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Summary Sheet

Summary

Climate change has been an essential issue because it exerts a tremendous impact on the world. Climate change can threaten a country' s cohesion, economic, social, political systems and increase its fragility. In this paper, we focus on how climate change will influence the fragility of a state.

Primarily, we establish a **Modified Fragile States Index Model (MFSI)** based on the Fragile States Index(FSI). MFSI incorporates three climate indicators to FSI. These indicators are temperature change indicator(TCI), precipitation per capita indicator (PCI)and extreme weather change indicator(WCI). As each indicator contributes differently to climate change, we apply **Analytic Hierarchy Process** to weight each climate change indicator. Then we use our model to Sudan and discover that climate change does increase its fragility We then analyze how climate change pushes Sudan to be more fragile.

Next, we select Sri Lanka and evaluate how climate change pushes it to become more fragile. To predict the tipping point, we conduct **Curve Fitting** to predict the change of temperature anomaly and adopt **Grey Forecasting Model** to predict the losses brought about by extreme weather (measured by Global Climate Risk Index). Combining the prediction of these climate change indicators, we conclude that Sri Lanka will reach its tipping point in the year 2121, with its temperature anomaly achieving 2.12℃ and Global Climate Risk Index lower than 20.

Then we formulate a more precise model, **Refined Fragile States Index Model (RFSI)** to analyze how interventions mitigate climate change risk. We employ **Partial Least Squares Regression** to find out a more direct relationship between three climate change indicators and the twelve original indicators of FSI. We next select eight state driven interventions and figure out that with these positive interventions, Sri Lanka will get rid of fragile state in 60 years.

Eventually we select South America, a larger "state" to test our model. We discover that we ignore the influence of the ecosystem's change and incorporate this change as a new climate change indicator.

Contents

1. Introduction

1.1 Background

Caused by improper human activities, climate change has been a critical issue for decades as it in turn exerts a huge impact on humans. According to National Climate Assessment, global annual average temperature (as measured over both land and oceans) has increased by more than 1.5°F (0.8°C) since 1880. Besides, global sea level has risen by about 8 inches since reliable record keeping began in 1880. With the current trend, it is estimated that the sea level would rise another 1 to 4 feet by 2100[1]. The results of these changes can bring about nature disasters such as droughts, hurricanes and floods which happen more frequently nowadays.

Climate change may also force people to migrate and fight for resources. People's pressure to survival under climate change can even intensify the social turbulence. Combined with the problems such as political conflicts and economic instability that already exist in a country, climate change can aggravate the fragile situations. It is inevitable that we should incorporate climate change when measuring a country's fragility.

1.2 Restatement of Problems

Our objective is to develop a model that determines a country's fragility and simultaneously measures the impact of climate change. Then we will identify when a state is fragile, vulnerable, or stable.

To determine how climate change may have increased fragility of that country, we select Sudan which is one of the top 10 most fragile states as determined by the Fragile State Index. We will compare the fragility between situations with and without consideration of climate change.

We next use our model on Sri Lanka which is not in the top 10 list to measure its fragility and figure out ways climate change pushes it to become more fragile. After defining a tipping point we predict when Sri Lanka will reach it.

Furthermore, we analyze state driven interventions that could mitigate the risk of climate change and prevent a Sri Lanka from becoming a fragile state. We will explain the effect of human interventions and predict the total cost of intervention for this country. Ultimately, we test our model work on s larger "states" and see if we should modify our model.

2. Assumptions

- The ways climate change influences a country's fragility index can be both direct and indirect. Besides, effective interventions of the government could mitigate the risk that climate change aggravates the fragile situation.

• Climate change indicators of fragility index mainly include temperature, precipitation and extreme weather. When considering the universality of the model , we do not consider other indicators of climate change, simply because we believe other factors has little impact on a state's fragility or they are particular.

• In assessing the indicators of climate change, we score the indicators from 0-10. The higher the score is, the more impact these indicators have on fragility. Furthermore, the larger the total fragility index is, the more fragile the state is,

• The standard that we score the indicators and a state's fragile are suitable

• The data we collect is both accurate and reliable.

3.Basic Model: Fragile States Index Model

Before formulating our Modified Fragile Index Model that incorporates climate change, we first review fragile states index model (FSI) developed by The Fund for Peace and use it as our basic model[2]..

FSI is based on a conflict assessment framework ("CAST") which absorbs twelve indicators to assess the vulnerability of states to collapse[3]. The indicators are shown in table 3-1.

Cohesion indicators(CI)	Security Apparatus(SA)
	Factionalized Elites(FE)
	Group Grievance(GG)
Economic indicators(EI)	Economic Decline(ED)
	Uneven Development(UD)
	Human Flight(HF)
Political indicators(PI)	State Legitimacy(SL)
	Public Service(PS)
	Human Rights(HR)
Social and cross-cutting(SI)	Demographics(DE)
	Refugees and IDPs(RI)
	External Intervention(EI)

Table 3-1 twelve indicators of FSI

Each indicator's maximum score is 10 and the lowest score is 0. FSI is calculated by adding up all the indicators' value, with a maximum of 120.

