Nat Hazards (2012) 64:511–529
DOI 10.1007/s11069-012-0254-x

ORIGINAL PAPER

Fine assessment of tropical cyclone disasters based on GIS and SVM in Zhejiang Province, China

Weiping Lou · Haiyan Chen · Xiaoling Shen · Ke Sun · Shengrong Deng

Received: 22 March 2012 / Accepted: 8 June 2012 / Published online: 24 June 2012

Abstract Tropical cyclones represent major natural disasters in low- and mid-latitude coastal areas. Effective assessment of tropical cyclone disasters provides a scientific reference for the formulation of tropical cyclone prevention and disaster-relief measures. Tropical cyclone disasters in Zhejiang Province are mainly studied based on GIS technology, by considering disaster-causing factors, disaster-affected bodies, the disaster-formative environment, and spatial distribution of disaster prevention and relief capacity. In light of an uncertain nonlinear relationship between assessment factors and disaster factors, we used support vector machines to establish a fine, quantitative assessment model. This model evaluates the following disaster indices: Disaster-affected population, direct economic loss, affected crop area, and number of damaged houses resulting from a tropical cyclone disaster in Zhejiang, with the county as basic assessment unit. Assessment of tropical cyclone No. 0908 shows that the developed assessment model is able to accurately evaluate the geographical distribution of losses caused by a tropical cyclone.

Keywords Tropical cyclone · Disaster · Assessment · GIS · Support vector machine · County

1 Introduction

Tropical cyclones represent one of the major meteorological disasters affecting China, and they impair sustainable social and economic development (Wang et al. 2008). Tropical cyclone Saomai (No. 0608) affected 5.92 million people, and 373 people died or went

---

W. Lou (✉) · K. Sun · S. Deng
Xinchang Weather Bureau, Xinchang County 312500, Zhejiang Province, China
e-mail: xclwp@163.com

H. Chen
Zhejiang Weather Station, Hangzhou, China

X. Shen
ShaoXing Weather Bureau, Shaoxing, China

missing in the disaster. The direct economic loss exceeded 20 billion RMB. The Earth is now experiencing a peak of strong cyclone activity. Global warming intensifies strong typhoons (hurricanes), increasing losses related to tropical cyclones (Knutson et al. 2010; Mann et al. 2009; Webster et al. 2005). Therefore, accurate prediction of tropical cyclone disasters, which provides scientific references for the government in formulating and implementing disaster prevention and relief for minimizing disaster-associated loss, is of great social and practical significance (Liu et al. 2009).

The current assessment model of tropical cyclone–associated loss can be divided into three categories. The first is a comprehensive assessment model of hurricane-associated loss, which is constructed by establishing the mechanism model to reveal interactions between disaster-affected bodies and disaster-causing factors. This is based on a disaster-affected body database (Vickery et al. 2006; Watson and Johnson 2004). The second category is an assessment model of the magnitude of tropical cyclone-associated loss, using historical characteristic parameters of tropical cyclones, meteorological data, and disaster-associated loss data. To build this model, the relationship between the intensity of disaster-causing factors and loss rate of disaster-affected bodies must be first established using mathematical means (Lou et al. 2011; Ma et al. 2008; Li et al. 2006; Ye et al. 2004; Imamura and Van To 1997). The third category is to grade tropical cyclone disasters by converting actual values of the loss of disaster-affected bodies using a comprehensive assessment method. By doing this, tropical cyclone disasters can be assessed (Wang et al. 2010; Wu et al. 2009). All these assessment models and methods consider disaster-causing factors and disaster-affected bodies, but not the disaster-formative environment and disaster prevention and relief capacity. Given rapid development of the social economy, the disaster-affected body, as one of the impact factors, may vary significantly. Discrepancies in disaster prevention and relief capacity across regions often result in considerable error in the assessment model during actual application. Furthermore, all these assessment models take the province as the basic assessment unit. Assessing economic loss associated with tropical cyclone disasters, or the grade of such disasters by integration of characterizing factors of the disaster situation, cannot reflect disaster-associated loss or its geographic distribution.

This study is built on previous research and focuses on tropical cyclones in Zhejiang Province, using GIS technology and support vector machines (SVM). By comprehensively considering spatial differences of disaster-causing factors, disaster-affected bodies, disaster-formative environment, and disaster prevention and relief capacity, we build a quantitative assessment model to assess indices of the disaster situation, with the county as the basic assessment unit. The indices include disaster-affected population, direct economic loss, affected crop area, and number of damaged houses. This model reflects the geographic distribution of assessment values of various types of loss associated with a tropical cyclone and provides a scientific basis for emergency assessment during cyclone disasters and post-disaster assessment.

2 Research area

Zhejiang Province is on China’s southeast coast, from E 118°01′–123°10′ and N 27°06′–31°03′, with a terrestrial area of 10.18×10^4 km^2. Hangjiahu Plain in the north is part of the Yangtze River Delta plain. Western and southern regions are part of the hilly areas of southeast China, with complex landforms. The eastern region faces the East China Sea, whose area is 260,000 km^2 and total coastline length is 6,486 km, the greatest in China.

Table 1 Tropical cyclone–caused severe disasters in Zhejiang Province

Tropical cyclone	Disaster			
	Death toll (person)	Damaged house (thousand houses)	Affected crop area (thousand ha)	Direct economic loss/GDP(%)
No. 5207	457	265.7	22.9	2.0
No. 5612	4925	715.0	400.0	4.5
No. 6214	224	685.3	40.6	10.4
No. 6312	186	410.5	51.8	7.3
No. 7413	136	215.9	22.6	3.1
No. 7504	179	138.0	29.0	2.1
No. 8807	162	218.0	66.9	1.5
No. 8923	184	317.3	15.0	1.6
No. 9417	1126	502.0	208.3	6.7
No. 9711	236	747.3	177.0	4.0
No. 0414	188	391.9	64.3	1.6
No. 0608	203	103.2	38.5	0.8

Tropical cyclones constitute the leading natural disaster for Zhejiang Province. During the 60 years from 1949 to 2008, 40 tropical cyclones made landfall in the province, averaging 0.67 per year; 322 tropical cyclones affected the province, averaging 5.37 per year. July through September is tropical cyclone season, during which 37 tropical cyclones made landfall in the province. These tropical cyclones caused numerous deaths and direct economic loss in the province (Chen et al. 2011) (Table 1). Owing to global warming, the frequency of strong typhoons has been increasing (Knutson et al. 2010). Landfall locations have tended to move northward, to the coastal area of middle China. Western Pacific tropical cyclones at their peak time also tended to move northward (Cao et al. 2006). Strong typhoon landfalls in Zhejiang are also increasing in frequency. Of seven super-strong typhoons landfalling in the province since 1949, four occurred after 2000. Because of the rapid increase of the provincial economy and growing population density, the loss in relation to tropical cyclones is also increasing.

According to the landforms and social economy of various counties of the province and to historical tropical cyclone disasters, the area affected by tropical cyclones can be divided into northern, southern, western, and coastal regions (Fig. 1) (Zhou et al. 2012). The northern region is mainly plains, namely Hangjiahu Plain and Ningshao Plain, with dense population and a developed economy. The cultivated area accounts for about 25 % of the total area. Since most of the cultivated area is low lying, it is likely affected by waterlogging. Coastal islands are composed of hills and plains. Wenhuang Plain is the lowest lying and covers the largest area. Its cultivated area makes up about 17 % of the total. The coastal islands are usually impacted by meteorological disasters, such as tropical cyclones and rainstorms, and have stronger disaster-bearing capacities. Southern and western regions have numerous mountains, hills, and basins. Mountains are low in the southern region and in most of the western region, except Jinqu Basin. The cultivated area in both southern and western regions makes up about 12 % of the total area. The regional economy is relatively underdeveloped; flooding and landslides and other geological disasters often occur in these regions.

