For office use only	Team Control Number	For office use only
T1 ________________	**89281**	F1 ________________
T2 ________________		F2 ________________
T3 ________________	Problem Chosen	F3 ________________
T4 ________________	**E**	F4 ________________

Impact of Climate Change on the Country Fragility

Summary

This paper focuses on a series of issues related with climate change and national fragility, and solve the problems reasonably through Analytic Hierarchy Process (AHP), Partial Least Squares Regression, Regression Analysis and other methods.

In task 1, based on the gathered abundant data, a popular system (CPIA) is selected as a metric. Then we construct a new AHP Fragile Scoring Model and list the final scores by using valid data of 20 countries, agreeably accepted by the authorized Fragile State Index. Moreover, we use two algorithms to measure the effect of climate change on fragility. Firstly, a optimized model with climate indicators is established, then the fragility rises as the scores decreasing. Secondly, a partial least squares regression model is adopted to quantitatively analyze the influence.

In task 2, Iraq is chosen, we compare two scores from our original and optimized models in task 1, the difference is subsequently revealed. Further, with the guidance of controlling variables, a Triple-Variable Regression Model is built to show the variation of FSI under the independent role of each single indicator (another variable is World Development Indicators, WDI). The WDI value of Iraq is around 0.19, ranked High Alert (FSI), the impact of climate is particularly tremendous.

In task 3, Senegal is the research object, with the similar research technique as task 2, the WDI is 0.33 in Senegal, sorted as High Warning. Although the influence of climate change is weaker, it is still not optimistic. Senegal is predicted to enter Alert rank in about 2020 after triple exponential smoothing forecast.

In task 4, the interventions towards climate change are divided into adaptive and mitigating parts, then we specifically offer separated proposals, varying with classification. Eventually, the cost of different interventions is estimated thoroughly.

In task 5, we modify the potential inadaptability of our model by amending the weight vectors of indexes.

Finally, aiming at the crucial variables and parameters in the model, a reasonable change interval is designed for the sensitivity analysis. Meanwhile, the robustness analysis is carried out, with satisfied result.

Key Words: FSI; Climate Change; AHP; Regression Analysis; PLS

Contents

1 Introduction

1.1 Backgrounds

When it comes to climate change, most people imagine gradual increases in temperature and only marginal changes in other climatic conditions, continuing indefinitely or even leveling off at some time in the future. However, the impact of various climate change is significant now, including global warming, increased droughts, natural disasters and sea level rise and so on.

Climate-related events have an enormous impact on different aspects of country. With over 400 million people living in drier, subtropical, often over-populated and economically poor regions today, climate change and its follow-on effects pose a severe risk to political, economic, and social stability. In less prosperous regions, where countries lack the resources and capabilities required to adapt quickly to more severe conditions. Eventually, negative effects weak the stability of the government to a certain extent, and the unstable government can easily lead to the fragile state[1].

1.2 Our Works

Overall, this paper addresses the impact of climate change on national fragility. To meet requirements, we need to solve the following problems in our model:

Problem One: the model should measure the fragility and direct/indirect impact of climate change, and should judge whether a country is fragile, vulnerable or stable.

Problem Two: select one of the top ten most fragile countries, then determine how climate change will increase the fragility of this country.

Problem Three: choose another country which is not in the alert list, measure its fragility and see how and when climate change may put it into a more fragile position. Then, define a threshold of fragility rank conversion and predict the reach time.

Problem Four: use models to indicate which national intervention can mitigate the risk of climate change and protect a country from becoming more fragile. Meanwhile, explain the effect of human interventions and predict the total cost.

Problem Five: whether these models can work on smaller or larger area, and if not, make some crucial changes.

2 Analysis of Problems

2.1 Problem One

Problem One requires us to establish a model to compare and classify countries by national fragility, and show the impacts of climate change on fragility. Measuring fragility is an evaluation problem with various solving methods, such as Principal Component Analysis and AHP. In this paper, AHP is adopted for its understandability. Meanwhile, there are different methods to measure the impact of climate change on fragility, such as Grey Relational Analysis and so on. In this paper, the popular Partial Least Squares Regression is adopted because of its strong applicability.

2.2 Problem Two

Problem Two asks us to choose one of the top ten most fragile countries to be judged by our model and show the negative impact of climate on its fragility. To this end, we choose Iraq as the research object, and apply the original and optimized model in Problem One to conduct the climate effects by comparison. Meanwhile, a regression model is established to quantitatively analyze the impact of a single climate change indicator on FSI in Iraq.

2.3 Problem Three

Problem Three suggests us to select another country which is out of the alert list to analyze. We choose Senegal, although the similar analysis method as Problem Two is also applicable, the specific national conditions in these two counties and the conclusions are noticeably different. Finding the critical time when it entering more fragile is a prediction problem, and the method includes gray prediction, time series and so on. This paper adopts three exponential smoothing to predict.

2.4 Problem Four

Problem Four requires us to screen out national interventions through our model that mitigate the risk of climate change, then explain the effects of interventions and estimate costs. We utilize the idea of classification to divide interventions into two parts, and make appropriate recommendations for different countries. Finally, the cost of interventions is estimated based on classification.

2.5 Problem Five

Problem Five requires us to test and refine our model so that it can be applied to smaller or larger countries/regions. The essence of this problem is the analysis and promotion of the model. Therefore, the weight vectors of indexes in the AHP Fragile Assessment Model are considered to be amended.

3 Model Assumptions

For a better study, we simplify our model by giving the assumptions:

1 Assume the relevant data found in the literature is true and reliable.

2 Suppose the data obtained from the website can correctly reflect the actual situation of one country.

We list more detailed assumptions in the following sections when using them.

4 Parameter Definitions

CPIA: Country Policy and Institutional Assessment
WDI：World Development Indicators
FSI：Fragile State Index

To facilitate subsequent discussion, the meaning of the symbols used is given in Table 1.

Table 1 Symbol Statement

Symbol	The Meaning of Symbol
F	Fragility Score
F'	Improved Fragility Score
w	Weight Vector
μ	Regression Error
P	Material Cost
Q	Labor Cost
R	Time cost

5 Modeling and Solving/ The Foundation of Model

5.1 Problem One

5.1.1 Fragility Assessment Index System (CPIA System)

At present, the research on the fragile countries has become a basic issue in the western academic discussion. Fragility is a highly abstract concept, and it appears recent decades. There is no unified content of fragility in academics[3].

In a narrow layer, a "fragile state" can not afford the responsibility, as a provider of basic services and public goods. Broadly speaking, a social community is entangled in various conflicts of violence, with unstable politics, social and economics. This paper adopts the judgment and assessment of fragility from a broad perspective[2].