FSI applies both qualitative and quantitative indicators which are closely related to a state's fragility. Moreover, the index can be compared over time, so it is of convenience to figure out whether the condition is improving or worsening. However, an obvious weakness of this model is that it does not consider climate change factors that may worsen the current situation. Climate change can do considerable damage to a state's economic, politics and culture. Consequently, the risks to a state's stability may increase.

4. Modified Fragile States Index Model

On the basis of FSI, we corporate climate change indicators (CCI) and construct our Modified Fragile States Index Model (MFSI). We divide climate change into three indicators and explore how climate change increases fragility.

4.1 MFSI Model: Fifteen Factors

Combining the original twelve indicators and climate change indicators, we get a new index. The combination is illustrated in figure 1. However, due to the fact that we add three indicators to FSI, the total scores would become 150 instead of 120. For the purpose of comparing fragility with and without climate change, we multiply the original score and 0.8 and get a full mark of 120.

$$\mathrm{MFSI} = 0.8(\mathrm{SI} + \mathrm{EI} + \mathrm{PI} + \mathrm{SI} + \mathrm{CCI})$$

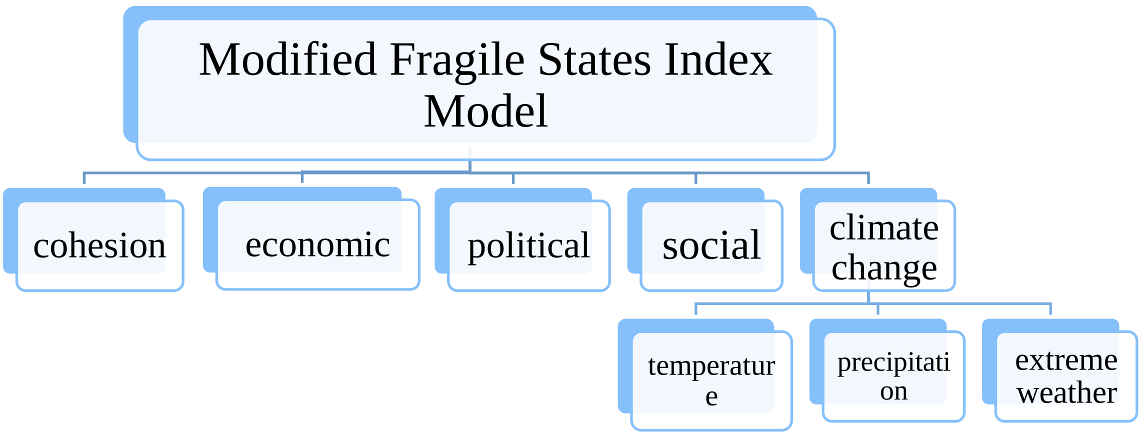

Figure 4-1

4.2 Climate Change Indicators

4.2.1 Temperature Anomaly Indicator(TCI)

Evidence shows that global average temperature is continually rising. It is recorded that the average global temperature for 2016 was 0.94°C above the 20th century average of 13.9°C[4]. The rising temperature could cause problems in the following ways: (1) Sea-level would rise because of the melting ice which is the result of higher temperature, affecting people who live in low-lying areas. They may be in of panic, increasing the risk of instability in a country. When they migrate to other places, conflicts may happen as a result of cultural difference or limited resources. (2) The change of temperature can alter the condition of land, reducing the area of arable land, so the food resources may decrease. As people fight for insufficient resources, there may be intensions and even violence, so the fragility would increase.

To quantify this indicator, we use Temperature Anomaly which is denoted as T_i of a state to measure the influence of temperature change and T_i is measured by the following equation:

$$\mathrm{TA}_i = T_i - T_m$$

Where

T_i = temperature in the current year

T_m = average temperature from year 1961 to 1990

As the most obtainable and reliable data about temperature change is from 1961 to 1990, it is reasonable for us to suppose the reference value is the average temperature from 1961 to 1990. Reviewing literatures, we discover that when temperature rises 1 degree Celsius, human' s life will be largely affected, so we regard the change of 1 degree Celsius as score 8. Once the temperature anomaly rises above 1 degree, any tiny increase could endanger humans' normal activities, so we set the change of 1.75 degrees Celsius as score 9 and the change that is greater than 3 degrees Celsius as score 10. Table 4-1 shows how we match the change of temperature and the score of the temperature anomaly indicator.

