Building Climate Resilient Safer Islands in the Maldives

Economic Analysis

Table of Contents

1 Introduction

According to page numbers 149-150 and Table 32 of the GCF Programming Manual (July 2020), economic and financial analyses are required in Annex 3 to assess the viability of the project and programme, also the analyses are divided into two categories, i.e., 1) direct assessment and 2) indirect assessment.

The former, an assessment of the efficiency and effectiveness of the investment criterion, is based predominantly on the economic and financial analyses in terms of cost effectiveness, cost-benefit ratio (CBR), economic internal rate of return/financial internal rate of return (EIRR/FIRR), and long-term economic and financial viability. The latter, the economic and financial analyses can form part of the assessment of the impact potential, paradigm shift potential, sustainable development potential, and needs of the recipient.

Based on the conditions aforementioned, criterion/factors that were analyzed for each component were presented as shown in Table 1.1. It is noted that for Component 1 (Establishment of ICZM), direct assessment was not conducted due to the difficulties in evaluation of effectiveness quantitatively because the component aims to implement non-physical (soft) measures such as establishing policies and plans. Results of the assessment for each item are shown in the corresponding sections as shown in the table.

Table 1.1 Assessment Factors Evaluated for Each Component

Category	Investment Criterion/Indicative Assessment Factors			
	Component 1	Component 2	Component 3	Component4
Indirect assessment	Impact potential /number of direct and indirect beneficiaries (Sec. 2.1.1)	Impact potential /number of direct beneficiaries (Sec. 2.2.1)	Impact potential /number of beneficiaries of coverage (Sec. 2.3.1)	-
	Paradigm shift potential/scalability and replicability/ transformation (Sec. 2.1.1)	Needs of the recipient/absence of alternative sources of financing (Sec. 2.2.2)	-	-
Direct assessment	-	Efficiency and effectiveness/cost-effectiveness (Sec. 2.2.3 and Chap.3)	Efficiency and effectiveness/cost-effectiveness (Sec. 2.3.2)	Efficiency and effectiveness/long-term economic and financial viability (Sec. 2.4.1)

Source: JICA

2 Assessment for Each Component

2.1 Component 1: Establishment of the Integrated Coastal Zone Management (ICZM)

The proposed Component 1 consists of the following activities (see FP main text for details).

Activity 1.1: Inventory study for risk assessment on present coastal and coral reef conditions
Activity 1.2: Preparation of basic policy of ICZM at the national level
Activity 1.3: Preparation of concrete ICZM Plan at representative inhabitant island as case study
Activity 1.4: Capacity development and information sharing of the relevant organizations for establishment of the ICZM

2.1.1 Impact Potential/Number of Direct and Indirect Beneficiaries

Direct beneficiaries: 5,346 people
In Activity 1.3, the ICZM Plan that will be prepared through Activities 1.1 and 1.2 will be practiced and examined as case studies in Gan in Addu Atoll and Fonadhoo Island in Laamu Atoll. The activities include the following: 1) Establishment of coastal and reef conservation plan, 2) Establishment and implementation of sediment budget control plan, 3) Study for strengthening measures on land use planning, 4) Study on coastal management system and its implementation, and 5) Study on regulation and law at island level.
The population of the two islands where the practices and case studies will be implemented are considered to be direct beneficiaries of Component 1. Based on the Census 2014, the number of direct beneficiaries is evaluated at 5,909, which is the sum of population at both Gan (3,080) and Fonadhoo (2,266) islands.

Indirect beneficiaries: 196,000 people
The ICZM basic policy and guidelines will be developed at the national level and the Government of Maldives (GoM) intends to incorporate the policies and guidelines into the planning and implementation of coastal conservation measures in the future.
Based on the State of Environment 2016, it was assumed that 52% of the national population lives either in reclaimed area or area with coastal protection measures implemented, which are already protected. The remaining population (i.e. 48% of total population of 407,660), therefore, was estimated as indirect, potent beneficiaries of ICZM concept.

- 407,660 x 48% = 196,000 people

2.1.2 Paradigm Shift Potential/ Scalability and Replicability/Transformation

Scalability and replicability: High

The draft regulations developed in the target islands (Gan in Addu Atoll and Fonadhoo in Laamu Atoll), identified as necessary for practicing the ICZM through case studies, are submitted for approval of the mayors of the islands during the implementation period. To start the formulation process of the ICZM guidelines at the national level, a public office/department in charge of finalizing the ICZM guidelines shall be appointed. The training for concerned agencies include "cascade" training to enable the trained officials to provide valuable advice during the replication stage. Further, the employment of the local consultants will be discussed by the Project Steering Committee, who will play an important role during the implementation of the case studies in the concerned agencies. With these activities, practicing the ICZM at the other islands is expected, therefore, the scalability and replicability of Component 1 are evaluated as high.

Transformation of the concept of coastal protection: High potential

One of the most serious factors of coastal vulnerability against climate hazard is the artificialization of the coast by the construction of harbors, reclamation, and other coastal facilities. These structures constructed along the coastal line or in shallow water areas usually prevent and change the manner of the original sediment transport and causes coastal erosion and even accelerate flooding caused by waves in the surrounding area. Component 1 aims to identify such issues on the coastal area in the Maldives through Activity 1.1 and prepare a new concept for coastal protection. These are part of the basic policy and concrete plan of ICZM to avoid or minimize such negative impact in the future. In addition, capacity development on ICZM will be implemented, through Activity 1.4, for relevant organizations who will be in charge of planning and design of the coastal conservation in the future. With these activities, it is expected that the concept of coastal protection by GoM will be transformed from protection-oriented to environment-conscious through Component 1 in terms of, for example, the layout of coastal facilities and ports and the way to select coastal protection measures.

2.2 Component 2: Implementation of Coastal Conservation/Protection Measures against Coastal Disasters

The proposed Component 2 consists of the following activities (see FP main text for details).

Activity 2.1: Detailed design of coastal conservation measures and capacity development of stakeholders
Activity 2.2: Implementation of coastal conservation/protection measures
Activity 2.3: Implementation of beach maintenance, establishment of structure and capacity development of stakeholders

2.2.1 Impact Potential/Number of Direct Beneficiaries

Direct beneficiaries: 9,071 people

Table 2.2.1 shows the islands where coastal conservation measures will be designed and implemented through the Activity 2.2. Direct beneficiaries are evaluated at 9,071 by summation of the islands' population where coastal conservation measures will be implemented.

Table 2.2.1 Target Islands and Proposed Measures

Atoll	Island	Population	Coastal Conservation Measures to be Applied	Fund Source
Laamu	Maamendhoo	896	· Beach nourishment and groins · Revetment and reclamation	GCF
	Fonadhoo	2,266	· Beach nourishment and groins	GCF
	Gan	3,080	· Revetment	GoM
	Ishdhoo	958	· Revetment	GoM
Addu	Meedhoo	1,871	· Beach nourishment and groins	GCF and GoM
Total		9,071		

Source: JICA

2.2.2 Needs of the Recipient/ Absence of Alternative Sources of Financing

Insufficient budget for coastal conservation:

The Maldives, as a Small Island Developing State (SIDS), is highly vulnerable to climate change. Each year, the GoM allocates approximately USD 5 million to USD 11 million for coastal protection with a total expenditure of USD 30 million from 2013 to 2017.

On the other hand, the necessary budget for coastal protection works for the inhabited areas within the Maldives is estimated to be from USD 3.3 billion to USD 55 billion. Since the population is scattered across 188 inhabited islands, many of which have less than 1,000 inhabitants, the limited resources at the government's disposal are insufficient to provide a lasting solution to the coastal erosion issues that these islands face.

Insufficient international assistance:

GoM published the Maldives's Intended Nationally Determined Contribution in 2015, raised coastal protection as one of the priority climate change adaptation measures, and requested for international assistance. However, the only assistance including structural measures announced by the international aid agency as of September 2018 is the Coastal Protection Project at Gn. Fuvahmulah (total project cost of USD 22 million) by the Netherlands (grant) and Kuwait Fund (loan). With this situation, expecting to obtain assistance from other international aid agencies would be difficult.

