The evaluation system model of fragility to counter the climate change

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The evaluation system model of fragility to counter the climate change

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Abstract. When assessing and predicting the security, development and poverty of a state, fragility becomes a research hot spot in recent years. The evaluation system model of fragility is established based on the Analytic Hierarchy Process (AHP) in order to analyze how climate change affects fragility directly or indirectly, then the abstract problem is transferred into a mathematic one. When the weight of index identified, the fragility could be calculated and the sensitive index can be obtained by Local Amplification. Since the trend of development can lead to the fluctuation of fragility, quadratic smooth in time series method is applied to predict the change of the fragility. Then strategies are put forward to mitigate the impact of climate change on fragility. Besides, Principal Component Analysis (PCA) is utilized to extend the model to evaluate the fragility of continents. When conducting the experiment, the result accords with the reality.

1. Introduction

Climate change, a heated debate worldwide nowadays, has a great influence on the national stability in many aspects, some of which would lead to the weakening and breakdown of social and governmental structures. Extreme climate disasters may cause unexpected trouble on economy and society.

The study of Hsiang and Jesse on 6712 typhoons in the world from 1950 to 2008[1] shows that the typhoon has an increasing horizontal effect, leading the world’s average annual GDP growth rate to drop by 1.3 percentage points. In 1972, the United Nations Conference on the human environment held in Stockholm remarked that the environmental issues would be included in the international political agenda[2], then the “United Nations Conference on environment and Development” and the “United Nations Framework Convention on climate change” signify that climate change officially enters the international political agenda[3]. Since then, Climate issues began to infiltrate into global relations, and became the main topic at the APEC conference, G7 summit and many bilateral meetings.[4]

A series of shocks caused by climate change will result in the negative impact on a state’s structure, such as the risk of violent conflict, which aggravates the burden of some fragile communities and degrades their resilience to recover from suffering. In this case, the concept of fragility is introduced to measure the stability of a state, although it is still a highly abstract concept.[5] Although some environmental stresses themselves do not trigger negative impact, the potential factors would indirectly account for the change of structure. Until now, identified by various aspects, there is no
precise definition of the fragility. In general, a fragile country is left behind in political, cultural, economic, environmental condition and when it suffers from a sudden blow, the ability of recovering to the pre-hit level is relatively low.[6] This paper not only establishes a model to measure the fragility of the state but also puts forward some suggestions to improve the stability of the state.

2. Data prepossessing

2.1. Selecting index

In order to study the relationship between climate change and the fragility of the country, some indexes are selected from the World Bank according to the analysis of the constitution of the social structure. The choice of indexes is based on three principles:

**Index Effectiveness** Related to climate change, it can directly or indirectly reflect a country’s fragility level. The higher the correlation is, the higher the utility will be.

**Data Acquisition** The reliable selected indexes have a large data base in the World Bank, which are convenient to quantify.

**Time Continuity** Selected data from past five years guarantee that the comparison is fair between different countries, which ensures the objectivity of comparison.

Considering the correlation between indexes and national fragility, the indexes are divided into three groups when dealing with data: Explicit, Implicit and Negative Index. The more fragile the country is, the more measures we should take. Specifically, explicit indexes have highly significant impact on the national fragility. Implicit indexes mean these aspects indirectly increase the national fragility. Negative indexes are special indexes, which could mitigate the negative effect on the stability of the country.

![Figure 1. Indexes based on explicit, implicit and negative impact.](image-url)

2.2. Data processing

Since finding that the index distribution is similar to normal distribution, linear interpolation is utilized to implement the missing values in the data. The explicit, implicit and negative indexes selected in figure 1 could be normalized respectively.

**Explicit Index** The following four indexes: Secondary School Enrolment, Renewable Freshwater Per Capita, GDP Per Capita and Improved Sanitation Facilities are dealt as follows

$$a_x = \frac{a-a_{\text{min}}}{a_{\text{max}}-a_{\text{min}}}$$

(1)
Where \( a \) and \( a_x \) respectively represent the variables before and after the normalization. \( a_{\text{max}} \) and \( a_{\text{min}} \) are the maximum and minimum of the variables \( a \).

**Negative Index** The following two indexes: GDP Inflation Rate and Number of Displaced People are dealt as follows

\[
a_x = \frac{a - a_{\text{max}}}{a_{\text{min}} - a_{\text{max}}}
\]

(2)

Where \( a \) and \( a_x \) respectively represent the variables before and after the normalization.

**Implicit Index** The following six indexes: Merchandise Trade, Population Density, \( CO_2 \) Emissions Per Capita, Energy Use, Electric Power Consumption, Total Debt Service. Data within 3\%~95\% of the index are considered to be normally distributed. Nevertheless, data out of the range will be processed as follows

\[
a = \begin{cases} 
  a_{\text{max}}, & a < a_{\text{min}} \\
  a - 10 \log_{10} e, & a > a_{\text{max}}
\end{cases}
\]

(3)

Where \( a_{\text{min}} \) for \( a_{\text{max}} \) are overflow of lower and upper bound.

