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2019
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Summary Sheet

Stable State Needed: a Glimpse of Climate Change Potency in Regional Fragility

Summary

With the advancement of technology, the world has become less war and violence, and climate change is one of the most pervasive global threats to peace and security in the 21st century. In order to sovle these problem, we first propose an evaluation model to measure the fragility of worldwide countries. Then we apply Yemen and Gabon to show their instability. Last but not least, we take human interventions into consideration and modify our model to different regional scale.

Firstly, 55 primary indicators are taken into consideration under the guide of four principles which is Society, Economics, Politics and Climate. And **Principal Component Analysis (PCA)** and **Entropy Weight Method(EWM)** are used to reduce indicator numbers and weight these indicators.

Secondly, **Multiplier Model is proposed to anaylsis the indirect impact of climate change on fragility through interacting with indicators.** Then we determined the direct impact of climate: Disaster, Arable land, Forest and indirect impact: precipitation, cereal production and extreme temperatures.

And we use **CFSFDP which is a clustering algorithm considering density peak to identify the tipping point.** The conclusion is that a country will reaches the tipping point when fragility index increase to 89.5, and it will probably fall into fragile state.

Next, **we select Yemen and Gabon as research objects and analysis their fragility situation and reveal the impact of climate change both directly and indirectly.** As for Yemen, a fragile country, the fragility decrease from 96.3 to 80.18 without climate change. And for Gabon, a vulnerable country, Forest is the main risk to push it to fragile state. **An optimaization model is developed to minimize the total cost to prevent fragility**, and the results is that 22.3% of its GDP which is about 3 billion dollars is needed for Gabon.

At least, **our model is modified to fit the different regional scale.** For smaller and larger states, the factors, data and weights have reconsidered in order to make the model more comprehensive.

Keywords: Climate change; Fragility, EWM, Clustering, Optimization

Contents

1 Introduction

1.1 Background

In a certain historical period, economic growth has played a huge role in improving people's living standards and national welfare, but economic growth is not without cost, and environmental destruction is one of its main costs. These environmental damages lead to a reduction in the ecosystem services supply, which also leads to a decrease in biodiversity.

For a country, when the marginal cost of economic growth exceeds its marginal benefit, this economic growth is uneconomic [5]. For a land use project, it is also uneconomical when the cost including the environmental costs is greater than the revenue. Therefore it makes great sense to incorporate environmental costs into the economic accounting system.

The economic accounting model for environmental costs of land use project is still in dispute [9]. We, the ICM team, trying to find a solution, faces the problems below:

- Create an ecological services valuation model taking ecosystem services into account to understand the real economic costs of land use projects.
- Perform a cost-benefit analysis of varying size project, from small community-based projects to large national projects.
- Evaluate the effectiveness of our model based on your analyses and model design.
- Consider the implications of land use project planners and managers.
- Explore the possible changes of the model over time.

1.2 Literature Review

After realizing the contribution of ecosystem bring to human welfare researchers have estimated the current economic value of ecosystem services non-systematically [3]. The proposal of System of Integrated Environmental and Economic Accounting (SEEA)[1] and The Economics of Ecosystems and Biodiversity (TEEB)[2] is a response to the shortcomings of traditional accounting methods. After that, some people applied those frameworks to various government levels [4] and several scarce resources such as water [8].

We expect to quantify the impact of ecological degradation on computing environmental costs and integrate environmental cost into land-use projects base on the previous wisdom and neccessary mathodology.

1.3 Anaylsis and Approch Overview

Since climate change is essential to state fragility, it is significant to propose an efficient model to give plans to detect and further predict the climate change poses in this problem. Therefore, index system is needed to evaluate the fragility of a region firstly. Two specific countries are selected to assess their fragility and effect of climate change through the index system. Then we have to propose feasible plans to help the fragile state get rid of the unfortunate situation and help countries that are vulnerable to maintain the status and further stabilise it. Moreover, the cost of human intervention should be considered in

[1]The System of Environmental-Economic Accounting 2012 —Central Framework (SEEA Central Framework) is a statistical framework consisting of a comprehensive set of tables and accounts, which guides the compilation of consistent and comparable statistics and indicators for policymaking, analysis and research.