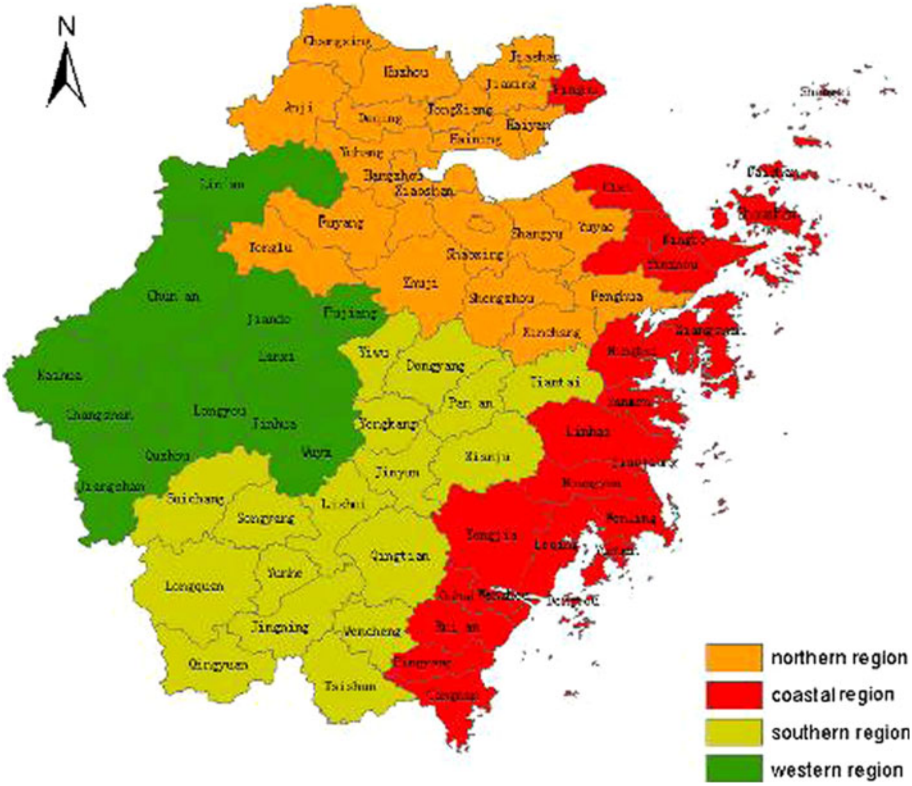


Fig. 1 Overview of study area

3 Data source and method

3.1 Data source

Data on 11 tropical cyclones affecting Zhejiang Province from 2005 to 2011 were provided by flood control and drought relief headquarters of each county in the province. Meteorological data and 1:50,000 DEM data were furnished by the network center of Zhejiang Meteorological Bureau. The total area of each county (unit: square kilometer), total population (unit: ten thousand), cultivated area (hectare), and GDP data from 2010 are given in the Zhejiang Statistical Yearbook.

3.2 Data processing

A disaster situation is determined by the interactions between disaster-causing factors, the disaster-formative environment, disaster-affected bodies, disaster prevention and relief capacity (Shi 1996). These are treated as assessment factors in this paper. Indices of a tropical cyclone situation include disaster-affected population, affected crop area, crop failure area, number of collapsed houses, number of damaged houses, direct economic loss, direct agricultural economic loss, damaged highway length and others.

3.2.1 Tropical cyclone disaster indices

Assessment indices need complete data. Therefore, we used disaster-affected population, affected crop area, number of damaged houses, and direct economic loss as indices. To exclude the impact on disaster situation indices of varying population and economic development in different counties, relative economic loss of each county, obtained by dividing direct economic loss by county GDP, was used as the assessment value. Tropical cyclone disasters mainly damage houses in rural areas (Fang et al. 2011). The cultivated area of a county represents its rural population. That is to say, cultivated area indirectly reflects the number of houses in a rural area. The relative number of damaged houses, obtained by dividing the number of damaged houses by cultivated area in the county, was used as the assessment value. Relative affected crop area, obtained by dividing actual affected crop area by cultivated area in each county, is used as the assessment value.

3.2.2 Disaster-causing factors

Disaster-causing factors of tropical cyclones include those related to strong wind, rainstorms, and typhoon storm surge. These factors are directly caused by the tropical cyclone itself, whose intensity and scope are the prerequisites and driving forces of tropical cyclone disasters (Lü and Yao 2006). Typhoon storm surge intensity, maximum wind velocity, extreme wind velocity, typhoon rainfall, 1, 3, 6, 12-h and daily maximum rainfalls are included as disaster-causing factors.

Typhoon storm surge intensity in island counties is divided into six grades according to Table 2 (Ji et al. 2007). The highest grade of typhoon storm surge in each county is converted to a relative intensity grade by the following formula:

$$x_1 = 1 - (6 - H)/6 \tag{1}$$

where x_1 is the relative intensity grade of typhoon surge and H is the intensity grade of the surge.

We selected wind velocities of 8.0 m/s (wind force 5), 10.8 m/s (wind force 6), 13.9 m/s (wind force 7), and 17.2 m/s (wind force 8), and rainfalls of 30, 50, and 100 mm as grading criteria. Through comparison with the disaster situation across counties, we found that no disaster situation occurred when the following criteria were met: maximum wind velocity $\leq$10.8 m/s, extreme wind velocity $\leq$13.9 m/s, tropical cyclone rainfall $\leq$50.0 mm, 1-h maximum rainfall $\leq$30.0 mm, 3-h maximum rainfall $\leq$30.0 mm, 6-h maximum rainfall $\leq$30.0 mm, 12-h maximum rainfall $\leq$30.0 mm, and daily maximum rainfall $\leq$50.0 mm. Then, tropical cyclone wind velocities and rainfalls in each county were processed with the following formulas to obtain the relative values:

Table 2 Intensity grade of typhoon surge

Grade	Intensity	Surge (cm)
0	Mild typhoon storm surge	30–50
1	Small typhoon storm surge	51–100
2	Medium typhoon storm surge	101–150
3	Large typhoon storm surge	151–200
4	Great typhoon storm surge	201–300
5	Super typhoon storm surge	300–450
6	Rarely occurring typhoon storm surge	≥451

$$\text{Relative maximum wind velocity} \quad x_2 = (v_1 - 10.8)/10.8 \tag{2}$$

$$\text{Relative extreme wind velocity} \quad x_3 = (v_2 - 13.9)/13.9 \tag{3}$$

$$\text{Relative typhoon rainfall} \quad x_4 = (RR_1 - 50)/50 \tag{4}$$

$$\text{Relative 1-h maximum rainfall} \quad x_5 = (RR_2 - 30)/30 \tag{5}$$

$$\text{Relative 3-h maximum rainfall} \quad x_6 = (RR_3 - 30)/30 \tag{6}$$

$$\text{Relative 6-h maximum rainfall} \quad x_7 = (RR_4 - 30)/30 \tag{7}$$

$$\text{Relative 12-h maximum rainfall} \quad x_8 = (RR_5 - 30)/30 \tag{8}$$

$$\text{Relative daily maximum rainfall} \quad x_9 = (RR_6 - 50)/50 \tag{9}$$

In formulas (2)–(9), v_1 is maximum wind velocity; v_2 is extreme wind velocity; RR_1 is tropical cyclone rainfall; RR_2 is 1-h maximum rainfall; RR_3 is 3-h maximum rainfall; RR_4 is 6-h maximum rainfall; RR_5 is 12-h maximum rainfall; RR_6 is daily maximum rainfall. If the values of $x_2 - x_9 < 0$, then they are taken to be zero.

3.2.3 Disaster-formative environment

The disaster-formative environment refers to the geographic environment and geological conditions likely to form disasters. We define the disaster-formative environment as that natural environment likely to form flood and drought disasters, debris flow, and landslides under the influence of disaster-causing factors of the cyclone. Factors of the disaster-formative environment include elevation, degree of topographic fluctuation, density of river networks, geological conditions, and others.

