基于 PSR 模型和熵权法的气候变化相关国家脆弱性评价模型

气候变化很可能影响一个国家的脆弱状况。因此，我们提出了一个评估模型，以推导出国家脆弱性的定量表达以及它与气候变化的关系。

首先，将 P-S-R(压力-状态-响应)模型应用于我们的模型中，为脆性与相关指标之间的关系提供了一个清晰的框架。该模型遵循域主题特征结构。气候变化是通过直接指标和对社会和经济环境的间接影响来参与的。然后，利用熵权法推导出脆性方程。此外，本文还应用判别分析方法，求出了极度脆弱、脆弱和稳定状态的取值范围。相应的结果分别为 0.4991-1、0.2196-0.4991 和 0-0.2196。

第二，我们确定苏丹从 2012 年到 2016 年的脆弱性，这显示了有限脆弱范围的波动。同时，通过灰色关联分析发现，气候变化主要影响苏丹的粮食安全。然后，通过建立没有直接气候指标的新框架，得到没有气候变化的脆弱性，其结果是脆弱性下降。

第三，对于埃及，我们的模型显示，脆弱局势从 2012 年到 2016 年总体上正在恶化，但仍被视为脆弱。我们得出气候变化主要影响埃及的健康状况。然后确定脆性临界点为 0.4991（脆性值）。通过线性回归方法，我们预测到 2028 年，埃及将成为一个脆弱的国家。

第四，基于该模型，我们提出了一系列干预措施，分别以气候控制和提高一国应对能力为重点。干预的总成本为 1120070 万美元，结果表明，实施干预后，埃及的脆弱性将改善 8.92%。

最后，为了更好地适用于不同大小的状态，我们对模型进行了综合修正，主要集中在我们选择的指标上。

关键词 PSR 模型、熵权法、判别分析

An Evaluation Model of State Fragility related to Clima Based on the PSR Model and Entropy Weight Me

Climate change is likely to influence the fragile situation of a sta propose an evaluation model in order to derive a quantitative expression of state fragility as well as the relationship between it and climate change.

First, theP-S-R (Pressure-State-Response) Model is applied in our model to offer a distinct framework of the relationship between fragility and related indicators. The model follows a domain-theme-feature structure. Climate change is involved through direct indicators and indirect impact on social and economic environment. Thereafter, we derive the equation of fragility by Entropy Weight Method. Furthermore, we apply the Discriminant Analysis to obtain the value range of fragile, vulnerable and stable states. The corresponding results are0.4991-1, 0.2196-0.4991, and 0-0.2196.

Second, we determine the fragility in Sudan from 2012 to 2016, which shows a fluctuation in the limited fragile range. Meanwhile, it is observed that climate change mainly influences on the food security in Sudan through Gray Relational Analysis. Then by establishing a new framework without climatic indicators directly, we acquire the fragility without climate change, and the result is that the fragility declines.

Third, for Egypt, our model shows that the fragile situation is generally deteriorating from 2012 to 2016 but still regarded as vulnerable. We obtain that climate change mainly impacts on health condition in Egypt. Then the tipping point of fragility is determined as 0.4991 (value of fragility) in this section. By Line Regression Method, we then predict that Egypt would become a fragile state in 2028.

Fourth, we propose a series of interventions based on the model, focusing on climate control and improving the coping capability of a country respectively. The total cost of interventions is calculated as 1,120,070,0000 dollars, and the results show that the fragile situation of Egypt would be 8.92% better after implementing interventions.

Lastly, we illustrate the comprehensive modifications of model for better applicable to different sizes of state, mostly concentrated on the indicators we choose.

1 引言

1.1 背景

气候脆弱性风险对国家和社会的稳定构成威胁。换言之，气候变化已经对环境[1]以及国家脆弱性产生了明显的影响。在本文中，我们将气候变化问题定义为自然变化周期与人类活动叠加的影响，而不是纯粹的人类活动归因或自然现象归因。〔2〕

如果国家缺乏履行正常职能和推动向前发展的能力，它们就被归类为脆弱国家[3]。在不平等现象持续存在、政府无法应对压力的脆弱地区，人们发现，气候变化对水、粮食和土地的影响将加大现有压力。也就是说，国家脆弱性的动态可能因气候变化的影响而加剧，其结果是适应能力下降[4]。反之亦然，国家稳定的下降趋势也会加剧气候变化。可怕的自然和政治环境进一步导致资源短缺、移徙、治理薄弱甚至暴力冲突。

1.2 问题重述

根据这一问题，我们需要建立一个适当的模式，有助于识别一个国家的脆弱性和气候变化的影响。之后，模型实例化应在具体国家实施。同时，提出一系列干预措施以减轻气候变化风险，并对不同规模的区域进行进一步的修改。

近年来，世界各国特别是西方国家纷纷开展了对脆弱国家的研究。[5]列出了 11 种现行的脆弱性指数，包括外交政策脆弱性指数(CIFP)、哈佛肯尼迪学院非洲治理指数(IAG)、脆弱国家指数(FSI)等。定量分析。然而，目前的指数很少把气候变化考虑在内，这越来越不可忽视。

在此基础上，建立了基于熵分析方法的综合评价模型，以表征脆弱性的程度以及气候变化对气候脆弱性的影响。接下来，我们根据我们的模型完成对脆弱的苏丹和相对并不那么脆弱的埃及的评估，得出临界点作为边界值。同时，对脆性进行了定量分析，得到了脆性级别。此外，还提出了以成本为代价的气候控制干预措施和更好的应对能力。最后，为了增强模型在小状态和大状态时的性能，我们提出了改进。

1 Introduction

1.1 Background

Climate-fragility risks pose threats to the stability of states and so
words, climate change has already had observable effects on envi
further on the state fragility. In this paper, we define the problem of c
the impact of superimposition of natural change cycle and human activities, rather than attribution of human activities or attribution of natural phenomena purely. [2]

States are classified as fragile if they lack the capacity to discharge their normal functions and drive forward development [3]. In fragile regions where inequality persists and the government is unable to respond to stresses, it has been found that the impacts of climate change on water, food and land will augment existing pressures. That is to say that dynamics of state fragility may be exacerbated by climate change impacts and that the consequence of this is reduced adaptation capacity [4]. Vice versa, the downward trend of state stability will also exacerbate the climate change. Terrible natural and political environment further enables resources shortage, migration, weak
governance and even violent conflict.

1.2 Restatement of the problem

According to the problem, we are required to develop an appropriate model which contribute to the identification of a country's fragility and the impact of climate change at the same time. After that, model instantiation should be implemented on concrete countries. Meanwhile, propose a series of interventions to mitigate the risk of climate change and further modifications for regions of different sizes.

Research work about fragile state has sprung up recent years around the world, especially for the west. 11 kinds of current indices for fragility are listed in [5], including Country Indicators for Foreign Policy Fragility Index (CIFP), Harvard Kennedy School Index of African Governance (IAG), Fragile States Index (FSI), etc. All these diverse evaluation indices are based on the Buckets effect and derived quantificationally. Nevertheless, scarcely do current indices take climate change into account, which becomes more and more non-negligible.

Thereby, on the foundation of the related work above, we establish a comprehensive evaluation model based on Entropy Analysis Method, so as to represent the extent of fragility as well as how climate change contributes to it. Next, we complete evaluation on both fragile Sudan and relatively not so fragile Egypt based on our model, deriving a tipping point as the boundary value. Meanwhile, we acquire both the fragility quantificationally and the level of fragility. Furthermore, interventions of climatic controlling and better coping capability are proposed with the cost. Finally, we put forward modifications in order to exacerbate the capability of our model on smaller and lager states.

2 假设与符号

2.1 问题假设

(1)一个国家的脆弱性指标主要是社会经济、生态和气候。在此基础上，建立了较为全面的指标选择评价模型，为综合考虑国家脆弱性提供了方便。

(2)干预期间，埃及政局稳定。虽然埃及在现实中政治不稳定，但这种假设对于计算我们干预的总成本是有益的。

(3)埃及将根据国内生产总值、人口和工业等指标来跟踪大国的发展趋势。这些趋势通常是正确的。因此，如果埃及遵循这些原则，我们就能够推导出若干指标之间的定量关系，以便根据当前指标的值预测埃及的经济增长。

2.2 符号说明

表 1 模型的符号

符号	含义
Xij	第 j 个指标在第 i 年中的值
Yij	指标对应的标准化数据
Pij	第 j 个指标在第 i 年中所占的比例
Ej	每个指标的信息熵
gj	变异系数
Wj	每个指标的权重
Fi	第 i 年的脆弱性 *th*

2 Assumptions and Notations

2.1 Assumptions

(1) The indicators of a country's fragility are mainly so ecological and climate. Based on that we establish our evaluation model, where the choice of indicators is comparatively comprehensive, since it offers convenience for a more integrated consideration of state fragility.

(2) The political situation in Egypt is stable during intervening. Although Egypt is politically unstable in reality, this assumption is beneficial for calculating the total cost of our interventions.

(3) Egypt will follow the trends in massive countries based on indicators like GDP,population and Industry. These trends are generally true. Thus, if Egypt follow them,we are able to derive quantitative relationship between a number of indicators so as to predict the economic growth in Egypt, based on current values of indicators.

