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T3 ________________	Problem Chosen	F3 ________________
T4 ________________	E	F4 ________________

2018
MCM/ICM
Summary Sheet

State Fragility Assessment Model Based on Climate Change

Abstract

In this paper, we build a model to evaluate a country's fragility and measure the impact of climate change. The index system includes five aspects: *climate, environment, economic, politic & security* and *society*. Moreover, each aspect is subdivided into several secondary indicators.

- **Model Construction**

We separately discuss the direct and indirect impacts of climate change on Fragility.

As for direct impact, firstly, **Analytic Hierarchy Process (AHP)** Model is established to determine the weight in a subjective way. All metrics are adequately filled into the three-hierarchy structure. Secondly, to overcome the weakness of excess subjective factors in AHP, **Fuzzy Synthetic Evaluation (FSE)** is built. This model uses **entropy method** and linear weighted method to calculate weights in an objective way. Afterwards, **Aggregation Model (AM)** is used to make a tradeoff between two kinds of weight calculated by different ways.

As for indirect impact, we utilize Empirical Function (EF) to estimate how climate affect other factors and indicators. Finally, we provide a standard to identify the country's state and analyze how climate change affect state fragility in direct and indirect way.

- **Model Application**

We select two countries to apply our model, South Sudan and Malaysia.

As for **South Sudan**, we firstly apply the model to discuss how climate change may have increased fragility. Then, we analyze the results that there are ways to make state less fragile, such as Improve the environment and increase the resource utilization without climate change effects.

As for **Malaysia**, we firstly calculate fragility value is **0.2904** which belongs to stable state. With some assumptions, we depict the relation between climate factor and state fragility by a 3-D graph, and define how and when state fragility can increase with definitive indicators. Finally, we define a tipping point, and apply **Grey Forecast Model (GFM)** to predict Malaysia's fragility value trend in the future with the past ten years' data we have collected. We have predicted that it will reach the point at year **2055**.

Then, we discuss effective state driven interventions like build water conservancy facilities in frequently flood areas, and explain the effect of human intervention. Also, we give the predict cost model (PCM) to estimate the expenditure of intervention. Furthermore, we try to apply **goal programming model (GPM)** to analyze how to improve the stability of country as much as possible under the condition of limited cost.

- **Model Extension**

In order to apply the model to the "state" of different sizes, we introduce the **Parameter Correction Model (PCM)**. Through suitable correction, our model can be further used for comprehensive evaluation such as national competitiveness and smart city.

Also, we compare our model's results with Fragile States Index through a colored world map, and analyze the difference. Then, **Sensitive Analysis** is conducted to evaluate the degree of different indicators' influence. At last, the strength and weakness of our mode are discussed.

Key words: Country's Fragility, Climate Change, AM, Grey Forecast, Goal Programming

Content

CONTENT 1

I. INTRODUCTION 2

II. SYMBOLS, DEFINITIONS AND ASSUMPTIONS 2

III. PREPARING OUR MODELS 3

IV. SOLUTION FOR TASK1—MODEL ESTABLISHMENT 7

V. SOLUTION FOR TASK2—SOUTH SUDAN 12

VI. SOLUTION FOR TASK3—MALAYSIA 13

VII. SOLUTION FOR TASK4—COST PREDICT 15

VIII. SOLUTION FOR TASK5—MODEL EXPLORATION 17

IX. MODEL EVALUATION & ANALYSIS 18

X. FUTURE WORK 20

REFERENCES 21

APPENDIX A 22

APPENDIX B 26

I. Introduction

1.1 Background

With the process of globalization continues to intensify, natural disasters caused by climate change have drawn more and more attention. Assessment of state fragility also appears to be particularly important. Actually, as International Strategy for Disaster Reduction [1] thinks, fragility is determined by the community, environment, economy and other factors and reduce the country's capability to disasters.

1.2 Previous Research

Some evaluation models and research objects in previous research are shown in the table1.1 below.

Tab1.1 previous research about establishing assessment system

evaluation model	research object	author
/	Climate affects state conflicts	Ole Magnus Theisen [2]
Principal component analysis	Vulnerability of coastal cities	Hua Zhang [3]
Analytic Hierarchy Process	Metropolitan Vulnerability	Bo Li [4]
Function model	state fragility	Li Cheng [5]
/	Ecological vulnerability	Youcheng Wang [6]

1.3 Our Work

Our main task is to establish a model to determine a country's fragility and measure the impact of climate change. Referring to the previous literatures, we decided to combine two evaluation models, AHP and FSE, to establish models from subjective and objective angles respectively. Using the established mathematical model, we choose the specific country to carry out an analysis to predict and estimate the impact of climate change on the fragility of the country. Then, we define a tipping point corresponding to the model. Finally, through the correction of the evaluation index calculation, the model is applied different states.

II. Symbols, Definitions and Assumptions

2.1 Symbols and Definitions

- Symbols for index system:

Symbol	Definition
C	Climate status
E	Environment & Resource
M	Economic development
P	Political & Security
S	Social development

- None Interpretation:

State fragility: State Fragility reflects the extent of a country's failure. It covers the politics, economy, society and security of a country, and determines the fragility of all sovereign states through various data and expert surveys.

Tipping point: the point at which a series of small changes or incidents becomes significant enough to cause a larger, more important change.

2.2 Assumptions

- For the purpose of this problem “state” refers to a sovereign state or country.
- The indicators that we have chosen play a vital role in the regional instability evaluation.
- The ignored indicators influence the country fragility to a very small extent.
- The data that we have collected is enough and accurate.

III. Preparing Our Models

3.1 Establish index system

In this paper, the selection of indicators mainly refers to *CIFP, FSI and The World Bank evaluation indicators* [8]. There are mainly five aspects that count: Environment, Politics, Security, Economics, and Society. In consideration of the five aspects and task, we eventually build our index system contained five main parts: Climate status, Environment and resources, Political and security, Economic Development, Social Development. To better demonstrate our conceptual frameworks, schematic representation of index system is displayed in Figure 3.1

