The Impact of Extreme Precipitation on the Vulnerability of a Country

Zengke Wang*

School of North China Electric Power University, Baoding 071000, China

*Corresponding Author Email: zickel@qq.com

Abstract. Recently, the impact of climate change on national instability is getting more and more attention. However, there is no explanation to how climate affects country's fragility. Based on some data and researches, we get eight indices provided by The World Bank and two climate indices, temperature difference and extreme precipitation. Researches show that temperature difference affects the fragility directly and extreme precipitation causes indirect influence. We choose South Sudan as the study target. In order to find out how climate change increases this state's fragility, multiple linear regression analysis is applied to get the relationship between extreme precipitation and three indices. After that, we choose Bangladesh, which is not in the top ten most fragile states to analyse. By calculating the weights of the ten indices above, the two indices, economy and refugees &IDPs (Internally-Displaced Persons), are more significant. Therefore, we conclude that climate change increases fragility by affecting rainfall in Bangladesh. The tipping point is defined as the year when rainfall exceeds 2100 mm and we adopt the GM (1,1) model based on gray prediction theory to get the point. Prediction shows that the next two tipping points of Bangladesh are 2022 and 2027.

Keywords: multiple linear regression analysis; gray prediction; national instability; extreme precipitation

1. Introduction

In the 21st century, climate change is one of the most pervasive global threats to peace and security for a country. Different levels of natural disasters, which threaten people seriously, such as increased droughts, sea level rise and flood are attributed to climate change. In addition to this, climate change will affect the normal functioning of the state. In other words, it can enlargement a country's fragility.

However, there are too many factors influencing country's instability. In most situations, climate change alone does not lead to a fragile state. It is interacted with the existing pressures, particularly the economic inequality, large-scale migration and competition for resources. If it is further compound with these issues, the likelihood of instability or violent conflict will rise. In view of those problems, more and more people are engaged in the study of national vulnerability and try to recognize the connection between climate change and the fragility of a country.

2. Assumptions

The government policy will not change in the short term.

The state is not affected by other countries' interference in purpose.
The data source is actual and reliable.
The country is relatively in a peace state.
The results of fragility index for a state is discussed in a relative short period.

3. Something Known

Temperature difference affects the fragility directly and extreme precipitation causes indirect influence.

Researches show the average annual rainfall and temperature data for many countries in The World Bank and use temperature difference and extreme precipitation as the climate change effect criteria. The primary indexes are shown as in Table 1.

Table 1. Framework of measurable indexes

Criteria	Explanation	Unit
Security Apparatus: U1	The department responsible for safety.	-
Factionalized Elites: U2	The excellent people in a certain class.	Percent
Economy: U3	It represents the development of a society.	-
Economic Inequality: U4	It refers to the economic difference in different class.	Percent
Public Services: U5	It refers to the medical care, education, security, etc.	Percent
Human Rights: U6	It refers to the freedom of speaking, faith, etc.	-
Demographic Pressures: U7	It represents the resource allocation pressure.	-
Refugees and IDPs: U8	It represents the migrant people because of disasters.	Percent
Temperature difference: U9	It refers to the maximum variation in a unit time.	-
Extreme precipitation: U10	It refers to the too much or little rainfall in a unit time.	-

The model named fuzzy evaluation is used for analyzing country's fragility.

4. Multiple Linear Regression Analysis

In this part, we will explore the way how climate change increases the fragility of South Sudan. We consider the direct reasons and the indirect reasons in two aspects. Because we remove the index temperature difference which is considered causing direct affects in the fragility, from this point, the membership degree surely decreases. As for the extreme precipitation index, it is connected with the three indexes, security apparatus, economy and refugees and IDPs. We need to determine the specific relationship among them. So, we apply the multiply linear regression analysis method to the study of the indexes. We first define some symbols. The basic model of multiply linear regression analysis is stated as:

$$\begin{cases} y = \beta_0 + \beta_1 x_1 + \cdots + \beta_m x_m + \varepsilon \\ \varepsilon \sim N(0, \sigma^2) \end{cases}$$

In the formula, β_i are regression coefficients and others are unrelated unknown parameters. If we get n independent observation data β_i (i=1,...,n,n>m). And we mark X, Y, β, respectively four matrices.