2.2 Notations

Table 1 Notations of the model

Symbol	Notation
X_{ij}	The value of the *jth* indicator in the *ith* year
Y_{ij}	The standardized data corresponding to indicatorsX_{ij}
P_{ij}	The proportion of the *jth* indicator in the *ith* year of that indicator
E_j	The information entropy of each indicator
g_j	Variation coefficient
W_j	The weight of each indicator
F_i	Fragilityin the *ith* year

3 脆弱性模型

基于 P-S-R 模型和熵权法，建立了状态脆弱性评价模型。首先，我们应用前者来确定和收集影响国家脆弱性的指标，特别是与气候变化相关的指标。然后，我们采用后者作为导出这些选定指标的方程的方法，使得状态脆弱性的定量表示和计算成为可能。然后，通过判别分析，确定了脆性、易损性和稳定性三个判别标准的范围。

3.1 P－S—R 模型

压力状态响应是环境质量评价领域中生态系统健康评价子学科常用的评价模型。PSR 模型通过思维逻辑“原因-效果-响应”反映人与环境的相互作用[6]。人类从自然环境中获取生存和发展所必需的资源，同时向自然界排放废物。这样，自然资源的储备和环境质量就会发生变化。作为回报，自然状态和环境的变化影响社会经济活动和人类的福利。此外，社会通过环境、经济和部门政策以及意识和行为的变化来应对这些变化。这种往复循环构成了人与环境之间的压力-状态-响应关系。

PSR 模型回答了可持续发展的三个基本问题，即“发生了什么，为什么发生了，我们如何去做”。为了更具体地表示和解决这些问题，PSR 模型定义了三类指标，即暴露、敏感性和适应能力。更具体地说，这些暴露的特征是各种社会经济活动如何影响环境，例如由于资源获取、材料消耗和各种工业造成的排放对环境的破坏和干扰。同时，敏感度反映了特定时期环境状况和环境本身的变化，包括生态系统和自然环境的现状、人类生活质量和健康状况。最后，适应能力是指社会和个人如何行动，以减轻、阻止、恢复和预防气候和经济因素的负面影响，以及对现有的不利于人类生存的生态环境变化采取补救措施。

3 The Model of Fragility

Our model for the evaluation of state fragility is based on the P-S-I Entropy Weight Method. Initially, we apply the former to detern indicators that influence the fragility of a state, especially the indi climate change. Then our model adopts the latter as the way of deri about these selected indicators, which enables the representation and calculation of state fragility quantificationally. After that, we determine the range of three criteria of fragility, namely fragile, vulnerable and stable, by Discrimination Analysis.

3.1 P-S-R Model

P-S-R (Pressure-State-Response) is an evaluation model commonly used in sub-disciplines of ecosystem health assessment in the field of environmental quality assessment. Through the thinking logic"reason-effect-response", the PSR model reflects the interaction between humans and the environment [6]. Mankind acquire the resources necessary for its survival and development from the natural environment and meanwhile,discharge the waste to the nature. In this way, the reserves of natural resources and the quality of the environment are changed. And in return, variation in the state of nature and the environment impacts on social-economic activities and welfare of human beings.Furthermore, the society responds to these changes by means of environmental, economic and sectoral policies, as well as changes in consciousness and behavior. This cycle of reciprocation constitutes a pressure-state-response relationship between humans and the environment.

The PSR model answers the three basic questions of sustainable development, that is, "what happened, why it happened, how we do it." To represent and solve these more concretely, three categories of indicators are defined in the PSR model, namely exposure, sensitivity and adaptive capability. More specifically, the exposure characterizes howmortal social-economic activities impact on the environment, such as the environmental damage and disturbance due to resource acquisition, material consumption and emissions caused by various industries. Meanwhile, the sensitivity characterizes the environmental status and the change of environment itself during a specific period of time, including the current status of ecosystems and the natural environment, the quality of life and health of human beings. Finally, the adaptive capacity refers to how societies and individuals act so as to mitigate, deter, recover and prevent the negative effects of climate and economic factors, as well as remedial measures for the existing change in ecological environment that is not conducive to human existence.

3.2 P-S-R Framework for state fragility

3.2.1 P-S-R Framework

The mutual effect between state fragility and environment (both political and natural) mentioned above accords with the basic background of PSR model, which means that

it is reasonable to interpret the relationship between state fragility and environment as a pressure-state-response relationship

3.2 国家脆弱性的 PS-R 框架

3.2.1 P—S R 框架

上述国家脆弱性与环境(政治和自然)的相互作用符合 PSR 模型的基本背景，即国家脆弱性与环境的关系应解释为压力-状态-响应关系。

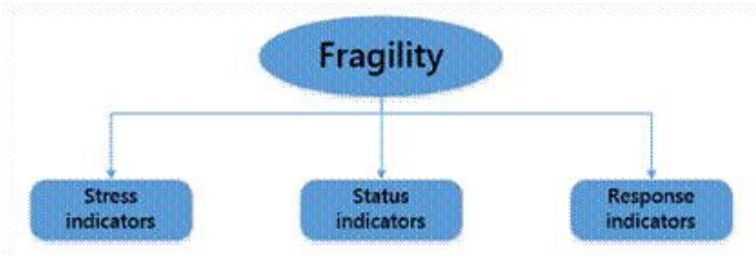

图 1 领域层

对于脆弱性，最初的三类指标分别对应于应力指标、状态指标和响应指标，如图 1 所示。更确切地说，压力指标指的是一个国家的灾难性条件，状态指标与脆弱性有着相对间接的关系，而响应指标则代表了应对国家负面影响的能力。注意，压力指标和状态指标之间没有明确的区别。这三个类别构成了领域层。

然后，主题层进一步细化领域层。首先，我们将压力指标的主题定义为气候变化和社会经济。具体的指标和结构如图 2 所示。

3.2 P-S-R Framework for state fragility

3.2.1 P-S-R Framework

The mutual effect between state fragility and environment (both political and natural) mentioned above accords with the basic background of PSR model, which means that it is reasonable to interpret the relationship between state fragility and environment as a pressure-state-response relationship

Figure 1 The Domain Layer

For fragility, the original three categories of indicators correspond to stress indicators, status indicators and response indicators respectively as shown in Figure1. More exactly, the stress indicators refer to the catastrophic condition of a state, the status indicators own relatively indirect relationship with fragility, and the response indicators represent the capability of coping with negative influence of a state. Note that no clear differentiation exists between the stress indicators and the status indicators. These three categories constitute the domain layer.

Then the theme layer further refines the domain layer. First, we define the themes of stress indicators as climate change and social-economic. The concrete indicators and the structure are shown in Figure 2.

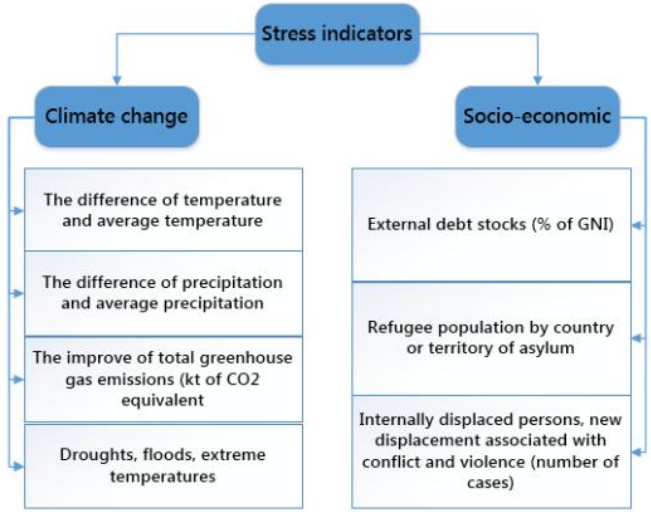

图 2 应力指标的主题层和特征层

第二，状态指标的主题被定义为水资源、生态系统、社会和经济发展、人口发展、健康和工业能源消费效率。主题层和特征层的结构如图 3 所示。

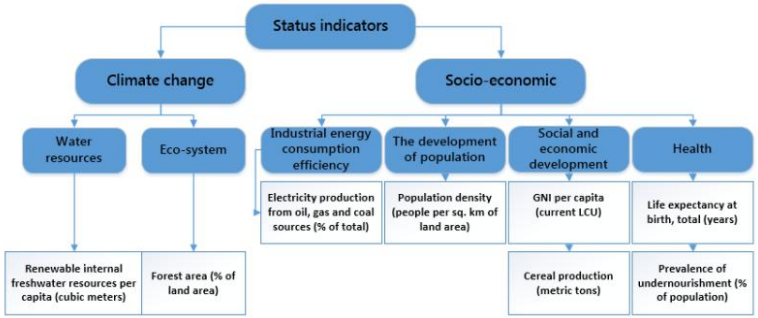

图 3 状态指标的主题层和特征层

最后，将应对指标的主题界定为经济能力、人力资源与社会保障、基础设施与技术保障。主题层和特征层的结构如图 4 所示。

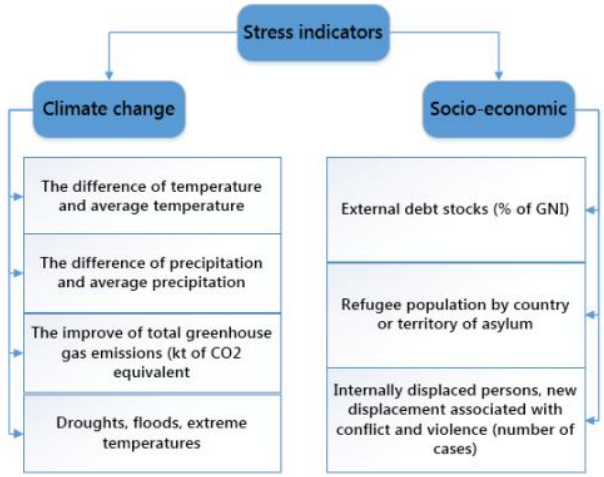

Figure 2 The Theme Layer and Feature Layer of Stress Indicators

Second, the themes of status indicators are defined as water resources, eco-system, social and economic development, the development of population, health and Industrial energy consumption efficiency. The structure of both theme layer and feature layer is shown in Figure 3.

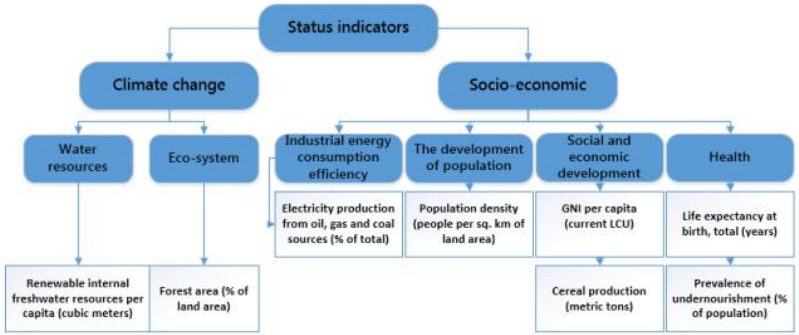

Figure 3 The Theme Layer and Feature Layer of Status Indicators

Finally, the themes of response indicators are defined as economic capability, human resources and social security, infrastructure and technical security. The structure of both theme layer and feature layer is shown in Figure 4.

