Akua Island

Coastal Development Plan 2017

Team RIOT

Contents

Executive Summary

Akua Island, a small developing state, is dependent upon a relative narrow resource base with precious yet vulnerable ecosystems. In the future, it is suggested that the coastal development should follow an environmentalist direction with eco-tourism as the main economic objective. This report first addresses the allocation of land uses for coastal zones (refer to the map and table below), which is obtained by decision matrix and combination run. It is then followed by the underlying rationale and possible trade-offs of the allocation.

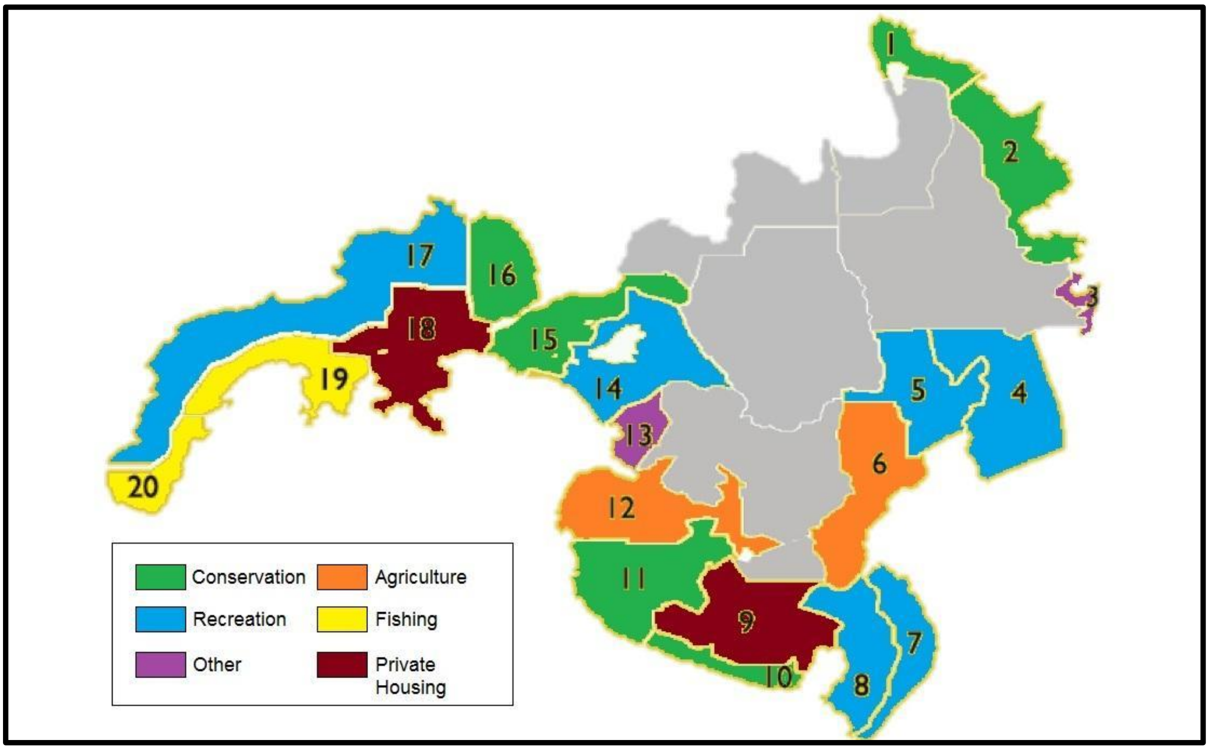

Figure 1: Map of Akua Island with coastal zones coloured by land uses

Land Type	Zone Count	Area (squre km)	Area Percentage	Wetland Area (squre km)	Grassland (squre km)	Forest Area (squre km)	No. of Akua Duck	Coastline Length (km)
Conservation	6	190.8	28%	19.772	106.742	49.662	217	76.3
Recreation	6	242.8	36%	22.786	134.515	73.061	379	88.9
Agriculture	2	76.4	11%	4.965	61.876	4.588	21	19.8
Fisheries	2	49.7	7%	4.642	43.86004	0.772	119	30.7
Private Housing	2	79.2	12%	5.038	65.916	3.594	169	18.7
Others	2	32.5	5%	2.028	21.944	6.032	32	10
Total	20	671.4	100%	59.231	434.85304	137.709	937	244.4

