The Synthetic Evaluation Model for Analysis of Flooding Hazards

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Background: Although many previous epidemiological studies have reported the incidence of diseases, mortality rate and economic losses after natural disasters, none of these studies has been comprehensive enough. Our aim was to establish a synthetic evaluation model (SEM) that can be used to analyze flood hazards.

Methods: Initial evaluation indicators were selected using systematic and literature data analysis. These indicators were tested with single or multiple variable analyses. Final evaluation indicators and their weights were determined using the Delphi procedure. We established a SEM of flood hazards using the hierarchy method and tested the model using jack-knife analysis.

Results: The SEM on flood hazards consists of 6 first-rank indicators and 24 second-rank indicators. First-rank indicators were: direct casualties (w = 0.2123), the increased incidence and prevalence rate of the disease (w = 0.1745), mental injury (w = 0.1038), epidemic focus expansion (w = 0.1572) and economic loss (w = 0.1807). The agreement of the model reached 98.2% tested with the jack-knife analysis.

Conclusion: A SEM of flood hazards was established with an agreement of 98.2%, which can be used to evaluate the hazards, and assist public health-care workers provide appropriate flood disaster management.

Keywords: Delphi method, flood hazards, jack-knife analysis, synthetic evaluation

Natural disasters are increasing in frequency because of the worldwide deterioration in the natural environment. The incidence of floods, storms, earthquakes and droughts and the number of people affected by them are escalating greatly.¹ Weather-related disasters throughout the world continue to rise, from an annual average of 200 in 1993–1997 to 331 per year in 1998–2002.² Floods are the most common of natural disasters, affecting more people across the globe (140 million per year on average) than are affected by all other natural or technological disasters.³ In 1998 a flood killed 3004 people in China.³ A flood in East Java destroyed 20,000 houses and thousands of hectares of rice fields in 130 villages.⁴

The investigation of distribution, hazards and risk factors of natural disasters is very important for preventing their occurrence and reducing hazards associated with such events. It is also very important to evaluate the disaster comprehensively and in time in order to initiate appropriate management and to reduce the effects of the event. Although many previous epidemiological studies have reported the incidence of infectious diseases such as waterborne dysenteries, and non-infectious diseases such as stroke or myocardial infarction, the mortality rate and the economic losses that follow natural disasters,⁵–¹¹ have not been reported comprehensively enough in these studies.

We therefore carried out a large retrospective study on flood hazards and established a synthetic evaluation model (SEM) that can be applied to these. This model can be easily used to manage the flood during the acute phase, as well as to implement disease prevention measures.

Methods

Setting and sample
An epidemiological study was carried out in 1999 in Hunan province, a severely flood-prone area, located in the South of China. A sample was selected randomly using a multiple-stage sampling method. In the first stage of sampling, 8 counties were selected among 38 flooded counties. In the second stage half of the flood affected towns in the eight counties were selected. In the third stage, half of the flood affected villages in the selected towns were selected. Non-flooded villages located near the selected flooded villages with similar social, environmental and economic conditions were used as controls. In the fourth stage of sampling, we selected half of the flood-affected families in the selected flooded villages and half of the families in the selected control villages. The family was the smallest sampling unit; we investigated all members of the selected families.

Contents and methods of investigating
We investigated the rate at which flood affected the populations, the number of casualties that directly resulted from the flood, which included drowning and accidental injury etc., the total, age-specific, sex-specific, cause-specific mortality and morbidity using the method of face-to-face investigation. The incidence rate of post-traumatic stress disorder (PTSD) was rated by an experienced psychiatrist using the diagnostic criteria of DSM-IV.¹² The spread of the focus of the epidemic of Schistosomiasis was rated by investigating the areas of embankment with snails and by looking at the incidence and mortality rate...
of Schistosomiasis during the flood years. The positive rate of Leptospira antibody and haemorrhagic fever with renal syndrome (HFRS) antibody in the local populations, the economic investment, as well as economic loss due to flood were all included in the study. All diseases and causes of death were then classified by ICD-10 criteria. The snails were picked up directly using a scoop, transferred to plastic containers, brought to the field laboratory and checked for cercarial shedding by placing them in small plastic containers and exposing them to light for 4 h. The infection of schistosoma was diagnosed by the faecal testing of each individual using the katokatz method, two slides being prepared for each faecal sample. The Leptospira antibody was detected using the microscopic agglutination test. The HFRS antigen was detected in the rodent lung using direct immunofluorescence; the population serum HFRS IgG antibody was detected using indirect immunofluorescence.

