

# Typhoon damage assessment model and analysis in Taiwan

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**Abstract** Typhoons are one of the world's most frequently occurring natural disasters that cause severe damage. The losses caused by typhoons are not only related to the strength and structure of a particular typhoon, but also to the population density, home range, and type of economy in the affected area. Taiwan is centrally situated in the main path arc of typhoons generated in the Northwest Pacific Ocean. On average, 3–4 typhoons approach or make landfall in Taiwan yearly. The associated strong winds, violent rains, landslides, and storm surges or upwelling in coastal areas often catastrophically impact the citizens of Taiwan and cause severe damage to the national economy. Losses may amount to billions, or even tens of billions of New Taiwan Dollars. Due to the limitations imposed by the lack of complete data in earlier years, this study focuses on those typhoons with complete records which landed and affected Taiwan from 1965 to 2004. This study considers meteorological indicators including maximum daily rainfall, maximum central wind speeds, lowest central pressure, radius of class seven winds, and period during CWB issued land and sea warning, as well as disaster indicators that reflect damages resulting from typhoons such as the numbers of dead or missing persons, totally destroyed houses, and actual amounts of crop losses. This study aims to statistically analyze the meteorological and disaster indicators, and build a disaster assessment model which allows for a quantified assessment to be conducted. This would enable the relevant government departments to immediately assess or evaluate the disaster upon the receipt of predicted or actual data from a particular typhoon. Additionally, this study evaluated precautionary building principles in terms of the positive effect they have on improving disaster management.

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## 1 Introduction

According to the statistics regarding the location and frequency of tropical cyclones from Gary (1979), there are around 80 typhoons generated every year. Not only is the greatest proportion of these generated in the northern Pacific Ocean and South China Sea (around 30 %), this area is also responsible for the strongest typhoons in the world. Furthermore, Taiwan is centrally situated on the prevalent track arc of typhoons originating in the northeastern Pacific Ocean. As a result, there are usually 3–4 typhoons per year that approach or make landfall in Taiwan. The abundant rainfall brought by the typhoons provides the main water source during summer and autumn, constituting half of the average yearly rainfall in Taiwan. However, the typhoons also produce violent rains, landslides, and even storm surges and saltwater intrusion into coastal areas. This often inflicts a disastrous toll on the lives of Taiwan's citizens as well as causing severe damage to the national economy. Losses commonly tally from billions to even tens of billions of New Taiwan Dollars (Zhang et al. 1995; Ye and Dong 1998; Chen et al. 2011; Chiu 2012).

*Disaster Risk Management Series No. 5: Natural Disaster Hotspots—A Global Risk Analysis*, issued by the World Bank in 2005, assesses six main global natural disasters, including geophysical hazards such as earthquakes and volcanic eruptions, and hydrological hazards such as floods, typhoons, landslides, and droughts. It shows that 73.1 % of the national territory and general population of Taiwan are exposed to over three kinds of natural disasters, which is the highest proportion around the world. In addition, almost all lands and all of the population (99 %) in Taiwan are exposed to over two kinds of natural disasters (Dilley et al. 2005).

UK's *Natural Hazards Risk Atlas* (2011) indicates that the economic exposure to natural hazards in Taiwan ranked 4th globally, categorized as one of the countries at “extreme risk,” at the same level as USA, Japan and China. Similar to China and Japan, Taiwan is densely populated in areas threatened by natural disasters. Consequently, the economic impact of natural disasters may be extremely high. Out of the 196 countries rated in total, USA, Japan, China and Taiwan were the only nations to be categorized at the “extreme risk” level.

This study constructs a database of typhoon disaster losses in Taiwan in order to alleviate the loss of lives and properties that result from typhoons as well as to fortify the foundation of policies regarding the evaluation of insurance claims, and develop risk prevention and reduction strategies. Moreover, by collating the historical data of typhoon disaster losses, this study builds index models and assessment models of typhoon disaster loss which are applicable to Taiwan in particular. The outcomes may provide a scientific basis for typhoon disaster assessment and disaster prevention and reduction in Taiwan (Lin 2004, 2007; Council of Agriculture, Executive Yuan 1988–2007; Emanuel 2007; Din 2007).