2.2.3 Efficiency and Effectiveness/ Cost-effectiveness

The benefit that is to be expected through the implementation of Component 2 is summarized in Table 2.2.2. The benefit at Maamendhoo and Fonadhoo was able to be evaluated in monetary value because the protection effect of residential property can be quantitatively evaluated using some reference unit of values. On the other hand, the effectiveness for the other three islands, namely; Gan, Ishdhoo, and Meedhoo, it is difficult to evaluate the effect quantitatively due to the difficulties in setting an appropriate unit for evaluation. Therefore, monetary benefit expected at Maamendhoo and Fonadhoo were directly used for cost-benefit analysis in this section.

Table 2.2.2 Benefit and Evaluation Methods by Measures

Atoll	Island	Measures	Effectiveness	Monetary Value
Laamu	Maamendhoo	· Beach nourishment and groins · Revetment and reclamation	Protection of residential property against flooding and erosion	Evaluated
	Fonadhoo	· Beach nourishment and groins		
	Gan	· Revetment	Protection of heritage site and cultural site from flooding and/or erosion	Not evaluated
	Ishdhoo	· Revetment		
Addu	Meedhoo	· Beach nourishment and groins		

Source: JICA

The evaluation was carried out assuming two cases, namely: with and without the project as shown in Table 2.2.3. It was assumed that the damage, in case of without the Project, will be prevented by the implementation of the Project, and the damage was considered to be equivalent to the benefit of the Project. The economic analysis was carried out according to the Guidelines for Cost and Benefit Analysis of Coastal Protection (In Japanese, June 2004, Ministry of Agriculture, Forestry and Fisheries, and Ministry of Land, Infrastructure, Transport and Tourism)

Table 2.2.3 Assumptions for Economic Analysis

Cases	Description
Without case	No coastal project will be implemented 1) Existing national land will keep eroding 2) Flooding occurs at hinterland due to wave overtopping
With case	Coastal conservation project will be implemented 1) Existing national land will be protected from erosion 2) Hinterland will be protected against flooding and safety is improved

Source: JICA

(1) Benefit

Chapter 3 of this Annex contains the detailed evaluation procedures of the benefit for Maamendhoo and Fonadhoo. The results of the expected annual benefit in each representative year for both erosion prevention and flooding protection are summarized in Table 2.2.4. The benefits expected for the other years were estimated by linear approximation based on values presented in the table and were used for the cashflow of the economic analysis.

Table 2.2.4 Expected Annual Benefit (USD/year)

Target Island	2019	2030	2050	2100
Maamendhoo	599,316	887,831	3,427,310	686,178
Fonadhoo	797,709	945,925	1,768,727	2,727,362
Total	1,397,025	1,833,756	5,196,037	3,413,540

Source: JICA

(2) Cost

The project cost for Component 2 used for the analysis is shown in Table 2.2.5. The cost includes the construction and the consultant for the whole Component 2 (see Annex 4 for details). The construction cost includes 20% contingency cost considering uncertainty of implementation such as material and machine procurement, price escalation, and construction schedule.

Table 2.2.5 Project Cost by Year for Component 2

Unit: 1,000 USD

2021	2020	2023	2024	2025
167	84	1,402	9,122	11,128
2026	2027	2028	**Total**	
7,447	241	441	**30,031**	

Source: JICA

2.3 Component 3: Development of Disaster Warning and Information Dissemination

The proposed Component 3 consists of the following activities (see FP main text for details).

Activity 3.1: Installment of Terrestrial Digital Broadcasting System
Activity 3.2: Establishment of Disaster Early Warning and Information Broadcasting System

2.3.1 Impact Potential/Number of Beneficiaries of Coverage

Beneficiaries of coverage: 372,000 people
Based on the preparatory survey report*, the proposed terrestrial broadcasting will cover 172 islands out of the 201 inhabitant islands. The coverage corresponds to 91.23% of the total population of the Maldives. Therefore, the number of beneficiaries of the coverage is estimated at 372,000, which is 91.23% of the total population (407,660 from the Census 2014) of the Maldives.

* Preparatory Survey Report on the Project for the Digital Terrestrial Television Broadcasting Network Development in the Republic of Maldives (October 2016, JICA)

2.3.2 Efficiency and effectiveness/cost-effectiveness

The benefit expected through the implementation of Component 3 is evaluated by the following procedures focusing on effect by the disaster warning system. Since there are very few knowledge and studies on the valuation of the system, this evaluation was conducted mostly refereeing to a case study in Samoa[1] to evaluate the benefit.

In the article[1], a benefit type due to EWS (early warning system) was estimated as a damage reduction by removal of items during the lead time, such as household items, possessions, money, machinery equipment, office equipment and furniture.

According to the article, monetary benefit due to EWS was evaluated by the Equation 1 and the damage amount, which corresponds to D in the equation, was applied from the damage estimation by Cyclone Evan in 2012. Since the damage by Cyclone Evan was reported by kind of industry, the benefits were also evaluated by industry basis in Samoa case.

B = D x R x F x P --(Equation 1)

B: Annual benefit (USD/year)

D: Damage amount (USD/ disaster)

R: Damage reduction ratio by EWS (estimated as 25% based on interview survey)

F: Frequency (times/year, once in five years)

P: Probability of correct forecast (0.9, 9 out of 10 cases)

In this study for Maldives, however, available and/ or reliable data for actual damage in details by past disasters such as storm surge and high wave is rather limited.

With conditions and limitations aforementioned, this analysis had to take an “indirect” approach to evaluate the damage in Maldives by referring to those reported in Samoa case. As shown in Table 2.3.1, ratio of the damage to GDP was calculated by industry in Samoa, then the same ratio was applied to estimate damage in Maldives by multiplying with its GDP by industry. It should be noted that a “direct”

[1] Bapon S.H.M. Fakhruddin, Lauren Schick (2019). Benefits of economic assessment of cyclone early warning systems – A case study on Cyclone Evan in Samoa

approach with site specific conditions is more desirable in future stage such as detailed design if relative conditions and data are available.

Table 2.3.1 Damage Estimation in Maldives based on Samoa Case

	Samoa			Maldives	
Representative industry	(1) GDP[1] (SAT mil.)	(2) Damage [2] (SAT mil.)	(3) Percentage (2) / (1)	(4) GDP[1] (USD mil.)	(5) Damage[3] (USD mil.) (4) x (3)
Agriculture	152.6	4.64	3%	55.6	1.7
Fishery	36.4	2.07	6%	180.6	10.8
Manufacturing	110.2	17.25	16%	109.6	17.5
Tourism	697.53	27.7	4%	1,317.5	52.7
Total					**82.7**

[1] 2018 for Samoa and 2019 for Maldives with exchange rate of 1MVR=0.065USD
[2] Estimated damage for each industry by Cyclone Evan (2012), considered as the event with 5-year return period
[3] Assumed damage by sector for Maldives by a disaster with similar return period of Cyclone Evan (i.e. 5-year return period)

Assuming that the damage estimated in Maldives will occur with similar frequency of Cyclone Evan, i.e. once in five years, the frequency of occurrence was simply estimated as 0.2 times/year. The population coverage of the system in Component 3, 91.23% was also considered to evaluate benefit. Finally, monetary benefit for Component 3 was calculated as follows. This estimated benefit is incorporated with the economic analysis in Chapter 4.

B= D x R x F x P x 0.9123(population coverage)

= 82.7 (mil USD/ disaster) x 0.25 x 0.2 (times/year) x 0.9 x 0.9123

= <u>3.395 (mil USD/year)</u>

2.4 Component 4: Development of Basic Data Collection and Sharing System Related to Climate Change

The proposed Component 4 consists of the following activities (see FP main text for details).