**Synthetic evaluation method**

The initial evaluation indicators were selected using systematic analysis and literature data analysis. All of the initial evaluation indicators were tested using the single or multiple variable analysis method. Indicators with no statistical significance were excluded from the study. A frame of evaluation indicators was drafted using variable cluster analysis and analytical hierarchy methods. The evaluation indicators and their weights were determined using the Delphi method. The SEM of the flood hazards was established using the hierarchy method; the model was tested by jack-knife analysis and correlation analysis. The Delphi method is a consensus method used to determine the extent of agreement on an issue or object, which was originally developed by the Rand Corporation in order to evaluate the appropriateness of medical and surgical techniques. It synthesizes the opinions of experts with the available evidence in order to provide detailed assessment.

Experts who participated in the Delphi procedure were polled individually and anonymously, with a self-administered questionnaire. The survey was conducted over three or four rounds, depending on the agreement coefficient. The result obtained in the first round of the survey was presented to experts in the second round, and so on. Experts were assembled for the Delphi survey questionnaire based on the following criteria: (i) they had had at least 10 years of experience in disaster management, (ii) they were familiar with flooding or other natural disaster information and (iii) they were willing to participate in the Delphi procedure.

Using the Delphi procedure, each expert was asked to assess the sensitivity, specificity and feasibility of the evaluation indicators for the evaluation of flood hazards and to rank the indicators against 0–10 scores. The mean score of the four values for each indicator–representative, sensitivity, specificity and feasibility, was regarded as the score of primary importance. The higher the value given by the expert, the more important the indicator became. The experts were also asked to self-rate themselves on authority (authority coefficient) in the indicator of evaluation. The product of the primary importance score and the authority coefficient of the indicator were defined as the initial weight of the indicator. The indicators whose initial weight <5.0 and had a coefficient of variance of >0.5 or mean score of feasibility <5.0 were excluded.

Some related variables in the Delphi procedure and model establishment are as follows.

The agreement coefficient (AC; ω) represents the harmony degree of all evaluating variables among all experts; it is defined as follows:

\[
\omega = \frac{12}{m^2(n^3 - n) - m \sum_{i=1}^n Y_i^2} \sum_{i=1}^n d_i^2
\]  

where ω is the signal of AC; n is the number of indicators in questionnaires; m is the number of experts in the rounds; \( T_i \) is the number of indicators with the same rank; \( d_i \) is the value of the rank sum of indicators minus the mean of rank sum of all indicators.

The authority coefficient (\( C_{ij} \)) is the authority degree of experts on the evaluating indicators, which is determined by two factors: one is the judgment criterion for the indicator and the other is the experts' familiarity with the indicators.

Weight (W) is a very important parameter in the evaluating model, reflecting the importance of indicators. The initial weight (\( W_{ij} \)) equal to the weighted mean of expert scores, the unitary weight (\( W_{cij} \)) equal to the initial weight divided by the sum of initial weights of all indicators in the same rank and the final combined weight (\( W_{cij} \)) is defined as follows:

\[
W_{cij} = W_{1ij} W_{2ij},
\]

where \( W_{1ij} \) represents the first-rank unitary weight and \( W_{2ij} \) represents the unitary weight of the second-rank indicator.

The SEM of flood hazards based on the analytic hierarchy method is defined as follows:

\[
\text{SEM}_{\text{HM}} = \sum_{j=1}^n W_{cij} Y_j,
\]

where \( n \) is the number of indicators in the SEM, \( W_{cij} \) is the combined weight of indicator \( J \) and \( Y_j \) is the value of indicator \( J \) in the flood area.