## 2 Literature reviews

### 2.1 Risk assessment of natural hazards

In modern society, disasters encompass the interaction of politics, the economy, and social development. The effects wrought by disasters include not only direct impacts such as

deaths or injuries and damage to property, infrastructure, and residential dwellings, but also geological impacts resulting from large-scale alterations to the earth's surface, associated impacts such as pollution from floods or from fires caused by earthquakes, and rippled impacts such as unemployment, industrial recession, and depression (Tierney et al. 2001). Additionally, disruptive changes in social structure and an increase in mental health disorders resulting from traumatic events and disaster reconstruction issues may also bring huge impacts on the society.

Due to the growing threat of natural disasters in recent years, risk management has become the current trend in disaster prevention around the world. Even if the raw natural force of two disasters is of a similar scale, the level of impact may be quite diverse due to variants such as the distribution of population and the participation of different populations in particular activities that inevitably vary in different time and spatial features where the disasters occur. This implies that the impacts of disasters may be affected by the degree of social quality existent in different regions (vulnerability). Hazard–risk–vulnerability analysis is crucial to community safety (Wang 2012). “Risk = Hazard  $\times$  Vulnerability” is a generally accepted and applied theory of risk assessment for natural disasters (Alexander 2002). United Nations International Strategy for Disaster Reduction (ISDR) also points out that the risk consists of the interaction of disasters, vulnerability, and capacity (Chung 2006).

“Hazards include any potential that may threaten human life and property before turning into disasters (Wang 2012),” which implies the level of danger inherent in natural disasters, while “vulnerability” refers to related factors that limit the reduction of disastrous impacts or provide for the efficient recovery of disaster-affected systems, i.e., vulnerability is the active tendency of things to cause disasters or their passive tendency to incur damage (Wang 2012).” These factors may involve the economy, society, engineering techniques, and the environment. For example, the lack of precautionary facilities, incomplete social support systems, shortages in rescue organizations, poor construction quality, and pre-existing damage to ecosystems may all increase the degree of vulnerability, thus causing more destructive disasters, enlarging the affected area, increasing the frequency of occurrence, and raising the level of uncertainty, which in turn hampers the adoption of preparation and prevention techniques. By contrast, complete urban development incorporating the organization and establishment of disaster management system may reduce the vulnerability, thus lowering the disaster loss toll (Water Resource Agency, Ministry of Economy Affairs 2014). Thus, hazards (e.g., typhoon) are part of the natural environmental processes. When the hazards interact with people and properties whom may be threatened by, and exceed people's capacity, mitigation, and preparedness efforts to confront with, disasters occur. Therefore, this study uses disaster history as its primary target and pre-categorizes sources and approaches regarding hazards that might turn into disasters.

From this, it can be seen that if disasters happen in areas without warnings or precautionary measures, the risk of damage will increase dramatically. Comparatively, if the disaster becomes more violent, but the vulnerability remains at the same level, the risk will still increase (Wang and Ling 2011). With regard to the concept of vulnerability, it is essential to consider the quality and condition of the environment and thus helps to evaluate the possible disaster occurrence and its consequences more accurately.

In recent years, the UN has dedicated resources to researching the levels of disaster risk in different countries. The disaster risk index (DRI) (Peduzzi et al. 2009), which covers earthquakes, typhoons, floods and droughts, has been formulated in order to understand the relationship between disaster risk and national development. DRI assesses the risk based on the number of deaths in each category of disasters. Disaster death risk (estimated number of deaths) is the product of frequency of occurrence, the number of individuals

exposed to disasters, and variables pertaining to vulnerability. The number of individuals exposed to disasters refers to the total number of individuals affected by disaster events. Vulnerability refers to the capability of response systems and their ability to adapt to dynamic disaster situations. The UN adopts 31 socioeconomic and environmental variables as the quantitative indicators of vulnerability (Water Resource Agency, Ministry of Economic Affairs 2014). However, due to a dearth of comprehensive data, the application of DRI is limited and this presents a crucial problem. For example, DRI only defines the death risk due to the number of deaths being the most easily acquired and accurate data. Since calculation of vulnerability is reliant on the availability of a range of data, the lack of suitable, accessible data currently limits the validity of vulnerability assessment.