Activity 4.1: Development of wave and sea level monitoring system
Activity 4.2: Development of beach, coral reef, and land use monitoring system

2.4.1 Efficiency and Effectiveness/ Long-term Economic and Financial Viability

The wave and sea level monitoring system that will be installed in this component aims to collect long-term data of at least ten years that is statistically reliable for analysis of wave characteristics at designated regions. The analysis will be applied to evaluate the degree of coastal risk due to climate change and to aid in the detailed design of coastal protection measures. The wave and sea level recorders which will be installed at offshore locations are exposed to solar rays and sea waves and thus, they require frequent maintenance and replacement of parts done by professional technicians during the monitoring period. To make the monitoring system sustainable in terms of finance, maintenance items required in the long term (i.e., ten years) as well as the yearly maintenance plan of the wave recorder should be prepared, as shown in Table 2.4.1. The costs required for equipment and professional technicians are all included in the budget plan for the Component 4.

Table 2.4.1 Maintenance Plan for Wave and Sea Level Recorder for Ten Years

Year		First five years					Latter five years				
		Initial installation	1	2	3	4	5	6	7	8	9
Overhaul Maintenance		-				Y					
Exchange	Electric accumulator	-			Y			Y			Y
	Rubber gasket	-	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Hood	-			Y			Y			Y
	Metallic material	-	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Packing	-	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Spacer	-	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Anticorrosion plate	-	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Float	-			Y			Y			Y
	Rope	-	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Shackle	-		Y		Y		Y		Y	

Y: Maintenance or exchange required
Source: JICA

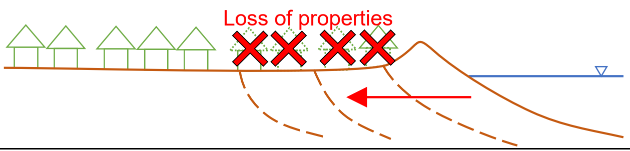
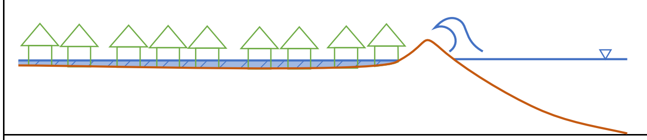
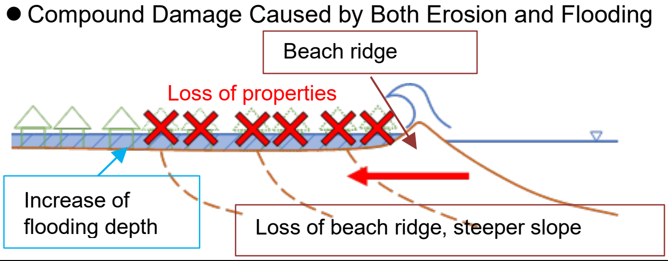
3 Benefits Estimated by the Implementation Measures against Coastal Erosion and Flooding

3.1 Overview of the Compound Damage by Coastal Erosion and Flooding

The schematic figure for the compound damage of coastal erosion and flooding is shown in Table 3.1.1. The following impacts are expected to accelerate due to this phenomenon:

- The beach ridge, which is a wave-deposited ridge parallel to the shoreline, is generally formed and developed after experiencing high waves. However, once the beach ridge erodes and disappears due to coastal erosion, the protection function of the beach would be reduced.
- The beach scarp, which is a steep slope or miniature cliff formed by wave action, will develop as coastal erosion progresses, and this will increase the wave overtopping at the hinterland.
- In addition to the abovementioned phenomenon, the wave force acting on the shore will increase and would further accelerate coastal erosion.

Table 3.1.1 Schematic Figure of the Compound Damage of Coastal Erosion and Flooding

<table>
<tr><th>Schematic Figure of the Compound Damage</th><th>Description</th></tr>
<tr><td>● Damage Solely by Coastal Erosion
</td><td>• National land will be lost due to coastal erosion.
• In case there are properties such as houses, their value will also be lost due to erosion.</td></tr>
<tr><td>● Damage Solely by Flooding
</td><td>• Flooding will occur at the hinterland due to severe wave overtopping at the shore.
• Properties located inside the flood area will suffer damage depending on the degree of flood depth.</td></tr>
<tr><td>● Compound Damage Caused by Both Erosion and Flooding
</td><td>• The beach ridge will be lost, and the beach slope will become steeper as coastal erosion progresses.
• This will weaken the protection function that the beach used to have and will increase wave overtopping at the hinterland.
• The wave force acting on the shore will increase and will increase the rate of coastal erosion.</td></tr>
</table>

Source: JICA

Considering the above, the compound damage was evaluated and the damage maps are shown in Figure 3.1.1 for Maamendhoo and in Figure 3.1.2 for Fonadhoo. Table 3.1.2 shows the evaluation condition for the compound damage. (See Chapter 6 of Annex 2 for the setting of evaluation condition)

The coastal erosion rate was set as the summation of the 1) maximum annual erosion rate from the shoreline change analysis using past satellite images (see Section 6.2.2 of Annex 2) and 2) the acceleration rate of erosion due to sea level rise (SLR) (see Section 6.2.3 of Annex 3). In general, the erosion rate is set as either the average rate of the target area or one of the maximum rates. In this study, the latter was adopted to evaluate the risk at the maximum side.

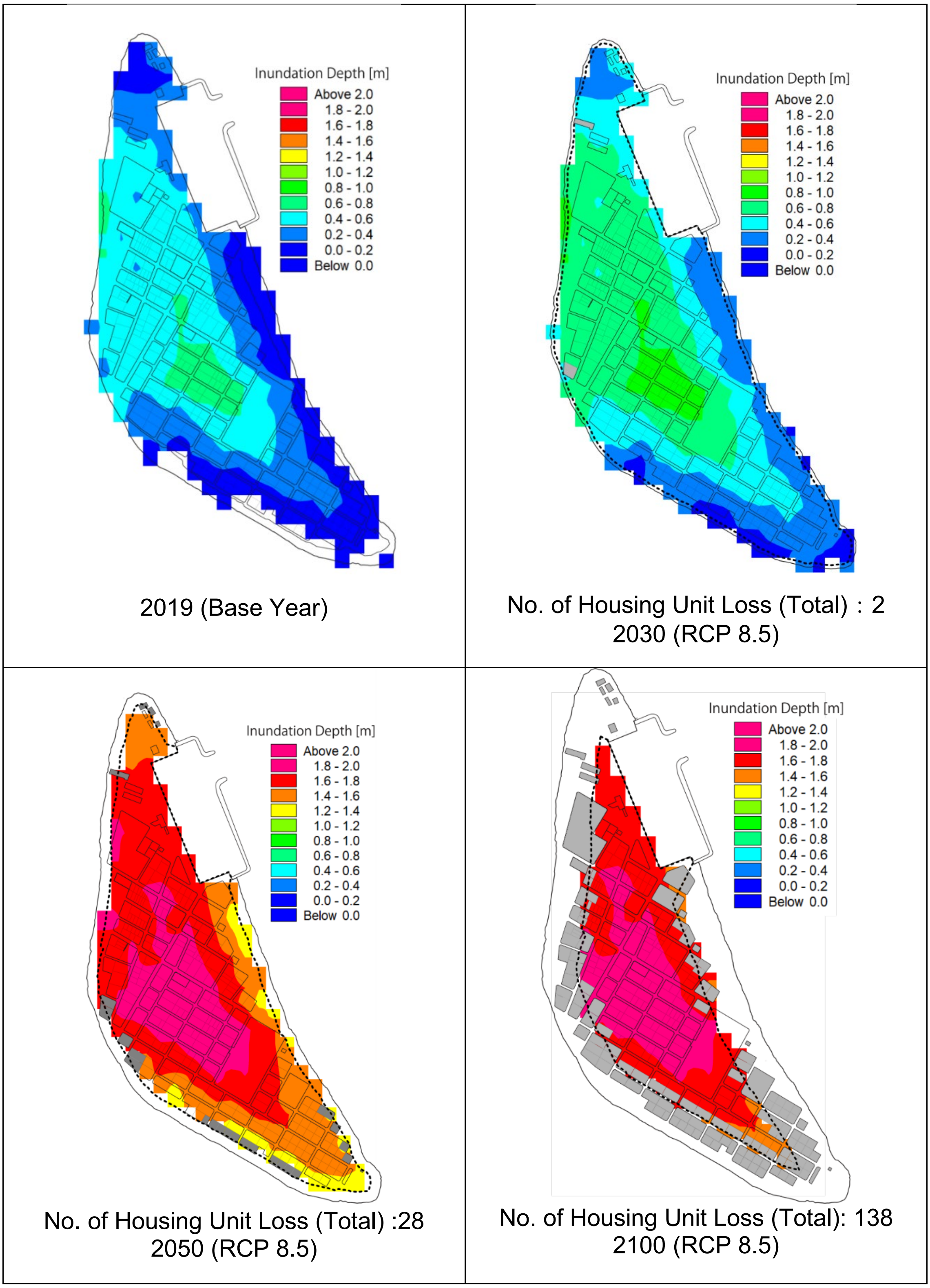
Table 3.1.2 Evaluation Condition for the Compound Damage of Erosion and Flooding