We choose a widely used system - CPIA, which consists of four main parts: Economic Management, Structural Policies, Policies for Social Inclusion and Equity, Public Sector Management and Institutions. There are several indicators under each major part, and we sort the statistics respectively.

Next, the index system can be established as follows:

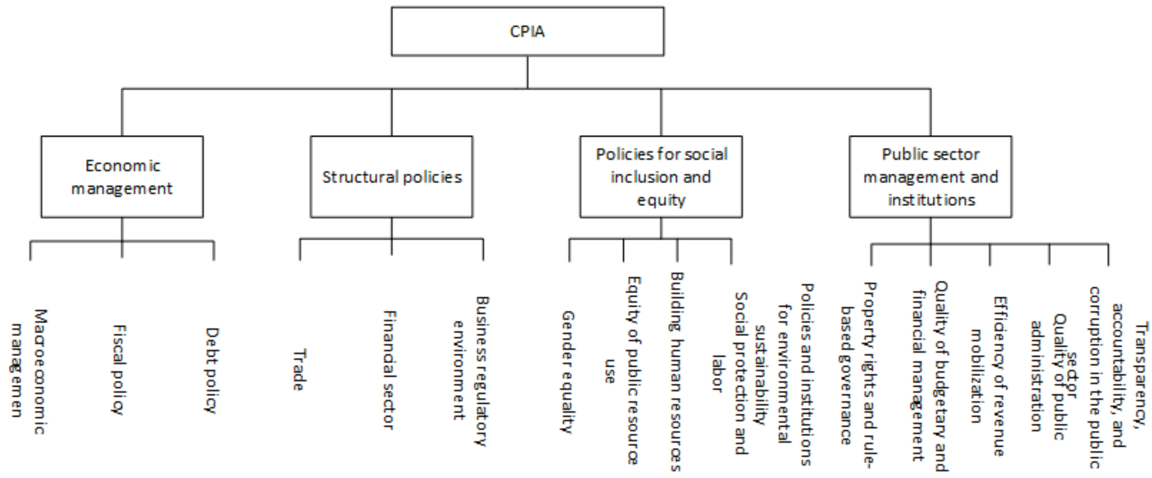


Figure 1. Evaluation of Vulnerability in CPIA Indicator System

5.1.2 Data Acquisition

Because the specific judgment criteria of CPIA is unlisted, we select related data, reflecting original indicators equally, which collected in Table 2 in Appendix 1.

5.1.3 Data Normalization

We classify the indicators according to the different effects on fragility, finally we divide these 16 indicators into two categories: positive and negative. Respectively, as shown in Table 3, Table 4 in Appendix 1.

After data normalization, we get a normalized data matrix $\mathbf{R}$.

For a country's standardized data $\mathbf{R}=(\mathbf{B}_1,\mathbf{B}_2,\mathbf{B}_3,\mathbf{B}_4)$,

$$\text{where as, } \begin{cases} \mathbf{B}_1=(C_1,C_2,C_3) \\ \mathbf{B}_2=(C_4,C_5,C_6) \\ \mathbf{B}_2=(C_7,C_8,C_9,C_{10},C_{11}) \\ \mathbf{B}_2=(C_{12},C_{13},C_{14},C_{15},C_{16}) \end{cases} \qquad (1)$$

5.1.4 AHP to Determine the Weight

According to the principles of AHP, we use the Saaty nine-demarcation method to determine the index weights, and construct judgment matrixes S. For example, when obtaining the weight between Objective Layer A and Criterion Layer B, the criterions are (from left to right): Economic Management, Structural Policies, Policies for Social Inclusion and Equity, Public Sector Management and Institutions.

So the judgment matrix is S:

$$S=\begin{pmatrix} 1 & 3 & 9 & 6 \\ \frac{1}{3} & 1 & 7 & 4 \\ \frac{1}{9} & \frac{1}{7} & 1 & \frac{1}{4} \\ \frac{1}{6} & \frac{1}{4} & 4 & 1 \end{pmatrix} \tag{2}$$

The weight $w^{(21)}$ between Criterion Layer B and Objective Layer A obtained by root-finding algorithm is: $w^{(21)}=(0.575,0.280,0.041,0.104)$, and the allowable coincidence indicators respectively are $CI=0.060174$, $CR=0.06686$, $RI=0.9$.

Similarly, we can get the weight vectors among Criterion Layer B and the Schematic Layer C, which are B_1, B_2, B_3, B_4. These weights value as follows:

$$\begin{cases} \mathbf{w}^{31}=(0.564,0.294,0.142) \\ \mathbf{w}^{32}=(0.282,0.381,0.337) \\ \mathbf{w}^{33}=(0.332,0.295,0.092,0.156,0.125) \\ \mathbf{w}^{34}=(0.326,0.116,0.087,0.341,0.130) \end{cases} \tag{3}$$

5.1.5 Establishing AHP Fragility Assessment Model

Using the normalized data above for a country, the score of fragility can be written as F. AHP Fragility Assessment Model is established:

$$F=\mathbf{w}^{21}(\mathbf{w}^{31}\mathbf{B}_1^{\mathrm{T}},\mathbf{w}^{32}\mathbf{B}_2^{\mathrm{T}},\mathbf{w}^{33}\mathbf{B}_3^{\mathrm{T}},\mathbf{w}^{34}\mathbf{B}_4^{\mathrm{T}})^{\mathrm{T}} \tag{4}$$

With each country's data, fragility scores can be calculated by MATLAB, collected into a sheet, which is the basis for judging ranks. Firstly, the boundaries of ranks are called. So we set the dividing lines at 0.2 and 0.5 by observing the data, separating fragile, vulnerable and stable.

Table 5 Fragility Scorecard for Each Country

Country	Score	Rank	FSI Score	FSI Rank
Iraq	0.199	Fragile	105.4	high alert
Malawi	0.266	Vulnerable	88	high warning
Belarus	0.273	Vulnerable	72.4	elevated warning
Kazakhstan	0.348	Vulnerable	65.9	warning
Bosnia and Herzegovina	0.350	Vulnerable	73	elevated warning
Moldova	0.354	Vulnerable	72.0	elevated warning
Kyrgyzstan	0.377	Vulnerable	80.3	high warning
Georgia	0.390	Vulnerable	76.5	elevated warning
Indonesia	0.394	Vulnerable	72.9	elevated warning
Jamaica	0.413	Vulnerable	65.2	warning

Samoa	0.418	Vulnerable	67.1	warning
Russian Federation	0.429	Vulnerable	79.2	elevated warning
Bhutan	0.430	Vulnerable	76	elevated warning
Solomon Islands	0.430	Vulnerable	84.8	high warning
Albania	0.443	Vulnerable	60.5	warning
United States	0.582	Stable	35.6	very stable
New Zealand	0.631	Stable	22.6	sustainable
Australia	0.651	Stable	22.3	sustainable
Singapore	0.656	Stable	32.5	very stable
Switzerland	0.741	Stable	21.1	sustainable

5.2 Measuring the Impact of Climate Change

5.2.1 Climate Change Indicators and Data Acquisition

We have reviewed numerous sources of literature on climate change and national stability, finding that four links of evidence frequently are mentioned in the paper: changes in precipitation and temperature, sea-level rise and natural disasters[4].