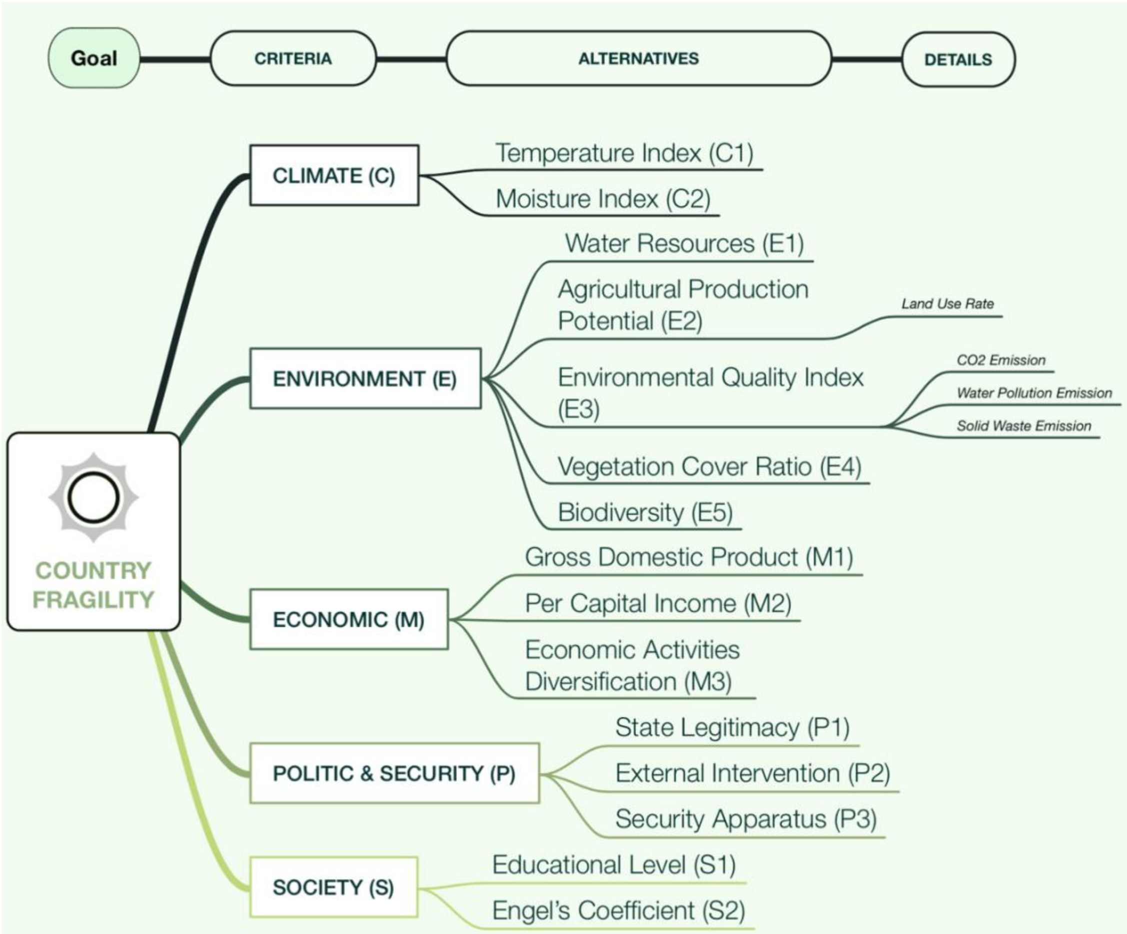

Figure 3.1 Schematic representation of indicators system

Then, we specify some important evaluation norms.

- **Climate status (C)**

  ✓ Temperature suitability index (C_1): Determined by the difference between the temperature and the optimum temperature. Because the temperature has an exponential relationship with the climate deterioration, the formula is as follows:

$$T_C = \tau^{|T-T_0|} \tag{3.1}$$

  T is the temperature of the country; T_0 is the optimum temperature for the country; τ is the deterioration factor differed from the specific country

  ✓ Moisture index (C_2): The humid index is a way to measure the degree of wetness. The wetness index is opposite to the drying index. The basic form is the ratio of surface revenue to water and the ratio of water to soil. The greater the ratio, the more humid the climate is. The calculation formula is as follows:

$$K_p = \frac{P}{E_p} \tag{3.2}$$

P annual precipitation; E_p amount of evapotranspiration

- **Environment and resources（E）**
  - ✓ Agricultural production potential index（E_2）: It mainly reflects the expectation of the development of agricultural production in the country in the future.

$$D = \frac{\sum \nabla P_{SJ}}{\sum (Y_{sj} \circ R_J)} \tag{3.3}$$

∇P_{SJ} output value potential of the j^{th} crop; Y_{sj} land productivity of the j^{th} crop; R_J constant price ratio of the j^{th} crop

  - ✓ Environmental Quality Index（E_3）: Environmental quality index is widely applied to environmental pollution evaluation and some environmental impact assessment.
    - ✧ Per capita CO_2 emission
    - ✧ Per capita water pollution emission
    - ✧ Solid waste emission
  - ✓ Biodivesity (E_5): A concept describing the degree of diversity in nature.
- **Political and security （P）**
  - ✓ State legitimacy (P_1): The representativeness and openness of government and its relationship with its citizen.
- **Economic Development（M）**
  - ✓ Economic activities diversification index (M_3):The index is used to reflect the economic structure and economic situation of the country. The calculation formula is as follows:

$$X_1 = \sum \left[Y_1 + (Y_1 + Y_2) + \cdots + (Y_1 + Y_2 + \cdots Y_N) \right] \tag{3.4}$$

$$X_2 = \frac{X_1 - X_0}{X_{max} - X_0} \tag{3.5}$$

X_1, X_0, X_{max} the original diversification index; $Y_1 \cdots Y_N$ the proportion of output value for various industrial sectors

- **Social development（S）**
  - ✓ Education level (S_1):Denoted by the educationed population ratio. The formular is as follows:

$$R_1 = \frac{P_1}{P_2} \tag{3.6}$$

P_1 colloge population; P_2 overall population

  - ✓ Engel's Coefficient (S_2): Proportion of expense on food to the consumption expense.

3.2 Data source

✧ Climate data is from World Weather Information Service and World Meteorological Organization.

✧ Environment, society and economic data is from Nation Bureau of Statistics of China.

✧ Political and security data is from The World Bank [8].

3.3 Data Preprocessing

3.3.1 Normalization

Normalization scales the data in proportion to a small specific interval. In this way, the unit restriction is removed and the data is transformed into a dimensionless pure value that facilitates comparison and weighting of different units. The specific method is as follows:

- If we want to normalize the sequence of $X = \{x_1, x_2, x_3, \dots, x_n\}$, then we should use the formula

$$y_i = \frac{x_i - \min\limits_{1\le j\le n}\{x_j\}}{\max\limits_{1\le j\le n}\{x_j\} - \min\limits_{1\le j\le n}\{x_j\}} \tag{3.7}$$

- Then we get the sequence of $Y = \{y_1, y_2, y_3, \dots, y_n\}, y_i \in (0,1)$, which is the normalized sequence without restriction.

3.3.2 Interpolation

When we collect data from Internet, we notice that some data is missing due to year. Given the fact, we have to preprocess the data from Internet. The solution adopt by us is filling the data mainly based on interpolation according to the ranking generated by the other metrics.

IV. Solution for Task1—Model Establishment

We establish a mathematical model considering climate impact both in a direct and an indirect way.

4.1 A Subjective Weights Model Based on AHP

When we try to obtain the weight of the first-class index and the weight of several second-class index, subjective judgment is ill-considered. So we choose the Analytic Hierarchy Process (AHP) as the way to conform the weighting coefficient of all the indicators in the evaluation system.

4.1.1 Model Theory

- Determine the judging matrix

We use the pairwise comparison method and one-nine method to construct judging matrix $A = (a_{ij})$.

$$a_{ik} * a_{kj} = a_{ij} \tag{4.1}$$

Where a_{ij} is set according to the one-nine method

- Calculate the eigenvalues and eigenvectors

The greatest eigenvalue of matrix A is λ_{max}, and the corresponding eigenvector is $u = (u_1, u_2, u_3, \dots u_n)^T$. Then we normalize the u by the expression:

$$x_i = \frac{u_i}{\sum_{i=0}^{n} u_j} \tag{4.2}$$

- Do the consistency check

The indicator of consistency check formula:

$$\mathrm{CI} = \frac{\lambda_{max} - \mathrm{n}}{\mathrm{n} - 1} \tag{4.3}$$

Where n denotes the exponent number of matrix.

