

The Culture of Enzymes: A Mathematical Model of Biological Enzyme Clustering as a Homology to Refugee Migration and Cultural Preservation in Environmentally Displaced Persons

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Environmentally Displaced Persons (EDPs) need to relocate, but there is also the risk of losing a unique culture, language, and way of life. This study uses mathematical models associated with the efficiency of biological enzyme clustering in order to assess the degree to which EDPs are at risk of loss of culture and determine the potential impact of proposed policies.

There were critical objectives of this study, firstly, to predict the number of people at risk of losing their homeland at a particular time in the future. Second, based on the aforementioned projections, find ethical and beneficial policies to move these Environmentally Displaced Persons (EDPs) in a way such that EDPs can honorably preserve their unique cultural heritage. We took into account that these small island nations have small populations and individual cultural differences exist within each different island.

A **Sea Level Rise-Based Climate Impact Migration Model** was proposed to find the number of people affected by the land lost from the Sea Level Rise (SLR). In the direction of accurate projections, our team designed two simulations that were executed on the SLR Model. Fundamentally, an **Exponential Regression Model** was used to calculate the future total population of Maldives (one of the at-risk-nations in danger of flooding) presuming the population followed the exponential growth. Next, we used a **Levenberg-Marquardt Algorithm** to find the non-linear model for the flooded area of the land and **Water Drop Waveform Model** to also calculate the flooded area on the island. We predict about **13% of people lose their homes by 2050, 72% by 2080, and 93% by 2100.**

Next, a **Two-Step Metabolic Pathway Model** was adopted to explain social heritage preservation within a confined area based on the idea that two-step metabolism and cultural transition work in a complementary fashion. It is known that communication between EDPs and individuals of the host country must go through an intermediate to communicate, this analogous phenomenon is seen in the one-way communication between an enzyme and its substrate to catalyze the formation of a product. In our mathematical model, the product is the cultural preservation and the enzyme-substrate complex is mathematically seen by the interaction between the EDPs and individuals of the host country. Just as humans are key to cultural preservation, enzymes-substrate complexes are essential for product formation and we contend that this notion should occur in optimized ratios. We predict there should be **twice as many** people absorbing the culture than the ones who transfer it. The area of the EDP cluster should be **2.96km².**

Finally, the sensitivity of our proposed mathematical models were evaluated and suggestions for future implementation of political decisions and improvements were promoted.

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1. Introduction

1.1 Overview

Recently, researchers have discovered several island nations at risk for completely disappearing due to rising sea levels.

1. The Maldives
2. Tuvalu
3. Kiribati
4. The Marshall Islands

Environmentally Displaced Persons (EDPs) need to relocate, but there is also the risk of losing a unique culture, language, and way of life. This study uses mathematical models associated with the efficiency of biological enzyme clustering in order to assess the degree to which EDPs are at risk of loss of culture and determine the potential impact of proposed policies.

With a particular focus on the preservation of cultural heritage and policy implementation, we establish predictive mathematical models to drive the formation of policies that attempt to preserve the cultures of at-risk nations. Using biological enzyme clustering as a homology of EDP relocation, the developed models provide an analysis to support a systemized response for EDPs. This analysis is considered in terms of both the number of people at risk and the risk of loss of cultural heritage.

We propose policies in order to address EDPs in terms of both human rights (being able to resettle and participate fully in life in their new home) and cultural preservation. The proposed

policy suggests that EDP migration should occur in clusters (e.g. certain optimal ratios) analogous to biological enzyme clustering, to promote cultural heritage preservation.

A description of the model used to measure the potential impact of proposed policies, and an explanation of how the model was used to design and/or improve our proposed policies is discussed in this paper. Furthermore, an explanation backed by analysis, of the importance of implementing such policy is also discussed.

1.2 Restatement of the Problem

1. Achieve the following objectives.
2. About when and how many people need to be migrating to other countries? (Time & Number Prediction)
3. How can we calculate the lost land to project the number of people in danger?
4. How could we minimize cultural loss and maximize cultural preservation?

1.3 Other Assumptions

In order to accurately quantify our model, the following assumptions were moderated:

1. All of the inputs for the sea level rise model are defined per zone, i , and time.
2. Cultural Transition follows the mechanism of two-path channeling of metabolism.
3. Many island nations share a similar shape geometry because of their unique geological traits.

4. We assume the relative sea rise level is 3 times faster than the average sea level rise of the world.

Providing protection to people fleeing in search of refuge is one of humanity's long-standing traditions -- a shared value embedded in many religious and cultural traditions, and now part of international law. It is a value that has stood the test of time and was most recently articulated by all 193 United Nations (UN) member states in the New York Declaration on Refugees and Migrants, adopted in September 2016.

2. Preparation of Approach

2.1 Outline of Approach

The beginning of this paper will discuss the theoretical framework and an outline of the predictive mathematical model to approximate the extent to which cultural preservation can exist in a biological enzyme clustering model as homology to the proposed EDPs clustering policy.

3. Statement of Models

3.1 SLR-Based Environmental Impacts Model

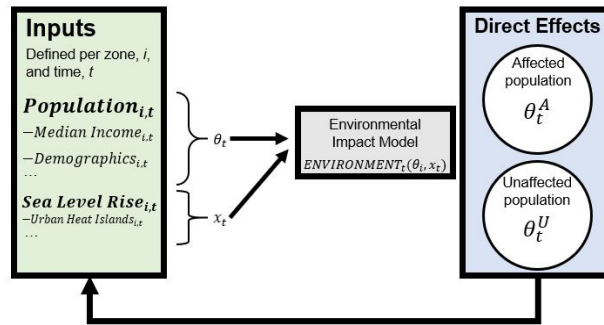


Figure I. Joint environmental impact and human migration modeling process.

We modified the methodology approached in Hauer et al., 2016. The number of people at risk can be assessed by modeling the future population projection and area of land affected by the sea level rise.

Assessing At-Risk Population Equation

We can assess the at-risk population of sea-level by the following equation,

$$PR_t = \sum_{PR_{ij}^{t-1}} + ((P_t - \sum_{PR_{ij}^{t-1}}) * (1 - A_t/A_{total}))$$

Where the population of people at-risk (PR_t) equals to the sum of previously impacted populations with a population of people expected at time t minus the sum of people at-risk on-time t-1 multiplied by the land lost (A_t) divided by the total land area of the island. The previously impacted people are subtracted to make sure there is no double counting.

3.1.1 Exponential Regression Model

Our second question was “*how do we calculate the projected population in the Island Nation?*” Our idea was, based on the data provided by the UN on the population of Maldives, we could analyze the data using an exponential regression model and project the future population. This model will assume the population rate follows that of an exponential curve fitting with a singular term.

