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Assessment Model of State Fragility and its Application Based on Climate Change

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Abstract: The current main stream researches on state fragility are mostly focusing on the social, political, ecological and economic aspects. However, as one of the most critical issues on this planet, climate change now is proposed may also play an essential role in the nation's structure stability. To examine the influence that climate factor has on state fragility will be our subject in this paper. According to the concept of fragile state, we propose National Structural Stability (NSS) to comprehensively describe a country's fragility. We then introduce triple-layer NSS indicator system with the assistance of Principle Component Analysis (PCA). The system contains 17 tertiary indicators that pertain to several secondary aspects, including: climate, social, economic, ecological and political. Subsequently, we deploy Entropy Weight Method (EWM) to get the weight of indicators. Meanwhile, we set standard of state stability by K-Means Algorithm. Finally, we deliver the NSS Evaluation Model and select Democratic Republic of Congo as our practice subject. The results show a decline of evaluation score when the climate factor enabled, which proves that climate will indeed exacerbate the country's fragility. Our model is fairly robust to parameter changes, which means that minor changes in parameters do not cause significant changes in results.
Keywords: State Fragility, Indicator System, Evaluation Model, Entropy Weight Method.

INTRODUCTION

The concept of fragility has its roots in the study on natural hazards. It involves a combination of factors that determine the degree to which someone's life and livelihood is put at risk by a discrete and identifiable event in nature or in society [1]. In the 1990s, The Intergovernmental Panel on Climate Change (IPCC) introduced fragility into the impact of climate change, and initially discussed the fragility. At present, the concept of fragility has been applied to many research fields, which involve disaster management, ecology, public health, climate change; land use, sustainable development science and many others research areas [2-8].

It is a recent field of research that Understanding the fragility of the states and dealing with the consequences of it [9]. The main content of research in fragile states is development, conflict, and stability [10-11]. S. Grimm investigated the emergence, dissemination and acceptance of the notion of "national fragility" and analyzed the conceptualization process [12]. M. Baliamoune-Lutz and M. McGillivray introduced several methods for assessing national vulnerabilities and issued personal opinions and queries [13]. R. J. Haar investigated the health status of fragile states and analyzed their impact [14]. M. Francois introduced the issues fragile states faced and the harms they caused, and described the current state of aid to vulnerable countries [15].

However, with regard to the state fragility based on climate change, there have been very few results and no universally accepted method of evaluation has been specified so far. Gabor and Griffith firstly proposed a framework of fragile problem showing the possibility about people being exposed to harmful substance [16]. In 1996, Blaikie explored a model to combine the research framework of political ecology with natural disaster research [17]. In contrast to the existing research methods, there has been little focus on mathematical models, but more on the comparative analysis of case studies. Therefore, this is a very meaningful study about evaluation model on climate change.

In this paper, we have established a National Structural Stability (NSS) indicator system, which included climate change to comprehensively assess the fragility of a country. Firstly, we used the PCA to select 17 key indicators from 66 indicators in five different aspects and set up the NSS indicator system. We combined AHP and Entropy Weight Method to determine the weight of each index, and we use K-means algorithm to get the stability evaluation standards. Then we got the NSS Evaluation Model. Subsequently, we used the evaluation model to analyze the NSS of Democratic Republic of Congo and found that climate change would exacerbate the DRC's fragility. Our model is fairly robust to parameter changes, which means that minor changes in parameters do not cause significant changes in results.

National Structural Stability Indicator System

Since fragility has become an essential concept to determine a country's stability, we defined National Structural Stability (NSS) to convert the fragility into quantifiable problem. Combined with evaluation model and evaluation standard, we shall obtain direct demonstration of one country's fragility. Meanwhile, climate change also been contained as one major factor of NSS.

As there are mutual actions, mutual influences and mutual relations between a large numbers of aspects during the development of a country, it is difficult to measure NSS of a country curtly. Hence we mainly referenced the Fragile State Index of FFP [18], and combined the evaluation criteria of some institutions, such as, Country Policy and Institutional Assessment (CPIA) , Country Indicators for Foreign Policy Fragility Index(CIFP), Peace and Conflict Instability Ledger (PCIL), Failed States Index, and Political Instability Index [19-21]. According to these indicator systems, we found 66 indicators in different aspects initially.