TA_i	TCI score
>=0	0
0.1	1
0.15	2
0.3	3
0.45	4
0.6	5
0.75	6
0.9	7
1	8
1.75	9
≥ 3	10

Table 4-1

4.2.2 Precipitation per capita Index(PCI)

Climate change could decrease the precipitation of a state, causing water shortage problems. Conditions can be more grievous in regions that have a rapid growing population or suffer from waterborne diseases[5]. There is much possibility that people would compete for water resources and atmosphere may be strained between communities. If people feel they are treated unequally because of the government's poor water management, the public may show resistance. Thus a state would become more fragile

To measure the change of precipitation, we first establish the precipitation ratio(PR). We use PR to judge the influence degree of precipitation to that region's residents.

$$\mathrm{PR} = \frac{Annual\ Precipitation}{Population}$$

Then we use PR to score PCI from 0 to 10. The higher the score is, the more influence precipitation exerts on the residents. The world average PR equals 1500 (m^3/year) per capita, so we determine that when PR=1500(m^3/year) per capita, the score is 5, which is moderate. Meanwhile, according to thresholds of Falkenmark Water Stress Indicator (Resources to Population Index), we decide that when annual renewable water resources per capita is below 700m^3, the water Scarcity reaches stress level and when renewable water resources per capita is below 500m^3, the state is water scarcity. To adapt the threshold to our PCI, we make some changes and form our standards. We display our standards in table 4-2

PR (m^3/year/cap)	PCI Score
≥40,000	0
15,000	1
11,625	2
8,250	3
4,865	4
1,500	5
1,100	6
700	7
600	8
500	9
0	10

Table 4-2

4.2.3 Extreme Weather Change Index (WCI)

Extreme weather is accompanied by natural disasters such as heat weaves, storms and floods[6]. It not only results in losses of assets, but also can cause fatalities. The consequence of extreme weather would cause complaints from people when government is unable or unwilling to provide effective recovery measures. The helpless and indignant people would protest or fight for their right, worsening the relationship between the public and the government.

To measure the WCI, we introduce the Global Climate Risk Index (CRI) which is developed by Germanwatch that analyses the quantified impacts of extreme weather events. It assesses the impacts in terms of fatalities as well as economic losses that occurred. The smaller the CRI is, the more vulnerable a country is to extreme weather. Because the fragile state index of each indicator is scored from 0 to10, we will modify the CRI to our WCI. The range of CRI in 2016 is from1 to 178, so we will normalize the data with the following equation:

$$\mathrm{WCI} = (200 - \mathrm{CRI})/20$$

4.3 Analytic Hierarchy Process

Each climate change indicator contributes differently to the total climate change indicators index, so we use Analytic Hierarchy Process (AHP) to weight each indicator. First we construct our hierarchy.

Goal	Criteria	Alternatives
Climate change (A)	Increased Droughts (B1) Decreased Arable Land (B2) Changing Animal and Plant Ranges (B3) Sea Level Rise (B4)	PCI (C1) TCI (C2) WCI (C3)

Table 4-3 Two-Layer Hierarchy Structure

Then we construct the judging matrix. The criteria judging matrix is the following matrix.

$$\begin{array}{cc} \mathrm{A} & \begin{array}{cccc} \mathrm{B1} & \mathrm{B2} & \mathrm{B3} & \mathrm{B4} \end{array} \\ \begin{array}{c} \mathrm{B1} \\ \mathrm{B2} \\ \mathrm{B3} \\ \mathrm{B4} \end{array} & \begin{bmatrix} 1 & 2 & 3 & 1/2 \\ 1/2 & 1 & 1/3 & 2 \\ 1/3 & 3 & 1 & 4 \\ 2 & 1/2 & 1/4 & 1 \end{bmatrix} \end{array}$$

And the alternative judging matrices are as follows:

$$\begin{array}{cc} \mathrm{B1} & \begin{array}{ccc} \mathrm{C1} & \mathrm{C2} & \mathrm{C3} \end{array} \\ \begin{array}{c} \mathrm{C1} \\ \mathrm{C2} \\ \mathrm{C3} \end{array} & \begin{bmatrix} 1 & 5 & 6 \\ 1/5 & 1 & 4 \\ 1/6 & 1/4 & 1 \end{bmatrix} \end{array}$$

$$\begin{array}{cc} \mathrm{B2} & \begin{array}{ccc} \mathrm{C1} & \mathrm{C2} & \mathrm{C3} \end{array} \\ \begin{array}{c} \mathrm{C1} \\ \mathrm{C2} \\ \mathrm{C3} \end{array} & \begin{bmatrix} 1 & 3 & 5 \\ 1/3 & 1 & 5 \\ 1/5 & 1/5 & 1 \end{bmatrix} \end{array}$$

$$\begin{array}{cc} \mathrm{B2} & \begin{array}{ccc} \mathrm{C1} & \mathrm{C2} & \mathrm{C3} \end{array} \\ \begin{array}{c} \mathrm{C1} \\ \mathrm{C2} \\ \mathrm{C3} \end{array} & \begin{bmatrix} 1 & 2 & 5 \\ 1/2 & 1 & 4 \\ 1/5 & 1/4 & 1 \end{bmatrix} \end{array}$$

$$\begin{array}{cc} \text{B3} & \begin{array}{ccc} \text{C1} & \text{C2} & \text{C3} \end{array} \\ \begin{array}{c} \text{C1} \\ \text{C2} \\ \text{C3} \end{array} & \begin{bmatrix} 1 & 1/6 & 2 \\ 6 & 1 & 7 \\ 1/2 & 1/7 & 1 \end{bmatrix} \end{array}$$

Next, we conduct consistency checking. The consistency indicator CI is calculated in the equation is as below.