## 2.2 Assessing disaster loss caused by typhoons

Of all the natural disasters, typhoons, with their violent winds and torrential rains, are the most destructive. The average financial loss caused by a single typhoon is around two billion NTD, which constitutes over 80 % of the total disaster loss per annum (Carpenter 2004). The scale of a typhoon's destruction depends on its track as well as the total amounts and types of rainfall (Wang and Ling 2010, 2011). Apart from meteorological factors such as seasonal conditions, the path of the typhoon, the levels of accumulated rainfall, and the suddenness and intensity of the rain, geographical factors such as land usage and population density also play important roles in the overall impact of the typhoon (Teng et al. 2005). The meteorological factors affecting the scale of damage can be divided into four categories: (1) the duration of time that the land is affected by the seventh wind radius; (2) the alert area of the typhoon, which can be divided into three sections: local, regional, and national; (3) rainfall conditions, including the amount of rainfall and area affected; (4) wind conditions, which can be categorized based on the central wind speed (Teng et al. 2005).

The disaster environment of a typhoon is comprised of four main features: uncertainty, timeliness, complexity, and interactivity (Water Resource Agency, Ministry of Economic Affairs 2014). In order to reduce the deaths and property losses resulting from typhoons and to react efficiently and immediately when disasters occur, the assessment of disaster losses is an essential reference data. However, post-disaster evaluation and investigation are also extremely challenging and require a great amount of time and effort. For example, after Typhoon Morakot, which devastated southern part of Taiwan in 2009, it took the Morakot Post-Disaster Reconstruction Council nearly 18 months to investigate and calculate the financial losses, which amounted to nearly 200 billion NTD (Li et al. 2013).

The Federal Emergency Management Agency (FEMA) bases its disaster assessment methods and models on geographical information system (GIS). With the data being processed by computers, they are able to assess and analyze likely disaster loss and have developed the software, Hazards United States (HAZUS), for this purpose. It is used to predict the probable losses before and after the disaster, and also calculate the impacts brought by each kind of hazard, such as financial losses and social effects, etc. So far, HAZUS is equipped with three modules, including earthquakes, floods, and hurricanes. The hurricane module is able to estimate the financial and social losses, and assist in the assessment, preparation, and alleviation of the damage brought by hurricanes (Chien 2007).

In order to enhance the analytical capabilities of disaster prevention and response, Taiwan introduced the HAZUS system in 1998 and developed a disaster analysis system, HAZ-Taiwan, which was optimized to fit local demands. However, HAZ-Taiwan focused

only on earthquakes and did not involve the analysis of typhoons (Chien 2007). The first disaster loss analysis system for typhoons was the flood loss analysis system of northern Taiwan established by Wang and Su (2002, 2003). Since then, other scholars have improved the module by developing GIS functions. A tool was created that could construct, manage, and analyze data, while a platform was developed to present the outcomes (Su et al. 2002; Kang et al. 2005; Chiang et al. 2005). Using GIS, the National Science & Technology Center for Disaster Reduction developed Taiwan typhoon loss assessment system (TLAS Taiwan), which is an efficient model for calculating losses of flood disasters based on previous research and the historical records of disaster losses. It is capable of analyzing pre-disaster engineering benefits, assessing risks, and calculating post-disaster losses (Li et al. 2013).

Current bulk of statistical information relating to typhoon impacts is collected post-event. There is no complete statistical bank of natural disaster losses that can be used to analyze impact. As such, the building of an assessment model for typhoon disaster loss by collating simplified meteorological variables would likely provide a useful mechanism for managing typhoon disasters in Taiwan and planning effective disaster reduction works.

### 3 Study design

#### 3.1 Source of data

- (1) List of typhoon warnings by Central Weather Bureau (CWB) historical typhoon database. Data used by this study include nine items: years, Chinese names, dates, scales, track categories, lowest central pressure, maximum central wind speed, the maximum amount of rainfall in each wether station, and the maximum daily rainfall. [http://rdc11.cwb.gov.tw/TDB/ntdb/pageControl/ty\\_warning](http://rdc11.cwb.gov.tw/TDB/ntdb/pageControl/ty_warning).
- (2) Development Council of Agriculture, agricultural statistical yearbook of agricultural disasters. Data used by this study include four items: counties and cities, date, name of disasters, crop losses amounts, and predicted amount of financial losses. <http://agrstat.coa.gov.tw/sdweb/public/book/Book.aspx>.
- (3) National Fire Agency, Ministry of the Interior website: Taiwan from 1958 to 2005 natural disaster loss statistics, using data that include six items: the date, the type, the totally destroyed house, partially collapsed, death, missing, and injured. [http://content.edu.tw/primary/society/ks\\_ck/new/shake/word/hm3.doc](http://content.edu.tw/primary/society/ks_ck/new/shake/word/hm3.doc).

