For office use only	Team Control Number	For office use only
T1 ________	82622	F1 ________
T2 ________		F2 ________
T3 ________	Problem Chosen	F3 ________
T4 ________	E	F4 ________

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Summary Sheet

Climate change can have a multifaceted impact on a country's politics, economy and society, thereby affecting the country's fragility. This paper discusses a country when and how to become a fragile country as well as the impact of climate change on a national fragility.

In order to determine the fragility of a country, to determine when a country is fragile, vulnerable and stable, and to measure the impact of climate change on the country's fragility, we establish three mathematical models and conduct analysis. By selecting two countries of greater variability, we use our model for fragility assessment and classification, respectively, and establish mathematical models to predict how and when climate change make the country become more fragile. The main work of this paper is as follows:

In Question 1, in order to comprehensively assess the fragility of each country and make classification results more accurate and reasonable, we select 60 representative countries at different stages of development and focus on the analysis of the economic, cultural, social, scientific and environmental 20 key indicators. Based on AHP, the gray relational degree and the K-means clustering are used to solve the defect that the weight of each factor of AHP is not easy to be determined. According to the index, the fragility of 60 countries is calculated and the fragility and clear it in which state. In order to determine the impact of climate change on each indicator, we use SPSS to analyze the correlation between Climate Change Performance Indicator (CCPI) and 20 indicators, and identify five direct factors affecting climate change (Cultivated Area, Forest Area, Elevation Less Than Five Meters Of The Land Area) and 3 indirect factors (GDP Per Capita, Total Social-health Expenditure).

In Question 2, we select Iraq from the ten most fragile countries as the research object and use the model of Question 1 to work out the fragile of Iraq. To remove the effects of climate change, we remove the five elements of the climate change impact from twenty indicators and use the model to calculate the national fragility with the remaining fifteen indicators. Through the comparison before and after, you can intutively show the impact of climate on the country's fragility.

In Question 3, in order to effectively compare with the result of Question 2, we select Britain for analysis. Using the model of Question 1, we can work out the fragility of Britain and conclude that Britain belongs to a stable country. In order to analyze how and when climate change makes Britain more fragile, we combine the GM(1,1) forecasting model with changes in indicators to cause fluctuations in the country's fragility and predict when Britain will become the critical point of fragile countries.

In Question 4, in order to show what kind of human intervention can mitigate the risk of climate change and prevent a country from becoming a fragile country, we take Russia with changeable climate as the object of study and compare and contrast the major intervention of climate behavior and the impact of climate change on the relationship among the five factors. Next, we determine the most effective human intervention (greening, energy conversion), the total Russian intervention cost ($ 2.47 billion) was calculated.

In Question 5, we apply the model to cities. However, many cities in the world have great differences in the aspect of climate, culture and economy, etc, and the data volume is even larger. Singapore is not only a city but also a country. According to the degree of fragility, cities are divided into three categories that can't reasonably reflect the hierarchy and difference of urban fragility. In order to work out the most reasonable number of clusters, we refer to the best clustering algorithm for solving. Finally, the use of K-means clustering algorithm for classification of fragility, which is a good solution to the problem of urban fragility analysis.

Finally, the paper carries out the promotion and evalution of the model, and analyzes the advantages and disadvantages.

Keys: Climate Change, Fragility, Grey Relation Grade Analysis based on AHP, K-means, GM(1,1), Optimal Clustering Algorithm

Contents

1 Introduction

Nowadays, the impact of climate change and the net damage costs are significant and it will change the way that humans live. It may cause the social and government departments to be weakened and collapsed, eventually leading to fragile states. Fragile countries are unable or unwilling to provide basic livelihood security to their people and they are more fragile to be influenced by external adverse factors such as climate shocks, scarce resources and political disagreements, leading to an increase in the level of national fragile. Over the past ten years, Western academia in the quantitative assessment of national fragility studies have emerged, the assessment of a number of national fragility index system, broadly divided into conceptualization, measurement index selection, and overall score calculation. [1 3] We mainly face four problems:

- Articulate our own metrics and development a mathematical model for the fragility. Define when and how a country is fragile ,vulnerable or stable
- Use our model to show in what ways the state may be less fragile without the climate effects.
- Calculate a tipping point to define what way and when climate change may push the state to become more fragile.
- Analyze the influences of the parameters, then discuss the strengths and weaknesses of our model and whether it could be applied into wide fields.

Based on the existing research, after a great deal of modeling and deduction, we set up an application model to measure the fragile of a country. We further judge the state of the country and take climate change as the breakthrough point, thinking about the ways how climate change impacts fragile. In order to prove the practicability of the model, we selected one country from the ten most fragile countries to determine the correlation between climate change and the country's fragile. In order to improve the universality of the model, we considered the ways in which climate change outside of 10 countries contributes to its fragile, and we established a critical point. To predict when a country reaches a critical point, we established a predictive model. In order to prevent countries from becoming more fragile, we analyzed models to find interventions that can mitigate climate change, and explained the impact of human intervention and the total cost of intervention. Finally, based on the applicability of the model, we perfected the model and came up with a set of more mature fragile assessment system.

2 Preparation of the Models

2.1 Assumptions

In order to improve the accuracy and applicability of the model, We make the following assumptions about establishing models process in this paper:

- The influence of topographical differences can be neglected.
- We do not take minor interactions into account between factors.
- The proportion of land area below five meters above sea level can reflect the sea level and a country's relations from the side. So we use it as one of factors to consider the fragile of the country.
- To measure the impact of climate change, after we search numerous data, we choose the Climate Change Performance Index as the basic data.
- We suppose the selected data is accurate and representative.
- When we think about the effects of the climate, we ignore extreme weather. It looks like dropping the lowest and highest score in a match calculation.

Additional assumptions are made to simplify analysis for individual sections. These assumptions will be discussed at the appropriate locations.

2.2 Notations

The primary notations used in this paper are listed in Table 1.

