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CARS: A material mechanics model for evaluating the impact of climate change on national fragility

Yuxin Niu, Yingtao Zhang and Mingyang Song
School of Highway, Chang'an University, Xi'an, China
Yunext1@126.com

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Abstract. Although the Intergovernmental Panel on Climate Change (IPCC) suggests that the net damage costs of climate change towards countries are likely to be significant, it remains a challenge in evaluating a country's fragility and measuring the impact of climate change, in a less-subjective manner, since considerable uncertainties exist with regard to the extent and geographical distribution of these changes. In this paper, we establish a model for determining a country's fragility through an analogical pattern: A country is modeled as a special kind of material and its fragility is formulated by four determinant capacities (i.e., the coping capacity, the adaptability, the resilience and the sensibility of risks, CARS for short) that models key endogenous factors under external forces. Compared to the PSR (Pressure-State-Response) model, the proposed CARS model provides an interesting explanation on national fragility.

Introduction

In recent years, the frequency of extreme climate increases rapidly, the temperature changes range, and the promotion effect of global warming on extreme climate is more and more obvious. The effects of climate change on natural and human systems have spread across all continents and oceans. In many regions, changes in precipitation or melting of ice and snow are changing the horological system, affecting water resources and water quality. It is said that human impact on the climate has exceeded the limits of self-regulation of the atmosphere, and the pressure of climate feedback on nature is affecting people's lives in a more dramatic way. Therefore, we must explore the relationship between climate and national development and sustainable development to prevent climate change from making countries and cities more and more fragile.

Fragility studies began in disaster management, ecology, geology, environmental science, and sustainable development science and other research fields. IHDP, IGBP, IPCC, and other countries Sexual scientific research programs or institutions view vulnerability as one of the frontier and hot topics of sustainable development and global evolution research [1].

The country is a socio-economic-natural and highly compounded comprehensive system, which interacts with and interacts with the natural environment and social environment. The state system itself has its own vulnerability. The sudden deterioration of the climate further exacerbates the country's vulnerability [2, 3, 4].

Therefore, we need to determine a model to not only determine a country's fragility, but also to measure the impact of climate change on the fragility so that policymakers can make use of positive impacts by assessing risks and adopting necessary interventions to effectively mitigate the negative effects of climate change. Many researchers explore the impact of the climate on national fragility from a qualitative point of view [4,5,6,7,8,9],

Based on PRS model and the DPSIR model, a new model, enlightened by the principles of the material mechanics, is proposed for evaluating the impact of climate change on national fragility in this paper. Then, the model is simply verified by using the principal component analysis. Finally, based on this model, the impact of climate change on the country's vulnerability is illustrated.

Modeling National Fragility by Using Material Mechanics

Four key endogenous factors

To describe the fragility of a country, we need to consider internal factors and external factors. Analogy with material mechanics, the properties of the material itself and the conditions under which external forces are applied. In our opinion, there are four key endogenous factors in this subject: resistance, resilience, adaptability, and sensibility of risks. The last one measures the degree of response to the outside world, while others correspond to the whole process of response when influenced by external factors. The external forces can be divided into two types: destructive and general. The Four key endogenous factors are explained as follows:

Coping capacity: It means that under the interference of external forces, the ability of the state to maintain its original steady state is the most basic core capability.

Adaptive capacity: This means the ability of a country to adapt to new changes under strong external interference and to make a transition to a new stable state as soon as possible.

Resilience: This indicates the ability of a state to gradually regain its original status under external attack, and is related to its adaptability.

Sensitivity of risks: This describes the degree of a country suffering from major disruption or major changes when disturbed by external forces, reflecting a fragile face in resisting intrusions.

Based on the existing PSR (Pressure-State-Response) model[10] and DPSIR (Driving forces-Pressure-State-Impact-Responses) model[11], we establish a model for determining a country's fragility through an analogical pattern: A country is modeled as a special kind of material and its fragility is formulated by four determinant capacities (i.e., the coping capacity, the adaptability, the resilience and the sensibility of risks, CARS for short) that models key endogenous factors under external forces。

CARS Model

A country's fragility is determined by the coping capacity P_1, resilience P_2 , adaptability P_3 , sensitivity of risks P_4, and the parameter of calamity k . And within these variables, resilience is affected by adaptability. It means that the more resilient a country is to events, the faster it will recover. Because of the different impact of variables on a country's fragility, we define fragility, CARS index, by the Eq. 1.

$$CARSI = [a_1 \cdot f_1(P_1) + a_2 \cdot f_2(P_2, P_3) + a_3 \cdot f_3(P_4)]^k \tag{1}$$

As for $f_1(P_1)$, we think that when a country's resistance is weakened to a certain extent, the state is extremely vulnerable, and even if it increases resistance, it has little relief for the fragility of a country.