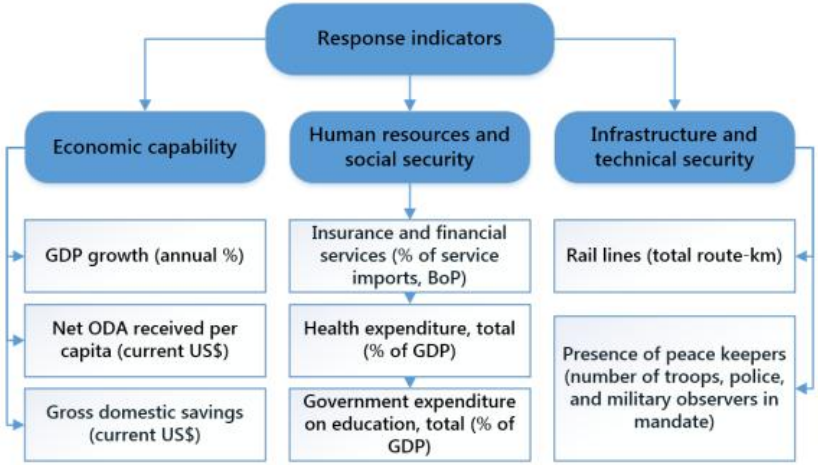

图 4 响应指标的主题层和特征层

在选择指标时，既要考虑科学性，又要考虑有效性，因为对于一些脆弱性较高的特殊区域，很难获得相关数据。此外，我们还考虑了政府对脆弱性的影响，并将其作为一个独立的部分，这对于更加具体地分析国家脆弱性以及减轻脆弱性的干预措施有很大的贡献。同样，我们将气候变化作为一个单独的主题，包括若干指标，这能够并增强气候变化如何影响脆弱性的代表性和解释。

3.2.2 气候影响分析

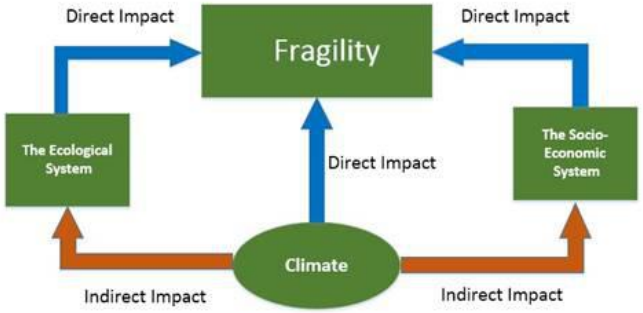

图 5 耦合系统

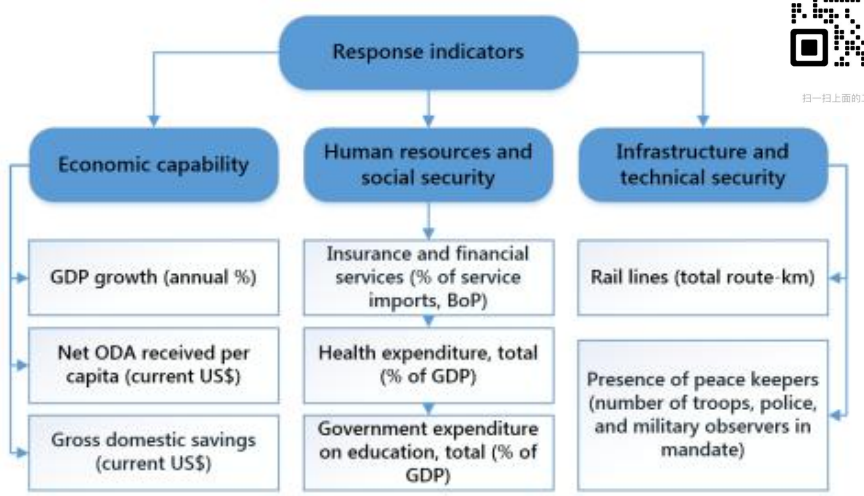

Figure 4 The Theme Layer and Feature Layer of Response Indicators

While selecting the indicators, we give consideration to both scientificity and effectiveness, since it is kind of difficult to acquire correlative date for some special regions whose fragility are comparatively high. Moreover, we take the influence of government on fragility into account and regard it as an independent part, which contributes greatly to the more concrete analysis of state fragility as well as the interventions to mitigate fragility. Similarly, we take climate change as an individual theme including several indicators, which enables and augments the representation and interpretation of how climate change impacts on fragility.

3.2.2 Analysis of Impact of Climate

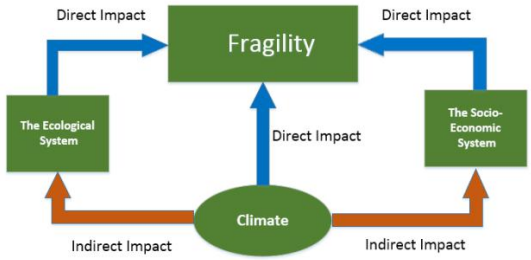

Figure 5 The Coupling System

除了涉及直接气候指标的 23 个指标外，我们在 3.2.1 节中选择上面的部分，我们进一步提出气候变化的间接部分作为更加具体和有效的解释。鉴于气候、生态环境和社会经济环境构成了如图 5 所示的耦合系统[7]，确定某种定量关系无疑是非常困难的。因此，这里的间接影响并不等于定量影响，而是作为进行干预的指导。

我们运用**灰色关联分析**（GRA）来获得对某些社会指标影响最大的气候变量，即最相关的指标，以便为提出干预措施提供有效的指导。灰色关联分析利用灰色关联度作为衡量目标与其他相关因素之间关联度的指标之一。在系统开发过程中，如果两个因素的变化趋势是一致的，即同步度变化程度高，两者之间的相关性就高，反之则低。也就是说，通过 GRA 可以得到因子和目标之间的数值关系，从而简化了进一步的工作。

根据 IPCC 第五次评估报告中的指标，我们选取了一些变化剧烈、对社会和经济影响明显的指标。最终选择的替代变量分别是 CO2、温度、土地覆盖率等。

3.3 评价国家脆弱性

3.3.1 熵权法（具体公式没弄）

利用与区域提供清洁水能力相关的主要因素，我们的评价模型的第二步是确定每个因素的权重，以便确定状态脆弱性方程。

在本节中，我们采用熵权法作为传递每个因素权重的方法。熵权法的基本思想是熵是系统无序程度的度量。如果指标的信息熵较小，则指标提供的信息量越大，指标在综合评价中所起的作用越大，权重应该越高。换句话说，指标变异性的大小决定了客观权重。它由几个步骤组成。

In addition to the 23 indicators which involving direct climatic i select above in section 3.2.1, we further present the indirect change as a more specific and effective explanation. Give ecological environment and social-economic environment coupling system [7] as shown in Figure 5, it is undoubtedly massively difficult to determine a certain quantitative relation. As a result, the indirect impart here is not equal to quantitative impact but works as guidance for proceeding interventions instead.

We apply the Gray Relational Analysis(GRA) to obtain climate variables with the largest impact on some social indicators, namely the most relevant indicators, in order to draw effective instructions for proposing interventions. Gray Relational Analysis use gray relational degree as one metrics of the relational degree between the target and other related factors. In the process of system development, if the tendency of the change of two factors is consistent, that is, the degree of synchronization changes is high, the correlation between the two is higher; on the contrary, it is lower. That is to say, through GRA we can get the relationship between factors and the target in a numerical way, which simplifies further work.

Based on the indicators provided in the Fifth Assessment Report of IPCC, we select some with dramatic change and obvious impacts on society and economy. The final selected alternative variables are respectively CO2, temperature, land cover rate,etc.

3.3 Evaluate the State Fragility

3.3.1 Entropy weight method

With the main factors related to the capability of a region to offer clean water, the second step in our evaluation model is to determine the weight of each factor so that the equationof state fragility can be determined.

In this section we adopt the Entropy Weight Method as the means of delivering each factor's weight. The basic idea of the Entropy Weight Method is that entropy is a measure of the degree of disorder of the system. If the information entropy of an indicator is smaller, the greater the amount of information provided by the indicator, the greater the role played by the indicator in comprehensive evaluation, and the higher the weight should be.

1)首先，假设状态脆弱性已经被观测了 m 年，并且指标数量是 n，我们将 Xij(i=1,2,…,m; j=1,2,…,n)作为 i 年 j 个指标的值。由此 Xij(i=1,2,…,m; j=1,2,…,n)构成矩阵 X。

2)标准化。每个指标的值应该标准化，以便进行以下步骤，这实际上是异构指标的同质化。我们分别定义与指标 Xij(i=1,2,…,m; j=1,2,…,n)相对应的标准化数据为 Yij(i=1,2,…,m; j=1,2,…,n)。

$$Y_{ij} = \frac{X_{ij} - min(X_i)}{max(X_i) - min(X_i)}$$

其中，i= 1,2，…，m；j=1，2，…，n。

3)计算第 j 个指标在第 i 年中的比例 Pij.

$$P_{ij} = \frac{X_{ij}}{\sum_{i=1}^{m} X_{ij}}$$

其中，i= 1,2，…，m；j=1，2，…，n。

4) 其次，推导出各因素的信息熵 Ej。根据信息熵的定义，将其表示如下

$$E_j = -\ln(n)^{-1} \sum_{i=1}^{n} p_{ij} \ln p_{ij}$$

$where p_{ij} = \frac{Y_{ij}}{\sum_{i=i}^{n} Y_{ij}}$, if p_{ij}=0, then $\lim_{p_{ij} \to 0} \ln p_{ij}$=0.

5)计算 J 指示器的变化系数。对于每个指标，差异越大，其评价越重要，信息熵越小。变异系数α定义如下。

$$g_j = \frac{1 - E_j}{m - \sum_{j=1}^{n} E_j}$$

$where 0 \le g_j \le 1 \; and \; \sum_{j=1}^{n} g_j = 1$

In other words, the size of the indicator variability determine weight. It consists of several steps.