Regions at high elevation are less likely to have extensive water accumulation, whereas those at low elevation are more easily affected by waterlogging. We divide Zhejiang Province into 10 elevation ranges. The total number of grid points and number of grid points for each elevation are read from a 100 m × 100 m topographic raster on a digital elevation model (DEM) map. The factors of elevation are thus obtained for the county.

$$H_j = \sum_{i=1}^{10} H_{ji}/H_{js} \times w_{hi}, \tag{10}$$

where H_j is the factor of elevation in the jth county; H_{js} is the total number of grid points in the jth county; H_{ji} is the number of grid points for the ith elevation in the jth county; w_{hi} is the weight of the ith elevation (Zhou et al. 2012).

Susceptibility to waterlogging is related not only to elevation but also topographic fluctuation. If the terrain fluctuates greatly, surface runoff will converge on ditches, where it is discharged. Therefore, extensive waterlogging is unlikely. However, if topographic fluctuation is relatively small, there will be extensive water accumulation and waterlogging once runoff exceeds local discharge capacity.

We first calculated the standard deviation of 25 neighboring grids on a 100 m × 100 m topographic raster grid to obtain topography standard deviation, which is then divided into 10 grades. The total number of grid points in each county and the number of grid points for each topography standard deviation grade were read from the 100 m × 100 m topographic raster on the DEM map. Thus, the degree of topographic fluctuation is attained for each county:

$$T_j = \sum_{i=1}^{10} T_{ji}/T_{js} \times w_{ti}, \quad (11)$$

where T_j is the degree of topographic fluctuation in the jth county; T_{js} is the total number of grid points in the jth county; T_{ji} is the number of grid points for the ith grade of topography standard deviation in the jth county; w_{ti} is the weight of the ith grade (Zhou et al. 2012).

When frequent and torrential typhoon rainfall exceeds the flood discharge and drainage capacity of river reservoirs, rainwater will spread to and inundate surrounding areas, causing waterlogging. The density of river networks is defined as the total length of river per unit drainage area. It is divided into 10 grades in Zhejiang. The total number of grid points and number of grid points for each grade of river network density were read from the 100 m × 100 m topographic raster on the DEM map for each county. We thereby obtained the factor of river network density for each county:

$$R_j = \sum_{i=1}^{10} R_{ji}/R_{js} \times w_{ri}, \quad (12)$$

where R_j is the factor of river network density in the jth county; R_{js} is the total number of grid points in the jth county; R_{ji} is the number of grid points for the ith grade of river network density in the jth county; w_{ri} is the weight of the ith grade (Zhou et al. 2012).

Tropical cyclone precipitation often causes mountain floods, landslides, and debris flow. These secondary disasters are related to persistence and intensity of disaster-causing factors, such as tropical cyclone precipitation, and to local geological conditions. An area can be easily prone, low-prone, medium-prone, and high-prone to disaster (four grades of disaster proneness). The number of grid points for each grade and total number of grid points were read from the 100 m × 100 m topographic raster on a distribution map of disaster proneness grade (Zhou et al. 2012). Thus, we acquired the factor of proneness of each county to disaster.

$$GD_j = \sum_{i=1}^{10} GD_{ji}/GD_{js} \times w_{gdi}, \quad (13)$$

where GD_j is the factor of proneness of the jth county to geological disaster; GD_{js} is the total number of grid points in the jth county; GD_{ji} is the number of grid points for the ith grade of disaster proneness in the jth county; w_{gdi} is the weight of the ith grade (Zhou et al. 2012).

In actual tropical cyclones, the four factors are not independent; instead, they interact to produce a joint impact. Therefore, we constructed a comprehensive disaster-formative environment coefficient, based on the four factors:

$$I_{zyj} = w_1 \times H_j + w_2 \times T_j + w_3 \times R_j + w_4 \times GD_j, \quad (14)$$

where I_{zyj} is the comprehensive factor of disaster-formative environment of the jth county; w_i is the weight of the corresponding factor in a linear combination determined by an analytic hierarchy process, after expert consultation (Zhou et al. 2012). Results are shown in Table 3.

Table 3 Weights of factors of disaster-formative environment

Factor	Elevation	Degree of topographic fluctuation	Density of river networks	Proneness to geological disasters
w_i	0.0781	0.1998	0.1998	0.5222

Since factors have completely different dimensions, they are standardized before linear combination. Then the standardized factors are introduced into the above formula to calculate the comprehensive disaster-formative environment coefficient of each county.

3.2.4 *Disaster-affected body*

Economic development level, agricultural density, and population density represent the degree of vulnerability of disaster-affected body to a disaster of a certain region and magnitude.

Since GDP per unit area varies, the absolute loss also varies significantly with a tropical cyclone of equal intensity. Concentration of wealth and economy increases the risk of tropical cyclone disaster. The GDP per unit area is used here to represent the economic development level of a county.

Land is the foundation of agricultural development. The percentage of cultivated area to total land area was used to represent cultural density.

The number of people affected by tropical cyclone disaster is directly related to population. Therefore, population per unit area, that is, population density, was used to characterize population magnitude.

Population density, GDP per unit area, and weight of cultivated area are selected as assessment indices of degree of vulnerability of a disaster-affected body. The normalized factors are then used to establish the vulnerability assessment model using a linear weighting method. The formula is shown below:

$$V_j = \sum_{i=1}^{3} w_{vi} \cdot D_{ij}, \tag{15}$$

where V_j is the vulnerability of disaster-affected body in the jth county; w_{vi} is the weight of the ith index; D_{ij} is the normalized value of the ith factor. Through expert consultation, we used the analytic hierarchy method to determine the weight of each index (Zhou et al. 2012). Results are shown in Table 4.

3.2.5 *Disaster prevention and relief capacity*

Differences in disaster prevention and relief capacity of each county in the province mainly arise from discrepancies of economic development. Therefore, we used fiscal revenue, per capita income of peasants, and cultivated area with yields affected by either drought or flood, which represent economic development of the county, to analyze differences of anti-disaster capacity.

A higher economic development level indicates greater fiscal income per unit area of the county. Hence, there will be more funds per unit area for the investment in construction of infrastructure and disaster prevention and relief facilities, which increase disaster resistance.

Rural areas are more susceptible to tropical cyclone disaster. The lower the per capita income of peasants, the more impoverished they are, and the poorer the disaster defense facilities and self-relief capacity will be.

Table 4 Weights of assessment indices of vulnerability of disaster-affected body in Zhejiang Province

Assessment index	Population density	GDP per unit area	Percentage of cultivated area
w_v	0.0852	0.6442	0.2706

Table 5 Weights of assessment indices of disaster prevention and relief capacity in Zhejiang

Assessment index	Annual fiscal revenue per unit area	Per capita income of peasant	Cultivated area with yield unaffected by either drought or flood
w_p	0.297	0.5396	0.1634

Cultivated area with yields unaffected by either drought or flood protects crops from flood disaster. The percentage of such land represents the anti-disaster capacity of agriculture.

Three factors, namely annual fiscal revenue per unit area, per capita income of peasants, and cultivated area with yields unaffected by either drought or flood, were normalized prior to the linear weighting method. Thus, we established the model for assessment of disaster prevention and relief capacity. The formula used is

$$P_j = \sum_{i=1}^{n} w_{pi} \cdot DP_{ij}, \tag{16}$$

where P_j is the potential vulnerability of disaster-affected body in the jth county; w_{pi} is the weight of the ith index; DP_{ij} is the normalized value of the ith index in the jth county. Through expert consultation, we determined the weight of each index by the analytic hierarchy process (Zhou et al. 2012). Results are shown in Table 5.

3.2.6 *Potential vulnerability of disaster-affected body*

Vulnerability of the disaster-affected body represents possible loss associated with the disaster, without considering disaster prevention and relief capacity. Disaster prevention and relief capacity represents the probability of loss reduction, and combination of the two reflects possible loss of the disaster-affected body in the face of disaster.

Therefore, potential vulnerability of the disaster-affected body $= f$ (vulnerability of disaster-affected body, disaster prevention and relief capacity).