#### 3.2 Research methods and definitions

##### 3.2.1 Building a typhoon disaster loss assessment model

Typhoon damage is caused by winds, violent rains, and storm surges, which result in landslides, mudslides, and floods, which, in turn, cause losses such as deaths and injuries, damaged or destroyed houses and farmland, damaged or destroyed roads and bridges, power outages, and communication interruptions. In general, the stronger the storm is, the more severe the resulting disaster will be. In order to simplify the discussion and benefit the actual execution of professional works, this study focuses on some of the more stable and reliable disaster loss indicators and examines the relationship which exists between disaster-causing factors. This study focuses on the typhoons with the period during CWB

issued land and sea warnings that impacted Taiwan during the 40 years between 1965 and 2004. The key indicators are numbers of dead or missing persons, numbers of totally destroyed houses, and actual crop losses. These three indicators represent the main impacts on the economy, citizens' lives and properties, as well as shedding light on the total scale of disaster losses (Chen 2009; Huang 2005; CWB 1998; Lou et al. 2006). The chosen disaster-causing factors are the maximum daily rainfall in all weather stations throughout Taiwan, maximum central wind speeds of the typhoons, lowest central pressure, the radius of class seven winds, and the duration of time that the land is affected by the radius of class seven winds. This study calculates the correlation coefficients between the five meteorological disaster-causing factors and the three key indicators, respectively, and applies regression analysis between disaster loss indicators and disaster-causing factors. With exponential regression, this study builds a Taiwanese typhoon disaster loss assessment model.

### 3.2.2 Definition of typhoon's tracks

According to the definition of CWB, typhoon tracks that impact Taiwan can be categorized into ten types (Fig. 1). In order to better understand the relationships between rainfall and the maximum wind speed near the center of the duration time and the correlation between disaster losses and also for the purpose of further analysis and organization, this study regrouped the tracks defined by the CWB into five types. Based on the analyzed disaster history and the affected conditions, tracks 1 and 2 were regrouped as type A; track 3 as type B; and track 4 and 5 as type C. Track 6 and 8 have very similar influences to the study

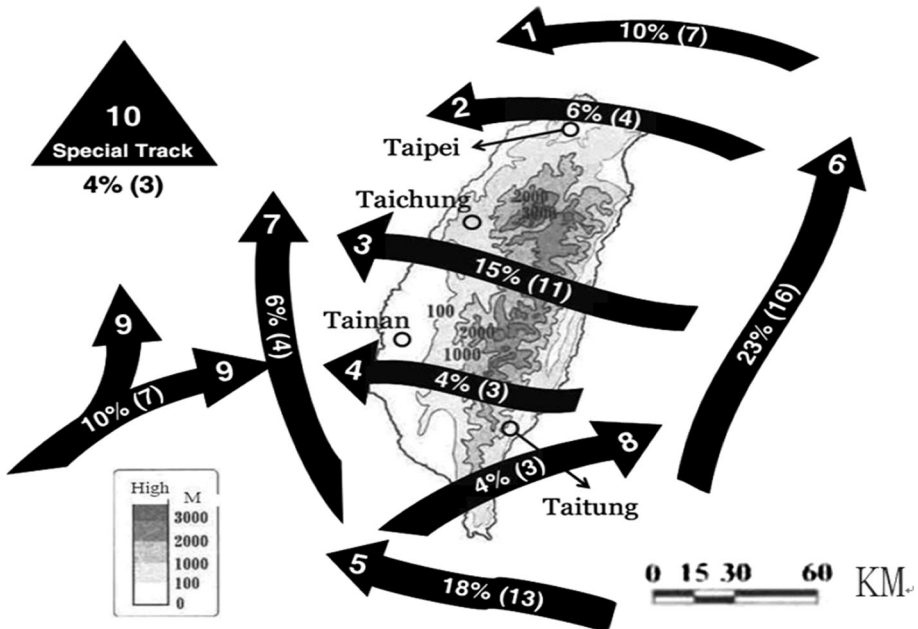


Fig. 1 Distribution of calamitous typhoons track affecting Taiwan from 1965 to 2004

area, so they were regrouped as type D in this study. Tracks 7 and 9 are regrouped as type E (Fig. 2). The five types of typhoons in this study are elaborated as follow:

- Type A The typhoon passes through Taiwan’s northern sea or northern territory and moves toward in the direction of west or northwest.
- Type B The typhoon moves toward west or northwest and passes through central Taiwan.
- Type C The typhoon passes through Taiwan’s southern sea or southern territory and moves toward in the direction of west or northwest.
- Type D The typhoon moves along east coast or eastern sea in the direction from south to north.
- Type E The typhoon moves along west coast or western sea in the direction from south to north.