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

We refer to the coincidence indicator table given by Saaty.

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Based on the calculation of CI and RI, we will get CR.

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

We find from our above calculation that $\mathrm{CR} = 0.0766$ and it is less than 0.01, so we believe the judging matrix is qualified. The weight vector is shown in the following table:

B / C	Increased Droughts	Decreasing Arable Land	Changing Animal and Plant Ranges	Sea Level Rise	W*
	0.3275	0.1567	0.3221	0.1937	
TCI	0.7091	0.6175	0.5695	0.1512	0.3700
PCI	0.2118	0.2969	0.3331	0.7582	0.5417
WCI	0.0791	0.0856	0.0974	0.0905	0.0882

Table 4-4

Because the score of CCI is from 0-30. We will use the weight vector $\mathrm{w} = [0.3700 \quad 0.5417 \quad 0.0882] * 3$ to weight each climate change indicator.

$$\mathrm{CCI} = 1.1100\mathrm{TCI} + 1.6251\mathrm{PCI} + 0.2646\mathrm{WCI}$$

Our MFSI is calculated in the following equation:

$$\mathrm{MFSI} = 0.8(\mathrm{SI} + \mathrm{EI} + \mathrm{PI} + \mathrm{SI} + \mathrm{CCI})$$

Where

$$\mathrm{CI} = \mathrm{SA} + \mathrm{FE} + \mathrm{GG}$$
$$\mathrm{EI} = \mathrm{ED} + \mathrm{UD} + \mathrm{HF}$$
$$\mathrm{PI} = \mathrm{SL} + \mathrm{PS} + \mathrm{HR}$$
$$\mathrm{SI} = \mathrm{DE} + \mathrm{RI} + \mathrm{EI}$$
$$\mathrm{CCI} = 1.1100\mathrm{TCI} + 1.6251\mathrm{PCI} + 0.2646\mathrm{WCI}$$

Where CI refers to Cohesion Indicator
EI refers to Economic Indicator
PI refers to Political Indicator
SI refers to Social Indicator

And TCL refers to temperature change indicator, PCI refers to precipitation per capita indicator and WCI refers to extreme weather change indicator

4.4 Threshold of MFSI

To determine the threshold of our model, we incorporate the threshold proposed by FFP and modify it to our own threshold. When the score is below 60, the state is stable. When the score is between 60 and 90, we regard it as a vulnerable state. When the score reaches 90, we consider the country to be fragile.

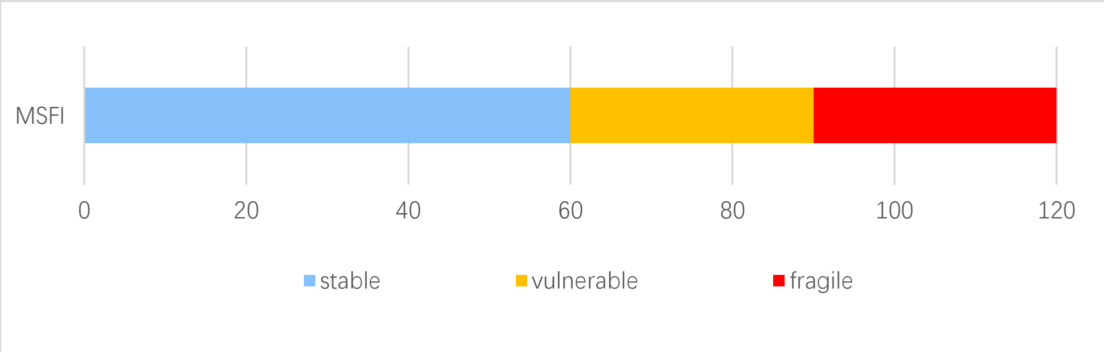

Figure 4-2

4.5 Case Study: Sudan

Known as North Sudan, the Republic of Sudan is a country located in North Africa. With a population of 39,578,000 it is the third largest country in Africa. However, about one half of its population live in poverty. Sudan has been in an unstable economic operation since it was separated from South Sudan. Its fragility is largely due to its war with South Sudan from 2005 to 2011. Together with problems like religious conflicts, armed threats and healthy issue, the dictatorship of the government aggravates its fragility. There are always conflicts and violence in this country[7].

4.5.1 Application of MFSI

According to FSI, Sudan is scored 110.6 and ranks as the 5th fragile country in the world. Based on the modified fragile states index, we will incorporate climate change indicators and calculate its fragility.

After collecting data, we obtain that the temperature anomaly is 1.75 degree Celsius, the annual precipitation is 179.6 m^3 per capita and the CRI is 38.5. Accordingly, the scores of three climate change indicators are 9, 10 and 8.075, respectively.