Table 1: Notations

Symbol	Definition
$X_i{}'$	Indicators of the i country (initial)
$y_i\left(j\right)$	The i's correlation coefficient of the j index
W_j	The weight of each indicator
S_i	Stability quantitative value
G_i	Fragility quantitative value
$c_t\left(i\right)$	The Cluster Center
c_{li}	The Climate Change Performance Index(CCPI)'S series
Δ	Fragility change value
E	The ten years fragility of the selected countries
K_{opt}	The best number of clusters

3 Problem Analysis

Problem One: To determines a country's fragility, we first select 60 representative countries at different levels and used AHP to derive the overall rankings. In the process of solving, we find it difficult to define the importance of each factor in a short period of time . So we decide to improve and extend model. We decide to use the Gray Relational Analysis to solve the stability problem and get the stability data of 60 countries. After a certain data processing, we get the fragile values. In order to classify the country, we decide to use K-Means Clustering Algorithm to given classification index. We find the Climate Change Performance Index $(CCPI)$ of 60 countries for measuring the impact of climate change, with twenty indicators, using SPSS Regression to analyze the correlation respectively . Then we get the correlation between the 20 indexes and the CCPI of countries and select the highest correlation index from it. Finally we make a classification of selected indicators.

Problem Two: We select a representative country among the top ten countries in terms of fragility provided by the title and apply it to the model in question one to get its frailty. We remove the five indicators obviously related to the climate impact from the first question ,and use the remaining 15 indicators to apply the model from the first question and recalculate the fragility. Then we calculate the difference between the data obtained and the previous data. The result we get is a quantified numerical reduction of the country's fragility after climate impacts are removed.

Problem Three: We collect 20 indicators from the UK over the past 10 years and explained how and where climate change affects national fragility. Afterwards, we calculate that the fragility of each year in the UK and used the GM (1.1) Model to predict the next ten-year fragility. And The twenty-year value is calculated by Least-squares Fitting as a function of the degree of fragility over time. We choose a country that is in second categories. By adjusting the twenty indicators constantly, we get the critical value when the country is allocated to the fragile countries, and finally we constitute a critical point.

Problem Four: We have screened several ways of human intervention and analyze them in relation to the five indicators that have the highest correlation with the climate impacts from problem one. Then we have come to impact on national fragility. And through data search we predict the total cost of intervention.

Problem Five: Our model work on bigger 'states', because the data is less affected by the special environment and the result is more accurate. In order to improve the applicability of the model in larger 'states'. We extend and improve the K-Means Clustering Algorithm to obtain a more applicable and more accurate model.

4 The First Question

4.1 Quantify National Fragility

4.1.1 AHP-Basic Model

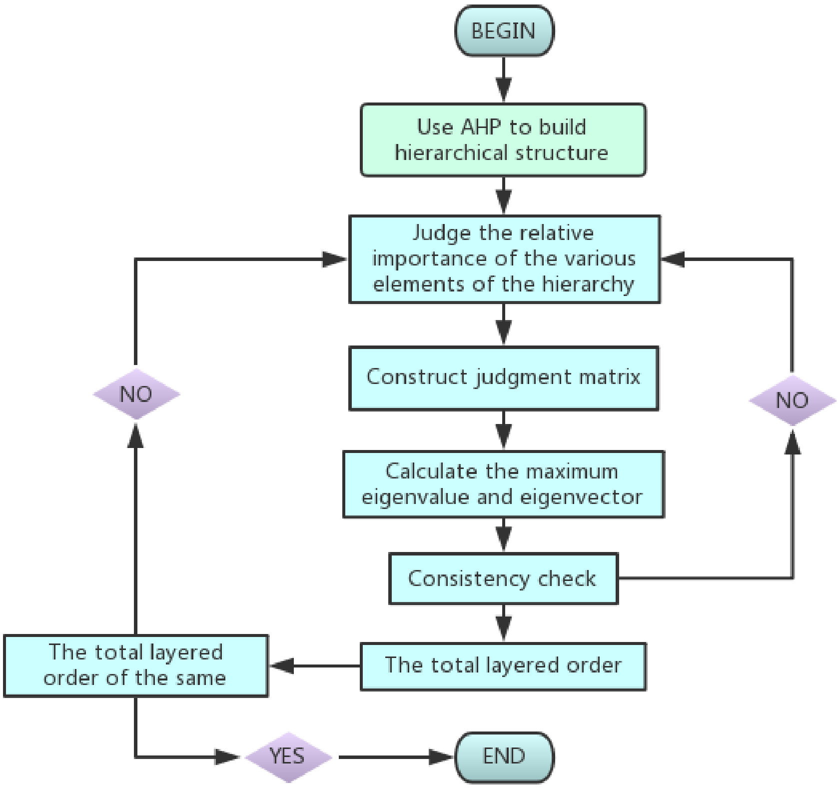

Figure 1: The basic steps of AHP

We give a brief introduction to the basic process of AHP in Figure I. The Analytic Hierarchy Process[4] takes the research object as a system, and makes the decision according to the way of decomposition, comparative judgment and comprehensive thinking. Combining qualitative and quantitative methods, it can deal with many practical problems that are unable to start with traditional optimization techniques, and have a wide range of applications. At the same time, this method enables decision-makers and decision makers to communicate with each other, and decision makers can even directly apply them, which increases the effectiveness of decision making. However, in the process of establishing the model, we find that the limitation of the analytic hierarchy process is that the importance of each factor needs to be defined when the judgment matrix is solved. Generally speaking, the importance level of each index needs to be discussed by many experts. Our team can't evaluate in the short term, that is, the importance level of each factor can not be drawn. For this problem, the index units of each country are not unified, and the numerical difference is large. The comparison, judgement and calculation process of the results in the model are rough, and are not suitable for the problem of high accuracy. Secondly, the stability and fragility ranking can only be obtained by the AHP, but the quantized value of the solution can not be transformed into a fragile quantized value. From the establishment of hierarchical structure model to the pairwise comparison matrix, people's subjective factors have great influence on the whole process, which makes the result difficult for all decision makers to accept.