It has been pointed out in the literature that the long-term impact of climate change on conflicts necessarily implies to a complex causal chain in factors which are difficult to isolate and test quantitatively and systematically. These four variables have small coverage rates and can reflect on climate change suitably, while these are sufficient to reflect the impact of climatic factors on national fragility. Therefore, we choose these four variables for research and analysis on climate change.

Against the four indicators determined, we find the corresponding data as shown in the following table.

Table 6 Data on Climate Change Indicators

Criterion Layer	Schematic Layer	Data Source
Climate Change	Changes in Precipitation	http://sdwebx.worldbank.org
	Change in Temperature	http://sdwebx.worldbank.org
	Rising Sea Level	https://tidesandcurrents.noaa.gov
	Natural Disasters	https://data.worldbank.org.cn

Four average points per 30 years are set from 1901-2015 for maximum and minimum to get the standard deviation, and natural disaster data refer to the annual average proportion of the population that is affected by natural disasters.

5.2.2 Research Objects & Research Ideas

We have also selected these 20 countries as study subjects and find data on their respective climate change indicators.

Table 7 Climate Change Indicators Data for Each Country

Country	Standard Deviation of Precipitation	Standard Deviation of temperature Difference	Natural Disaster
Albania	15.52	0.40	5.27
Australia	7.67	0.08	3.05
Belarus	4.07	0.83	0.49
Bhutan	23.57	0.19	0.01
Bosnia and Herzegovina	9.14	0.50	0.02
Georgia	4.86	0.22	0.77
Indonesia	12.82	0.10	0.00
Iraq	2.33	0.36	0.21
Jamaica	21.15	0.10	0.27
Kazakhstan	1.27	0.61	0.16
Kyrgyzstan	1.56	0.66	0.01
Malawi	9.46	0.19	1.14
Moldova	5.74	0.77	2.07
new Zealand	12.51	0.22	0.09
Russian Federation	2.36	0.61	0.00
Samoa	28.48	0.13	8.82
Singapore	38.29	0.21	0.00
Solomon Islands	0.49	0.05	0.01
Switzerland	10.09	0.29	0.34
United States	2.54	0.37	0.22

In order to measure the impact of climate change on fragility quantitatively, we also take the above-mentioned indicators of climate change into consideration in the indicator system, and obtained the revised CPIA indicator system.

5.2.3 Fragility scoring revision model considering the impact of climate change

According to the revised CPIA index system after incorporating climate change indicators, we establish an AHP model that incorporates climate change indicators.

$$F' = \mathbf{w}^{21}(\mathbf{w}^{31}\mathbf{B}_1^{\mathrm{T}}, \mathbf{w}^{32}\mathbf{B}_2^{\mathrm{T}}, \mathbf{w}^{33}\mathbf{B}_3^{\mathrm{T}}, \mathbf{w}^{34}\mathbf{B}_4^{\mathrm{T}}, \ \mathbf{w}^{35}\mathbf{B}_5^{\mathrm{T}})^{\mathrm{T}} \qquad (5)$$

Using MATLAB to calculate the scores after incorporating climate indicators. We select six countries, which are Australia, Russian Federation, Solomon Islands, Ukraine, Singapore and New Zealand, to make a comparison of fragility scores affected by climate change (Figure 3).

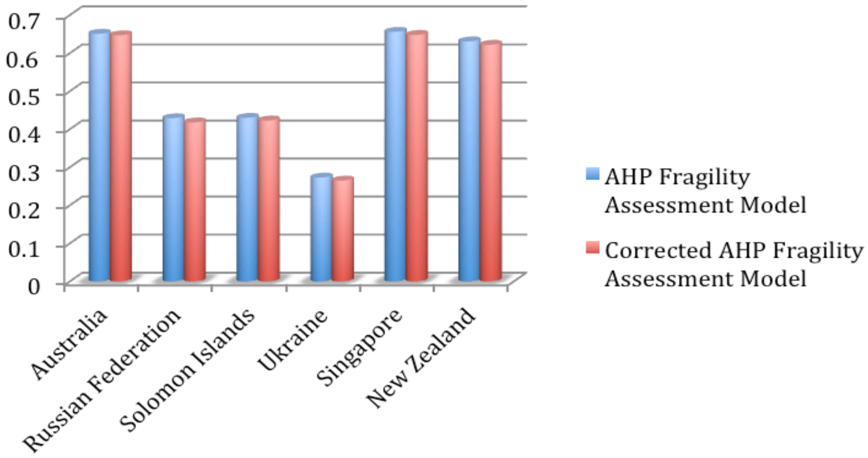


Figure 3 Comparisons of fragility scores affected by climate change

5.2.4 Using Partial Least Squares Regression Analysis

Partial Least Squares (PLS) can solve many problems that can not be solved by ordinary multiple regression. Regression modeling (multiple linear regression), data structure simplification (principal component analysis), and correlation analysis between two groups of variables (canonical correlation analysis) can be achieved simultaneously. This is a leap in multivariate statistical analysis.

Based on least-squares regression analysis, we set a model to derive the relationship among the various indicators (precipitation standard deviation, temperature standard deviation, natural disasters), climate change and the FSI directly to measure the impact of climate change on fragility more accurately and quantitatively, to derive the relationship among the various indicators (precipitation standard deviation, temperature standard deviation, natural disasters), climate change and the FSI directly.

It is worth mentioning that our model that is based on AHP fragility Assessment Model can measure World Development Indicators (WDI). Because the Indicator system of WDI can also be applied to CPIA. Therefore, WDI can be used to measure a country's level of development.

5.2.5 Partial Least Squares Regression Model Results Analysis

We formulate partial least squares regression models that quantitatively measure the effects of climate change:

$$PSI = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_3 + \alpha_4 WDI + \mu \tag{6}$$

x_1、x_2、x_3 are on behalf of standard deviation of precipitation, standard deviation of temperature and the number of natural disaster respectively.

Using MATLAB to solve the problem, we can get the following formula:

$$PSI = 141.93 + 0.34x_1 + 15.23x_2 + 0.74x_3 - 164.35WDI + \mu \tag{7}$$

According to the model analysis, the standard deviation of precipitation, temperature and the number of natural disasters are all positively correlated with PSI. Because the larger the three data are, the worse climate will be. Furthermore, the country becomes more vulnerable. At the same time, WDI is positively correlated with PSI, which means the better governance will be, and it will less fragile.

