VULNERABILITY ASSESSMENT OF PUERTO GALERA BAY TO CLIMATE CHANGE AS AFFECTED BY ITS BIOPHYSICAL CHARACTERISTICS AND URBANIZATION

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Abstract

The Puerto Galera Bay in the Mindoro Island of the Philippines is undoubtedly one of the most ecologically salient environments in the Philippines, serving as home to rare and endemic species of corals, reef fishes and seagrasses. It was cited as one of the most beautiful bays in the world, a distinction that has put environmental pressures in the bays with the increased tourist influx.

The study aimed at updating the Bay's biophysical attributes and doing a vulnerability assessment of the bay using GIS and Remote Sensing. Spatial modelling was done using parameters that included slope, land cover, climate, geology, and soil characteristics. Map overlays and calculations were done during the process of analysis.

The spatial modelling was able to determine the vulnerable areas to hazards like soil erosion, landslides, biodiversity loss and environmental degradation due to urbanization and increased human and tourist activities. With the advent of climate change, results showed that the Bay's criticality is because of its physical form and rugged terrain. Siltation due to unregulated land use changes, unsustainable urban developments, and tourist activities had resulted in biodiversity loss in marine environments (coral reefs, marine fishes and sea grasses). Policy recommendations included local and regional legislation for the protection and conservation of the bay, and regulation of tourist activities.

Keywords: urbanization, biodiversity loss, unsustainable development, vulnerability assessment

1. INTRODUCTION

Puerto Galera is one of the two Man and Biosphere (MAB) Reserves in the Philippines and as such, must be managed through protection and sustainable use of its resources. Within its bound is Puerto Galera Bay, which is undoubtedly one of the most ecologically salient ecosystems in Mindoro. In terms of biodiversity, the Bay serves as home to rare and endemic species of corals, reef fishes and seagrasses. Dr. J.E.Veron, a world renowned coral systematist and ecologist from Australia, upon seeing the unfamiliar coral species in the area concluded that the Bay and its harbors should be studied well because of the rich assemblage of unknown coral taxa in the area. The beauty that attracts many local and foreign tourists to its picturesque mountains, white beaches and underwater garden of coral reefs, makes this coastal niche essential to the economic and social wellbeing of the municipality of Puerto Galera.

A European-based environmental organization recently cited the Bay as one of the most beautiful bays in the world. This distinction further exerted greater environmental pressures with the anticipated tourist influx. Tourism has been associated with harsh impacts such as congestions, pollution and unsustainable use of coastal resources. These impacts would involve conflict of use between the social, economic and environmental sectors. Already, and despite the various national and local laws to instill and ensure protection measures, telltale signs of environmental degradations are becoming evident. Fortes (1997) reported on the environmental issues in the Bay which include increasing water pollution, disappearance of many marine organisms, sedimentation and eutrophication.

In light of these, there is an urgent need to formulate a rational management plan for the sustainable use of coastal and marine resources in the Bay. Towards this, one of the glaring weaknesses is the lack of spatial database to extract information from, to do environmental assessments that will serve as inputs to management plans. Presently most of the existing information and profiles of the Bay are in narrative, listings and tabular forms. A bio-physical characterization and vulnerability assessment must initially be done thru recent advances in spatial data gathering and processing techniques like remote sensing and Geographic Information systems (GIS).

The main aim of this study therefore is to upgrade the biophysical characterization of the Bay and render them in spatial database form for vulnerability assessment. The result of the study can ultimately serve as input in formulating management and zoning plans, rehabilitation and protection measures and doing carrying capacity studies.

2. OBJECTIVES

Conduct a biophysical characterization and vulnerability assessment of Puerto Galera Bay related to urbanization.

2.1 Conduct spatial analysis of the Bay and characterize it as to its existing landuses, slopes, soil, climate, geology, elevations, landforms, flora, fauna and bathymetry.

2.2 Assess the Bay as to its spatial vulnerability related to erosion/landslides.

2.3 Formulate recommendatory measures for rehabilitation and conservation of the Bay's resources.

3. METHODOLOGY/APPROACH

Methodologies involved the characterization and the vulnerability assessment phases of the study. Inputs for the vulnerability assessment came mostly from the characterization of the Bay.