We then compare the results between the original index and our index. Our comparison shows that climate change has adverse impact on the fragility evaluation.

Modified fragile states index	Fragile states index	Difference
111.2	110.6	0.6

4.5.2 Climate Change Indicators' Influence

The reasons that climate change increases the fragility can be concluded by the following respects:

(1) Temperature
Sudan is a costal country and the rise of temperature can lead to the rise of sea-level. Though people's life is not influenced greatly now, they may feel panic and attempt to migrate. When people migrate to inner regions, conflicts may arise as they may compete for resources with local people. Besides, the change of temperature may reduce the area of arable land, so the food resources may decrease. When people compete for food resources, violence may also occur. When temperature rises, the possibility of being infected with diseases would also increase and people' life will be affected. Thus, Sudan could become more fragile.

(2) Precipitation
The annual precipitation per capital in Sudan is only 179.6 m^3, which is an extremely small amount[8]. Water is highly critical to rain-fed agriculture, especially in Sudan, where water is the main resources that people require for farming and grazing. Water shortage problems have provoked conflicts between tribes, which increases fragility in Sudan.

(3) Extreme Weather
In 2016, there were 171 people who died from extreme weather and Sudan suffered $58 million losses[7]. Because the frequency of nature disasters increases and the government dose not introduce effective policy, the public's security could not be guaranteed and the economic could not maintain stable.

4.5.3 Conditions Without Climate Change Effects

To measure what the situation will be without climate change effects, we will consider the condition when climate change is not so disadvantageous. First, we suppose that temperature increases 0.9 degrees Celsius, which is the global temperature change. Then the score of temperature indicator for Sudan would become 7. In the same way, we assume the precipitation per capita in Sudan equals the world's average level, which is about 1,500m^3[9]. Then the condition in Sudan would be improved considerably and the precipitation indicator would be scored 5. As for extreme weather indicator, we use Algeria as reference. Algeria is the fourth largest economy in Africa and has relatively moderate weather. Using Algeria's CRI (103.5), we get a new score, 4.8. Combining the changes mentioned above, we would get a new MFSI score, which is 102.2[7].

MFSI	MFSI without climate change effects	Difference
111.2	102.2	10

We can conclude that without climate change effects, condition will be much better and Sudan will be less fragile. Reasons are that (1) the temperature change become smaller, so the change would decrease the risk of a series of severe problems such as the rise of sea-level and food shortage. (2) the increased precipitation is far above its original data , so the conflict raised by water resources would be less. (3) the higher CRI means less damage created by extreme weather, so the quality of people' life would be better and economic would be stable. Consequently, Sudan would be less fragile without climate change effects.

5. Case Study: The Tipping Point in Sri Lanka

Sri Lanka lies on the Indian Plate and the climate is tropical and warm[10]. Sri Lanka's fragile states index is 86.6 and ranks 47th. In this section, we will analyze how climate change affects its fragility and predict when Sri Lanka will reach the tipping point.

5.1 Application of MFSI

We can learn from data that the temperature anomaly has increased by 0.64 degrees Celsius, so the TCI score is 5.27. Besides, the annual precipitation is 524 m^3 per capita and PCI score is 8.76. The country's CRI is 11.5, so the extreme weather indicator is 9.425. As a result, the modified fragile states index for Sri Lanka is 87.3, which is greater than the original FSI, 88.6. It is clear that climate change pushes it to become more fragile.

Modified fragile states index	Fragile states index	Difference
87.3	86.6	0.7

5.2 Analysis of the Tipping Point

To determine the tipping point, we analyze each of the three climate change indicators and figure out the circumstance that each indicator endanger the fragility most.

5.2.1 Influence of Precipitation

According to UNFCC, "Rainfall is projected to increase by 48% for the Southwest Monsoon by 2050, which affects the wetter southern part of the country, while the Northeast Monsoon, which occurs in the drier northern region, is predicted to decrease by 27–29%. Therefore, the wet zone is expected to become wetter and the dry zone drier with climate change"[11].

We can discover that when the precipitation decreases in one region of Sri Lanka, the precipitation in another region may increase, and as a result, the overall annual precipitation changes slightly. This score has almost reaches the greatest impact that precipitation can do to fragility index. Consequently, we do not consider the impact that precipitation has when determining the tipping point.

5.2.2 Influence of Temperature

Through consulting literatures, we learn that the global temperature's rise of more than three degrees Celsius would bring about disastrous consequences to human beings. Meanwhile, it is estimated that 275 million people will be flooded at two degrees Celsius of global warming. The world is now attempting to control the change of temperature and struggling to make the change to be less than two degrees Celsius[12]. Then we collect data about the average temperature of Sri Lanka from 1991 to 2015 and conduct curve fitting on $\mathrm{TA}_i(\mathrm{TA}_i = T_i - T_m$, we mentioned this in section 4.2) to figure out future temperature of Sri Lanka. Figure 5-1 proves the result.

