Research of Environmental Assessment Model Based on Fragile State Index

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Abstract. The effects of climate change, including increasingly severe droughts, shrinking glaciers, changes in the range of plants and animals and rising sea levels, are already being realized, and vary by region. A fragile state is one where the state government is not able to, or chooses not to, provide the basic essentials to its people. This paper establishes the Fragile Evaluation Model based on Fragile State Index (FSI) to determine a country’s fragility and measure the impact of climate change. We determine the indicators that affect the national climate and quantify them to establish the Climatic Stress Model. Then, based on this model, we combine the climactic stress index with 12 sub-indicators from FSI to develop the Fragile Evaluation Model. Next, we select Yemen as one of the top 10 most fragile countries from the FSI to determine how climate change increases the country’s fragility. The result shows that Yemen suffers a lot from strong wind and desertification which adds to the fragility of country.

Keywords: Climatic Stress Model; Environmental Assessment Model; Fragile State Index.

1. Introduction
The global climate is undergoing major changes, and the types and extent of climate change vary from region to region, such as increased droughts, shrinking glaciers, changes in the range of animals and plants, and sea level rise.

The Intergovernmental Panel on Climate Change suggests that the net damage costs of climate change are likely to be significant. These effects may alter the way humans live, and have the potential to cause the weakening and breakdown of social and governmental structures.

While facing abrupt climate change, such as natural disasters, arable land reduction, unpredictable weather, and rising temperatures, a stable national government system has strong resistance to them, and an unstable government system may lead to an increase in the state Vulnerability and in crisis.

In developing countries, the unsustainable and persistent problems of environmental protection measures, relocation and resource shortage are extremely serious. These problems are likely to further aggravate the instability of government governance in some countries. Drought has further exacerbated the conflicts between the already fragile nations.

There is evidence that when environmental stress is combined with weak governance and social fragmentation, it can enhance a spiral of violence, typically along latent ethnic and political divisions. The spatial distribution of contemporary environmental pressures is widespread and unevenly
distributed. Modern trends indicate that environmental-driven violence is concentrated in developing countries and regions where there is extreme social polarization and differentiation.

2. Model Overview
In our basic model, our goal is to establish a quantitative relationship among climate, other indicators and country’s fragility.

We started with the Climate Stress Model. At first, we introduce four conventional climate elements. Then we use these elements to get the climate stress. Afterwards, we add extreme climate into the Climate Stress model to perfect our model.

Then, based on the Climate Stress model, we introduce 12 sub-indicators (including 12 indicators such as social, economic, political and military) that the U.S. Fund for Peace evaluates the fragile states index and finally establish the Fragile Evaluation Model based on the FSI Model to improve the climate-related fragility assessment system.

The whole modeling process can be shown as Fig.1.

![Figure 1. Fragile evaluation model process](image)

3. Climatic Stress Model Establishment

3.1. Model Based on Four Climatic Elements
In this paper, we select the temperature, relative humidity, wind speed and sunshine rate as four climatic elements to establish the climatic stress model. The days of temperature, relative humidity, wind speed and sunshine rate are the annual average.

For the climactic elements of living environment, the smaller the Gini coefficient in a certain average state, the farther the extreme state deviates from the average state. And one of the extreme states must
deviate from the most comfortable range in which its average state is near. Therefore, the Gini coefficient is an important factor that affects the comprehensive score of climatic elements.

Based on the above considerations, the climatic stress model can be established as following. If $P_i$ is in the most comfortable state, $R$ can be replaced as zero.

$$ R = \sum \left| C_i - P_i \right| \times G_i \times W_i / M_i \quad (i = 1,2,3...) \tag{1} $$

Where:

- $R$ is climatic stress index.
- $P_i$ is the actual condition of the climactic elements in the living environment.
- $G_i$ is the gini coefficient of distribution uniformity degree of different climatic elements.
- $W_i$ is weight of different climactic elements.
- $M_i$ is the value of the most comfortable state far from $P_i$.

According to the Formula 1, the climatic stress index of four climactic elements can be defined as following:

Temperature:

$$ R_T = \begin{cases} 0 & (15^\circ C \leq T \leq 24^\circ C) \\ \left[ \left| 15 - T \right| / 24 \right] \times G_T \times W_T & (T < 15^\circ C) \\ \left[ \left| 24 - T \right| / 15 \right] \times G_T \times W_T & (T > 24^\circ C) \end{cases} \tag{2} $$

Relative humidity:

$$ R_{RH} = \begin{cases} 0 & (0.65 \leq RH \leq 0.75) \\ \left[ \left| 0.65 - RH \right| / 0.75 \right] \times G_{RH} \times W_{RH} & (RH < 0.65) \\ \left[ \left| 0.75 - RH \right| / 0.65 \right] \times G_{RH} \times W_{RH} & (RH > 0.75) \end{cases} \tag{3} $$