General Model for Exponential Population Projection:

$$f(x)_{Population\ Projection} = ae^{bx}$$

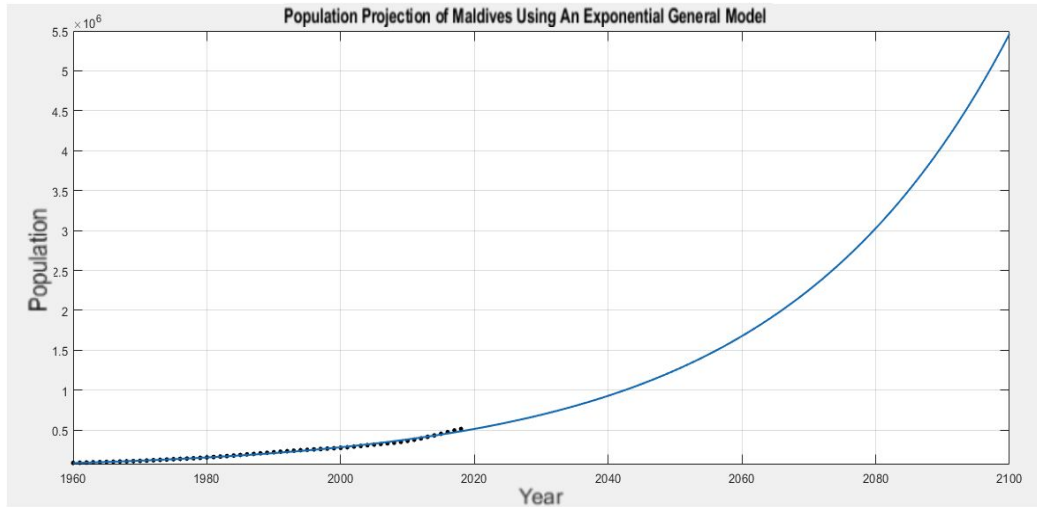


Figure II. MATLAB plot of population projection using an exponential curve fitting model

In the exponential population projection model, x is normalized by the mean and standard deviation calculated by:

$$\text{Mean : } \bar{x} = \frac{1}{N} \sum_{i=1960}^{N=2020} x_i$$

$$\text{Standard Deviation : } \sigma = \sqrt{\frac{\sum_{i=1960}^{N=2020} (x_i - \bar{x})^2}{N-1}}$$

$$\text{Covariance : } s_{XY} = \frac{\sum_{i=1}^n (x_i - \bar{X})(y_i - \bar{Y})}{n-1}$$

A particular emphasis was put on calculating covariance because it enables the estimation of the statistical relationship between the two sets of population data X and Y generated from the exponential population projection {1960, 2020} and {2020, 2080}.

The sampling means most likely follows a normal distribution. In this case, the standard error of the mean (SEM) can be calculated by:

$$\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{N}}$$

From these equations, $\bar{x} = 1296551$, $\sigma = 1387337$, and $\sigma_{\bar{x}} = 116835$ as seen by the equations above. Based on the Standard Error of the Mean (SEM), the following margins of error (confidence intervals) at varying confidence intervals indicate that a confidence level of 95% (statistical significance of 5%) is adequate for data representation.









Confidence Level	Margin of Error	Error Bar
68.3%, $\sigma_{\bar{x}}$	1,296,550.8449 \pm 116,834.852 (\pm 9.01%)	
90%, 1.645 $\sigma_{\bar{x}}$	1,296,550.8449 \pm 192,193.331 (\pm 14.82%)	
95%, 1.960 $\sigma_{\bar{x}}$	1,296,550.8449 \pm 228,996.31 (\pm 17.66%)	
99%, 2.576 $\sigma_{\bar{x}}$	1,296,550.8449 \pm 300,966.578 (\pm 23.21%)	
99.9%, 3.291 $\sigma_{\bar{x}}$	1,296,550.8449 \pm 384,503.497 (\pm 29.66%)	
99.99%, 3.891 $\sigma_{\bar{x}}$	1,296,550.8449 \pm 454,604.409 (\pm 35.06%)	
99.999%, 4.417 $\sigma_{\bar{x}}$	1,296,550.8449 \pm 516,059.541 (\pm 39.80%)	
99.9999%, 4.892 $\sigma_{\bar{x}}$	1,296,550.8449 \pm 571,556.095 (\pm 44.08%)	

Figure III. Confidence intervals with varying confidence levels to indicate proper data representation

Coefficients (with 95% confidence bounds: $\alpha = 0.05$):

$$a = 6.867 * 10^{-21} \{-3.189 * 10^{-21}, 1.692 * 10^{-20}\}$$

$$b = 0.0295 \{0.02876, 0.03023\}$$

$$\text{in the form : } f(x) = a * e^{(b*x)}; \{x \in \mathbb{R}\}$$

Goodness of Fit

$$SSE : 5.263 * 10^9$$

$$R^2 : 0.9932$$

$$\text{Adjusted } R^2 : 0.9931$$

$$RMSE : 9609$$

$$\text{Degrees of Freedom for Error (DFE) : } 57$$

Based on the above data, it is safe to assume the general exponential population projection. Past population data of the Maldives was extracted from the UN, and input into the generated exponential curve fitting model to predict future population values. This study utilized the exponential regression function in MATLAB to project the future population.

Table I. Projected population from 2030 to 2100

Year	Projected Population
2030	674768
2040	906271
2050	1217199
2060	1634802
2070	2195678
2080	2948983
2090	3960735
2100	5319605

Projected Population Extracted From Exponential Regression Model in MATLAB

3.1.2. Function-Based Surface Integral Model

Lost Land Projection Model

We imagined the restricted area to simulate the amount of land expected to flood from the exceptionally high sea-level rise in the island nations.

We first focused on representing the island in a function. The contour plot was used to answer the question:

How does Z change (over time) as a function of X and Y ?

Z : the land that people can live in

Contour lines emphasize the altitude in which the three-dimensional surfaces are plotted with constant z slices on a two-dimensional format. The contour plot shown in Figure X highlights the surface symmetry and peaks seen by the theoretical island model. [1]

The contour plot exists in the form:

1. *Vertical Axis : Independent variable Y*
2. *Horizontal Axis : Independent variable X*
3. *Lines : Iso – Response values*

The technique for determining the correct iso-response values was generated by an in-house MATLAB program (MathWorks, Natick, MA, USA). It is important to note that

two-dimensional interpolation was used to form a regular grid. A Design of Experiment (DOE) contour plot was used because of its particular success in maximizing (or minimizing) a response variable. The DOE contour plot will enable one to determine settings that result in a response variable hitting a predetermined target value and therefore the next iteration of the study. Ergo, the definition of settings for a full factorial or response surface design based on a smaller fraction can be accomplished.