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3.1.1 Data Gathering

Electronic base maps were acquired from different agencies that included the Mapping and Resources Information Authority (NAMRIA), Mines and Geosciences Bureau (MGB) and Bureau of Soils. Rainfall data were also acquired from the Philippine Atmospheric, Geophysical and Astronomical Services Administration. Past records were researched from the municipal development plan of Puerto Galera and other relevant information.

3.1.2 Field Work

Field work were mostly done for ocular observations and field verification of gathered data on land use/vegetation, imageries and other base maps.

3.1.3 Vulnerability Assessments

Five biophysical factors that include slopes, landuse/vegetation, climate (Rainfall and Typhoon Incidence), soil, geology were used in modelling the vulnerability of the area to landslides/soil erosion. These factors were given % weights and vulnerability ratings shown in **Table 1** (climate, landuse/vegetation and slopes), ERDB indexes were used in rating geology and soil (Appendix 1). The values of the weights and ratings were taken from the indexes developed by Ecosystems Research and Development Bureau (ERDB).

Combining these factors involved the reclassification of the maps that contained information of these factors using the vulnerability ratings of 1 to 5 with 1 as very high in vulnerable and 5 as very low. Indices used for the final computed vulnerability map with its rating were given color representations as shown in **Table 2.**

Table 1. Vulnerability indices for rainfall, Slope and land cover used in vulnerability assessment to landslide/soil erosion (Source: ERDB indices)

VulnerabilityRates (% Weight)	**Rainfall (20 %)**	**Slope (40 %)**	**Land use/cover (20 %)**
Very high (5)	>2500	>50	Most of area sparsely vegetated
High (4)	2000- 2500	30-50	50-70% sparsely vegetated
Moderate (3)	1500 - 2000	18-30	20-50% sparsely vegetated;30-40% forest
Low (2)	1000-1500	8-18	<20% bare/ Cultivated; 40-50% forest
Very low (1)	<1000	0-8	Close canopy >50% forest

Table 2. Indices for final map computed vulnerability Ratings and Color Codes

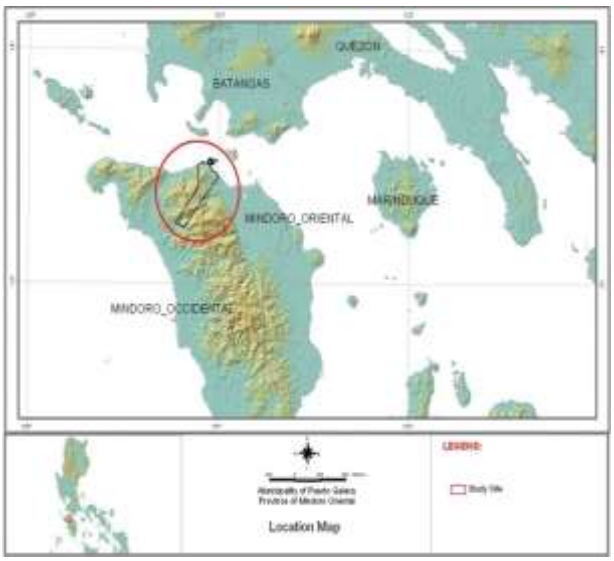
Map Computed Value from 5 Variables	Vulnerability Rating	Color Code
> 4.2	Very High	Red
3.5 - 4.19	High	Green
2.8 – 3.49	Moderate	Dark Blue
2.1 – 2.79	Low	Light Blue
< 2.1	Very Low	Yellow

4.0 BIOPHYSICAL CHARACTERIZATION OF THE BAY

4.1 Site Location

Puerto Galera Bay (longitude 120°56'24" to 121°59'30" East; latitude 13°30' to 13°31'58" North), is located in the north eastern part of the municipality of Puerto Galera in Mindoro Island. It is about 123 km. South of Manila. The total land area is 865.28 hectares (based on map calculations done through GIS). Its irregular coastline that forms series of headlands, promontories and coves is 35 kilometers long, to include its island coastlines. Medio Island which caps the Bay on its northern tip provides two entrances: the Manila Channel on its western seaboard; the Batangas Channel on its eastern side. **Figure 1 and 2** shows the location and political boundary maps of Puerto Galera..