**Results**

Our study in Hunan province, China, included 55 towns, 438 villages, 20 230 families and 75 033 people. The non-flooded control group consisted of 15 towns, 129 villages, 7008 families and 25 136 people. The flooded group consisted of 40 towns, 309 villages, 13 222 families and 49 897 people. Subjects were selected randomly and 96.2% of the subjects responded. The direct injury rate was 191 per 100 000 and the direct mortality rate was 77 per 100 000 in the area of the collapsed embankment. The incidence rate of infectious diseases (44.3‰) and the prevalence rate of non-infectious diseases (68.8‰) were significantly higher in the flooded group compared with the non-flooded group (23.9 and 52.1‰, respectively, \( P < 0.01 \)). The incidence and prevalence rates of all types of disease increased with the severity of the flood. The total mortality rate was significantly higher in the flooded group (939 per 100 000) than in the non-flooded control group (726 per 100 000; \( P < 0.01 \)). In the flooded group the rate of PTSD was 32.6% in the population in the age group of above 6 years. The rate of PTSD was higher in the severely flooded area than in the mildly flooded area. The rate of Schistosoma infection (8.76%) and acute Schistosomiasis (6.92 per 10 000), was significantly higher in the flood years than in the non-flood years (5.47%, 3.54 per 10 000). The density of rats (6.95%) and rate of rats infected with Leptospira (4.63%) and HFRS virus (15.07%) were significantly higher in the flooded area than in non-flooded area (5.98, 1.35, and 9.25%). The total economic loss was 13.2 billion Chinese Yuan (£1 billion) in 40 flooded towns. The investment in flood prevention strategies before and during the flood years was negatively related to the economic loss caused by the flood. The cost–benefit ratio of investment in anti-flood strategies was calculated to be 1:250.

Using systematic analysis and literature data analysis methods, 128 initial evaluation indicators were selected, of which 54 indicators having no statistical significance in the single variable analysis or in the multiple regression analysis were excluded. The remaining 74 indicators were divided into six categories—direct casualties, mental injury, incidence and prevalence rates of diseases, mortality rate, economic loss and infectious vector
We calculated the synthetic evaluation value of every flooded town using this model and classified the towns based on slight flooding (<P50), moderate flooding (P50–P75), severe flooding (P75–P94) and the severest flooding (≥P95) by the percentile method.

We tested this model by comparing the classification results of the SEM classification with traditional classification and jack-knife analysis for the 55 investigated towns and by one-way ANOVA and correlation analysis. The traditional flood classification method is based on the flooded acreage: slight flood (<50%), moderately severe flood (50–75%) and severe flood (75%). The flood classification result by SEM is significantly different from the result by the traditional classification method. The total agreement rate was 34.55%. Eighty percent of the non-flooded control towns were classified as flooded (table 4). The agreement rate of flood classification of the SEM and the jack-knife analysis reached 98.2% (table 4). This showed that the model is reliable and repeatable. We compared the mean values of SEM among different classified flood by one-way ANOVA and LSD test; the results showed that the mean value of SEM was 0.87 for non-flooded areas [95 confidence interval (95% CI) of mean −0.65 to 2.39], 13 228.49 for slightly flooded areas (95% CI of mean 42 346.68–47 719.40), 119 884.42 for severely flooded areas (95% CI of mean 116 844.93–122 923.91) and 236 149.48 for the most severely flooded areas (95% CI of mean 226 258.40–246 040.56); there were significant differences among the mean values of SEM in different classified flood (F = 107.3, P < 0.001); the model had satisfied differentiability. The correlation analysis showed that there only 38 (13.8%) correlation coefficients had statistical significance among 276 correlation coefficients (24 × 23)/2 = 276; most of the evaluation indicators were independent.