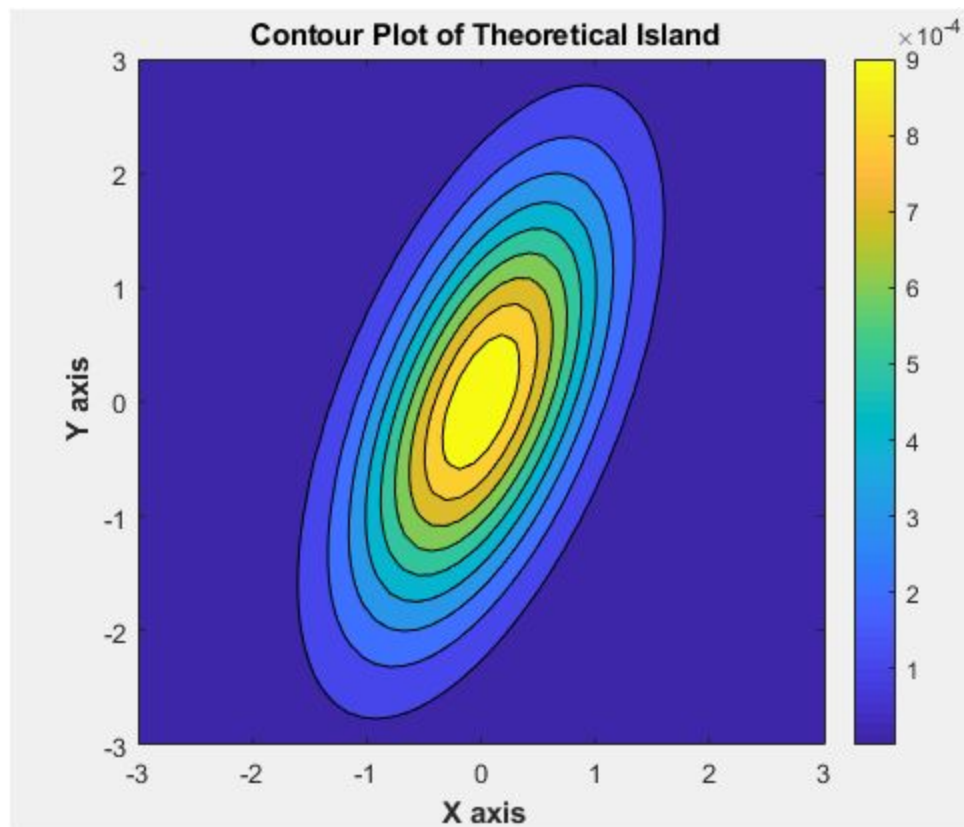


Figure IV. MATLAB Contour Plot Simulation Results.

The linear DOE contour plot assumes the model: [2]

$$Y = \mu + (\beta_1 * U_1) + (\beta_2 * U_2) + (\beta_{12} * U_1 * U_2)$$

Although the above algorithm assumes a linear model for the design, a related concept to consider is that the average for the center points do not fall in the range defined by vertex points (i.e. there is a curvature in the theoretical model) so therefore we must assume a quadratic formula. Consequently, the construction of a linear DOE contour plot will not suffice and a quadratic model was generated computationally using a MATLAB script. Additionally, a three-dimensional surface was constructed using these averaged values in order to visually determine if the regression was appropriate. The generalized model of the theoretical island is seen by:

$$f(x,y) = ae^{(bx^2+c(x-y)^2)}$$

over the varying regions of D defined by projected land loss in certain years (e.g. 2050, 2080, and 2100).

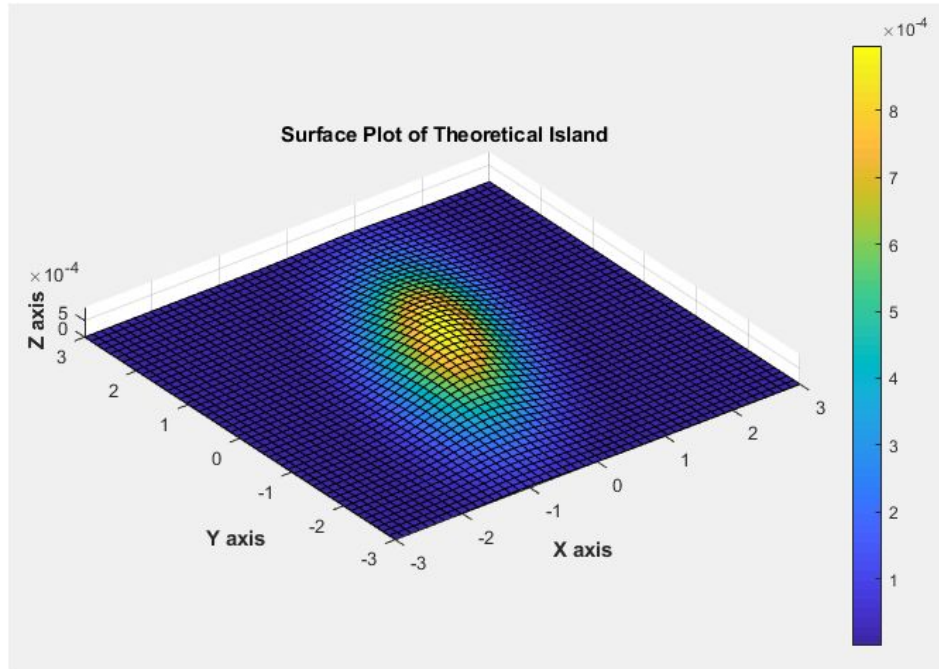


Figure V. MATLAB Surface Plot Simulation Results. Theoretical Island with a generalized $f(x,y)$