1) Above all, assuming that state fragility has been observed f the number of indicators is n, we regard Xij(i=1,2,…,m; j=1 value of the *jth* indicator in the *ith* year. Thereby, Xij(i=1,2,…,m; j=1,2,…,n) constitutes the matrix X.

2) Standardization. The value of each indicators should be standardized so as to proceed the following steps, which is actually the homogenization of heterogeneous indicators. We define the standardized data corresponding to indicators Xij(i=1,2,…,m; j=1,2,…,n) as Yij(i=1,2,…,m; j=1,2,…,n) separately.

$$Y_{ij} = \frac{X_{ij} - min(X_i)}{max(X_i) - min(X_i)}$$

Where, i= 1,2，…，m；j=1，2，…，n.

3) Calculate the proportion Pij of the jth indicator in the ith year of that indicator

$$P_{ij} = \frac{X_{ij}}{\sum_{i=1}^{m} X_{ij}}$$

Where i=1,2,…,m; j=1,2,…,n

4) Next, derive the information entropy E> of each factor. According to the definition of information entropy, it is expressed as follows.

$$E_j = -\ln(n)^{-1} \sum_{i=1}^{n} p_{ij} \ln p_{ij}$$

$where p_{ij} = \frac{Y_{ij}}{\sum_{i=i}^{n} Y_{ij}}$, if p_{ij}=0, then $\lim_{p_{ij} \to 0} \ln p_{ij}$=0.

5) Calculate the coefficient of variation of the *jth* indicator. For each indicator, the larger the difference, the more important it accounts for the evaluation, the smaller the information entropy. The variation coefficient gi is defined as follows.

$$g_j = \frac{1 - E_j}{m - \sum_{j=1}^{n} E_j}$$

$where 0 \le g_j \le 1 \; and \; \sum_{j=1}^{n} g_j = 1$

6)给定信息熵 E1,E2,E3...,每个指标 Wj 的权重可以由如下方程导出。

$$W_j = \frac{g_j}{\sum_{j=1}^{n} g_j}$$

其中 i= 1,2，…，m；j＝1，2，…，n。

3.3.2 状态脆弱性方程

最后，我们确定状态脆弱性方程可确定为**各指标权重和值的乘积之和**，具体如下.

$$F_i = \sum_{j=1}^{n} W_j * Y_{ij}$$

其中 i=1,2,…,m;j=1,2,…,n;Fi 是 i 年的国家脆弱性。

3.5 模型试验

3.5.1 对 30 个国家的模型试验

鉴于我们的评估模型是一个广义模型，其参数在选择目标状态之前无法确定，我们分别在 30 个国家进行了测试，以验证其鲁棒性和有效性。30 个国家是南苏丹、也门、叙利亚、乍得、伊拉克、埃塞俄比亚、尼日尔、利比亚、缅甸、朝鲜、尼泊尔、莫桑比克，布基纳法索、柬埔寨、马达加斯加、老挝、土耳其、俄罗斯、阿塞拜疆、加蓬、巴拉圭、萨摩亚、博茨瓦纳、黑山、阿根廷、波兰、美国、比利时、加拿大和挪威。

6) Given the information entropy E1,E2,E3,..., the weight of each indi

be derived as the following equation.

$$W_j = \frac{g_j}{\sum_{j=1}^{n} g_j}$$

Where i= 1,2，…，m；j＝1，2，…，n.

3.3.2 Equation of State Fragility

At last, we determine the equation of state fragility can be determined as the sum of multiplication of the weight and value of each indicator as follows.

$$F_i = \sum_{j=1}^{n} W_j * Y_{ij}$$

Where i= 1,2，…，m；j＝1，2，…，n; Fi is the state fragility in the ith year.

3.5 Model Test

3.5.1 Model Test on 30 countries

Given that our evaluation model is a generalized model whose parameters cannot be determined until the target state is chosen, we test it on 30 countries respectively so as to certify its robustness and validity. And the 30 countries are South Sudan, Yemen, Syria, Chad, Iraq, Ethiopia, Niger, Libya, Myanmar, North Korea, Nepal, Mozambique, BurkinaFaso, Cambodia, Madagascar, Laos, Turkey, Russia, Azerbaijan, Gabon, Paraguay, Samoa, Botswana, Montenegro, Argentina, Poland, United States, Belgium,
Canada, and Norway

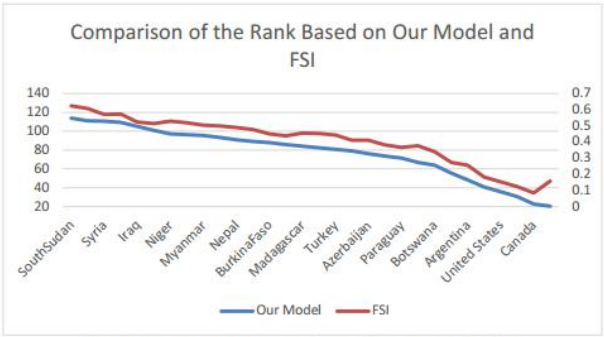

Figure 6 Comparison of The Rank Based on Our Model And FSI

从上面的图 6 可以看出，根据我们模型的评估，脆弱状态的等级不同于根据脆弱状态指数的等级，但是在一个合理的范围内。这两条线的趋势是相似的。这有几个原因可以理解，尤其是我们的模型考虑了有关气候变化的指标。以这种方式，规模相对较小、易受气候变化影响的国家容易表现出脆弱性的增加。例如，与脆弱国家指数相比，萨摩亚的脆弱性增加，因为它位于全年气候极端波动的太平洋岛屿。同样，经常遭遇台风等自然灾害的老挝，与脆弱国家指数相比也显示出相对的增长。

3.5.2 脆弱、脆弱和稳定状态的分类

然后，根据第 3.5.1 节中 30 个国家的结果，我们致力于获得极度脆弱性、脆弱性和稳定性这三个级别的相对准确的范围。这里，我们采用判别分析，一种统计分析，通过一个或多个连续或二元自变量（称为预测变量）来预测分类因变量（称为分组变量）。更具体地说，在本节中，我们选取了脆弱国家指数排名中相对较高、中部和后部的一些国家样本进行分类。同时，我们把其他国家作为差异分析的输入，把处于两类结合点的国家的脆弱性作为边界值。结果如下表 2 所示。

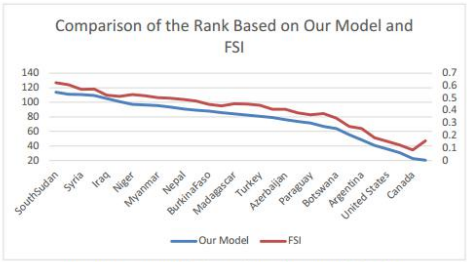

Figure 6 Comparison of The Rank Based on Our Model And FSI

From Figure 6 above, it can be interpreted that the rank of states of fragility according to the evaluation from our model differs from that according to the Fragile State Index, but in a reasonable range. The tendency of the two lines is similar. It is understandable for several reasons, especially for that our model takes indicators about climate change into account. In this way, countries with relatively small size and impressionable to climate change are prone to show an increase in fragility. For example, the fragility of Samoa increases compared with that in Fragile State Index, for it is located in Pacific isles suffered from extreme fluctuant climate throughout the year. Similarly, Laos that often encounters natural disasters like typhoons also shows a relative increase when compared with Fragile State Index.

3.5.2 Classification of Fragile, vulnerable and stable states

Based on the outcome of 30 countries in section 3.5.1, we then work on obtaining a relatively accurate range of three levels of fragility, namely *fragile, vulnerable* and *stable*. Here, we adopt the Discriminant Analysis, a statistical analysis to predict a categorical dependent variable (called a grouping variable) by one or more continuous or binary independent variables (called predictor variables). More specifically, in this section, we select certain countries in the relatively top, middle and back part in the rank of Fragile State Index as samples for classification. In the meantime, we take other countries as input for Discriminant Analysis and regard the fragility of countries in the junction between two categories as the boundary value. The results are shown below in Table 2.

表 2 三级范围

水平	范围
极度脆弱的	0.4991-1
脆弱的	0.2196-0.4991
稳定的	0-0.2196

4 苏丹脆弱性与气候变化

在这一部分中，我们实施了苏丹的评价模型，确定了苏丹的脆弱性，客观地分析了气候变化对苏丹的影响。此外，我们在另一个没有考虑气候变化影响的情况下通过去除气候指标来实例化我们的模型，这表示国家以这种方式会更加脆弱。

4.1 脆弱形势与气候影响

4.1.1 苏丹的脆弱性

根据世界银行收集到的数据，将模型应用于苏丹，我们确定苏丹的脆弱性和 2012 年至 2016 年的水平如下。苏丹脆弱性

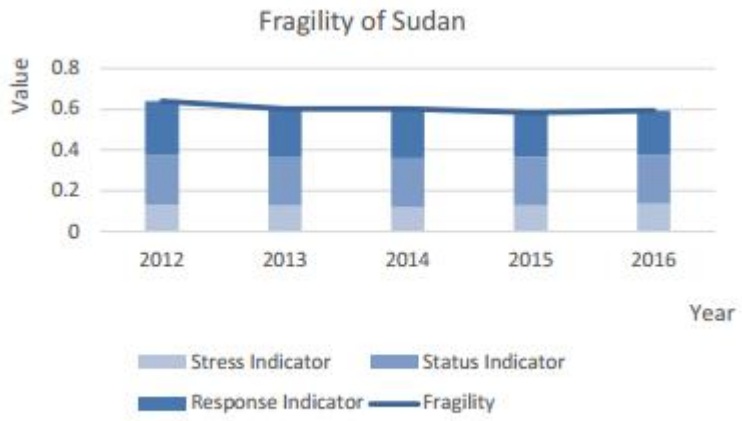

Figure 7 Fragility of Sudan

图 7 苏丹脆弱性

Table 2 Range of three levels

Level	Range
Fragile	0.4991-1
Vulnerable	0.2196-0.4991
Stable	0-0.2196

4 Fragility and Climate Change in Sudan

In this section, we implement our evaluation model on Sudan, determining its fragility and analyze the influence of climate change on it objectively. Furthermore, we instantiate our model in another condition where the effect of climate change is not taken into account through removing climatic indicators, which indicates that the state would be less fragile in this way.

