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Evaluation on the Meteorological Service for Mitigating the Severe Impacts of Typhoon Rammasun

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Abstract

This study takes the meteorological service of super typhoon Rammasun as an example, and proposes a multi-dimensional quantitative assessment method for meteorological service. Rammasun was the strongest typhoon that landed in China from 1949 to 2019. It hit the coastal areas of China three times, with a rare landing intensity in history. Guangdong, Guangxi, Hainan, Yunnan and other provinces have suffered disasters of varying degrees, with a total affected population of 12.084 million and a direct economic loss of 44.89 billion CNY. During this period, the total investment in meteorological services was approximately 1.213 billion CNY, and the economic benefits of disaster prevention and mitigation in the four disaster-stricken provinces were worth 16.1 billion CNY. According to the cost-benefit analysis of economics, the input-output ratio for disaster prevention and mitigation in Typhoon Rammasun was 1:13.

Keywords

meteorological services, economic benefits, typhoon, Rammasun, mitigation

Introduction

Meteorological services provide information to forecast the occurrence and impact of extreme weather and climate events such as storms, droughts, and heat waves. Due to global climate change, the frequency of extreme weather events will significantly increase (Intergovernmental Panel on Climate Change, 2012). By providing effective forecasting and early warnings, meteorological services can help alleviate the damage caused by these extreme events (World Bank, 2013). Thus, there is an urgent need to determine the specific factors contributing to effective meteorological services. The scientific assessment of meteorological services will provide information to improve these services. Evaluation also provides scientific support for decision makers about the kind of services needed, the value of the services, and how to improvement services in response to the risks related to climate in a changing world, because extreme weather and climate events and their impacts can occur in complex combinations shaped by natural and societal factors (Intergovernmental Panel on Climate Change, 2014; Raymond et al., 2020).

The internet, smart-phone, and other scientific, technological and social developments have insured an ongoing revolution in the demand for, and availability of, weather and climatic information and related services. Billions of people are gaining access to these services and using them in decision-making, greatly enhancing public and private benefit. Providing information on typhoons is one of the most important focuses of weather service during recent decades.

Since significant progress has been made in the methodology of objective assessment of early warning

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services (Wu et al., 2013), it is now possible to quantitatively evaluate the benefits of early warning services. Nevertheless, the current practice of meteorological service assessment is still confronted with a number of problems, including outdated evaluation methods, insufficient use of statistical data, and minimal consumer awareness (Li et al., 2013).

The No. 9 typhoon Rammasun was formed on July 12 in 2014 over the northwest Pacific Ocean and developed into a super typhoon at 05:00 on the 18^{th} at the South China Sea. It made the first landing in Wengtian Town of Wenchang City in Hainan Province, China around 15:30. Around 19:30 of the same day, Rammasun struck the Longtang Town of Xuwen County in Guangdong Province with the same intensity. At 07:10 on the 19^{th}, it made the third landfall in Guangpo Town, Fangcheng Port, Guangxi Province, with a reduced strength as a strong typhoon.

At the time of landfall in Hainan Province, Rammasun was on a Beaufort scale of 17, making it the most powerful typhoon in China during 1949–2019 (Bai et al., 2016; Wan et al., 2016). It brought strong winds and rainstorms. Specifically, in the north-east of Hainan and Leizhou Peninsula of Guangdong, the mean wind scale was generally 10–12, and increased to 15–16 along the coastal areas. In Haikou City and Changjiang County of Hainan Province, the precipitation was up to 500–714 mm, Rammasun has caused huge disaster losses (Table 1).