In the same way, when a country's resistance is strong enough, a certain change in resistance will not affect the stability of the country to a great extent because the country is fairly steady. Based on this condition, therefore, we use the Sigmoid function for its S-Curve. We describe the relationship between resistance and fragility by the Eq. 2 .

$$S(x) = \frac{1}{1+e^{-x}} \tag{2}$$

It can be seen in Fig. 1 that the Sigmoid function is monotonically increasing, but resistance is negatively correlated with fragility. So we select the interval of [-5,5] which has the corresponding

value range of [0.007,0.993]. And we use this function on the Y-axis symmetry to decrease its monotonicity, then we reduce the interval to [0, 1] for the standardization of resistance(Fig. 2). Therefore, we define by the adjusted Eq .3.

$$f_1(P_1) = \frac{1}{1+e^{10P_2-5}} \tag{3}$$

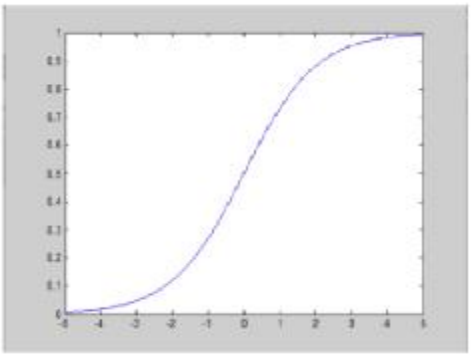

Fig1. Unadjusted Sigmoid function

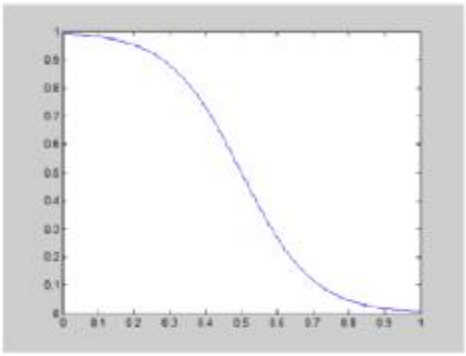

Fig2. Adjusted function

As for $f_2(P_2, P_3)$, in order to reflect the impact of resilience on adaptability, we use the exponential function which is P_2 as the base and P_3 as the exponent. Because of the standardization of P_2, the bigger P_2, the smaller value we will obtain. To avoid this trend, therefore, we define $f_2'(P_2, P_3)$ by the Eq .4.

$$f_2'(P_2, P_3) = (1+P_2)^{\ln(1+P_3)} \tag{4}$$

As the adaptability increases to a certain extent, its rate of improving resilience decreases. So we use natural logarithm in the exponent. Then we standardize the results of f_2' to facilitate the weight of several influencing factors. Thus, we define f_2 by the Eq .5.

$$f_2 = \frac{f_2'-1}{2^{\ln 2}} \tag{5}$$

Concerning P_4, we keep its linear relationship. And we do not embark on any data processing but indicate the positive and negative correlation.

The last variable, k, comprehensively and directly affects the fragility of states. So we use it as the overall exponent of the fragility equation.Meanwhile, k can be partly described by CRI. And k is related to the history of extreme weather. If this kind of weather happens more often, people will prepare more. This awareness reduces the impact of weather when it appears again. If we do not consider extreme weather, k equals 1. In summary, we obtain the fragility equation:

$$CARSI = \{a_1 \cdot \frac{1}{1+e^{10P_1-5}} + a_2 \cdot [1 - \frac{(1+P_2)\ln(1+P_3)-1}{2^{\ln 2}-1}] + a_3 \cdot P_4\} \tag{6}$$

We use analytic hierarchy process to determine the weight of three aspects.Among the process, A represents coping capacity, B represents sensitivity of risks, C represents resilience and adaptability.The judgment matrix we use is in Table1.

Table 1 Judgment matrix

	A	B	C
A	1	4	2
B	1/4	1	3
C	1/2	1/3	1

After the consistency check, $CR = 0.003422 < 0.1$,the result indicates that the judgement matrix has a good consistency.Therefore, the eigenvector $\vec{E} = (0.57822,0.26267.0.15910)$ can be the weight coefficients of these aspects. In summary, $a_1 = 0.57822, a_2 = 0.15910, a_3 = 0.26267$ among the fragility equation。

Experiments and Evaluation

Data Collection

We collect 17 categories of develop factors data from 264 countries or regions (from 2006 to 2017).However, due to the serious lack of data, we select statistics of 13 indicators in 2010 from 26 countries as the basis.