4.1 Fragile Situation and Climatic Impact

4.1.1Current Fragility in Sudan

Applying our model to Sudan with the collected data from the World Bank, we determine the fragility of Sudan and the level from 2012 to 2016 as follows.

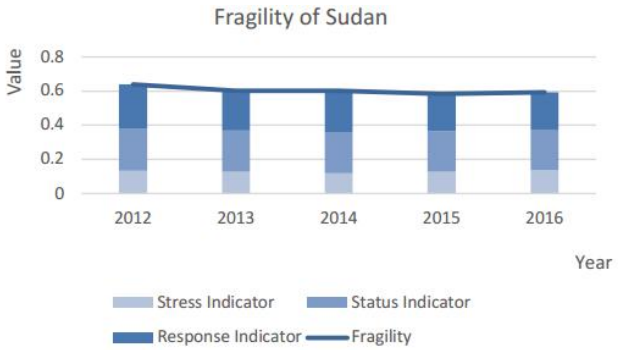

Figure 7 Fragility of Sudan

从图 7 可以看出，尽管苏丹的脆弱性在“W”等相对较小的范围内波动，但五年来苏丹仍处于严重的脆弱状态，总体上呈下降趋势，符合现实。更具体地说，

压力指示器、状态指示器、响应指示器如图 8 所示。可以得出结论，从 2012 年到 2015 年，脆弱性的变化主要来源于响应指标的变化为 57.39%，而从 2015 年到 2016 年，脆弱性的增加主要来源于压力指标的增加为 78.1%。

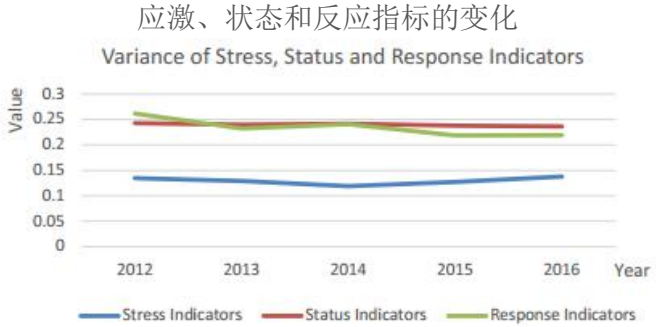

Figure 8 Variance of Stress, Status and Response Indicators in Sudan

图 8 苏丹地区压力、状况及应对指标的变化

- **应激指标**

对于包括气候变化和社会经济在内的压力指标，旱季和雨季降水量的变化都显示出从 2012 年到 2016 年几乎相同的波动。因此，我们可以得出这样的结论：在这 5 年中，全球气候仍然对它造成了更大的威胁和影响，生态系统失衡尚未得到根本缓解。此外，国家或避难地区的难民人数持续急剧增加，这直接加重了政府的压力，同时也反映了政府措施和行动的低效率。

- **状态指示器**

在自然环境和社会经济状况指标方面，人均国民总收入呈上升趋势，尤其在 2014-2015 年间，人均国民总收入几乎翻了一番，而五年间人均耕地和森林面积均呈下降趋势。综上所述，与状态指标相关的指标总体上呈现出良性发展态势。

It can be obtained from the Figure 7 that during the five years, s severe fragile condition though its fragility fluctuated in a r range like “W”, and on the whole it declined, which meets th specifically, the stress indicators, the status indicators, the resp are shown in Figure 8. It can be concluded that from 2012 to 2015, the change of fragility mainly comes from the change of response indicators as 57.39%, while from 2015 to 2016, the increase in fragility mainly comes from the increase in stress indicators as 78.1%.

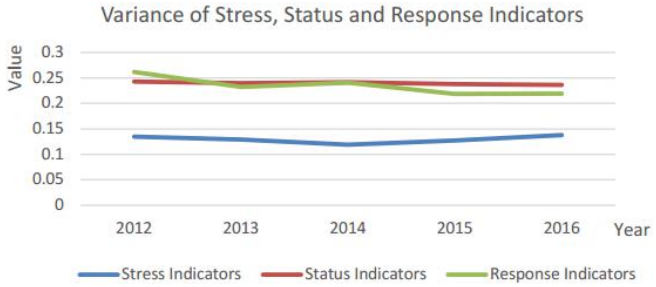

Figure 8 Variance of Stress, Status and Response Indicators in Sudan

- **Stress Indicators**

For the stress indicators including climate change and social-economic, the variance of precipitation in dry and wet season both showed almost the same fluctuation from 2012 to 2016. Therefore, we can conclude that during the 5 years, it still received a greater threat and impact from the global climate, and the imbalance of Eco-system has not yet been fundamentally alleviated. Moreover, the population of refugee by country or refuge area kept increasing dramatically, which directly compounded the pressure on the government and reflected the poor efficiency of government's measures and action at the same time.

- **Status Indicators**

For the status indicators including natural environment and social-economic, GNI per capita showed an upward trend especially between 2014 and 2015 when it almost doubled, meanwhile, both arable land per capita and forest area kept declining during the five years. To sum up, indicators pertaining to the status indicators showed a benign development condition on the whole.

反应指标

在经济能力、人力资源与社会保障、基础设施与技术保障等应对指标上，政府教育总支出（占 GDP 的比重）虽然变化缓慢，但总体呈正向变化趋势，卫生支出（占 GDP 的比重），而净支出则呈正向变化趋势。人均收到的官方发展援助保持逐年显著下降。这些变化表明，苏丹对外部环境的适应性得到了提高。

4.1.2 气候变化对脆弱苏丹的影响

将灰色关联分析应用于苏丹，确定气候指标与一些社会经济指标之间的关系，如表 3 所示。

表 3 气候指标与社会经济指标的关系

	人均可再生内陆淡水资源	谷物生产	营养不良患病率
二氧化碳	0.0171	**0.1367**	0.0942
温度	0.0324	0.0942	**0.1023**
降水量	0.0514	**0.1023**	0.0786
土地覆盖	0.0223	**0.0786**	0.0622
极端天气	0.0308	0.0522	**0.1367**

从上表可以看出，气候指标主要影响粮食生产，即苏丹的粮食安全，因为它们之间的关系程度总体上比较高。因此，在苏丹，气候变化主要通过粮食安全影响脆弱性。

4.2 没有气候影响的苏丹

为了了解在不受气候变化影响的情况下，苏丹的脆弱性将如何变化，我们直接删除模型中与气候相关的指标，然后再次运行。包括苏丹在内的 10 个国家的调查结果以原始和后续排名的形式列于表 4。

● **Response Indicators**

For the response indicators including economic capability, hu and social security, infrastructure and technical security, government expenditure on education totally (% of GDP) showed a positive tendency though the change is slow and, as well as health expenditure (% of GDP), while Net ODA received per capita maintained decreasing year by year significantly. All of the change indicates that adaptability of Sudan to external environment improved.

4.1.2 How Climate change impacts on fragile Sudan

Applying the Gray Relational Analysis to Sudan, we determine the relationship between climatic indicators and some social-economic indicators as shown in Table 3.

Table 3 Relationship Index between climatic indicators and social-economic indicators

	Per capita renewable inland freshwater resources	Cereal production	Prevalence of undernourishment
CO2	0.0171	**0.1367**	0.0942
Temperature	0.0324	0.0942	**0.1023**
Precipitation	0.0514	**0.1023**	0.0786
Land coverage	0.0223	**0.0786**	0.0622
Extreme Weather	0.0308	0.0522	**0.1367**

From the table above, we can conclude that climatic indicators mostly impact the cereal production, namely the food security of Sudan, since the degree of relationship between them is relatively high on the whole. Therefore, in Sudan, climate change mainly influences the fragility through food security.

4.2 A Less Fragile Sudan without influence of Climate

In order to get the how the fragility of Sudan would change without the influences of climate change, we directly remove the indicators related to climate in our model and run it again. The results of 10 countries including Sudan are shown below in Table 4 in the form of original and subsequent rank.

表 4 有无气候影响的国家脆弱性等级

国家	秩与气候影响	无气候影响等级	等级变更
南苏丹	2	1	-1
索马利亚	1	2	+1
中非	4	4	0
也门	3	3	0
苏丹	**6**	**7**	**+1**
叙利亚	5	5	0
公信力公报	7	6	-1
乍得	8	9	1
阿富汗	9	10	+1
伊拉克	10	8	-2

从表格中可以推断出，苏丹的脆弱局势相对地受到抑制，因为其排名下降，忽视了气候变化的影响。

5 埃及脆弱性与气候变化

在这一部分中，我们根据我们的评估模型，完成了另一个关于埃及脆弱性的案例研究，该模型超出了前十个脆弱国家。通过模型的计算，我们测量了埃及的脆弱性，以及气候变化如何以及何时会加剧这种脆弱性。基于以上工作，我们进一步确定一个国家变得脆弱的临界点，并作出相关预测。

5.1 脆弱形势与气候影响

5.1.1 当前脆弱性

根据世界银行收集的数据，将模型应用于埃及，我们确定苏丹的脆弱性和 2012 年至 2016 年的水平如下。

Table 4 Ranks of countries' fragility with and without climate imp

Country	Rank with climatic impact	Rank without climatic impact	
SouthSudan	2	1	
Somalia	1	2	+1
CentralAfricanRepublic	4	4	0
Yemen	3	3	0
Sudan	**6**	**7**	**+1**
Syria	5	5	0
CongoDemocraticRepublic	7	6	-1
Chad	8	9	1
Afghanistan	9	10	+1
Iraq	10	8	-2

It can be inferred from the table that the fragile situation of Sudan is relatively dampened since its rank goes down, neglecting the impact of climate change.

5 Fragility and Climate Change in Egypt

In this part, we complete another case study on Egypt about fragility based on our evaluation model, which is out of the top 10 fragile states. Through calculation of the model, we measure the fragility of Egypt, as well as how and when climate change may increase that. Based on the work above, we further determine the tipping point that a country become fragile and make relevant predictions.