China has built an integrated real-time typhoon monitoring system based on the data from meteorological satellites of Fengyun (FY), Doppler weather radars, and ground automatic meteorological stations. In the typhoon monitoring and forecasting service, the meteorological data obtained by Fengyun satellites can be used to extract information regarding the current location, intensity changes and moving path of typhoons, as well as the forecasted precipitation. In particular, data from the FY-2F Satellite with 6-minute regional scanning for intensified observations provide more detailed monitoring information. The monitoring data recorded every six minutes by the Doppler weather radar network along the coast are important supports for the real-time monitoring and nowcasting of position and intensity changes of typhoons, as well as the intensity and distribution of precipitation induced by typhoons. The surface information observed by the ground automatic meteorological stations every 10 minutes make it possible to accurately monitor the wind speed and rainfall brought by typhoons. Those monitoring information in turn can be employed to verify the short-term rainfall forecast made by numerical weather prediction models which assimilates the data from radars (Xu et al., 2010). Despite the above monitoring system, there is no direct and objective method to predict the moving path of or the rainstorm brought by typhoons at present.

In this paper, a multi-dimensional approach to make quantitative assessments of meteorological services is proposed based on the case of Typhoon Rammasun. The forecasting of typhoon paths, the life-saving rate, and the economic benefits from disaster mitigation are considered in this method. It is hoped this approach can help improve the meteorological services so as to mitigate disaster risks.

Method

Evaluation on Typhoon Change Forecast

The monitoring data of typhoons collected from Fengyun satellites, Doppler weather radars, and ground observations are incorporated into half-theoretical and half-empirical statistical methods for typhoon forecast. In this way, the forecasting information about the changes in typhoon location and intensity, and about the intensity and area of precipitation brought by typhoon, can be delivered to the public. Meanwhile, the warnings are issued according to the relevant standards for typhoon disaster mitigation. With these forecasts and warnings, the public can better cope with various severe situations whether directly or indirectly caused by typhoons.

In this paper, the typhoon forecast is assessed by the product of 24-hour path deviation and wind speed. It is assumed the series obtained was subjected to range normalization, and the mean value was calculated to evaluate the accuracy of the proposed method in forecasting typhoon paths (Ying et al., 2014).

Table 1. Disaster Data of Typhoon Rammasun.

Affected provinces	Emergency transfer population (10,000)	Affected area of crops (10,000 hectares)	Number of damaged houses (room)	Direct economic loss (10,000 CNY)	Typhoon landing wind speed (m/s)
Hainan	18.8235	16.33762	182,934	1,191,119.3	60
Guangdong	34.9378	12.15513	72,947	1,286,389.297	55
Guangxi	32.0261	145.670127	187,197	1,389,863.94	48
Yunnan	4099.7265	917.409145	34,381	308,748.78	16

Evaluation on Benefits From Life Saving

No systematic theoretical model has been established so far although many attempts have been made to evaluate the meteorological services regarding life protection (Mei & Lu, 2007). Meteorological prediction models have attracted increasing attention due to the recent increase in the size and frequency of weather disasters and the resultant human casualties. Researchers have made quantitative analysis of the value of human life by various methods, including human capital approach and the willingness to pay approach (Liao & Tan, 2007). Nevertheless, in view of the complexity of life value computation at different times and under different environments, as well as the controversial reliability of the results obtained by these methods, in this study, the benefits from saving life are assessed by the actual reduced death toll. To this end, a death reduction model is constructed to estimate the rate of death reduction. The model was:

$$A = \sum \left(\frac{D}{\sum P} \right) \tag{1}$$

where A is the rate of death reduction, D is the number of reduced deaths, and P is the number of possible deaths caused by floods.

Evaluation of Economic Benefits

A significant proportion of the expenditure on typhoon warning services is spent on the research, monitoring, and forecasting of typhoons. In the current study, input analysis is carried out primarily from three aspects. The first is the input in the detection, forecasting and analysis of meteorological information, including investments in meteorological satellites, atmospheric sounding, weather station construction, maintenance of meteorological equipment, and meteorological forecast analyses. This is typically the largest cost. The second is the input in the dissemination of information provided by the meteorological service, including investments in meteorological service web sites, project preparation and operation, and other information dissemination channels like telecommunications and broadcasting. The third input involves investments in personnel and administrative operations, including cost of professional staff for maintenance and warning services, processing and analysis of monitoring data, maintenance of equipment, and daily administrative operations.

