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Models to Predict the Number of Climate Refugees and the Optimal Flow

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Abstract: The issue of climate refugee resettlement due to climate change has recently attracted attention. In order to better understand and effectively deal with this problem, the authors decomposed the problems to be solved and established corresponding models. The definition of climate refugees in this article was simplified to be those due to sea level rise. Through establishing models, it is estimated that by 2080, there will be about 200,000 to 300,000 climate refugees. This article also reached the optimal matching between climate refugees and receiving countries.

Keywords: Climate Refugee; Reselltement; Model; Optimal Flow

1. Introduction

Along with changes in global climate patterns, ocean surface temperatures have continued to rise, global ocean storms have continued to increase in duration and intensity, and sea levels have continued to rise. Several island nations such as the Maldives, Tuvalu, Kiribati and Marshall Islands are in danger of disappearing completely. The actual or potential large number of climate migrants caused by climate change and its adverse effects have become a serious challenge facing human society in the 21st century[1].

A recent UN ruling has made environmental refugees a matter of great concern[2]. Hired by the International Climate Migration Foundation (ICM-F), the authors developed models to advise the United Nations on climate refugee resettlement. Through the establishment of a model, six countries at risk were selected to predict the number and development trend of climate refugees due to sea level rise in the future. At the same time, the model established should determine the mechanism by which selected factors affect the risk of cultural heritage loss to climate refugees. Then the authors established an index system consisting of subtypes to measure the degree of fit, and built a bipartite graph model between climate refugees and receiving countries based on the fit. This model was used to optimally match the two to determine the optimal flow of climate refugees.

2. Assumptions

The authors made several assumptions in their models.

(1) When the sea level of a country is below 5 meters, the residents of that country will be considered as climate refugees and need to be relocated.

(2) Assuming that the selected countries are representative, the identified cultural loss impact mechanism can be applied to other countries.

(3) Climate refugee migration must be carried out in groups, that is, the population of the country of origin moves completely into the same receiving country. However, the receiving country can accommodate multiple groups.

(4) Refugees do not choose which countries they are settled in; they are told this by the UNHCR and other

organizing groups.

(5) Refugee-receiving countries must accept refugees allocated by international organizations, but they can be refused when the capacity is reached.

(6) After the climate refugees moved in, there will be no unexpected terrorist incidents or disasters in the receiving country.

3. Forecast of refugee numbers

By analyzing the sea level data of the past ten years, and combining the specific terrain data of each country, the method of regression analysis was used to predict which countries will face a crisis due to sea level rise in the next few years. This article mainly analyzed the island states of Kiribati, Nauru, Marshall Islands, Bahamas, Maldives, and Tuvalu. Because according to related reports, these countries are most likely to face an environmental crisis caused by sea level rise in the coming decades[3]. By consulting the relevant sea level data of these countries and the landforms and population distribution of these countries, the authors preliminary predicted that by 2080, there will be about 200,000 to 300,000 environmental refugees.

In terms of the possibility of cultural loss, six indicators were selected, including the nationalist tendency of the receiving country, the geographic location of the refugees, the fit of production and lifestyle, the carriers required by culture, the cohesion of refugees, and the economic benefits of culture. To determine the range of these cultural risk indicators, principal component analysis was adopted.

By predicting the number of future climate refugees and the risk of cultural loss due to transfer, it can be recognized that climate change has had a great negative impact. In order to better resettle climate refugees, the authors used a graph theory method to evaluate the number of climate refugees.

Table 1. Possible orientation modeling.

Country name	Population (10,000 people)	Proportion of land area below 5 meters	Terrain strength (m)	Annual sea level growth (mm)	Whether the population lives below 5m above sea level
Kiribati	12.2	54.56%	1	4.1	T
Nauru	1.3	6.65%	31.1	4.2	T
Bahamas	41	51.94%	5.5	4.1	T
Marshall Islands	5.3	43.82%	1.4	4.1	T
Tuvalu	1	32.65%	2.5	4.3	T
Maldives	44	45.51%	1.2	4.1	T

The authors conducted a regression analysis of the sea level data collected in previous years and found that the sea level of these island countries rose at a rate of about 4 mm per year. Referring to relevant literature and combining relevant map data, it has been found that by the end of the 21st century, many territories of these countries will no longer be habitable, and they must have residents move out of the area for migration. It is expected that there will be about 300,000 to 400,000 refugees due to rising sea level.

4. Possible cultural loss due to transfer

In terms of the risk of cultural loss, after considering the characteristics of culture and some examples of the European refugee crisis, the following factors were taken into account to measure the cultural loss risk of immigrants: nationalist tendencies, the geographical location of refugees, the fit of production and lifestyle, and needed carriers, refugee cohesion, and cultural economic benefits[4–6].

The principal component analysis method provides a simple and comprehensive evaluation method, through which the authors can select the most important characteristic roots and use them as weights to construct a comprehensive evaluation model of principal components. From the above data, it is not difficult to obtain several feature roots yi with high contribution rates and their corresponding feature vectors bi. To obtain a comprehensive evaluation index for the risk of cultural loss:

The most basic characteristics of each self-risk: first, the deeper the refugees' dependence on culture, the lower the risk of loss. There is also the degree of exclusion of the receiving country from the foreign population. The more intense the exclusion of the foreign population, the higher the risk. Then there is the right carrier for the culture itself. The more complicated the carrier, the higher the risk.

