Global Sea Level Forecast Based on Markov Model

Xue Qu, Yingying Wang, Heng Zhang

School of Information Science and Engineering, Qufu Normal University, Rizhao, Shandong, 276826

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Abstract: In recent years, due to global warming and rising sea levels, some island countries are in danger of being submerged and gradually disappearing. The inhabitants of these island countries will also become environmental displaced persons (EDP) as a result of their loss of territory. In response to this problem, we take the Maldives and Kiribati as examples to establish a series of models to discuss how to resettle these EDP in terms of the number of EDP and the protection for their human rights and cultural heritage. First, we build a Markov Model to predict the average global sea levels in each year in the future, and then calculate based on the current altitude of the island nation, calculate how many years the island nation will disappear completely, that is, how many years it can survive. Then, using statistics, we built the Population Prediction Model of Maldives and Kiribati to predict the population in the year when the island country will be completely submerged, and divide the predicted total population by the number of years that the island country will survive, we can calculate how many people should migrate each year to become EDP, that is, the number of people at risk.

1. Introduction

Global warming, the melting of polar ice caps and the expansion of the upper layers of the ocean have all contributed to the rise of sea levels [1]. Studies show that global sea levels have risen by 10-20cm since the 20th century [2]. So on, Island nations such as Maldives, Tuvalu, Kiribati are at risk of disappearing completely [3]. Therefor, people in these countries will also be displaced by environmental issues and need to be resettled. So, the placement of these people needs to consider many issues such as the number of people, distribution methods, protection of their human rights and protection of their culture [4]. As members of the international union for modeling, we should help the United Nations address this difficult, multidimensional problem by building models, analyzing phenomena, and providing recommendations and policies [5].

2. The model for predicting the number of EDP

2.1 Establishment

We take Maldives and Kiribati as examples for discussion. Based on the data of the global average sea level rise in recent years, we build Markov model to predict the sea level rise in the next few years [6]. We can calculate the sea level rise from the perspective of the submerged island countries each year [7]. Supposing that the elevation of these two island countries is always positive before they completely disappear at time i, and in the following n years, these two island countries still exist, but the land area that can provide residents for survival is gradually shrinking [8]. However, in n+1 year, the island countries are completely submerged and disappeared [9]. For the elevation of these two island countries in time i:

B_0=The elevation of the island in this year.

B_1=The elevation of the island in one year.

...

B_j=The elevation of the island in j years.

...

B_n=The elevation of the island in n years.

In general, we can get B_{jk} to represent the change in height from above sea level to below sea level in a unit of years from being in j at time i to being in k at time i+1. Using this notation, we can change the elevation of the island at time i to that at time i+1. It is important to note that there should also be a "time" state (the height of the island nation unit that has been submerged during the year) added to the described state (the height of the unsubmerged island nation and the height that will be submerged during the year), denoted by $\bar{0}$. For any classification state at time i, the elevation of island countries from 0 to n years ago may change to state $\bar{0}$ at time i+1. In this way, the height of the island at time i that is about to be submerged can be represented by an (n+2) dimensional matrix. Each term B_{jk} in the matrix represents the changing height of the state j at time i to the state k at time i+1, as shown below:

$$B = \begin{bmatrix} B_{\overline{00}} & \cdots & B_{\bar{0}k} & \cdots & B_{\bar{0}n} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ B_{j\bar{0}} & \cdots & B_{jk} & \cdots & B_{jn} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ B_{n\bar{0}} & \cdots & B_{nk} & \cdots & B_{nn} \end{bmatrix} \tag{1}$$

According to the matrix B of n+2 dimension which is about to be submerged, we can derive the transformation probability matrix P of n+2 dimension. Each term in the transformation probability matrix P represents the probability that the states existing at this height of an island state will change from one state to another at a given time, that is, the probability. According to the matrix B of the height and B_{jk} of the submerged island country, the transformation probability P_{jk} can be defined as:

$$P_{jk} = \frac{B_{jk}}{\sum_{\bar{0}}^{n} B_{jk'}} (k = \bar{0}, 0, 1, \ldots, n) \tag{2}$$

When applying the transformation matrix P, we should note that the height of $\bar{0}$ state cannot be changed to other states. The transformation probability of $\bar{0}$ state height is in order.

$$P_{\overline{00}} = 1, P_{\bar{0}0} = 0, P_{\bar{0}1} = 0, \ldots, P_{\bar{0}k} = 0, \ldots, P_{\bar{0}n} = 0 \tag{3}$$

Taking full advantage of Markov’s theory and existing research, we can predict the rise of sea level in the next unit of time based on the rise of sea level in the present time, and then predict how many years these island countries will be completely submerged in, that is, how many years they can survive.