Sunshine rate:

$$ R_S = \begin{cases} 0 & (0.55 \leq S \leq 0.65) \\ \left[ \left| 0.55 - S \right| / 0.65 \right] \times G_S \times W_S & (S < 0.55) \\ \left[ \left| 0.65 - S \right| / 0.55 \right] \times G_S \times W_S & (S > 0.65) \end{cases} \tag{4} $$

Wind speed:

$$ R_W = \begin{cases} 0 & (W \leq 2.0) \\ \left[ \left| 2.0 - W \right| / 2.0 \right] \times G_W \times W_W & (W > 2.0) \end{cases} \tag{5} $$

Therefore, we can get the total climactic stress index based on four climactic elements as Formula 5.

$$ R = R_T + R_{RH} + R_S + R_W \tag{6} $$
3.2. Add Extreme Climate into Model

Same as the above four kinds of climactic elements, extreme climate can also affect the humans way of life, and have the potential to cause the weakening and breakdown of social and governmental structures, resulting in fragile states.

According to the global annual extreme climate and its influence on the social, political and economic aspect, we select high temperature days ($Htd$), low temperature days ($Ltd$), strong precipitation days ($Ipd$), arid area percentage ($Dap$), landing typhoon frequency ($Tcf$), dust weather days ($Dsd$) and strong wind days ($Swd$) as seven kinds of extreme climactic elements to establish the extreme climactic index. The extreme climactic elements are defined as follows:

| Definition                | Interpretation                                                                 |
|---------------------------|--------------------------------------------------------------------------------|
| high temperature days     | Day maximum temperature $> 90$th percentile of days                            |
| low temperature days      | Day minimum temperature $< 10$th percentile of days                           |
| strong precipitation days | Daily precipitation $> Total precipitation day for the 95$th percentile       |
| arid area percentage      | The percentage of area under drought and the area of observation              |
| landing typhoon frequency | Statistics on the number of typhoons landing in coastal areas                 |
| dust weather days         | The average number of sandstorm days over the observation period              |
| strong wind days          | Number of days with instantaneous average wind speed $> 17$ m $\cdot$ s$^{-1}$ |

In fact, the impacts of the extreme climate mentioned above are quite different and cannot be treated equally. Considering the degree of the impact of different extreme climate, including direct economic losses, the number of deaths caused by disasters and social influence or social attention, the relative importance of extreme climate elements can be determined. Accordingly, each extreme climate element is given a corresponding weighting factor in Table 3.

| Extreme climactic element | Weighing factor |  |
|---------------------------|-----------------|---|
| high temperature days     | 0.07            |  |
| low temperature days      | 0.08            |  |
| strong precipitation days | 0.30            |  |
| arid area percentage      | 0.30            |  |
| landing typhoon frequency | 0.15            |  |
| dust weather days         | 0.05            |  |
| strong wind days          | 0.05            |  |

Therefore, we can get the extreme climactic index $R_E$ and the most comfortable state of extreme climate is defined as $0 \sim 0.049$.

$$E = \sum \delta_i E_i \ (i = 1, 2, 3...7) \quad (7)$$

$$R_E = \begin{cases} 
0 & (E \leq 0.049) \\
\left[0.049 - E\right] / 0.049 \times G_E \times W_E & (E > 0.049) 
\end{cases} \quad (8)$$

Where:

- $\delta_i$: The weighing factor of each extreme climate element.
$E_j$: The standardized value for each extreme climate element.

Considering the extreme climate, we establish an accurate climactic stress model, and the climactic stress index $R$ is revised as following.

$$R = R_T + R_{RH} + R_S + R_W + R_E$$  \hspace{1cm} (9)

4. Fragile Evaluation Model Establishment

Based on the Climatic Stress Model, we introduce 12 indicators that the U.S. Fund of Peace use to assess states' vulnerability and publish Fragile States Index (FSI). In this paper, we establish our Fragile Evaluation model based on the FSI.

The 12 separate indicators from FSI are related to various aspects of state stability and strength. Each indicator is scored between 0 and 10, with a higher number indicating a higher level of fragility. 12 Indicators are divided into three categories as Table 4.

| Categories          | Indicators                                      |
|---------------------|-------------------------------------------------|
| Social indicators   | Demographic pressures(S1), Refugees and IDPs(S2), Group grievance(C3), Human flight and brain drain(E3) |
| Economic indicators | Uneven economic development(E2), Poverty and economic decline(E1) |
| Political indicators| State legitimacy(P1), Public services(P2), Human rights and rule of law(P3), Security apparatus(C1), Factionalized elites (C2), External intervention(X1) |

By analyzing the data and information from Fragile States Index, we find that the evaluation steps of the Fragile States Index are as follows:

- Scan millions of documents from over 100,000 English-language or translated sources (social media are excluded) and assign each score based on specific algorithm.
- Standardize each score to make 12 indicators scored between 0 and 10.
- Sum up 12 indicators linearly to make a comprehensive assessment.