5.1 Fragile Situation and Climatic Impact

5.1.1 Current Fragility

Applying our model to Egypt with the collected data from the World Bank, we determine the fragility of Sudan and the level from 2012 to 2016 as follows.

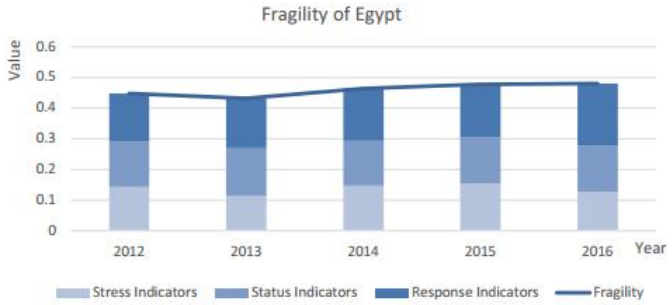

Figure 9 Fragility of Egypt

图 9 埃及脆弱性

从图 9 可以看出，随着埃及的脆弱性波动，埃及的脆弱性状况从 2012 年到 2016 年呈现出总体恶化的趋势。更具体地说，压力指标、状态指标、反应指标如图 10 所示。12-2013 年，脆弱性的变化主要来源于响应指标和状态指标的变化，分别为 77.87%，而 2013-2016 年，脆弱性的增加主要来源于响应指标的增加，为 83.4%。

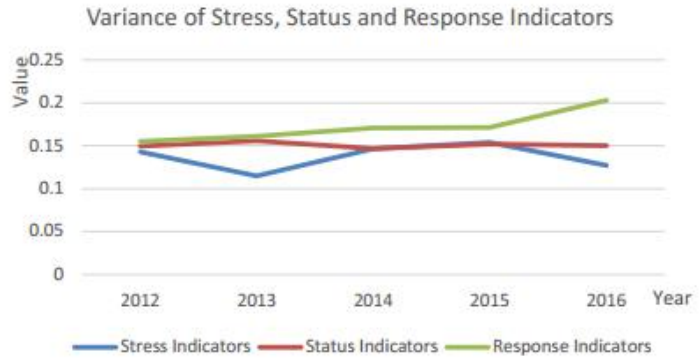

Figure 10 Variance of Stress, Status and Response Indicators in Egypt

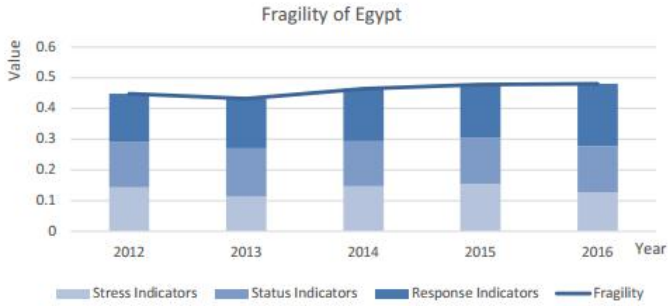

Figure 9 Fragility of Egypt

It can be inferred from the Figure 9 that the fragile situation of Egypt showed a generally deteriorate trend from 2012 to 2016 as its fragility fluctuated.More specifically, the stress indicators, the status indicators, the response indicatorsare shown in Figure 10.It can be concluded that from 2012 to 2013, the change of fragility mainly comes from the change of response indicators and status indicators as 77.87%, while from 2013 to 2016, the increase in fragility mainly comes from the increase in response indicators as 83.4%.

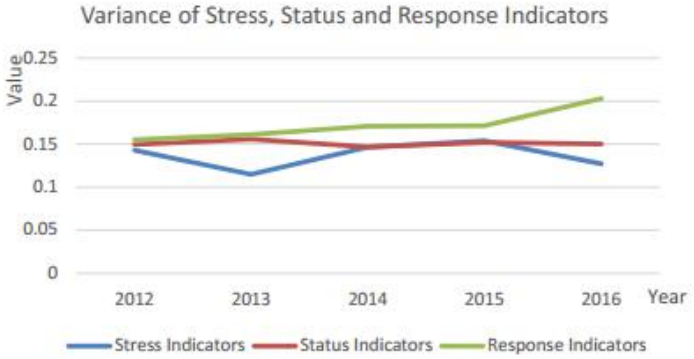

Figure 10 Variance of Stress, Status and Response Indicators in Egypt

应激指标

在应力指标上，旱季降水量变化相对稳定，而湿季降水量则呈递减趋势。湿季和旱季的气温也有明显的变化。因此，我们可以得出这样的结论：在这 5 年中，苏丹受到比苏丹更严重的全球气候威胁和影响，生态系统失衡尚未得到根本缓解。此外，其他指标如外债现值（国民总收入的百分比）和按国家或避难地区分列的难民人口的增加，反映了政府措施的效率低下。

状态指示器

除了从 2012 年到 2013 年略有上升外，这些状况指标在 5 年中保持了相对稳定的趋势。其结果是，大多数具体指标变化很小，如森林覆盖率、人口密度等。然而，尽管变化不大，但仍然显示出埃及恶劣的生活环境。

反应指标

如图所示，响应指标首先经历了从 2012 到 2013 的埃及相对减少，这主要是由于人均收到的净 ODA 减半。如果没有足够的援助，埃及政府可能会更难处理麻烦。因此，虽然与其他两种指标相比贡献较少，但在评价国家脆弱性时，反应指标仍占很大比重。

5.1.2 气候变化对脆弱苏丹的影响

将灰色关联分析应用于埃及，确定了气候指标与社会经济指标之间的关系，如表 5 所示。

表 5 气候指标与社会经济指标的关系指数

	人均可再生内陆淡水资源	谷物生产	营养不良患病率
二氧化碳	0.0223	0.1076	**0.1431**
温度	0.04545	0.0998	**0.0879**
降水量	0.0583	**0.11415**	0.11006
土地覆盖	0.0282	**0.08925**	0.0622
极端天气	0.0368	0.0677	**0.1367**

- **Stress Indicators**

For stress indicators, the variance of precipitation in dry seas steady while that in wet season decreased dramatically. The both wet and dry season also showed an apparent change. Therefore, we can conclude that during the 5 years, it suffered from more severe threat and impact from the global climate than Sudan, and the imbalance of eco-system has not yet been fundamentally alleviated as well. Moreover, increase in other indicators like Present value of external debt (% of GNI) and the population of refugee by country or refuge area reflected the poor efficiency of government's measures.

- **Status Indicators**

The status indicators, except for the slight rise from 2012 to 2013, retained a relatively stable tendency during the 5 years. What resulted in this is that most concrete indicators involved change quite gently like forest coverage, dense of population and so on. However, though slight, the variance still showed the rough living environment in Egypt.

- **Response Indicators**

As shown in the figure, the response indicators first experienced a comparatively reduction in Egypt from 2012 to 2013, which mainly on account of the halving of Net ODA received per capita. Without enough aid, it may be much more difficult for Egyptian governments to deal with troubles. Thereby, though contributed less compared with other two kinds of indicators, the response indicators still account greatly when evaluating the state fragility.

5.1.2 How Climate change impacts on fragile Sudan

Applying the Gray Relational Analysis to Egypt, we determine the relationship between climatic indicators and some social-economic indicators as shown in Table5.

Table 5 Relationship Index between climatic indicators and social-economic indicators

	Per capita renewable inland freshwater resources	Cereal production	Prevalence of undernourishment
CO2	0.0223	0.1076	**0.1431**
Temperature	0.04545	0.0998	**0.0879**
Precipitation	0.0583	**0.11415**	0.11006
Land coverage	0.0282	**0.08925**	0.0622
Extreme Weather	0.0368	0.0677	**0.1367**

从上表我们可以得出结论，气候指标主要影响营养不良的流行，即埃及的医疗状况，因为它们之间的关系程度总体上相对较高。因此，在埃及，气候变化主要通过医疗条件影响脆弱性。

5.2 脆弱的转折点

正如脆弱性分类中所说明的，临界点实际上是脆弱性和脆弱性之间的边界值。因此，我们将临界点定义为 0.4991（脆弱性价值），达到这个临界点意味着这个国家是脆弱的。

之后，我们采用多因素线性回归方法，通过预测指标，包括按国家划分的难民人数、降水量、人口密度、健康状况等，预测埃及何时会成为脆弱国家。

Figure 11 Prediction of Fragility in Egypt

图 11 埃及脆弱性预测

如图所示，我们可以得出结论，埃及在经历了 2017 年以来的 11 年的斗争之后，将在 2028 年达到真正脆弱的局面。没有额外的干预，这种趋势在某种程度上是不可避免的。

6 提高稳定性的干预计划

根据我们的评估模型，结合埃及的案例，我们提出了一系列两类干预措施，一是控制气候变化，二是从应对指标出发，加强应对能力。这些干预措施如何发挥作用已经通过我们的模型得到证明，同时，我们清楚地列出了总成本。

From the table above, we can conclude that climatic indicators the prevalence of undernourishment, namely the medical cond since the degree of relationship between them is relatively high Thus, in Egypt, climate change mainly influences the fragility through medical condition.

5.2 The tipping point of fragility

As what illustrated in classification of fragility, the tipping point is actually the boundary value between *fragile* and *vulnerable*. Thereby, we define the tipping point as 0.4991 (value of fragility), arriving at which means this country is fragile.

After that, we adopt Multi Factor Line Regression Method to predict when Egypt would become a fragile country as defined, by forecasting indicators including the population of refugee by country, precipitation, density of population, health condition, etc. The outcome is shown in Figure11 as follows.

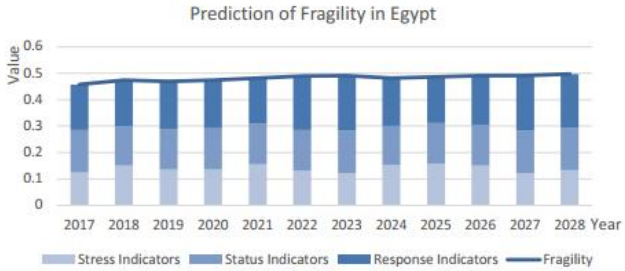

Figure 11 Prediction of Fragility in Egypt

As indicated in the figure, we can conclude that Egypt would arrive at a truly fragile situation in2028, after struggling for 11 years since 2017. Without additional interventions, this tendency is unpreventable in a way.