Then, we collected the population of Maldives and Kiribati in the past 60 years, calculated and obtained the population prediction model through regression linear analysis. By dividing the predicted total population by the number of years of survival of the island, we could calculate the estimated number of people who would migrate each year to become EDP.

2.2 Solving

Through the rearrangement of the square matrix of (n+2) dimensional transformation probability in the Markov model established above, we put the height of the submerged states together, and the height of the other states together, so that the matrix P can be divided into:

$$\mathbf{P} = \begin{bmatrix} I & O \\ R & Q \end{bmatrix} \tag{4}$$

Where I is a 2-by-2 identity matrix, O is a 2-by-n 0 matrix, R is an n-by-2 matrix, and Q is an n-by-n matrix. We define the matrix:

$$N = (1 - Q)^{-1} = I + Q + Q^2 + Q^3 + \ldots + Q^n \tag{5}$$

For all the entries of an n by 2 order matrix, N and R give the probability of each state being transferred to 0.

Case 1: Nothing but climate affects sea level rise Assume that at time i, Bi = (B_{i0}, B_{i1}, B_{in-1}) with n partial vectors gives the height that will be submerged each year in each state. Let b be equal to the sum of all these heights, then vector π=((1/b) B) is a probability vector with no non-negative components and a sum of all 1. In addition, we assume that A is any matrix. Let A_{sq} denote the result of squaring each term in A, and let denote the result of squaring the root of each term of Art, then we have the following conclusions:

$$A = b * [\pi NR - \pi NR_{sq}] \tag{6}$$

If β represents the rate of sea level rise each year, we assume that B is the vector of the imminent submergence height, and R1 is the first column component of the matrix, then BR1 represents the submerged altitude in the current period. From the next phase, the altitude of BQR1 is only BQR1, and so on, the value of BQkR1 in the period (k + 1) is only kBQkR1. Add these values together and we can get the current value of the submerged height:

$$BR_1 + \ldots + \beta^k BQ^k R_1 + \ldots = B[I + \beta Q + \ldots + \beta^k Q^k + \ldots]R1 = BN_\beta R_1 \tag{7}$$

Among them

$$N_\beta = I + \beta Q + \ldots + \beta^n Q^n \tag{8}$$

Case 2: When something other than climate affects sea level, the effect remains the same. If the Markov process starts to change every year with the initial probability η, the sum of the height to be submerged within a certain period of time can be expressed as:

$$\eta + \eta Q^2 + \eta Q^3 + \ldots = \eta(I + Q = Q^2 + Q^3 + \ldots) = \eta N \tag{9}$$

When the climate makes different changes to the annual rise in sea level. The height to be submerged is expressed as:

$$\mathbf{A_i} = \left[\sum_{k=0}^{r-1} C_{i-k} Q^k\right] N_\alpha \tag{10}$$

The unsubmerged height is expressed as:

$$\alpha_{\mathbf{i}}\mathbf{i} = \left[\sum_{k=0}^{t-1} C_{i-k} Q^k\right] N_\alpha \xi \tag{11}$$

The height that has been submerged since the measurement year is expressed as:

$$\mathbf{D_i} = \left[\sum_{k=0}^{t-1} C_{i-k} Q^k\right] N_\alpha R \tag{12}$$

Taking all three scenarios into account, and plugging in data on sea-level rise over the past few years, we can predict that global sea levels will rise at a rate of about 3.2mm per year over the next few years.

(1) Risk prediction for the number of Maldives EDP.

In 2019, 80% of the islands in the Maldives are less than 1 meter above sea level. For the sake of calculation, we assume an average elevation of 1m. Maldives has a large population density. Suppose that when the sea level rises further by 0.2 meters, that is, when the average elevation of Maldives is 0.8 meters, the nationals shall start to migrate from the country, and only migrate within their own country in the previous period. The time t required for sea level rise of 0.2 meters is:

$$t = \frac{0.2 * 1000mm}{3.2mm/y} = 62.5(years) \tag{13}$$

By about 2082, people will need to start moving out. From 2082 to the complete inundation of the Maldives island, the time T1 is:

$$T_1 = \frac{0.8 * 1000mm}{3.2mm/y} = 250(years) \tag{14}$$

That is, by about 2332, the Maldives will be completely submerged, meaning that by 2332 all the people will have moved out. A total of 2332-2082=250 years from the beginning of migration to the completion of migration.