[2]The Economics of Ecosystems and Biodiversity (TEEB) is a global initiative focused on making nature’ s values visible and its principal objective is to integrate the values of biodiversity and ecosystem services into economic decisions.

this problem. Eventually, We need to make sure the model works well in different regional scale sizes.

This article is about a regional stability issue of in the worldwide, especially the impact of the climate change. We aim to design a measuring system to detect and predict how climate is and will change the regional fragility based on large quantities of data.Through the above analysis, the flow chart of this paper is shown in Figure 3 as follows.

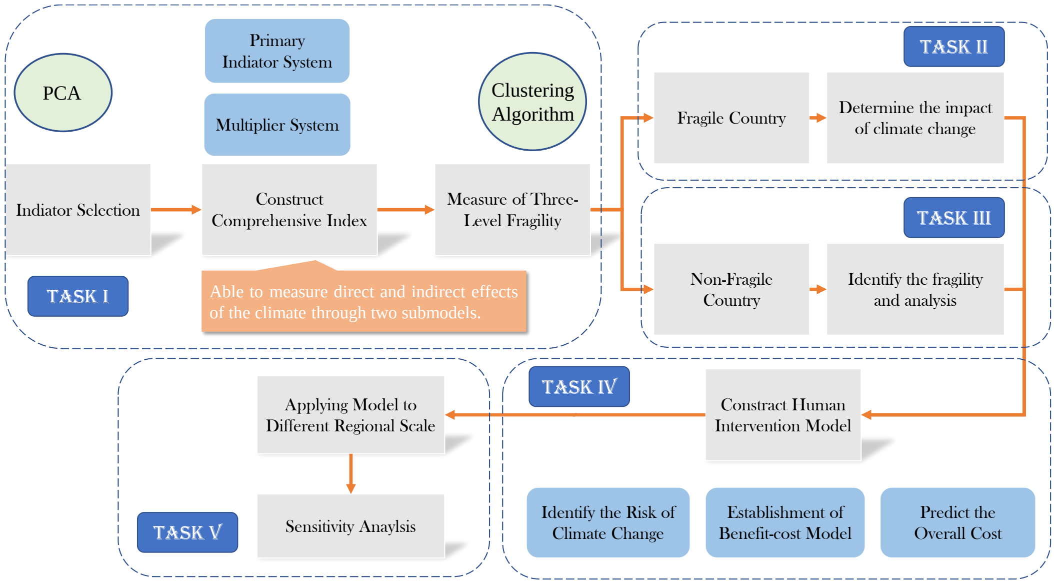

Figure 1: The flow chart in this paper

1.4 Main Assumptions

- **There are limits to the demand for earth resources** [10].
  Due to the planet boundaries [3], the environment is a scarce resource essentially, and it has economic value as well.
- **The value of the environment is not fully reflected in the market.**
  There is a negative externality in the use of ecosystem resources, that is, environmental costs are not truly included in economic costs.
- **Ignore inflation and deflation of money.**
  The value of money remains unchanged.

[3] Planetary boundaries define the safe operating space for humanity with respect to the Earth system and if these thresholds are crossed, then important subsystems could shift into a new state, often with deleterious or potentially even disastrous consequences for humans.

2 Preliminaries

2.1 Terms and Mathematical Notations

In order to be clear and consistent through the paper, we now settle down some terms and mathematical notations:

Table 1: Symbol Table

Symbol	Definition
AL	Arable land(synthetic action of precipitation and temperature)

2.2 Data Pre-processing

2.2.1 Data Collection

Collecting sufficient data is the basis of developing a complete index system. We searched the database and found 88 indicators of about three hundreds countries firstly. Most of the data come from the World Bank [4] , and some data comes from NASA [5] and OWID(Our World In Data) [6] , which is an publication that presents empirical data developed at the University of Oxford.

2.2.2 Data Filling

It is crucial that all data presented are authentic and easily verifiable. No model can provide stable assessments if based on unreliable or untruthful data. Notwithstanding, we spare no efforts looking for data, there still has some missing data because not all data is provided on the website. To ameliorate this situation, three methods are proposed to complete the data, which are as follows:

- If the timo before and after data is available, the average value can be taken as the missing.
- We fill data using same location data of countries which have similar geographical locations.
- The interpolation method is used in data fitting.