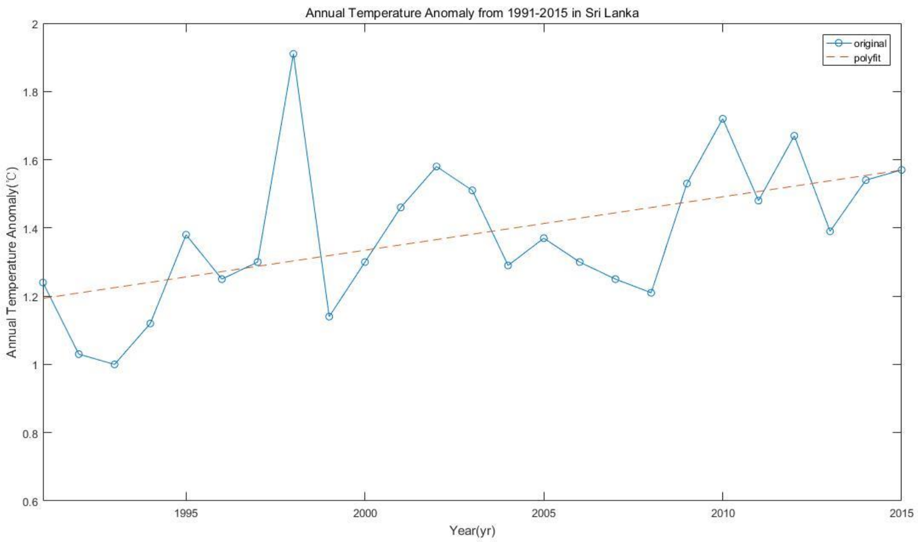

Figure 5-1

From figure 5-1 we can estimate that in 2120, temperature in Sri Lanka will increase by 2.12 degrees Celsius. Therefore, we regard the temperature change of 2.12 in 2120 as tipping point for temperature.

5.2.3 Influence of Extreme Weather

The consequence of extreme weather can be measure by CRI (Global Climate Risk Index, mentioned in section4.2). We believe when CRI is greater than 20, the city will suffer grievous losses. The available data of CRI is from 2007 to 2016 (table5-1) To predict future CRI, we will apply Grey Forecasting Model because it can give a precise prediction even with few data. We choose to use GM (1,1) which is the most widely used Grey Forecasting Model.

2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
54.75	30.83	83.5	56.67	16.50	38.50	55.00	23.50	86.00	11.50

Table 5-1 CRI from 2007 to 2016

Because we presume a country will reach the tipping point of climate change influence when it reaches the tipping points of temperature change and extreme weather simultaneously, the point will be the time after 2120(the time temperature changes 2.12°C). Through our forecast, the earliest time after 2010 that CRI is below 20 is in 2021 and the CRI will be 6.72.

Consequently, our tipping point is 2021 when temperature change is 2.12 degrees Celsius and CRI is lower than 20.

6.A More Precise Model: Refined Fragile States Index

6.1 Partial Least Squares Regression

While analyzing how interventions could mitigate fragility, we discover that when action is taken to improve climate situation, it will also influence the other 12 indicators of Fragile States Index. Besides, we find that the way climate change aggravates a state' fragility is by affecting other factors. To figure out the relationship between climate change indicators and cohesion indicators, economic indicators, political factors and social indicators, we conduct Partial Least Squares Regression.

The first step is data normalization.

$$\widetilde{x_j} = \frac{x_j - {u_j}^{(1)}}{{s_j}^{(1)}}, j = 1,2,3$$

where x_1, x_2 and x_3 denote the temperature indicator, precipitation indicator and extreme weather indicator, respectively.

${u_j}^{(1)} = \frac{1}{10}\sum_{m=1}^{10} x_{mj}$; ${s_j}^{(1)} = \sqrt{\frac{1}{10-1}\sum_{m=1}^{10}\left(x_{mj} - {u_j}^{(1)}\right)^2}$ (x_{mj} denotes the m^{th} year data on the j^{th} indicator)

In the same way,

$$\widetilde{y_i} = \frac{y_i - {u_i}^{(2)}}{{s_i}^{(2)}}, i = 1,2 \ldots 12$$

Where $y, y_2 \ldots y_{12}$ denote security apparatus indicator, factionalized elites indicator, …and external intervention indicator respectively.

