitation ≥ 70mm	-0.3874	19.6049
Normalized index of the maximum station process precipitation	-0.3904	19.9547
Normalized index of the maximum station daily precipitation	-0.4010	21.2753
Normalized index of the average of process precipitation at all the stations	-0.3556	16.0711
Normalized index of the average of daily precipitation at all the stations	-0.3679	17.3726
Count of stations with maximum wind ≥ 13.9m/s	-0.5907	59.4764
Count of stations with gust wind ≥ 20.8m/s	-0.5797	56.1699
Normalized index of the extreme value of max. winds among all the stations	-0.5955	60.9938
Normalized index of the extreme value of gust wind among all the stations	-0.5689	53.1290
Normalized index of the average of maximum wind at all the stations	-0.4381	26.3622
Normalized index of the average of the gust wind at all the stations	-0.3487	15.3604

Table 2. Fitting of the regression model with real disaster situations

Equation result Y^*	Impacting counts	Counts of disaster (Y=1)	Counts of no disaster (Y=0)
>=0.9	20	20	0
[0.8-0.9）	7	6	1
[0.7-0.8）	8	7	1
[0.6-0.7）	4	3	1
[0.5-0.6）	10	8	2
[0.4-0.5）	8	3	5
[0.3-0.4）	12	1	11
[0.2-0.3）	8	2	6
[0.1-0.2）	22	5	17
＜0.1	19	0	19

After conducting an analysis of the fitting results, the threshold is determined to be 0.6 with Y^* to judge the presence of disasters. According to the model, there are 39 instances of “disaster” when Y^*>0.6, and there are 36 instances of real “disaster,” constituting 3 false “disaster” reports on the part of the model. In addition, there are 20 instances of “disaster” when $Y^* \geq 0.9$, and there are 20 instances of real “disaster,” showing no error on the part of the model. Some extreme cases are listed in Table 3.

Table 3. X_1, X_2, Y^* and real disaster situations (Y)

TC code	X_1	X_2	Y^*	Y
0509	0.006009717	0.039916157	1.209484	1
9711	0.0187209	0.071643804	1.1786532	1
6312	0.073795698	0.00581629	1.1715704	1
7708	0.0187209	0.11902272	1.1491719	1
8506	0.073795698	0.06345855	1.1357028	1
9015	0.113260733	0.049990507	1.1096565	1
6123	0.705587	1.00	0.0018107	0
7010	0.705587	1.00	0.0018107	0
7203	0.705587	1.00	0.0018107	0
7207	0.705587	1.00	0.0018107	0
7617	0.705587	1.00	0.0018107	0
7805	0.705587	1.00	0.0018107	0
9022	0.705587	1.00	0.0018107	0
9120	0.705587	1.00	0.0018107	0
7815	1	0.644976358	–0.034104	0

The product of X_1 and X_2 or the average of X_1 and X_2 can also indicate the disaster risk, especially for serious disasters or no disaster cases. Serious disasters occurred when the product $<$ 0.01 or the average $<$ 0.1. In this model, TC 0509 (Matsa), TC 6312 (Gloria), TC 9711 (Winnie), TC 7708 (Babe), TC 8506 (Jeff), TC 9015 (Abe), and TC 6126 (Tilda) were classified as typical cases. There was no disaster when the product ≥ 0.7 or the average ≥ 0.8. Typical cases were TC 6123 (Nancy), TC 7010 (Fran), TC 7203 (Rita), TC 7207 (Winnie), TC 7617 (Fran), TC 7805 (Trix), TC 9022 (Hattie), and TC 9120 (Nat). Results of these indications are listed in Table 4.

Table 4. Disaster risk and disaster rates

Products of X_1& X_2	Impacting counts	Rate of disaster (%)	Rate of no disaster (%)
<0.01	7	100.00	0.00
[0.01,0.1)	25	80.00	20.00
[0.1,0.2)	16	75.00	25.00
[0.2,0.3)	14	35.71	64.29
[0.3,0.4)	16	12.50	87.50
[0.4,0.5)	10	10.00	90.00
[0.5,0.6)	13	23.08	76.92
[0.6,0.7)	4	0.00	100.00
>=0.7	8	0.00	100.00

Average of X_1&X_2	Impacting accounts	Rate of disaster (%)	Rate of no disaster (%)
<0.1	6	100.00	0
[0.1,0.2)	5	100.00	0
[0.2,0.3)	10	90.00	10
[0.3,0.4)	13	76.92	23.08
[0.4,0.5)	9	88.89	11.118
[0.5,0.6)	18	27.78	72.228
[0.6,0.7)	20	15.00	80
[0.7,0.8)	20	20.00	80
＞=0.8	12	0.00	100

5 TESTS FOR 2007–2008

There were three impacting TCs in Shanghai from 2007–2008: TC 0713 (Wipha) on September 18–20, 2007; TC 0716 (Krosa) on October 7–9, 2007; and TC 0808 (Fung-wong) on July 28–30, 2008. These cases were used as independent samples to test the risk assessment model. The results are listed in Table 5. Model results indicated that Krosa and Wipha were likely to induce disasters; in contrast, no disaster or weak disaster would occur during Fung-wong. The model also predicted that the disaster caused by Krosa would be more serious than that caused by Wipha. The results were all verified by real situations.

Table 5. Test results of the disaster risk of TC 0713 (Wipha), TC 0716 (Krosa), and TC 0808 (Fung-wong)

	Extreme value of gust wind among all stations (m/s)	Maximum station daily precipitation (mm)	X_1	X_2	Products of X_1 & X_2	Average of X_1&X_2	Risk estimat e Y^*
TC 0713 (Wipha)	17.3	110.3	0.6792	0.1532	0.1041	0.4165	0.5518
TC 0716 (Krosa)	21.4	138.4	0.3199	0.0964	0.0308	0.2082	0.9005
TC 0808 (Fung-wong)	19.1	35.3	0.6367	0.6335	0.4033	0.6351	0.29

6 CONCLUSIONS AND DISCUSSIONS

A method to assess the TC disaster risk was designed in this study based on the exceedance probability analysis of hazard factors of impacting TCs. The historical fitting and independent tests for 2007–2008 demonstrated the potential capability of the method, though there are some shortcomings in this work. For example, the test sample is limited, influencing the credibility of the model to some extent. Thus, the method needs to undergo more tests. In addition, the estimates of the extent of disasters were not dealt with in the study. Finally, the suitability of the method outside the Shanghai area must also be tested. All these issues need further study, and related results will be reported in the future.

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