3.2.3 Typhoon disaster loss assessment criteria for the classification

In order to simplify the comparison, the study classifies disaster losses into five levels.

- A: Indication of extremely accurate:  
 $\text{when } 1/2 \times (\text{actual disaster losses}) \leq \text{estimated losses caused by disasters} \leq 3/2 \times (\text{actual disaster losses})$

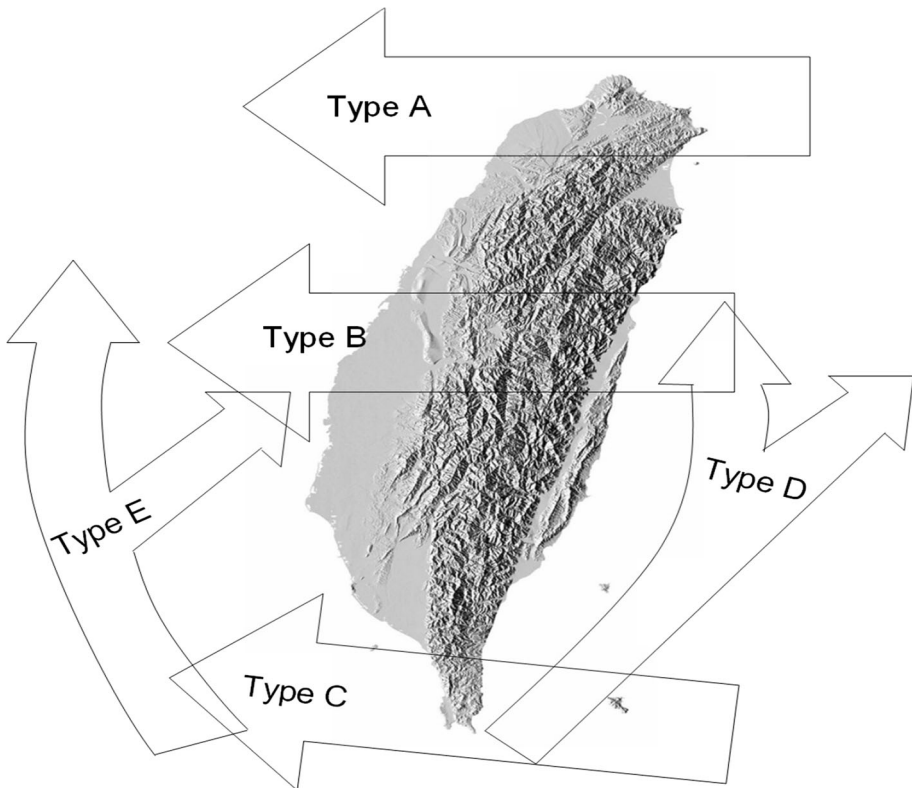


Fig. 2 Regrouped five types of tracks defined by the CWB



- B: Indication of very accurate:  
when  $1/3 \times (\text{actual disaster losses}) \leq \text{estimated losses caused by disasters} < 1/2 \times (\text{actual disaster losses})$  or when  $3/2 \times (\text{actual disaster losses}) < \text{estimated losses caused by disasters} \leq 2 \times (\text{actual disaster losses})$
- C: Indication of accurate:  
when  $1/4 \times (\text{actual disaster losses}) \leq \text{estimated losses caused by disasters} < 1/3 \times (\text{actual disaster losses})$  or when  $2 \times (\text{actual disaster losses}) < \text{estimated losses caused by disasters} \leq 3 \times (\text{actual disaster losses})$
- D: Indication of less accurate:  
when  $1/5 \times (\text{actual disaster losses}) \leq \text{estimated losses caused by disasters} < 1/4 \times (\text{actual disaster losses})$  or when  $3 \times (\text{actual disaster losses}) < \text{estimated losses caused by disasters} \leq 4 \times (\text{actual disaster losses})$
- E: Indication of not accurate:  
when the estimated losses caused by disasters outside the above range.