**Discussion**

We investigated 55 towns, 438 villages, 20 230 families and 75 033 people in Hunan province, China, focusing on the number of direct casualties resulting from the flood, infectious and non-infectious disease mortality and morbidity, the incidence rate of PTSD, spread of the epidemic focus of schistosomiasis, leptospirosis, and HFRS, as well as economic investment and economic loss during and after the floods. Based on these data, we established a SEM using the analytical hierarchy method, which included six first-rank indicators and 24 second-rank indicators, and which can be used to evaluate flood hazards. The results of model testing showed that the agreement rate of the model reached 98.2% in the flood classification, compared with the result of the jack-knife analysis. This model is the most practical flood evaluation model among all models reported so far in the literature.

The analytic hierarchy method is a method commonly used to establish a SEM. Ramanthan et al.18 used this method to establish an evaluation indicator system regarding the effect of the environment on human health, and Hummel et al.19 used this method to evaluate the medical instruments in hospitals. We used this method to establish a SEM on flood hazards, which included 6 first-rank indicators and 24 second-rank indicators, reflected the influence of flood on human health, environment, as well as the economic loss. To our knowledge, this is the most comprehensive and practical SEM of flood hazard evaluation including six main fields of flood hazards compared with other studies.20,21 It is the first time that mental injury has been included, and the evaluation indicator frame is most comprehensive and reasonable.

The Delphi procedure is a common method used to determine the synthetic evaluation indicators and their weight and a key process used in order to obtain a reliable result. In our study, all the experts who participated in the Delphi

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**Table 1** The expert’s authority coefficient (Cj) in Delphi procedure

<table>
<thead>
<tr>
<th>Indicators</th>
<th>First rank</th>
<th>Second rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct casualties</td>
<td>0.80</td>
<td>0.70–0.83</td>
</tr>
<tr>
<td>Increases of diseases incidence or prevalence rate</td>
<td>0.75</td>
<td>0.65–0.85</td>
</tr>
<tr>
<td>Excess mortality rate</td>
<td>0.72</td>
<td>0.65–0.87</td>
</tr>
<tr>
<td>Mental injury</td>
<td>0.65</td>
<td>0.50–0.65</td>
</tr>
<tr>
<td>Expansion of epidemic focus</td>
<td>0.76</td>
<td>0.60–0.80</td>
</tr>
<tr>
<td>Economic loss</td>
<td>0.73</td>
<td>0.70–0.87</td>
</tr>
</tbody>
</table>

**Table 2** The expert’s agreement coefficient (AC, ω) after three round Delphi procedures

<table>
<thead>
<tr>
<th>Indicators</th>
<th>ω</th>
<th>X²</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>First rank indicators</td>
<td>0.82</td>
<td>11.07</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Second rank indicators</td>
<td>0.52</td>
<td>6.51</td>
<td>&lt;0.050</td>
</tr>
<tr>
<td>Direct casualties</td>
<td>0.52</td>
<td>6.51</td>
<td>&lt;0.050</td>
</tr>
<tr>
<td>Increases of diseases incidence or prevalence rate</td>
<td>0.72</td>
<td>7.34</td>
<td>&lt;0.050</td>
</tr>
<tr>
<td>Excess mortality rate</td>
<td>0.65</td>
<td>12.37</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Mental injury</td>
<td>0.75</td>
<td>12.34</td>
<td>&lt;0.010</td>
</tr>
<tr>
<td>Expansion of epidemic focus</td>
<td>0.64</td>
<td>13.50</td>
<td>&lt;0.050</td>
</tr>
<tr>
<td>Economic loss</td>
<td>0.82</td>
<td>11.62</td>
<td>&lt;0.050</td>
</tr>
</tbody>
</table>
An Evaluation Model for Flood Hazards

Table 3 All indicators and their weights included in the final synthetic evaluation model after three round Delphi procedures