Through expert consultation, the empirical formula is established:

$$BP_j = V_j \times \left(0.3 + (1 - 0.3) \times \left(1 - P_j\right)\right) \tag{17}$$

where BP_j is potential vulnerability of the disaster-affected body in the jth county.

3.3 Assessment method based on SVM

In light of the highly nonlinear relationship between disaster-causing factors of tropical cyclone disaster and the disaster situation, we used SVM to assess tropical cyclone disaster in each county of Zhejiang Province. SVM is a nonlinear system, which requires neither explicit understanding of the mechanism nor the building of a complex mathematical model; it also has a strong nonlinear mapping ability (Pozdnoukhov et al. 2011).

We used a Data Processing System software–based SVM module to assess tropical cyclone disaster by division (Tang 2010). ε-SVM regression in a radial basis function (RBF) kernel function was used; gamma was determined by a trial-and-error method.

4 Result

4.1 Model and calibration

The factors selected in the first round are shown in Table 6.

Correlation analysis was done between the selected factors in Table 6 and four characterization factors of the disaster situation in each division. Therefore, assessment factors of each characterizing factor of disaster situation in the division area were obtained (Table 7).

We used four characterization factors of disaster situation as output values, namely, relative disaster-affected population, relative economic loss, relative affected crop area, and relative number of damaged houses. Corresponding assessment factors were used as

Table 6 Factors chosen in first round of selection

Factor	Description	Factor	Description
x_1	Typhoon storm surge	x_{13}	Proneness to geological disaster
x_2	Relative maximum wind velocity	x_{14}	Comprehensive factor of disaster-formative environment
x_3	Relative extreme wind velocity	x_{15}	GDP per unit area
x_4	Relative tropical cyclone rainfall	x_{16}	Percentage of cultivated area
x_5	Relative 1-h maximum rainfall	x_{17}	Population density
x_6	Relative 3-h maximum rainfall	x_{18}	Vulnerability of disaster-affected body
x_7	Relative 6-h maximum rainfall	x_{19}	Annual fiscal revenue per unit area
x_8	Relative 12-h maximum rainfall	x_{20}	Cultivated area with yield unaffected by either drought or flood
x_9	Relative daily maximum rainfall	x_{21}	Per capita income of peasant
x_{10}	Elevation	x_{22}	Disaster prevention and relief capacity
x_{11}	Degree of topographic fluctuation	x_{23}	Potential vulnerability of disaster-affected body
x_{12}	Density of river networks		

Table 7 Assessment factors of characterization factors of disaster situation in each division

Division	Northern region	Coastal islands	Southern region	Western region
Relative disaster-affected population	x_2, x_3, x_4, x_8, x_{15}, x_{17}, x_{18}, x_{19}	x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{12}, x_{14}	x_2, x_3, x_4, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{12}, x_{15}, x_{16}, x_{18}, x_{23}	x_2, x_3, x_4, x_9, x_{10}, x_{17}, x_{20}
Relative economic loss	x_4, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{12}, x_{14}, x_{16}	x_1, x_2, x_3, x_5, x_6, x_7, x_8, x_9, x_{21}, x_{22}	x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{15}, x_{16}, x_{18}, x_{20}, x_{23}	x_2, x_4, x_7, x_8, x_9, x_{10}, x_{11}, x_{12}, x_{13}, x_{15}, x_{16}, x_{17}, x_{18}, x_{19}, x_{20}, x_{23}
Relative affected crop area	x_2, x_3, x_7, x_8, x_9	x_2, x_3, x_4, x_7, x_8, x_9, x_{12}, x_{14}, x_{16}	x_2, x_3, x_4, x_6, x_7, x_8, x_9, x_{10}, x_{15}, x_{18}, x_{19}, x_{20}, x_{21}, x_{22}, x_{23}	x_2, x_3, x_4, x_7, x_8, x_9, x_{10}, x_{11}, x_{12}, x_{13}, x_{16}, x_{17}, x_{18}, x_{23}
Relative number of damaged houses	x_2, x_3, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{14}, x_{16}, x_{20}, x_{21}, x_{22}	x_2, x_3, x_7, x_9, x_{10}, x_{12}, x_{13}, x_{14}, x_{16}, x_{17}	x_2, x_3, x_7, x_8, x_9, x_{10}, x_{23}	x_2, x_3, x_4, x_7, x_8, x_9, x_{10}, x_{11}, x_{12}, x_{13}, x_{16}, x_{17}, x_{18}, x_{21}, x_{23}

input values. Data on tropical cyclones No. 0509, No. 0513, No. 0519, No. 0601, No. 0608, No. 0709, No. 0716, No. 0807, and No. 0813 were used as training values; those on No. 0813 were used as fitted values. ε-SVM regression in the RBF kernel function was performed; gamma was determined by the trial-and-error method. The assessment model is thereby constructed.

4.2 Validation and application

Since 2009, tropical cyclone Morakot (No. 0908) was the only one that caused heavy disaster loss in Zhejiang Province. It was generated in the northwest Pacific at 20:00 local time on August 4th, 2009, and intensified to typhoon strength at 14:00 on August 5th. Morakot made landfall in Xiapu County of Fujian Province, with central pressure 970 hPa. Maximum wind velocity near its center was 33 m/s (wind force 12). The tropical cyclone weakened and became a strong tropical storm at 18:00, and it entered the area of Wenzhou at 06:00 on the 10th. It passed through Lishui, Jinhua, Shaoxing, Hangzhou, Jiaxing, and Huzhou and later entered the area of Jiangsu at 01:50 on the 11th.

Under the onslaught of Morakot, there was strong wind with force exceeding level 8 at Wenzhou, Taizhou, Ningbo, and Zhoushan (coastal areas), as well as Hangzhou, Jinhua, and Quzhou (inland areas). About 33,000, 8,000, and 2,000 km^2 areas experienced wind with force exceeding levels 8, 10, and 12, respectively (Fig. 2).