The expression of consistency ratio:

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{4.4}$$

As we have confirmed the weighting coefficient of all the indicators in the evaluation system, now we quantify the importance of indicators.

- The evaluation grade Y_1 should be:

$$\mathrm{Y}_1 = \sum_{\mathrm{i}=1}^{5} \mathrm{CW}_i * \sum_{\mathrm{j}=1}^{mi} \mathrm{AW}_j * \mathrm{F}_j \tag{4.5}$$

CW_i denotes the weight of i^{th} criteria level factor, where AW_j is the weight of j^{th} secondary critical level factor, and F_j denotes the j^{th} secondary critical level factor.4.1.2 Results & analysis

We solve the model and obtain the following results:

$$\begin{aligned} \mathrm{Y} = {} & 0.0188E_1 + 0.0188E_2 + 0.1202E_3 + 0.0501E_4 + 0.0501E_5 + 0.2570C_1 \\ & + 0.2570C_2 + 0.0338M_1 + 0.0137M_2 + 0.0056M_3 + 0.0265S_1 \\ & + 0.0265S_2 + 0.0776P_1 + 0.0315P_2 + 0.0128P_3 \end{aligned}$$

After calculating the total consistency of the model, we get $\mathrm{CI} = 0.0096$ $\mathrm{RI} = 0.2151$ satisfying $\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} = 0.0445 < 0.1$. Therefore, our model is reasonable.

4.2 An Objective Weights Model Based on FSE

FSE (Fuzzy Synthetic Evaluation) method is based on fuzzy mathematics. It applies the membership degree principle to quantify qualitative indicators, considers various factors related to the research objects, and makes comprehensive evaluation of the plans which are restricted by many factors.

4.1.1 Model theory

- Determine factor

According to the index system, the first level index:$\Lambda = \{C, E, M, P, S\}$ The second level index: $U = \{C_1, C_2, E_1, E_2, E_3, E_4, E_5, M_1, M_2, M_3, P_1, P_2, P_3, S_1, S_2\}$

- Determine comment

According to the problem, we divide the fragility score into three level, and the relevant comments are as follows

$$\mathrm{V} = \{\text{fragile, vulnerable, stable}\} \tag{4.6}$$

- Conduct fuzzy relation matrix R

$$R = \begin{bmatrix} r_{11} & \cdots & r_{1m} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{bmatrix} \tag{4.7}$$

Among matrix R, element in line i and column j, r_{ij} refers to the membership grade of U_i to V_j.

- Determine the weights using ***Entropy Method***

According to the data matrix

$$D = \begin{bmatrix} d_{11} & \cdots & d_{1m} \\ \vdots & \ddots & \vdots \\ d_{m1} & \cdots & d_{mn} \end{bmatrix} \tag{4.8}$$

Using Entropy formula

$$x_j = -\frac{1}{\ln(m)} \sum_{i=1}^{m} d'_{ij} \ln(d'_{ij}), 1 \le i \le m, 1 \le j \le n. \tag{4.9}$$

we can get weights matrix $W_1 = (w_{11}, w_{12}, \dots, w_{1n})$

$$w_{1j} = \frac{1-x_j}{n-\sum_{j=1}^{n} x_j}, 1 \le j \le n. \tag{4.10}$$

- Determine the final score Y for each country;

$$\mathrm{Y} = W \cdot R \tag{4.11}$$

4.2.2 Results

Based on the data, we have already collected, we solve the model and obtain the following results:

$$\begin{aligned}\mathrm{Y} = 0.0172E_1 + 0.0183E_2 + 0.1301E_3 + 0.0432E_4 + 0.0613E_5 + 0.2470C_1 \\ + 0.2783C_2 + 0.0322M_1 + 0.0133M_2 + 0.0041M_3 + 0.0165S_1 \\ + 0.0365S_2 + 0.0677P_1 + 0.0215P_2 + 0.0128P_3\end{aligned}$$

4.3 Models Combination—Aggregated Model

4.3.1 Model Theory

AHP is a subjective method, it largely depends on artificial scoring. Relatively, Fuzzy Synthetic Evaluation is an objective method. It all depends on the data. To comprehensively consider the effect of subjective and objective factors, we adopt **linear weighted method**:

$$\begin{cases} \mathrm{W_1 + W_2 = 1} \\ \mathrm{Y = W_1Y_1 + W_2Y_2} \end{cases} \tag{4.12}$$

Y_1 is the evaluation grade of AHP model, YY_2 is the evaluation grade of Fuzzy Synthetic Evaluation model. All of them range from 0 to 1.

In conclusion, our final model can be defined as:

$$\mathrm{Y = W_1Y_1 + W_2Y_2} \tag{4.13}$$

4.3.2 Result & Analysis

To make a tradeoff between objective and subjective weights, we use **Programming Model** to minimum the difference from **AM** result and original result. Finally, we get the result. $\mathrm{W_1} = 0.4$ $\mathrm{W_2} = 0.6$ Therefore, $\mathrm{Y} = 0.4\mathrm{Y_1} + 0.6\mathrm{Y_2}$.

The direct impact model is:$\mathrm{Y} = 0.0178E_1 + 0.0185E_2 + 0.1261E_3 + 0.0460E_4 + 0.0568E_5 + 0.2510C_1 + 0.2698C_2 + 0.0328M_1 + 0.0135M_2 + 0.0047M_3 + 0.0205S_1 + 0.0325S_2 + 0.0717P_1 + 0.0255P_2 + 0.0128P_3$

4.4 Indirect Impact Based on Empirical Function [7]

4.4.1 Basic Theory

According to a large number of examples, the general equation of the empirical study on the impact of climate change is as follows

$$y = f(C, X) \tag{4.14}$$

$\boldsymbol{y}$ can be variable such as economy (like GDP), agricultural output value, industrial output value, immigration and political stability; Climate variables C include temperature, precipitation or extreme climate events. Explanatory variables **X** refers to other factors.

To state the problem clearly, we choose climate impact on economic as an instance. Unfolding the equation, we get the final formula:

$$y_{it} = \alpha + \beta C_{it} + \gamma X_{it} + \mu_i + \theta_{it} + \varepsilon_{it} \tag{4.15}$$

Where, according to different research objects, y_{it} is the economic variable; $\boldsymbol{C_{it}}$ includes climatic variables such as temperature, precipitation, or extreme climatic events; $\boldsymbol{X_{it}}$ refers to other influencing factors, and $\boldsymbol{\alpha, \beta}$ are constant coefficients; $\boldsymbol{i}$ is a space sample; $\boldsymbol{t}$ is time; $\boldsymbol{\varepsilon_{it}}$is the unexplainable residual, $\boldsymbol{\mu_i}$ is the variable of fixed space effect and $\boldsymbol{\theta_{it}}$ is the variable of fixed time effect.