4.1.2 The Gray Correlation Analysis-Extended Model

The Gray Relational Analysis[5] method is based on the similarity or dissimilarity of the trend of the development of the factors, namely 'the grey correlation degree', as a way to measure the correlation degree between the factors. The basic idea is: Based on the data sequence of factors, we study the geometric correspondence between factors by mathematical method, that is, the closer the geometry of sequence curves is, the larger the grey correlation degree between them is, the smaller the contrary. We set up a stable country where all the indicators are idealized. We use the indicators of each country with the relative index of the ideal country to get on relational level analysis, finding out the correlation coefficient of each index and the stability of the country. We use it as a weight, and then find the stable quantified values of each country. Compared with the previous basic model, we have the data first valued in the extended model, making the final steady quantized value between 0 and 1. So one minus the stable quantization value is the fragile quantization value. And the results are more accurate and reliable. In 224 countries and regions around the world, we have selected 60 countries at different levels. These include developed countries, developing countries, and underdeveloped countries. While a country's fragility is related to economic, political, social, cultural and other factors.We select the most representative 20 indicators as criteria, such as: gdp birth rate, mortality, water resources per capita and so on. Each country's indicators have accurate data.[6 10]

- Date processing: We select 60 countries, including developed countries, developing countries and underdeveloped countries. Each country has 20 quantitative indicators as a criterion, such as: GDP, birth rate, death rate, per capita water resources, etc. We use array to representative the indicators of country i:

$$X_i{}' = \left(x_{i(1)}{}', x_{i(2)}{}', x_{i(3)}{}', ..., x_{i(20)}{}'\right)(i = 1, 2, ..., 60)\,. \tag{1}$$

  Among them, $x_{i(j)}{}'$ represents item j of the i country. Since the evaluation indexes usually have different dimensions and orders of magnitude, they cannot be compared directly. In order to ensure the reliability of the results, it is necessary to normalize the original quantitative data. Generally, there are two kinds of processing methods: mean and initial value processing, and we use initial value processing. That is:

$$X_{i(j)} = \frac{x_{i(j)}{}' - x'_{(j)min}}{x_{(j)max}{}' - x_{(j)min}{}'} \tag{2}$$

Among it, $X_{(j)min}{}'$ is the minimum of the j indicator in 60 countries and $X_{(j)max}{}'$ is the maximum of the j indicator in 60 countries. So we get the after processing array:

$$X_i = \left(x_{i(1)}, x_{i(2)}, x_{i(3)}, ..., x_{i(20)}\right) (i = 1, 2, ..., 60) . \quad (3)$$

- Model establishing: We select the reference sequence:

$$X_o = \left(x_{o(1)}, x_{o(2)}, x_{o(3)}, ..., x_{o(20)}\right) = (1, 1, ..., 1) . \quad (4)$$

The comparison sequence is:

$$X_i = \left(x_{i(1)}, x_{i(2)}, x_{i(3)}, ..., x_{i(20)}\right) (i = 1, 2, ..., 60) . \quad (5)$$

Correlation coefficient between the j index of the i evaluation object and the optimal index of the j index is obtained by the method of association analysis. That is:

$$y_{i(j)} = \frac{a + b\rho}{\theta i\,(j) + b\rho}. \quad (6)$$

Among it:

$$\begin{cases} \theta_{i(j)} = \left| x_{i(j) - x_{o(j)}} \right|; \\ a = \underset{1 \le i \le 60}{min} \underset{1 \le j \le 20}{min}\, \theta i\,(j)\,; \\ b = \underset{1 \le i \le 60}{max} \underset{1 \le j \le 20}{max}\, \theta i\,(j)\,; \\ \rho = 0.5. \end{cases} \quad (7)$$

ρ is the resolution coefficient. It's value range of 0 to 1. When taking $\rho = 0.5$ directly, usually it's the best resolution.

- Next, we calculated the average correlation coefficient for each of the 60 countries:

$$Z_j = \frac{1}{60} \sum_{i=1}^{60} y_{i(j)}\,(j = 1, 2, ..., 20) . \quad (8)$$

The greater the Z_j ,the higher the correlation with the optimal index, the smaller the Z_j , the lower the correlation with the optimal index. So we can use Z_j as a measure of the weight of the indicators. We calculate the weight of each indicator:

$$W_j = \frac{Z_j}{\sum_{j=1}^{20} Z_j}\,(j = 1, 2, ..., 20) . \quad (9)$$

The level of stability in each country can be quantified as follows:

$$S_i = \sum_{j=1}^{20} X_{i(j)} \cdot W_j = X_{i(1)} \cdot W_1 + X_{i(2)} \cdot W_2 + ... + X_{i(20)} \cdot W_{20}\,(i = 1, 2, ..., 60) . \quad (10)$$

The level of fragility in each country can be quantified as follows:

$$G_i = 1 - S_i. \quad (11)$$

4.2 K-Means Clustering Algorithm - Category

After quantifying the level of stability and fragility in each country, we need to classify the data into three categories. Therefore, two distinguishing cut-off values are obtained, respectively, the cut-off value of a stable country and a vulnerable country and the cut-off value of a vulnerable country and a fragile country.

4.2.1 Model Establishing

According to model 1, we have sorted the fragility degree of 60 countries quantitatively. Next, we use K-Means Cluster Algorithm to divide 60 countries into three categories: fragile countries ,vulnerable countries and stable countries. The basic idea of K-Means Cluster Algorithm is to divide N objects into K clusters. The clustering results should make the objects of high similarity be divided into the same cluster, while the larger difference objects are stored in different clusters. The algorithm steps are as follows: The process of K-means Clustering Algorithm is as follows.

- Selecting k objects at random, each representing the initial mean or center of a cluster;
- For each remaining object, it is assigned to the nearest (or most similar) cluster based on its distance from each cluster center;
- Calculating the new average of each cluster to get the updated cluster center;
- Repeating until the criteria function converges;

4.2.2 Algorithm Steps

Input: The level of fragility of 20 countries quantitative value

$$G = \{G_1, G_2, ..., G_{20}\}\,. \tag{12}$$

The number of clusters:k=3

- In the data, setting G randomly selected three objects $G_a, G_b, G_c\ (a, b, c \in [1, 20])$ as the initial cluster center $c_{1(1)}, c_{1(2)}, c_{1(3)}$.
- Calculating the distance from each object in data set G to cluster centers $c_{t(1)}, c_{t(2)}, c_{t(3)}$. Which is:

$$\begin{vmatrix} G_i - c_{t(1)}; \\ G_i - c_{t(2)}; \\ G_i - c_{t(3)}. \end{vmatrix}, (i = 1, 2, ..., 20)\,. \tag{13}$$

The t is the number of iterations. Assigning the minimum distance for each object in data set G to the corresponding cluster:

$$min\left\{\left|G_i - c_{t((1))}\right|, \left|G_i - c_{t((2))}\right|, \left|G_i - c_{t((3))}\right|\right\}(i = 1, 2, ..., 20)\,. \tag{14}$$

- Calculating the average of all objects in each cluster, using this average as a new cluster center:

$$C_{t+1(d)} = \frac{\sum G_{t(d)}}{N_{t(d)}}\,(d = 1, 2, 3)\,. \tag{15}$$

Among it, $\sum G_{t(d)}$ represents the sum of all the objects in the d cluster at the t iteration; $N_{t(d)}$ represents the number of objects in the d cluster at the t iteration; $C_{t+1(d)}$ represents the d cluster center value at the $(t+1)$ iteration.