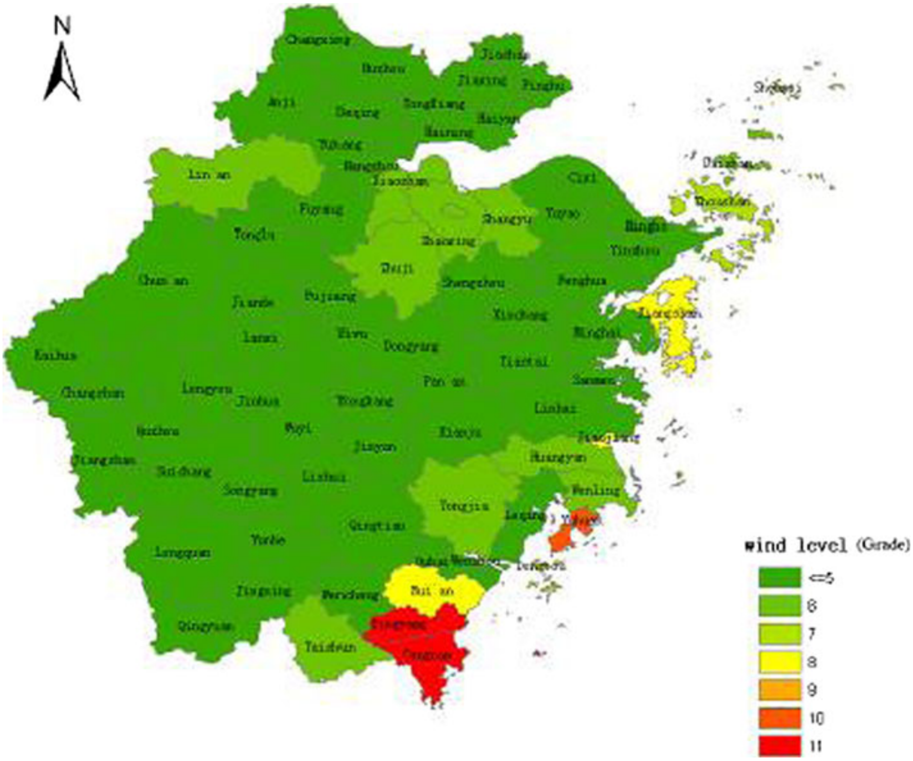


Fig. 2 Wind force map for tropical cyclone Morakot from August 6th to 10th

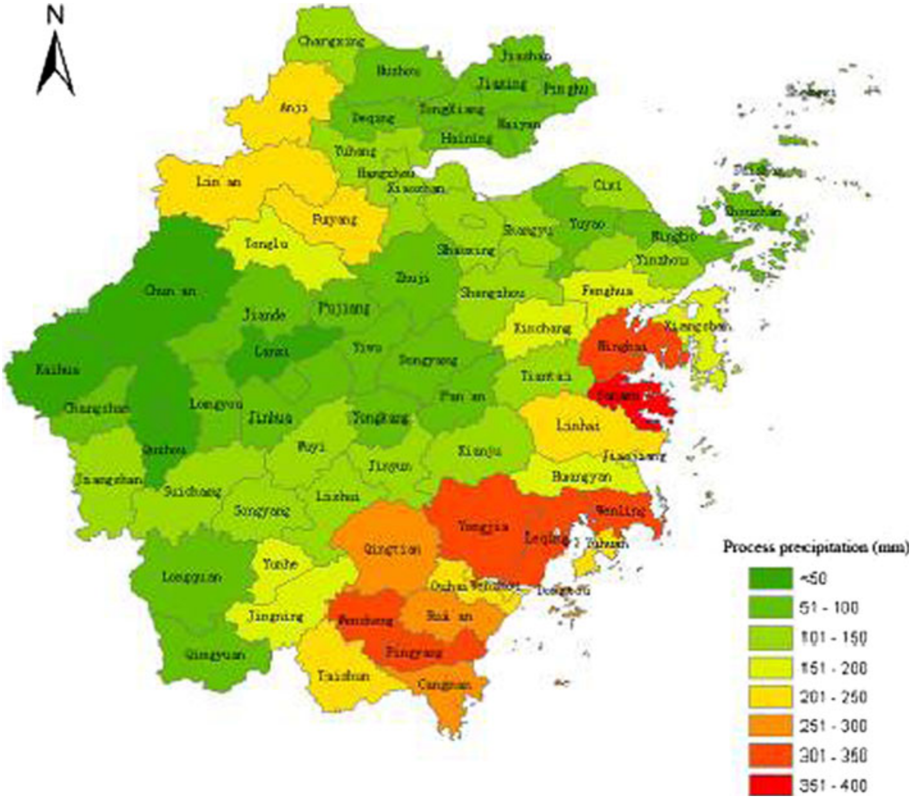


Fig. 3 Precipitation map for tropical cyclone Morakot from August 7th to 11th

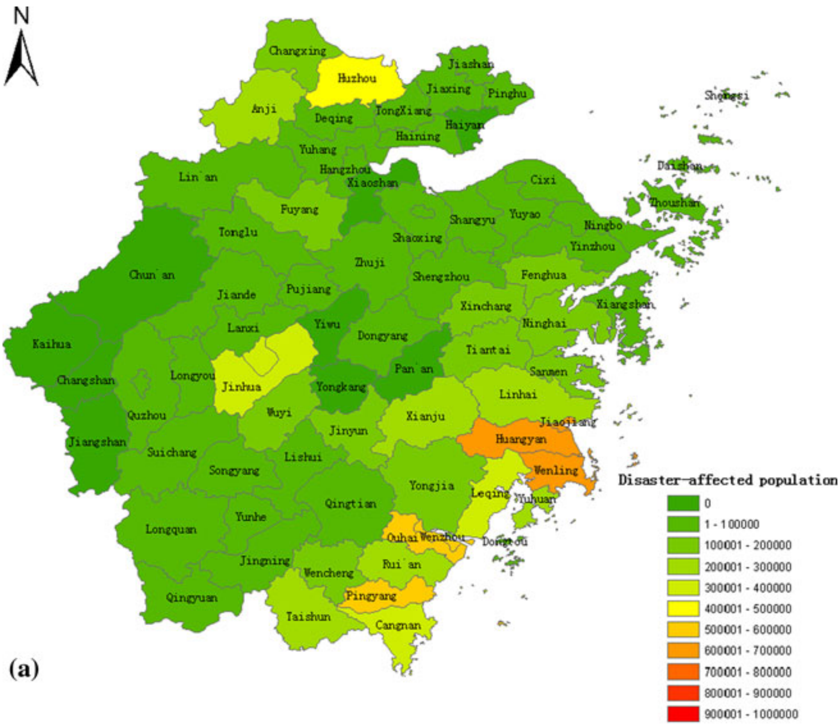
Precipitation began on the 7th in Zhejiang and ended on the 11th. Rainfall in Zhejiang reached 153 mm. Some 74,000 km^2 of the area (73 %) had rainfall over 100 mm; 20,000 km^2 (29 %) had over 250 mm, and 6,500 km^2 (6.5 %) had over 500 mm (Fig. 3).

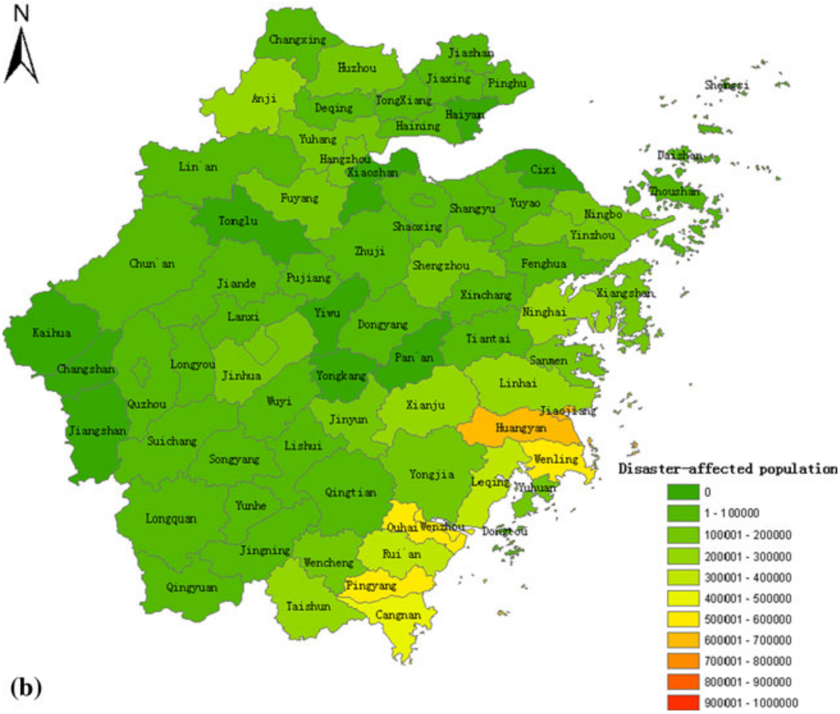
Based on data of wind velocity, rainfall, and tidal level for Morakot, we used the assessment model to fit the disaster situation of the tropical cyclone. Results are shown in Fig. 4 and Table 8.

Figure 4 Maps comparing assessment values and actual values associated with tropical cyclone Morakot in Zhejiang Province.