Table 1: Environmental data for coastal zones under the six land types

Strategic Approach

We suggest Akua Island to pursue a three-pronged strategy to strive for a sustainable future. Such a strategy could derive benefits to existing economic sectors and diversify the economy by promoting eco-tourism, support social well-being and conserve natural environment.[1]

Small island developing states (SIDS)[2] adapt the approach that builds a sustainable development framework, highlighting a diversification of land uses and maximizing the potential reversibility of resources. The economic and ecological uniqueness of the island needs to be recognized first before key objectives are identified and addressed.[3]

Akua duck, Snapper fish and the ecologically valuable wetland are the island's unique treasures. However, the island is inevitably affected by climate and environmental changes. Therefore, an approach that prioritizes conservation and complies with the commission on protecting the environment of Akua's coastline is used.

Tourism-related objective is another highlight in our strategic framework. According to the United Nations World Tourism Organization, about half of the tourists picked seaside as their destinations. For more than half of SIDS, tourism generates foreign exchange, contributes 20-50% of its GDP and over 30% of its employment.[4] Sufficient recreation

[1] Kanayathu Koshy, Melchior Mataki, and Murari Lal, *Sustainable Development – A Pacific Islands Perspec*tive (UNESCO, 2008), http://www.unesco.org/fileadmin/MULTIMEDIA/FIELD/Apia/pdf/PACIFIC-SD%20report.pdf.

[2] From our perspectives, Akua Island highly resembles the descriptions of SIDS (refer to Appendix I for more explanation)

[3] Stephen Bass, and Barry Dalal-Clayton, *Small Island States and Sustainable Development: Strategic Issues and Experience* (International Institute for Environment and Development, 1995), http://pubs.iied.org/pdfs/7755IIED.pdf.

[4] *The Oceans Economy: Opportunities and Challenges for Small Island Developing States* (UNCTAD, 2014), http://unctad.org/en/PublicationsLibrary/ditcted2014d5_en.pdf.

lands are planned to appeal investment and develop ecotourism. It leads to middle-class employment and reduces reliance on existing industrial segments. Tourists and residents could explore different facets of Akua Island through recreational facilities.

Besides public land usage, it is necessary for the island to be self-sufficient in its major economic activities like fisheries and agriculture. The team has made a 20-year projection on Akua's population, food and housing needs (Refer to Appendix II). Together with forecasts on sea level, ample private lands are allocated to support the self-containment principle.

Figure 2 shows the allocation for zones. More explanations on the percentage can be found in the section on decision rationale.

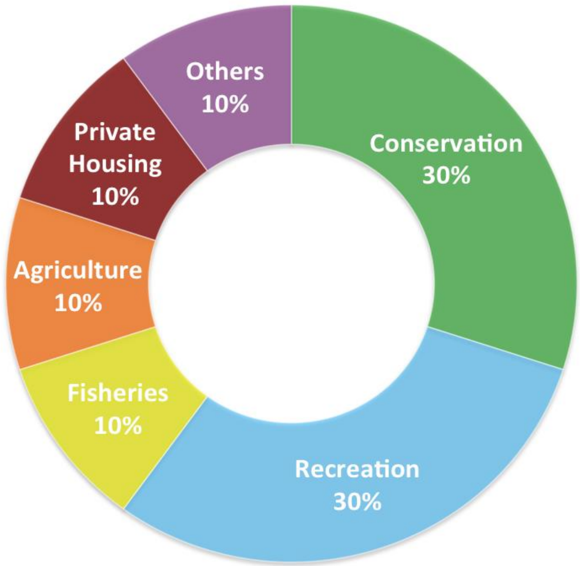

Figure 2: Pie chart showing the zone allocation percentage by land uses

Data Modelling

We quantified the utilities of each of the 20 coastal zones for each land use based on the environmental dataset and formatted the result into a decision matrix. The optimal combination of zone designation with maximized overall utilities was then obtained by method of exhaustion.