${u_i}^{(2)} = \frac{1}{10}\sum_{n=1}^{10} y_{mi}$; ${s_j}^{(2)} = \sqrt{\frac{1}{10-1}\sum_{m=1}^{10}(y_{mi} - {u_i}^{(2)})^2}$ (y_{mi} denotes the m^{th} year data on the i^{th} indicator)

Then we get a 12*12 Correlation Matrix (we do not put it in this paper because of the space limitation). After converting normalized data to original data, we can obtain our regression equation.

$$y_i = a_{i0} + a_{i1}x_1 + a_{i2}x_2 + a_{i3}x_3, i = 1,2 \dots 12$$

Based on the construction of PLSR, we can generate a new index, Refined Fragile states Index which is more accurate and reliable.

$$\text{RFSI} = \sum y_i \ , i = 1,2 \dots 12$$

Applying our PLSR to Sri Lanka, we have the following results in table 6-1 and table 6-2.

i	1	2	3	4	5	6
a_{i0}	17.2875	5.6819	8.3338	8.4484	4.3987	4.7481
a_{i1}	-0.1343	0.0526	0.0179	-0.0365	0.0584	0.0392
a_{i2}	-0.8150	0.2917	0.1329	-0.1842	0.3773	0.2816
a_{i3}	0.0993	0.0915	-0.0326	-0.0984	-0.0003	-0.0546

Table 6-1

i	7	8	9	10	11	12
a_{i0}	16.3662	14.7131	-14.4793	11.5966	2.2795	0.5404
a_{i1}	-0.1232	-0.1328	0.3590	-0.0731	0.1021	0.0875
a_{i2}	-0.7942	-0.8478	2.2899	-0.4838	0.6714	0.4979
a_{i3}	-0.0026	-0.0191	0.0531	0.0231	-0.0227	0.1277

Table 6-2

Using our Refined Fragile States Index model, Sri Lanka is scored 93.15.

6.2 Interventions for Sri Lanka

6.2.1 Specific Interventions

Although climate change will increase the fragility of a state, we believe effective interventions could mitigate the risk of climate change. Based on our previous analysis about climate change and fragility, we propose eight interventions that may be helpful to Sri Lanka.

To control temperature change, there are three interventions.
(1) Energy conservation.
There is no denying that the increasing Greenhouse Gas like CO_2 in the atmosphere leads to global warming. The government should introduce relevant policies to reduce greenhouse gas emissions. For example, Sri Lanka can limit people 's frequency of using cars as transportation and develop more public transportation.

(2) Exploring new energy
If Sri Lanka uses new energy such as electricity, it is clear that the emission of greenhouse gas will be reduced.

(3) Increasing the vegetation coverage
Plants can absorb greenhouse gas through photosynthesis. If Sri Lanka take measures to plant more trees, these trees can reduce greenhouse gas produced by human activities.

We believe these interventions would decrease the rise of temperature in some degree. Then the adverse impacts caused by temperature change, such as the rise of sea-level, would be mitigated. In this way, there will be less conflicts and fragility level would be lowered.

As for decreasing the impact of precipitation, we come up with two interventions.
(1) Perfecting water conservancy facilities
Sri Lanka does not possess abundant water resources, so it is significant for the Sri Lanka to prefect water conservancy facilities to make full use of the limited water resources.

(2) South-to-north water project
In southern Sri Lanka, there is relatively abundant precipitation. However, in northern Sri Lanka, droughts often occur. If it conducts south-to-north water project, the condition in the north would be improved. Besides, Sri Lanka can use experience from other countries which successfully conducted this water project as reference[13].
We are convinced that these interventions can mitigate the water scarcity problem, thus the violence caused by water resource would decrease and Sri Lanka would become less fragile.

With regard to losses from extreme weather, there are three interventions.
(1) Strengthening the security education
To lessen the losses from extreme weather, the government should educate its people concerning how to escape from natural disasters and how to protect themselves.

(2) Studying and predicting disasters
The government should devote more money and energy to studying and predicting disasters. Through this method, Sri Lanka is capable of prepare for disasters in advance.

(3) Post-disaster reconstruction
Sri Lanka is supposed to conduct post-disaster reconstruction to assist people who suffer great losses to start a new life and relieve them from panic.
Adopting these measures can reduce losses from extreme weather, so the economy would stay stable and people' safety can be guaranteed. Accordingly, Sri Lan would become a less fragile country.

Table 6-3 summarizes the state driven interventions and our predicted improvements every ten years[14].

Climate change indicators	State driven interventions	Impact on climate indicators (ten years)		Total impact on climate change indicators
TCI	Energy Conservation	Decreases the index by 1.2%	Decrease the index by 3.8%	Decrease the index by 11.4%
	Exploring new Energy	Decreases the index by 1.0%		
	Increasing the Vegetation Coverage	Decreases the index by 1.6%		
PCI	Perfecting Water Conservancy Facilities	Decreases the index by 2.1%	Decrease the index by 4.0%	
	South-to-north Water Project	Decreases the index by 1.9%		
WCI	Strengthening the Security Education	Decreases the index by 0.9%	Decrease the index by 3.6%	
	Studying and Predicting Disasters	Decreases the index by 1.1%		
	Post-disaster Reconstruction	Decreases the index by 1.6%		

Table 6-3

6.2.2 Evaluation of Human Interventions

After devising the eight interventions for Sri Lanka, we evaluate the effect of these interventions using our RFSI. The score of fragile index will be decreased to 89.98 in 60 years, which is lower than the original score (93.15) and also lower than 90. Sri Lanka's fragility state will switch from fragile state to vulnerable state, showing that state driven interventions can mitigate the risk of climate change.