- If the clustering center of each cluster no longer changes or the members of the cluster no longer change, the algorithm ends; Otherwise, return to the second step to continue the iteration loop.

4.3 SPSS Linear Regression-Analyze the Correlation Between Climate Change and Indicators

The Climate Change Performance Index(CCPI) can assess and rank the efforts made by major carbon emissions economies in the world to control climate change. We look for the Climate Change Performance Index of 60 countries. Some of these countries are shown in Figure II. The climate change performance in-

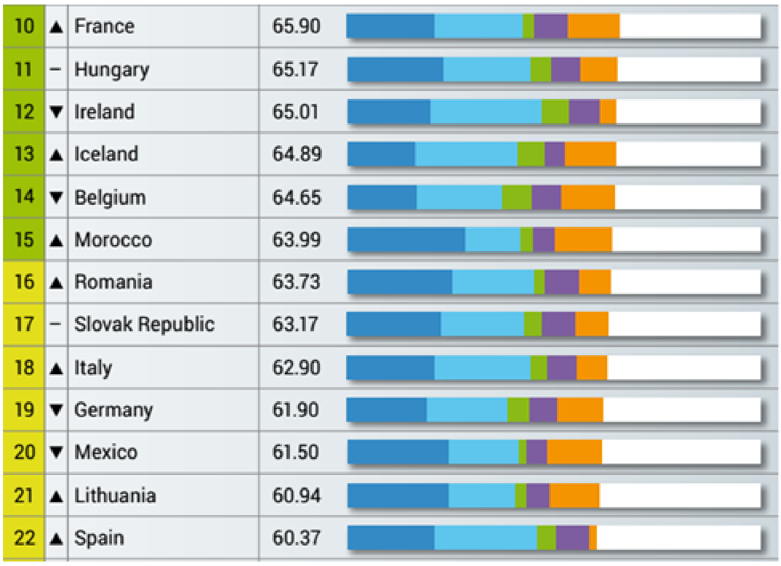

Figure 2: Partial nationsąŕ Climate change performance index

dex for the selected 60 countries $C_{li} = (C_{li}(1), C_{li}(2), ..., C_{li}(60))$, will be used to do correlation analysis with 20 indicators $Y_j = (y_1(j), y_2(j), ..., y_{60}(j))\, j = 1, 2, ..., 20$. In order to achieve this goal,we use SPSS Regression for correlation analysis.And then select the most relevant indicators.Among them, some of the indicators can be directly affected by the climate, and some indicators can be indirectly affected by the climate.The specific distinction we will discuss in the model solution.

4.4 Analysis of programming results

The relationship between fragility, indicators, and climate change performance index is shown in Figure III. Using the above model, the stability of 60 countries

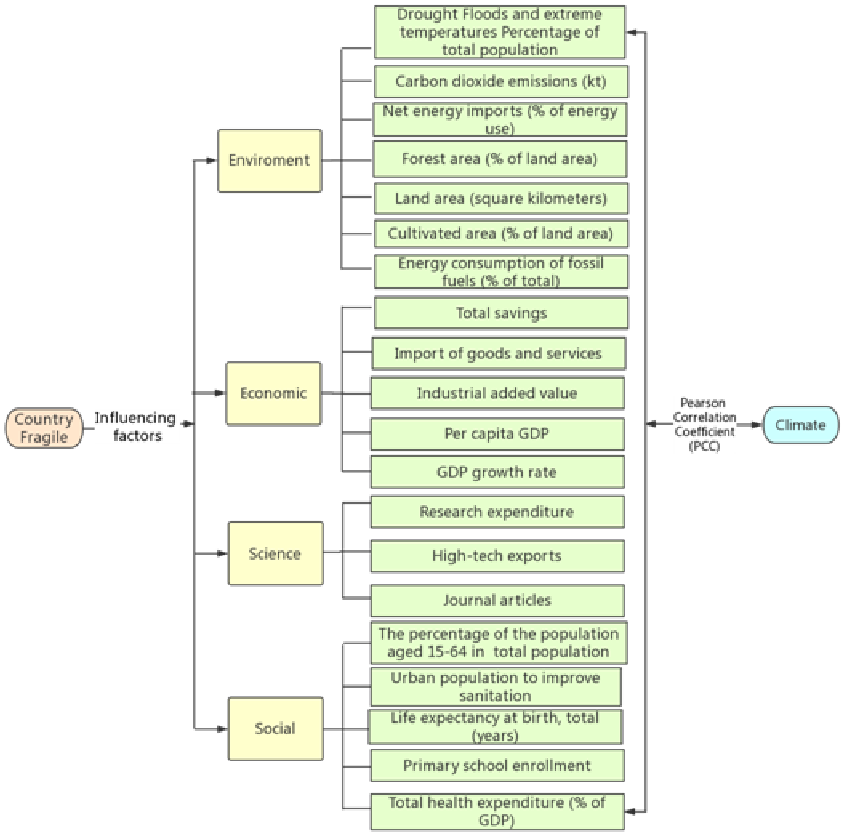

Figure 3: Relationship between fragility and indicators

is solved according to 20 indicators, and then the fragility is calculated. Finally, all countries' fragility are clustered. The results are distributed in Figure IV. Among them, the blue area represents a stable country, the orange area represents a vulnerable country and the red area represents a fragile country. The lower-left histogram shows the fragility of the most four fragile countries. The countries in each category are ranked according to their fragility, and the maximum and minimum values of fragility are extracted from each category as shown in Figure V. It can be seen from the figure: the demarcation value of the fragility between the fragile country and the vulnerable country located in the interval $[0.6758, 0.7572]$, and we take the median 0.7165.The demarcation value of the fragility between the stable country and the vulnerable country located in the interval $[0.5397, 0.5461]$, and we take the median 0.5429. Then we can come to determine the type of crite-