Figure VI. Bird's eye view of the Maldives island

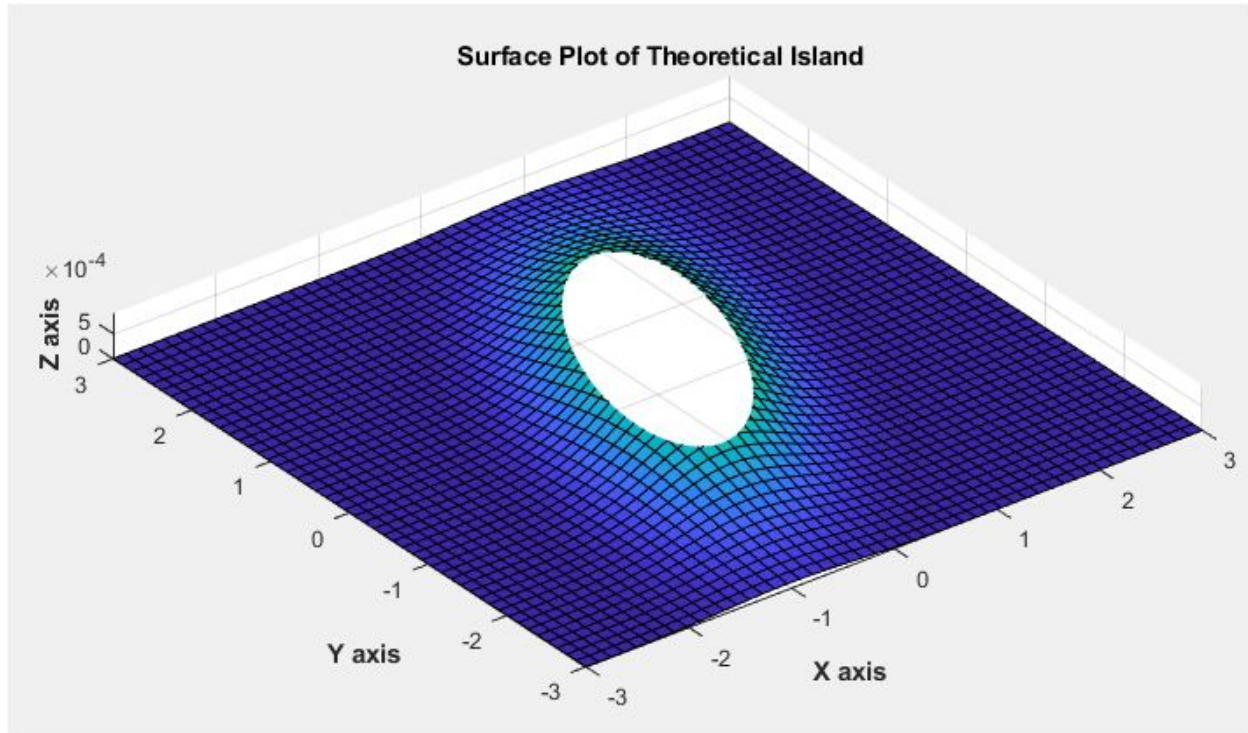


Figure VII. MATLAB Surface Plot Simulation Results. Projected land loss in 2050

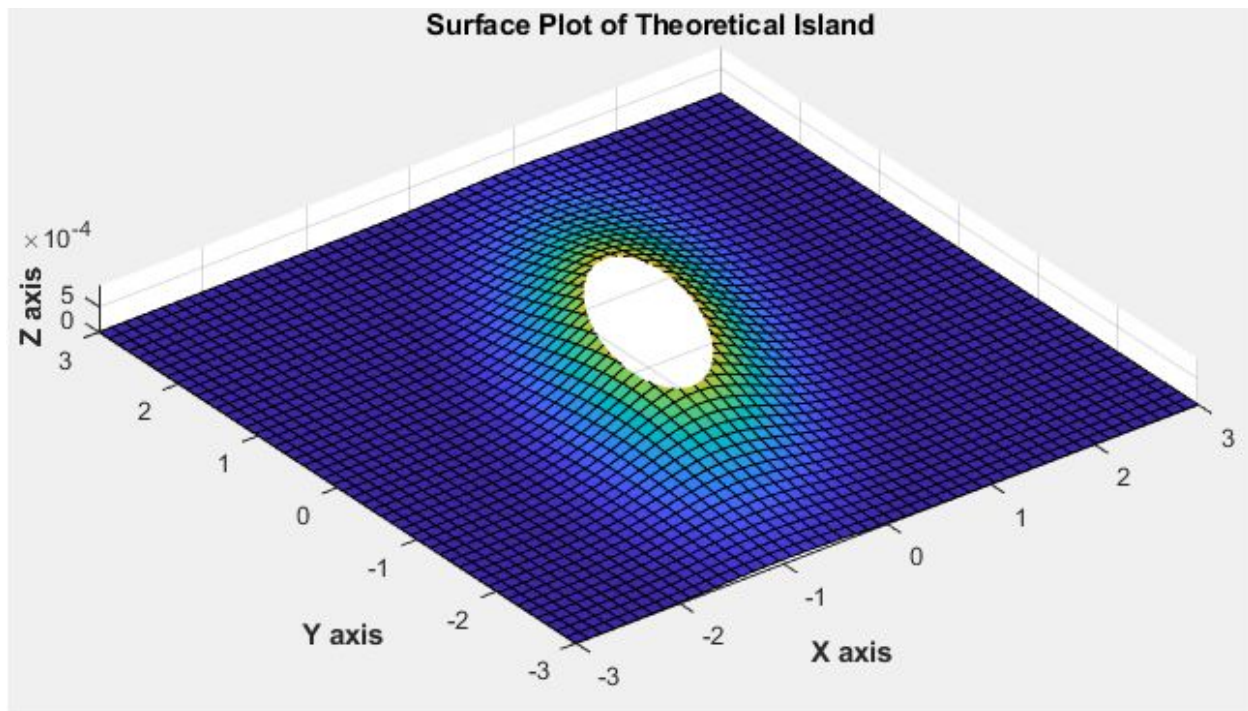


Figure VIII. MATLAB Surface Plot Simulation Results. Projected land loss in 2080

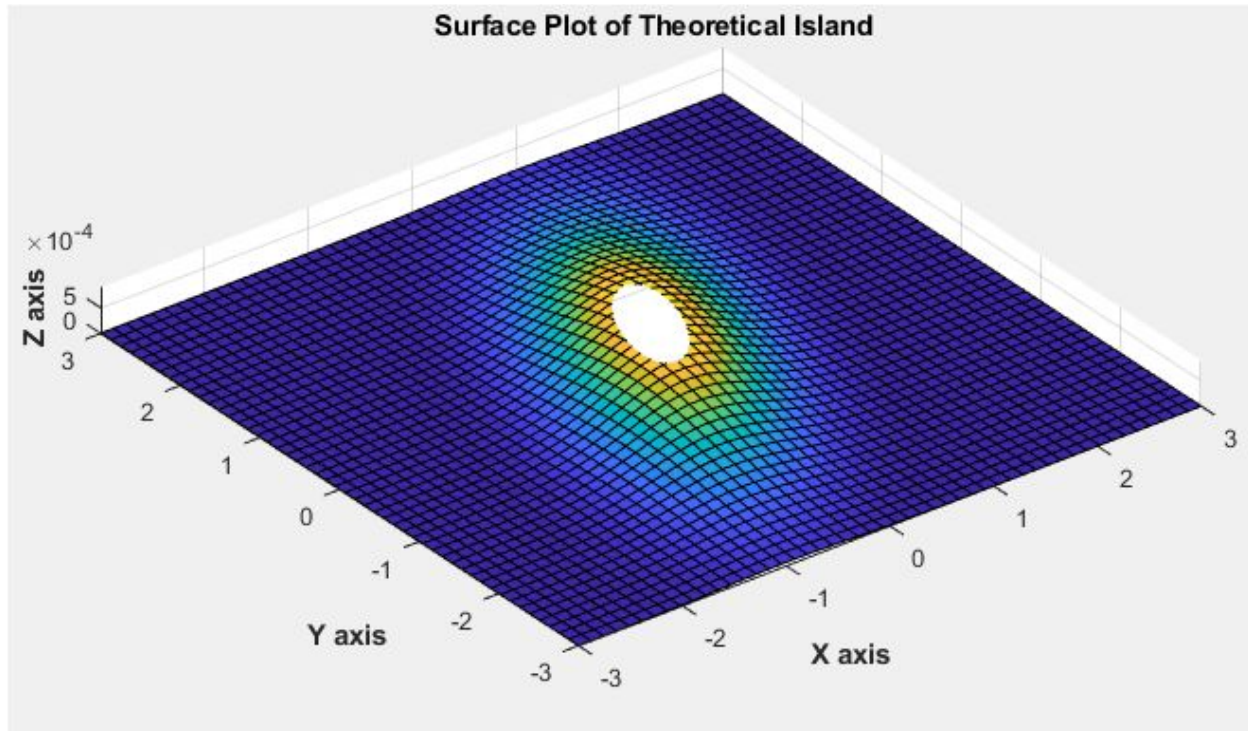


Figure IX. MATLAB Surface Plot Simulation Results. Projected land loss in 2100

Succeeding the construction of the DOE contour plot, varying surface plots were generated with minor changes to the MATLAB script. A surface plot, in this case, is essential to analyze three-dimensional data of loss of land projections, rather than showing individual data points. Surface plots enable a visual representation of the functional relationship between a designated dependent variable (Y) and two independent variables (X and Z). It is important to note that the surface plot is a companion plot to the contour plot, but establishes desirable response values and operating conditions for the theoretical island model.

A simplified methodology was used to calculate the land lost from Sea-Level-Rise (SLR). This was accomplished by computing simple surface integration along with the projected loss of land output from MATLAB. Firstly, an appropriate model for the shape of the island was

found, then surface integration was calculated according to SLR, we can limit the range from 0 to until the risen sea level then calculate the surface area of the function which gives us the result for the lost land projection at particular time T.

$$A(t) = \iint_S \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2 + 1} dx dy, \quad 0 \leq z \leq \frac{dz}{dt}$$

The area of Maldives is 115 mi^2 according to BBC News.⁴ The general model estimated the area of the Theoretical Island (Maldives) to be **154.165** mi^2 . Utilizing the surface area formula as seen by $A(t)$, the Projected Island Area can be calculated. The initial hypothesis is that there will be an exponential decay in the island area from 2020 to 2100. Because the function is a nonlinear equation, using a Levenberg-Marquardt algorithm in a least-squares curve fitting, a given set of m empirical pairs (x_i, y_i) of independent and dependent variables, find the parameters β of the model curve $f(x, y)$ so that the sum of the squares of the deviations $S(\beta)$ is minimized:

$$\beta \in \operatorname{argmin}_{\beta} S(\beta) \equiv \operatorname{argmin}_{\beta} \sum_{i=1}^m [y_i - f(x_i, y_i)]^2$$

Our algorithm, like other minimization techniques, provides an initial guess for the parameter vector β , in which only one minimum uninformed standard guess: $\beta^T = (1, 1, \dots, 1)$ is sufficient. In each succeeding step of the algorithm, the parameter vector β is replaced by a new estimate $\beta + \delta$. To determine δ , the function $f(x_i, \beta + \delta)$ is approximated by its linearization:

$$f(x_i, \beta + \delta) \approx f(x_i, \beta) + J_i \delta$$

where,

$$J_i = \frac{\partial f(x_i, \beta)}{\partial \beta}$$

indicative of the gradient (row-vector) of f with respect to β .

The output of the Levenberg-Marquardt algorithm is seen as:

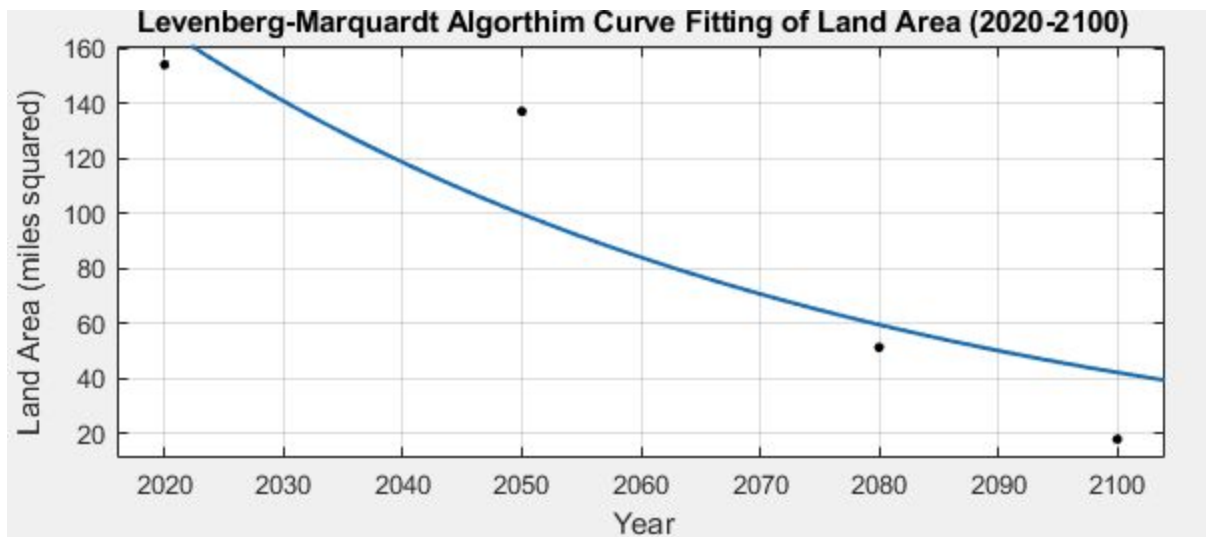


Figure X. The projected island area until the year 2100

Projected Island Area in 2020: 154.17 mi^2

Projected Island Area in 2050: 137.04 mi^2

Projected Island Area in 2080: 51.38 mi^2

Projected Island Area in 2100: 18.03 mi^2

Projected Number of People at Risk

We presume the number of people that immigrated to other countries are 10,000 at 2020. Utilizing the number of people affected by the equation above we can calculate the projected numbers.

Projected Island Population at Risk in 2020: **10,000 (0.02% of total population)**

Projected Island Population at Risk in 2050: **156,064 (13% of total population)**

Projected Island Population at Risk in 2080: **2,172,865 (73% of total population)**

Projected Island Population at Risk in 2100: **4,951,597 (93% of total population)**

3.1.3 Water Drop Waveform Model

In order to calculate the area of the flooded land, We first assume a $f(x,y)$ that represents the coastline. Then, we draw discrete numbers (n) of circles in which the center of the circles follow scaled $f(x,y)$. We first presume we know the relative change of sea level in island nations and the slope of the seashores. This model is intrigued by the idea that water travels in a circular waveform, and the waves are essentially the same as the water.