4.4.2 Result & Analysis

As the economic factors have been taken as an example, the factors in the model are corrected.

$$M_i' = \alpha + \beta C_i + \gamma X_i + \mu_i + \theta_i + \varepsilon_i$$

the final result is as follows:

$$\begin{aligned} \mathrm{Y} = 0.0178E_1 + 0.0185E_2 + 0.1261E_3 + 0.0460E_4 + 0.0568E_5 + 0.2510C_1 \\ + 0.2698C_2 + 0.0328M_1' + 0.0135M_2' + 0.0047M_3' + 0.0205S_1 \\ + 0.0325S_2 + 0.0717P_1 + 0.0255P_2 + 0.0128P_3 \end{aligned}$$

✧ Only on account of indirect impact of climate on economic

4.5 Judgement of State Fragility

As the normalization, our model result is between 0 and 1. The closer the result is to 1, the more fragile the city is. Therefore, when $0 < \mathrm{Y} < 0.3$, the state is stable; when $0.3 < \mathrm{Y} < 0.7$, the state is vulnerable; when $0.7 < \mathrm{Y} < 1$, the state is fragile.

Table 4.2 State judgment table

State	stable	vulnerable	fragile
Fragility value	0~0.3	0.3~0.7	0.7~1

4.6 Identify how climate change increases fragility

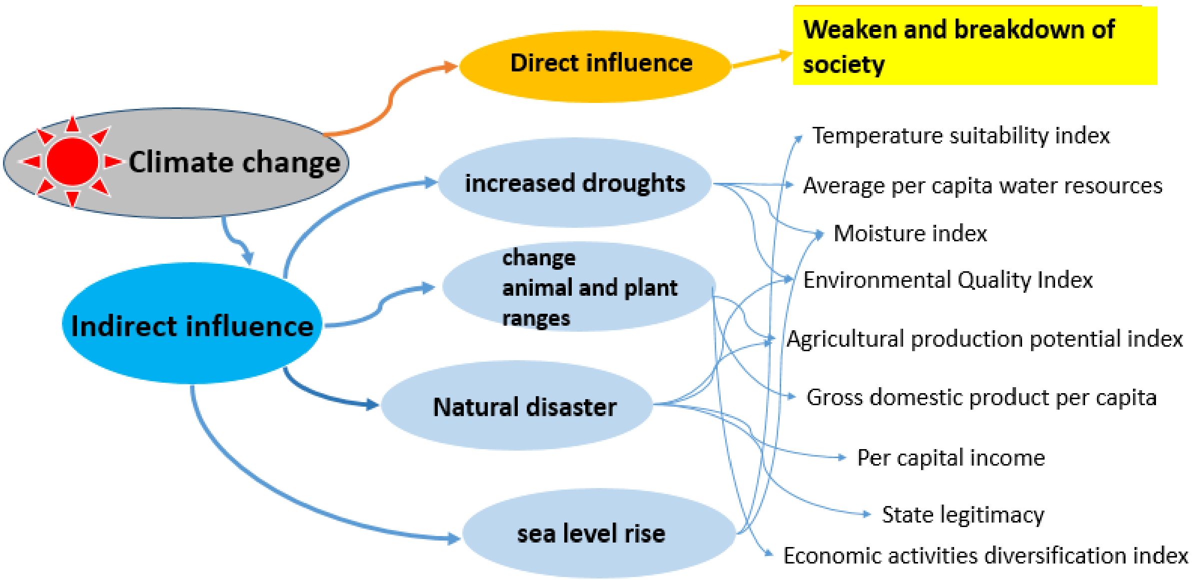

Figure 4.1 Impact of climate change

- **Conclusion from our model**

Using the empirical function, we discuss the result of how climate change affects the economic indicators and then affects country fragility as follows:

> **Changes in precipitation and temperature** results in a reduction in essential resources for livelihood, such as food or water. those affected by the increasing scarcity may start fighting over the remaining resources. Ultimately it will affect social stability and economic development.

> **Natural disasters**: Global warming and the change of climate are predicted to increase the frequency and intensity of natural disasters. Natural disasters are expected to exacerbate conflict risk primarily through economic. It will lead to loss and a weakening of government authority.

> **Sea-level change and migration**: Sea-level rise will threaten the livelihood of the populations on small island states.

V. Solution for Task2—South Sudan

We select ***South Sudan*** from top 10 most fragile states as the instance to verify our model in this section.

5.1 Basic Conditions [8]

South Sudan, a landlocked country in East Africa, is one of the world's least developed countries. The climate of country is tropical grassland. The average temperature is about 25°C.

5.2 Discuss the impact of climate change

We consider the impact of the climate in two aspects, direct impact and indirect impact.

- **Direct impact**

Considering the availability of data, we select nearly 30 years climate data from two cities in South Sudan, Malakal and Juba, to measure two indicators, Moisture index (C_1) and Temperature suitability index (C_2) [9] [10]. The results are shown in Figure 5.1.

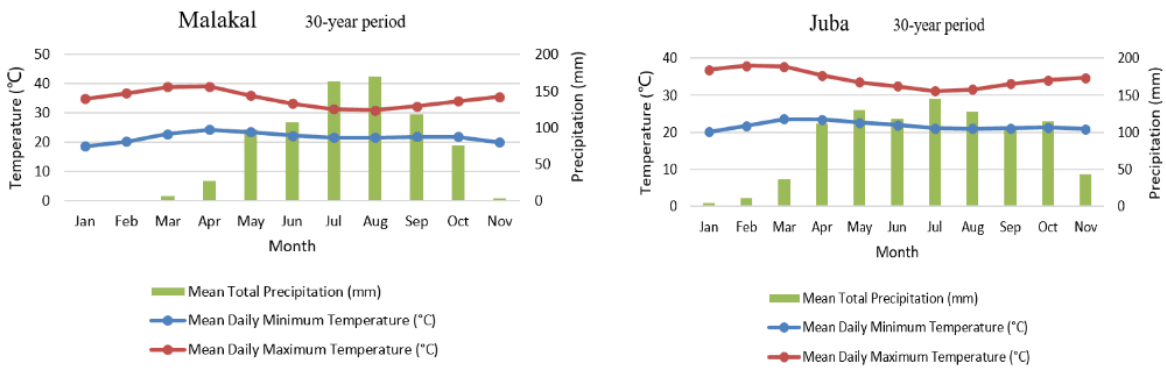

Figure 5.1 The data of Malakal and Juba

Compared with two cities, climate directly the Moisture index (C_1) and the Temperature suitability index (C_2). When the Moisture index (C_1) or the Temperature suitability index (C_2) increases, the total score AM will increase, and the state fragility will deteriorate

- **Indirect impact**

According to the report of the World Meteorological Organization (WMO) [11], during the last 10 years between 2001 and 2010, the long-term drought in South

Sudan seriously affected the state's fragility. And according to the conclusion of the Working Group II's Fifth Assessment Report of the IPCC [12], the future temperature rises of about 2℃ may lead to the global annual economic loss of 0.2% to 2% of the total income.

