Saudi Journal of Engineering and Technology (SJEAT)
Scholars Middle East Publishers
Dubai, United Arab Emirates
Website: http://scholarsmepub.com/

ISSN 2415-6272 (Print)
ISSN 2415-6264 (Online)

An Impact Model of Climate Change on the Development of Country Development: A Case Study on Yemen

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Original Research Article

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Article History
Received: 25.02.2018
Accepted: 07.03.2018
Published: 30.03.2018

DOI:
10.21276/sjeat.2018.3.3.8

Abstract: In the past decade, academic world established a variety of fragile states index systems. They were generally based on the evaluation of society, environment, economy and government. Given that climate change has far-reaching impact for the quality of humankind and the development of a country, we have reasons to believe that climate change may have increased fragility of a country. We used analytic hierarchy process and established fuzzy synthetic evaluation models to identify when a sate is fragile, vulnerable, or stable. And we used the gray correlation method to analyze the correlation between climate change and each evaluation indicators. Then, we combined with Yemen's specific situation; we found that climate change makes its more fragile through the impact to food production, water supply, natural disasters and other evaluation indicators. We also demonstrated that Yemen will not become so vulnerable without these adverse weather effects.

Keywords: Climate change; fragile states; analytic hierarchy process; fuzzy synthetic evaluation models; Yemen.

INTRODUCTION

The adverse effects of climate change on the global environment are unequivocal [1]. But how about the impact on regional instability?

Climate change is one of the principal challenges of our era and adds considerable stress to the environment and to our societies [2].

We know that carbon dioxide levels in the air are at their highest in 650,000 years [3], but we do not know that how much extreme weather will happen, how many species will extinct, and how many governments will collapse. Thus, the effects of climate change are uncertain in some respects and vary from region to region.

Perhaps the greatest uncertainty lies not in science, nor in the climate system [4], but in us. Many of the effects can change people's daily life and have possibilities to weaken a society and governmental structures. If a state with weak governance and social fragmentation suffers environmental stress at the same time, it will be very hard for the government to continue its rule.

METHODS

This problem is a typical evaluation model. On the basis of the following assumptions, we establish a fuzzy comprehensive evaluation model based on AHP to judge the condition of a state.

- The selected evaluation indicators are independent of each other.
- The score of each evaluation index is reasonable.
- The data we used and referenced are believable.

As there are many evaluation criteria for judging the vulnerability of a state, to make the evaluation of national vulnerability more reasonable, we build some most commonly accepted indicators of state fragility assessment as follow:

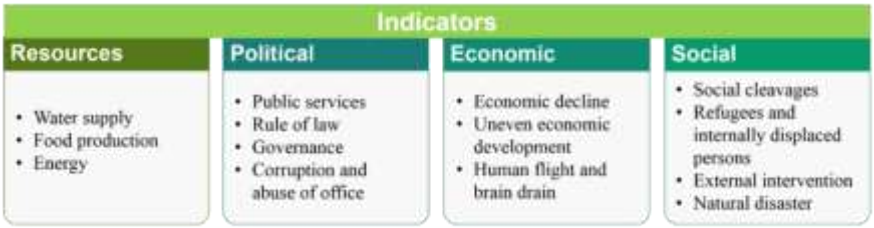

Fig-1: Indicators of state fragility

We assume that the fragile states index is$\{x_1, x_2, \cdots x_i\}$. Then the model of national vulnerability assessment is

$$y = \sum_{i=1}^{14} \alpha_i x_{iscore} \qquad (1)$$

Where y denotes comprehensive evaluation score, α_i demotes the weight of each evaluation indicator, x_{iscore} denotes the score of each evaluation indicator.

We also determine the weight of each evaluation indicator, find the score of them, and calculate the score of each country to identify when a state is fragile, vulnerable, or stable.

Determine the score of each evaluation indicator

As the dimensions of these evaluation indicators are different, and some of them can only be described qualitatively, we need to adopt fuzzy comprehensive evaluation method to describe all the evaluation indexes quantitatively.

The fuzzy comprehensive evaluation method transforms the qualitative evaluation into the quantitative evaluation according to the membership degree theory of fuzzy mathematics. Based on the optimal evaluation factors, it compares the evaluation factors with each other and uses a 10-point scale. In this task, we need to assess the state's fragility, so the optimal evaluation factor represents the most fragile state, which has a corresponding score of 10. The scores of those who were not good enough were reduced by their degree. We evaluate all their scores in the end.