## 4 Results and discussion

### 4.1 Analysis of disaster losses and disaster-causing factors

This study focuses on 131 typhoon cases with completed records between 1965 and 2004, including 109 cases with dead or missing persons, 99 cases with crop losses, and 84 cases with totally destroyed houses. After analyzing the relevance of maximum daily rainfall, maximum central wind speeds, lowest central pressure, radius of class seven winds, and period during CWB issued land and sea warning in relation to disaster losses, the results (Table 1) show that the figures of dead or missing persons, destroyed houses, and crop losses are positively correlated with maximum daily rainfall, maximum central wind speeds, and radius of class seven winds, period during typhoon land and sea warning while being negatively correlated with lowest central pressure. Further analysis of the data reveals that the figures for dead or missing persons and crop losses show a higher positive correlation ( $r = 0.293\text{--}0.581$ ) with maximum daily rainfall, and the period during CWB issued land and sea warning. Moreover, the number of totally destroyed houses has a higher correlation with the lowest central pressure, and the period during CWB issued land and sea warning.

### 4.2 Assessment of typhoon-triggered disaster losses

Disaster losses from typhoons are a product of the interaction between disaster-causing factors, hazard-prone environments, and disaster-affected elements. Among these, the typhoon tracks play a key role in disaster conditions. Due to the limitations of the data regarding the assessment of typhoon disaster losses, this study focuses on 131 typhoon cases with complete records between 1965 and 2004. Furthermore, the typhoon tracks are categorized into five types A, B, C, D, and E. By conducting in exponential regression analysis, establishing disaster loss indicators based on typhoons which have affected Taiwan, the maximum central wind speeds, the lowest central pressure, the radius of class seven winds, and the period during CWB issued land and sea warning, ultimately, the study obtains the functions that are for the typhoon of Taiwan disaster assessment model. (Qian



**Table 1** Correlation coefficient of typhoon disaster and climatic factor

Category disaster losses	Correlation	Lowest central pressure	Maximum central wind speeds	Maximum daily rainfall	The radius of class seven winds	Period during CWB issued land and sea warning
The total amount of crop losses	Pearson correlation	-0.235 <sup>b</sup>	0.202 <sup>b</sup>	0.581 <sup>a</sup>	0.254 <sup>b</sup>	0.392 <sup>a</sup>
	Statistical significance (two tailed)	0.019	0.045	0.000	0.011	0.000
	Sample/number	99	99	99	99	99
Dead or missing population	Pearson correlation	-0.232 <sup>b</sup>	0.148	0.416 <sup>a</sup>	0.085	0.293 <sup>a</sup>
	Statistical significance (two tailed)	0.015	0.124	0.000	0.382	0.002
	Sample/number	109	109	109	109	109
Destroyed houses	Pearson correlation	-0.309 <sup>a</sup>	0.255 <sup>b</sup>	0.090	0.122	0.285 <sup>a</sup>
	Statistical significance (two tailed)	0.004	0.019	0.418	0.268	0.009
	Sample/number	84	84	84	84	84

<sup>a</sup> It is significantly related with the level of significance 0.01 (two tailed)

<sup>b</sup> It is significantly related with the level of significance 0.05 (two tailed)

et al. 2001; Liu et al. 2003; Wu and Wang 2004; Zhou et al. 2004; Lu et al. 2005; Meng et al. 2007; Shi et al. 2008; Huang 2010; Chen et al. 2012; Wei et al. 2012).

1. The model for crop losses assessment:

$$\text{Type A} = \text{EXP} (17.163572 + 0.004610 \times X_1)$$

$$\text{Type B} = \text{EXP} (20.468344 + 0.026008 \times X_2)$$

$$\text{Type C} = \text{EXP} (0.040556 \times X_1)$$

$$\text{Type D} = \text{EXP} (0.020601 \times X_3)$$

$$\text{Type E} = \text{EXP} (16.630067 + 0.019747 \times X_4)$$

2. The model for death or missing assessment:

$$\text{Type A} = \text{EXP} (0.054615 \times X_5)$$

$$\text{Type B} = \text{EXP} (0.002318 \times X_3)$$

$$\text{Type C} = \text{EXP} (0.038868 \times X_5)$$

$$\text{Type D} = \text{EXP} (0.004354 \times X_1)$$

$$\text{Type E} = \text{EXP} (0.011020 \times X_4)$$

3. Evaluation model for totally destroyed houses:

$$\text{Type A} = \text{EXP} (0.018025 \times X_4)$$

$$\text{Type B} = \text{EXP} (0.07081 \times X_2)$$

$$\text{Type C} = \text{EXP} (0.016007 \times X_4)$$

$$\text{Type D} = \text{EXP} (0.069183 \times X_5)$$

$$\text{Type E} = \text{EXP} (0.089778 \times X_5)$$

$X_1$  is the maximum daily rainfall in each weather station during the typhoon-affected period;  $X_2$  is the period during CWB issued land and sea warning;  $X_3$  is the lowest central pressure;  $X_4$  is the radius of class seven winds;  $X_5$  is the maximum central wind speeds.

