Impact and Suggestions of Sea Level Rise on the Survival of Tuvalu: Evidence from Mathematical and Computer Modeling

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Abstract. Existing research indicates that many countries are in danger of disappearing completely due to sea level rise. Therefore, many environmentally displaced persons (EDPs) will be generated. The number of these EDPs and the ways of resettling with humanitarianism are promising issues. Tuvalu is the fourth smallest country in the world, and its country has stated that it has plans to relocate the country, so it has attracted our attention. Firstly, assuming that the population of the area is not affected by sea level, establish block population growth model, predict the future normal population. At the same time, build the prediction model of BP neural network based on EMD to predict the future sea level, and the connection between the two models is time. When the sea level reaches a certain threshold, the area's environment is no longer stable, and in this time the year when the threshold was reached and the corresponding population were determined. We use the analytic hierarchy process to evaluate the influences of various social policies on cultural loss risk, which can effectively adjust the policy and protect the diversity of culture. Accepting refugees to the society, economy and culture of a country is a great challenge. Later, we set up the secondary fuzzy comprehensive evaluation model, and a lot of impact factors are classified as economic, social, ecological and other categories. Standardize and normalize the data. Using the entropy weight method to determine the weight of each index. Give a score for every country, and countries or regions of high scores have the ability to accept the refugees. Last, we use the analytic hierarchy process to evaluate the influences of various social policies on cultural loss risk, which can effectively adjust the policy and protect the diversity of culture.
1. Introduction

1.1. Background
With the development of human society and the deterioration of the environment, the global temperature is warming and the sea level is rising. For some low-altitude areas, living in the origin place will be sooner or later overwhelmed as time passes. However, if you choose to leave the place of residence, it means a flight, and it takes a lot of effort to find a new place to live. For some countries, it is not easy to accept foreign residents, which is a huge impact on the society, economy and culture of the host country. At the same time, people who come to a new place will face new culture, new environment and new languages. People need to pay attention to whether the original culture will be lost in communication and how to protect the integrity of cultural heritage.

1.2. Restatement of the problem
In order to solve the topic problem completely, we divided it into the following sub-problems:
- The number of people at risk and the risk of cultural loss;
- Propose policies for EDP human rights (the ability to resettle and participate fully in life in new homes) and cultural protection;
- Establish models to measure the potential impact of these proposed policies;
- Modify and improve the models.

1.3. Assumptions
To simplify conditions, we made the following assumptions:
- The vertical movement of the land is not considered.
- Data from the measuring station at Funafuti, capital of Tuvalu, are used as the standard.
- The nature of migration is national migration.
- Factors affecting migration are not considered except the sea level.
- The rate of population growth has no relationship with the changes in sea level.

1.4. Notations
To simplify expressions, we made the following notations:
\[ x(t) \]: Monthly mean sea level time series
\[ c(t) \]: IMF with monthly mean sea level time series smoothed by EMD
\[ c(t)_{\text{norm}} \]: Standardized IMF
\[ c_i(t) \]: Future IMF predicted by Network
\[ r(t) \]: Residue amount in EMD conversion
\[ r(t)_{\text{f}} \]: Future residue amount predicted by Network
\[ J \]: Objective function loss cost
\[ f \]: Network sigmoid activation function
\[ W \]: Network weight coefficient
\[ \bar{Y} \]: Future monthly mean sea level time series predicted by Network

2. Before the migration
Firstly, for the population of island countries, national submersion caused by sea level rise is an important factor to become EDP, which is also the main standard to define the population of EDP in island countries. Sea level and population are two important factors in determining how many people
are EDPs in a given place. Based on the theory of Sandbox, assuming that the area is not affected by sea level, predict the normal population number in the future (Module of Preventing Increasement). Meanwhile, predict the sea level height in the future (The Prediction Model of BP Neural Network Based on EMD), so as to determine the year when the threshold is reached and the corresponding population number. The chief forecaster of the Tuvalu Meteorological Office has stated that a local sea level rise of about 9 cm will lead to a 2% reduction in land area. Therefore, when 60% of Tuvalu's land is below the sea, the entire Tuvalu will not be able to withstand the impact of the tide, it can be obtained that the 38 cm rise in sea level can be used as the threshold for uninhabitable.