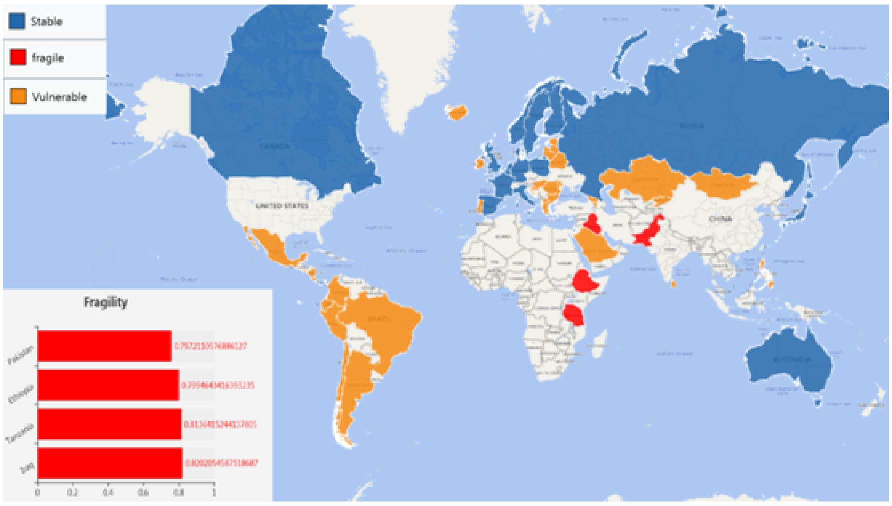

Figure 4: Fragile-Vulnerable-Stable Nation Map

The National Category Fragility	Fragile Country		Vulnerable Country		Stable Country	
maximum	Iraq	0.8202	El Salvador	0.6758	Poland	0.5397
minimum	Pakistan	0.75721	Saudi Arabia	0.5461	Japan	0.4090

Figure 5: Maximum and minimum fragility in every category

ria:

$$fragilityG = \begin{cases} (0, 0.5429) & stable; \\ (0.5429, 0.7165) & vulnerable; \\ (0.7165, 1) & fragile. \end{cases} \tag{16}$$

Next we use the climate change performance index of each country and 20 indicators to carry on correlation analysis separately. we use SPSS Regression Analysis to solve the correlation degree. The result is shown in Figure VI. From the Fig-

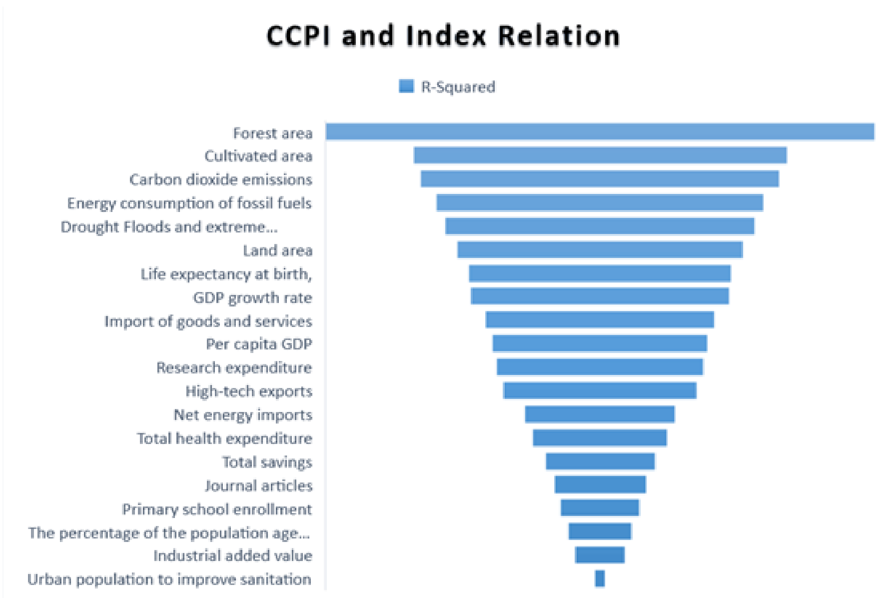

Figure 6: CCPI and Index Relation

ure VI, the most relevant indicators to the climate change performance index are shown in Figure VII. From the five indicators, climate change can directly or indi-

Related indicators：	Relevance with the CCPI：
Forest area（percentage of the total land area）	+0.749
cultivated area（percentage of the total land area）	+0.509
Per capita GDP	+0.488
Social-health Total expenditure (percentage of GDP)	+0.445
Elevation of land area below five meters（percentage of the total land area）	+0.422

Figure 7: The most relevant indicators to the climate change performance index

rectly affect certain indicators, and then affect the national fragility. For example, as global warming leads to sea level rise, the area of land below five meters in elevation is reduced and the national fragility increases. The tropical, arid climate leads to arid desertification of land, the reduction of arable land and forest area, and then the fragility of the nation will increase. These are direct indicators of climate change impact. Sudden change in temperature or extreme weather can lead to the spread of infectious diseases and flu. As a result, the national Social-health Total expenditure will increase, the national fragility will increase. Or the warm climate will be more suitable for the development of the agricultural as well as manufacturing industry,and then promote the growth of national per capita GDP.Eventually,the national fragility will reduce. These are indirect indicators of climate change.