$$\varepsilon = \begin{bmatrix} \varepsilon_1 & \cdots & \varepsilon_n \end{bmatrix}^T \quad \beta = \begin{bmatrix} \beta_0 & \beta_1 & \cdots & \beta_m \end{bmatrix}^T$$

$$X = \begin{bmatrix} 1 & x_{11} & \cdots & x_{1m} \\ \vdots & \vdots & \cdots & \vdots \\ 1 & x_{n1} & \cdots & x_{nm} \end{bmatrix} \quad Y = \begin{bmatrix} y_1 \\ \vdots \\ y_n \end{bmatrix}$$

So, we can simplify the formula into 2 conditions. is the unit matrix with a dimension of n.

$$\begin{cases} Y = X\beta + \varepsilon \\ \varepsilon \sim N(0, \sigma^2 E_n) \end{cases}$$

Applying this model to the climate index problem, we can get the definite regression equation:

$$\mathbf{Y} = \mathbf{0.8798U1} + \mathbf{0.0.251U2} + \mathbf{0.2424U8}$$

The confidence interval of the regression coefficients and residual vector is shown in Table 2.

Table 2. The confidence interval for the three regression coefficients and residual vector

Regression Coefficients	Confidence Interval	Residual Vector	Confidence Interval
0.8798	[-1.9471, 3.7067]	0.203-	[-2.0912, 2.4972]
0.0251	[-3.1532, 3.2035]	-2.2196	[-3.0662, -1.3729]
0.2424	[-3.7023, 4.1871]	1.3679	[-5.5327, 8.2686]
-	-	0.8513	[-8.6168, 10.3194]
-	-	-0.4174	[-0.4981, -0.3367]

According to the consequences of the multiply linear regression analysis, we conclude that the extreme precipitation has a positive correlation with the Security apparatus, economy and refugees and IDPs. That is to say, the extreme precipitation increases with the increase of the other indexes. If we remove the climate index, the indicator of the three indices will change certainly.

5. Gray Prediction for a Country

For simplification, we choose Bangladesh as the study object. And we list the weight of the ten indexes in Table 3.

Table 3. The weight of the ten indexes for Bengal

Index	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10
Weight	0.0890	0.0988	0.1622	0.0950	0.0946	0.0865	0.0877	0.1006	0.0900	0.0956

From table 3, we can see that the weight of refugees and IDPs and economy are over 0.1. Thus, they have a stronger impact on the fragility of Bengal. As they are connected with the precipitation concluded before, we consider the fragility affected by refugees and IDPs and economy are caused by the extreme precipitation. We find out the extreme precipitation may cause flooding. So, we define the tipping point as the time when the state will experience a flooding. We seek the average annual rainfall of Bangladesh from 1991 to 2015 shown in a figure. And we number the years from 1 to 25 as shown in figure 1 (For example, 1991 corresponds to the 1st year).
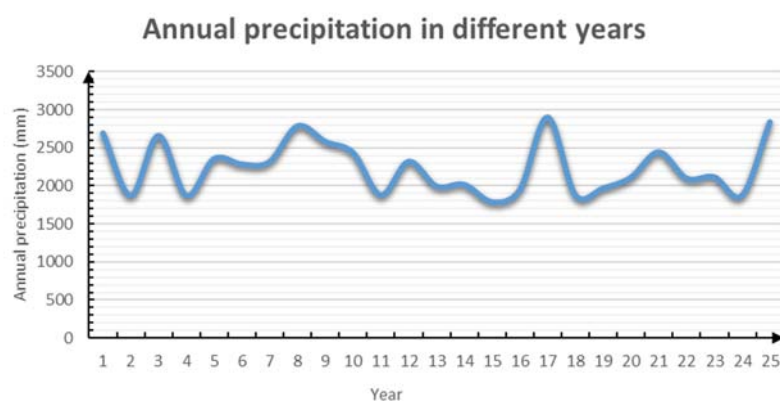

Figure 1. Annual precipitation in different years

In order to predict the tipping point for Bengal, we apply the gray prediction theory to realize the prediction. We set a rainfall value when the flooding will break out if the average annual rainfall exceeds that. Taking into account that Bangladesh is a state which always happens rainstorm, we cannot take the general criteria to measure it. According to [4], we set the criteria rising to 2100 mm. That is to say, it is more possible to appear a flooding if the average annual rainfall is over 2100 mm. In terms of the data, we conclude 14 years corresponding to the criteria presented by the serial number.