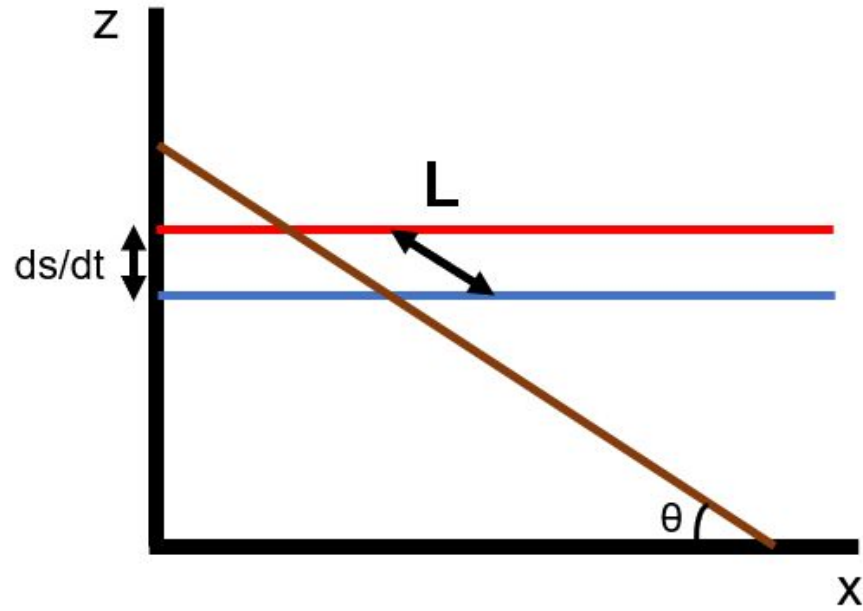


Figure XI. 2D representation of the area land lost due to sea-level rise

In Figure VIII, we first calculate the diagonal length of the land affected by the sea level rise.

$$y = \frac{ds}{dt} \csc \theta$$

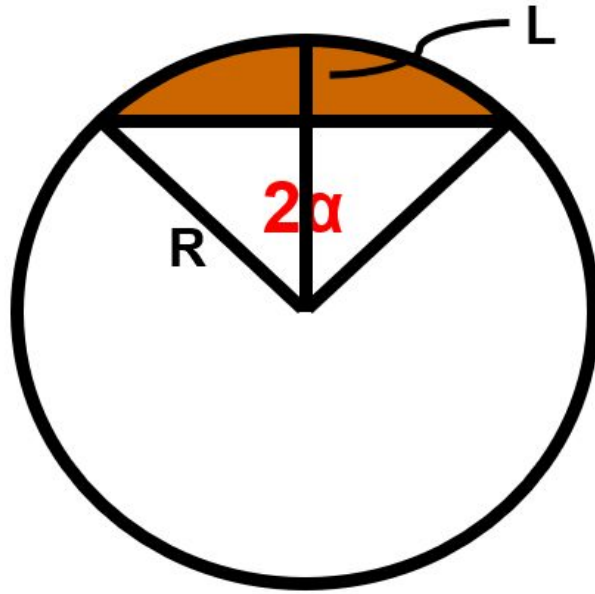


Figure XII. Top view representation of the land loss due to sea-level rise

Then, we presume that the length calculated above is the length drawn in the above figure. The reason for this is because waves move in circular waves.



Figure XIII. Water droplet real-life representation

The area that affects the mainland is the area painted in brown [figure]. To find the area of this area, we first have to find the angle α .

$$\sin\alpha = \frac{R - \frac{ds}{dt} \csc\theta}{R}$$

After finding the angle α , we can then calculate the area.

$$S = R^2\alpha - \frac{1}{2}R^2\sin 2\alpha$$

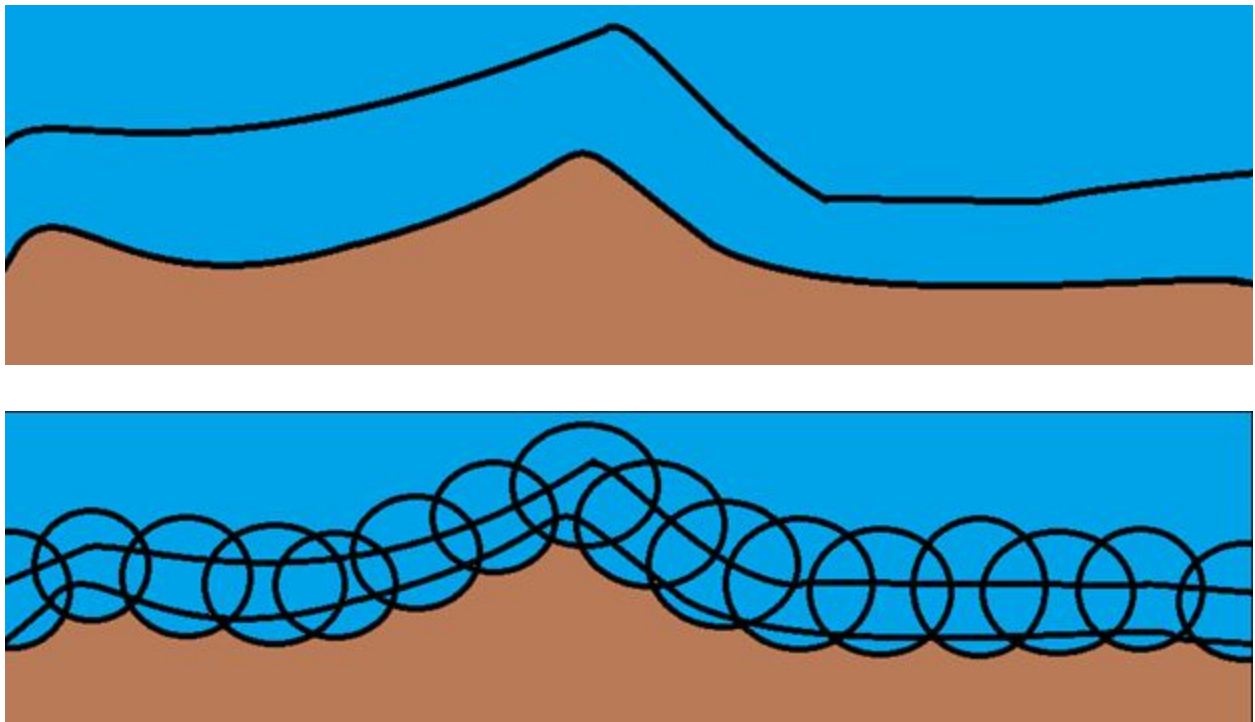


Figure XIV. A graphical representation of the Water Drop Waveform Model

In the final process, to calculate the rate of the area lost from the relative sea rise level rate, we multiply the area by the perimeter of the island.

$$\frac{dA}{dt} = \int_a^b f(r(t)) |r'(t)| dt \times (R^2 \alpha - \frac{1}{2} R^2 \sin 2\alpha)$$

$s(t)$ = *sea level rise*

$y(t)$ = *actual affected land diagonal length*

θ = *slope of the land*

3.2 Two-Step Metabolic Pathway Model

We employ cellular metabolism into the preservation of cultural heritage. During the entirety of the proposed model, we assume that cultural heritage follows a similar reaction-diffusion.