5.3 Problem Two

5.3.1 The Fragility Score of Iraq Obtained by Using the Fragility Fcore Revision Model

Based on the FSI, we select Iraq in the top ten fragile countries list for our study. We calculate the final fragility score for Iraq by the corrected AHP model in Problem (1), which is compared with the original FSI (Table 8) to obtain the impact of climate change on the Iraq's fragility.

Table 8 Iraq Fragility score compared with FSI value

Evaluation Standard	Final Score	Type
AHP Fragility Assessment Model	0.198744	Fragile
Fragility Score Revision Model	0.182547	Fragile
Fragile States Index	105.4	High Alert

In our model calculations, Iraq scores the lowest. In numerous aspects of Iraq, the continuing impacts of the war remain, thus some areas are not satisfactory enough, such as foreign debt, government efficiency and etc.

To date, the situation remains turbulent and there is increasingly obvious impact of the war in Iraq. As the result, massive infrastructure is damaged or paralyzed, and post-war economic reconstruction is also difficult to carry out in Iraq due to the continuing unrest. At present, a large amount of infrastructure, including water and electricity supply systems, has not yet fully recovered. Meanwhile, unemployment, high prices and poverty have seriously plagued the Iraqi.

We find the scores relatively decreasing after adding climate factors through analysis. Crucially, one of the most pivotal causes is Iraq's geographic location, with little precipitation, leading to the prolonged water scarcity. Therefore, Iraq has lagged behind the world average level in various aspects of national governance, and this aggravates the lack of its fragility.

5.3.2 Regression Model of Single Climate Index and FSI

Although the Partial Least Squares Regression Model above can reflect the impact of climate change on FSI to some extent, it is tough to understand because of redundant independent variables. Thus quantitative analysis with single climate indicator is needed for FSI of Iraq.

In[5] order to obtain specific relationship between each climate change index and FSI clearly and concretely, we establish a series of regression models with single climate change index：

$$FSI = \beta_0 + \beta_1 x + \beta_2 WDI + \beta_3 x \cdot WDI + \mu \qquad (8)$$

Among them, x is different climate change indicators in 3 studies, which are standard deviation of precipitation, standard deviation of temperature and the number of natural disasters; WDI (World Development Indicators) is a national development indicator; $x \cdot WDI$ is the cross item, which measures the interaction between x and WDI ; μ is the error of regression.

Where as, x for the indicators of climate change, x_1 for the standard deviation of precipitation, x_2 for the standard deviation of temperature, and x_3 for the number of natural disasters respectively in three studies.

Obtain the model using MATLAB:

Standard Deviation of Precipitation, WDI, FSI Triple Variable Regression Model

$$FSI = 131.03 + 0.24x - 156.01WDI - 0.36x \cdot WDI + \mu \qquad (9)$$

Standard Deviation of Temperature, WDI, FSI Triple Variable Regression Model

$$FSI = 131.92 + 0.17x_2 - 156.34WDI - 0.16x_2 \cdot WDI + \mu \qquad (10)$$

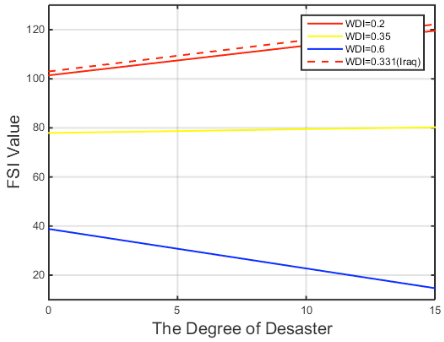
Number of Natural Disasters, WDI, FSI Triple Variable Regression Model

$$FSI = 132.73 + 2.62x_3 - 156.54WDI - 7.05x_3 \cdot WDI + \mu \qquad (11)$$

The control variable method is adopted in all 3 studies. For example, we assume

WDI as a constant when we study the relationship between the number of disasters and the change of FSI. Then take a series of constants (*WDI*)to reflect various ranks of fragility, and show the relationship in Figure 4.

Through 3 studies, we get variations of FSI, with standard deviation of precipitation, standard deviation of temperature and the number of natural disasters respectively (Figure 4 - Figure 6):



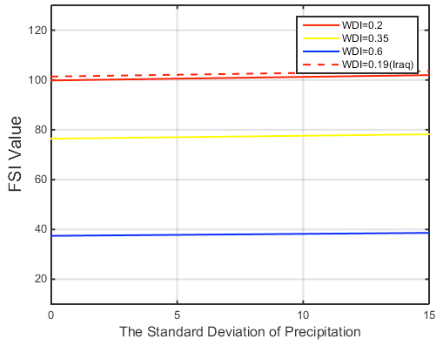


Figure 4 (left) Relationships between the Number of Natural Disasters and FSI in Iraq
Figure 5 (right) Relationships between the Standard Deviation of Precipitation and FSI in Iraq

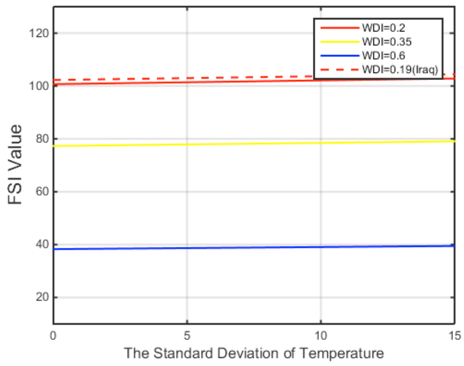


Figure 5 Relationships between the Standard Deviation of Temperature and FSI in Iraq

5.3.3 Results Analysis of Regression Model

By analyzing the above figure, we can draw a lot of useful conclusions combined with the Iraqi national conditions.

Combined with the national conditions of Iraq, we draw many useful conclusions by analyzing figures above.

This figure shows the relationships between FSI and the degree of natural disasters when the WDI stays around 0.2, 0.35 and 0.6, respectively.

The figure demonstrates the following points:

1. **Red solid line (WDI = 0.2):** the slope of FSI value changing with the degree of natural disasters is extremely steep, indicating that as the severity of the disaster increases, there is a significant positive correlation between the natural disasters degree and FSI value. (The lowest value calculated by the

sampling data is about 0.198, which is the final score of Iraq)

2. **Yellow solid line (WDI = 0.35):** the slope decreases to around 0 and FSI value almost no longer has any positive correlation to natural disasters degree.
3. **Blue solid line (WDI = 0.6):** the model is operating in the counterintuitive area, which is an area where natural disasters no longer play a part in contributing to a fragile state.

In addition, a more in-depth analysis can be conducted. From the result of the problem (1), the final score of Iraq reaches the lowest point in our model, and it also has the largest FSI value. The figure shows that the lower the WDI value, the larger the intercept, which confirms that the scoring standard we set up are consistent with the FSI.