6.2.3 Prediction of Total Intervention Cost

In this section we evaluate the total cost of our interventions. We estimate the cost of each climate change indicator respectively and then get the total cost.

$$CTCI=CEC+CEN+CRV$$

where CTCI is the cost of interventions measured by TCI, CEC is the cost of Energy conservation, CEN is the cost of Exploring New Energy, and CRV is the cost of Increasing the vegetation coverage.

$$CPCI=CPW+CSN$$

Where CPCI is the cost of interventions measured by PCI, CPW is the cost of Perfecting Water Conservancy facilities and CSN is the cost of South-to-North Water Project.

$$CWCI=CSE+CSP+CPR$$

Where CWCI is the cost of interventions measured by WCI, CSE is the cost of Strengthening the Security Education, CSP is the cost of Studying and Predicting Disasters, CPR is the cost of Post-disaster Reconstruction.

The total cost of intervention for Sri Lanka is

$$TTI=CTCI+CPCI+CWCI$$

Our calculation of total cost is illustrated in table 6-4.

Climate Change Indicators	State driven interventions	The cost of detailed items (in millions, U.S $)		Total cost
TCI	Energy Conservation	The cost of construction of public transportation and human resources	30.50	178.60
	Exploring new Energy	The cost of technology development and purchasing of equipment	73.40	
	Increasing the Vegetation Coverage	The cost of saplings and management cost	74.70	
PCI	Perfecting Water Conservancy Facilities	The cost of water conservancy facilities and maintenance	91.20	144.96
	South-to-north Water Project	The cost of the facilities	53.76	
WCI	Strengthening the Security Education	The cos of education and propaganda	31.50	77.7
	Studying and Predicting Disasters	The cost of technology and experts	13.99	
	Post-disaster Reconstruction	The cost of reconstruction and daily necessities	32.21	
Total intervention cost: 401.26				

Table 6-4

7.Applying our model to South America

To further test our model, we choose a larger “state”, South America and examine whether we should modify our model.

In South America, there are many interesting and unique species of animals. The Amazon rainforests, which lie in the north of South America, possess high biodiversity and contain a major proportion of the Earth's species.

Research reveals that Amazon rainforests are highly sensitive to climate change. Even a slight change of climate would destroy its ecosystem. Once the balance of ecosystem is broken, the environment in South America will be damaged, threatening people's survival. People may need to migrate to other safer places and conflicts may appear when they compete for available resources. Additionally, people 's life may be threatened because of lacking adequate water and food. Meanwhile, the economy will suffer greatly because the ecosystem's change may a country's normal operation. Consequently. South America may become fragile as a result of the change of ecosystem.

However, when evaluating climate change indicators, we ignore the change of ecosystem, which is an essential indicator that may increase a state' s fragility. To optimize our model, we should incorporate the change of ecosystem. Therefore, there are four climate change indicators to measure how climate change may increase fragility. We believe that this modified model will be more thoughtful and the result will be precise.

8.Strengths and Weakness

8.1 Strengths

• Our models are simple and calculable. Our models use very fundamental indicators and they can be easily calculated.

• Our models are understandable and convincing. In MFSI, by using AHP, we weight three indicators, which means we think they contribute differently to a state's fragility. In RFSI, we use Regression Analysis to measure the effects of three indicators on 12 original indicators. Thus, we can find out how these three indicators affect a state's fragility by influencing the original 12 indicators.

• We update our model immediately when we find it is no longer suitable for further analysis. In order to modify the model, we have tried many methods and finally choose the most suitable one. Thus, the process of forming the ideal model is cautious.

8.2 Weakness

• Although We have reviewed many literatures and website information, it is inevitable that the data we obtained are not absolutely accurate.

• When calculating intervention cost, we only select eight interventions and we just roughly estimate the costs of each intervention. If we have more, we will have a thorough evaluation.

9.Conclusions

In this paper, we analyzed the way climate change may influence the fragility of a state.

To begin with, we established a Modified Fragile States Index Model (MFSI) based on the Fragile States Index(FSI). To construct MFSI, we added three climate change indicators to FSI. We use Analytic Hierarchy Process to weight each climate change indicator. Then we applied our model to Sudan and discovered that climate change had adverse impact on its fragility. We then explained the reasons.

Next, we selected Sri Lanka and evaluated how climate change made it more fragile. We conducted Curve Fitting to predict the change of temperature in order to predict its tipping point, and we adopted Grey Forecasting Model to predict when CRI is less than 20. Based on our predictions, we concluded that Sri Lanka will reach its tipping point in year 2121.

Then we formulated a more precise model, Refined Fragile States Index Model to analyze how interventions mitigated climate change risk. We employed Partial Least Squares Regression to figure out the relationship between three climate change indicators and the twelve indictors of FSI. We next selected eight state driven interventions and figured out that with these interventions situations will be better in Sudan.

Finally, when we applied our model to South America, we found that we ignored the influence of ecosystem, so we added ecosystem indicator to our model.

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