3 Ecological Cost Evaluation Model

The unconventional characteristic of this report's model comes from its derivation. In the assessment of the environmental cost of a land use project, We classify the environmental cost into two main parts: Cost of ecosystem services loss and Cost of pollution, and we will demonstrate the quantitation analysis of them respectively.

[4] https://data.worldbank.org/indicator
[5] https://climate.nasa.gov/vital-signs/sea-level/
[6] https://ourworldindata.org/charts

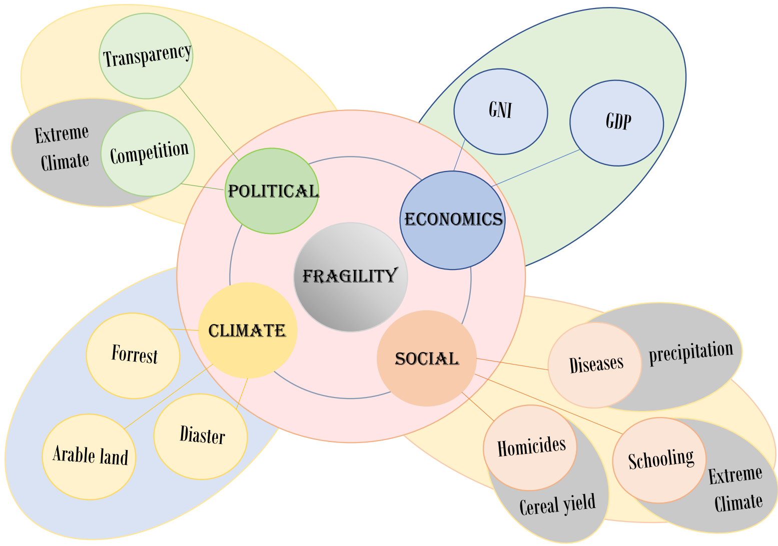

Figure 2: Process flow for the creation of the Fragility Index model. The model incorporated all ten indicators of smart growth and grouped them together into four principles. The sum of these metrics is the overall fragility Index.

3.1 The cost of ecosystem services loss

Under the guide of Ecosystem Services [1] and Environmental Degradation, we classify the factors into four main fields: provisioning services, regulating services, cultural services and environmental degradation caused by biodiversity loss. Factors in separate fields contribute to environment cost in diverse ways. We introduce the quantification of impact from various actors field by field. The quantification of every factor's impact will be presented below.

3.1.1 Provisioning Services

We use four provisioning services indicators in this field. These four indicators measure the decline of the potential material benefits people can obtain from ecosystems.

Product Amount Method (PAM) and Value Amount Method (VAM) are selected to cope with the quantification process. These two methods comprehensively assess the services provided by the ecosystem from the perspective of product amount and the value amount perspectively [11].

- **Conservation of water**

$$V = W \times P = (R - E) \times A \times P \tag{1}$$

where V represents the economic cost of the annual water-conservation capacity of the area; W is the water-conservation capacity (m^3); R stands for the annual amount of precipitation (m^3); E is the average annual evapotranspiration (mm) of the area; A means the area size (hm^3); P is the water storage cost per unit ($\$/m^3$)

- **Reduced waste lands**

$$\begin{aligned} E_s &= \tfrac{(V \times B)}{(10000 \times L \times D)} \\ V &= S \times (P - Q) \end{aligned} \tag{2}$$

where E_s represents the value of reduced waste lands ($\$/year$); V is the reduced soil erosion amount ($t/year$); D stands for the average density of soil (t/m^3); L is the forest soil thickness (t/m^3); B is the average benefits of forestry ($\$/hm^2$); S means forest area ($hm^2$); P is the modulus of potential soil erosion ($t/(hm^2 \cdot year)$); Q is the modulus of realistic soil erosion ($t/(hm^2 \cdot year)$)

- **Land fertility**

$$E_f = \sum V \times C_i \times \frac{P}{10} \times 1000(i = N, P, K) \tag{3}$$

where, E_f is the economic benefits of maintaining soil fertility ($\$/year$); C_i is the net contents of N, P, and K in soil; P is the price of N, P, K ($\$$).

- **Reduced sediments in rivers**

$$E_n = \frac{P \times V \times U}{10000} \tag{4}$$

Where, E_n represents the economic benefits of reducing sediments deposit ($\$/year$); U stands for the costs of reservoir project ($\$$). P is the percent of the erosive soils that are deposited in reservoirs, rivers, and lakes.