Moreover, the greater slope evokes larger fragility to natural disasters. In figure, the dashed line with the largest slope represents Iraq, so it is extremely fragile to natural disasters and the consequences are dramatically severe.

5.4 Problem Three

5.4.1 Senegal's Fragility and the Impact of Climate Change

We choose Senegal as study object out of the above mentioned list, Senegal scores 0.402 in our AHP Fragility Assessment Model, ranked Vulnerable; and scores 82.3 in FSI in 2017 report, ranked Highly Warning. The results of these two standards are in good agreement to prove the correctness of our new model.

Senegal, it has high levels in trade index and gender equality. From the perspective of economic management, the GDP per capita of Senegal is 958 U.S. dollars, which is significantly lower than the average of stable countries. However, the overall development level is poor in Senegal, and especially in social equality and human resources building.

Senegalese development period is limited and the internal situation is turbulent. In recent years, riots evoke political chaos, which are obvious threats to the development of economy, trade and so on.

According to statistics, the annual precipitation of Senegal is small, and the water scarcity leads to limited national development, putting Senegal at a more fragile place.

Using the corrected model with climate change impacts, we can get the fragility score, and compare them with FSI values (Table 9):

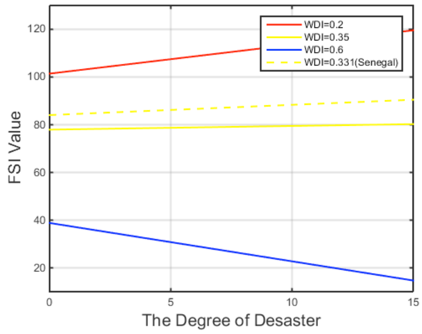
Table 9 Senegal's Fragility score compared with FSI value

Evaluation Standard	Final Score	Type
AHP Fragility Assessment Model	0.355	Vulnerable
Fragility Score Revision Model	0.346	Vulnerable
Fragile States Index	74	High warning

As seen from the table, the score including climate change effects is relatively lower, which means that the country's fragility increases and climate change has a direct impact on the fragility.

5.4.2 Quantitative Analysis of the Impact of Climate Change Indicators on Senegal Vulnerability Index

Using the similar method in the analysis of Iraq in Problem (2), we also get the relationships among FSI and standard deviation of precipitation, standard deviation of temperature and the number of natural disasters in Senegal, respectively (Figure 7 - Figure 9). We can draw similar important conclusions after analysis.



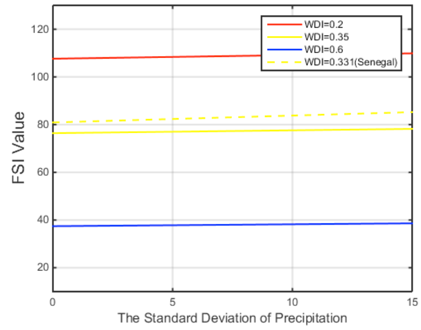


Figure 7 (left) Relationships between the Number of Natural Disasters and FSI in Senegal
Figure 8 (right) Relationships between the Standard Deviation of Precipitation and FSI in Senegal

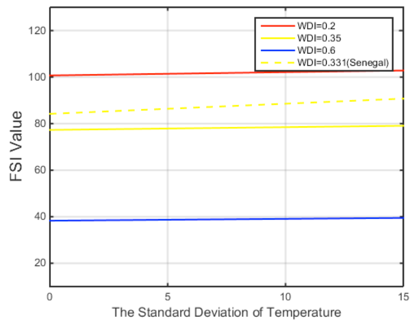


Figure 9 Relationships between the Standard Deviation of Temperature and FSI in Senegal

With limited length of this paper, we only show detailed analysis of Figure 7. First of all, we notice the FSI in Senegal is 82.3, thus the line of Senegal with positive slope should be in the gap between red solid line and yellow solid line, indicating that as the degree of natural disasters intensifies, the FSI value will continuously increase, while the significant impact on country's fragility can not be neglected.

As the climate change impact aggravates, the forecast trend of FSI in Senegal increases, so it will become more fragile, and then at some point it may exceed a threshold before entering a more severe hierarchy.

5.4.3 The critical time when Senegal Entering Alert

According to FSI data, Senegal scores 82.3 in 2017, ranked High Warning, with a narrow gap to the next more dangerous rank (Alert).

To this end, we predict the time when Senegal falls to Alert rank from the sufficient FSI data (2006 – 2017). The variation of FSI value is a time series, so we choose Triple Order Exponential Smoothing Method.

The forecast results are shown in Figure 10:

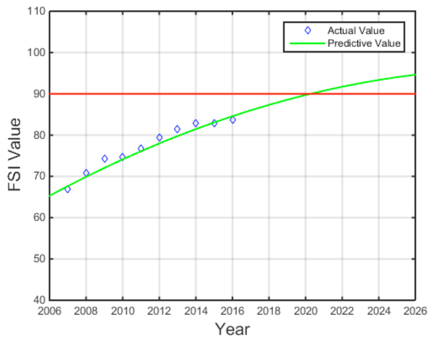


Figure 10 The Predict of Senegal Projections from High Warning to Alert

We choose 90 in FSI as the same threshold in our model for entering fragile countries. According to the statistics in the last 12 years, Figure 10 directly illustrates that Senegal will be one of the fragile countries in 2020 or so, keeping the alike trend of development.

5.5 Problem Four

5.5.1 Interventions to reduce the impact of climate change

We find that intervention policies in most countries fall broadly into two broad categories: mitigation and adaptation policies after reviewing a large amount of literature, like Table 10 below[7].

Table 10 National Intervention Policy Classification Table

Classification	Policy	Explain	Time	Example
Status / Consequences	Adaptive	Accept the facts of climate change, assess its impact on national vulnerabilities, and adjust the structures of all aspects of country to adapt to various climate change.	Short	1. Make the necessary maintenance and renovation of the existing infrastructures; 2. Adjust the current national industrial structure to adapt responsively to climate change; 3. Strengthen the monitoring and forecast of the occurrence and development of high-impact climate events through scientific and technological means.

Source / root	Mitigating	From the perspectives of awareness and forecast, take a forward-looking approach to climate change.	Long	1. With regard to the newly-built infrastructures, the current and future climate conditions must be taken into account in all aspects; 2. Promulgate corresponding policies or regulations to encourage the development of environment-friendly industries; 3. Use publicity efforts to raise public awareness of environmental protection.