From Fig. 4 and Table 8, we see that the provincial total of model assessment values correspond well with actual values. The coastal region encompassed the most serious tropical cyclone disaster areas and is the major area of tropical cyclone prevention in Zhejiang Province. Assessment values of disaster-affected population and affected crop area correspond well with actual values. Assessment values of damaged houses and direct

Fig. 4 **a** Actual values of Morakot-affected population in Zhejiang Province. **b** Assessment values of Morakot-affected population in Zhejiang Province. **c** Actual values of Morakot direct economic loss in Zhejiang Province. **d** Assessment values of Morakot direct economic loss in Zhejiang Province. **e** Actual values of Morakot-affected crop area in Zhejiang Province. **f** Assessment values of Morakot-affected crop area in Zhejiang Province. **g** Actual numbers of Morakot-damaged houses in Zhejiang Province. **h** Assessment values of Morakot-damaged house numbers in Zhejiang Province ▶


N
(a)
Changxing
Huzhou
Jiashan
Jiaxing
Pinghu
Anji
Deqing
TongXiang
Haiyan
Haining
Yuhang
Hangzhou
Xiaoshan
Lin an
Fuyang
Tonglu
Shaoxing
Shangyu
Yuyao
Cixi
Ningbo
Yinzhou
Shengsi
Daishan
Zhoushan
Chun an
Jiande
Pujiang
Zhuji
Shengzhou
Fenghua
Xinchang
Xiangshan
Ninghai
Lanxi
Yiwu
Dongyang
Kaihua
Ti ant ai
Pan an
Sanmen
Changshan
Longyou
Jinhua
Yongkang
Linhai
Quzhou
Wuyi
Xianju
Jiaojiang
Jiangshan
Jinyun
Huangyan
Suichang
Lishui
Wenling
Songyang
Yongjia
Leqing
Yuhuan
Qingtian
Yunhe
Longquan
Ouhai
Wenzhou
Dongtou
Jingning
Rui an
Wencheng
Qingyuan
Pingyang
Taishun
Cangnan
Disaster-affected population
0
1 - 100000
100001 - 200000
200001 - 300000
300001 - 400000
400001 - 500000
500001 - 600000
600001 - 700000
700001 - 800000
800001 - 900000
900001 - 1000000


N
(b)
Changxing
Huzhou
Jiashan
Jiaxing
Pinghu
Anji
Deqing
TongXiang
Haiyan
Haining
Yuhang
Hangzhou
Xiaoshan
Lin an
Fuyang
Tonglu
Shaoxing
Shangyu
Yuyao
Cixi
Ningbo
Yinzhou
Shengsi
Daishan
Zhoushan
Chun an
Jiande
Pujiang
Zhuji
Shengzhou
Fenghua
Xinchang
Xiangshan
Ninghai
Lanxi
Yiwu
Dongyang
Kaihua
Ti ant ai
Pan an
Sanmen
Changshan
Longyou
Jinhua
Yongkang
Linhai
Quzhou
Wuyi
Xianju
Jiaojiang
Jiangshan
Jinyun
Huangyan
Suichang
Lishui
Wenling
Songyang
Yongjia
Leqing
Yuhuan
Qingtian
Yunhe
Longquan
Ouhai
Wenzhou
Dongtou
Jingning
Rui an
Wencheng
Qingyuan
Pingyang
Taishun
Cangnan
Disaster-affected population
0
1 - 100000
100001 - 200000
200001 - 300000
300001 - 400000
400001 - 500000
500001 - 600000
600001 - 700000
700001 - 800000
800001 - 900000
900001 - 1000000