Unlike metabolism, where actual products are produced, here, we are going to presume that cultural effects from social interactions could be measured numerically.

We first propose imaginary sections that will encompass residents from one of the small islands of the at-risk-nation. By using the two-step metabolic pathway model derived from [7], we will find the best-optimized resident distribution and size of the section and resident cluster size.

The two-step metabolic pathway for cultural preservation was proposed because of its similarity between culture and two-step metabolism. First, these two are unidirectional. Second, they both have an intermediate process.

There have been past researches on using reaction-diffusion equations on cultural transmission equations to analyze spatial dynamics of the cultural and social spread. [4].

First, we use reaction-diffusion equations to describe cultural heritage transition. Then given the particular distribution of enzyme, we determine the preservation rate of cultural heritage.

$$\begin{aligned}\frac{\partial c_0(r,t)}{\partial t} &= -\alpha_0(c_0(r,t) - c_0^*) - k_1 n_1(r) c_0(r,t) + D \nabla^2 c_0(r,t) \\ \frac{\partial c_0(r,t)}{\partial t} &= k_1 n_1(r) c_0(r,t) - k_2 n_2(r) c_0(r,t) - \beta c_1(r,t) + D \nabla^2 c_0(r,t)\end{aligned}$$

where D is the diffusion coefficient of the cultural transition.

Since we imagined the area of sections would be the same, we can think of a vector \hat{r} as one dimensional variable with no-flux boundary conditions, where $0 \leq r \leq R$.

$$\begin{aligned}0 &= -\alpha_0(c_0(r) - c_0^*) - k_1 n_1(r) c_0(r) + \frac{D}{r} \frac{d^2(r c_0(r))}{dr^2} \\ 0 &= -\alpha_0(c_0(r) - c_0^*) - k_1 n_1(r) c_0(r) + \frac{D}{r} \frac{d^2(r c_0(r))}{dr^2}\end{aligned}$$

No-flux boundary conditions, $\frac{\partial c_0(r,t)}{\partial t} \Big|_{r=R} = 0 \ i = 0, 1$

Now we introduce cultural preservation efficiency ε , where $0 \leq \varepsilon \leq 1$. Cultural preservation efficiency measures the total rate of production of cultural interaction in volume V divided by the maximum possible rate of cultural propagation by a person 1.

$$\varepsilon[n_1, n_2] \equiv \frac{k_2 \int_A d^2r n_2(r) c_1(r)}{a_0 A c_0^*}$$

Because we assumed all imaginary sections to have the identical size,

$$\varepsilon[n_1, n_2; R] = \frac{k_2 \int_0^R dr 2\pi r n_2(r) c_1(r)}{a_0 \pi R^2 c_0^*}$$

Optimization Theory For Efficiency

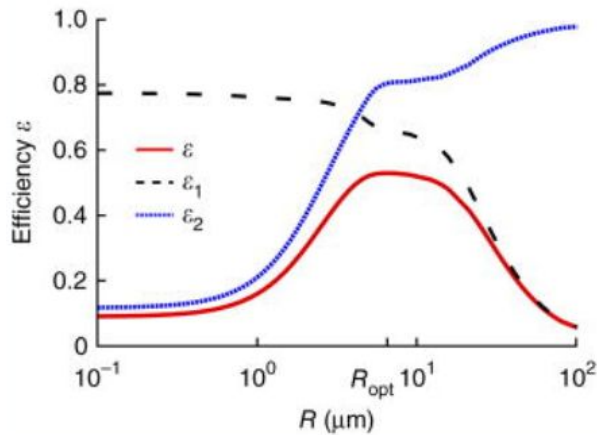


Figure XV. Optimization of efficiency. Graph extracted from Castellana et al.

Research done by Castellana et al. emphasize the best-optimized result by using the SLSQP optimization program. They found out that the best efficiency possible is 0.53 when the radius of the basin is 0.65 μ m. More importantly, the radius of the cluster was 0.04% of the radius of the basin. They developed a simple analytical theory to predict optimal efficiency:

$$\varepsilon_1 \approx \frac{\varepsilon_{1,r^-} * \varepsilon_{1,r^+}}{\varepsilon_{1,r^-} + \varepsilon_{1,r^+}}$$

$$\varepsilon_2 \approx \frac{k_2 n_2}{k_2 n_2 + \beta + D / (\frac{L^2}{2})^2}$$

Where, $\varepsilon = \varepsilon_1 * \varepsilon_2$.

3.3 Best Optimized Result

This is a constrained optimization because $n_1(r) + n_2(r) \leq n_{max}$. The optimization gives us the answer that the densities of the two groups should follow $n_1/(n_1 + n_2) = 0.33$. This is best achieved when the ratio of the radius of the section and the radius of the EDP cluster follows 25:1 (Considering the best efficiency is achieved at $r/R = 0.04$). In this particular situation, $n_1 = 2n_2$ should be satisfied, meaning there should be twice more people to absorb new cultural heritage than people who already have knowledge.

n_1 : the density of the people who are transferring the past cultural heritage to the younger generation

n_2 : the younger generation gaining cultural knowledge from n_1 .

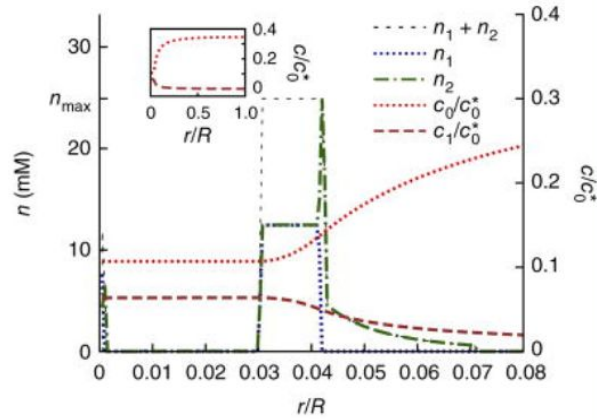


Figure XVI. Optimal distribution of refugee

4. Policy Guidelines

When a nation is sinking as a result of slowly rising sea levels, then there are issues about how migration could be coordinated or planned or even how the loss could be mitigated through land-preserving measures taken by the at-risk nation with or without internal support. It is not clear how the timescale of the loss would impact or should impact, the ultimate decisions that need to be made concerning the resettlement of a population, the protection of their human rights, and the preservation of the culture.

4.1 EDPs Clustering Policy

4.1.1. Outline of the Proposed Policy

Assuming the cultural preservation follows the metabolism, we can say the efficiency of cultural preservation with immigrants will follow the efficiency of two-path channeling. Based on the aforementioned results, the policy should consider the optimal results gained from two-path modeling.

First, we propose a policy that divides such host countries and cities into equivalent sections, and within those sections, the distribution of immigrants should follow the optimal distribution gained from the efficiency theory.