Decision Matrix Construction

1. A scoring matrix is first constructed from "current environmental data", evaluating the performance of each coastal zone with respect to each environmental variable. Since variables have different scales and directions, they are first converted into their respective normalized scores based on the degree of deviation from mean.

   The normalized score is calculated as follows: 3 marks are awarded to the zone attaining the mean. +/- 0.5 marks is applied on top of the mean score for every 0.5 standard deviation from its mean; i.e. a zone area with area percentage 1.5 s.d. less than the mean should be awarded 1.5 (3-0.5*3) marks.

2. In parallel with the scoring matrix is a criteria matrix which specifies the weight of each criterion for score calculation of different zone types, with sum equaling 1 (Refer to Appendix III). For example, "Akua Duck Population" and "Wetland Area" are considered equally important to conservation area, hence a weight of 0.5 is assigned to each of the factors.

3. The decision matrix is obtained by multiplying the scoring matrix and the criteria matrix together.

Combination Optimization

4. A combination run is conducted to simulate the composite score generated by allocating different land uses to the 20 regions; using the relative utility as suggested by the decision matrix. Constraints are set in the combination run to adhere to our overall strategy.

5. In case of tied score, priority would be given to the combination in line with our strategic approach.

Opportunities

Balance between Tourism and Conservation

Economic activities and exploitations inevitably affect the ecological system of the island, especially when tourism-related objective is stressed in public land use planning. Human development and tourist activities may lead to pollution, congestion, disruption of local cultures and accelerate stress on natural resources.[5] Striking a delicate balance between development and conservation is a precarious task. The Coastal Commission has to set a clear tourism vision with regulations to effectively manage recreational activity and keep the conserved zones undisturbed and pristine.

Challenges Brought by Climate Change

Small island states are particularly vulnerable to climate change and coastal inundation because of their small size, low elevation and concentration of infrastructure along coastlines. Although sea levels are projected to minimize risks, El Niño and La Niña events would create considerable variability, threatening ecosystem and economy of Akua Island.[6] Forecasting and early warning systems should be built, together with risk reduction, disaster prevention and changes adaptation. Provided with the virtue of Akua Island's location, the island's governments may explore the use of renewable energy.[7]

[5] *Small Islands and Tourism: Finding a Balance* (United Nations Department of Public Information, 1994), www.ecotourism.org.hk%2Fother%2520files%2Fsmall%2520island%2520and%2520tourism.doc.
[6] *Climate Impacts in the U.S. Islands* (United States Environmental Protection Agency), https://www.epa.gov/climate-impacts/climate-impacts-us-islands.
[7] *Climate change, small island developing States* (UNFCCC, 2005), http://unfccc.int/resource/docs/publications/cc_sids.pdf.

Tradeoffs

Required Weighting of Public and Private Land Allocation

We have to follow the Coastal Act rules and objectives, which states that at least 30% of the coastal zones must be public land and at least 40% for private development. Some coastal zones may be favourable for both public and private development. Hence, the decision model we used inevitably faces tradeoffs in deciding the final allocation of zones with distinctive resources, which are favourable for more than one land uses.

A Particular Example: Coastal Zone 17

Zone 17 has the longest coastline, largest Akua duck population and the least Snapper exploitation rate on Akua Island. Every land use is ideally the best option for the zone based on the environment (refer to Appendix III). However, due to the limitation on land allocation, the zone is allocated to recreational use in our model. Thus, zone 17 would experience a substantial tradeoff between public and private land use.

More Public Land Development Based on Reversibility

There would be potential population growth on Akua Island in the coming future. Small island states have limited land for further development, and cautious planning is undoubtedly essential. Currently, we should prioritize the allocation of coastal zones to public use since the transformation of public land into land for private use is reversible in the future[8]. We aim to reserve land for further population growth and future development.