In fact, there are many factors affecting the assessment of the benefits from typhoon-related meteorological services, such as the intensity of typhoon, quality of forecasts, decision of governmental department, level of meteorological service, and action of the population. Nevertheless, given that many of these factors cannot be quantified, only the major influencing factors can be utilized to assess the effectiveness of meteorological service for typhoon-induced disaster mitigation. Thus, in this paper, the major factors adopted for evaluating the meteorological service for Typhoon Rammasun are the level of meteorological service (M), the decision and organization of government regarding disaster prevention and mitigation (G), and inevitable loss (S).

Results

Typhoon Paths

The evaluation of typhoon path prediction considers the product of 24-hour path deviation and wind speed. The obtained series is subjected to range normalization, and the mean value of forecast deviation is 0.36 (Table 2). Therefore, the estimated quality of the meteorological service for typhoon path forecasting is 0.64.

Life Saving

In order to estimate life savings and potential loss of life, we searched historic records and found that the No. 5612 Typhoon Wanda (Li et al., 2013), which landed in Nanzhuang Township, Xiangshan County of Ningbo City, Zhejiang Province with a center pressure of 923 HPA and a wind speed of 65 m/s on August 1, 1956, was extremely similar to the Rammasun in landing time and intensity. Wanda was the second strongest typhoon to strike China since 1949 (Bai et al., 2016). Owing to the low level of weather service at that time, there was basically no forecasting services for Wanda, let along typhoon evacuation. According to the historical records, the ultra-strong No. 5612 Typhoon caused a mortality rate of 7.45‰ in the disaster area.

In order to reduce the potential casualties from Rammasun, the four provinces Hainan, Guangdong, Guangxi and Yunnan required timely evacuation of the main areas likely to be affected by Rammasun according to the typhoon forecast information. Unfortunately, due to the effects of factors like the deviation of forecasted path, Rammasun still caused storm-related deaths in Hainan, Guangxi, and Yunnan. Table 3 shows the number of persons evacuated and the death toll in different provinces.

Based on the disaster statistics in Table 3, the number of reduced deaths is calculated to be $886{,}800 \times 7.45‰ \approx 6607$

With the death reduction model (Rate of death reduction = Number of reduced deaths/(Number of reduced deaths + Number of actual deaths) × 100%), it can be calculated that the rate of death reduction

Table 2. Evaluation of Typhoon Path Forecasting (Two Digits After the Decimal Point).

Typhoon level	Forecast path difference (km)	Evaluation on range normalization forecast	Typhoon level	Forecast path difference (km)	Evaluation on range normalization forecast	Typhoon level	Forecast path difference (km)	Evaluation on range normalization forecast
TS	93.92	0.26	TY	163.00	0.95	TY	63.85	0.33
TS	186.92	0.59	STY	128.95	0.94	TY	43.29	0.20
TS	303.68	1.00	STY	129.21	0.94	STY	11.12	0.02
TS	271.22	0.89	STY	86.46	0.61	STY	15.25	0.05
TS	254.97	0.83	STY	54.65	0.36	STY	10.42	0.01
TS	91.55	0.25	STY	79.21	0.55	STY	20.78	0.09
TS	89.61	0.25	STY	85.42	0.60	SuperTY	24.53	0.16
TS	62.10	0.15	TY	64.13	0.33	SuperTY	10.33	0.03
STS	70.08	0.27	TY	73.97	0.40	SuperTY	32.88	0.24
STS	70.47	0.27	TY	76.92	0.41	SuperTY	23.41	0.15
TY	44.70	0.21	TY	84.51	0.46	SuperTY	32.73	0.24
TY	11.12	0.00	TY	71.80	0.38	SuperTY	39.16	0.30
TY	10.80	0.00	TY	54.05	0.27	SuperTY	30.25	0.22
TY	48.57	0.24	TY	53.93	0.27	SuperTY	10.24	0.03
TY	97.67	0.54	TY	63.16	0.33	STY	72.32	0.50
TY	86.20	0.47	TY	57.05	0.29			

Note. TS = Tropical Storm; STS = Severe Tropical Storm; TY = Typhoon; STY = Severe Typhoon; SuperTY = Super Typhoon.