		2019	2030	2050	2100
Tide Level：H.W.L.		+0.64 m			
SLR (RCP 8.5)		—(Base)	0.04 m	0.17 m	0.65 m
Offshore Wave Height	Maamendhoo	$H_{1:10}$= 2.0 m, T= 10 s			
	Fonadhoo	$H_{1:10}$= 3.0 m, T= 16 s			

Erosion Rate	Maamendhoo	0.55 m/year	0.55 m/year	0.60 m/year	0.84 m/year
	Fonadhoo	0.47 m/year	0.47 m/year	0.67 m/year	0.92 m/year

Source: JICA

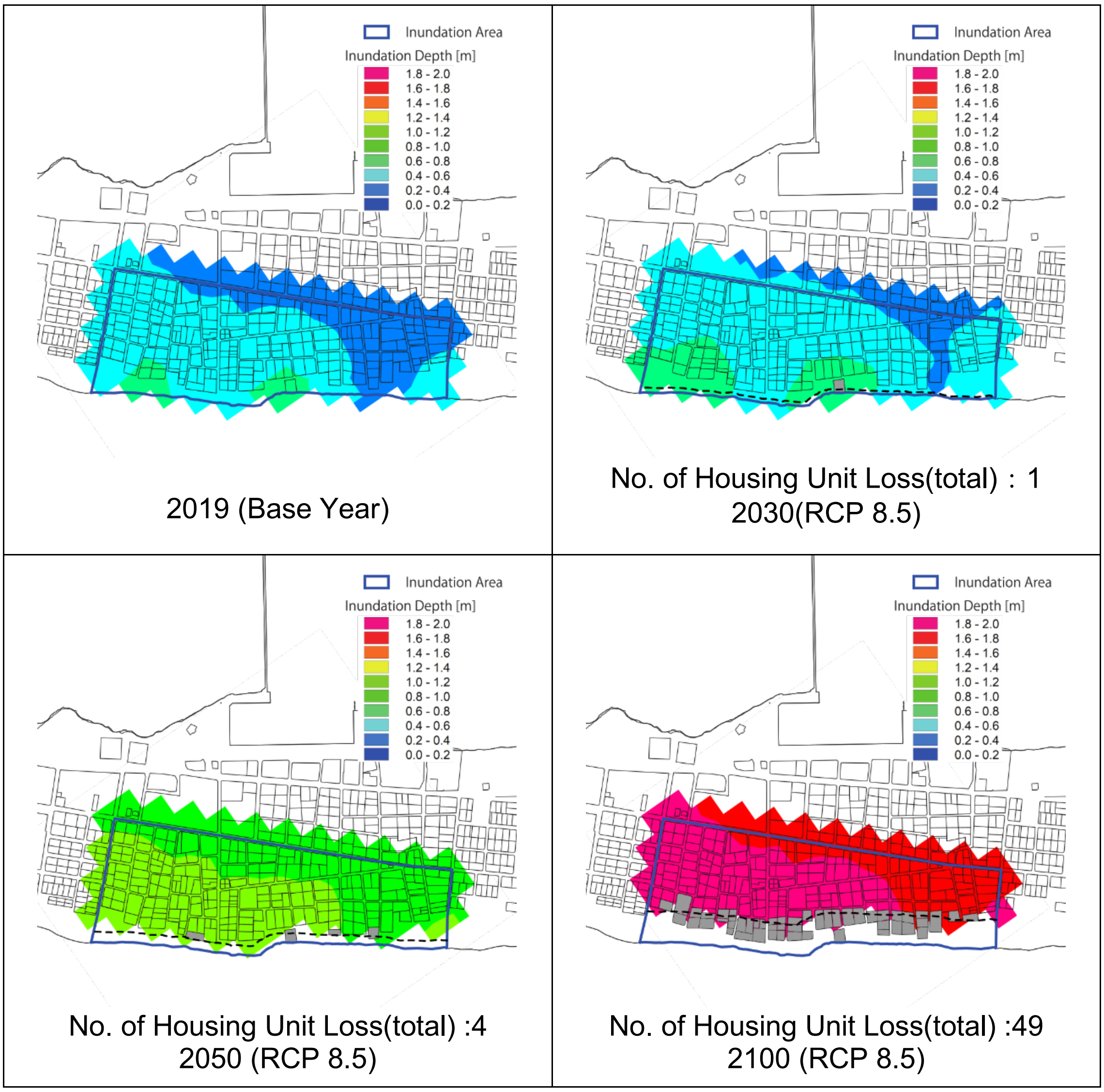
With the evaluation condition shown in Table 3.1.2, erosion and flooding analysis was conducted for Maamendhoo and Fonadhoo in each target year and the results are shown in Figures 3.1.1 and 3.1.2, respectively (See Sec. 6.3.2 of Annex 2 for procedures of the analysis).



*Black dotted line: Eroded shoreline, Gray highlighted: Houses lost

Source: JICA

Figure 3.1.1 Compound Damage Map Due to Erosion and Flooding with SLR for Maamendhoo



*Black dotted line: Eroded shoreline, Gray highlighted: Houses lost。

Source: JICA

Figure 3.1.2 Compound Damage Map Due to Erosion and Flooding with SLR for Fonadhoo

3.2 Classification and Calculation of the Compound Damage

(1) Classification of the Compound Damage

The compound damage caused by coastal disasters (coastal erosion and flooding due to high wave) was classified into the four groups listed in Table 3.2.1. In the study, items marked with “Y” in the table were evaluated in monetary value while items marked with “–” were not evaluated quantitatively due to difficulties in assuming the primary unit required for calculation.

Table 3.2.1 Classification of the Compound Damage

Damage Type	Item	Quantitative Evaluation
1) Physical Damage	Flooding damage on properties (houses)	Y
	Erosion damage on properties (loss of houses)	Y
	Erosion damage on national land (loss of land)	Y
2) Damage on People's Lives	Resettlement forced due to loss of houses	Y
	Difficulties and inconvenience on beach use	-
3) Economic Damage	Loss of work opportunities due to business suspension	Y
	Damage on island's economic function such as logistics and tourism	-
4) Environmental Damage	Damage on biological environment	-

Y: Calculated in this study
- : Not calculated
Source: JICA

(2) Calculation of Damage Amount

1) Physical Damage

As shown in Table 3.2.1, the physical damage was classified into damage due to coastal erosion (properties and national land) and flooding.

i) Flood Damage

Assumption : It was assumed that the hinterland was flooded due to high wave under extreme weather condition and properties (houses and household commodities) would be affected in accordance with the degree of flood depth.

Calculation Overview : Flood damage was calculated based on the assumed flood area and flood depth (see Figure 3.1.1 for Maamendhoo and Figure 3.1.2 for Fonadhoo), with mainly three items listed in Table 3.2.2.