In combination with the reports and EF model (see formula 4.14), we can get that the deterioration in climate will hinder the development of our society and economy, which leads to a raise in fragility.

Finally, it is concluded that when the temperature rises above the optimum temperature and causes drought, it will adversely affect the economic and environmental indicators, which eventually leads to the increase of the fragility.

5.3 How to make the state less fragile without these effects

We can analyze the measures based on the model in task1.

- Environment & Resource: The largest proportion of indicators is environmental quality index (E_3). This indicator can be improved by strengthening environmental pollution control, thus effectively reducing the national vulnerability.
- Economic: From the index results, the economy is a major factor affecting South Sudan's vulnerability. So, government should Speed up economic development, especially increase GDP.
- Political & Security: state legitimacy（E_2）is most influential,so state should try to improve government credibility and reduce the Probability of dangerous incidents.
- Social development: Accelerate the construction of social infrastructure is urgent.

VI. Solution for Task3—Malaysia

We select ***Malaysia*** as the instance to verify our model in this section.

6.1 Basic Conditions [13]

Malaysia, a federal constitutional monarchy in Southeast Africa, is one of the world's developed countries. The climate of country is tropical rainforest climate. The average temperature is about 24~28°C.

6.2 Measure fragility

Taking data into the model, we obtain the fragility value **0.2904**, and it is known to be a stable state.

6.3 How to become more fragile

We only consider the direct effects of climate change on fragility including C_1 and C_2. When the variable is continuous, we get the 3D-curve showing relation between C_1, C_2 and fragility as the following figure6.1.

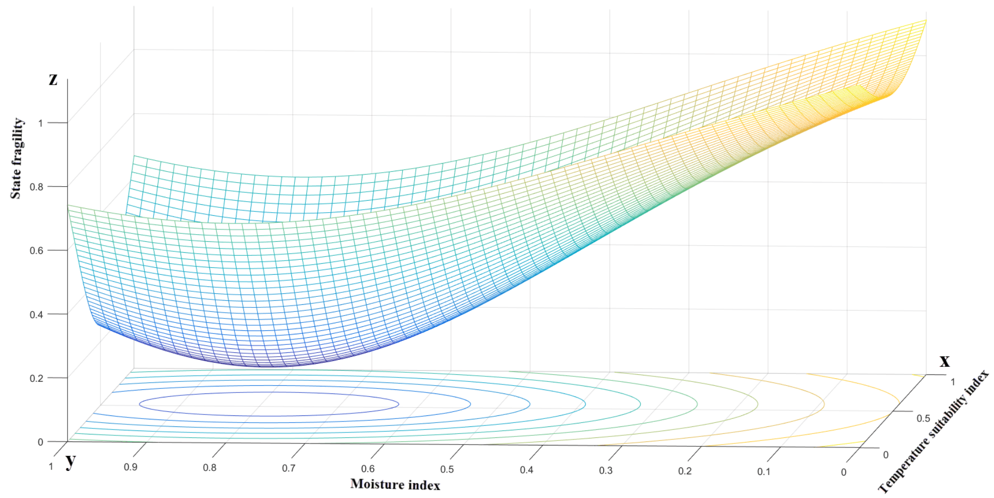

Figure 6.1 Trend of indications change

It can be obtained from the 3d-curve. When C_1 reaches 0.6 and C_2 reaches 0.8, the fragility comes to the lowest. The corresponding original data are $T_0 = 26°\text{C}$ $M_0 = 203$.

We assume that climate change temperature deterioration ratio is α, and moister deterioration ratio is β. Thus, when the deterioration satisfying

$$A\alpha + B\beta > 0 \tag{6.1}$$

A, B is the correction factor to eliminate the error caused by different between gradient along X axis and Y axis.

6.4 Predict tipping point—Grey Forecast Model

The Grey Forecast Model requires few information, convenient modeling and can get a precise outcome. It is widely used in all kinds of prediction fields.

- In this chapter, we **define** tipping point: when Malaysia begin to change from **stable to vulnerable**.

Using GFM together with the last ten years data we collect, we predict the future data. The specific data can be found in the appendix A. The data is replaced into AHP model to get the fragile value of Malaysia in different years.

- Malaysia will reach tipping point **in 2055 year.** Then, we draw a line diagram with MATLAB to get a curve of the relationship between vulnerability and year.

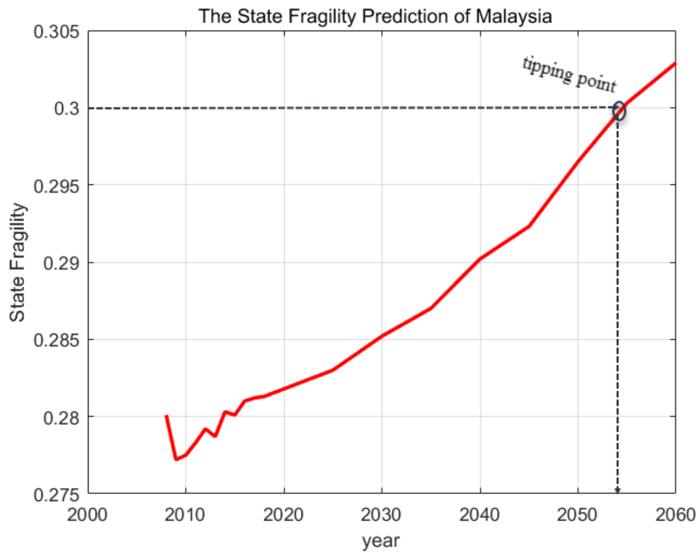

Figure 6.2 The relationship between vulnerability and year

To better demonstrate the changing trend of each indicator, schematic representation of each second-level indicator is displayed in Radar map as following figure shows.

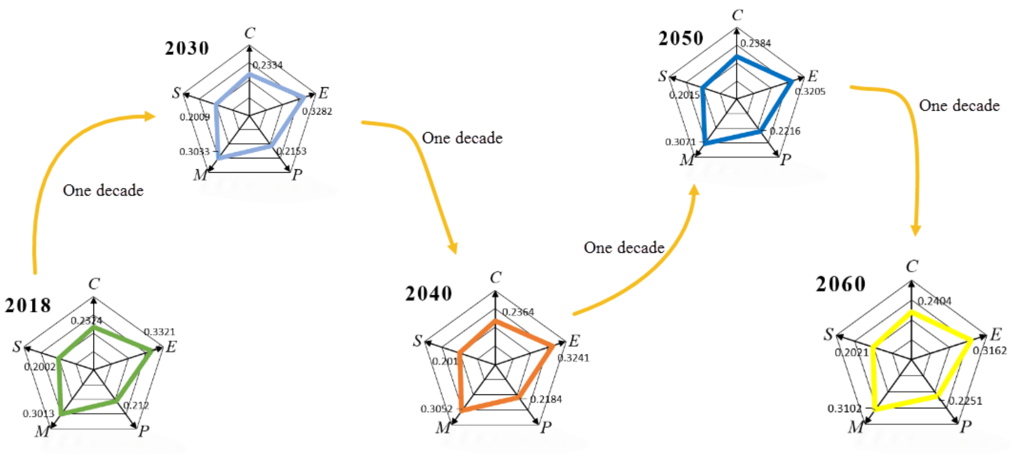

Figure 6.3 Change trend displayed in radar map

VII. Solution for Task4—Cost Predict

7.1 State driven interventions

There is a need for human interventions to decrease the risks posed by climate change in order to prevent country from becoming fragile. We analyze the interventions based on the **positive and negative coefficients** of indicators in the model. The interventions mainly fall into two categories:

- Interventions that combine the characteristics of the local environment, such as:
  1. Build water conservancy facilities in frequently flood areas.
  2. Build reservoirs in arid areas.
- General interventions, such as promote economic development, improve government authority and so on.