### 4.3 Empirical study

This study selects cases of typhoons which invaded Taiwan between 2005 and 2013 and resulted in dead or missing persons or totally destroyed houses or crop losses. Upon application of the assessment models, the calculation of the predicted disaster losses to compare with the actual disaster losses, the research discovers:

(1) The model for crop losses assessment:

Between 2005 and 2013, the typhoons which caused crop losses have namely 20. Upon application of crop losses assessment model, the results indicates that extremely accurate is 10, accurate and less accurate are 2, respectively, and not accurate is 6.

**Table 2** Amount of the predicted and the actual crop losses

Years	Typhoon name	Typhoon tracks	Amount of crop losses Actual amount/predicated amount	Disaster prediction grading	Error
2005	Haitang	Type B	7,549,393,318/5,041,250,483	A	0.33
2005	Longwang	Type B	1,809,810,697/2,700,568,113	A	0.49
2005	Talim	Type B	3,239,936,715/2,700,568,113	A	0.17
2006	Bilis	Type A	337,276,902/190,946,148	A	0.43
2006	Chanchu	Type E	226,311,551/3,381,117,118	E	13.94
2006	Kaemi	Type B	256,166,378/2,771,725,812	E	9.82
2007	Sepat	Type B	2,605,988,529/3,689,748,000	A	0.42
2007	Krosa	Type A	8,176,676,237/2,704,686,916	D	0.67
2008	Kalmaegi	Type A	1,498,951,285/467,001,020	D	0.69
2008	Fung-Wong	Type B	2,250,967,024/3,156,646,289	A	0.40
2008	Sinlaku	Type A	1,930,431,146/1,090,696,151	A	0.43
2008	Jangmi	Type A	6,596,021,668/786,239,491	E	0.88
2009	Morakot	Type B	10,635,139,605/4,312,881,159	C	0.59
2010	Fanapi	Type E	768,680,805/865,715,595	A	0.13
2011	Nanmadol	Type C	194,860,801/168,029,816	A	0.14
2012	Saola	Type A	10,856,552,056/448,021,598	E	0.96
2012	Talim	Type E	1,877,477,029/322,565,573	E	0.83
2013	Trami	Type A	2,628,287,000/408,561,087	E	0.84
2013	Usagi	Type A	300,713,000/142,159,752	C	0.53
2013	Soulik	Type B	3,489,936,000/2,844,758,457	A	0.18

**Table 3** Amount of the predicted and the actual dead or missing people

Years	Typhoon name	Typhoon tracks	Dead or missing people Actual amount/predicated amount	Disaster prediction grading	Error
2005	Haitang	Type B	15/8	A	0.47
2005	Talim	Type B	6/8	A	0.33
2006	Bilis	Type A	3/4	A	0.33
2007	Krosa	Type A	11/16	A	0.45
2008	Kalmaegi	Type A	26/6	E	0.77
2008	Sinlaku	Type A	22/16	A	0.27
2008	Jangmi	Type A	4/18	E	3.50
2009	Morakot	Type B	703/9	E	0.99
2010	Megi	Type E	38/16	C	0.58
2012	Saola	Type A	7/8	A	0.14
2013	Soulik	Type B	3/9	C	2.00

The estimations of total amount of crop losses and actual amount of losses are <50 % error which counted 10. The accuracy reaches 50 %. Among them, type B and type C have 8 and 1 typhoons, respectively, caused crop losses. The assessment model indicates 6 and 1 typhoons, respectively, which predicted amount of losses and the actual amount of losses error is within 50 %. The accuracy rate reaches above 75 % (Table 2).

(2) The model for dead or missing assessment:

During 2005–2013, typhoons caused dead or missing which is counted for 11. Upon application of the dead or missing assessment model, extremely accurate is 6, accurate is 2, and not accurate is 3.