Another explanation for dividing the region into imaginary partitions is because we wanted to preserve the diversity of the island nations. Countries like the Maldives, Marshall Island consist of many different small islands that each have their own indigenous cultures that need to be protected. By putting them into nearby, but different sections, we believe this will best preserve each unique culture.

4.1.2. Results of the Proposed Policy

Following the above result by Castellana et al., we can conclude that the cultural preservation efficiency is best achieved by 0.53 by having the R/r of 0.04, where R is the radius of the imaginary section and r for the radius of the cluster within the section. Also, the best distribution within the cluster should satisfy, $n_1/(n_1 + n_2) = 0.33$. Therefore $n_1 = 2n_2$ should be

satisfied, where n_1 is the density of the people who are transferring the past cultural heritage to the younger generation, which is n_2 in this case.

If we choose the size of the city Richardson, TX as the basis for the imaginary section, $74.2km^2$, the area of the EDP cluster would approximate to $2.96km^2$. The number of EDP immigrants who are moving to other countries and have knowledge of the past cultural heritage should be half of the number of younger generations. This means the hosting government should work towards having more childbirth so that the number of people who can learn cultural heritage is about twice the number of people who can transfer their knowledge.

4.1.3. 80 Year Term Immigration Policy

We looked at migrating EDPs in long term policy because the immigration plan should not be dealt so lightly and in a short period of time. We propose the plan to be planned up to 80 years from now until 2100. The year 2100 was chosen because about 93% of people living in our modeled island lost their homes.

By 2050, about 13% of people are expected to be affected, this might not be a large number, but starting in 2050, the number starts getting higher every year. Hosting countries should have finished their guidelines by 2050.

5. Conclusions

5.1 Strengths and Weaknesses

5.1.1. Strengths of the Proposal

- We establish a multi-level dynamic analysis framework utilizing a two-step biological enzyme clustering model as a homology to cultural heritage preservation
- We creatively proposed ideas and mathematical models that are accurate at predicting the loss of land area and population growth.
- The model is suitable for analysis under a variety of theoretical island models that are considered at-risk-nations
- The model is applicable to various other systemic responses for EDPs
- The model proposes a variety of policy tools to resolve problems ranging from cultural heritage preservation of EDPs with an accurate representation of the implications of the proposed policy.
- Utilization of MatLab to handle challenging surfaces and grids of the Surface and Contour Plots.

5.1.2. Weaknesses of the Proposal

- The population prediction was not taking into account the fact that the population growth in island nations cannot grow exponentially fast. Normally due to the

division of the country by separated islands, they have factors that slow down the population growth.

- The model proposes a variety of complicated quadratic and nonlinear formulas that are difficult to generalize.

5.2 Conclusion

We first predict the number of people at risk of losing their homeland at a particular time in the future. Second, based on the aforementioned projections, we find ethical and beneficial policies to move these Environmentally Displaced Persons (EDPs) in a way such that EDPs can honorably preserve their unique cultural heritage. A **Sea Level Rise-Based Climate Impact Migration Model** was proposed to find the number of people affected by the land lost from the Sea Level Rise (SLR). Furthermore, a **Two-Step Metabolic Pathway Model** was adopted to explain social heritage preservation within a confined area based on the idea that two-step metabolism and cultural transition function in a complementary fashion. Finally, we consider possible improvements by assessing the strengths and weaknesses of the current proposed mathematical models.

6. Appendix

6.1 MatLab Source Codes

6.1.1. MatLab Source Code for Population Projection

```
a = 6.867e-21;
b = 0.0295;
N = 141;
dx = 1;
x = 1960:dx:2100;
%Generalized Exponential Function
y = a*exp(b*x);
plot(x,y)
xlabel('Year');
ylabel('Population');
title('Population Projection of Maldives Using An Exponential General Model');
```

6.1.2. MatLab Source Code for Theoretical Island Surface Plot

```
[x,y] = peaks(50);
z = 0.001*exp(-0.9*(x.^2+0.5*(x-y).^2));
surf(x,y,z);
xlabel('\bf X axis');
ylabel('\bf Y axis');
zlabel('\bf Z axis');
title('\bf Surface Plot')
daspect([450 450 1])
zlim([0 0.0009])
colorbar
```

6.1.3. MatLab Source Code for Theoretical Island Contour Plot

```
[x,y] = peaks(50);  
z = 0.001*exp(-0.9*(x.^2+0.5*(x-y).^2));  
contourf(x,y,z);  
xlabel('\bf X axis');  
ylabel('\bf Y axis');  
zlabel('\bf Z axis');  
title('\bf Contour Plot')  
daspect([450 450 1])  
zlim([0 0.0009])  
colorbar
```

6.2 Torus Model to Calculate Land Loss Surface Area

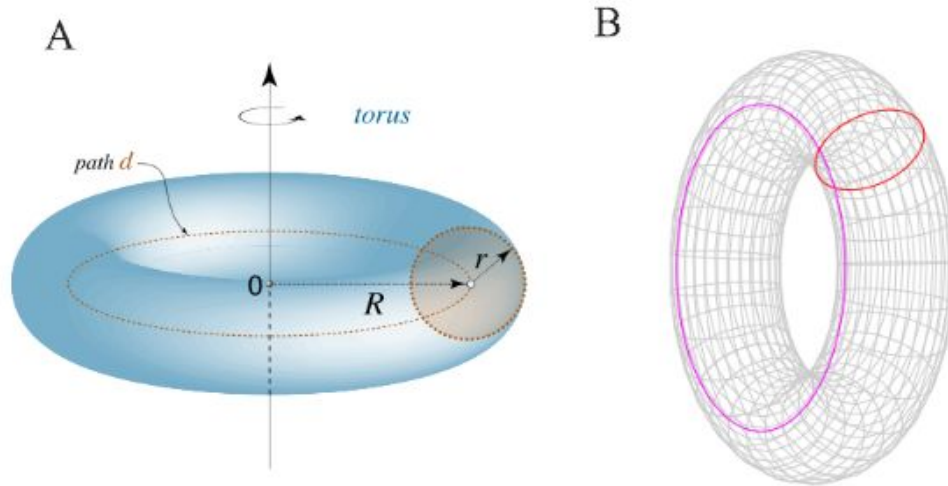


Figure XVII. Torus model of lost land emphasizing the major and minor radius¹⁰.

The general model of lost land can be computed by generalizing a torus as the area in which:

$$Surface Area_{Lost Land} = 4 * \pi^2 * R * r$$

Where R the “major radius” and r “minor radius” are seen by Figure XVI and parametrically by:

$$x(\theta, \phi) = (R + r\cos(\theta))\cos(\phi)$$

$$y(\theta, \phi) = (R + r\cos(\theta))\sin(\phi)$$

$$z(\theta, \phi) = r\sin(\theta)$$

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This work is the responsibility of the authors of this paper and nothing we say should necessarily be taken to represent the view of the Department of Natural Sciences & Mathematics at the University of Texas at Dallas under the team control number 2019341.

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