Table 3.2.2 Items Used for the Calculation of Damage

Item	Description
a) Value of asset (house)	Interview survey results were used to determine value of houses as there was no statistical data available. → USD 30,000/house (Since no official construction cost per house available, this figure was set based on average construction cost per house from the interview survey results by the JICA Expert Team)
b) Damage rate by inundation depth	Cited from the Guidelines for Cost and Benefit Analysis (Refer to Table 3.2.3)
c) Probability of occurrence	Cited from the Guidelines for Cost and Benefit Analysis

(flooding)	(Refer to Table 3.2.4)

Source: JICA

Table 3.2.3 Damage Rate of Property by Inundation Depth

Property \ Degree of Flooding	Below Floor Level	Above Floor Level				
		Below 50 cm	50-99 cm	100-199 cm	200-299 cm	Above 300 cm
House	0.045	0.151	0.229	0.480	1.000	1.000
Household Product	0.021	0.189	0.489	0.889	1.000	1.000

Source：The Guidelines for Cost and Benefit Analysis of Coastal Protection (Japanese, June 2004, Ministry of Agriculture, Forestry and Fisheries, and Ministry of Land, Infrastructure, Transport and Tourism)[10)]

Table 3.2.4 Probability of Occurrence and Damage

Return Period	Probability of Exceedance	Expected Damage	(1) Annual Ave. of Occurrence Probability	(2) Annual Ave. of Expected Damage	Expected Annual Damage With the Probability (1) × (2)
1-year return period	$N_1=1$	$L_1(=0)$	N_1-N_{10} (=1-1/10)	$(L_1+L_{10})/2$	$((N_1-N_{10})\times(L_1+L_{10}))/2$
10-year return period	$N_{10}=1/10$	L_{10}			

Source：The Guidelines for Cost and Benefit Analysis of Coastal Protection[10)]

ii) Coastal Erosion Damage

A) Loss of Properties (Houses)

Assumption：It was assumed that property (house) will be lost due to coastal erosion as the basement of the house would be affected by erosion. Once lost, the property will be eliminated from the damage evaluation to avoid overestimation.

Calculation Overview：Prosperity was counted as lost when the eroded shoreline reaches the property. The damage amount due to loss was calculated based on the value of the assets shown in Table 3.2.2.

B) Loss of National Land

Assumption：It was assumed that the land area inside the present shoreline is all national land, and coastal erosion across this border was evaluated as loss of national land. Once lost, the land will be eliminated from the damage evaluation to avoid overestimation.

Calculation Overview：The damage amount was calculated using the formula below. Land unit value was set at USD 5/m^2 referring to the guidelines* as a reliable statistical value was not available in the Maldives.

* The Guidelines for Cost and Benefit Analysis of Coastal Protection (Japanese, June 2004, Ministry of Agriculture, Forestry and Fisheries, and Ministry of Land, Infrastructure, Transport and Tourism)

<Calculation Formula>

Damage of loss of national land (USD/year) = Annual erosion rate (m/year) × Shoreline distance (m) × Land unit value (USD/m^2)

iii) Calculation Results of the Compound Damage

The calculation results are shown in Table 3.2.5 for Maamendhoo and Table 3.2.6 for Fonadhoo.

Although the damage amount is generally presented on an annual basis, the accumulative damage over the years was also presented for coastal erosion as reference. Even though the damage due to erosion is much smaller than that of flooding on an annual basis, it should be noted that coastal erosion is a type of irreversible disaster that progresses slowly. In fact, if evaluated as accumulated damage, as shown in Figure 3.2.1, the damage due to erosion is not negligible even compared with the damage due to flooding. Thus, it is indicated that taking specific countermeasures against coastal erosion is essential especially in the long term.

In Figure 3.2.1, a slight decrease of damage due to flooding is observed from 2050 to 2100. This is because the number of properties affected by flooding decreased during the period due to coastal erosion. On the other hand, damage due to erosion increased during the same period.

Table 3.2.5 Estimated Damage for Maamendhoo (RCP 8.5, $H_{1/10}$)

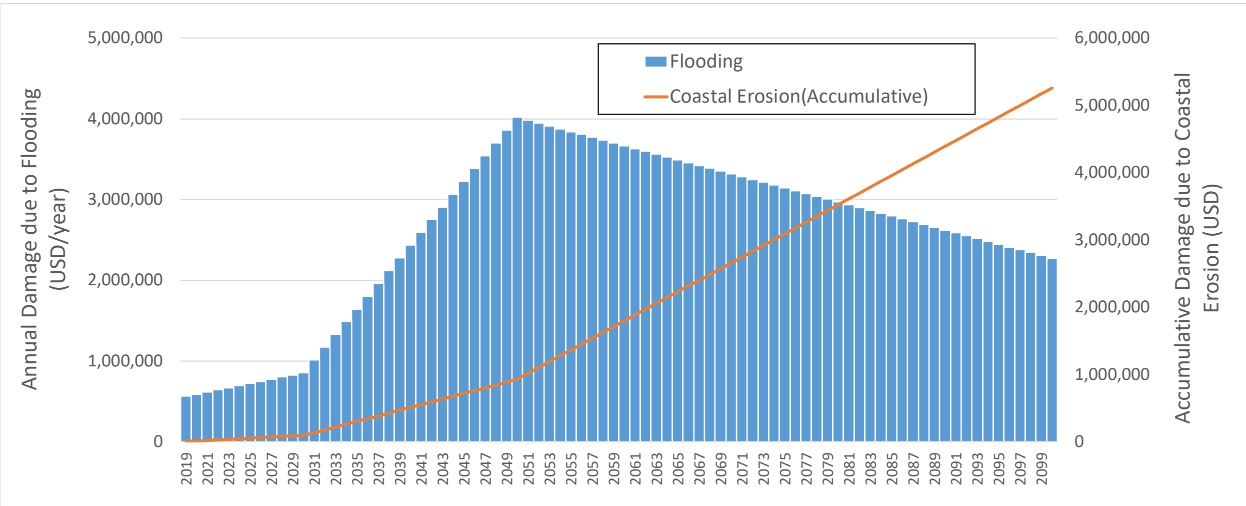
Damage	Unit	2019	2030	2050	2100
Flooding	USD/year	564,084	855,900	4,017,074	2,273,225
Erosion	USD/year	7,909	7,909	41,700	69,794
	USD (Accumulative)	7,909	94,909	928,909	4,418,615

Source: JICA

Table 3.2.6 Estimated Damage for Fonadhoo (RCP 8.5, $H_{1/10}$)

Damage	Unit	2019	2030	2050	2100
Flooding	USD/year	555,498	664,686	1,568,133	2,753,744
Erosion	USD/year	4,736	4,736	7,348	31,550

Source: JICA



Source: JICA

Figure 3.2.1 Comparison of Damage Amount for Maamendhoo Case: Flooding (USD/year) VS Coastal Erosion (USD, Accumulative)

2) Damage on People's Lives

Assumption: In case houses and housing land would be lost due to coastal erosion, the owner would be obliged to resettle to other areas or island because reconstruction of the house at the original area would not be realistic in terms of the physical and safety aspects.

Calculation Overview: The damage was estimated using the equation below considering the reconstruction cost required for the number of lost properties (houses).

<Calculation Formula>

B=A×C

B: Annual damage (USD/year)
A: Number of affected properties
C: Value of asset (USD 30,000/house, cited in Table 3.2.7)

Table 3.2.7 Estimated Damage on People's Lives (RCP 8.5, $H_{1/10}$)

Target	Unit	2019	2030	2050	2100
Maamendhoo	USD/year	5,455	5,455	39,000	66,000
Fonadhoo	USD/year	2,727	2,727	4,500	27,600

Source: JICA

3) Economic Damage

Assumption: If a house was affected by flooding, this will affect the resident's work environment and force residents to spend a certain period of time before getting back to work as usual. The lack of work opportunities during this period was evaluated as the damage to the economy.