We develop a model that determines a country's fragility. Since the fragility is a very vague concept but the result of the proposed model is a specific value, we need to determine the range of the degree for "fragile", "vulnerable", and "stable". The specific range of the degree is shown in tab.1.

Tab-1: The definition of the state's fragility

Condition	Range of the score
Fragile	>7.5
Vulnerable	≥5~7.5
Stable	<5

After calculating a state's comprehensive score, we can use the table above to judge the state's condition.

Determine the weight of each evaluation indicator

Supplement on Knowledge Points of AHP

As for the construction of the index system, our main objective is to calculate the weight for society, economy, politics and resources by AHP. After surveying the relevant data, we calculate the specific weights of the various indicators that affect the state fragility. Finally, we complete the evaluation of the state fragility. The flow chart is shown in fig.2.

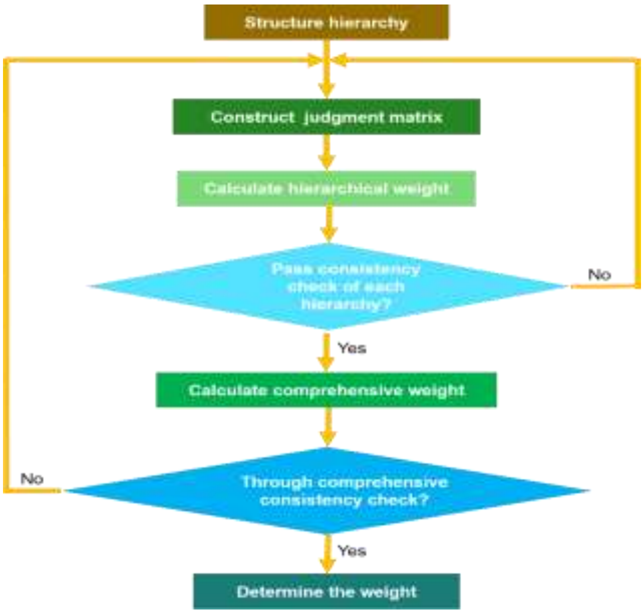

Fig-2: The flow chart of AHP

Establish the progressive hierarchy

Through the analysis of the target system, we decompose the complex target problem into several components and group these components in more detail. When we group them, we form different levels according to their distinctive attributes. The same level of factors as a standard, not only to control some of the next level of factors, but also by a certain level of constraints and domination. This top-down relationship becomes a progressive hierarchy and it is generally a tree structure. The top hierarchy is for objectives; the middle hierarchy is for criteria; the lowest hierarchy is for projects. It is shown in Fig.3.

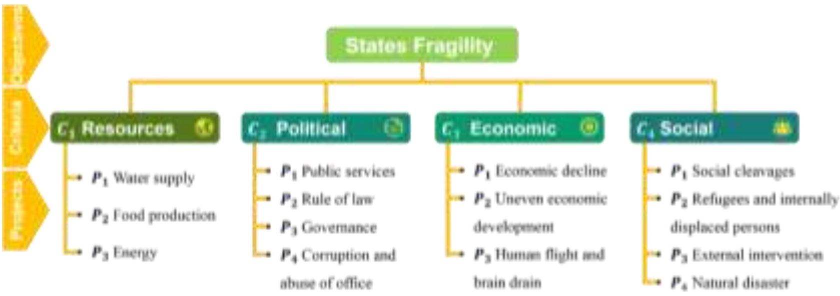

Fig-3: analytic hierarchy process

Construct the judgement matrix

After establishing the indicator hierarchy, we determine the affiliation between the upper and lower indicators. Constructing a judgment matrix is a matrix formed by comparing a certain factor of one level with a certain factor of a higher level in a hierarchical organizational model. We quantify the result of the comparison with a scale. We use the 1-9 scale method proposed by an American Operations Research Professor. Then we make comparisons between different evaluation indicators to construct the judgment matrix. The 1-9 scale method is shown in Tab.2.

Table-2: Saaty's scale

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement slightly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another, its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption

Judgment matrix construction is based on the importance of comparison. We compare each indicator and assign the value at the same level one by one to obtain a judgment matrix. The matrix table is shown as follow.

Table -3: Matrix of Objectives

O	C_1	C_2	C_3	C_4
C_1	1	3	7	5
C_2	1/3	1	5	3
C_3	1/7	1/5	1	1/3
C_4	1/5	1/3	3	1

Similarly, we can calculate the four secondary indicators of the judgment matrix.