The population of Maldives from 1959 to 2018 is linearly fitted, as shown in FIG. (1) and FIG. (2). The population prediction model of Maldives can be obtained:

$Y_1 = 6464.902x - 12623247.6$

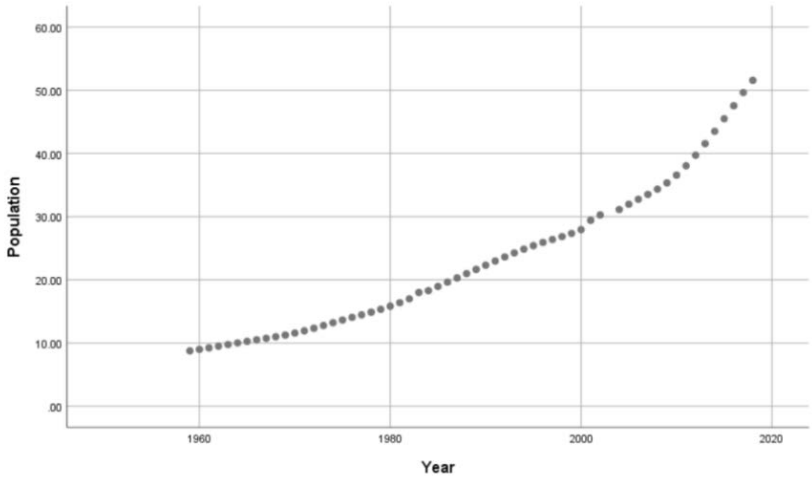

Figure 1. Population of Maldives

Table 1. Coefficient of the Maldives population function

	Unstandardized coefficient		Normalization coefficient		
	B	**Standard Error**	**Beta**	**t**	**Significance**
Constant	-12623247.6	422166.335		-29.901	0
Year	6464.902	212.296	0.97	30.452	0

a. Dependent variable: Population

It can be found that when the Maldives did not sink, the total population in 2332 was:

$$P_1 = \frac{2452904}{188} \approx 13{,}047 \tag{15}$$

(2) Risk prediction for the number of Kiribati EDPs

The average elevation of Kiribati in 2019 is 2 meters. Its population density is low. We assume that when the sea level rises by a further 1.4 meters, i.e., when Kiribati is 0.6 meters above sea level, the population begins to migrate outward from the country, and only within its own country for the period prior to that. The time t required for sea level rise of 1.4 meters is:

$$t = \frac{1.4m}{3.2mm/y} = 437.5(yers) \tag{16}$$

That is, by about 2644, the Kiribati will be completely submerged, meaning that by 2457 all the people will have moved out. A total of 2644-2457=187 years from the beginning of migration to the completion of migration.

The population of Kiribati from 1959 to 2018 is linearly fitted, as shown in FIG. (3) and FIG. (4). The population prediction model of Kiribati can be obtained:

$$Y_2 = 1258.758x - 2430260.416 \tag{17}$$

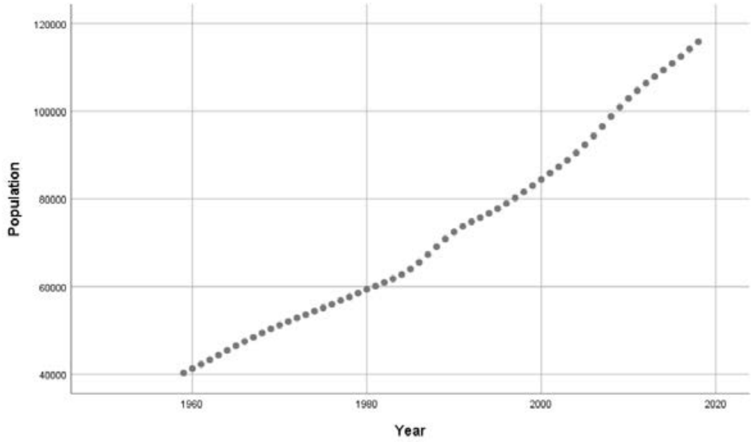

Figure 2. Population of Kiribati

Table 2. Coefficient of the Kiribati population function

	Unstandardized coefficient		Normalization coefficient		
	B	**Standard Error**	**Beta**	**t**	**Significance**
Constant	-2430260.416	47676.514		-50.974	0
Year	1258.758	23.975	0.99	52.502	0

a. Dependent variable: Population

It can be found that when the Kiribati did not sink, the total population in 2644 was:

$$Y_2 = 1258.7582644 - 2430260.416897,896 \tag{18}$$

Furthermore, we can predict that the average number of EDPs produced each year is:

$$P_2 = \frac{897896}{187} \approx 4801 \tag{19}$$

3. The model for predicting the risk of losing culture

3.1 Establishment

There are many factors that cause the loss of culture in island nations such as Maldives and Kiribati, and some of them have a less obvious impact. Therefore, in order to facilitate discussion and calculation, we mainly consider the risk of cultural loss from the four major aspects of the island's own cultural heritage, the destination of the EDP migration, the density of the EDP population settled in the migrating country, and whether the EDP individual is willing to move to a country, building a Delphi model.