2.1. The Prediction Model of BP Neural Network Based on EMD

2.1.1. Data processing. The data used to test the model in this paper is the RLR processed monthly mean sea level time series of the Tuvalu capital Funafuti obtained from PSMSL [1], starting from January 1993 and ending in December 2018, with a sampling interval of a month (an average of one month). If the number of maxima (or minima) of a time series $x(t)$ is more than two or more than the number of zero crossing points, the time series is nonstationary, then it needs to be stabilized. Obviously, the monthly mean sea level series is a non-stationary data, so we can't use ARIMA or SARIMA, so we need to use EMD to stabilize the non-stationary time series. The steps are as follows: find out the monthly mean sea level time series: all the maximum points in $x(t)$ and use the cubic spline function to synthesize the upper envelope of the original data; find out all the minimum points of $x(t)$ to synthesize the lower envelope; the mean value of the upper and lower envelope is the average envelope of the original series $m_1(t)$; put the original series by subtracting the average envelope from $x(t)$, we get a new sequence without low frequency $h_1(t)$:

$$h_1(t) = x(t) - m_1(t)$$ (1)

Generally, $h_1(t)$ is still not stable, and the above process needs to be repeated K times until the average envelope tends to 0, so the first IMF component $c_1(t)$ is obtained:

$$c_1(t) = h_k(t) - m_k(t)$$ (2)

The first IMF represents the highest frequency component of the original sequence. Subtracting the first IMF component $c_1(t)$ from the original sequence $x(t)$, you can get the first difference sequence $r_1(t)$ with high frequency components removed. Performing the above-mentioned stationary process on $r_1(t)$ can obtain the second IMF component until it cannot be decomposed. Then $r_n(t)$ is a residual amount after the decomposition is completed, which represents the average trend of the original sequence:

$$r_2(t) = r_1(t) - c_2(t)$$ (3)

$$r_n(t) = r_{n-1}(t) - c_n(t)$$ (4)

Finally, the monthly mean sea level height data series: $x(t)$ was smoothed by EMD to obtain $c_1(t), c_2(t)\ldots c_7(t)$ (IMF) and a residual quantity, that is, there are 312*8 data sample sets.
2.1.2. Establishment of model. The monthly mean sea level height data is trained by BP neural network: \( x(t) \) 7 IMFs and residuals after EMD processing, and the corresponding 7 IMFs and residuals in the next 50 years [2]. The establishment of the BP neural network model is based on the following most basic mathematical formulas. Equation of state of the network along the direction of network propagation, \( \text{in}^{(i)} j \) and \( \text{Out}^{(i)} j \) represent the input and output [3]. The input-output relationship of each layer in the network layer can be described as follows.

The first layer (input layer): the input is introduced into the neural network.

\[
\text{out}^{(i)}_i = \text{in}^{(i)}_i = x \quad i = 1, 2, \ldots, n
\]  

(5)

Second layer (hidden layer):

\[
\begin{cases}
\text{In}^{(2)}_i = \sum_{j=1}^{n} w_{ij}^{(3)} \text{Out}^{(1)}_i \\
\text{out}^{(2)}_j = f\left(\text{In}^{(2)}_j\right)
\end{cases}

j = 1, 2, L, l
\]

(6)

\( f(x) \) is Activation function, \( \text{sigmod()} \) was used:

\[
f(x) = \frac{1}{1 + e^{-x}}
\]  

(7)

The third layer (output layer):

\[
y_k = \text{Out}^{(3)}_i = \text{In}^{(3)}_i = \sum_{j=1}^{l} w_{ij}^{(2)} \text{out}^{(2)}_j \quad k = 1, 2, 3, L, m
\]

(8)

Based on the conditions of this model: \( i = 6, \quad j = 14, \quad k = 6 \), The above completed the three-layer network of the neural network. Next, initialize the network parameters: Random initialization of \( w_{ij} \) in grid with normal distribution, learning rate is 0.001 and Iteration times are 500. In this network, BP algorithm is used to adjust the weight.

The objective function of definition ology (mean square deviation method) is:

\[
J = \frac{1}{2} \sum_{i=1}^{m} (d_i - y_i)^2 = \frac{1}{2} \sum_{i=1}^{m} e_i^2
\]

(9)

At the same time, BP algorithm adjusts the connection weight \( W_{ij} \) in reverse and threshold \( \theta j \) corrects n+1 times iteration quantity:

\[
\Delta W_{ij}^{(n+1)} = \eta \delta_j x_j + \alpha \Delta W_{ij}^p
\]

(10)

\[
\Delta \theta_j^{(n+1)} = \eta \delta_j + \alpha \delta_j^p
\]