Figure 1 Location map of Puerto Galera



4.2 Climate

The municipality of Puerto Galera falls under two climatic types according to the Coronas Classification (Type I occur on the upper areas characterized by two pronounced seasons; dry from November to April and wet during the rest of the year. The lower portion and the coastal areas where

Puerto Galera Bay is located belong to the Type III classification that is characterized by season of not very pronounced maximum rain period. It has only a short dry season lasting from one to three months.

Rainfall

Puerto Galera receives 2,000 mm rainfall annually as seen in **Figure 3**. The isohyetal map in the figure was interpolated from the 50-year data of 4 PAGASA meteorological stations located in Oriental Mindoro, Marinduque, Batangas and Quezon. Interpolation was done using the ArcGIS Program.

Wind and Tropical Cyclones

Typhoons have a big influence to the climate and weather condition of the Philippines. Significant percent and degrees of rainfall, humidity and cloudiness are due to the influence of typhoons. Oriental Mindoro for example receives generally low frequency of tropical cyclone passage ranging from 11-19 %. This means that out of the 24 average cyclones, storms and typhoons that enter the Philippines annually, 2-6 are expected to pass Mindoro from March to December. However occasional off season typhoons may occur. **Figure 4** shows the typhoon map of the Philippines where Puerto Galera Bay is rated in the high typhoon incidence location.

Figure 2. Political boundary map of Puerto Galera Bay (Source: 2015 Google Imagery).

4.3 Land Characteristics

Geology and Morphology

"Mindoro island started during the later cretaceous period when the existing basement metamorphics and Mansalay sedimentary rocks were intruded by ultrabasic rocks. This process resulted in the transformation of the basic metamorphics into a narrow-folded bed of hills along the hinterlands and likewise the transformation of flat lying Mansalay sedimentaries into a series of chevron like folds or rolling hills. Also, the intruding ultrabasic rocks formed a stocked like hills. During the Paleocene (oligocene) period, kerotophypic volcanism resulted in the upbuilding and thrusting of the earlier formed paleocen sedimentary rocks which in return resulted to another series of rolling sedimentary rocks and again resulted to another series of rolling sedimentary and volcanic hills. This diastrophism continued up to the middle miocene where the final horst-like divide between the two Provinces of Mindoro was uplifted and, in the process, formed the different mountains..." (Mines and Geosciences data)

This geologic base in the lands of Puerto Galera Bay is pliocene-pleistocene (**Figure 5**), which has a high rating in terms of susceptibility to landslide and erosion. **Figure 6** shows the rock arrangement in the molave forest area. This parallel rock formation is prone to landslide and when saturated during heavy storms, the rocks can easily slip thereby triggering a massive landslide.

Figure 3 Isohyetal Map of Puerto Galera interpolated from the 50-year rainfall data in 4 PAGASA stations.

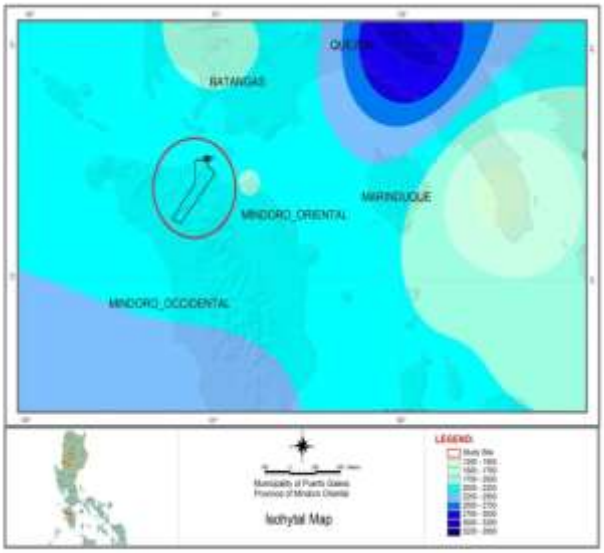


Figure 4. Typhoon incidence Map of Puerto Galera Bay (Source: PAGASA)