7.2 Explain the effect of human intervention

We discuss the effect of human intervention as follows.

- ✓ Strengthening climate change advocacy → Raising public awareness of risk → Strengthening national stability
- ✓ Establish public protection measures → Improve the ability to resist natural disasters and enhance the credibility of the government → Reduce the fragility of the country
- ✓ Strengthen the development of new technologies and improve the utilization rate of resources → Increase the gross domestic product and the per capita resource share

7.3 Predict Cost model

To calculate the cost of measures that a country takes, we divide the climate into two types: average state climate and the extreme climate.

- **Average state climate** refers to the slowly changing process of temperature and humidity, such as global warming. The average state climate is denoted as AC.
- **Extreme climate** refers to the small probability of occurrence, but strong impact, such as typhoons, tsunamis. The average state climate is denoted as EC.

We establish the following mathematical model to predict the cost of intervention for this country:

$$\text{Cost} = \sum EC_i + \sum AC_i \tag{7.1}$$

Where: EC_1 denotes direct economic losses; EC_2 denotes post-disaster maintenance costs; EC_3 denotes pre-disaster prevention costs; AC_1 denotes the cost of loss of agriculture and sideline; AC_2 denotes the maintenance costs; AC_3 denotes the invisible costs of climate.

7.4 Further discussion—goal programming

When the budget expenditure is limited, how to reduce the vulnerability more effectively is clearly what the government need to consider. We try to build a goal programming model to further analyze what interventions can be taken to better improve national stability. The mathematical expression for Goal Programming Model is displayed as follows.

$$min \quad Y^{-} \tag{7.2}$$

$$\begin{cases} Y_1 = \sum CW_i * \sum AW_j * F_j \\ Y_2 = w \cdot R \\ Y = W_1 Y_1 + W_2 Y_2 \\ W_1 + W_2 = 1 \\ \sum EC_i + \sum AC_i = const \\ 0 \le Y_m \le 1, m = 0,1,2 \\ 0 \le W_n \le 1, n = 1,2 \end{cases} \tag{7.3}$$

Where: Y^{-} denotes the state fragility after state interventions are carried out.

VIII. Solution for Task5—Model Exploration

8.1 Model works on smaller or lager "states"

It's obvious that the evaluation of the model and its application are pretty important. In this chapter, we will explain in detail how our model can be applied across all possible "states".

There are mainly **3 steps** to apply the model in different type "states". We take smaller "states" —cities for example.

✧ **Step1:** According to the selected city, adjust some **metrics** of parameter

1. Due to the impact of the cities' own factors, such as Resource-based cities, Tourism City, we need to introduce city type indicators. And some types of cities are generally less stable due to their over-unity of stability.
2. When discussing city fragility, we do not need to think about external intervention index.

✧ **Step2:** Adjust the indicator **weights**.

When take into account the impact on urban vulnerability, we need increase the proportion of economy, climate and environment, then appropriately reduce the proportion of political security indicators to make the model more flexible and adapt to city evaluation.

✧ **Step3: Solve** the Aggregation model again and **analyze** the results.

The following figure shows the steps of applying the model into all possible states

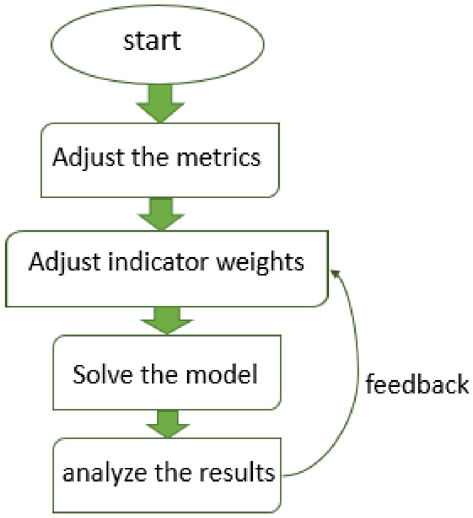

Figure 8.1 The flow chart of the model

IX. Model Evaluation & Analysis

9.1 Sensitivity Analysis

In this chapter, we run sensitivity analysis of AM in task1. Maintaining other indicators of certain and appropriate situation, we utilize MATLAB to analyze the sensitivity of climate indicators. The result is shown in figure 9.1.

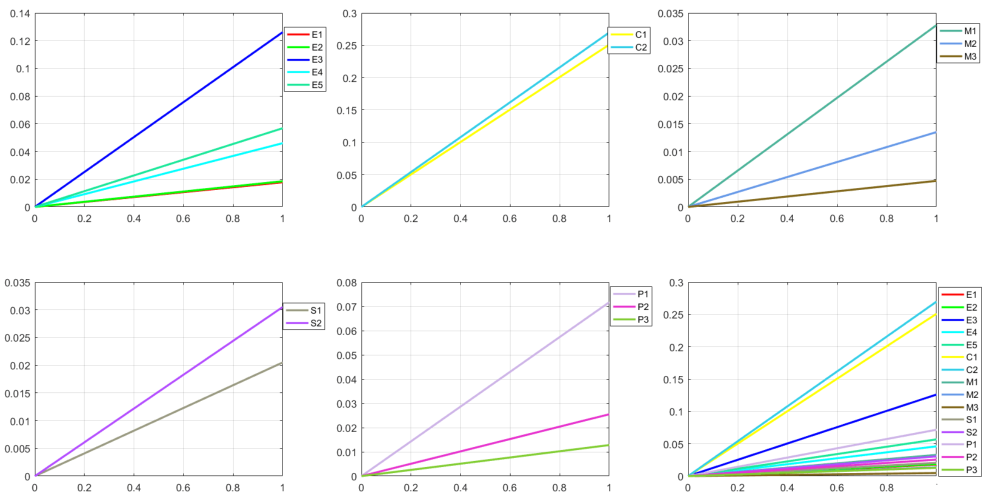

Figure 9.1 Sensitivity analysis

9.2 Model Evaluation

9.2.1 Result Comparison

We apply the model described in task 1 with other countries, and create a world map of state fragility. Then we compare the world map with the map provided by Fragile States Index [14].