Calculation Overview: The damage was estimated using the formula below. In the formula, income per capita was used as the unit to estimate economic loss. Thus, it is interpreted that the damage contains losses on industries such as fishery and tourism.

<Calculation Formula>

B=A×C×D×R×P

B: Annual damage (USD/year)
A: Income per capita, USD 10,626/person (National Accounts (Maldives) - Analysis of Main Aggregates, United Nations, 2019)
C: Number of affected people (number of people inside the flooding area)
D: Period for loss of work opportunities (assumed to be six months at the maximum, classified by flooding depth)
R: Damage rate by flooding depth (The Guidelines for Cost and Benefit Analysis of Coastal Protection (Japanese, June 2004, MAFF and MLTI))
P: Probability of occurrence (associated with return period of offshore wave)

Table 3.2.8 Estimated Damage on Economy (RCP 8.5, $H_{1/10}$)

Target	Unit	2019	2030	2050	2100
Maamendhoo	USD/year	254,936	363,834	1,170,850	723,207
Fonadhoo	USD/year	234,748	273,776	422,446	858,411

Source: JICA

(3) Summary of Estimated Annual Damage and Damage Reduction Effect by Countermeasures

Table 3.2.9 and Table 3.2.10 show the summation of the damage for Maamendhoo and Fonadhoo, respectively. The estimated damage amount rapidly increases due to SLR. The annual damage is estimated to be about USD 5 million/year from 2050 to 2100 for each island.

Table 3.2.9 Estimated Annual Damage for Maamendhoo (USD/year)

Damage Type	Items	2019	2030	2050	2100
Physical Damage	Flooding	564,084	855,900	4,017,074	2,273,225
	Coastal erosion (loss of properties and national land)	7,909	7,909	41,700	69,794
Damage on People's Lives	Resettlement	5,455	5,455	39,000	66,000
Economic Damage	Loss of work opportunities	254,936	363,834	1,170,850	723,207
Total		832,384	1,233,098	5,268,624	3,132,226

Source: JICA

Table 3.2.10 Estimated Annual Damage for Fonadhoo (USD/year)

Damage Type	Items	2019	2030	2050	2100
Physical Damage	Flooding	555,498	664,686	1,568,133	2,753,744
	Coastal erosion (loss of properties and national land)	4,736	4,736	7,348	31,550
Damage on People's Lives	Resettlement	2,727	2,727	4,500	27,600
Economic Damage	Loss of work opportunities	234,748	273,776	422,446	858,411
Total		797,709	945,925	2,002,427	3,671,305

Source: JICA

Table 3.2.11 and Table 3.2.12 show the damage amount estimated in case the proposed countermeasures were implemented for Maamendhoo and Fonadhoo, respectively (see Chapter 9 of Annex 2 for the details of the countermeasures).

Damage due to erosion was estimated to be zero assuming that the shoreline would not erode inland from the existing shoreline using the following two measures: 1) Beach nourishment with about 30 m beach width at high water level (H.W.L.) and 2) technology transfer program to realize future adaptive measures by applying stockpiled sand.

No damage is estimated in 2019 (present) and 2030 if the said countermeasures were implemented. Certain degree of damage will be estimated after 2050. However, the damage will be greatly reduced due to the countermeasures.

Table 3.2.11 Estimated Annual Damage with Countermeasures for Maamendhoo (USD/year)

Damage Type	Items	2019	2030	2050	2100
Physical Damage	Flooding	0	0	338,364	1,652,157
	Coastal erosion (loss of properties and national land)	0	0	0	0
Damage on People's Lives	Resettlement	0	0	0	0
Economic Damage	Loss of work opportunities	0	0	170,106	560,644
Total		0	0	508,470	2,212,801

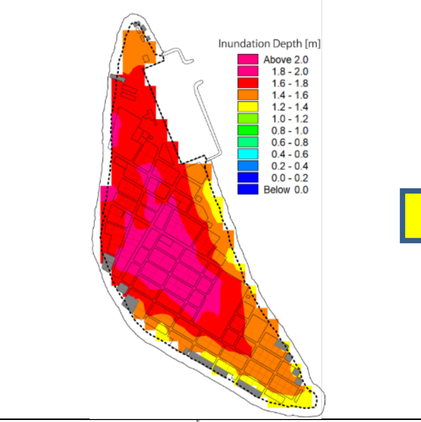
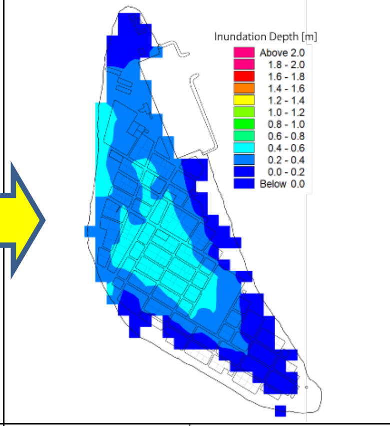
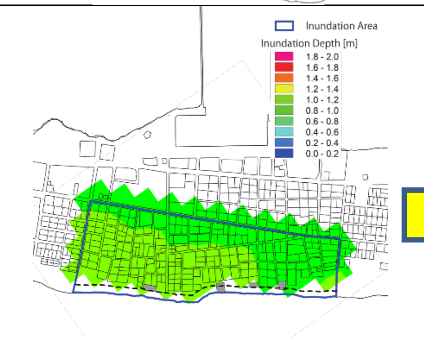
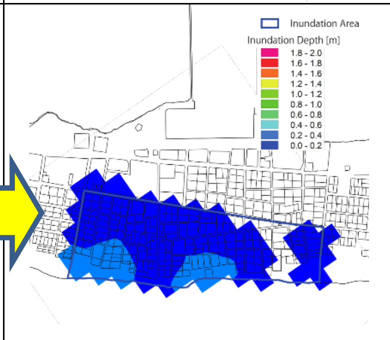
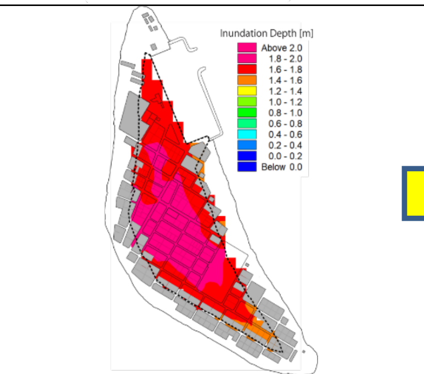
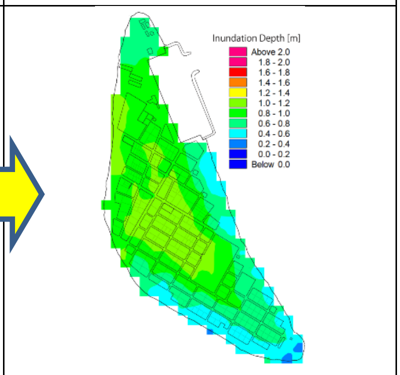
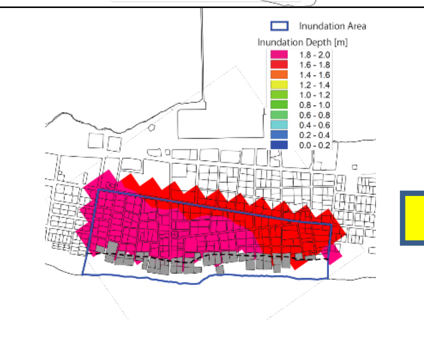
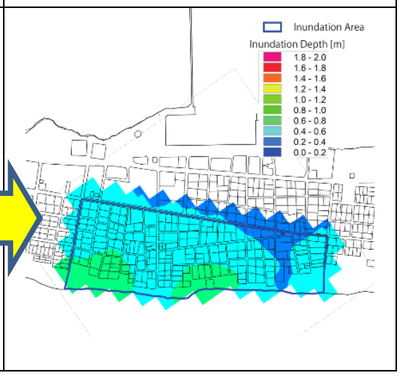
Source: JICA