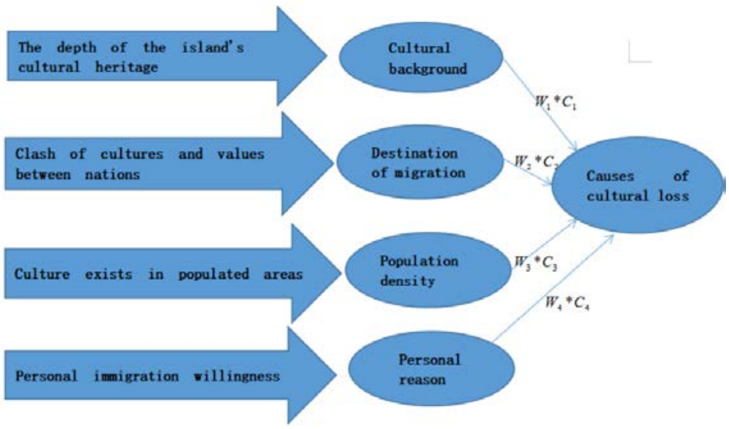

Figure 3. Risk of cultural loss

The first step is to determine the weight W of each risk factor. Considering the current development trend and situation of these island countries, we assume that the weight of these four factors is 0.3, 0.4, 0.1 and 0.2 respectively. Secondly, the weight should be determined, that is, the level of risk C. Let's divide it into four levels according to the probability, let's say 0.25, 0.5, 0.75, and 1. Then multiply the weight W of each risk factor and the grade value C to find the score of the risk factor. Finally, we add the risk scores to find the total, $\sum W*C$, of the risk factor, namely the degree of risk. The higher the score, the greater the risk. From this, we can identify the main factors that cause the risk of cultural loss.

3.2 Solving

Through the establishment of the Delphi model, the following table on the degree of risk of cultural loss can be obtained Table.

From the risk table of cultural loss, we can see the risk of cultural loss caused by these four factors, and the degree of influence is: Destination of migration > Cultural background > Personal reason > Population density. So there are four kinds of cultural loss:

(1) The EDPs are not properly housed, and their culture disappears.

(2) In the process of EDPs placement, the culture is not properly handled, and there are religious beliefs, language and other conflicts, resulting in losses of both "absorbing country" and "migrating country".

(3) In the process of EDPs' placement, the culture is properly settled and willing to obey the domestication. The original culture is gradually integrated and a new culture is formed.

(4) In the process of settling, the EDPs properly settle the culture, but they are not willing to obey the naturalization. The original culture is retained in the "absorbing country" and becomes a characteristic population with the nature of "sojourn.

Table 3. The cultural loss on the degree of risk through Delphi model establishment

Cultural risk factors	The weight W	The level of risk C				W×C
		Lower 0.25	Middle 0.5	Higher 0.75	High 1	
Cultural Background	0.3	0.075	0.15	0.225	0.3	0.75
Destination of Migration	0.4	0.1	0.2	0.3	0.4	1
Population Density	0.1	0.025	0.05	0.075	0.1	0.25
Personal Reason	0.2	0.05	0.1	0.15	0.2	0.5

The risk of cultural loss caused by these four factors can be seen from the risk table of cultural loss, and the degree of influence is: migration destination > own culture > personal factors > population density. Therefore, the following four kinds of cultural losses will occur:

(1) EDPs has not been properly settled and its culture has disappeared.

(2) In the resettlement process of EDPs, the culture was not properly handled and conflicts such as religious beliefs and languages occurred, causing losses to both the "absorbing country" and the "migrating country".

(3) In the process of resettlement, EDPs received proper cultural resettlement and was willing to submit to naturalization. The original culture gradually merged to form a new culture.

(4) EDPs was properly resettled in the process of resettlement, but was unwilling to submit to naturalization. The original culture remained in the "absorbing country" and became a characteristic population of a "sojourn" nature.

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