Data Collection and Normalization

We get each case corresponding indicators data from World Bank, Fund for Peace, official websites, related documents and other channels. In the process of searching data, we found that some of the data was missing. In order to ensure the continuity of the data, we proposed the following methods: If the data changes smoothly over time, the missing data can be replaced by previous on; otherwise, we will take the average of the former and latter data to replace the missing one.

Consider there are too many indicators; we adopted the method of Principal Component Analysis (PCA) to reduce the quantity of the indicators. After our treatment, we obtained 17 indicators which are independent with one another. Since all the features have a broad range of values and alternative dimensions, in order to make all features equal, we need to normalize the data. If we don't process their value, the result of our evaluation model may be governed by one of them.

All of the 17 indicators can be classified into three types, that is, benefit-type, cost-type and moderate-type. Among these types of indexes, the bigger the benefit-type index is, the stronger the NSS will be. Correspondingly, the cost-type index has an opposite influence. Moderate-type index is better when it is closer to a specific value. Because of the different contribution of indexes, the three types of data are normalized in different ways as follows.

- **Benefit-type index**

Let C_i denotes the aggregate for the i^{th} indicator over several years. Thus the benefit-type index can be expressed as:

$$c_{ij}' = \frac{c_{ij} - c_i^{\min}}{c_i^{\max} - c_i^{\min}}, \quad i = 1, \cdots, 17; j = 1, 2, \cdots, n \tag{1}$$

Where c_{ij} is the i^{th} indicator in the j^{th} year of the region, n is the quantity of years, $c_i^{\max}$ and $c_i^{\min}$ are the largest and smallest indicator of $\mathbf{C}_i$, that is:

$$\begin{aligned} c_i^{\max} &= \max\{x_{i1}, x_{i2}, \cdots, x_{in}\} \\ c_i^{\min} &= \min\{x_{i1}, x_{i2}, \cdots, x_{in}\} \end{aligned} \tag{2}$$

- **cost-type index**

$$c_{ij}' = \frac{c_i^{\max} - c_{ij}}{c_i^{\max} - c_i^{\min}}, \quad i = 1, 2, \cdots, 17; j = 1, 2, \cdots, n \tag{3}$$

- **moderate-type index**

$$c_{ij}' = \begin{cases} 1-\dfrac{c_b - c_{ij}}{\max\{c_b - c_i^{\min}, c_i^{\max} - c_b\}}, & c_{ij} < c_b \\ 1 & , \quad c_{ij} = c_b \\ 1-\dfrac{c_{ij} - c_m}{\max\{c_b - c_i^{\min}, c_i^{\max} - c_b\}}, & c_{ij} < c_b \end{cases} \quad (4)$$

Where c_b is the best value of the indicator C_i.

Sub-system clarification

- **Politics sub-system(PSS)**

Politics plays an essential role in NSS; it directly reflects the stability of a country's structure. In this paper, we utilize Military expenditure to evaluate whether a country is capable of coping potential threaten from both internal and external. Besides, domestic credit provided by financial sector and statistical capacity score of the country are also considered as the reflection of governance ability. In addition, we also consider the impact of government corruption on the country's fragility.

- **Society sub-system (SSS)**

This sub-system directly reflects the living condition of a country's resident, such as life expectancy and Gini Coefficient. Besides, we can predict the possibility of turmoil in this country in the coming years according to these indicators.

- **Economic sub-system (ENSS)**

The economic performance of a country reflects the current financial conditions of the its people, and the country's talent pool is linked to the future development of this country. Therefore, this sub-system mainly contains two parts: economic aggregate and uneven economic development, economic decline and brain drain.

- **Ecology sub-system (ECSS)**

Ecological sub-system mainly refers to the ecological environment of this country. The natural resources of a country, especially water and energy, will have an impact on the stability of this country. Therefore, we mainly study the country's water resources, forest resources and annual carbon emissions, and use these indicators to describe the impact of ecosystems on state fragility.

- **Climate sub-system(CSS)**

In recent years, global climate change has gathered more and more attention. In our opinion, climate impacts such as the intensification of the greenhouse effect, rising sea levels and the El Niño-Southern Oscillation (ENSO) may exacerbate the fragility of a country, especially if the country's social security capacity is weak.