Table 3.2.12 Estimated Annual Damage with Countermeasures for Fonadhoo (USD/year)

Damage Type	Items	2019	2030	2050	2100
Physical Damage	Flooding	0	0	146,124	670,167
	Coastal erosion (loss of properties and national land)	0	0	0	0
Damage on People's Lives	Resettlement	0	0	0	0
Economic Damage	Loss of work opportunities	0	0	87,577	273,776
Total		0	0	233,701	943,943

Source: JICA

Table 3.2.13 Comparison of Flood Depths With and Without Countermeasures (RCP 8.5)

Year	Target	Without Countermeasures	With Countermeasures
2050	Maamendhoo		
	Fonadhoo		
2100	Maamendhoo		
	Fonadhoo		

Source: JICA

Table 3.2.14 (Maamendhoo) and Table 3.2.15 (Fonadhoo), which illustrate the damage reduction effect through the implementation of the proposed countermeasure, were derived from the difference of Table 3.2.9 and Table 3.2.11, and Table 3.2.10 and Table 3.2.12, respectively. These values were used as benefit for the cost-benefit analysis. It is noted that the effect for Maamendhoo used for the cost-benefit analysis was evaluated considering the coverage ratio of the coastal protection measure to avoid overestimation of the benefit. The ratio was calculated to be 72% based on the length of coastal conservation measures (1,440 m) out of total coast line distance (2,000 m).

Table 3.2.14 Damage Reduction Effect of the Proposed Countermeasures (Maamendhoo)

Damage Type	Items	2019	2030	2050	2100
Physical Damage	Flooding	564,084	855,900	3,678,710	621,068
	Coastal erosion (loss of properties and national land)	7,909	7,909	41,700	69,794
Damage on People's Lives	Resettlement	5,455	5,455	39,000	66,000
Economic Damage	Loss of work opportunities	254,936	363,834	1,000,743	162,563
(1) Total		832,384	1,233,098	4,760,153	919,425
(2) Total (Applied in cost-benefit analysis) (1) X 72%		599,316	887,831	3,427,310	661,986

Source: JICA

Table 3.2.15 Damage Reduction Effect of the Proposed Countermeasures (Fonadhoo)

Damage Type	Items	2019	2030	2050	2100
Physical Damage	Flooding	555,498	664,686	1,422,009	2,083,577
	Coastal erosion (loss of properties and national land)	4,736	4,736	7,348	31,550
Damage on People's Lives	Resettlement	2,727	2,727	4,500	27,600
Economic Damage	Loss of work opportunities	234,748	273,776	334,870	584,635
Total		797,709	945,925	1,768,727	2,727,362

Source: JICA

4 Economic Analysis for the Whole Project

Economic analysis using cost-benefit analysis was employed in order to evaluate the economic feasibility of the whole Project which consists of the components in the Table below. The purpose of the economic analysis is to evaluate the proposed project from the viewpoint of the national economy. Economic analysis is evaluated using the CBR, EIRR, and net present value (NPV).

(1) Cost and Benefit Condition

Cost and benefit conditions used in the analysis were shown in the following tables.

Table 3.2.1 Cost and Benefit used for Economic Analysis by Component

Project Component	Cost (1,000 USD)	Monetary Benefit
Component 1 (ICZM)	2,255 (3%)	N/A
Component 2 (Coastal Conservation Measure)	30,031 (46%)	2030: 1.83 mil USD/year 2050: 5.20 mil USD/year (See Chap.2.2 and 3)
Component 3 (Digital Broadcasting and Disaster Warning system)	29,500 (45%)	3.395 mil USD/ year (See Chap.2.3)
Component 4 (Data acquisition)	800 (1%)	N/A
Project Management Component	3,421 (5%)	N/A
Total	66,008 (100%)	

Table 3.2.2 Project Cost by Year (1,000 USD)

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	Sub Total
Comp. 1	-	-	103	748	748	656	-	-	-	-	2,255
Comp. 2	-	-	167	84	1,402	9,122	11,128	7,447	241	441	31,416
Comp. 3	463	12,392	15,258	925	463	-	-	-	-	-	29,500
Comp. 4	-	-	59	249	249	243	-	-	-	-	800
PM	-	-	110	492	740	567	513	509	412	78	3,421
										Total	66,008

Source: Annex 4 Detailed Budget Plan

(2) Calculation Conditions

The following conditions are used for the economic analysis:

- Base year for evaluation: 2019
- Beginning year of benefit : 2027 for Component 2 and 2024 for Component 3
- Duration period of benefit :
  - Component 2: 50 years (a general evaluation period for coastal conservation measure)
  - Component 3: 30 years based on the preparatory survey report
- Discount rate : 5%

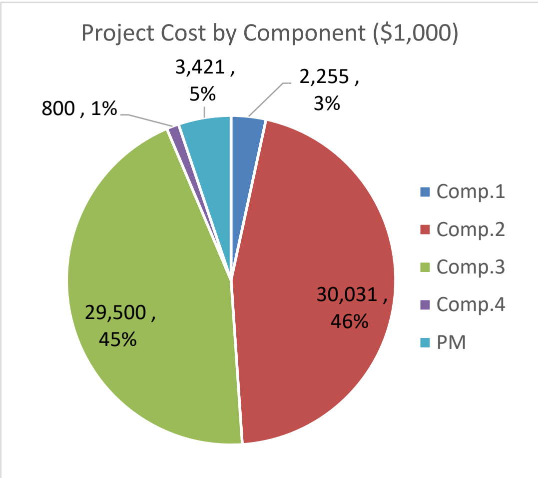
  Discount rate of 0%-4% is proposed for public works as countermeasures against climate change*. In this study, a discount rate of 5% was applied as a safety side of the evaluation.

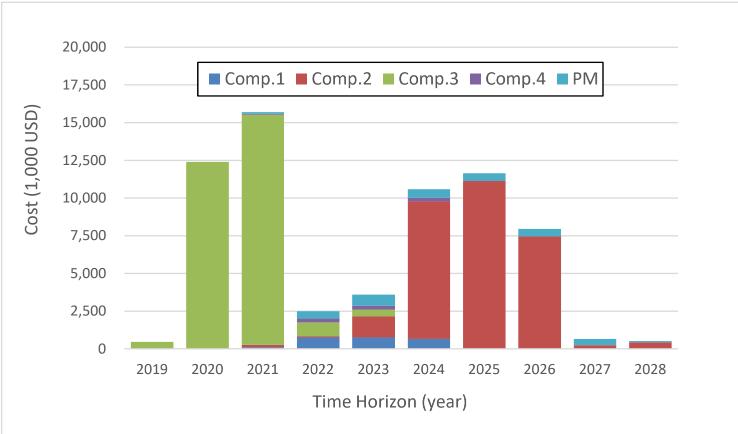
  *Ref) Economic Costs and Benefits of Climate Change Impacts and Adaptation to the Maldives Tourism Industry (2015)