6 Intervention Plan for Better Stability

Based on our evaluation model accompanied with the cases of Egypt, we come up with a series of interventions of two kinds, the one is to control climate change and the other is to strengthen the coping capability starting from response indicators. How these interventions work has been shown through our model, at the same time, we list the total cost clearly.

6.1 干预

6.1.1 气候控制计划

1）干旱、洪水、极端气温

承办水利工程是解决旱涝灾害的良好办法，因为水利可以起到调节和补充河水的作用。更具体地说，它能够在洪水期间关闭一些水并且从水库释放水以缓解干旱。此外，退耕还林还草也是可取的，因为树木和草可以保护一部分水。因此，减少碳排放和减缓地球变暖可能是缓解极端天气的有效途径。

2）温室气体排放总量（CO2 当量的 Kt）

CO2 浓度是全球变暖的最决定性指标之一，因此减少 CO2 浓度也能够抑制环境退化。通过技术改造、提高能源利用效率、节能降耗、调整产业结构、发展节能环保产业等多种手段可以有效地实现这一目标。

6.1.2 应对能力计划

1) 经济能力

- **产业结构优化升级**

为了提高经济能力，产业结构需要优化升级。政府应加快传统产业转型升级，深化信息化与工业化一体化，大力培育战略性新兴产业，积极培育新形式、新业务模式，构建新型发展体系。现代工业的发展。综合国力的竞争归根结底是创新的竞争。因此，必须进一步实施创新驱动型发展战略，促进各类科技创新。

6.1 Interventions

6.1.1 Plan about climate control

1) Droughts, floods, extreme temperatures

Undertaking water conservancy projects is an excellent solution for droughts and floods, since water conservancy can play a role of regulating and replenishing the water of the river. More specifically, it is able to shut down some of the water during floods and release the water from reservoirs to ease the drought. Additionally, returning farmland to forestry or grassland is also recommendable, since trees and grass can conserve part of water.Thereafter, reducing carbon emissions and slowing the warming of the earth may be effective ways to mitigate extreme weather.

2) Total greenhouse gas emissions (kt of CO2 equivalent)

The CO2-concentration is one of the most decisive indicators of global warming, thus reducing it is also capable of dampening the environmental degradation. Multiple means can be effective for that, like modifying technology, improving energy efficiency, energy saving, adjusting industrial structure, the development of energy-saving and environment-protecting industry

6.1.2 Plan about coping ability

1) Economic capability

- **Optimization and upgrading of industrial structure**

For the purpose of improving economic capability, industrial structure is in need of optimizing and upgrading. Governments should better speed up transformation and upgrading of traditional industries, deepen the integration of informatization and industrialization, strive to foster strategic emerging industries, and actively cultivate new formats and new business models and build a new system for the development of modern industry. In the final analysis, the competition of comprehensive national strength is a competition of innovation. Thereby, it is necessary to further implement the innovation-driven development strategy and promote scientific and technological innovation of all kinds.

- **发展优势地方产业**

从地方实际出发，以市场为导向，因地制宜地发展特色经济，具有重大的帮助和意义。这样有利于调整生产结构、增加收入、增强产品竞争力的地方条件多种对策，包括结合地方优势和市场需求，发展特色产业和产品。

2)人力资源和社会保障促进巨灾保险

- 针对保险和金融服务

巨灾保险能否在一个国家得到推广和广泛应用是有帮助的。灾难是较少但破坏性的风险。政府和保险业应加强巨灾风险预测和预警以及巨灾风险管理，尽快建立有效的巨灾预防体系和巨灾补偿机制[8]。

3）基础设施和技术安全

- **增轨与维和**

能源短缺和环境恶化之间的矛盾迫使许多国家重新认识到加快铁路发展的重要性[9]。此外，对于战区，维和人员是安全保障的重要来源。

6.2 以埃及为基础

以埃及为例，我们分析和估计上述干预措施的总成本，如下表 6 所示。计算公式如下：

Develop advantageous local industries

Starting from local reality, it is of great help and significance to guideline and develop economy with special characteristics tl measures with local conditions. In this way, the local readjusting production structure, increasing income and enhancing product competitiveness can be benefited. Multiple countermeasures include combining local advantageous with market requirement and develop industry and product with special characters.

2) For human resources and social security

- **Promote catastrophe insurance**

In allusion to Insurance and financial services (% of service imports, BoP), it helps if catastrophe insurance can be promoted and applied widely in a country. Catastrophe is a less frequent but destructive risk. Government and insurance industry should strengthen catastrophe risk prediction and early warning, as well as catastrophe risk management, building effective catastrophe prevention system and catastrophe compensation mechanism as soon as possible [8].

3) Infrastructure and technical security

- **Augment railroading and peacekeeping**

The contradiction between the shortage of energy resources and the deterioration of the environment has forced many countries to re-understand the importance of accelerating the development of the railway [9]. Moreover, for war zones, peacekeepers work as an important source of security safeguard.

6.2 Costbased on Egypt

Take Egypt as example, we analyze and estimate the total cost of above interventions, listed in Table 6 below. Some calculation formulas are listed as follows.

表 6 干预与成本

措施	成本
巨灾保险	50000000 美元
维和人员	70000 美元
教育类	40000000 美元
铁路运输	460000000 美元
医疗	50000000 美元
经济转型	500000000 美元
气候改善	20000000 美元
总成本	
1120070000 美元	

教育成本是通过将埃及的教育支出从 3.75 亿增加到 4 亿来得出的，同样，医疗费用也是通过将卫生支出（占国内生产总值的百分比）从 5.64 增加到 5.8 来得出的。对于铁路运输来说，我们通过增加 3%的里程来获得成本。这些变化在相关理论支持下是合理的。

此外，在合理的范围内，总成本几乎占埃及国内生产总值的 3.365%。因此，我们的干预措施是可行的，没有太多的财政负担。

6.3 种干预效果

通过我们的评估模型模拟对埃及实施的干预措施，我们获得了如下图 12 所示的干预措施的效果。

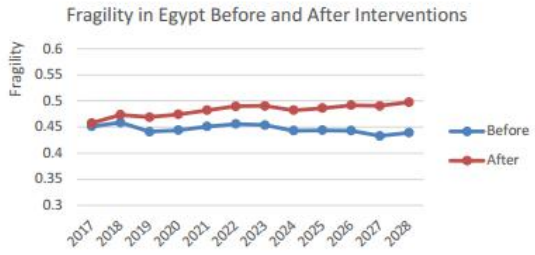

Figure 12 Fragility in Egypt Before and After Intervention

Table 6 Interventions and the cost

Measure	Cost
Catastrophe Insurance	50,000,000 dollars
Peacekeepers	70,000 dollars
Education	40,000,000 dollars
Railroading	460,000,000 dollars
Medical treatment	50,000,000 dollars
Economic Transition	500,000,000 dollars
Climatic improvement	20,000,000 dollars
Total Cost	
1,120,070,000 dollars	

The cost of education is derived by increasing the expenditure on education of Egypt from 375 million to 400 million, similarly, the cost of medical treatment is derived by increasing the health expenditure (% of GDP) from 5.64 to 5.8. And for railroading, we obtain the cost through increasing the mileage by 3%. These changes are reasonable with related theoretical support.

Furthermore, the total cost makes up for almost 3.365% of the GDP in Egypt, in a rational range. Therefore, our interventions are feasible without too much financial burden.

6.3 Effects of interventions

Simulating the implement of interventions on Egypt through our evaluation model, we obtain the effects of interventions as shown below in Figure 12.

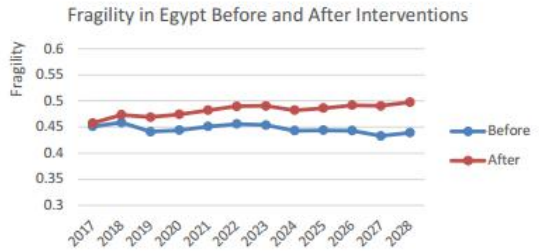

Figure 12 Fragility in Egypt Before and After Intervention

可以认为，我们的干预措施使脆弱性平均下降约 8.93%，这进一步证明气候变化的影响得到缓解，埃及的应对能力得到增强。

7 不同尺寸区域的修改

7.1 小于或大于状态的模型的不适用性

1）对于较小地区如城市

应用我们的模型来评价像城市这样的小区域的脆弱性是不合适的。首先，现有模型中的一些指标可能不可用。例如，长期外债、CPIA 等指标被用来评估一个国家的状况，这对于一个城市来说可能意义不大。第二，我们认为一个国家在政治和经济上是独立的实体，而城市不是这种性质的。城市受国家政策和其他因素的影响，其脆弱性是增加还是减少。例如，一些国家呼吁各种资源来维持其经济和政治中心的稳定，这导致了一个不那么脆弱的地区。

2）对于较大地区如大洲

在压力指标方面，一个大陆的情况比一个国家更复杂。例如，亚洲横跨热带气候、温带和寒带，这意味着直接测量一个大陆的气候指标太粗糙，无法衡量脆弱性的风险。在一个大陆上比一个国家更复杂。国家制度的多样性和国家间的独立性强。对于模型中使用的一些指标，如人均耕地，如果直接平均耕地，则不考虑各国之间的差异。在应对指标方面，当谈到经济能力时，经济基础稳定的国家可能非常健全，从而提高了整个大陆处理偏离现实的脆弱因素的经济能力。

It can be included that our interventions enable the declina by almost8.93% on average, which further testifies that the im change is mitigated and the coping capability of Egypt.

7 Modifications for regions of different sizes

7.1 Inapplicability of model for smaller or larger states

1) For smaller regions like cities

It is not so suitable to apply our model to evaluate the fragility of such a small region like a city. First, some indicators in the existing model may be unavailable. For example, indicators such as long-term foreign debt and CPIA are utilized to evaluate the condition of a country, which may be less meaningful for a city. Second, we regard a country as a politically and economically independent entity, whereas cities are not of this nature. A city is influenced by national policies and other factors and then the fragility increases or decreases. For example, some countries tend to call various resources to maintain the stability of its economic and political center, which leads to a less fragile area.