Table -4: Matrix of C_1

C_1	P_{11}	P_{12}	P_{13}
P_{11}	1	1	3
P_{12}	1	1	3
P_{13}	1/3	1/3	1

Table -5: Matrix of C_2

C_2	P_{21}	P_{22}	P_{23}	P_{24}
P_{21}	1	1/3	1/7	1/5
P_{22}	3	1	1/5	1/3
P_{23}	7	5	1	3
P_{24}	5	3	1/3	1

Table -6: Matrix of C_3

C_3	P_{31}	P_{32}	P_{33}
P_{31}	1	3	5
P_{32}	1/3	1	3
P_{33}	1/5	1/3	1

Table -7: Matrix of C_4

C_4	P_{41}	P_{42}	P_{43}	P_{44}
P_{41}	1	3	1/3	1/3
P_{42}	1/3	1	1/5	1/5
P_{43}	3	5	1	1
P_{44}	3	5	1	1

Consistency check

Criterion for the consistency test is $CI = \frac{\lambda_{max}-n}{n-1}$, where *n* denotes the order of the judgment matrix. For example, there are three first-level indicators and the random coincidence indicator *RI*=0.58. Since $CR = \frac{CI}{RI} < 0.10$, the judgment matrix passes the consistency test. Otherwise, it is necessary to adjust the value of the element of the judgment matrix and test again. The value of the random coincidence indicator is shown in Tab.8.

Table -8: The value of the random coincidence indicator

N	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.44	1.45

After calculation, we get the result as follow:

For the Matrix of Objectives, *CR*=0.0439 < 0.1 **Pass** the consistency test.
The weight vector $\alpha = (0.5779, 0.2633, 0.0569, 0.1219)^T$.
For the Matrix of C_1, *CR*=0 < 0.1 **Pass** the consistency test.
The weight vector $\alpha_1 = (0.4286, 0.4286, 0.1429)^T$.
For the Matrix of C_2, *CR*=0.0439 < 0.1 **Pass** the consistency test.
The weight vector $\alpha_2 = (0.0569, 0.1219, 0.5579, 0.2633)^T$.
For the Matrix of C_3, *CR*=0.0334 < 0.1 **Pass** the consistency test.
The weight vector $\alpha_3 = (0.6333, 0.2605, 0.1062)^T$.
For the Matrix of C_4, *CR*=0.0163 < 0.1 **Pass** the consistency test.
The weight vector $\alpha_4 = (0.1535, 0.0687, 0.3889, 0.3889)^T$.

So, we get the weights of states fragility index as Tab.9.

Table-9: The weights of states fragility index

Objective Layer	Criterion Layer	Weight	Project Layer	Weight	Comprehen-sive Weight
States Fragility	Resources	0.5579	Water supply	0.4826	0.2692
			Food production	0.4826	0.2692
			Energy	0.1429	0.0797
	Political	0.2663	Public services	0.0569	0.0150
			Rule of law	0.1219	0.0321
			Governance	0.5579	0.1469
			Corruption and abuse of office	0.2633	0.0693
	Economic	0.0569	Economic decline	0.6333	0.0369
			Uneven economic development	0.2605	0.0148
			Human flight and brain drain	0.1062	0.0060
	Social	0.1219	Social cleavages	0.1535	0.0187
			Refugees and internally displaced persons	0.0687	0.0084
			External intervention	0.3889	0.0474
			Natural disaster	0.3889	0.0474

As the table above shows, among the 14 evaluation indicators for assessing states fragility, there are five indicators include human flight and brain drain, refugees and internally displaced persons, uneven economic development, public services, and social cleavages occupy a very little weight. So, when we evaluate the states fragility, these indicators cannot be considered. Subsequently, we simplify the evaluation index, leaving the remaining nine indicators to redistribute their weights. The correction method is as follow:

$$\alpha_i' = \frac{\alpha_i}{\sum_{i=1}^{9} \alpha_i} \quad (2)$$

The result is shown in Tab.10.

Table -10: The weight of each indicator

Indicators x_i	**Weight α_i**
Water supply（x_1）	0.2700
Food production（x_2）	0.2700
Energy（x_3）	0.0799
Rule of law（x_4）	0.0322
Governance（x_5）	0.1473
Corruption and abuse of office（x_6）	0.0695
Economic decline（x_7）	0.0361
External intervention（x_8）	0.0475
Natural disaster（x_9）	0.0475

Determine the impact of climate change on state fragility

Climate (mainly includes temperature and precipitation) change do not necessarily give rise to violent conflicts, but evidence demonstrates that when combined with weak governance and social cleavages it can trigger violent conflicts and make the country fragile. Therefore, we believe that climate change affects the state fragility by affecting the other evaluation indicators. However, climate change does not affect each of the evaluation indicators, so we need to conduct a correlation analysis to find out which indicators are relevant. The correlation analysis figure is shown in fig.4.