[8] Mediell, Maud, and Eric Dionne,eds, *Program Evaluation and Performance Measurement: An Introduction to Practice (*The Canadian Journal of Program Evaluation, 2015).

Decision Rationale

	Land Type				Other Attributes				
Zone Type	Wetland	Grassland	Forest	Other Area	Akua Duck	Snapper	Soil Matter	Coastline	Sea Level
Conservation	50%				50%				
Recreation		30%*	30%*					70%	V
Agriculture		100%*					100%*		
Fisheries						100%*		100%*	
Private Housing		70%						30%	V
Others									

Table 2: Weights on different environmental factors to be considered under each zone type
* Calculation methods will be explained below

Public Land

1. Conservation

As stressed before, conservation is the key development area in the future. Following World Parks Congress' recommendation[9], 30% of the zones should be allocated for conservation.

With reference to Laysan Duck[10], an endangered species in Hawaii, managing the habitat for ducks' nesting and scavenging behaviors is of utmost importance. It is well researched[11] that an island's ecosystem and birds have "wetland dependence" for life-support systems like breeding. Substantial wetland should be reserved. As a result, equal

[9] *World Parks Congress recommends target of 30% no-take MPA coverage worldwide (*MPA News, 2014), https://mpanews.openchannels.org/news/mpa-news/world-parks-congress-recommends-target-30-no-take-mpa-coverage-worldwide.
[10] *Laysan Duck profile* (Hawaiian Bird Conservation Action Plan, 2012), https://www.pacificrimconservation.org/wp-content/uploads/2013/10/Laysan%20Duck.pdf.
[11] *Technical Aspects of Wetlands Wetlands as Bird Habitat*. United States Geological Survey. https://water.usgs.gov/nwsum/WSP2425/birdhabitat.html.

weights are to be placed only on two criteria: wetland surface area and Akua duck population.

2. Recreation

Nature-based tourism is our main goal for future development, and recreation land is what travelers are looking for. In the same recreation zone, parks and trails should be developed alongside with coastline development.

Take Caribbean tourism as an example[12]. The tropical "three S's" (Abundant sunlight, attractive white sand beaches and azure seas) contributes the general pattern of mass tourism development. From The Insider[13], popular islands attract people with their sandy beaches. These show that coastline development should be given emphasis.

Hence, it is decided to put a heavier weight of 70% to coastline length, with the remaining 30% attributed to total area of grassland and forest.

Private Land

1. Agriculture and Fishing

These two areas provide self-sufficient food supply to the island. Based on the estimation, 10% of the zones should be allocated to each of these two land uses (refer to Appendix II).

[12] Meyer-Arendt, Klaus, and Alan A. Lew, eds, *Understanding tropical coastal and island tourism development* (Routledge, 2016).

[13] Sophie-Claire Hoeller, *The 10 best islands in the world, according to travelers* (Insider, 2016), www.thisisinsider.com/worlds-10-best-islands-2016-7.

For farming purpose, the only factor considered is farming capability, which is equal to total grassland area multiplied by average amount of soil organic matter.

For fishing purpose, the only factor considered is the fish abundance, calculated by the formula:

$$(1 - \text{Exploitation rate}) \times \text{Coastline length}$$

2. Private Housing

As the development of private housing is potentially irreversible, it is recommended that the conversion of grassland to housing be delayed. 10% of the zones are designated as it is estimated to be adequate for now.

To maximize the quantity of housing development, it is decided to emphasize the factor of grassland area with 70% weight and remaining 30% to coastline length.

3. Others

These will be reserved for other forms of economic development for the future benefits of Akua Island. As per the recommendation of the SIDS, sustainable energy development and clean water management are important aspects to consider.[14]

[14] *Small Island Developing States* (UN-OHRLLS, 2011), http://unohrlls.org/custom-content/uploads/2013/11/SIDS-Advocacy-Booklet.pdf.

A Note on Sea Level:

For the land use of recreation and private housing, it is noted that risk of sea level rise is of vital importance to the human activities. As a result, they will NOT be allocated to the zones with “high flooding risk” (refer to Appendix III and IV).