Determination of Indicators

First of all, we select a number of indicators from the evaluation object. Referring to the third assessment report of the IPCC, we formulate four aspects and their corresponding indicators: coping capacity-military expenditure, legal rights, Social inclusion policy, poverty rate, electrified rate and GDP per capita; resilience- labor rate, energy use and Gini coefficient; adaptability- literacy rate, the number of technicians per million people and macroeconomic management; sensitivity of risks-agricultural value added and water resources per capita. Secondly, we divide the indicators of each aspect into two categories. We adopt a method that satisfies comprehensiveness and representativeness. 264 countries that appear in FSI are divided into 11 groups, and then we conduct Kruskal-walls test for each indicator groups. The indicators with on significant difference are in the same group. Thirdly, we choose the most representative indicators in each aspect. When there are two indicators in the same group, we calculate the complex correlation coefficients of them with other indexes in this aspect. If there are more than two indicators in the same group, we compare the Spearman rank correlation coefficient of each index with that of other indicators in this classification. In summary, the indicators we select for the four aspects are: Coping capacity-poverty rate, electrified rate and GDP per capita; Resilience- energy use and Gini coefficient; Adaptability- literacy rate, the number of technicians per million people; Sensitivity of risks-agricultural value added and water resources per capita.

The Impact of Climate on National Fragility

Climate index is divided into two kinds, the extreme and the non-extreme. The extreme is included in parameter of the CARS model. But we cannot directly measure the non-extreme climate, because every country has its own basic attributes in all abilities. Here, we come up with a model based on mechanics. In mechanics of materials, bending normal stress is mainly composed of three elements: bending moment, distance of the neutral axis and moment of inertia to the Z-axis. The impact of climate can be abstract as an external force. It is the relative level of a certain data to the average and the attribute of the object. So we simulate this mechanical model and establish an actual perception model. It equals with the degree of response to climate change in a country's fragility index. This degree is related with various indexes of social and economic ability, overall level of the world and fragility of the country. We define the impact as function below:

$$s = \frac{f(c)\frac{w_i}{w_0}}{\frac{1}{F}} \tag{7}$$

Among them, *f(c)* is climate change function and *F* is country Fragility, $w_i (i = 1 \mathbf{L} 9)$ is the average of one index in countries, and w_0 is value of different indicates.

As to how climate change can increase the fragility of the country, because the situation cannot be summarized together, we make the following qualitative description(Fig3).

Figure 3: The Impact of Climate on Fragility

Conclusion

Based on the PRS model and the DPSIR model, this paper uses the model of material mechanics to propose a new model for evaluating the country's vulnerability, and gives a calculation formula for the response degree of a country's vulnerability index to climate change. The model is still relatively crude, and further research is needed to make it more refined.

References

[1] IHDP.IHDP update,Update Issue3/01[R].Focus:Vulnerability,IHDP,2001.
[2]Schwartz, P. and Randall, D.,An Abrupt Climate Change Scenario and Its Implications for United States National Security", October 2003.
http://eesc.columbia.edu/courses/v1003/readings/Pentagon.pdf
[3]Theisen, O.M., Gleditsch, N.P., and Buhaug, H. "Is climate change a driver of armed conflict?" Climate Change, April 2013, V117 (3): 613-625.
[4] "Climate change, impacts and vulnerability in Europe 2012",EEA Report,2012
[5] Krakowka, A.R., Heimel, N., and Galgano, F. "Modeling Environmenal Security in Sub-Sharan Africa – ProQuest." The Geographical Bulletin, 2012, 53 (1): 21-38.
[6] Wang A. "Evaluation of urban vulnerability and analysis of influencing factors under climate change"[D],Shaanxi Normal University,2016.
[7] Hanne Fjelde, Nina von Uexkull . "Climate triggers: Rainfall anomalies, vulnerability and communal conflict in Sub-Saharan Africa", Political Geography,2012, 31:444-453
[8]Yu Ou,Yan Jianzhong,Zhang Yili. "Research progress on comprehensive assessment of regional climate change vulnerability",Progress in Geography, 2012,V30(1): 127-34.

[9]Tobias Ide, Janpeter Schilling, Jasmin S.A. Link , Jürgen Scheffran, Grace Ngaruiya ,Thomas Weinzierl. “On exposure, vulnerability and violence: Spatial distribution of risk factors for climate change and violent conflict across Kenya and Uganda”,Political Geography,2014,43:68-81
[10]Rapport D,Friend A. Towards a comprehensive framework for environmental statistics: A stress-response approach[M]. Ottawa: Statistics Canada,1979.
[11]Smeets E, Weterings R. Environmental Indicators: Typology and Overview[M]. Copenhagen: Technical Report, European Environmental Ageney, 1999.