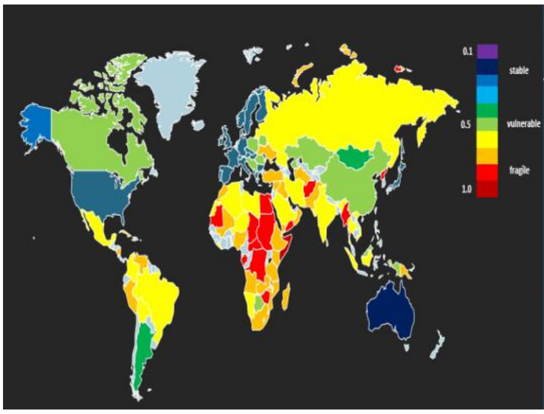

Figure 9.3 Results of our model

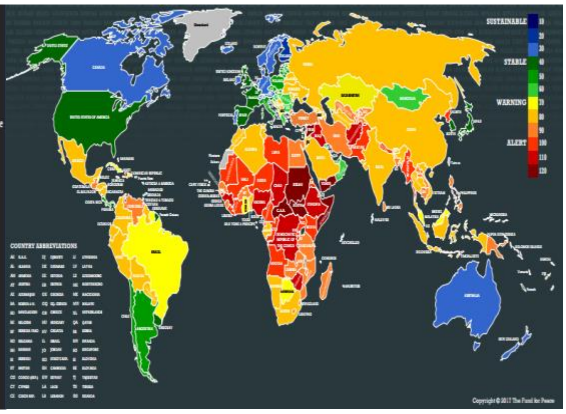

Figure 9.4 Results of Fragile States Index [14]

Conclusion:

- The model built in this paper focuses on the impact of climatic and environmental factors on state fragility. However, Fragile States Index pays more attention to political and economic impact.
- In the world map of state fragility, the fragility of Africa is generally high and on the other hand, fragility of North America is pretty low.

9.2.2 Strength & Weakness

Strength:

- Any type of state with accurate data and stable changes can measure their country fragility.
- The parameters and components represent most of the major factors that determine the state fragility, making the models relatively reliable and inclusive.
- We set up two different models to form an aggregation model. AHP includes more subjective factors while FSE appears to be more objective. The aggregation model is devoted to make clear the tradeoff between the two sides.
- We apply grey forecast model to predict the trend of indicators accurately.

Weakness:

- Weights are widely used in the model, but some weight assignments might not be the best scheme.

- the model need a lot more data to guarantee the accuracy

X. Future Work

- In task 1, this paper discusses in detail the indirect effects of climate change on other factors and indicators. In order to make the relationship between the two more intuitive, we can apply **correlation analysis** further to identify how climate change increases fragility through indirectly influences in other factors and indicators.
- In task 3, we can also apply **neural network model** for prediction. Both models have their own advantages and disadvantages. When the data is large and volatility, it is better to choose the neural network model. When the data is less and more stable, the grey prediction model is chosen as far as possible.
- Using the modified model in task 5, appropriately modifying the index and proportion according to the steps, we can evaluate national **competitiveness, smart city rankings** and so on further.

References

[1] https://en.wikipedia.org/wiki/United_Nations_International_Strategy_for_Disaster_Reduction

[2] Ole Magnus Theisen, Nils Petter Gleditsch, Halvard Buhaug. “Is climate change a driver of armed conflict?” CLIMATIC CHANGE (2013) 117:613-625

[3] Hua Zhang Urban Ecological Environment Vulnerability Measurement Division and Regulation. [J]. Chinese Environmental Science,2015,35(07):2200-2208.

[4] Bo Li. Ecological Environment Vulnerability Assessment Model and Application [D]. 2014.

[5] Li Cheng. Impacts of Climate Change on Water Resource Vulnerability in Monsoon Region of East China [J]. Progress in Climate Change Research,2015,11(01):8-14.

[6] Youcheng Wang. Study on Evaluation of Ecological Fragility in Mountain Scenic [D].2013.

[7] Liu Changyi，He Wei. “Review on the Relationship Between Climate Change and Economic Growth.” Journal of Tianjin University (Social Science),2016,18(5)：424-431.

[8] http://www.fmprc.gov.cn/web/gjhdq_676201/gj_676203/fz_677316/nsd_678308/nsdgg_678310/

[9] http://worldweather.wmo.int/en/city.html?cityId=1540

[10] http://worldweather.wmo.int/en/city.html?cityId=1541

[11] World Meteorological Organization. The global climate 2001–2010-A decade of climate extremes. WMO-No.1103.P56 https://library.wmo.int/pmb_ged/wmo_1103_en.pdf

[12] IPCC．Climate Change 2014: Impacts，Adaptation，and Vulnerability．Part a: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [M].Cambridge: Cambridge University Press，2014.

[13] http://www.fmprc.gov.cn/web/gjhdq_676201/gj_676203/yz_676205/1206_676716/1206x0_676718/

[14] Fragile States Index: http://fundforpeace.org/fsi/

Appendix A

1.The results of weight vector and consistency test of each indications using AHP

The judging matrix of l Environment and resources (E):

Judging Matrix						
1	1	0.2	0.333	0.333	Consistency Indicator (CI)	0.013911
1	1	0.2	0.333	0.333	Consistency Ratio (CR)	0.01242
5	5	1	3	3		
3	3	0.333	1	1	The result of consistency test	Pass
3	3	0.333	1	1		
Weight vector	0.072841	0.072841	0.46649	0.19392	0.19392	

The judging matrix of Climate (C) and Society (S):

Judging Matrix			
1	1	The result of consistency test	Pass
1	1		
Weight vector		0.5	0.5

The judging matrix of Economic Development (M) and Political & security(P):

Judging Matrix				
1	3	5	Consistency Indicator (CI)	0.019256
0.333	1	3	Consistency Ratio (CR)	0.033199
0.2	0.333	1	The result of consistency test	Pass
Weight vector	0.63699	0.25828	0.10473	

The judging matrix of state fragility indicators:

Judging Matrix						
1	0.333	5	5	3	Consistency Indicator (CI)	0.034015
3	1	7	7	5	Consistency Ratio (CR)	0.030371
0.2	0.143	1	1	0.333		
0.2	0.143	1	1	0.333	The result of consistency test	Pass
0.333	0.2	3	3	1		
Weight vector	0.25797	0.51395	0.052867	0.052867	0.12234	

2.Data of changes in temperature and precipitation over the last 30 years in Malakal

Month	Mean Daily Minimum Temperature (°C)	Mean Daily Maximum Temperature (°C)	Mean Total Precipitation (mm)	Mean Number of Precipitation Days
Jan	18.7	34.9	0.0	0.4
Feb	20.3	36.8	0.4	1.3
Mar	22.9	38.9	6.7	3.0
Apr	24.3	39.1	26.9	4.5
May	23.5	36.0	97.4	8.7
Jun	22.3	33.2	107.8	9.8
Jul	21.7	31.4	163.9	11.7
Aug	21.6	31.0	170.2	11.8
Sep	21.9	32.3	117.8	6.7
Oct	21.9	34.0	75.6	4.3
Nov	20.0	35.6	3.6	0.3
Dec	18.7	35.2	0.0	0.0