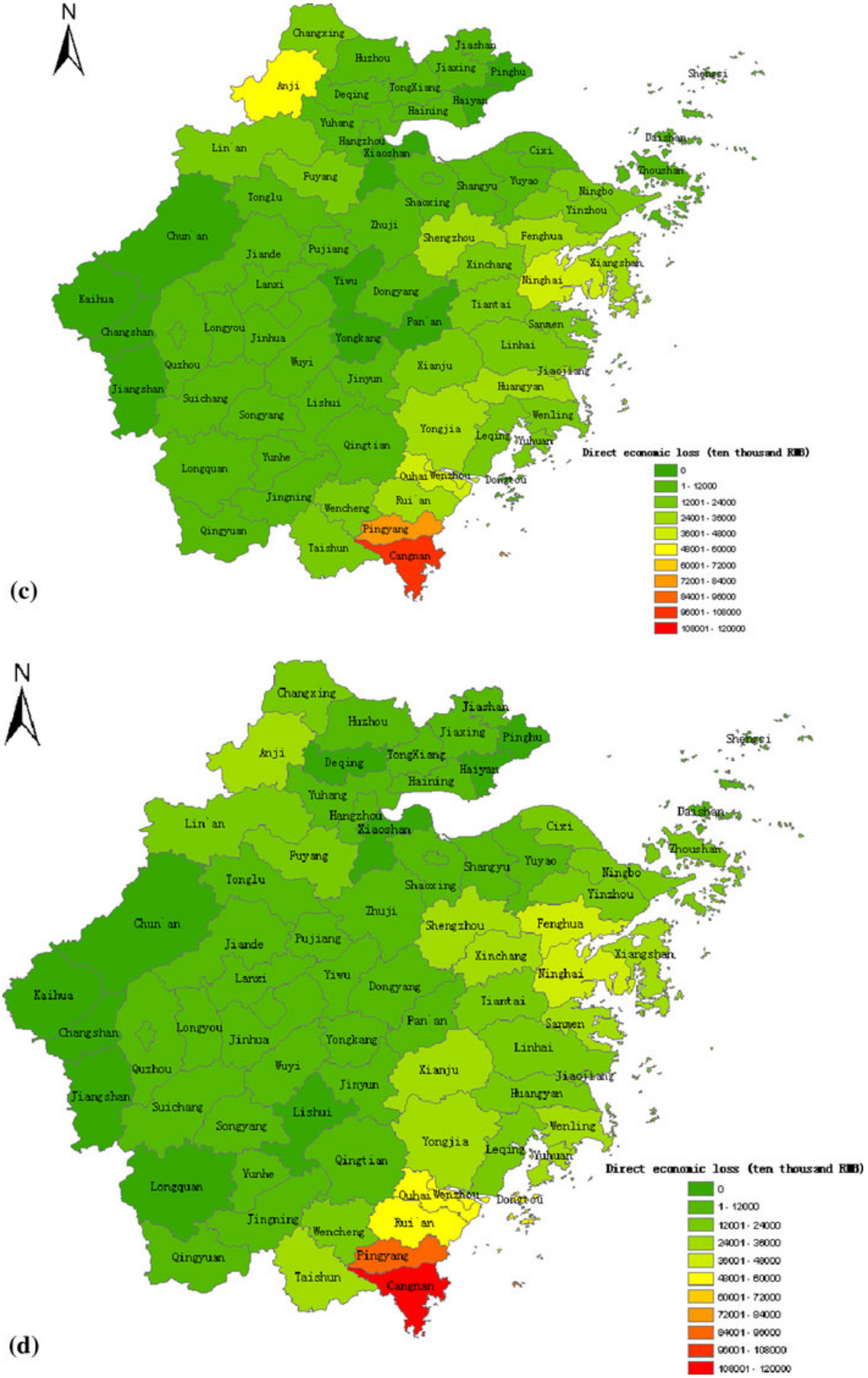


Fig. 4 continued

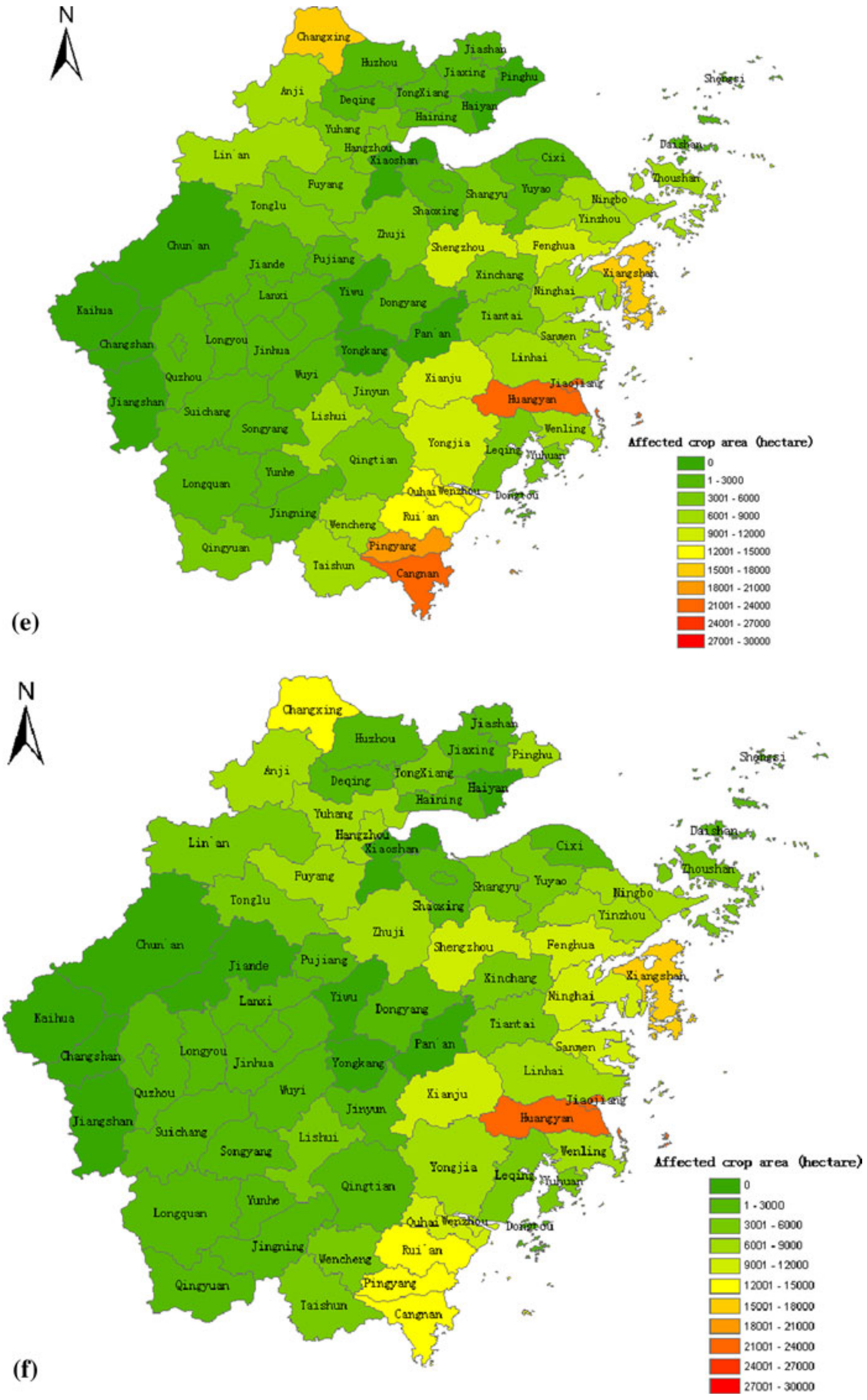


Fig. 4 continued

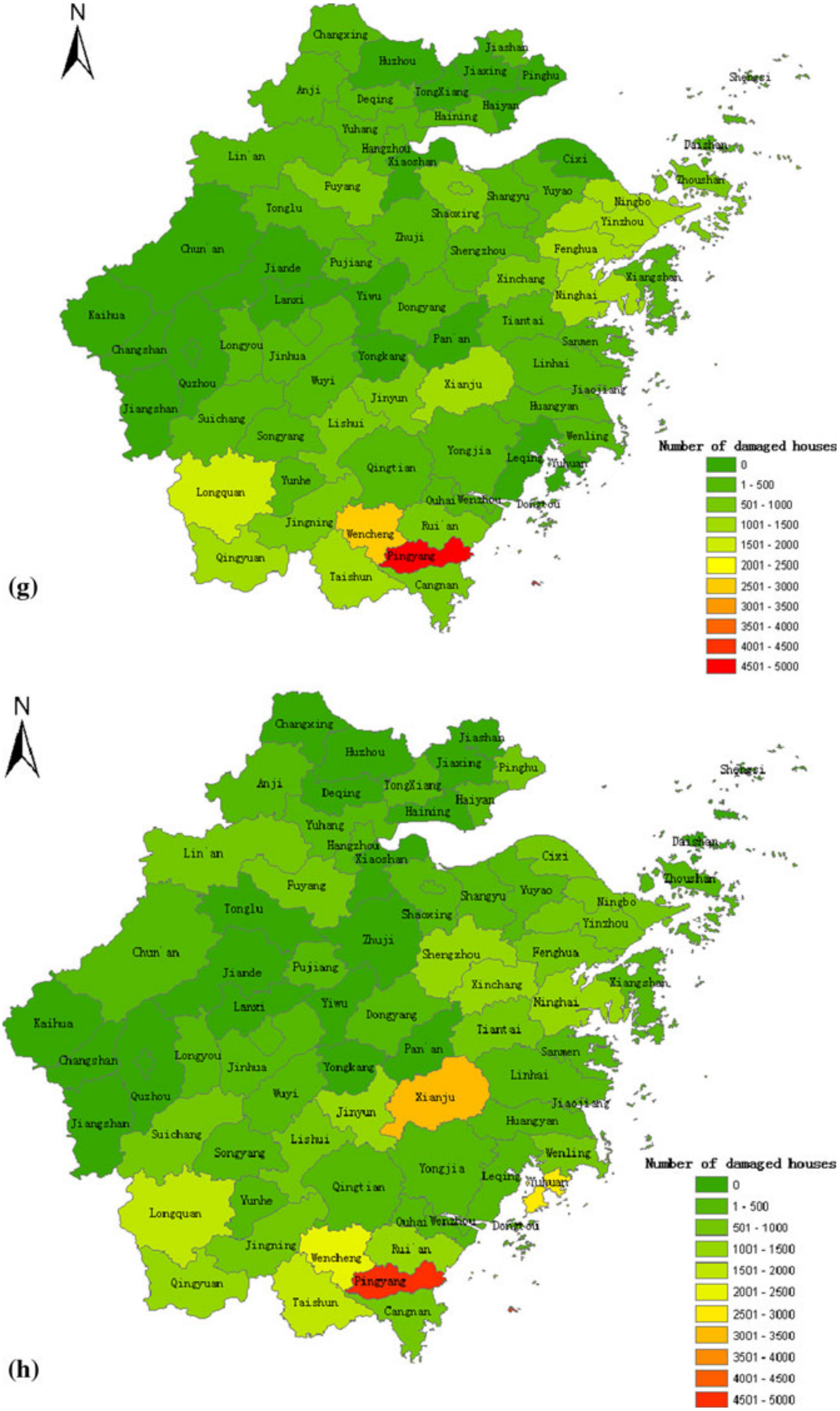


Fig. 4 continued

Table 8 Comparison between assessment values and actual loss values associated with tropical cyclone Morakot in Zhejiang Province

Area	Factor	Number of damaged houses	Disaster-affected population (person)	Direct economic loss (ten thousand RMB)	Affected crop area (ha)
Northern region	Assessment value	5,282	1,349,563	210,729	85,396
	Actual value	5,010	1,723,429	194,376	81,362
	R	0.7057	0.5964	0.902	0.9656
	MAE	162	52,883	3,155	783
Southern region	Assessment value	15,456	1,342,946	149,587	46,952
	Actual value	11,661	1,265,105	156,408	55,234
	R	0.7498	0.8906	0.8726	0.8736
	MAE	335	23,620	4,865	1,016
Western region	Assessment value	1,397	481,691	39,337	14,640
	Actual value	1,092	686,000	30,780	19,481
	R	0.6504	0.8244	0.8220	0.8057
	MAE	77	32,325	1,254	677
Coastal region	Assessment value	18,709	5,100,214	755,665	192,498
	Actual value	13,973	4,866,811	563,079	195,872
	R	0.7627	0.9781	0.8851	0.8988
	MAE	413	30,870	9,538	2,045
Zhejiang Province	Assessment value	39,943	8,174,666	1,112,793	326,435
	Actual value	30,393	8,386,368	908,248	340,074
	R	0.7781	0.9195	0.8904	0.9157
	MAE	273	35,605	5,453	1,263

R is correlation coefficient of assessment value and actual value; MAE is mean absolute error of assessment value and actual value

economic loss are larger than actual values; this reflects the effects of tropical cyclone prevention. The southern region showed the second greatest level of tropical cyclone disaster effects. Assessment values of disaster-affected population correspond well with actual values, whereas assessment values of direct economic loss and affected crop area are smaller than actual. This region has mountainous and hilly areas, so heavy rainfall from Morakot caused landslides, debris flow, and other geological disasters. This aggravated direct economic losses and affected crops (Li et al. 2010). The northern and western regions did not experience serious tropical cyclone disaster. Morakot caused the most severe tropical cyclone damage since 2005, making for relatively large error.