According to the above table and analysis, the country must understand the current degree of fragility firstly and the amount of time they can devote into when they consider the intervention policy. Specifically, a country that is extremely vulnerable wants to rescue themselves from its original state during less time, while those countries with less serious sense of urgency will have more time to improve. And now that the countries that are already in a stable state often have strong political domination and climate change adaptation capabilities, so we do not discuss them in details here.

Next we use regression models to discuss the countries that are already in a vulnerable and vulnerable state separately.

1. Fragile countries

Against fragile countries, we get a comparison chart of the effect curve and the original curve after the implementation of mitigation and adaptation policies in fragile countries by revising the chart on the impact of climate change on fragility.

Figure 11 Comparison of mitigation and adaptation policies in fragile states

We can draw the following conclusions combined with the figure.

(1) Adaptability policy: Short-term effect is significant. However, a series of new adaptation policies need to be constantly added due to the short duration of action, so the effect is a rising curve. In the long run, a state that is more stable than the original state but with a relative smaller gap will be reached.

(2) Mitigation policy: Short-term impact is weak, while it will be less vulnerable than the adaptation policy and there is still the potential ability to continue to become more stable under the long-term effect. However, it is very difficult to meet the needs of economic and social development because of its high cost.

According to it, we can put forward suggestions for the intervention of fragile states. In order to help these countries to emerge from the fragile state in a short period of time, the effect of adaptive policies is more pronounced. However, this is not a long-term solution. Therefore, some mitigation policies are also needed as a supplement.

2. Vulnerable and stable countries

Intervention policy recommendations for more vulnerable countries are that they can choose the mitigation policy mainly because their sense of urgency is weak, adaptive policy can be decided as a remedy in case of an emergency.

5.5.2 Intervention Cost

By referring to the data, we classify the costs of intervention firstly which is as shown in the following table[7].

Table 11 Intervention Cost Classification Table

Classification	Example	Unit (USD/year)
Material Cost(P)	Facilities (newly-construction and maintenance)	The country's total investment in environmental facilities per year
Labor Cost(Q)	Administrative staff, workers, designers, etc	The country's average annual income
Time Cost(R)	(Abstraction)	

1. Set the total cost of C (USD / year)

$$C=P+Q+R \tag{11}$$

In the formula

P = Depleted duration×(1 + standard service life / average life)×investment in environmental protection equipment per year/one country

Q = (1 + labor ratio)×average annual income /one country

R = Duration of failure×average annual income /one country

Description:

Depleted duration - Average life of the equipment involved by intervention

Labor ratio - The workforce population involved by intervention / total population

Duration of failure - The number of years from the time the intervention takes effect to no longer have any effect

Adaptability policy: P>Q>R

Mitigation policy: R>Q>P

For different types of state intervention, we need to make a detailed analysis of the exhaustion period, the proportion of the labor force and the duration of the failure, then estimate the total cost according to the national conditions of the country.

5.6 Problem Five

The states observed in this study and the indicators used were chosen because of data availability. Data for this model were only available at the state level. We acknowledge that arable land per capita and access to fresh water can vary greatly within state boundaries, thus the picture is not as precise as we might hope. However, we believe that local environmental degradation (which we do not have data for) can still influence national political stability, which is captured by our dataset. We collected arable land data from the Food and Agriculture Organization (FAO, 2009), and population data from the World Bank (World Bank, 2010). We derived water access data from the U .N. Millennium Development Goal Database (U.N. 2009). The Joint Monitoring Program (2008), which monitors the WHO and UNICEF in water supply and sanitation studies.

To solve incompatibility of potential models, we consider to amend the weight of each index in AHP fragility assessment model.

Firstly, we classify the indicators in our model according to correlation of indicator weights and studied subjects (positive or negative correlation). Secondly, we know that the area of land is basically related to the population from the literature. Therefore, in the measurement of some indicators, we choose to carry out the analysis through the population.

At last, the weights of the indicators for larger areas are shown in the table (Table 12).

Table 12 the Weights of the Indicators for Larger Areas

	Increased	Decreased	Unchanged
Weight of Indicator	Financial Sector		Macroeconomic Management
	Building Human Resources	Debt Policy	Fiscal Policy
	Social Protection and Labor	Trade	Financial Sector
	Quality of Budgetary and Financial Management	Equity of Public Resource Use	Gender Equality
	Efficiency of Revenue Mobilization	Property Rights and Rule-based Governance	Policies and Institutions for Environmental Sustainability
	Quality of Public Administration		Transparency, Accountability, and Corruption in the Public Sector

As can be seen from the table above, taking the demographic factors into consideration, the weights of some indicators will change significantly with the area accretion of implementation region: the weights of Building Human Resource and

Quality of Public Administration will rise rapidly; on the contrary, the weights of Trade and Equity of Public Resource Use will fall noticeably, while the weights of Macroeconomic Management and some other indicators remained relatively stable.

Therefore, when using our model in a smaller (such as cities) or larger (such as continents) regions, we should grasp the unique principles of local conditions and fully understand all aspects of the local community, then make reasonable changes of weights to meet various actual situations and guarantee the model well reflect the relationship between climate change and national fragility, which can analyze the degree of threat to the stability of a region from climate factors.

6 Sensitivity Analysis

Since GDP per capita is a key indicator, we mainly conduct sensitivity analysis on per capita GDP in this paper to study the effect on the model results when the parameters change.

In order to analyze the sensitivity of the WDI index, we keep other variables unchanged and only change the GDP per capita to simulate the changes of the WDI index. According to the results of model calculation, it can be found that the WDI index has a certain change while it is not obvious, indicating that the parameter is insensitive and the model is stable.

7 Robustness analysis

AHP has a subjective effect on the results. So we should examine the impact of AHP on the evaluation results. The degree of influence is measured by the following formula:

$$\bar{v} = \frac{1}{n}\sum_{i=1}^{n}\left|v_i - v_{io}\right|$$

$\bar{v}$ -The average change score of 20 countries

v_i - The score of the ith country under the subjective weight determined by a certain AHP

v_{io} -The score of the ith country

First, on the basis of the original matrix, the measure of importance is added to 0.01 times of the original. After the overall rating, the scores of 20 countries are counted to obtain the average change score $\bar{v} \approx 0.002$.

Secondly, on the basis of the original matrix, the measure of importance is reduced to 0.01 times of the original. After the overall rating, the scores of 20 countries are counted to obtain the average change score $\bar{v} \approx 0.001$.

The above analysis shows that the national vulnerability score for the stability of the chromatographic analysis is very suitable.

8 Evaluation of the Model

8.1 The Advantages of Models

Our model is stable and reliable, the results obtained reasonable and accurate, close to reality. At the same time, the model is clear and intuitive, concise and easy to understand. Then, our model has reference support, and makes full use of the data found.