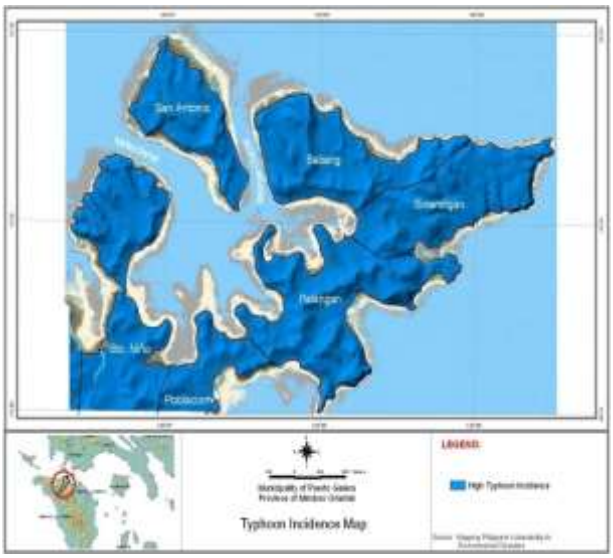


Figure 5. Geologic Map of Puerto Galera Bay (Source: Mines and Geosciences Bureau, DENR)

Figure 6 Rock formation in the Molave forest showing a parallel rock formation, which is susceptible to landslide especially during typhoon seasons.

Soils

The technical soil description of Puerto Galera Bay is tropudults w/tropudalfs as seen in f**igure 7**. This type has a very high rating in terms of susceptibility to soil erosion and landslides. The high amount of calcium and magnesium is expected since fieldspar, biotite, calcite and carbonate are the dominant minerals in the area. Data source is from the Philippines Bureau of Soils.

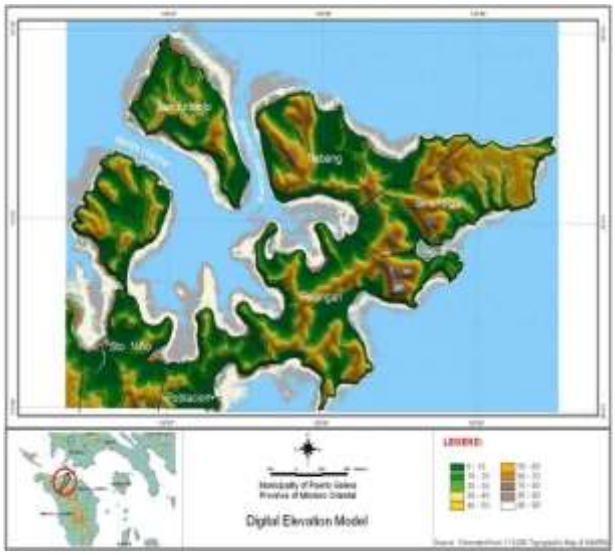
Elevation and Slopes

The highest elevation in Puerto Galera is 98 meters above sea level located in the mountain peaks of Palangan as seen in the digital elevation model (DEM) of the Bay (**Figure8**). Elevations and slopes of Puerto Galera Bay were extracted and processed using GIS.

Although the peaks around the bay are not that high, its ridges and promontories and coastal fronting hills are dominated by very steep slopes of 50 percent and above as seen in **Figure 9**. Sides of ridges are still considered steep with slopes ranging from 18 to 30 percent and 30 to 50 percent. Pocket land strips of mild slopes are located in San Antonio, Sinandigan and Sto Niño. Areas with mild slopes are mostly residential/commercial and tourist zones.

Figure 7 Soil map of Puerto Galera Bay (Source: Bureau of Soils Data)

Figure 8 Digital Elevation Model (DEM) extracted from the 1:10,000 topographic map of NAMRIA



Existing Land Use/Land Cover

Puerto Galera Bay is dominated by secondary forests and molave beach type forest. These larger tracts of Molave beach forests are located in Sabang, Palangan and Sinandigan, These forests are seen fronting the Coves of the Bays and cover critical areas like promontories and headlands (**figure 10**). Coconut and buri also covers many areas in the Bay especially in Sabang, San Antonio and Sinandigan and Sto Niño. The barangays of Sabang and poblacion have larger areas used for

residential, commercial and tourist areas while large open and bare areas can be found in Sinandigan, Palangan and Sabang. Existing Landuse map was processed from the Goggle imagery using the multispect which is a remote sensing program.

Figure 9. Slope map of Puerto Galera Bay extracted from the Digital Elevation Model (DEM) of the Bay.