Based on gray prediction theory, we adopt the GM (1,1) model which consists of a first-order differential equation of a single variable. We assume that the system has N behavioral factors, namely the initial sequence can be listed and the AGO (accumulated generating sequences) sequences are also available.

$$x^{(0)} = (x^{(0)}(1), x^{(0)}(2), \cdots, x^{(0)}(n))$$

$$x^{(1)} = (x^1(1), x^1(2), \cdots x^1(n)) = (x^{(1)}(1), x^{(1)}(1) + x^{(0)}(2), \cdots, x^{(1)}(n-1) + x^{(0)}(n))$$

$$x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i), (k = 1, 2, \cdots, n)$$

We can get the mean sequence through and construct the gray differential equations. In addition, we introduce the vector matrix mark Y, u, B. Thus, the gray differential equations consist of n variance are presented Y=Bu. The Y is the known data vector and B is the known data matrix. u is the parameter vector. Then we can establish the corresponding whitening differential equation. By the use of the least squares method, we can get the minimum of u vector.

$$u = (a, b)^T$$

$$B = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ \vdots & \vdots \\ -z^{(1)}(n) & 1 \end{bmatrix}$$

$$Y = (x^{(0)}(2), x^{(0)}(3), \cdots x^{(0)}(n))^T$$

$$z^{(1)}(k) = 0.5x^{(1)}(k) + 0.5x^{(1)}(k-1), k = 2, 3, \cdots n$$

And we can get the final relationship between the dependent variable and the independent variable by the calculation of the differential equation.

$$\frac{dx^{(1)}}{dt} + ax^{(1)}(t) = b$$

$$x^{(1)}(k+1) = (x^{(0)}(1) - \frac{b}{a})e^{-ak} + \frac{b}{a}, k = 0, 1, \cdots, n-1, \cdots$$

Applying the average annual rainfall to the gray prediction model GM (1,1), we get the prediction relationship between the future year serial number t and the average annual rainfall y.

Namely,

y =29.0965*exp(0.148845*t) - 28.0965

We use the prediction function to calculate the theoretical value of the year serial number and compare it with the actual value. The year serial number which the average annual rainfall exceeds 2100 mm is listed together. To test the accuracy of the prediction relationship constructed by the gray prediction function, we also calculate the residual error, relative error and the class ratio deviation.

Table 4. The theoretical value and actual data of the year

Actual Value	Theory Value	Residual Error	Relative Error	Class Ratio Deviation
1	1	0	0	
3	4.6698	-1.6698	0.5566	0.6131
5	5.4193	-0.4193	0.0839	0.3035
6	6.2890	-0.289	0.0482	0.0327
7	7.2983	-0.2983	0.0426	0.005
8	8.4697	-0.4697	0.0587	-0.0157
9	9.8290	-0.829	0.0921	-0.0318
10	11.4065	-1.4065	0.1406	-0.0447
12	13.2372	-1.2372	0.1031	0.0327
17	15.3616	1.6384	0.0964	0.1806
20	17.8271	2.1729	0.1086	0.0133
21	20.6882	0.3118	0.0148	-0.1055
23	24.0085	-1.0085	0.0438	-0.0599
25	27.8617	-2.8617	0.1145	-0.0679

From table 4, we clearly see that the model is greatly suitable to the prediction. We set the condition that y is more than 2100, and we get the recent two tipping point years, respectively the year 2022 and the year 2027. In other words, the next flooding breakout in Bangladesh is in 2022 and 2027.

6. Summary

As the above study, we took South Sudan, which ranks the top ten countries in terms of vulnerability, as an example. We analyzed the indirect effects of extreme precipitation using multiple linear regression methods, and then obtained the parameters of extreme precipitation indirectly affecting the country's vulnerability. At the same time, taking Bangladesh as an example, a statistical analysis of the years of extreme precipitation in the country was conducted, and forecasts were made using grey forecasts. It is predicted that extreme precipitation that will affect the country's vulnerability will occur in 2022 and 2027 in the future. The model can provide some new ideas on the impact of extreme precipitation on the country's vulnerability, reminding the world that while developing countries, don't forget to protect the environment, pay attention to climate change, protect the country's stability and reduce the country's vulnerability.

References
[1]   Liu Tianxu, Wu Tao. Evaluation Criteria for Fragile Countries. Leading Science Forum, 2016 (13): 17-26.
[2]   DONG Qiao-ling. Effects of different errors in the overall least square method on multivariate linear regression. Taiyuan University of Technology, 2016.
[3]   Guo Jing. Western "national vulnerability" research status and limitations. Chinese Journal of Social Sciences, 2017-07-26 (007)
[4]   Liu Longsheng. Interaction between storm activity in the Bay of Bangladesh and circulation over the Tibetan Plateau. China Meteorological Administration