Indicator clarification

After the analysis of the data, we obtained 17 indicators ultimately and integrate them into five sub-systems. They are shown in the following Tab 1.

Table-1: Indicators of each sub-system

Sub-system	Indicator	Explanation
Economic sub-system (ENSS)	Proportion of primary industry C_1	It reflects the industrial structure of a country.
	Gross National Income per capita C_2	It is the total domestic and foreign output claimed by residents of a country.
	GDP growth rate C_3	It reflects the economic growth.
Society sub-system (SSS)	Population density C_4	It reflects a measurement of population per unit area.
	Urbanization rate C_5	It reflects the degree of urbanization.
	Life expectancy C_6	It represents the physical quality of life of an area.
	Gini Coefficient C_7	It reflects the fairness of income distribution.
Ecology sub-system (ECSS)	Energy use C_8	It represents a country's total energy use.
	Vegetation coverage C_9	Divide the area of vegetation by the total area of the region.
	CO_2 emissions C_{10}	It reflects the energy efficiency of a country.
Politics sub-system (PSS)	CPIA transparency, accountability, and corruption in the public sector rating C_{11}	It reflects the degree of transparency and corruption in a country.
	Military expenditure C_{12}	It reflects the military power of a country.
	Domestic credit provided by financial sector C_{13}	It reflects the financial capacity of a country.
	Statistical Capacity score C_{14}	It reflects the government's control ability.
Climate sub-system (CSS)	The incidence of extreme weather events C_{15}	Droughts, floods, extreme temperatures (% of population)
	Annual precipitation changing rate C_{16}	It reflects the changes of annual average precipitation of a country.
	Annual temperature changing rate C_{17}	It reflects the changes of annual average temperature of a country.

National Structural Stability Evaluation Model

Weight Calculation

In the previous sections, we have obtained 17 indicators of NSS, along with the data normalization approach. However, the importance of these indicators is different. Therefore, our next job is to weight the indicators. We randomly search the data of 20 countries [18]. We use the data from 20 selected countries to obtain the weights distribution of NSS indicator system.

Considering using a single method to calculate the weight might lack of contrast, we use the Entropy Weight Method (EWM) [22] and AHP [23] to perform the weighted average, and derive the correction score of each index weight. Here we mainly introduce EWM.

According to information theory, information is a measure of the degree of systematic orderliness, and entropy is a measure of the degree of systematic disorder. The larger information entropy is the more information the indicator provides, thus the indicator is more important than the others, and has a higher weight obviously. EWM uses this principle to get the weight of each evaluation index. The detailed steps as follow.

Step 1

According to the data of indicators we have got, we can standardize the data as what mentioned before. Then we can get a standardized matrix calculation as follow:

$$A_{ij} = \begin{array}{c} \text{index } C_1 \\ \text{index } C_2 \\ \vdots \\ \text{index } C_m \end{array} \begin{bmatrix} A_{11} & A_{12} & \cdots & A_{1n} \\ A_{21} & A_{22} & \cdots & A_{2n} \\ \vdots & \vdots & & \vdots \\ A_{m1} & A_{m2} & \cdots & A_{mn} \end{bmatrix} \quad (5)$$

Where m denotes the quantity of indexes of NSS, n denotes the quantity of years.

Step 2

Let denote the ratio of each indicator, it can be calculated by the following formula:

$$P_{ij} = \frac{A_{ij}}{\sum_{j=1}^{m} x_{ij}} \quad (6)$$

Where the entropy value e_i can be obtained by the following formula:

$$e_i = -k\sum_{j=1}^{m} p_{ij} \ln p_{ij} \quad (7)$$

Step 3

The correction coefficient can be expressed as:

$$r(E,S) = \frac{\sum_{i=1}^{n}(e_i - \bar{e})(s_i - \bar{s})}{\sqrt{\sum_{i=1}^{n}(e_i - \bar{e})^2}\sqrt{\sum_{i=1}^{n}(s_i - \bar{s})^2}} \quad (8)$$

Where S denotes the standard index entropy obtained by clustering a large amount of data.