Data Limitation

Lack of Population Information

The population size of Akua Island is a determining factor in coastal zone allocation. With the goal of sustainable development, it must be guaranteed that the lands designed for private housing, fisheries and agriculture are sufficient to support the increasing demand resulting from population growth.

Due to unavailability of the relevant population information, a guesstimate of population size, determined by referencing other small island states, is used in justifying zone allocation decision. Nonetheless, the resulting figures are subject to over and under estimation due to variability of small island states, and therefore the allocation decision may not necessarily reflect the actual need of the island population.

Incomplete Dataset of Sea Level

The historical sea level data of Akua Island serve as the basis for quantifying the risk of sea level rise. Nonetheless, for many zones there are periods where data are missing in the provided dataset. To facilitate time series prediction, missing values are imputed by conducting linear regression on sea level data of adjacent zones. Yet, the imputed values are subject to estimation discrepancies and the errors are accumulated to forecasting process. Hence, the sea level projection may not be accurate due to data incompleteness.

Ending Note

Akua Island, a small developing state, is anticipating visitors around the globe. The final allocation of land uses for coastal zones coincides with our main economic objective, following an environmentalist direction. Eco-tourism is of immense importance in supporting conservation and wildlife protection. By this development plan, the exclusivity and magnificence on Akua Island will be enjoyed for generations to come.

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Appendix I: Description of Small Island Developing States (SIDS)

Following the definition of The United Nation, SIDS are islands identified with limited size and dependent on narrow resource bases. They have to tackle a typical series of developmental and environmental issues such as population growth and threatened biodiversity.

The Island States would suffer most from the adverse effects of climate change and sea level rise and could in some cases become uninhabitable. There is an urgent need of SIDS to address the problem of unsustainable development, including scarce land resources, which lead to difficult land and agriculture use decisions.

Appendix II: Population Estimation and Self-Sufficiency

Population Projection

Country Name	Population	Land Size	Population Density
Dominica	73,757	751	98.21
Federated States of Micronesia	104,719	702	149.17
Guam	162,742	544	299.16
Kiribati	106,925	811	131.84
Saint Vincent and the Grenadines	164,464	606	271.39
Seychelles	197,541	964	204.92
Trinidad and Tobago	106,513	717	148.55
Average			186.18

Table 3: Population Density of SIDS with similar size [15]

In projecting the island population, we refer to the population density of other SIDS comparable to Akua and island size. An average population density of 186.18 people per square km is applied in our projection. This implies an initial population of 223,971 based on the island size of 1203 square km. The average annual SIDS population growth rate of 1.3% is applied in our projection. [16]

Self Sufficiency

Year	Population	Required Private Housing Size (km sq)	Required % of Private Housing in Coastal Region	Required Food Amount (kg)	Required Land Size (km sq.)	Required % of Agriculture in Coastal Region
5	238,913	4.78	7.94%	71,673,807	206.07	9.55%
10	254,851	5.10	8.47%	76,455,318	204.84	9.50%
15	271,853	5.44	9.04%	81,555,813	203.61	9.44%
20	289,989	5.80	9.64%	86,996,574	202.39	9.38%

Table 4: Forecast of agriculture and housing needs in numbers for Akua Island

[15] *The World Fact Book* (Central Intelligence Agency, 2016), https://www.cia.gov/library/publications/the-world-factbook/

[16] *Small Island Developing States (SIDS) Statistics* (UN-OHRLLS, 2013), http://unohrlls.org/custom-content/uploads/2013/09/Small-Island-Developing-States-Factsheet-2013-.pdf.

Agriculture and Fishery

The total food need of Akua population is estimated by multiplying the above projected population with a 300 kg per capita annual food consumption[17]. The global annual average crop yield is 324,100 kg per km sq of farmland[18], with 1.422% 10 year compound annual rate of yield growth. It is projected that self-sufficiency in food production can be attained by allocating 10% of total coastal area to agricultural use, conditioning that food production is uniformly spread based on land size across coastal area and inland area.

Allocation of land use in fishery will follow the percentage in agricultural use as a supplement in food production. The excess amount of fishery yield will be exported.