Predicted number of people dead or missing and the actual number of dead or missing error is <50 % which have 6. It reaches the accuracy rate of 55 %. Among which type A has 4 typhoons cause death or missing. With the assessment of the model, there are 4 typhoons which the predicted number of dead or missing and the actual number of dead or missing error is within 50 %. The accuracy rate attains the best of 67 % (Table 3).

(3) Evaluation model for totally destroyed houses:

During 2005–2013, typhoons had caused 7 totally destroyed houses. Upon the application assessment model, the results of totally destroyed houses are: extremely accurate is 3; very accurate is 1; and not accurate is 3.

The number of predicted totally destroyed houses and the number of actual destroyed houses error is within 50 % which have 3. The accuracy rate is up to 43 %. Among which type A and type E have 3 and 1 typhoons, respectively, that cause totally destroyed houses. The result of the model assessment: There are 2 and 1 typhoons, respectively, that caused the predicted number of totally destroyed houses, and the actual number of totally destroyed houses error is within 50 %. The accuracy is above 67 % (Table 4).

**Table 4** Amount of the predicted and the actual destroyed houses

Years	Typhoon name	Typhoon tracks	Amount of destroyed houses Actual amount/predicated amount	Disaster prediction grading	Error
2006	Kaemi	Type B	2/32	E	15.00
2007	Krosa	Type A	4/186	E	45.50
2008	Kalmaegi	Type A	8/7	A	0.14
2008	Sinlaku	Type A	66/84	A	0.27
2009	Morakot	Type B	722/107	E	0.85
2010	Megi	Type E	96/74	A	0.23
2011	Nanmadol	Type C	11/18	B	0.64

## 5 Conclusion

The assessment models produced by this study recorded a decent performance. In actuality, if the actual or predicted value of maximum daily rainfall, maximum central wind speeds, lowest central pressure, radius of class seven winds, and period during CWB issued land and sea warning during the typhoon-affected period is provided, it is possible to calculate the actual or predicted value of the disaster loss indicators. According to the disaster loss indicators, it is also possible to estimate the numbers of dead or missing persons, the actual value of crop losses, and the number of totally destroyed houses by calculating the inverse functions. This may serve to equip the government or related organizations with quantified and scientific tools for assessing and evaluating natural disasters.

In the past 50 years, there have been significant changes in the numbers and structures of populations and residences in Taiwan. The population rose from 11.15 million in 1961 to 23.16 million in 2010, and the residential area rose from 148,837 to 705,542 (ha.) between 1987 and 2010. This increase in population and housing numbers has resulted in more physical exposure to typhoons. However, thanks to the improvements in the economy, enhancement of architectural structures and the “precautionary evacuation” policies implemented by the relevant government departments, the actual numbers for injuries, deaths, and destroyed houses have stabilized or even declined (in comparison with previous typhoons with similar wind speeds and rainfall).

Additionally, there was an increase in the number of floodgates installed from 690 in 1997–1492 in 2010, while the length of levees also rose from 1314 (km) in 1981–2861 (km) in 2010. Due to these improvements in hydro constructions, it takes less time to evacuate floods from the flooded zone, which also lowers the toll inflicted by disasters (with the rainfall being equal). Due to these factors, different values for disaster losses may result for earlier years compared to more recent years even though the input figures are similar. This fact may significantly affect the assessment of disaster loss resulting from typhoons. The degree of disaster loss for typhoons is a product of the interaction among disaster-causing factors, hazard-prone environments, and disaster-affected elements. Although disaster-causing factors do play a crucial role in the eventuation of disasters, this study does not take into account the contributions of hazard-prone environments and disaster-affected elements. Consequently, the building of a quantified assessment of disaster losses is therefore compromised. Moreover, it is also necessary to develop a deeper understanding of the factors that were taken into consideration. For example, when

assessing rainfall, not only should the total rainfall amounts of weather stations be considered, but also the level of rainfall intensity, while analysis of maximum central wind speed should be expanded to include time duration. In order to build a more accurate, scientific model for disaster loss assessment, further research in the future should take these factors into consideration.

The systematic classification of typhoon types as proposed has revealed characteristic rainfall patterns that can be used for more effective disaster management. Effective hazard management, for which the presented model contributes to, increases mitigation/response capacity to influence whether and to what extent interaction between natural process and people before they turn to disasters. Disaster formation is unquestionably a dynamic process, with its uncertainty and complexity. If it can be applied alongside the relevant tested data in the future, the presented model will be more satisfying to both practical and theoretical demands.

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