5 The Second Question

5.1 Application of the Model of Question 1

In Question 1, we have used model 1 to find out the weight of 20 indicators, the fragility of 60 countries and the demarcation points of the three stable- fragility states. We think that the weights of all the indicators in solving the problem one generally stabilize. After initializing the parameters of each selected country, we can calculate the selected country's fragility based on the above weights.

$$G = 1 - \sum_{j=1}^{20} x\left(j\right) \cdot w\left(j\right) = 1 - \left[x\left(1\right) \cdot w1 + x\left(2\right) \cdot w2 + ... + x\left(20\right) \cdot w20\right]. \quad (17)$$

In Question 1, we get the five indicators that are most relevant to climate change through the correlation analysis of climate change indices of various countries with 20 indicators, namely per capita GDP , total social-medical expenditure , cultivated land cover, forest cover, and the elevation below 5 meters . We remove the five indicators from the 20 indicators, leaving the remaining 15 indicators the same weight, that is, still using the correlation coefficient solved by the model as a weight, the country in the absence of climate factors under the influence of fragility degrees have the following algorithm:

$$G' = 1 - \sum_{j=1}^{15} x(j) \cdot w(j) = 1 - [x(1) \cdot w1 + x(2) \cdot w2 + ... + x(15) \cdot w15]. \quad (18)$$

In summary, changes in vulnerability are as follows:

$$\Delta = G' - G. \quad (19)$$

Among them:

$$\begin{cases} \Delta > 0 \quad Climate \quad factors \quad mitigate \quad national \quad fragility; \\ \Delta < 0 \quad Climate \quad factors \quad exacerbates \quad national \quad fragility. \end{cases} \quad (20)$$

5.2 Programming Solution

According to the question, we choose Iraq as the research object and solve the fragility of Iraq by using the model in question 1:

$$G = 0.8193323006004134. \quad (21)$$

We remove the 5 indicators that are most relevant to climate change from the 20 indicators and use only the remaining 15 indicators to solve the fragility of Iraq:

$$G' = 0.785308366888869243. \quad (22)$$

Solve the difference of before and after:

$$\Delta = G' - G = -0.1080146391154416 < 0 \quad (23)$$

Therefore, in the absence of the impact of climate change, the country's fragility will be reduced by 0.108, in other words, the country is more stable. So climate change has made Iraq more fragile. Combined with the actual situation, we can determine how climate change increase the fragility of this country. 1. The climate of Iraq: The northeastern mountainous area has Mediterranean climate and the rest has tropical desert climate with high temperature and few rainfall. The crisis of water resources and the sandstorms have become the primary factor in increasing the country's fragility. 2. War: The use of inumerable non-conventional weapons, such as depleted uranium bombs and cluster bombs, in the war, causing serious environmental damage and endangering the Iraqi people's long-term physical and psychological health and environment. Only for depleted uranium bombs, the research data show that the fine particles generated after the bombardment of depleted uranium will destroy the ecological environment for a long time, resulting in obvious increase of tumor, cardiovascular and nervous system diseases in the contaminated area. It may also lead to cataracts, hematopoietic system disorders and births decreased ability to even die. That anthropogenic change of climate factors has increased the country's fragility.

6 The Third Question

6.1 Distinguish the Type of Country Selected

In Question 2, we use this model to address the fragility of a fragile country. We think there is some similarity between Question 2 and Question 3 in that we can solve and classify the fragility of a country. In view of this problem, we select the UK as the research object. On the basis of initializing the index data of all selected indicators after collecting the parameters of selected countries, we use the model of the first question to solve the national fragility.

$$G = 1 - \sum_{j=1}^{20} x\left(j\right) \cdot w\left(j\right) = 1 - \left[x\left(1\right) \cdot w1 + x\left(2\right) \cdot w2 + ... + x\left(20\right) \cdot w20\right] = 0.52173550914844391. \tag{24}$$

In Question 1, we have roughly obtained the cutoff value of 0.5429 between stable and vulnerable countries and the cutoff value of 0.7165 between vulnerable and fragile countries. The selected country fragility G is compared with the two cutoff values.

$$G = \begin{cases} (0, 0.5429) & belongs \quad to \quad the \quad stable \quad countries; \\ (0.5429, 0.7165) & belongs \quad to \quad the \quad vulnerable \quad countries; \\ (0.7165, 1) & belongs \quad to \quad the \quad fragile \quad countries. \end{cases} \tag{25}$$

So Britain is a stable country.

6.2 Predict National Vulnerability

After we have completed the classification of the selected countries, we need to collect 20 indicators of the country for nearly a decade and use the second of the two algorithms to calculate the annual vulnerability. Nearly a decade of fragility constitutes an array:

$$E = (e_1, e_2, ..., e_{10}) = \begin{pmatrix} 0.519709943275091 \\ 0.513640503543797 \\ 0.512682080322897 \\ 0.513886398362205 \\ 0.514331527543557 \\ 0.515581997027318 \\ 0.518410770717033 \\ 0.520119557692043 \\ 0.521735509148443 \\ 0.520844841376714 \end{pmatrix}^T \tag{26}$$

To predict the fragility of this country in the coming years, we use the Gray Prediction GM(1.1) Model.

6.2.1 GM(1.1) Model

- Model establishment: Original fragility data:

$$E = \left\{ f^{(0)}(1), f^{(0)}(2), ..., f^{(0)}(10) \right\} = \{e_1, e_2, ..., e_{10}\}. \tag{27}$$

The original data is accumulated oncečž

$$f^{(1)}(1) = f^{(0)}(1), \tag{28}$$

$$f^{(1)}(2) = f^{(0)}(2) + f^{(1)}(1), \tag{29}$$

$$f^{(1)}(3) = f^{(0)}(3) + f^{(1)}(2), \tag{30}$$

$$... \tag{31}$$

$$f^{(1)}(10) = f^{(0)}(10) + f^{(1)}(9). \tag{32}$$

Create a data matrix:

$$g^{(1)}(2) = 0.5 \cdot \left[f^{(1)}(1) + f^{(1)}(2) \right], \tag{33}$$

$$g^{(1)}(3) = 0.5 \cdot \left[f^{(1)}(2) + f^{(1)}(3) \right], \tag{34}$$

$$... \tag{35}$$

$$g^{(1)}(10) = 0.5 \cdot \left[f^{(1)}(9) + f^{(1)}(10) \right]. \tag{36}$$

According to the GM (1.1) theorem:

$$A = \begin{pmatrix} f^{(0)}(2) \\ f^{(0)}(3) \\ ... \\ f^{(0)}(10) \end{pmatrix}, B = \begin{pmatrix} -g^{(1)}(2) \\ -g^{(1)}(3) \\ ... \\ -g^{(1)}(10) \end{pmatrix}, \begin{pmatrix} \alpha \\ \beta \end{pmatrix} = \left(B^T B \right)^{-1} B^T A. \tag{37}$$

Albino equation:

$$f^{(0)}(q) + \alpha g^{(1)}(q) = \beta \frac{df^{(1)}}{dts} + \alpha f^{(1)} = \beta. \tag{38}$$