Step 4

We use the following optimization model to make the entropy weight.

$$\max = \sum_{k=1}^{m} r_k W_k$$

$$s.t. \begin{cases} \sum_{k=1}^{m} W_k = 1 \\ W_k \geq 0, k = 1, 2, \cdots, m \end{cases} \quad (9)$$

According to the aforementioned optimization model, we can get the final weight. Since the correlation entropy is proportional to the weight, the final determined weight has a positive correlation with the entropy in the modified optimization model. The specific weight distribution of NSS indicator system shown as Tab.2.

Table-2: NSS System Weight Distribution Table

Sub-system	Weight(%)	Indicator	Weight(%)
Economic sub-system (ENSS)	25.4	Proportion of primary industry	56.3
		Gross National Income(GNI) per capita	23.4
		GDP growth rate	20.3
Society sub-system (SSS)	12.5	Population density	21.9
		Urbanization rate	26.8
		Life expectancy	18.7
		Gini Coefficient	32.6
Ecology sub-system (ECSS)	12.1	Energy use	31.3
		Vegetation coverage	46.6
		CO_2 emission	22.1
Politics sub-system (PSS)	29.9	CPIA transparency in the public sector rating	39.7
		Military expenditure	17.4
		Domestic credit provided by financial sector	26.5
		Statistical Capacity score	16.4
Climate sub-system (CSS)	20.1	The incidence of extreme weather events	12.8
		Annual precipitation changing rate	41.1
		Annual temperature changing rate	46.1

Evaluating Approach

In our previous work, we have identified the indicators and their weights that determine a country's NSS. Now we present a method to calculate the comprehensive score of the NSS of a country. That is:

$$Score = \sum_{i=1}^{m} w_i c_i \qquad (10)$$

Where w_i denotes the weight of the i^{th} indicator, and c_i denotes the normalized value of the i^{th} indicator.
By applying formula (1) to process the indicators of our NSS indicator system and combine the weight of which, we shall obtain the NSS score of a country by equation (10).

Evaluation Standard

However, without a comparable parameter, we can't judge the degree of fragility of a country intuitively. So it is necessary to make a reasonable standard for reference. In this section, we use K-means Algorithm (KA) [24] to complete this work.

In this algorithm, the data set A includes 17 indicators. And K denotes the number of the layer of NSS, which is 3 in our paper. The data objects are organized into 3 partitions by KA. Let μ_k denote the sort center of partitions, thus the sum of squares of the distances from the sort center can be expressed as:

$$J(c_k) = \sum_{a_i \in C_k} \|a_i - \mu_k\|^2 \qquad (11)$$

Where $J(c_k)$ is the sum of the squares of the distances from the sort center, and we have to solute the following optimization problem:

$$\min = \sum_{k=1}^{4} \sum_{i=1}^{16} d_{ki} \|a_i - \mu_k\|^2$$
$$s.t. \quad d_{ki} = \begin{cases} 1, & a_i \in c \\ 0, & a_i \notin c_i \end{cases} \qquad (12)$$

We can get assessment result according to the KA. For each index, two class centers are calculated by clustering 20 countries' data. Then the mean of the indicator centers is used as the standard boundary. We use *fragile*, *vulnerable* and *stable* to describe the stability of NSS and each sub-systems as well. The evaluating standard of overall NSS and the spider chart of sub-systems is shown in the following Tab.2 and Fig.1.

Table-3: Grading Standard of NSS

Fragile	Vulnerable	Stable
[0, 0.475967]	(0.475967, 0.695439)	[0.695439, 1]

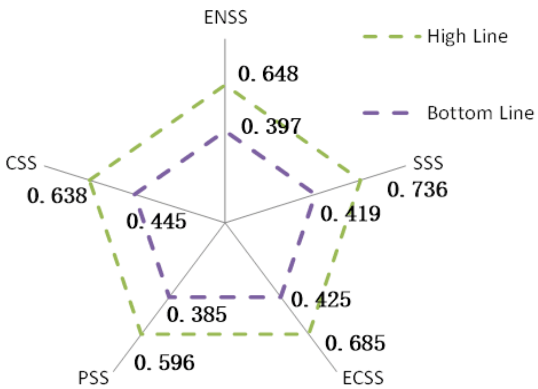

Fig-1: Grading Standard of Each Sub-system

NSS evaluation & analyze of Democratic Republic of the Congo

We choose Democratic Republic of the Congo (DRC) from Fragile State Index [18], which be classified as one of top 10 fragile states. We discuss the climate factor to the DRC's fragility by deploying our NSS indicator system, which contents five sub-systems: Climate sub-system (CSS), Ecology sub-system (ECSS), Economic sub-system