The mathematical expression for provisioning services indicators in the environmental cost evaluation model has a form of

$$Provisioning = P_{cons} + P_{wast} + P_{land} + P_{send} \tag{5}$$

3.1.2 Regulating services

We use two provisioning services indicators in this field. These two indicators measure the loss of the value of air and soil, providing flood and disease control, or pollinating crops.

- **Carbon fixation and oxygen release**

$$\begin{aligned} U_c &= A_i \times C_c \left(63 \times R_c \times B_n + F_c\right) \\ U_o &= 1.19 \times A_i \times C_c \times B_n \end{aligned} \tag{6}$$

where, U_c is the annual carbon fixation price of the area; U_o represents the annual oxygen release price of the area ($\$/year$); C_c is the price of fixed carbon, and C_o is the price of oxygen, yuan/year; R_c is the carbon content in CO2 (taking 27.27%); B_n is the annual net productivity of the area, and F_c is the annual carbon content per unit area of the area, $(t/(hm^2 \cdot year))$.

- **Purification of the air**

$$\begin{aligned} &U_f = \frac{5.256 \times 10^{15} \times A_i H K_f \left(Q_f - 600\right)}{L} \\ &U_c = A_i K_c Q_c + A_j K_{fo} Q_{fo} + A_i K_{ro} Q_{no} + \; A_i K_{r_n} Q_{no} \; + K_z A_z + A_1 K_{sc} Q_{xc} \end{aligned} \tag{7}$$

where Uf is the anion value provided by the area, and Uc represent the annual absorption of sulfur dioxide, fluorine, nitrogen oxides by the area, the annual value of reducing noise and detaining dust of the area, $(\$/year)$; H is the height of the area (m); K_f is the cost generated by an anion $(\$/one)$; Q_f is the anion concentration of the area(one/cm^3); L is the lifetime of an anion (min); K_e, K_{fo}, K_{no}, and K_{zc} stand for the costs of pollution governance and dust fall cleaning of sulfur, fluoride and nitrogen oxides $(\$/kg)$; A_z is the mile of sound-proofing walls converted from the area (km); Q_e, Q_f , Q_{no}, and Q_{zc} are amounts of sulfur dioxide, fluoride, nitrogen oxides and dust retention absorbed by the area per unit area $[kg/(hm^2 \cdot a)]$.

The mathematical expression for regulating services indicators in the environmental cost evaluation model has a form of

$$Regulating = R_{carb} + R_{puri} \tag{8}$$

3.1.3 Cultural services

Cultural services measure the loss of the the non-material benefits people obtain from ecosystems.

3.2 Environmental degradation caused by biodiversity loss

There is a positive relationship between biodiversity and most ecosystem services. Biodiversity has multiple roles in the delivery of ecosystem services, as a regulator of ecosystem processes, as the service and good [7].

表 1 生物多样性与生态系统服务的多重关系

Table 1 Multiple relationships between biodiversity and ecosystem services

生态系统过程的调节者 Regulator of ecosystem processes	最终生态系统服务 Final ecosystem services	商品 Goods
土壤动物和微生物:有机质分解与土壤养分循环; 初级生产者(陆地和水中的植物):生物量生产和碳储存、空气质量调节、水质净化; 捕食者:种群调节、食物网调节、减少害虫爆发; 传粉动物:非农业生态系统的稳定性。	野生作物和牲畜亲缘植物(动物):确保遗传多样性,提供食品生产系统的弹性以应对未来气候变化/疾病等; 具有次级化合物的生物体:具有商业开发潜力,例如新型药物; 传粉动物:许多粮食作物的安全。	大型脊椎动物,尤其是鸟类、哺乳动物和供人观赏的开花植物:因其魅力和审美情趣而被认可; 旗舰树种或伞护种:为更广阔的群落和动物栖息地提供保护; 系统发育不同的物种:维持进化多样性; 濒危物种:保持分类学多样性

Figure 3: The flow chart in this paper

3.2.1 Biodiversity Regulator

The extent of human impact on an ecosystem is a key factor in assessing the provision of different categories of ecosystem services [2]. In this paper, we mainly talk about the land use projects' impact on ecosystem, and they cause change on ecosystem services by impacting the biodiversity directly.[?] Biodiversity plays an important role in regulating ecosystem services, which means that it can buffer environmental changes and maintain ecosystem services in the face of disturbance. The prevailing view is that when biodiversity is lost, ecosystems become less resilient, so the sum provision of different categories of ecosystem services is impacted by the varying degrees of biodiversity.