In order to achieve a uniform fragile evaluation criterion., we need to standardize the climactic stress index $R$ to make it scored between 0 and 10 as the other 12 indicators. We select the related climate data from more than 20 countries in the world and use formula 8 to calculate the climactic stress index. Then we apply these data to the same normalization as the Fragile States Index rules to get their relative values.

In order to ensure the normalized climatic stress data is universal, the national locations we select should be representative and extensive. The selected locations are shown as Fig.2.

![Figure 2. The selected locations](image)

Finally, we get the fragile evaluation index as following.

$$FE = FSI + CS$$  \hspace{1cm} (10)
Where:

- **FE**: the fragile evaluation index.
- **FSI**: the total score of 12 indicators from FSI.
- **CS**: the normalized climatic stress index.

The Fragile Evaluation Model determines a country’s fragility through the fragile evaluation index. Like the FSI, a higher index indicates a higher level of fragility. The model can also measure the impact of climate change. Extreme climate will improve the climatic stress index and push a country to become more fragile.

5. Model Validation

According to the top 10 most fragile states as determined by the Fragile States Index, we choose Yemen (YEM) to check the Fragile Evaluation Model we have established.

Through the Climatic Stress Model, we can calculate and normalize the values of Yemen’s climatic stress index. The results are shown in Table 5.

| Year | air temperature | relative humidity | sunshine rate | wind speed | extreme weather | Climatic Stress Index | Normalized Climatic Stress Index |
|------|------------------|-------------------|---------------|------------|-----------------|-----------------------|----------------------------------|
| 2006 | 0.151668282      | 0.2787763         | 0.183989      | 0.2384     | 0.0625          | 2.8080578             | 5.439220071                      |
| 2007 | 0.150768927      | 0.2501756         | 0.201437      | 0.1649     | 0.0933333       | 2.8332892             | 5.584859226                      |
| 2008 | 0.151558149      | 0.2024357         | 0.1943        | 0.1911     | 0.0633333       | 2.8485814             | 5.673127869                      |
| 2009 | 0.152173734      | 0.2256743         | 0.2011        | 0.0933333  | 0.0625          | 2.8140373             | 5.473734587                      |
| 2010 | 0.15350779       | 0.2183023         | 0.2283        | 0.0625     | 0.0625          | 2.8264529             | 5.54539833                       |
| 2011 | 0.153360332      | 0.2083443         | 0.217883      | 0.0875     | 0.0941667       | 2.8527283             | 5.697063871                      |
| 2012 | 0.153639711      | 0.1948567         | 0.269763      | 0.1899     | 0.0866667       | 2.8545971             | 5.707850759                      |
| 2013 | 0.153141158      | 0.1958799         | 0.186322      | 0.2011     | 0.0866667       | 2.8496115             | 5.67907363                      |
| 2014 | 0.153690597      | 0.2206735         | 0.200034      | 0.1983     | 0.0633333       | 2.8347559             | 5.5933252                       |
| 2015 | 0.152969663      | 0.2156394         | 0.20197       | 0.2232     | 0.0941667       | 2.8562216             | 5.71727701                      |
| 2016 | 0.152544067      | 0.2134244         | 0.186723      | 0.2071     | 0.0683333       | 2.8232906             | 5.527145999                     |
| 2017 | 0.153162166      | 0.1956343         | 0.193734      | 0.2102     | 0.1183333       | 2.8849716             | 5.883176573                     |

The analysis of data in the Table 5 shows that Yemen suffers a lot from drought. That is because Yemen is located in southwestern Asia and the southern tip of the Arabian Peninsula. Yemen’s climate is largely driven by tropical arid climate. And due to overgrazing, land desertification in Yemen is serious and sandstorms are extremely common.

Then we get the fragile index of Yemen (2006–2017) through Fragile Evaluation Model. The fragile evaluation index and FSI can be clearly compared in Fig.3.
From Figure 3, we can draw a conclusion that the harsh climate in Yemen makes the climate vulnerable, which adds to the fragility of country. Obviously, the country will be less fragile without these climate changes.

6. Summary
In this model, we have determined and quantified the indicators affecting national climate and established the climate pressure model. In this paper, various climatic factors on states fragility are taken into account. At the end of the article, we get the vulnerability index of Yemen and the causes of vulnerability. Meanwhile, we have several consistency and sensitivity examinations, and this model can be prove reasonable and valid.

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