Private Housing

With 20 metres sq. of average floor area per capita assumed[19], the required land size for private housing is 5.8 km sq. Allocating 10% of coastal land to private housing will be sufficient to accommodate the entire Akua population to the coastal area while keeping the plot ratio as low as 5%.

[17] Per capita annual food consumption in 2025. Source from: *OECD-FAO Agricultural Outlook 2016-2025* (OECD & FAO, 2016), http://www.oecd-ilibrary.org/agriculture-and-food/oecd-fao-agricultural-outlook-2016_agr_outlook-2016-en;jsessionid=5vsd68onntbb2.x-oecd-live-03.

[18] *Cereal yield (kg per hectare)* (The World Bank, 2016), http://data.worldbank.org/indicator/AG.YLD.CREL.KG.

[19] Less than 10% of countries in less developed region achieves 20 metres sq. of average floor area per capita. Source from: *Charting the Progress of Populations* (United Nations Population Division, 2000), http://www.un.org/esa/population/pubsarchive/chart/14.pdf.

Appendix III: Criteria Matrix and Ranking in Scoring Matrix

Land Use	Akua Duck Population	Coastline Length	Agriculture Metric	Fishery Metric	Wetland Area	Grassland Area	Total Grassland and Forest	High Sea Rise Risk
Conservation	0.5	0	0	0	0.5	0	0	
Recreation	0	0.7	0	0	0	0	0.3	✓
Agriculture	0	0	1	0	0	0	0	
Fisheries	0	0	0	1	0	0	0	
Private Housing	0	0.3	0	0	0	0.7	0	✓
Others	0	0	0	0	0	0	0	

Table 5: Criteria matrix with weights

Zone	Land Use	Akua Duck Population	Coastline Length	Agriculture Metric	Fishery Metric	Wetland Area	Grassland Area	Total Grassland and Forest	High Sea Rise Risk
1	Conservation	12	7	18	16	10	17	16	✓
2	Conservation	12	2	14	9	4	8	4	✓
3	Others	12	15	18	16	18	17	20	✓
4	Recreation	12	3	10	5	1	17	1	
5	Recreation	12	18	6	16	10	6	7	
6	Agriculture	12	7	2	9	10	3	4	✓
7	Recreation	12	3	14	3	4	8	13	
8	Recreation	12	15	18	9	7	8	7	
9	Private Housing	12	18	6	20	19	2	3	
10	Conservation	7	7	10	9	7	15	19	✓
11	Conservation	7	7	6	9	10	8	7	✓
12	Agriculture	7	7	6	9	10	4	7	✓
13	Others	7	18	14	16	19	17	18	✓
14	Recreation	4	15	10	9	10	15	4	
15	Conservation	4	7	14	5	7	8	7	
16	Conservation	3	7	10	5	4	8	13	
17	Recreation	1	1	1	1	1	1	1	
18	Private Housing	2	3	3	3	3	4	7	
19	Fisheries	4	3	3	2	17	6	13	
20	Fisheries	7	7	3	5	10	8	16	✓

Table 6: Ranking in scoring matrix

Appendix IV: Sea Level Projection

To gauge the risk of sea level rise in each coastal zone, the historical sea level dataset provided by Akua Coastal Commission is leveraged to forecast the change of sea level in the upcoming 5 years. The paragraphs below explain the time series modelling methodology, followed by a discussion on forecasting result.

Data Processing

The dataset provided contains the monthly mean sea level data of each coastal zone since January 1992. It is noted that some sea level data are missing due to unavailability or malfunction of tide gauge. To facilitate time series analysis and forecasting, the missing values are first imputed from available data by the mean of cross-sectional linear regression.

The combinations of zones listed below are selected to fit linear regression model of each zone separately:

- Inland adjacent zones
- Maritime adjacent zones
- Each coastal zone independently

The choice of inland adjacent and maritime adjacent zones is based on the assumption that zone adjacency would contribute to high correlation between sea level, while fitting the data to each coastal zone separately serves as a backup plan to impute the sea level data lest the data of adjacent zones are simultaneously unavailable. The table below summarizes the sea zone adjacency of Akua Island.