Table 3. Numbers of People Evacuated and the Numbers of Deaths in Areas Affected by Typhoon Rammasun.

Affected province	Hainan	Guangdong	Guangxi	Yunnan
Number of people evacuated (10,000 persons)	18.82	34.94	32.03	2.89
Number of deaths	26	0	10	37

achieved by the meteorological service for Rammasun is $6607/(6607+73)\times100\% \approx 99\%$.

Economic Cost and Disaster Mitigation

Input Cost. From 2001 to 2014, the meteorological departments of China invested 19.5 billion CNY in the construction of weather satellites and approximately 45 billion CNY in meteorological observation, weather station construction and forecast projects. From 2009 to 2014, 14 billion CNY was invested in the dissemination of meteorological information. This included the construction of platforms for issuing meteorological early warnings and the collaboration with the telecommunications industry. In 2014, the input cost for the administrative operation was 2.3 billion CNY.

The service life of equipment can vary greatly. After taking various factors into account, the service life of equipment is set to 15 years in this study. The SLN function that includes three variables (cost, salvage, and life) is used to calculate equipment depreciation. Cost is the initial value, namely the amount of initial investment on the equipment; salvage is the value of the equipment at the end of its lifetime; life is the lifetime or service life of the equipment. In this calculation, the initial value of the total investment on meteorological equipment is 64.5 billion CNY, and the lifetime is 15 years. The salvage rate is set to 5% as this value is conventionally used for electronic devices (Wu et al., 2013). The salvage value is thus 3.225 billion CNY. Therefore, the value of SLN (645, 32.25, 15) is calculated to be 4.085 billion CNY. In other words, the input cost on meteorological information detection, forecasting, and analyses was 4.085 billion CNY. The investment on dissemination of meteorological information was 14 billion CNY in 2014. Similarly, the input cost for meteorological information dissemination calculated from SLN (140, 7, 15) is 890 million CNY.

In summary, the total meteorological input in 2014 was 7.275 billion CNY, which was composed of the input in meteorological information detection, forecasting, and analyses (4.085 billion CNY), the input in meteorological information dissemination (890 million CNY), and the input in personnel and administrative operation (2.3 billion CNY). Assuming that the impact of Typhoon Rammasun lasts for 60 days, the total input cost for meteorological service over this period is about 1.213 billion CNY.

The Economic Benefits From Disaster Mitigation. From July 18 to 22, 2014, China Weather Network conducted a questionnaire survey on the overall assessment of the meteorological services provided during Rammasun, including the timeliness, accuracy and practicability of the weather warning information, as well as the actual results of self-protection. A total of 442 people participated in this survey. The survey was designed as a Likert scale questionnaire, so there was no invalid questionnaire. The survey results showed that 47.54% of the respondents were satisfied with the meteorological services provided by the weather sector during Typhoon Rammasun, and 25.7% were roughly satisfied, and 15.42% thought the services were "acceptable". Thus, a total of 88.66% of the respondents approved of the work done by the meteorological sectors, residents are generally satisfied with meteorological service, particularly during the typhoon season (Wu et al., 2019). In this study, 88.66% is used to represent the role of the government in disaster prevention and mitigation, so G = 0.89.

This evaluation is based on the direct economic loss induced by the typhoon disaster, which was obtained from statistical data. To calculate the benefit of typhoon-related meteorological services, this paper establishes an integrated evaluation model that includes typhoon forecasting service level, decision and organization of government regarding disaster prevention and mitigation, and inevitable loss. Since this model calculates the benefits of meteorological service from the direct economic loss, it is called an inverse projection algorithm (Zhang & Zhang, 2011).