<table>
<thead>
<tr>
<th>Indicator (X)</th>
<th>Initial weight (Wi)</th>
<th>Unitary weight (Wuj)</th>
<th>Combined weight (Wuj)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct casualties*</td>
<td>7.75</td>
<td>0.2123</td>
<td></td>
</tr>
<tr>
<td>Affected rate in total population by flood (X1.01b)</td>
<td>6.23</td>
<td>0.3348</td>
<td>0.0711</td>
</tr>
<tr>
<td>Injury incidence to flood (X1.02)</td>
<td>5.43</td>
<td>0.2917</td>
<td>0.0619</td>
</tr>
<tr>
<td>Mortality rate attribute to floods (X1.03)</td>
<td>6.95</td>
<td>0.3735</td>
<td>0.0794</td>
</tr>
<tr>
<td>Increases of diseases incidence</td>
<td>6.26</td>
<td>0.1715</td>
<td></td>
</tr>
<tr>
<td>Total prevalence rate (X5.01)</td>
<td>4.99</td>
<td>0.2999</td>
<td>0.0514</td>
</tr>
<tr>
<td>Digestive system diseases prevalence rate (X2.08)</td>
<td>5.08</td>
<td>0.3053</td>
<td>0.0524</td>
</tr>
<tr>
<td>Infectious and parasitic diseases incidence rate (X5.11)</td>
<td>6.57</td>
<td>0.3948</td>
<td>0.0677</td>
</tr>
<tr>
<td>Excess mortality</td>
<td>6.37</td>
<td>0.1745</td>
<td></td>
</tr>
<tr>
<td>Total death rate (X5.01)</td>
<td>5.72</td>
<td>0.2634</td>
<td>0.0460</td>
</tr>
<tr>
<td>Death rate in 20- to 64-years-old (X5.06)</td>
<td>5.27</td>
<td>0.2426</td>
<td>0.0423</td>
</tr>
<tr>
<td>Infectious and parasitic diseases mortality (X5.11)</td>
<td>6.04</td>
<td>0.2781</td>
<td>0.0485</td>
</tr>
<tr>
<td>Death rate of injury (X3.13)</td>
<td>4.69</td>
<td>0.2159</td>
<td>0.0377</td>
</tr>
<tr>
<td>Mental injury</td>
<td>3.79</td>
<td>0.1038</td>
<td></td>
</tr>
<tr>
<td>Total rate of PTSD in adult (X4.01)</td>
<td>2.62</td>
<td>0.2589</td>
<td>0.0269</td>
</tr>
<tr>
<td>Rate of persistent re-experiencing symptoms in adult (X4.03)</td>
<td>2.32</td>
<td>0.2292</td>
<td>0.0238</td>
</tr>
<tr>
<td>Rate of increased arousal symptoms in adult (X4.04)</td>
<td>2.64</td>
<td>0.2609</td>
<td>0.0271</td>
</tr>
<tr>
<td>Rate of PTSD in older than 60 population (X4.09)</td>
<td>2.54</td>
<td>0.2510</td>
<td>0.0261</td>
</tr>
<tr>
<td>Expansion of epidemic focus</td>
<td>5.74</td>
<td>0.1572</td>
<td></td>
</tr>
<tr>
<td>Number of acute schistosomiasis patient (X5.07)</td>
<td>5.54</td>
<td>0.1803</td>
<td>0.0283</td>
</tr>
<tr>
<td>Prevalence rate of schistosomiasis (X5.08)</td>
<td>5.17</td>
<td>0.1682</td>
<td>0.0264</td>
</tr>
<tr>
<td>Rat density (X5.10)</td>
<td>4.86</td>
<td>0.1582</td>
<td>0.0249</td>
</tr>
<tr>
<td>Positive rate of HFRS antibody in 15- to 49-years-old (X5.15)</td>
<td>4.35</td>
<td>0.1416</td>
<td>0.0222</td>
</tr>
<tr>
<td>Positive rate of leptospirosis antibody in population (X5.19)</td>
<td>4.66</td>
<td>0.1516</td>
<td>0.0238</td>
</tr>
<tr>
<td>New appeared snail areas inside embankment (X5.22)</td>
<td>6.15</td>
<td>0.2001</td>
<td>0.0315</td>
</tr>
<tr>
<td>Economic loss</td>
<td>6.59</td>
<td>0.1807</td>
<td></td>
</tr>
<tr>
<td>Type of floods (X6.02)</td>
<td>6.18</td>
<td>0.2769</td>
<td>0.0500</td>
</tr>
<tr>
<td>Total losses per family attributed to floods (X6.03)</td>
<td>5.09</td>
<td>0.2280</td>
<td>0.0412</td>
</tr>
<tr>
<td>Average social losses per person attribute to floods (X6.04)</td>
<td>5.16</td>
<td>0.2312</td>
<td>0.0417</td>
</tr>
<tr>
<td>Rate of destroyed house (X6.08)</td>
<td>5.89</td>
<td>0.2639</td>
<td>0.0476</td>
</tr>
</tbody>
</table>