$f^{(1)}(1) = f^{(0)}(1)$,get the response function:

$$\begin{cases} \hat{f^{(1)}}_{(q+1)} = \left(f^{\{1\}}_{(1)} - \frac{\beta}{\alpha} \right) e^{-aq} + \frac{\beta}{\alpha}; \\ \hat{f^{(0)}}_{(q+1)} = \hat{f^{(1)}}_{(q+1)} - \hat{f^{(1)}}_{(q)} q = 1, 2, ..., 9; \\ \hat{f^{(1)}}_{(1)} = f^{(1)}_{(1)}. \end{cases} \tag{39}$$

Solve and get the forecast data from 2008 to 2017:

$$\left\{ \hat{f^{(0)}}_{(1)}, \hat{f^{(0)}}_{(2)}, ..., \hat{f^{(0)}}_{(10)} \right\}. \tag{40}$$

Original data:

$$\left\{ f^{(0)}_{(1)}, f^{(0)}_{(2)}, ..., f^{(0)}_{(10)} \right\}. \tag{41}$$

Compare the accuracy of the two tests: Residual sequence:

$$\varepsilon^{\circ} = \left(\varepsilon^{\circ}(1), \varepsilon^{\circ}(2), ..., \varepsilon^{\circ}(3)\right) = \left(f^{(0)}_{(1)} - \hat{f^{(0)}}_{(1)}, f^{(0)}_{(2)} - \hat{f^{(0)}}_{(2)}, ..., f^{(0)}_{(10)} - \hat{f^{(0)}}_{(10)}\right). \tag{42}$$

Relative error sequence:

$$\varphi = \left(\left|\frac{\varepsilon^{\circ}(1)}{f^{(0)}_{(1)}}\right|, \left|\frac{\varepsilon^{\circ}(2)}{f^{(0)}_{(2)}}\right|, ..., \left|\frac{\varepsilon^{\circ}(10)}{f^{(0)}_{(10)}}\right|\right). \tag{43}$$

Mean relative error:

$$\overline{\varphi} = \frac{n}{1}\sum_{i=1}^{10}\left\|\frac{\varepsilon^{\circ}(i)}{f^{(0)}_{(i)}}\right\|. \tag{44}$$

If the average relative error is within the allowable range, then the model is applicable and the above response function can be used to solve the fragility of the next ten years.

- Model Solving: Ten years of Britain's fragility is substituted into model III to find the average relative error:

$$\overline{\varphi} = 0.042 < 0.05. \tag{45}$$

That is, the accuracy test is passed, the predicted data is highly consistent with the original data, and this model is applicable.We use the original data and response function to solve the fragility of the next ten years in Figure VIII. So we get the regression equation:

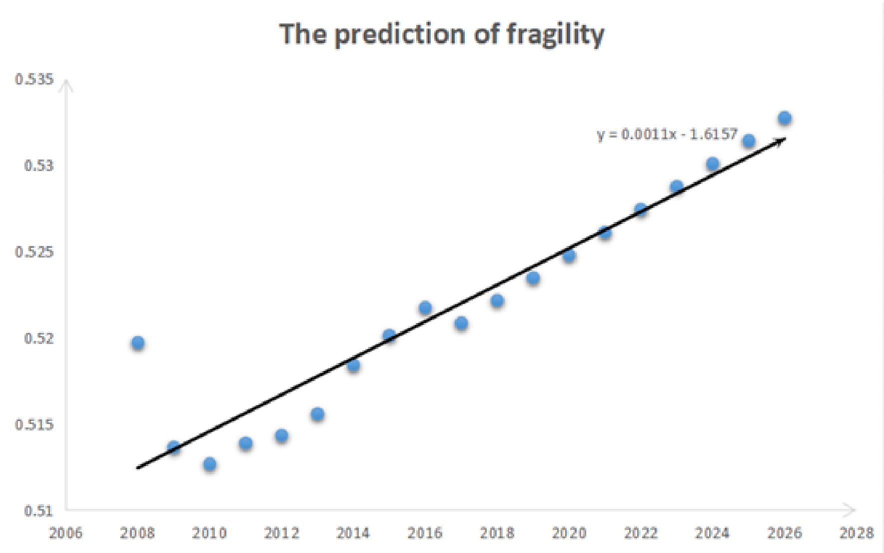

Figure 8: The prediction of fragility

$$G = 0.0011t - 1.6157. \tag{46}$$

6.3 Define the Critical Point

In order to determine how and when climate change will make this country more vulnerable, we may select a country that is in a vulnerable category$(category2)$ where the country's fragility ranks at the forefont of the fragile countries. By adjusting 20 indicators, calculating the fragility of this country-adjusted indicator and re-clustering 60 countries, if the country is assigned to a very fragile country, then the parameters of the 20 indicators at this time are the corresponding critical value, and a point with a dimension of 20 of the 20 critical values is called a critical point.

7 The Fourth Question

7.1 Analysis of Human Intervention Climate

In Question one, we have identified the most relevant indicators of the climate change performance index as follow: Per capita GDP, Total health expenditure , Cultivated area , Forest area , Land area below 5 meters above sea level . After discussion and analysis, we refer the materials and screened out several ways for human intervention, namely: lightning suppression, Artificial rainfall and snowfall, Landscape engineering , Artificial promotion of energy transformation, Artificial prevention and control of desertification. Analysis the relation with the most relevant five indicators of climate impact, we can get the result from Figure IX . We further explain this:

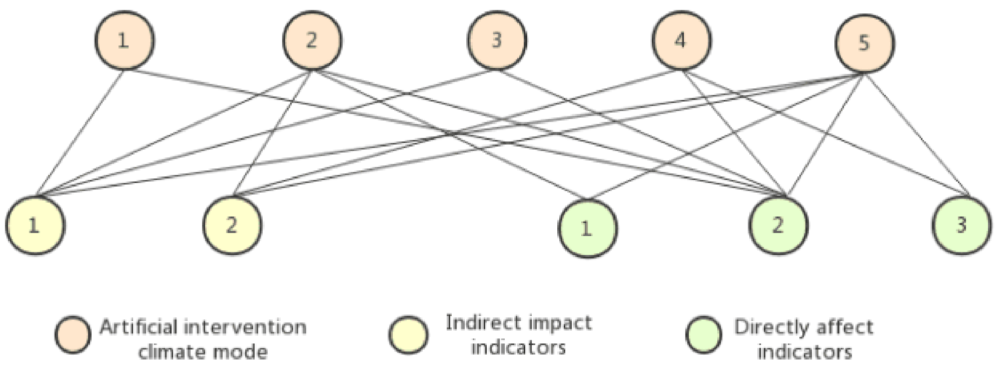

Figure 9: The relation between artificial intervention and impact indicators

- Lightning Suppression: It provides people with jobs, so that GDP per capita rise. And It also can prevent the occurrence of forest fires, forest area to improve the proportion of benefit.