The formula for the benefit of typhoon disaster prevention and mitigation is as follows:

$$\frac{A+B}{B}=\frac{1}{MG(1-S)} \tag{2}$$

where $0 \le M \le 1,\ 0 \le G \le 1,$ and $0 \le S \le 1$. A is the direct economic loss of a certain area caused by a major meteorological disaster; B is the benefit value of disaster prevention and mitigation in that disaster; A+B represents the possible direct economic loss the meteorological disaster cause to the area in the absence of disaster prevention and mitigation measures; S is the inevitable loss; 1-S is the coefficient of avoidable loss, i.e., the maximum value of economic loss that can be avoided in a major meteorological disaster; G represents government's contribution to disaster prevention and mitigation.

From the above equations, the formula for the benefit of prevention and mitigation of a major meteorological disaster can be obtained.

$$B=\frac{AMG(1-S)}{1-MG(1-S)} \tag{3}$$

The unknown factors in the formula for the benefit from disaster mitigation will be calculated below.

The factor of inevitable loss S.

A fuzzy comprehensive evaluation method is used for the calculation.

The four provinces most affected by the typhoon are taken as the study areas to evaluate the disaster reduction benefits. Four indices (the area of submerged farmland A1, the number of damaged houses A2, the direct economic loss A3, and the typhoon intensity A4) are used to show the major impacts of the typhoon. The relevant data collected are as follows:

$$\begin{pmatrix} 16.33762 & 182934 & 1191119.3 & 60 \\ 12.15513 & 72947 & 1286389.297 & 55 \\ 145.670127 & 187197 & 1389863.94 & 48 \\ 917.409145 & 34381 & 308748.78 & 16 \end{pmatrix}$$

In fuzzy theory, the determination of membership function should reflect the specific characteristics of objective fuzzy phenomenon and conform to the objective rules. However, due to each expert's strong points in practical experience and judgment ability, the determination and understanding of the same fuzzy concept will be different, so the determination of membership function has certain subjectivity and experience (Kim & Park, 1990; Zhang et al., 2013). R_i(x) is the membership function of typhoon disaster impact index x. When the value of typhoon disaster impact index x is greater than a certain value, it can cause disaster, otherwise it can be regarded as no disaster. With the increase of data x, the value of membership function representing the impact of disaster will also increase.

$$R_i(x)=\begin{cases} 0, & x \le a \\ 1-e^{-k(x-a)^2}, & x > a, k > 0 \end{cases} \tag{4}$$

$$a = x_{\min} \tag{5}$$

where a and k are parameters.

In formula (5), a is the minimum value of the disaster impact index. Let the membership value corresponding to the maximum value of the physical disaster impact index be 0.99, then the value of k can be obtained:

$$k=\frac{4.605}{(x_{\max}-x_{\min})^2} \tag{6}$$

For each disaster impact index, after a and k are calculated according to formulae (5) and (6), assessment matrix is computed through the membership function (4). The obtained assessment matrix is as follows:

$$R = \begin{pmatrix} R_1 \\ R_2 \\ R_3 \\ R_4 \end{pmatrix} = \begin{pmatrix} 9.8 \times 10^{-5} & 0.99 & 0.95 & 0.99 \\ 0 & 0.25 & 0.98 & 0.97 \\ 0.1 & 0.99 & 0.99 & 0.91 \\ 0.99 & 0 & 0 & 0 \end{pmatrix}$$

Given that the impact of each indicator varies in different disasters, different weights are assigned to these indices. Here the weights for the index factors are calculated by the Analytic Hierarchy Process (AHP) (Saaty, 1980; Zhang & Zhang, 2011) as reported by Zhang and Zhang, and the obtained values are listed in the Table below.