a: First rank indicators
b: Second rank indicators

directly in the Delphi procedure were specialists or experienced flood managers, and the mean of their working years was 24.5. The authority coefficient was 0.6 in first-rank indicators and 0.5 in the second-rank indicators. The experts’ respondent rate ranged from 77.8 to 100% from the first to the third round; all of the expert agreement coefficients reached 0.50 or more for the second-rank indicators and 0.82 for first-rank indicators. These results showed that the experts were qualified for the Delphi procedure. The experts’ consulting result is reliable and better than Rivara and Lavioli’s result.

Our SEM is more sensitive and specific than the traditional method of flood hazard evaluation. Traditional methods evaluate flood hazards only according to the flooded acreage; however flooded acreage is not the only determinant of flood hazard, flood hazard being related also to flood type, period of time, affected population and economic loss. Our model includes 24 evaluation indicators and is more sensitive in evaluating the flood hazard than previous methods. Our SEM classified 12 of the 15 non-flooded towns as flooded towns. This was reasonable and consistent with the facts, as the selected non-flooded towns (control) were near the flooded towns, most of the population in the non-flooded towns participated the anti-flood work, experienced the flood disaster and subsequently suffered a decrease in their income, as well as increase in infectious diseases during the flood year.

Every flooded area can have an index value of synthetic evaluation applied to it by our SEM and can subsequently be classified into a particular flood grade. This would help public health-care decision-makers and workers develop appropriate
rescuing measures and help the flood victims in the most efficient way possible.

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Key points

- We investigated the flood hazards in 6 fields on 75,033 people in flooded areas of China. Based on these results, a synthetic evaluation model on flood hazards consisting of 6 first-rank indicators and 24 second-rank indicators was established with an agreement of 98.2%, which is the first synthetic evaluation model for flood hazards assessment and can be used to evaluate flood hazards, as well as to assist public health-care workers provide appropriate flood disaster management.

References


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Table 4 The comparison of flood classification by synthetic evaluation model, traditional classification method, and jackknife analysis

<table>
<thead>
<tr>
<th>Classified by traditional method</th>
<th>Classified by jackknife analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-flood</td>
<td>Non-flood</td>
</tr>
<tr>
<td>Slight flood</td>
<td>Slight flood</td>
</tr>
<tr>
<td>Middle flood</td>
<td>Middle flood</td>
</tr>
<tr>
<td>Severe flood</td>
<td>Severe flood</td>
</tr>
<tr>
<td>Severeest flood</td>
<td>Severeest flood</td>
</tr>
<tr>
<td>No. of towns</td>
<td>No. of towns</td>
</tr>
<tr>
<td>Non-flood</td>
<td>3*</td>
</tr>
<tr>
<td>Slight flood</td>
<td>0</td>
</tr>
<tr>
<td>Middle flood</td>
<td>0</td>
</tr>
<tr>
<td>Severe flood</td>
<td>0</td>
</tr>
<tr>
<td>Severeest flood</td>
<td>0</td>
</tr>
</tbody>
</table>

a: Number of towns