According to a simplified set of relationships between the sum provision of different categories of ecosystem services and the degree of loss of biodiversity, we consider biodiversity as a multiplier. When biodiversity change from high to low, this multiplier increase first, then decrease. The formula is as follow:

3.2.2 Biodiversity service and good

We make a reasonable assumption that individuals in aggregate would be willing to incur these costs if the natural services were no longer available.

When biodiversity plays as goods or plays as a kind of ecosystem services, it's a direct component of ecosystem service cost when running a land use project. To measure this direct cost, replacement/restoration cost technique is our best choice. The restoration cost (RC) approach assesses the value of an ecosystem service by how much it costs to replace/restore it after it has been damaged [6].

$$U_s = S_s \times A_i \tag{9}$$

where, U_s represents the value of protecting species of area ($\$/year$); S_s is the annual opportunity cost of lost forest species per unit area ($(yuan/(hm^2 \cdot a)$).

3.3 The Cost of Pollution

3.4 Calculation

4 Cost-benefit Analysis Model

5 Anaylsis for Two Project

6 Effectiveness Analysis

7 Sensitivity Analysis

8 Strengths and Weaknesses

8.1 Strengths

- **Wide application**
  Our model is based on most countries' data so that it can be applied to most countries.

8.2 Weaknesses

- **Lack of ability to deal with special problems**
  Lack of ability to deal with particular problems There might be some errors when our model is applied to some specific countries.

9 Future Work

Uncontrovertibly, there are many drawbacks in our model, such as the few data to analysis. We have to do a lot more to improve our work.

- **More data is needed**
  More statistical data will be needed in the future work, especially some extreme climate data and some long term climate change data. As a result, the prediction may not as precise as we anticipate

References

[1] Millennium Ecosystem Assessment. Millennium ecosystem assessment. *Ecosystems and Human Well-Being: Biodiversity Synthesis, Published by World Resources Institute, Washington, DC*, 2005.

[2] Jérôme Cimon-Morin, Marcel Darveau, and Monique Poulin. Fostering synergies between ecosystem services and biodiversity in conservation planning: a review. *Biological Conservation*, 166:144–154, 2013.

[3] Robert Costanza, Ralph d'Arge, Rudolf De Groot, Stephen Farber, Monica Grasso, Bruce Hannon, Karin Limburg, Shahid Naeem, Robert V O'neill, Jose Paruelo, et al. The value of the world's ecosystem services and natural capital. *nature*, 387(6630):253, 1997.

[4] Silvana Dalmazzone and Alessandra La Notte. Multi-scale environmental accounting: Methodological lessons from the application of namea at sub-national levels. *Journal of environmental management*, 130:405–416, 2013.

[5] Herman E Daly. *Beyond growth: the economics of sustainable development*. Beacon Press, 1997.

[6] Guy Garrod, Kenneth G Willis, et al. Economic valuation of the environment. *Books*, 1999.

[7] Georgina M Mace, Ken Norris, and Alastair H Fitter. Biodiversity and ecosystem services: a multilayered relationship. *Trends in ecology & evolution*, 27(1):19–26, 2012.

[8] María Pedro-Monzonís, Pedro Jiménez-Fernández, Abel Solera, and Pablo Jiménez-Gavilán. The use of aquatool dss applied to the system of environmental-economic accounting for water (seeaw). *Journal of Hydrology*, 533:1–14, 2016.

[9] Gaël Plumecocq. The second generation of ecological economics: How far has the apple fallen from the tree? *Ecological Economics*, 107:457–468, 2014.

[10] Johan Rockström, Will Steffen, Kevin Noone, Åsa Persson, F Stuart Chapin III, Eric F Lambin, Timothy M Lenton, Marten Scheffer, Carl Folke, Hans Joachim Schellnhuber, et al. A safe operating space for humanity. *nature*, 461(7263):472, 2009.

[11] CHENG Zhiming, LIAO Fangjun, XIE Yong, and LIU Zongjun. Valuation on forest ecosystem services of nanling national nature reserve. *Journal of Landscape Research*, 9(3), 2017.