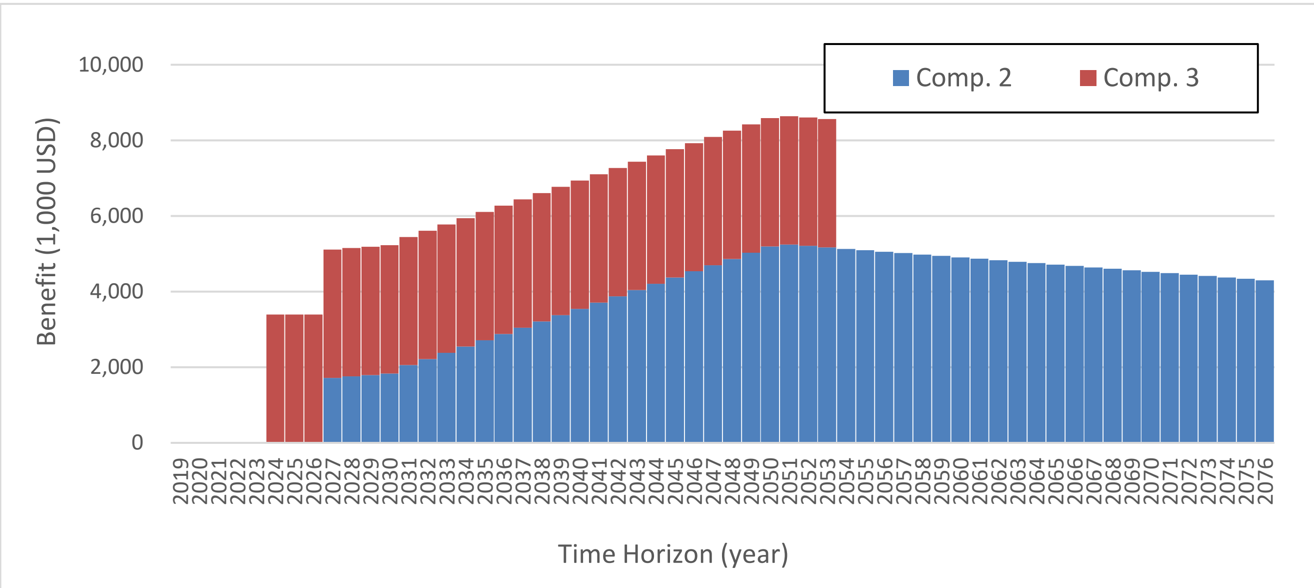
- <u>Maintenance cost</u>:
  - <u>Component 2</u>: Beach nourishment in general needs periodic sand replenishment after the initial implementation. Frequency of replenishment usually ranges from every three to ten years, while five years was adopted as an intermediate value for this evaluation. Maintenance cost was estimated at 0.5% of total construction cost, which is usually applied for coastal projects in Japan. Since frequency and cost for maintenance are quite site specific, a detailed study will be needed to estimate concise maintenance costs.
  - <u>Component 3</u>: According to JICA report, the maintenance cost for 30 years will be covered by revenue from the system, therefore, maintenance cost is not included in this analysis.

(3) Result of Economic Analysis

Time series of cost and benefit is shown in Figure 3.2.1 and the analysis result is shown in Table 3.2.3, where B/C ratio is 1.58 and the EIRR is 8.00%, which shows viability for implementation as public works.







Source: JICA

Figure 3.2.1 Time Series of Annual Cost (upper) and Benefit (lower) (Without Discount Rate)

Table 3.2.3 Economic Analysis Result

ECONOMIC ANALYSIS

The Whole Project:

- **Component 1: Establishment of ICZM**
- **Component 2: Implementation of Coastal Conservation Measure**
- **Component 3: Development of Disaster Warning System**
- **Component 4: Development of Basic Data Collection**
- **Project Management(PM) Component**

Discount rate	5%
Analysis year	2019
Total Project Period	(10 years)
Start	2019
Complete	2028

Analysis Result	
CBR(B/C)	1.58
NPV(B-C)	31,958 (x $.1000)
EIRR	8.00%

No	Year	Project Cost					Monetary Benefit		Net Benefit	Discount rate		Cost Based on 2019	Benefit Based on 2019
		Comp.1 (x $.1000)	Comp.2 (x $.1000)	Comp.3 (x $.1000)	Comp.4 (x $.1000)	PM (x $.1000)	Comp. 2 (x $.1000)	Comp. 3 (x $.1000)	(x $.1000)	multi-plier	Value	(x $.1000)	(x $.1000)
	Total	2,255	30,031	29,500	800	3,421	203,643	101,850	238,102	–	-	55,360	87,318
0	2019	-	-	463	-	-	-	-	(463)	0	1.00	463	-
1	2020	-	-	12,392	-	-	-	-	(12,392)	1	0.95	11,802	-
2	2021	103	167	15,258	59	110	-	-	(15,698)	2	0.91	14,238	-
3	2022	748	84	925	249	492	-	-	(2,497)	3	0.86	2,157	-
4	2023	748	1,402	463	249	740	-	-	(3,602)	4	0.82	2,963	-
5	2024	656	9,122	-	243	567	-	3,395	(7,192)	5	0.78	8,296	2,660
6	2025	-	11,128	-	-	513		3,395	(8,246)	6	0.75	8,687	2,533
7	2026	-	7,447	-	-	509	-	3,395	(4,561)	7	0.71	5,654	2,413
8	2027	-	241	-	-	412	1,715	3,395	4,457	8	0.68	442	3,458
9	2028	-	441	-	-	78	1,754	3,395	4,631	9	0.64	334	3,319
10	2029	-					1,794	3,395	5,189	10	0.61	-	3,186
11	2030	-					1,834	3,395	5,229	11	0.58	-	3,057
12	2031	-	138				2,052	3,395	5,309	12	0.56	77	3,033
13	2032	-					2,218	3,395	5,613	13	0.53	-	2,976
14	2033	-					2,383	3,395	5,778	14	0.51	-	2,918
15	2034	-					2,549	3,395	5,944	15	0.48	-	2,859
16	2035	-					2,714	3,395	6,109	16	0.46	-	2,799
17	2036	-	138				2,879	3,395	6,136	17	0.44	60	2,738
18	2037	-					3,045	3,395	6,440	18	0.42	-	2,676
19	2038	-					3,210	3,395	6,605	19	0.40	-	2,614
20	2039	-					3,376	3,395	6,771	20	0.38	-	2,552
21	2040	-					3,541	3,395	6,936	21	0.36	-	2,490
22	2041	-	138				3,707	3,395	6,963	22	0.34	47	2,428
23	2042	-					3,872	3,395	7,267	23	0.33	-	2,366
24	2043	-					4,038	3,395	7,433	24	0.31	-	2,305
25	2044	-					4,203	3,395	7,598	25	0.30	-	2,244
26	2045	-					4,369	3,395	7,764	26	0.28	-	2,183
27	2046	-	138				4,534	3,395	7,791	27	0.27	37	2,124
28	2047	-					4,700	3,395	8,095	28	0.26	-	2,065
29	2048	-					4,865	3,395	8,260	29	0.24	-	2,007
30	2049	-					5,031	3,395	8,426	30	0.23	-	1,949
31	2050	-					5,196	3,395	8,591	31	0.22	-	1,893
32	2051	-	138				5,245	3,395	8,502	32	0.21	29	1,813
33	2052	-					5,207	3,395	8,602	33	0.20	-	1,719
34	2053	-					5,169	3,395	8,564	34	0.19	-	1,630
35	2054	-					5,132		5,132	35	0.18	-	930
36	2055	-					5,094		5,094	36	0.17	-	879
37	2056	-	138				5,056		4,917	37	0.16	23	831
38	2057	-					5,018		5,018	38	0.16	-	786
39	2058	-					4,980		4,980	39	0.15	-	743
40	2059	-					4,942		4,942	40	0.14	-	702
41	2060	-					4,904		4,904	41	0.14	-	663
42	2061	-	138				4,866		4,728	42	0.13	18	627
43	2062	-					4,829		4,829	43	0.12	-	592
44	2063	-					4,791		4,791	44	0.12	-	560
45	2064	-					4,753		4,753	45	0.11	-	529
46	2065	-					4,715		4,715	46	0.11	-	500
47	2066	-	138				4,677		4,539	47	0.10	14	472
48	2067	-					4,639		4,639	48	0.10	-	446
49	2068	-					4,601		4,601	49	0.09	-	421
50	2069	-					4,563		4,563	50	0.09	-	398
51	2070	-					4,526		4,526	51	0.08	-	376
52	2071	-	138				4,488		4,349	52	0.08	11	355
53	2072	-					4,450		4,450	53	0.08	-	335
54	2073	-					4,412		4,412	54	0.07	-	317
55	2074	-					4,374		4,374	55	0.07	-	299
56	2075	-					4,336		4,336	56	0.07	-	282
57	2076	-	138				4,298		4,160	57	0.06	9	266

Source: JICA