Besides, the Merchandise Trade data format has been in a percentage form according to the World Bank, so it can be directly applied without processing.

3. The evaluation system model of fragility

3.1. Establishing the model

The model is formulated to account for the influential factors of fragility and analyze how climate change would directly or indirectly affect the overall fragility of the country.

Since the national fragility is affected by many factors in diverse aspects, it does need human experience to evaluate the influence of those indexes on the social structure. In this case, it is necessary to take a subjective measure as long as it is logically rational. Besides, excessive pursuit of objectivity will lead to inevitable deviation. Therefore, the Analytic Hierarchy Process (AHP) method is suitable to analyze the fragility.[7] It regards a complex fragility problem as a system, decomposes the target into three aspects, and then decomposes it into multiple indexes. Through quantifying the indexes, the weights number and the total sort are calculated to help optimize the solution. So the judgment matrix for the explicit, implicit and negative indexes is established and the weights of each index are measured respectively.

3.1.1. Measuring the weights of three types of indexes. The coefficient matrix is established based on the AHP method, which refers to the human experience.

| Comprehensive Impact | Explicit Index | Implicit Index | Negative Index |
|----------------------|----------------|----------------|----------------|
| Explicit Index       | 1              | 6              | 2              |
| Implicit Index       | 1/6            | 1              | 1/7            |
| Negative Index       | 1/2            | 7              | 1              |

Table 1. The weights of three indexes.

From Table 1, it can be concluded that the weights relationship among the indexes are as follow

\[
W_E > W_N > W_I
\]

(4)

Where \( W_E, W_N, W_I \) respectively represent the weight of the explicit, implicit and negative indexes.

3.1.2. Explicit index. Although there are different levels of development around the world, freshwater is the basic need for everyone, which is the most important. This reason can explain why freshwater index outweighs that of GDP per capita growth, enrollment rate and the sanitation facility. In addition,
health is a physiological index while educational level is a demanding one. In economically backward countries, not all members have the demand for education, so the need of basic physiology and GDP growth are more essential than overall self-perfection, so the weights of the Implicit Index are displayed in the Table 2.

Table 2. The weight of the explicit index.

| Comprehensive Impact | Improved Sanitation Facilities | Renewable Freshwater | GDP Per Capita | Secondary School Enrollment |
|----------------------|-------------------------------|----------------------|----------------|-----------------------------|
| Improved Sanitation Facilities | 1                              | 1/2                 | 2              | 4                           |
| Renewable Freshwater      | 2                              | 1                   | 6              | 6                           |
| GDP Per Capita           | 1/2                            | 6                   | 1              | 3                           |
| Secondary School Enrollment | 1/4                           | 1/6                 | 1/3            | 1                           |

3.1.3. Implicit index. Among the implicit indexes, the debt can reflect the overall economic level and, in turn, affects human behavior at all levels. Electric power consumption can reflect the modern social activities more than the merchandise trade and the $CO_2$ emission do. In the civilized society, electric power consumption, as a basic element, is as important as the density of population and the energy use.

Since the degree of development is quite unequal and the global polarization is serious, population density and energy use can reflect the basic living level of the people’s life more than merchandise trade and $CO_2$ emissions do. In addition, if energy shortage exists, population density is difficult to grow. In sum, the weights of the Implicit Index are displayed in the Table 3.

Table 3. The weight of the implicit index.

| Comprehensive Impact | Electric Power Consumption | Total Debt Service | CO2 Emission | Merchandise Trade | Population Density | Energy Use |
|----------------------|-----------------------------|--------------------|--------------|--------------------|---------------------|------------|
| Electric Power Consumption | 1                            | 1/2                | 4            | 2                  | 1                   | 1          |
| Total Debt Service | 2                            | 1                  | 2            | 2                  | 3                   | 2          |
| CO2 Emission | 1/4                          | 1/2                | 1            | 1/3                | 1/3                 | 1/2        |
| Merchandise Trade | 1/2                          | 1/2                | 3            | 1                  | 1/4                 | 1/2        |
| Population Density | 1                            | 1/3                | 3            | 4                  | 1                   | 1/2        |
| Energy Use | 1                            | 1/2                | 2            | 2                  | 2                   | 1          |

3.1.4. Negative index. As for weight comparison between inflation and mortality, human life is more significant than inflation. The weights of the Implicit Index are displayed in the Table 4.

Having analyzed the weight of each index respectively, available data are constructed to identify the fragility. In order to quantify the index, the linear formula is used to determine the fragility.

$$F = E + I + N$$ (5)
Where $F$ represents the fragility, $E$, $I$, $N$ respectively represent the explicit, implicit and negative fragility index.