2) For larger regions like continents

In terms of stress indicators, situation of a continent is more complicated than a country. For example, Asia stretches across the tropical climate, the temperate zone and the frigid zone, which means that directly measuring the climatic indicators of a continent is too rough to measure the risk of becoming fragile.In terms of status indicators, the situation of ethnic groups and religions in a continent is more complex than a country as well. Diversity of national system and strong independence among countries exist. For some indicators we use in the model like per capita arable land, the differences of countries are not taken into account if arable land is directly averaged. In terms of response indicators, when it comes to economic capability, countries with steady economic base may be very sound, boosting the economic ability of the entire continent to deal with the fragile factors deviating from reality.

7.2 不同尺寸区域的修改

1）对于像城市这样的较小地区

当具体到一个城市时，我们的模型的总体框架可以保持，即指标类别包括压力、状态和应对指标以及权重，以得到该区域的脆弱性。对于一些国家一级的指标，改为在区域一级使用相应的指标。在考虑应对指标时，只考虑城市的指标是不可行的，但应包括国家对区域和国家的政策作出反应的能力等指标。

2）对于大洲等大洲

一个大陆是由不同的国家组成的。因此，现有的模型可以用来计算大陆内每个国家的脆弱程度。然后根据一个国家的人口、国土面积等指标，运用层次分析法确定各个国家的权重。最后，通过脆弱性倍增与各国权重之和，得到大陆的脆弱性。

8 优点与缺点

8.1 优点

1)关于脆弱性的全面、主要是客观的指标。

在寻找和选择关于敏捷的指标时，我们尽可能全面、细致地考虑它的等式。与气候变化相关的指标和其他不相关的指标，如国内生产总值，都被考虑在内。此外，大多数指标是根据脆弱状态指数考虑的因素来选择的，这意味着我们的模型是有效的、有意义的基础。

2）模型比较正确的结果。

在指标和数据数量有限的情况下，模型的脆弱性等级仍与和平基金提出的脆弱性国家指数相似。特别地，结果突出了气候变化的影响，这是新颖和有效的。

3）广泛的评价指标体系。

在脆弱性评价模型中，根据“压力-状态-响应”框架，从风险度、敏感性和脆弱性三个方面选取评价指标，设计了反映国家脆弱性、国家脆弱性、国家脆弱性、国家脆弱性、国家脆弱性、国家脆弱性三个方面的综合评价指标体系。国家对风险的处理能力和应对能力。

7.2Modifications for regions of different size

1) For smaller regions like cities

When specific to a city, the overall framework of our model can mai
categories of indicators including stress, status and response indicato
to get the fragility of the region. For some national-level indicators, use the corresponding indicators at the regional level instead. When considering the response indicators, it is not feasible to consider the indicators of the city only, but such indicators as the country's ability to respond to the policies of the region and the country should be included.

2) For larger regions like continents

A continent is composed of various countries. Therefore, existing models can be used to count the degree of fragility of each country within a continent. Then based on a country's population, territorial area and other indicators, the analytic hierarchy process can be applied to determine the weight of each country. Finally, we can obtain the fragility of a continent through the sum of the multiplication of fragility and the weight of each country.

8 Strengths and Weaknesses

8.1 Strengths

1) Comprehensive and mostly objective indicators about fragility.

While searching for and selecting indicators about agility for its equation, we consider as comprehensively and meticulously as possible. Both indicators relevant with climate change and other irrelevant indicators like GDP are considered. Moreover, most of the indicators are selected as per what Fragile State Index takes into account, which means that our model is on a valid, significative basis.

2) Comparatively correct results of the model.

With restricted number of indicators and data, the fragility rank of our model is still similar to that of Fragility State Index proposed by the Fund for Peace. Particularly, the impact of climate change is highlighted in the results, which is novel and valid.

3)Extensive evaluation index system.

In our model of fragility, according to the "stress-state-response" framework, indicators are selected from three aspects including risk degree, sensitivity and vulnerability .The comprehensive evaluation index system is designed this way, reflecting the fragility of the country, the sensitivity of the state to risks and the capability to deal with the risk.

8.2 缺点

1)指标选择过程中的主体性和局限性。

虽然参考了相关文献以及脆性状态指数的影响因素，但仍然选择了具有主观概念的指标。没有足够的文献，这是不可避免的。2）脆性的不精确分类。

我们对脆弱性的分类，即脆弱、脆弱和稳定的范围，是基于第 3.5.1 节中 30 个选定国家的结果。有限的国家数量限制了分类的准确性，即使我们采用判别分析进行更好的分类。

3）不包括苏丹和埃及在内的所有分析。

在对苏丹和埃及的分析中，我们只评估了 2012-2016 年 5 年的脆弱状况，日期相当有限。以这种方式，我们的分析结果不够全面和精确，不足以代表两国的脆弱性。

9 未来工作

正如在模型的缺点中所讨论的，开发更精确的模型形式存在多种可能性。因此，在未来，将以以下方式开发更全面、更明确的模型：

1）更精确、更全面的数据

我们的模型是建立和分析的基础上的假设，我们所收集的数据都是可靠的，由于有限的时间，这是相对不符合现实世界的。因此，需要通过更加细致的研究来获得更加真实可靠的数据。

2）考虑特殊国家

尤其是那些指标可能太过极端，导致整个国家崩溃，无法保障人口基本生活的国家。例如，水资源的极端缺乏可能对该国的脆弱性产生重大影响，而在今后的工作中，我们可能不会将该国列入脆弱地区名单。我们可以将每个指标的标准化值定义为严重限制民生安全的临界点。如果达到这个值，这个国家人口的基本生活条件将受到严格限制，脆弱性将大大提高。

8.2 Weaknesses

1)Subjectivity and Limitation in the Process of Selecting the Indic

Although referring to other related literature as well as the factors inv
Fragile State Index, we still select the indicators with kind of subjecti
is unavoidable without enough literature.

2) Imprecise Classification of Fragility.

Our classification of fragility, namely the range of fragile, vulnerable and stable, is based on the outcome of 30 selected countries in section3.5.1. The limited number of countries restricts the accuracy of the classification, even if we apply the Discrimination Analysis for better classification.

3) Not All-inclusive Analysis of Sudan and Egypt.

In the analysis of Sudan and Egypt, we only assess the fragile condition for 5 years from 2012 to 2016, the date for which is rather restricted. In that way, our results of the analysis are not comprehensive and precise enough to represent the fragility of the two states.

9 Future work

As discussed in the weaknesses of the models, multiple possibilities exist for the development of a more precise form of our model. Therefore, in the future, a more comprehensive and definitive model would be developed in the following ways:

1) More precise and comprehensive data

Our model is built and analyzed based on the assumption that all of our collected data is all reliable due to the limited time, which is relatively inconsistent with the real world. Therefore, more dependable and realistic data corresponding to the real world is ought to be acquired by more careful researching.

2) Consider special countries

In particular countries where an indicator may so extreme that leads to the collapse of the entire country, failing to guarantee the basic livelihood of population. For instance, the extreme lack of water resources may have a significant impact on the country's fragility, while in the future work we may not include the country in the list of fragile regions. We can define a normalized value of each indicator as a critical point that seriously limits people's livelihood security. If this value is reached, the basic living conditions of population in the country would be severely restricted and the fragility would be greatly enhanced.

3)考虑气候与社会经济活动之间的耦合关系

由于气候与社会经济活动的耦合关系，必然存在相互影响。我们的模型，以气候贯穿模型为出发点，只考虑了气候的一系列间接和直接的影响，而这些影响只是从气候开始的。因此，有必要考虑未来气候与社会经济活动之间的耦合关系。

10 结论

最后，建立了基于 PSR 模型和熵权法的脆弱性综合评价模型，对脆弱性进行了定量描述。此外，本文还应用判别分析方法，分别确定了脆性、脆弱性和稳定状态的脆性范围。对 30 个国家的试验表明，我们的模型是稳健的、正确的。

此后，我们在苏丹（一个非常脆弱的国家）和埃及（一个相对不那么脆弱的国家）上实现了模型实例。这些结果表明，气候变化通过苏丹的粮食安全和埃及的医疗条件对脆弱性产生重大影响。如果不改变影响，苏丹的脆弱性将得到缓解。之后，我们将临界点定义为 0.4991（脆弱性价值）和完整的预测，得出埃及将成为一个脆弱的国家。

在此基础上，提出了缓解气候变化、提高应对能力的一系列干预措施，以及基于模型的干预成本。我们的干预措施能够减轻气候变化的影响，进一步有助于国家的稳定。最后，在保持框架结构的同时，通过替换原有的一些指标，对模型进行了修正，以更好地适用于小城市和大陆。

3)Consider the coupling relationship between climate and s activities

The mutual influence is bound to exist due to the coupli between climate and social-economic activities. Our model, wi through the model as the starting point, only takes into account a series of indirect and direct impacts of climate that only starting from climate. Therefore, it is necessary to consider the coupling relationship between climate and social-economic activities in the future.

10 Conclusion

To conclude, we first establish a comprehensive evaluation model based on the PSR model and Entropy Weight Method, so as to represent the fragility quantificationally. Furthermore, we apply Discriminant Analysis to determine the range of fragility for fragile, vulnerable and stable states respectively. Test of 30 countries shows that our model is robust and correct.

Thereafter, we implement model instantiations on Sudan, an extremely fragile state, and Egypt, a relatively not so fragile state. It can be illustrated from the results that the climate change mainly influences fragility through food security in Sudan and through medical condition in Egypt. Without the impact change the fragility of Sudan would be alleviated. After that, we define the tipping point as 0.4991 (value of fragility) and complete predictions, deriving that Egypt would become a fragile country.

Then we put forward a series of interventions about mitigating climate change and improving coping ability,as well as the cost based on our model. Our interventions are able to mitigate the influence of climate change and further contributes to the stability of a state. At last, we modify our model to be applicable to smaller cities and larger continents better through substituting some original indicators while maintaining the framework.