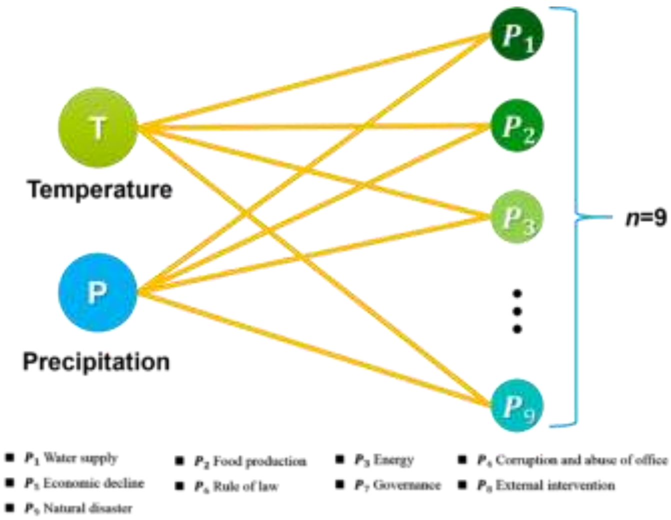

Fig-4: correlation analysis figure

Gray relational analysis

1) Analysis principle

Gray relational analysis is to use gray relational model to quantitatively measure the impact of the relationship between system variables. It describes the relative changes between factors in the process of system development. If the relative changes in the process of system development are basically the same, then the correlation between the two is high; on the contrary, the correlation between the two is small.

2) Calculations and steps

A. Select and determine the data sequence

In this section, we select China's data from 2010 to 2015 as the basis. Then we use water supply, food production and other nine indicators for the comparison of several series, with temperature and precipitation as a reference series, to find the correlation among temperature, rainfall and other nine indicators.

B. Make indexes being dimensionless

In solving the scores of each country's evaluation index, we have normalized each evaluation index, so we can directly use the score of each evaluation index as a non-dimensional reference data, the specific data are as Tab.11.

Table -11: The non-dimensional reference data

Indicators	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
2015	6.2	6.6	4.1	2.9	4	3.8	4.1	4.2	6.3
2014	6.3	6.4	4	3	3.8	3.9	3.9	4	6.7
2013	6.2	6.3	4.2	2.9	4	4	4	4	6.6
2012	6.1	6.2	4.1	2.9	3.9	3.9	4.1	4.1	6.5
2011	6.2	6.3	4.3	3	4.1	4	4	4	6.8
2010	6.1	6.3	4.1	3.2	4	4.2	4.2	4.2	6.7

Then we standardize the data of temperature and precipitation. The specific data is shown in tab.12.

Table-12: The non-dimensional reference data

Indicators	Temperature	Precipitation
2015	7.4	6
2014	6.9	5.8
2013	7.1	5.7
2012	6.5	5.7
2011	6.8	5.6
2010	7	5.3

C. Solve the corresponding difference sequence. Calculate $|T - x_i|$ and $|Q - x_i|$. That is, make T and Q in Table 2 minus the value of each row in X1, X2, X9 respectively and seek absolute value. The result is shown in tab.13.

Table -13: Absolute difference between the temperature reference sequence and the comparison sequence

Absolute difference	$\|T - x_1\|$	$\|T - x_2\|$	$\|T - x_3\|$	$\|T - x_4\|$	$\|T - x_5\|$	$\|T - x_6\|$	$\|T - x_7\|$	$\|T - x_8\|$	$\|T - x_9\|$
2015	1.2	0.8	3.3	4.5	3.4	3.6	3.3	3.2	1.1
2014	0.6	0.5	2.9	3.9	3.1	3	3	2.9	0.2
2013	0.9	0.8	2.9	4.2	3.1	3.1	3.1	3.1	0.5
2012	0.4	0.3	2.4	3.6	2.6	2.6	2.4	2.4	0
2011	0.6	0.5	2.5	3.8	2.7	2.8	2.8	2.8	0
2010	0.9	0.7	2.9	3.8	3	2.8	2.8	2.8	0.3

From the table above, we know that

$$\min_{i=1}^{9} \min_{k}^{6} \left| T(k) - x_i(k) \right| = 0 \quad (3)$$

$$\max_{i=1}^{9} \max_{k}^{6} \left| T(k) - x_i(k) \right| = 4.5 \quad (4)$$

Similarly, we calculate the value about precipitation. The result is shown in tab.14.