From the fuzzy relation of factor set assessment A*R,

$$B = (b_1, b_2, \ldots, b_m) = A * R \quad (7)$$

The factor of inevitable loss induced by typhoon can be obtained:

$$b_j = \sum a_j r_{ij} \quad (8)$$

Through this method, it can be calculated that the inevitable loss factors for Hainan, Guangdong, Guangxi and Yunnan are 0.62, 0.35, 0.65 and 0.37, respectively.

Then by substituting the values of inevitable loss factor (S) for the four provinces, the value of government's contribution to disaster prevention and mitigation (G, 0.89), and the value of the factor meteorological service level (M, 0.64, herein replaced with the value of the quality of typhoon path forecasting) into Equation 3, the economic values of disaster mitigation for the four provinces are obtained. Finally, all provincial economic values of disaster mitigation are added together to obtain the total economic value of disaster prevention and mitigation during Typhoon Rammasun. This value amounted to 16.1 billion CNY.

Benefit-Cost Ratio of Disaster Mitigation. According to cost-benefit analysis in economics, it is found that the input-output ratio for disaster prevention and mitigation during Typhoon Rammasun is 1:13, it shows that meteorological service is particularly important when typhoon disaster is seriously affected (Xing et al., 2019).

Discussion

For the calculation of input in typhoon monitoring, forecast and warning services, this paper mainly considers the investments in three modules. They respectively are the investment on meteorological satellites, atmospheric sounding, weather station construction, and platform construction for the forecasting and warning system, the investment on information dissemination, and the investment in personnel and administrative operations. That's because these data can be obtained from published financial records and they cover all the major inputs in typhoon forecasting services. The problem is that the improvement in forecasting the typhoon path, intensity, winds, and precipitation cannot be realized by merely investments in the above three modules. Research investment in typhoon forecasting, in particular, plays a key role in improving weather services. Nevertheless, because such hidden inputs are not taken into account in this calculation, the total input in typhoon forecasting service may be underestimated.

It should be pointed out that the final statement from which the data were collected is published annually, and meanwhile most budgets are made annually, so the values used for our input calculations are all calculated based on the annual values. In this paper, according to the proportion of the duration of the Typhoon Rammasun in the total number of days in a year, the input in forecasting services during the Typhoon Rammasun is calculated, and thus the obtained total input may be different from the actual one. In fact, during the flood season, manpower and fiscal inputs in forecasting services are supposed to increase as compared to other periods of the year. Thus, the input during the typhoon period obtained in this paper should be smaller than the practical value.

In this paper, the lifetime of equipment is set to 15 years, and the salvage ratio of electronic equipment is set to 5% to calculate the depreciation. In practical situation, however, not all devices can last as long as its expected lifetime. In addition to the complete destruction of some devices by typhoon disasters, equipment lifetime can be divided into technical lifetime and economic lifetime. Technical lifetime refers to the duration from the time when a device is put into service to the time when it is replaced due to its outdated technology. Economic lifetime is the duration from the time when a device is first put into service to the time when it is replaced due to economic factors. Economic lifetime is composed of the construction cost and annual operating cost of the device. The actual service time of meteorological satellites for commercial use is 3 to 5 years, after which they are no longer fit for typhoon forecasting service and can be only be used for experimental purposes. For radar, the economic lifetime is 14 to 19 years.

In the present paper, the level of meteorological service is obtained through the comprehensive analysis of the forecast errors in the typhoon path and intensity.

Table 4. Adjusted Standards for Determining Threat Score (TS), the Accuracy of 24-Hour Accumulated Precipitation Forecasting.

