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Population and Cultural Disasters Caused by Sea Level Rise B ased on Regression Model

Jiapan Wang¹, Yi Gao², Haoqi Lin³

¹ School of Remote Sensing Information Engineering, Wuhan University, Wuhan, Hubei, 430072

² School of Electronic Information, Wuhan University, Wuhan, Hubei, 430072

³Beijing Normal University-HongKong Baptist University United International College, Zhuhai, Guangdong, 519000

Abstract--With the worsening environment, more people become EDPs since their homeland become inhabitable. Leaving the place they once called home, their rights may not be guaranteed. Meanwhile, their unique culture are also facing the edge of extinction. To determine the scope of the issue, we discuss the number of people at risk and specify the cultural loss. When predicting EDP population, we start by using the regression model to predict the trend of sea level rise due to the greenhouse effect and find out by 2120, the world's average sea level will probably rise by 60mm. Considering the effect of greenhouse gas makes this model more persuasive than if we only use sea level data to predict. Then, we build a spherical cap model to resemble to geographical features of tropical islands. It greatly simplifies the complexity of island topography and extends our prospective from a few islands to the whole world. With the help of the spherical cap model, on conservative estimate, the current number of EDP is about 67 million; by 2050, the potential EDPs will reach 130 million and over 400,000 square kilometers of land will be submerged. In the aspect of culture, with island residents becoming refugees, the potential lost of religious rituals, folk stories, traditional techniques, intangible arts and unique languages lead to the huge loss of cultural heritage.

1. Introduction

Environmental problems have resulted in the displacement of many people and Environ- mentally Displaced Persons (EDPs) have caused great attention in recent years [1]. Especially, due to the sea level rise caused by the greenhouse effect, the people who live on small islands are facing a situation of being forced to evacuate from their own country, the estimation of potential EDP number and their resettlement will become difficult tasks [2].

However, a policy to give protection to these refugees has not been offered as much as tradi- tional refugees. The status and definition of environmental refugees still remain controversial [3]. Governments and international organizations need to cooperate to build the legal foundations of a global governance regime to deal with environmental refugees' problems [4]. In addition, it is vital to consider the rights of EDPs and the duties of the countries in the rest of the world. However, this issue has not been addressed enough in international legal regimes. What's more, during the EDP immigration, there could also be a cultural impact on these people that should be taken into consideration [5].

As a result, in the process of formulating resettlement policies for these EDPs, it is necessary to

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consider not only the economic strength of the host country, but also their environmental protection contributions [6]. Also, human rights and culture integration should also be taken into account in order to find the most suitable destination for the refugees [7].

2. MODEL DESIGN

2.1 Risk Prediction of EDPs

We analyzed four islands including Maldives, Tuvalu, Kiribati and Marshall Islands, to study the features of the countries that are becoming EDP refugee countries.

2.1.1 Regression Model

As we mentioned in the assumption, our paper mainly discusses the effect of sea level rise on the people becoming EDPs in tropical island countries. For these countries and regions, once the sea level rises to a certain extent, homes will be submerged and people will have to evacuate and immigrate to another country.

Therefore, we establish a model of sea level rise height and a physical model of small islands to simulate the trend of sea level rise and the extent of island inundation over time, so as to deduce the population of the island countries at risk, classify them as the currently existing EDPs. We further speculate the population of the islands that may be inundated in the future, and classify them as the potential EDPs.

First of all, we collected the average sea level height (SL/mm) data of Earth from 1993 to 2019. After data wrangling, we drew the curve indicating the change of the average sea level height over time. Using the method of straight line fitting, we estimated the speed of sea level rise. The results are shown in Figure 1.



According to Figure 1, as time goes by, the sea level height increases as a linear function of time, so we construct the function:

$$SL = a_1t + a_2$$

Where SL is the height of sea level, t is the time, a1, a2 is the fitting coefficient.

From Figure 1, we also find that before 2015, the sea level height data (red curve) basically conforms to the fitting line (blue line), which is evenly distributed up and down the line. But since 2015, most of the sea level height data are above the fitting line, so we speculate that the speed of sea level rise is increasing in recent years [8].

In order to verify our speculation, we found some data that shows that the greenhouse effect is one of the most important factors causing sea level rise. Of course, there are many other factors that cause sea level rise, but we only discuss the main and most important factor here—the greenhouse effect [9]. According to Figure 2 from United States Environmental Protection Agency4, it is obvious that CO_2 is

the "culprit" of greenhouse effect.



Figure 2 Global Greenhouse Gas Emissions by Gas

Hence, we found the data of global CO_2 emissions (CE/million ton) from 1970 to 2018, after data wrangling, we drew Figure 3, which shows the change of CE over time. With the method of quadratic curve fitting, we estimated the trend and speed of CE rise .





According to Figure 3, as time goes by, global CO_2 emissions continue to grow. We use a quadratic curve to fit, the fitting results generally match the growth of the original data, so we build the function:

 $CE = b_1 t^2 + b_2 t + b_3$ (1)

2.2 United States Environmental Protection Agency

Where CE is the global CO_2 emissions, t is the time, b1, b2, b3 is the fitting coefficient.

According to data, we know that CO_2 emission is one of most important reasons for sea level rise, but we don't know how big the impact is, so we conducted a correlation analysis between sea level rise height and CO_2 emissions, the results are as shown in Figure 4.

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Figure 4 Correlation between sea level and CO₂ emissions

Figure 4 shows that sea level rise has a strong positive correlation with CO_2 emissions. Therefore, we believe that the yearly increasing CO_2 emissions leads to the yearly rise of sea level height. The trend of increasing CO_2 emissions shows a quadratic polynomial fitting, which demonstrates that the rising speed of sea level height has become faster since about 2015. So we predict that in the future, sea level will rise faster as CO_2 emissions keep increasing [10].