Data of changes in temperature and precipitation over the last 30 years in Juba

Month	Mean Daily Minimum Temperature (°C)	Mean Daily Maximum Temperature (°C)	Mean Total Precipitation (mm)	Mean Number of Precipitation Days
Jan	20.1	36.8	5.1	1.4
Feb	21.7	37.9	11.0	2.0
Mar	23.6	37.7	36.7	6.6
Apr	23.4	35.4	111.5	11.6
May	22.6	33.5	129.9	12.4
Jun	21.9	32.4	117.8	10.3
Jul	21.1	31.1	144.7	13.0
Aug	21.0	31.6	127.5	11.5
Sep	21.1	33.1	103.7	8.6
Oct	21.3	34.0	114.5	10.4
Nov	20.9	34.7	43.1	6.5
Dec	20.0	35.9	8.2	1.9

3.Data of various indicators in Malaysia in recent 10 years

year	Climate		Environment and resources					Economic			Political			Society	
	C_1	C_2	E_1	E_2	E_3	E_4	E_5	M_1	M_2	M_3	P_1	P_2	P_3	S_1	S_2
2005	25.2	195	1254.17	0.59	26.87	63.6	0.95	1379.53	0.53	9.3	5.9	5.8	6.5	29.96	10.2
2006	25.5	193	1503.06	0.63	26.34	64.7	0.96	1566.01	0.59	9.3	5.9	5.4	6.5	27.92	9.8
2007	25.8	180	1654.27	0.64	25.97	65.0	0.92	1867.77	0.69	8.3	5.9	5.1	6.5	28.59	9.5
2008	25.6	200	2064.50	0.67	24.47	65.4	0.89	2227.44	0.81	8.6	6.1	5.2	6.5	30.27	9.2
2009	25.5	184	2522.66	0.78	23.09	66.9	0.9	1929.12	0.69	10	5.9	5.0	6.8	33.75	9.1
2010	25.7	192	2855.54	0.93	21.2	68.7	0.91	2377.97	0.84	10	6.0	5.1	6.9	35.76	8.8
2011	25.8	196	3177.56	0.97	20.91	69.5	0.87	2786.71	0.97	9.2	6.5	4.8	7.4	37.13	8.5
2012	26.0	203	3500.72	1.01	19.9	70.3	0.9	3035.26	1.04	10.1	6.2	4.5	7.1	35.4	8.2
2013	25.8	189	3702.76	1.98	18.93	72.5	0.89	3124.35	1.05	11.5	6.6	4.6	6.9	35.87	7.3
2014	26.1	206	4053.20	1.92	18.52	73.4	0.93	3269.33	1.09	9.8	6.9	4.7	7.2	36.4	6.8

4. 10 most fragile countries and state fragility

rank	**country**	**state fragility**
1st	South Sudan	0.9223
2nd	Yemen	0.9221
3rd	Chad	0.9158
4th	Haiti	0.9147
5th	Sudan	0.9068
6th	Nepal	0.9068
7th	Kenya	0.9002
8th	Zimbabwe	0.8999
9th	Niger	0.8997
10th	Burundi	0.8992

5. The data of the radar map

Indicators / year	C	E	P	M	S
2018	0.2324	0.3321	0.2120	0.3013	0.2002
2030	0.2334	0.3282	0.2153	0.3033	0.2009
2040	0.2364	0.3241	0.2184	0.3052	0.2010
2050	0.2384	0.3205	0.2216	0.3071	0.2015
2060	0.2404	0.3162	0.2251	0.3102	0.2021

6. The data of state fragility by grey prediction

Time	State Fragility
2008	0.2701
2009	0.2772
2010	0.2775
2011	0.2783
2012	0.2792
2013	0.2787
2014	0.2803
2015	0.2801
2016	0.281
2017	0.2812
2018	0.2813
2025	0.283
2030	0.2852
2035	0.287
2040	0.2902
2045	0.2923
2050	0.2965
2055	0.3003
2060	0.3029

7.Indicator weight data

Methods / Indicators	AHP	FSE	AM	Methods / Indicators	AHP	FSE	AM
E_1	0.0188	0.0172	0.0178	M_1	0.0338	0.0322	0.0328
E_2	0.0188	0.0183	0.0185	M_2	0.0137	0.0133	0.0135
E_3	0.1202	0.1301	0.1261	M_3	0.0056	0.0041	0.0047
E_4	0.0501	0.0432	0.0460	S_1	0.0265	0.0165	0.0205
E_5	0.0501	0.0613	0.0568	S_2	0.0265	0.0365	0.0325
C_1	0.2570	0.2470	0.2510	P_1	0.0776	0.0677	0.0717
C_2	0.2570	0.2783	0.2698	P_2	0.0315	0.0215	0.0255
P_3	0.0128	0.0128	0.0128				

Appendix B

1. The program of AHP using MATLAB

```
clc ;clear;
%A=[1 1/3 5 5 3;3 1 7 7 5;1/5 1/7 1 1 1/3;1/5 1/7 1 1 1/3;1/3 1/5 3 3 1];
%A=[1 3 5;1/3 1 3;1/5 1/3 1];
%A=[1,1;1,1];
A=[1 1 1/5 1/3 1/3;1 1 1/5 1/3 1/3;5 5 1 3 3;3 3 1/3 1 1;3 3 1/3 1 1];
[n,n]=size(A);
[v,d]=eig(A);
r=d(1,1);
CI=(r-n)/(n-1);
RI=[0 0 0.58 0.90 1.12 1.24 1.32 1.41 1.45];
CR=CI/RI(n);
if CR<0.1
    CR_Result='Pass';
else
    CR_Result='Fail';
end
w=v(:,1)/sum(v(:,1));
w=w';
disp('The judging matrix weight vector calculation report:');
disp('Consistency Indicator CI:');
disp(num2str(CI));
disp('Consistency Ratio CR:');
disp(num2str(CR));
disp('The result of consistency test£º');
disp(CR_Result);
disp('Characteristic root:');
disp(num2str(r));
disp('Weight vector:');
disp(num2str(w));
```

2. Entropy weight method to calculate weight

```
function G=EntropyWeights(x)
a=min(x);%The minimum value of each column of the   matrix X
b=max(x);%The maximum value of each column of the   matrix X
[m,n]=size(x);
p=1/log(m);
Dir=ones(n,1);%Generating a unit array of n*1
%Standardization of index
```

```
A=x;
for i=1:m
    for j=1:n
        if Dir(j)==1
            x(i,j)=(x(i,j)-a(j)/b(j)-a(j));%High quality index treatment
        else
            x(i,j)=(b(j)-x(i,j)/b(j)-a(j));%Low quality index treatment
        end
    end
end
T=sum(x);
%calculate the sum of each column of the normalized matrix
%calculate the probability of the value of the j-th indicator of the i-th candidate
solution
for i=1:m
    for j=1:n
        q(i,j)=x(i,j)/T(j);
    end
end
%Calculate the entropy value
for i=1:m
    for j=1:n
        if q(i,j)==0
            z(i,j)=0;
        else
            z(i,j)=log(q(i,j));
        end
    end
end
e=zeros(1,n);
for i=1:m
    for j=1:n
        e(j)=e(j)+q(i,j)*z(i,j)*(-p);
    end
end
%Calculate the weight coefficient of the indicator
for i=1:n
    g(i)=1-e(i);
end
%Calculate the weights
for i=1:n
    w(i)=g(i)/sum(g);
end
G=zeros(1,m);
```