- Artificial Rainfall and Snowfall: It provides people with jobs and increases GDP per capita. Rainfall and snowfall can cure smog and reduce the total expenditure on health care. It also can help prevent the death of crops and the necrosis of land caused by drought and help to replenish water to forests.
- Landscape Engineering (Vegetation Coverage): It provides people with jobs, so that per capita GDP rise. It also increases the proportion of forest area and reduces soil erosion.
- Artificial Promotion of Energy Transformation: It reduces the use of polluting coal and other polluting energy sources, reduces the air pollution index, reduce the prevalence of related diseases caused by air pollution and reduce the prevalence of related diseases caused by air pollution and reduce the total expenditure on health care. It also can reduce coal burning help to reduce carbon dioxide emissions, thus mitigating the greenhouse effect, melting glaciers and reducing the proportion of land below five meters above sea level.
- Artificial Prevention and Control of Desertification: It provides people with jobs, so that per capita GDP rise. It reduces the sandstorm benefit, reduce the incidence of sandstorm-related diseases and reduce the total expenditure on health care to improve the proportion of arable land and improve the proportion of forest area. Consolidate the soil while reducing soil erosion.

7.2 Case Analysis-The Cost Forecast in Russia

We take greening project as an example: The average unit price of seedings is 50.67 $/ha. The average preparation unit price is 71.09 $/ha. The average planting unit price is 91.81 $/ha. And the average unit price of support management is 60.75 $/ha. The management price per ha of seeding planting is 274.33 $/ha. As of now, there are still 4.725 million square kilometers of the area of Russia is a wilderness area, consider more than 10% of the wilderness area for seeding greening project, the cost of 1.94 billion US dollars. Then we take energy transformation as the second example: We find Russia's energy transformation in scientific research funds up to 530 million US dollars.

8 The Fifth Question

In Question 1, the model we set up is more suitable for a country. However, for cities, the indexes are more differentiated and the features of the cities are more distinct. It is apparently irrational to divide each city into three categories to the degree of vulnerability. Therefore we need to determine the number of categories. The K-means algorithm for the number of categories k is given in advance. Many times we don't know the given data set should be divided into the most appropriate number of classes, which is an inadequate K-means algorithm, so improving the model of Question 1 should be lie in how to solve the most appropriate number of categories.

8.1 Algorithm Improvement of the K-Means Algorithm

For a specific data set, the clustering algorithm is run to generate clustering results with different clustering numbers within the scope of searching for the determined number of clusters. Appropriate validity indexes are selected to e-valuate the clustering results. Based on the evaluation results, the optimal poly number of classes. Correlation algorithm for determing the optimal number of clusters: To solve the problem that K-means algorithm can't accurately determine the number of clusters in advance, Zhou ShiBing [12] proposed a new K-means algorithm. The basic idea of the algorithm is shown in Figure X. As the represen-

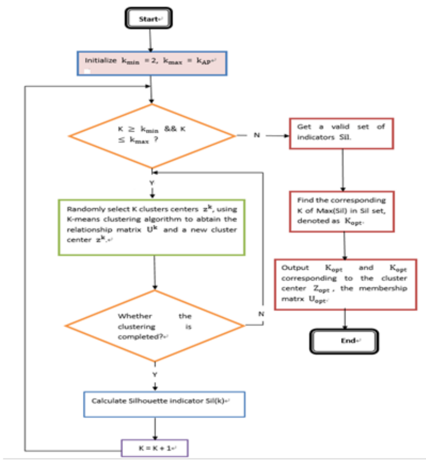

Figure 10: Algorithm to determine the optimal number of clusters

tative index data of each is not easy to collect in the short term, we only describe the model here to provide a solution for this question.

9 Evaluations of Solutions

9.1 Strength

- In Question 1, we use the gray correlation model and K-means clustering algorithm to classify the fragility of different countries, which effectively avoids the limitation of AHP, that is, we canąŕt reasonably determine the importance of each index. At the same time, our model algorithm is easy to operate and has high computing speed, which can effectively deal with small and medium-sized datasets, laying a foundation for the research on the second and third problems. In addition, we use regression analysis of

SPSS to determine the correlation between each indicator and the index of climate change performance, and obtain the more reliable indicator of the impact of climate change.

- In Question 3, we predict the future development trend of the country's fragility through the model and test the prediction accuracy to ensure the rationality and accuracy of the forecast. Secondly, we continuously change the parameters of the selected countries, and cluster analysis before and after the change, so that the selected countries from the original stability became extremely fragile, the final multidimensional critical point more concretely reflects the country's fragility degree of mutation and the relationship between indicators.
- In Question 5, in view of the large differences among various urban indicators, we set up the model to solve the optimal number of clusters and improve the clustering effect of urban fragility.

9.2 Weakness

- The initial clustering centers of K-means algorithm are chosen randomly. The selection of the initial center points will lead to the final clustering results, which may cause the final classification results to fall into the local optimum rather than the global optimal solution. Moreover, the calculation process of K-means algorithm repeatedly calculates a large number of distances between objects, so the K-means clustering process consumes a lot of time and reduces the effiency of clustering operations.
- Our model shows that the rankings of fragilities in 60 countries are slightly different from the reference rankings given on the official website, which we believe is due to the fact that the selected indicators do not cover a broad enough range to measure a country's fragility.
- In Question 1, through our model, the boundary between the stable countries and the vulnerable countries and the demarcation between the vulnerable countries and fragile countries are obtained. However, the process of solving the problems is rather rough, and only two ambiguous intervals can not be obtained. Determine the specific cut-off value.

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