Maritime Zone Adjacency

Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1		X																		
2	X		X																	
3		X																		
4					X															
5				X		X														
6					X		X													
7						X		X												
8							X		X	X										
9								X		X										
10								X	X		X									
11										X		X								
12											X		X							
13												X		X						
14													X		X					
15														X		X		X		
16															X		X			
17																X				X
18															X				X	
19																		X		X
20																	X		X	

Once all the regression models are fitted and model coefficients are obtained, the models for imputing data of a particular coastal zone are ordered based on their adjusted R square. The missing data of each coastal zone are then imputed using the regression model with the highest adjusted R square and available data. The table below exhibits the adjusted R square of linear regression model on sea level data of maritime adjacent and inland adjacent zones.

Adjusted R Squared of Linear Regression Model

Zone	Maritime Adjacency	Inland Adjacency
1	0.8164	0.8164
2	0.9135	0.8164
3	0.9094	0.0000
4	0.9522	0.9522
5	0.9709	0.9709
6	0.9619	0.9424
7	0.9364	0.9226
8	0.9835	0.9833
9	0.9566	0.9721
10	0.8826	0.8451
11	0.0000	0.0000
12	0.0000	0.0000
13	0.0000	0.9113
14	0.9772	0.9772
15	0.0000	0.9812
16	0.9868	0.0000
17	0.9584	0.0000
18	0.9810	0.0000
19	0.9869	0.9899
20	0.9585	0.9585

Time Series Forecasting

After imputation, a time series model would be fitted to the sea level dataset for each zone. An exponential smoothing is adopted for its ability to handle non-stationary data. By using simple exponential smoothing method, the mean and 95% confidence interval of sea level change in 5 years could be obtained. By integrating the current average sea level data with sea level change projection, the 97.5 percentile of sea level in 5 years could be computed. The table below summaries the sea level projection of each coastal zone with those highlighted exceeding our benchmark of 5 meters.

Zone	5 Years Projected Sea Level Change (in mm)			Current	5 Years Projected Sea Level (in m)		High Risk of Sea Level Rise
	Mean	95% Lower Limit	95% Upper Limit		Mean	97.5 Percentile	
1	0.01361	-1402.44	1402.47	9.50	9.500014	10.9025	✓
2	-0.00050	-1555.68	1555.68	6.40	6.400000	7.9557	✓
3	0.00160	-1590.28	1590.29	3.60	3.600002	5.1903	✓
4	-0.00840	-1585.03	1585.01	0.40	0.399992	1.9850	
5	-0.00500	-1629.63	1629.62	0.30	0.299995	1.9296	
6	0.01090	-1590.17	1590.19	3.90	3.900011	5.4902	✓
7	0.01000	-1563.51	1563.53	0.40	0.400010	1.9635	
8	0.01230	-1533.92	1533.95	2.60	2.600012	4.1339	
9	0.01450	-1504.28	1504.31	2.80	2.800015	4.3043	
10	0.00270	-1227.60	1227.60	4.80	4.800003	6.0276	✓
11	0.01170	-1622.52	1622.54	4.60	4.600012	6.2225	✓
12	0.01170	-1396.03	1396.05	3.90	3.900012	5.2961	✓
13	0.01030	-1369.10	1369.12	3.80	3.800010	5.1691	✓
14	0.00320	-1223.83	1223.83	0.60	0.600003	1.8238	
15	0.00270	-1170.11	1170.11	0.30	0.300003	1.4701	
16	0.00140	-1161.35	1161.35	0.10	0.100001	1.2614	
17	0.00360	-1046.61	1046.62	3.50	3.500004	4.5466	
18	0.00340	-986.07	986.08	0.40	0.400003	1.3861	
19	0.00290	-955.20	955.20	3.80	3.800003	4.7552	
20	0.00170	-1019.17	1019.18	7.20	7.200002	8.2192	✓

Table 7: Sea level projection and risk for each coastal zone