(ENSS), Society sub-system (SSS) and Politics sub-system (PSS). We derive each sub-system's historical data (Last ten years) from World Bank, NASA and official websites. Subsequently, we process the data by normalization and weight calculation procedure from aforementioned section, and convert these data into a formation that can be deployed by our evaluation model.

As we are demonstrating climate factor influencing NSS grading, we present the NSS score of DRC in two scenarios:

- Climate Factor Enabled: During this NSS evaluating process, we shall consider the climate sub-system along with the rest four. The weight distribution table (Tab. 2) of five sub-systems has been given out in the former section. By deploying the NSS Evaluation Model, we shall obtain the climate affected NSS score of DRC.
- Climate Factor Disabled: Since climate factor been removed in this NSS evaluating procedure, the weight distribution of the rest four sub-systems shall need recalibration. By applying the Entropy Weight Method, we obtain the four sub-systems' weight distribution table (Tab. 4.). Once again deploying the NSS Evaluation Model, we have the NSS score of DRC with the climate factor removed.

Table-4: Weight Distribution of four sub-systems

Sub-system	ENSS	SSS	ECSS	PSS
Weight（%）	31.8	15.6	15.2	37.4

Combined with specific evaluation standard, the NSS score curve of DRC shown as Fig.2. We also present the Spider Chart Fig.3 to visualize the score of all five sub-systems in the year 2008 and 2017.

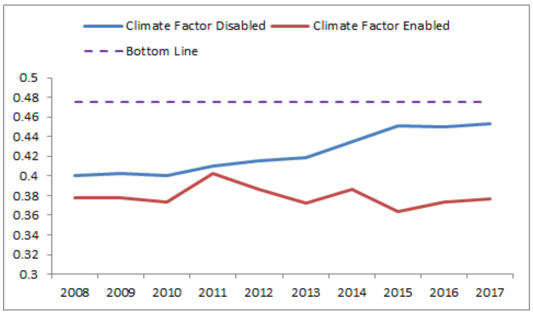

Fig-2: Overall NSS Score Curve of DRC

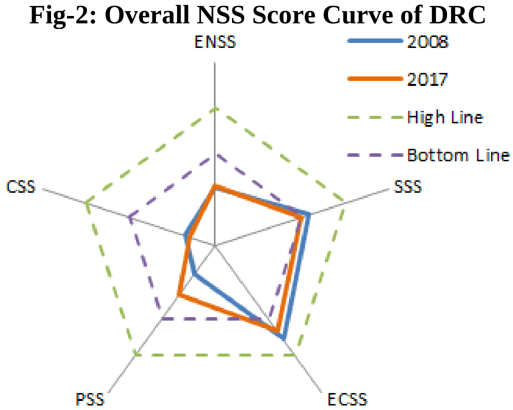

Fig-3: Score of Each Sub-system

Fig. 2 and Fig. 3 show the overall NSS score of DRC is keeping a rising trend without the interference of climate change. However, when we put climate factor into consideration, the NSS score of past decade begin to vibrate and tend to decline. The above result reflects that climate change will distinctively cause the attenuation to the NSS grading, and turned the already fragile country even worse.

CONCLUSION

We have established a National Structural Stability (NSS) indicator system, which included climate change to comprehensively assess the fragility of a country.

Firstly, we used the PCA to select 17 key indicators from 66 indicators in five different aspects and set up the NSS indicator system. We combined AHP and Entropy Weight Method to determine the weight of each index, and we used K-means algorithm to get the stability evaluation standards. Then we got the NSS Evaluation Model. Subsequently, we used the evaluation model to analyze the NSS of Democratic Republic of Congo and found that climate change would distinctively cause the attenuation to the NSS grading, and exacerbate the DRC's fragility.

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