5. Refugee destination

In order to properly arrange the climate refugees who have lost their homes, the graph theory and analog analytic hierarchy process (AHP) were used to model the optimal flow of climate refugees. The authors first calculated the degree of matching between refugee countries and countries that might accept them. Then they used the KM algorithm to calculate the best match for refugees to the country. In this model, r indicated the degree of matching between refugees and receiving countries. More specifically, it was an evaluation index for whether refugees can be integrated into receiving countries. The authors also categorized the risks that affected the degree of matching for accurate modeling. After consulting relevant literature, the authors decided to divide r into three main influencing factors: the acceptance of foreign migrants in receiving countries r1 (including but not limited to the economic development level and national education level of receiving countries), and the degree of adaptation in refugees receiving countries r2 (including but not limited to language, production and lifestyle), natural factors of migration r3 (including but not limited to distance and climate difference). Receiving countries have different degrees of matching refugees from different countries.

Here, is the weight vector. Obviously, sub-risks are affected by many factors. In order to simplify the model, only the most important ones for each have been considered.

First, referring to previous surveys of the willingness of many European media to accept refugees, it is believed that the higher the education level of the people in the receiving country and the more developed the economy, the higher their acceptance of foreign immigrants. So r1 should be equal to the education level of the people times the level of economic development. The education level was divided into 6 levels and the average education level of the people was calculated. Then the per capita GDP was used to measure the economic development level of a country. For example: if the education level of a country's nationals is 2.8, and the per capita GDP is 1 (US $ 10,000), then its acceptance of immigrants is 2.8.

Secondly, refugee adaptation to the country can be affected by the degree of language similarity between refugees and receiving countries, differences in production and lifestyle, and ethnic differences. As these data are difficult to quantify directly, the authors considered using the situation of those who have migrated into the recipient country from the country of origin of the refugee. That is to say, the immigrants who have moved into country B are people S, and the people who can live in stability (no crime, having a stable job, and having not moved out again) are S1, then the adaptation degree of Country A to the residents of Country B is S1/S.

Influencing factors in the migration process also need to be considered, including distance and policy. Comparison of the refugee crisis in Europe indicates that distance is the main natural factor affecting migration, so distance is used to measure the impact of natural factors. The longer the distance, the more difficult it is.

At the same time, the authors also referred to the Paris Agreement, and believed that some large carbon-emitting countries should assume more responsibility for accepting refugees[7]. It is considered that some developed countries now pass carbon dioxide emissions to developing countries through trade, so the consumption-based carbon dioxide emissions are taken to measure the obligation of a country to receive refugees. In this way, the ratio of carbon dioxide emissions at the consumer end to the distance between countries can be regarded as an indicator of the influencing factors in the migration process.

In the analytic hierarchy process, the weights of different standards on the target are estimated according to the importance comparison between different standards. The comparison result is stored in a reciprocal matrix, and the feature vector is calculated. Similarly, the weight of different sub-risks to the total risk should be determined through likelihood comparison. For example, if the probability of r11 is greater than r12, then the first row and second column of elements (1,2) will range from 1 to 9, which indicates the degree of probability. The following matrix represents a reasonable likelihood:

Table 2.

	r1	r2	r3
r1	1	3	4
r2	1/3	1	2
r3	1/4	1/2	1

The weights thus obtained are: = (0.57,0.34,0.08).

Here is an example to illustrate the model: the refugees from country A want to migrate to country B, then the local acceptance is 3.1, the refugee's fitness is 0.8, and the factor in the migration process is 0.0327. Then the matching degree from country A to country B should be:

In this way, the fit between each refugee and the potential recipient country has been modeled. A complete bipartite graph from the refugee country to the receiving country can be drawn. The degree of agreement between the two countries is taken as the weight of the corresponding side.

This bipartite graph can be represented by an association matrix (as seen in Figure 1).

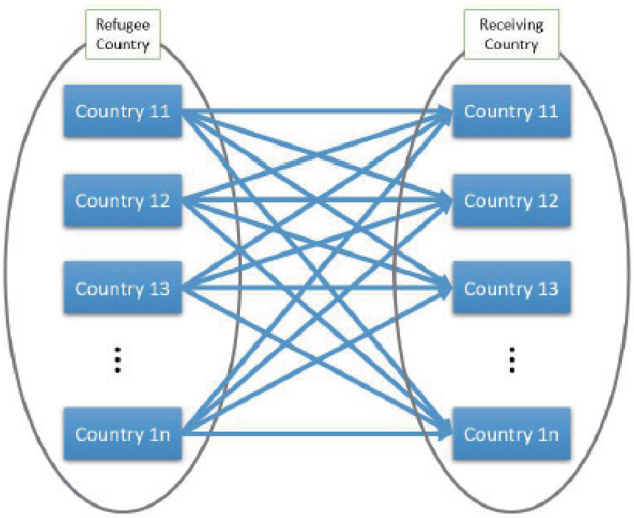

Figure 1

Here, each point on the left indicates a refugee country, and that on the right indicates a receiving country. The paths between them indicate the degree of matching between the refugee country and the receiving country.

Then the KM algorithm can be used to continuously recurse to solve the optimal matching of the weights of this bipartite graph, which corresponds to the best destination of the refugees.

6. Conclusion

In the refugee optimal flow model, the environmental responsibility of the receiving country has been considered. More importantly, the measurement is based on the indicators of consumer-side carbon emission to avoid unfair distribution caused by trade-off emissions. However, there are some obvious weaknesses in the models: only 6 representative countries have been selected to reduce the scope of prediction; the establishment of the index system is measured by representative influence factors, and there may be deviations.

To optimize the modeling in the future, more indicators should be considered when predicting future refugee numbers, such as the rate of temperature rise, the rate of disappearance of organisms like “coral reefs” and “marine fishes”, because coral reefs can protect the land. The definition of disappearance of land and emergence of climate refugees must be clarified again. Is the hurricane and tsunami brought by the rise of sea level that make residents unable to survive and have to flee? Or is the land completely sunk to survive? Or is it because of the salinity of the land that the crops cannot grow and the people have no food?

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