5 Conclusion and discussion

1. Precise assessment of tropical cyclone disasters provides an important basis for disaster prevention and relief, and issuance of disaster-relief funds and insurance claims. It is also crucial for the formulation of disaster prevention and relief policies, assessment of disaster prevention and relief benefits, and social and economic development plans. In this study, we established a tropical cyclone assessment model accurate on a county level. Using this model, we quantitatively assessed four representative indices of a disaster situation, including number of damaged houses, disaster-affected population, direct economic loss, and affected crop area.
2. A disaster situation encompasses loss of life, resources, and material wealth, within a specific disaster-formative environment and under the influence of disaster-causing factors on the disaster-affected body. We mainly evaluated four representative disaster situation indices, namely the number of damaged houses, disaster-affected population, direct economic loss, and affected crop area. Compared with the conventional assessment methods in which only economic loss is appraised or the tropical cyclone disaster is evaluated by integrating disaster situation characterization factors into the grade of disaster, our model can more comprehensively represent impacts of a tropical cyclone disaster on the human population. Because of considerable differences in social and economic levels between counties, the same disaster-causing factor can produce varying impacts on disaster-affected bodies. Therefore, we used as assessment values the percentage of disaster-affected population to total county population, percentage of direct economic loss to county GDP, number of damaged houses per unit cultivated area, and percentage of affected crop area to total cultivated area in a county. By doing so, the effect of differences in county population and social and economic development level was excluded. We then treated characterization factors of a disaster situation in the counties as one sample. The problem of small samples for tropical cyclone disasters in a county was thus overcome. Our disaster data processing method can also be applied in precise assessment of other disasters, including that from floods.
3. Because of complex topography and considerable differences in the disaster-formative environment across various parts of Zhejiang, identical disaster-causing factors commonly have different impacts on the disaster-affected body. We divided the tropical cyclone-affected area of the province into four regions, according to topography, social and economic conditions, and historical tropical cyclone disasters. From Table 7, we see that one characterization factor of disaster situations has varying assessment factors across different regions. The four regions were separately modeled to reduce the influence of varying disaster-formative environments on the tropical cyclone disaster situation and to enhance the accuracy of model assessment.
4. GIS technology was used to collect precise economic, geographic, and environmental data. Through combination with fixed-point meteorological forecasts provided by the meteorological department, we use SVM to deal with the uncertain nonlinear relationship between assessment factors and the cyclone disaster situation. Assessment results of tropical cyclone No. 0908 suggest that our model can accurately evaluate tropical cyclone disasters.

Acknowledgments This work is supported by a major agricultural project from the Science Technology Department of Zhejiang Province, China (Grant No. 2011C22082), the China Meteorological Administration (CMATG 2008M40), and Zhejiang Research Institute of Marine Meteorology Science (Kf2009002).

References

Cao C, Peng JY, Yu JH (2006) An analysis on the characteristics of landfalling typhoons in China under global climate warming. J Nanjing Inst Meteorol 29(4):455–461 (in Chinese)

Chen HY, Yan LN, Lou WP, Xu HE, Yang SF (2011) On assessment indexes of the strength of comprehensive impacts of tropical cyclone disaster-causing factors. J Tropical Meteorol 27(1):139–144 (in Chinese)

Fang WH, Zhong XC, Qiao Y, Lin W, Xu H, Li Y (2011) Estimation or rural residential building vulnerability to tropical cyclone hazards by insurance claim data: case study in zhejiang province of China. J Beijing Normal Univ (Nat Sci) 47(4):409–414 (in Chinese)

Imamura F, Van To D (1997) Flood and typhoon disasters in Viet Nam in the half century Since 1950. Nat Hazards 15(1):71–87

Ji YX, Xiong YY, Ma RY (2007) Fuzzy synthetic method applied in assessment of storm tide disaster losses. Guangxi Water Resour Hydropower Eng 36(2):16–19 (in Chinese)

Knutson TR, McBride JL, Chan J, Emanuel K, Holland G, Landsea C, Held I, Kossin JP, Srivastava AK, Sugi M (2010) Tropical cyclones and climate change. Nat Geosci 3:157–163. doi:10.1038/ngeo779

Li CM, Lou XL, Liu JL et al (2006) Application of analytical hierarchy process in the assessment model on tropical cyclone disaster's influence. J Tropical Meteorol 22(3):223–228 (in Chinese)

Li YM, Zhao LN, Tian FY, Zhang GP (2010) Weather forecast analysis for geological disasters caused by Morakot in 2009. In: Senior Symposium sudden geological disasters emergency response and disaster control techniques. China association for disaster prevention, Lanzhou, 2010 (in Chinese)

Liu DF, Pang L, Xie BT (2009) Typhoon disaster in China: prediction, prevention, and mitigation. Nat Hazards 49:421–436. doi:10.1007/s11069-008-9262-2

Lou WP, Chen HY, Qiu XF, Tang QY, Zheng F (2011) Assessment of economic losses from tropical cyclone disasters based on PCA-BP. Nat Hazards 60(3):819–829. doi:10.1007/s11069-011-9881-x

Lü ZP, Yao YW (2006) Typhoon disasters in Zhejiang Province and the establishment of emergency response mechanism. J Catastrophol 21(3):69–71 (in Chinese)

Ma QY, Li JY, Wang XR, Wang WG, Gao LY (2008) A fuzzy synthetic evaluation model for typhoon disaster. Meteorol Monthly 34(5):20–25 (in Chinese)

Mann ME, Woodruff JD, Donnelly JP, Zhang ZH (2009) Atlantic hurricanes and climate over the past 1,500 years. Nature 460:880–883. doi:10.1038/nature08219

Pozdnoukhov A, Matasci G, Kanevski M, Purves RS (2011) Spatio-temporal avalanche forecasting with Support Vector Machines. Nat Hazards Earth Syst Sci 11:367–382. doi:10.5194/nhess-11-367-2011

Shi PJ (1996) Theory and practice of disaster study. J Nat Disasters 5(4):6–17 (in Chinese)

Tang QY (2010) DPS data processing system: experimental design, statistical analysis and data mining (in Chinese). Science Press, Beijing

Vickery PJ, Skerlj PF, Lin J, Twisdale LA Jr, Young MA, Lavelle FM (2006) HAZUS-MH hurricane model methodology. II: damage and loss estimation. Nat Hazards Rev 7:94–103

Wang XL, Wu LG, Ren FM, Li WJ (2008) Influences of tropical cyclones on china during 1965–2004. Adv Atmos Sci 25(3):417–426

Wang XR, Wang WG, Ma QY (2010) Model for general grade division of typhoon disasters and applicationg. Meteorol Monthly 36(1):67–71 (in Chinese)

Watson CC, Johnson ME (2004) Hurricane loss estimation models:opportunities for improving the state of the art. Bull Am Meteorol Soc 85:1713–1726

Webster PJ, Holland GJ, Curry JA, Chang HR (2005) Changes in tropical cyclone number, duration, and intensity in a warming environment. Science 309:1844–1846. doi:10.1126/science.1116448

Wu H, Chen DM, Wu SAWuCK (2009) Application of grey relation analysis for evaluation of tropical cyclone disaster. Chin J Trop Crops 30(2):244–248 (in Chinese)

Ye W, Liu MN, Chen XH (2004) The application of the perception approach in the evaluation of typhoon storm surge disaster degree. Acta Sci Nat Universitatis Sunyatseni 43(2):117–120 (in Chinese)

Zhou F, Chen HY, Lou WP, Yan LN (2012) Typhone disaster assessment and risk zonation in Zhejiang Province (in Chinese). Zhejiang Province Education Press, Hangzhou