1.Hierarchy

Our model in Problem (1) uses a hierarchy of indicators to measure a country's vulnerability. By looking for real statistics and standardizing them to estimate the vulnerability of a particular country. In the meantime, countries can also be obviously ranked, and countries in crisis will receive attention and reasonable advice.

2.Unique Classification

Firstly, the concept of fragile states is ambiguous, and the classification standards are highly subjective. Different organizations have different classifications. They similarly give equal weights to various dimensions, then simply add up to get the scores, which lacks the objective rationality. However, our model takes full account of different weights to make the problem more accurate and the classification more reasonable.

3.Algorithm and Intersectionality

Our model has enough technical support, and each theory is used flexibly and appropriately. Besides, we simplify the problems with reasonable assumptions. To embody the process of adjusting a country in fragile into good conditions is a daunting task, we add the impact of the intervention policy to the model and show the results reasonably in graphs.

8.2 The Disadvantages of Models

1.Simplified and Subjective

Simplifying assumptions had to be made in order to create a solvable model. Thus, some valuable data and information are unable to use, and some of the assumptions can not be realized in real life. Meanwhile, there are many subjective methods in the model and some of the weights of indexes are put forward by our own experience and intuition.

2.Weak Comprehensiveness

Due to the limited time, this paper mainly considers the relationships between national vulnerability and governance level or climate change, weakens the indirect influence of climate factors, so it can not guarantee the comprehensiveness and efficiency, making the final scores have certain deviation with actual situation.

3.Lack of Data Support

We'd better conduct more sufficient quantitative analysis on how human intervention is directly linked to the performance of national vulnerabilities. This requires us to collect more research data on a wider range, but some of which is hard to obtain. More statistical data we collect, more correctly will we estimate a country， such as adding valid data of arable land per capita, and modify the model parameters and variables, so as to achieve a more optimized model. And our model is based on local conditions, with real-time data, this also brings some limitations.

8.3 The Promotion of the Models

Generally uses the AHP to analyze the vulnerability of the country. It is of great significance to deal with similar problems, such as issues to determine national development and ranking. To solve the problems of the national assessment of comprehensive national strength, we can adjust the weight vectors for reality. This model has high value in application and promotion, which can be widely used in the practical life of different fields.

Generally, uses regression analysis to analyze the impact of climate change on national vulnerability. It mainly solves the problem of quantitative impact of climate change. Therefore, it is beneficial to deal with the problem of quantitative influence, such as problem that aims to find the relationship between the lack of water resources and the development of a country. We can appropriate modification of the model, multilevel regression analysis. It can be seen that the model can be widely applied to solve problems in different fields.

References

[1] Schwartz, P. and Randall, D. "An Abrupt Climate Change Scenario and Its Implications for United States National Security", October 2003.

[2] Tianxu Liu. The rise of research in fragile states: status, causes and limitations [J]. Foreign social science,2012(06):68-75.

[3] Tianxu Liu, Tao Wu. Evaluation criteria of fragile states [J]. Leadership science BBS,2016(13):17-26.

[4] Theisen, O.M., Gleditsch, N.P., and Buhaug, H. "Is climate change a driver of armed conflict?" Climate Change, April 2013, V117 (3), 613-625.

[5] Krakowka, A.R., Heimel, N., and Galgano, F. "Modeling Environmenal Security in Sub-Sharan Africa – ProQuest." The Geographical Bulletin, 2012, 53 (1): 21-38.

[6] Li Ji,Bofu Deng, HongTao Mao.Budget Constraints, Government Intervention and Project Cost. Nankai management review.2017,17（3）:94-102.

[7] Pengfei Zhou, Bin Zhou, Zhifei Xie. Government intervention in the adjustment of energy infrastructure in the context of climate change -- taking Germany as an example. Yuejiang Academic Journal. 2017，10（5）：37-44.

Appendix 1 Schedule

Table 2 Indicators System Corresponding Data Description

Objective Layer	Criterion Layer	Schematic Layer	Data Sources
A. Fragility	B1 Economic Management	C1 Macroeconomic Management: GDP per capita (current US$)	https://data.worldbank.org.cn
		C2 Fiscal Policy : GDP per capita growth (annual %)	https://data.worldbank.org.cn
		C3 Debt Policy: Liquid Liabilities to GDP (%)	Financial Development and Structure Dataset https://data.worldbank.org.cn
	B2 Structural Policies	C4 Trade: Net barter terms of trade index (2000 = 100)	https://data.worldbank.org.cn
		C5 Financial Sector: Inflation, consumer prices (annual %)	https://data.worldbank.org.cn
		C6 Financial Sector: Regulatory quality	The Worldwide Governance Indicators www.govindicators.org
	B3 Policies for Social Inclusion and Equity	C7 Gender Equality: Children out of school, primary, female/male	The Gender Statistics database https://data.worldbank.org.cn
		C8 Equity of Public Resource Use: Improved water，urban rural disparities (percentage of population receiving access to improved water resources)	https://data.worldbank.org.cn
		C9 Building Human Resources: Unemployment, total (% of total labor force) (modeled ILO estimate)	https://data.worldbank.org.cn
		C10 Social Protection and Labor: Labor force participation rate, total (% of total population ages 15+) (modeled ILO estimate)	https://data.worldbank.org.cn
		C11 Policies and Institutions for Environmental Sustainability: Renewable energy consumption (TJ)	Sustainable Development Goals https://data.worldbank.org.cn
	B4 Public Sector Management and Institutions	C12 Property Rights and Rule-based Governance: Rule of law(ranges from approximately -2.5 (weak) to 2.5 (strong) governance performance)	The Worldwide Governance Indicators www.govindicators.org
		C13 Quality of Budgetary and Financial Management: Total debt service (% of GNI)	https://data.worldbank.org.cn
		C14 Efficiency of Revenue Mobilization: Time to prepare and pay taxes (hours)	https://data.worldbank.org.cn
		C15 Quality of Public Administration: Government effectiveness(ranges from approximately -2.5 (weak) to 2.5 (strong) governance performance)	The Worldwide Governance Indicators www.govindicators.org

	C16 Transparency, Accountability, and Corruption in the Public Sector: Control of corruption(ranges from approximately -2.5 (weak) to 2.5 (strong) governance performance)	The Worldwide Governance Indicators www.govindicators.org

Table 3 Positive Correlation Indicator Table

Objective Layer	Criterion Layer	Schematic Layer
A Fragility	B1 Economic Management	C1 Macroeconomic Management: GDP per capita (current US$)
	B2 Structural Policies	C3 Debt Policy: Liquid Liabilities to GDP (%)
		C4 Trade: Net barter terms of trade index (2000 = 100)
		C6 Financial Sector: Regulatory quality
	B3 Policies for Social Inclusion and Equity	C11 Policies and Institutions for Environmental Sustainability: Renewable energy consumption (TJ)
	B4 Public Sector Management and Institutions	C12 Property Rights and Rule-based Governance: Rule of law(ranges from approximately -2.5 (weak) to 2.5 (strong) governance performance)
		C15 Quality of Public Administration: Government effectiveness(ranges from approximately -2.5 (weak) to 2.5 (strong) governance performance)
		C16 Transparency, Accountability, and Corruption in the Public Sector: Control of corruption(ranges from approximately -2.5 (weak) to 2.5 (strong) governance performance)