Then we conduct a line fitting between sea level rise and CO_2 emissions, the results are shown in Figure 5.



Figure 5 The fitting line of sea level and CO₂ emission Figure 5 shows that the hight of sea level rise and CO₂ emissions has a linear relation, we set it as $SL = c_1CE + c_2$

where c1, c2 are fitting coefficients.

We have Equation 1 then,

$$SL = c_1(b_1t^2 + b_2t + b_3) + c_2$$

so

$$SL = k_1 t^2 + k_2 t + k_3$$

where SL is sea level hight, t is time, k1, k2, k3 are fitting coefficients.

According to our prediction, the sea level height may rise in a quadratic polynomial trend over time, then we draw Figure 6.

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Figure 6 Sea level prediction

According to our prediction, by 2120, the world's average sea level will probably rise by 60mm relative to the current altitude. This is a result based on global CO₂ emissions, only one of the factors impacting the sea level. If we don't take measures to reduce CO_2 emissions, in the future, the sea level hight might increase much more than what we predicted.

2.2.1 Spherical Cap Model

Now that we have the mathematical relationship of sea level height rising over time, in order to predict the potential EDP number more accurately, we conducted a spherical cap model (Figure 7) to simulate these island countries. This model is based on the geographical features of most tropical island countries, being usually high in the middle, low in the borders and surrounded by the sea.



Figure 7 Spherical cap model For this spherical cap model, we know the surface area,

$$s = 2\pi rh \qquad (2)$$

where s is the surface area of the sperical cap model, r is the radius of curvature, h is the height. For most island countries in the world, each country we collect the data of total land area and also the proportion of land area below 5m altitude. Then we can have the following derivation: according to Equation 2, we have

$$\begin{cases} S_1 = 2\pi R(H-5) \\ S_2 = 2\pi RH \end{cases}$$

then we can get

$$p = (S_2 - S_1) / S_2$$
$$H = 5 / p$$

- S1 is the area of land over 5m in the island
- S2 is the total area of the island
- R is the radius of curvature of the approximate
- h is the unsubmerged height of the island
- H is the highest altitude of the island
- p is the percentage of the island below 5m in elevation

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According to Equation 3, the highest altitude of the island country is negatively correlated to the proportion of land area below 5m. So we look up the proportion of land area under 5m of most island countries in the world, and we found that there are dozens of island countries with p greater than 10% and even nine island countries with p greater than 25%. They are: Turks and Caicos Islands, Netherlands, Kiribati, Bahamas, Maldives, Marshall Islands, Bahrain, Tuvalu, British Virgin Islands. We can roughly estimate the highest elevation of these countries by using our formula. The specific results are as the following table:

U		
Country	p(%)	H(m)
Turks and Caicos Islands	55.9	8.94
Netherlands	55.6	8.99
Kiribati	54.6	9.16
Bahamas	52.9	9.45
Maldives	45.5	10.99
Marshall Islands	43.8	11.42
Bahrain	34.0	14.71
Tuvalu	32.7	15.29
British Virgin Islands	28.0	17.86

TABLE I. Highest altitude of nine countries

According to the Table I, the highest altitudes of these countries are generally very low. However, because islands have high altitude in the center and low in the boarders, most people live in flat ground near the sea. Therefore, when the water submerge certain percent of the islands total area, the island may become uninhabitable, we set this percent as N.

The model of seawater flooded land can be simulated as follows:



Figure 8 The spherical cap submerged model We set the ratio of inundation area to P , according to Equation 3, we can get $P=(S_2-S_1)/S_2=1-h/H$, $P=(S_2-S_1)/S_2=1-h/H$

when P=N, we can get

h = (1 - N)H

If we assume N = 0.2, then h = 0.8H. After calculation, we found most island have H around 10, so if H = 10, h = 8, then H h = 2, which means that when the altitude submerged rises by 2m, the island can no longer be inhabited.

According to our prediction, the altitude of the sea level may increase by 60mm by 2120. It seems that these islands are still safe, but according to relevant data, the average altitude of the Maldives is only 1.2m, and the average altitude of most other island countries is also far below their highest altitude. Also, in the tropical Pacific and Indian Ocean regions, interannual changes in sea level are related to factors such as extreme weathers and the ebb and flow of seawater. That is, for these islands, a sharp rise in sea level will be fatal.

Therefore, according to our model, if the sea level is still rising, most tropical Pacific and Indian Ocean island countries will disappear after a few years, and the residents of these island countries will all become EDPs. In addition, people who live in peninsular seaside countries are also facing the risk of becoming EDP due to the sharp decline in land.

Because the data we have collected is limited, in order to simplify the model, we believe that the current EDPs include people living below 5m altitude in all island nations and in peninsular seaside countries. The number of current EDPs is about 67 million. With the sea level constantly rising, we

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believe that after 30 years, the number of potential EDPs will include the entire population of all island countries and the population living below 5m in peninsular seaside countries. In addition, considering the natural population growth rate, the number of potential EDPs will reach 130 million. Sadly, we only consider the country where we can collect data, yet many island countries and coastal areas lack population data. They will also facing the problem of losing their homes and having to immigrate, therefore, the number of potential EDPs in the future may greatly exceed our estimate.

The great number of current EDPs and potential EDPs lead us to a tougher question-the resettlement of EDPs. With such a large number of EDPs, if we do not have an appropriate policy to help these EDPs resettle, these countries and regions suffer immeasurable losses, including demographic and economic losses, as well as mental and cultural losses. More seriously, this problem also pose a major threat to the steady development and the harmony of the entire world. In the aspect of culture, with island residents becoming refugees, the potential lost of religious rituals, folk stories, traditional techniques, intangible arts and unique language all lead to the huge loss of cultural heritage.

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