(11)
2.2. Module of Preventing Increment

Let \( x(t) \) be the population in year \( t \), and let the population growth rate \( r(x) \) be a linear function of \( x \), and others do not described in this article. Establish the most conventional Logistics population model:

\[
\begin{align*}
\frac{dx}{dt} &= r \left( 1 - \frac{x}{x_m} \right) x \\
x(t_0) &= x_0
\end{align*}
\]

(12)

\[
x(t) = \frac{x_m}{1 + \left( \frac{x_m}{x_0} - 1 \right) e^{-r(t-t_0)}}
\]

(13)

**Figure 1.** Change of Mean Sea Level Height in 1993-2047, Taking 10 Years as A Unit.

**Figure 2.** Population Growth in 1993-2047, Taking 10 Years as A Unit.
According to the model, as shown in Fig. 1, 2038-2047 is the time period when the threshold of uninhabitability is reached. Therefore, as shown in Fig. 2, about 14500-15500 people in Tuvalu are at risk of becoming EDPs.

3. During the migration process
For a country, accepting EDPs is not an easy job, which need to consider many problems. For example, the population density of the recipient country, GDP per capita, CO2 emissions and so on [4]. To classify and evaluate the factors, we will establish a second-level fuzzy comprehensive evaluation model, classify different indexes, select appropriate membership functions, and determine the weight of each index by entropy weight method. As shown in Fig. 3, the countries with the highest rankings for suitable living are marked on the map. The darker the color, the higher the score, the more suitable for survival. In summary, after EDM leaves the original place of residence, EDPs can choose a new place of residence based on the comprehensive evaluation scores of suitable living in various countries.

![World Map for Comprehensive Evaluation Score of Tuvalu Migration.](image)

4. After the migration
When people living in new places, they will face new cultures, new environment and new languages. But in the strange environment, as a result of various reasons, the original culture cannot be protected and inherited well. There is a great risk of cultural loss. Culture is different from civilization. Culture is difficult to define. It is the product of people's long-term creation and the sediment of social history. Culture can be either material or immaterial. Therefore, we think culture is more like an ideology. That is, as long as it is created by people, what is generated through human behavior is culture. The value of culture is reflected in all aspects. We hope to analyze the risk of cultural loss. According to the references, we think economics, geographic position, cultural diversity and politics play important roles in the cultural loss. AHP can be used to determine the weight of each category, and each policy affects culture by affecting one or several categories. But this method is more subjective and this method helps to translate our subjective preferences into measurable weights to assess the importance of different factors [5].
Geographically, as outsiders, the risk of cultural loss is greatly reduced if they live in a compact community. Take Chinatown as an example. However, if people live in too scattered places, it is difficult for the same culture to flourish, and it is easy to disappear when they interact with other cultures. Therefore, the government should divide into special areas to accept foreigners, protect foreign cultures and reduce the conflict of cultural concepts.

In terms of politics, how to guarantee the rights and interests of foreign workers and how foreign workers can have equal voice and social status are all issues to be considered in the implementation of policies. In the international community, the legal rights and interests of climate migrants are often not guaranteed. Climate change forces the generation of climate migrants. In the existing framework of international law, there is no complete law to protect the rights and interests of climate migrants. Building aid centers close to the gathering places would also go a long way towards protecting the legitimate rights of outsiders.

Improving the capacity and knowledge of migrants to promote adaptation and mitigate risk to migrants in areas of origin can also reduce their vulnerability and promote adaptation by creating new livelihood opportunities and diversifying sources of income. Knowledge and understanding will enable them to mitigate where they have moved and the danger of their remaining there.

References
[1] Holgate SJ et al. (2013) New Data Systems and Products at the Permanent Service for Mean Sea Level Journal of Coastal Research:493-504 doi:10.2112/jcoastres-d-12-00175.1
[2] Huang, J., Luo, H., Wang, H. & Long, B. Prediction of Time Sequence Based on GA-BP Neural Net. Journal of University of Electronic Science and Technology of China 38, 687-692 (2009).
[3] Wang, B., Fei, S. & Yi, M. Prediction of China stock market based on EMD and neural network. Systems Engineering-Theory & Practice 30, 1027-1033 (2010).
[4] Li, H. Evaluation of training effect of grass-roots civil servants based on AHP and fuzzy evaluation. Statistics & Decision, 59-62 (2015).
[5] Shi, Y. & Liu, H. The Dilemma and Countermeasures of the International Law Protection of Climate Migration. Nankai Journal (Philosophy, Literature and Social Science Edition), 68-77 (2016).