Table-14: Absolute difference between the temperature reference sequence and the comparison sequence

Absolute difference	$\|Q - x_1\|$	$\|Q - x_2\|$	$\|Q - x_3\|$	$\|Q - x_4\|$	$\|Q - x_5\|$	$\|Q - x_6\|$	$\|Q - x_7\|$	$\|Q - x_8\|$	$\|Q - x_9\|$
2015	0.2	0.7	1.8	3	1.9	2.1	1.8	1.7	0.4
2014	0.5	0.6	1.8	2.8	2	1.9	1.9	1.8	0.9
2013	0.5	0.6	1.5	2.8	1.7	1.7	1.7	1.7	0.9
2012	0.4	0.5	1.6	2.8	1.8	1.8	1.6	1.6	0.8
2011	0.6	0.7	1.3	2.6	1.5	1.6	1.6	1.6	1.2
2010	0.8	1	1.2	2.1	1.3	1.1	1.1	1.1	1.4

From the table above, we know that

$$\min_{i=1}^{9} \min_{k}^{6} \left| Q(k) - x_i(k) \right| = 0.2 \quad (5)$$

$$\max_{i=1}^{9} \max_{k}^{6} \left| Q(k) - x_i(k) \right| = 3 \quad (6)$$

D. Calculate the correlation coefficient

With the formula below, we calculate the correlation coefficient between each comparison sequence and the corresponding element of the reference sequence.

$$\xi_i(k) = \frac{\min_i \min_k |T(k) - x_i(k)| + \rho \cdot \max_i \max_k |T(k) - x_i(k)|}{|T(k) - x_i(k)| + \rho \cdot \max_i \max_k |T(k) - x_i(k)|} \quad (7)$$

Where ρ denotes resolution ratio and takes value in (0,1). We usually take ρ as 0.5.

E. Calculate the degree of correlation

We calculate the average value of the correlation coefficient of each evaluation index to reflect the correlation between the evaluation object and the reference series. That is

$$r_i = \frac{1}{m} \sum_{k=1}^{m} \xi_i(k) \quad (8)$$

The result is shown in tab.15.

Table -15: The degree of correlation between climate and evaluation indicators

Indicators	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
Temperature	0.751	0.793	0.446	0.363	0.431	0.431	0.438	0.441	0.882
Precipitation	0.857	0.782	0.564	0.408	0.534	0.537	0.550	0.555	0.711
Average	0.804	0.788	0.505	0.386	0.483	0.484	0.494	0.498	0.796

From the table above, we know that food production, water supply and natural disasters are more relevant to the climate change. Therefore, it is believed that climate change affects the state fragility by affecting the other evaluation indicators indirectly.

SENSITIVITY ANALYSIS

It is a key factor when using gray relational model to find out the relation between climate change and each evaluation index. The selection of the valueβ has a great influence on the correlation coefficient. If it is too small, the correlation coefficients differ so much that it makes it impossible to give a correct assessment of the relevance of each evaluation index to the reference data series. If it is too large, the correlation coefficient difference is too small; resulting in absolute difference has little effect on the evaluation results. Therefore, the value of β is the key to determining the degree of association between climate change and each evaluation index.

In the calculation process, the value is generally 0.5, in order to analyze its sensitivity, in the (0,1) interval, we pass the allocation step of 0.2, calculate the impact of resolution on the evaluation of relevance. Computer-based calculations show that, for different climate change indicators and indicators of the degree of relevance as shown below:

From the results of above figure, it is obviously to find that evaluation results are divided into two parts, because of changes of resolution ratio. The erratic stage as $\beta \leq 0.3$ and the stable stage as$\beta > 0.3$.

- When$\beta \leq 0.3$, result of correlation change greatly and the rank is erratic. If assign resolution ratio small value, stable control capability is weak. Therefore, we couldn't use β in this range.
- When$\beta > 0.3$, result of correlation change weakly. We find that when$\beta > 0.5$, the change of resolution ratio has no effects on ranks, all of the ranks are consistent. Therefore, in our paper, it's reasonable to assign$\beta = 0.5$. Meanwhile, the result is stable.

ANALYSIS

In this part, we select Yemen as the research object and combine with the specific climate change in Yemen to explain why it will become increasingly fragile.