	TS%				
	100	90	50	30	0
Heavy rain $25. \le R_f < 50.$	$25. \le R_{obs} < 50.$	$10. \le R_{obs} < 25.$ $50 \le R_{obs} < 100.$		$5.0 \le R_{obs} < 10.$ $100 \le R_{obs} < 175$	$R_{obs} \le 5.0$ $R_{obs} \ge 175.$
Heavy rain to rainstorm $38. \le R_f < 75.$	$38. \le R_{obs} < 75.$	$17. \le R_{obs} < 38.$ $75 \le R_{obs} < 100.$	$100 \le R_{obs} < 150$	$10 \le R_{obs} < 17.$ $150 \le R_{obs} < 250$	$R_{obs} < 10.$ $R_{obs} \ge 250.$
Rainstorm $50. \le R_f < 100$	$50 \le R_{obs} < 100$	$38 \le R_{obs} < 50.$ $100 \le R_{obs} < 150$	$25. \le R_{obs} < 38.$ $150 \le R_{obs} < 250.$	$17 \le R_{obs} < 25$	$R_{obs} < 17$ $R_{obs} \ge 250.$
Heavy rainstorm $100 \le R_f < 250$	$100 \le R_{obs} < 250$	$50 \le R_{obs} < 100.$ $R_{obs} \ge 250$			$R_{obs} < 50.$
Super heavy rainstorm $R_f \ge 250.$	$R_{obs} \ge 250.$	$100 \le R_{obs} < 250$		$50 \le R_{obs} < 100$	$R_{obs} < 50.$

Note. R_f and R_{obs} Are the forecasted and the actual values of precipitation, respectively.

This is because among the key factors involved in the evaluation of typhoon forecasting services (including path forecasts, intensity forecasts, wind field radius forecasts and precipitation forecasts), path and intensity forecasts are the most critical, which are the two indexes with the largest weight coefficient in the Comprehensive Grade Evaluation Model of Typhoon Disaster (Wang et al., 2018). In actual forecasting tests, the precipitation threat score (TS) is also often used. To calculate the TS, the number of weather stations for which the forecasted precipitation and the actual precipitation fall in the same level in the test area within the forecasting period are counted, and this represents the number of hits. The number of stations that forecast precipitation but it does not actually occur is counted as the number of false alarms. The number of stations which fail to forecast precipitation when precipitation actually occurs is counted as the number of misses. TS = number of hits/(number of hits + number of false alarms + number of misses). In practice, TS performs satisfactorily in testing the forecasts of small to moderate rainfalls. However, in forecasting heavy rains or rainstorms caused by typhoon, TS performs rather poorly. Hence, this study adjusts the standard for determining TS by including the magnitude and range of precipitation levels. The adjusted standards are shown in Table 4. The standard differs from the conventional one for TS calculation, and may serve as a reference for future TS evaluation of meteorological services.

Implications for Conservation

Meteorological disasters account for approximately 71% of the total economic losses induced by natural disasters (UN Office for Disaster Risk Reduction in Advance of International Day for Disaster Reduction, 2018). Meteorological service emerges as a new source of providing Meteorological information to support adaptation and mitigation decisions, which are undertaken in the public and private sectors at global, regional, and cross-ecosystem scales. Good meteorological service can reduce the impact of disasters and protect the diversity of animals and plants.

With the development of eco-meteorological services and the strengthening of climate monitoring of typical ecosystems such as forests, grasslands, deserts and wetlands, accurate meteorological services and early warning of meteorological disasters will be more conducive to people to carry out refined and diversified ecological protection, and support major ecological projects such as returning farmland to forests and grasslands, protecting natural forests, preventing and controlling desertification, wetland protection and restoration, and water ecological management, the achievements of ecological protection will promote the harmonious development of human society and community (Sun et al., 2020).

More than half of the world's population currently lives in cities and 4% in coastal megacities, making them an area of particular concer (Sekovski et al., 2012). The continued growth in urban population would be accompanied by the expansion of cities, with urban areas facing unique meteorological hazards (Güneralp et al., 2015; Rosenzweig & Solecki, 2014). Good meteorological service is the foundation of sustainable development of society, which contributes to people's well-being and the conservation of ecological diversity.

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