### Table 4. The weight of the negative index.

| Weight of the Negative Index | Mortality Impact | GDP Inflation Rate |
|------------------------------|------------------|--------------------|
| Mortality                    | 1                | 5                  |
| GDP Inflation Rate           | 1/5              | 1                  |

#### 3.2. Solving the model

Taking the fuzziness into consideration when people analyze the complex matters can avoid the shortcomings of AHP’s being too rigid, so using some relatively abstract concept to analyze these indexes is reasonable. Improvement strategy is as follows: When rating, for every element $a_{ij}, a_{ij}$ of the judgment matrix $A: (a_{ij})_{n \times n}$, we use Triangular Fuzzy Number $(M, a, b)$ to indicate the interrelationship between two indexes. The upper and lower bound $a$, $b$ respectively represent the possible highest and the lowest score. The value $M$ represents the basic evaluation of the relationship between two indexes. The weight of each index is calculated and shown in the Table 5. The weight of the index $i$ relative to the index $j$ is

$$a_{ij} = \frac{a + 4M + b}{6}$$

Having calculated the weight vectors, the fragility index can be required according to the linear relation. The distribution chart is displayed in the Figure 2. Considering the amount of countries and the fragility degree, the fragile index is stable between 0%-78%, vulnerable between 78%-92%, fragile between 92%-100%, which is shown in the Figure 3. Then the top ten extremely fragile countries are displayed in Table 6.

### Table 5. The weight of each index.

| Weight of Each Index | Weight |
|---------------------|--------|
| Explicit Index      | 0.3484 |
| Improved Sanitation Facilities | 0.12 |
| Secondary School Enrollment | 0.06 |
| Renewable Freshwater Per Capita | 0.18 |
| GDP Per Capita      | 0.06  |
| Implicit Index      | 0.0695 |
| Merchandise Trade   | 0.04  |
| Population Density  | 0.05  |
| Electric Power Consumption | 0.04 |
| Implicit Index      | 0.0695 |
| Improved Sanitation Facilities | 0.12 |
| Negative Index      | 0.3484 |
| GDP Inflation Rate  | 0.06  |

Having calculated the weight vectors, the fragility index can be required according to the linear relation. The distribution chart is displayed in the Figure 2. Considering the amount of countries and the fragility degree, the fragile index is stable between 0%-78%, vulnerable between 78%-92%, fragile between 92%-100%, which is shown in the Figure 3. Then the top ten extremely fragile countries are displayed in Table 6.
After getting the weights of the index that are consistent with each country, this paper analyzes how climate change could directly or indirectly influence the fragility.

1) Based on each index and the weight for each country, we get the corresponding score for each country’s index. When natural disaster happens, each index multiplies the corresponding coefficient of variation to obtain the new score.

2) Measuring the difference between new index score and the original index score, we get the contribution of each index value.

3) The contribution reflects the impact of natural disasters on national fragility. The larger the contribution is, the greater impact it will be. When finding the maximum contribution, the most significant factor can be acquired in national fragility.

Taking The Syrian Arab Republic for an example, the most significant index when facing climate changes is Sanitation Facilities. Thus, the condition of the medical industry could be promoted by adding the amount of institutions or experienced doctors.[8]

Collecting data from 184 countries in the past four years, quadratic smooth in time series prediction[9] is applied to predict the fragility situation of the country after five years. By adding the
influence of climate factors, the top ten fragile countries in the future are: The Syrian Arab Republic, Yemen, Eritrea, Somalia, Sudan, Curacao, New Caledonia, Tuvalu, Nigeria, Afghanistan.

4. The improved model

Due to the scope of influence and the measurement being different, the continents cannot be regarded as the same situation as countries. Since the environmental capacity of the continent is more robust, the political impact on the continent is less than that of the country. The existing models cannot satisfy the demand of measuring the fragility of continents. Therefore, some irrelevant data are deleted and some indexes are merged using linear fitting and Principal Component Analysis (PCA)[10]. The weight of Merchandise Trade is added because trade exchange booms the economic growth in continents. When qualifying the indicators, we should minimize the loss of information, so as to achieve the purpose of comprehensive analyzing the collected data. PCA is used to project the high dimensional data to low dimensional space by linear fitting.[11]

Following indexes are selected: Improved Sanitation Facilities, Merchandise Trade, Secondary Density, Electric Power Consumption, Energy Use, Total Debt Service, CO$_2$ Emissions Per Capita, GDP Inflation Rate.

Finally, inputting the impact factors into the intercontinental model, the scores of all continents after climate change can be obtained. The result shows that Europe, the Middle East, East Asia and the Pacific are extremely sensitive to climate change.

5. Conclusions

Based on the definition of fragility, the influential indexes under climate change are selected to establish the evaluation system model of fragility on basis of analytic hierarchy process (AHP). The fragility value is calculated and corresponding sensitive indexes are solved. Meanwhile, the strategies to mitigate the impact of climate change on fragility are put forward. In addition, the principal component analysis (PCA) is utilized to establish the extensible model evaluating the fragility of continents. Also, the time series prediction is applied to analyze the trend of each country’s development when affected by climate change. The result is convincing when compared with the real world.

Since climate change has worldwide impact on many aspects. Some precious experience from different fields, such as economy, biology and computer science and so on, can be referred in order to enhance resilience of the countries and take measures when affected by climate change.

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