Table 4 Negative Correlation Indicator Table

Objective Layer	Criterion Layer	Schematic Layer
A Fragility	B1 Economic Management	C2 Fiscal Policy : GDP per capita growth (annual %)
	B2 Structural Policies	C5 Financial Sector: Inflation, consumer prices (annual %)
	B3 Policies for Social Inclusion and Equity	C7 Gender Equality: Children out of school, primary, female/male
		C8 Equity of Public Resource Use: Improved water，urban rural disparities (percentage of population receiving access to improved water resources)
		C9 Building Human Resources: Unemployment, total (% of total labor force) (modeled ILO estimate)
		C10 Social Protection and Labor: Labor force participation rate, total (% of total population ages 15+) (modeled ILO estimate)
	B4 Public Sector	C13 Quality of Budgetary and Financial Management: Total debt service (% of GNI)

Management and Institutions	C14 Efficiency of Revenue Mobilization: Time to prepare and pay taxes (hours)

Appendix 2 Programs and codes

```
function y=pls(pz)
[row,col]=size(pz);
aver=mean(pz);
stdcov=std(pz); %pingjunzhihebiaozhuncha
rr=corrcoef(pz);     %qiuxiangguanxishujuzhen
stdarr = ( pz - aver(ones(row,1),:) )./ stdcov( ones(row,1),:);
x0=pz(:,1:col-1);y0=pz(:,end);
e0=stdarr(:,1:col-1);f0=stdarr(:,end);
num=size(e0,1);
temp=eye(col-1);%duijiaozhen
for i=1:col-1
    w(:,i)= ( e0'* f0 )/ norm( e0'*f0 );
    t(:,i)=e0*w(:,i)
    alpha(:,i)=e0'*t(:,i)/(t(:,i)'*t(:,i))     e=e0-t(:,i)*alpha(:,i)'     %jisuanchengfentidedefen
    e0=e;
    if i==1
        w_star(:,i)=w(:,i);
    else
        for j=1:i-1
            temp=temp*(eye(col-1)-w(:,j)*alpha(:,j)');
        end
        w_star(:,i)=temp*w(:,i);
    end
    beta=[t(:,1:i),ones(num,1)]\f0
    beta(end,:)=[];   î
    cancha=f0-t(:,1:i)*beta;
    ss(i)=sum(sum(cancha.^2));
    for j=1:num
        t1=t(:,1:i);f1=f0;
        she_t=t1(j,:);she_f=f1(j,:);   ´
        t1(j,:)=[];f1(j,:)=[];
        beta1=[t1,ones(num-1,1)]\f1;
        beta1(end,:)=[];
        cancha=she_f-she_t*beta1;   %qiucanchaxiangliang
        press_i(j)=sum(cancha.^2);
    end
    press(i)=sum(press_i)
    if i>1
```

```
            Q_h2(i)=1-press(i)/ss(i-1)
        else
            Q_h2(1)=1
        end
        if Q_h2(i)<0.0985
            fprintf('tichudechengfengeshu r=%d',i);
            r=i;
            break
        end
end
beta_z=[t,ones(num,1)]\f0;
beta_z(end,:)=[];
xishu=w_star*beta_z;
mu_x=aver(1:col-1);mu_y=aver(end);
sig_x=stdcov(1:col-1);sig_y=stdcov(end);
ch0=mu_y-mu_x./sig_x*sig_y*xishu;
xish=xishu'./sig_x*sig_y; Rc=corrcoef(x0*xish'+ch0,y0)
sol=[ch0;xish']          %xianshihuiguifangchengdexishu
```

Code 2

```
clc,clear;
load('climate_data2');
rain=climate_data(:,1);
tem=climate_data(:,2);
des=climate_data(:,3);
wdi=climate_data(:,4);
% %zheshiyinrujiaochaxiangde



w=[0.2 0.35 0.6 0.331];
x1=linspace(0,50,100);
x2=w;
yy1=132.73+2.62*x1-156.542*x2(1)-7.0453*x1*x2(1);
plot(x1,yy1,'r','LineWidth',1.5);
hold on
yy2=132.73+2.62*x1-156.542*x2(2)-7.0453*x1*x2(2);
plot(x1,yy2,'y','LineWidth',1.5);
hold on
yy3=132.73+2.62*x1-156.542*x2(3)-7.0453*x1*x2(3);
plot(x1,yy3,'b','LineWidth',1.5);
% hold on
% yy4=132.73+2.62*x1-156.542*x2(4)-7.0453*x1*x2(4);
```

```
% plot(x1,yy4,'r--','LineWidth',1.5);
hold on
yy4=132.73+2.62*x1-156.542*x2(4)-7.0453*x1*x2(4);
plot(x1,yy4,'y--','LineWidth',1.5);

xlabel('desaster','fontsize',15)
ylabel('FSIzhi','fontsize',15)
legend('WDI=0.2','WDI=0.35','WDI=0.6','WDI=0.331(saineijiaer)');
set(gca,'linewidth',1.5);
title('desasterduiFSIdeyingxiang','fontsize',23);
grid on;%xianshigexian
axis([0,15,10,130]);
```

Code 3

```
load('A1')
t1=2007:2016;
A=A1(2:11);
B=cumsum(A);   %yuanshishujuleijia
n=length(A);
for i=1:(n-1)
    C(i)=(B(i)+B(i+1))/2;   % shengchengleijiajuzhen
end
D=A;D(1)=[];
D=D';
E=[-C;ones(1,n-1)];
c=inv(E*E')*E*D;
c=c';
a=c(1);b=c(2);
F=[];F(1)=A(1);
for i=2:(n+10)    F(i)=(A(1)-b/a)/exp(a*(i-1))+b/a ;
end
G=[];G(1)=A(1);
for i=2:(n+10)
    G(i)=F(i)-F(i-1);
end
t2=2007:2026;
disp('yucechucong2006dao2017geniandeFSIzhi')
G
plot(t1,A,'o',t2,G)   %yuanshishujuyuyuceshujudebijiao
xlabel('nianfen','fontsize',15)
ylabel('FSIzhi','fontsize',15)
legend('zhijizhi','yucezhi');
```

```
set(gca,'linewidth',1.5);      %shezhizuobiaozhouxiankuan
title('FSIyuce','fontsize',23);
grid on;%xianshigexian
```