Yemen's natural environment

Yemen's geographical location

Geographically, Yemen, an area of 530,000 square kilometers, is actually not a whole area. The Rubu Desert, stretching from the northern part of Yemen to the central hinterland, separates Yemen into two parts that are not intimately connected. The fragmented nature of the geography determines the loose links between the Yemeni plates, and the climate in Yemen is also very different. Compared to western and eastern Asia, where climate is suitable and rainfall is abundant, most parts of Yemen are not livable.

Affected by the subtropical high-pressure zone all the year round, water vapor is blown by the wind from the mainland to the sea, causing water evaporation rate to be far greater than its recharge rate. Thus, making Yemen year-round high temperature and drought. There is a province in eastern Yemen called Hadelamao. The native language literally translated as death, showing the desolation of most parts of the east.

Yemen's precipitation

The annual average precipitation in Yemen from 2006 to 2015 is as follows:

Table-16: Yemen's average precipitation over the past decade

Years	Precipitation (mm)
2006	45.33
2007	69.25
2008	98.50
2009	47.83
2010	134.42
2011	90.58
2012	50.25
2013	55.75
2014	39.33
2015	35.75

From the table above, we can see that the precipitation in most of Yemen is only a mere 50 millimeters, which is much lower than the 400 millimeters required for farming. Without artificial irrigation, most areas of Yemen will not grow any crops at all. In addition, there is not a regular river throughout Yemen that cannot divert water to irrigate farmland. As a result of such harsh natural environment, most of the land in Yemen is extremely barren. Only 2.91% of the country's land is available for farming and most are concentrated in the northwest.

Subject to the harsh natural environment, Yemen's food production is very limited and it is difficult to provide enough food for the population explosion in Yemen (27.58 million in 2016, close to a much larger Saudi area). The difficult natural environment is doomed to Yemen as an unstable nation: the integration of the east and the west is difficult, the food crisis is severe, and the regime is easy to hollow out.

Changes in Yemen's evaluation indicators

According to the collected data, Yemen became more and more vulnerable from 2006 to 2015, and scores of all the evaluation indicators changed as shown in Tab.17.

Table -17: Changes in Yemen's evaluation indicators

Indicators	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
2015	9.9	10	8.5	9.1	9.6	8.4	9.3	9.5	9.2
2014	9.8	9.7	8.4	9.0	9.5	8.3	9.1	8.5	8.5
2013	9.6	9.5	8.4	8.7	9.8	8.6	9.2	8.7	8.3
2012	9.5	9.4	8.3	8.4	9.7	8.4	8.7	8.3	7.9
2011	9.3	9.2	8.1	7.7	9.3	8.3	7.7	8.2	7.8
2010	9.2	8.9	8.0	8.0	8.9	8.4	7.6	7.8	7.6
2009	8.9	8.9	7.8	7.7	8.4	8.2	7.5	7.3	7.4
2008	8.8	8.7	7.9	7.5	8.2	8.2	7.5	7.2	7.5
2007	8.7	8.5	7.7	7.2	8.0	8.3	7.4	7.2	7.4
2006	8.6	8.3	7.6	7.2	9.4	8.2	7.2	7.5	7.2

As can be seen from the figure above, from 2006 to 2015, the more significant changes in the evaluation indicators are:x_1, x_2, x_4, x_7, x_8, x_9.

The Impact of Climate Change on Yemeni Vulnerability

From the model we have established, we know that food production, water supply and natural disasters are more relevant to the climate change. Climate change affects the state fragility by affecting the other evaluation indicators indirectly. In the absence of eliminating the effects of climate change, using the model we have established, the composite score of Yemen in 2015 is

$$y = \sum_{i=1}^{9} \alpha_i \, x_{iscore} = 9.57 \quad (8)$$

Now, if we eliminate the impact of climate change, the ratings of food production, water supply, economic decline and natural disasters will be lowered. Using the model established, the composite score of Yemen in 2015 will be less than 9.57.

By comparing the overall scores, we conclude that if there is no change in the climate, Yemen will not be so fragile.

CONCLUSIONS

Through our research, we establish a model to evaluate state fragility and identify when a state is fragile, vulnerable, or stable. We also use the gray correlation method to analyze the correlation between climate change and each evaluation indicators. Through the research on Yemen, we find that climate change can push it to become more fragile. There are some deficiencies in procedure of modeling. The deviations existing in each measurement step are accumulated, and the systematic deviations will be serious. So, our model still not good enough to evaluate state fragility. But we sure that climate change can indirectly affect a country's development and the topic about climate change is still needed to be considered.

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