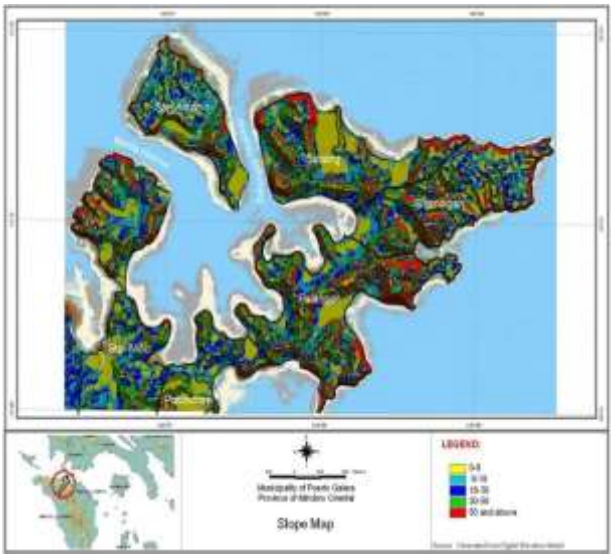
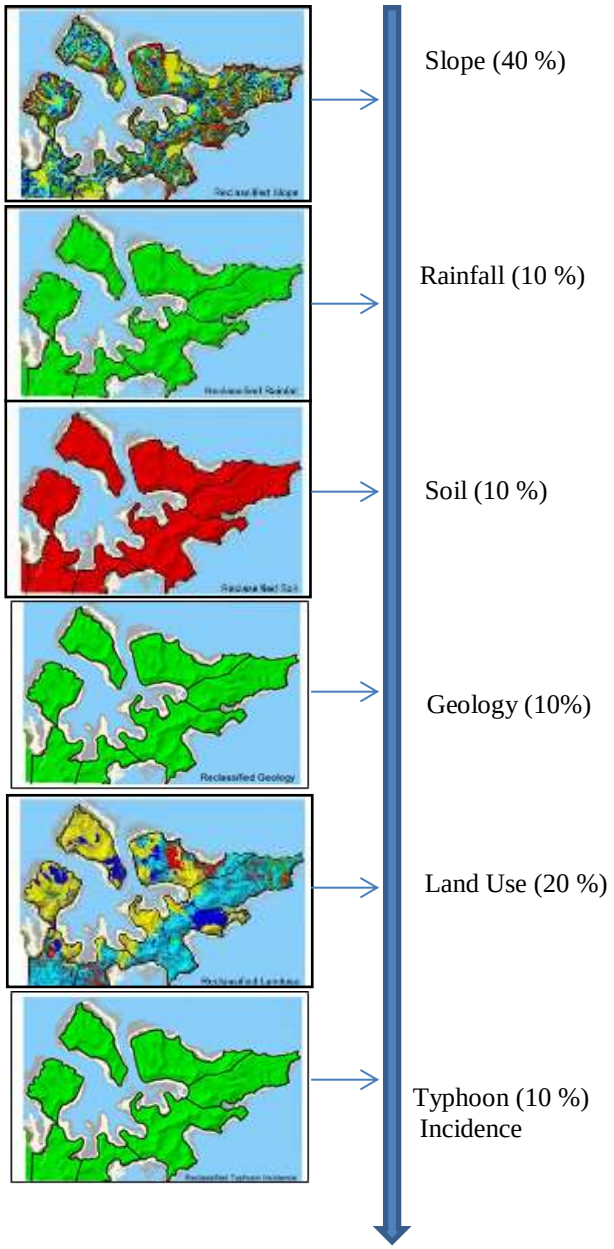


Figure 10 Existing land use map of Puerto Galera Bay delineated from the 2015 Google Imagery

5.0 RESULTS OF VULNERABILITY ASSESSMENT

The vulnerability map

The combination of factors that include climate, slope, land use/vegetation, Geology and soils were used to come up with the general vulnerability map of Puerto Galera Bay. The vulnerability map shown in **Figure 11** shows that majority of the area exhibits high vulnerability to landslide and soil erosion. These areas usually are of very steep slopes and landforms that are ravines or cliffs. Ocular validations also show that these areas are prone to landslides and mass soil movement especially during strong typhoons and inclement weather **(Figure 12)**. One factor that prevents excessive and heavy sedimentation and rampant landslides is the beach/molave and secondary forests that still abound in the bay. It also helps that these types of vegetation and land use covers steep slopes and mountain ridges.



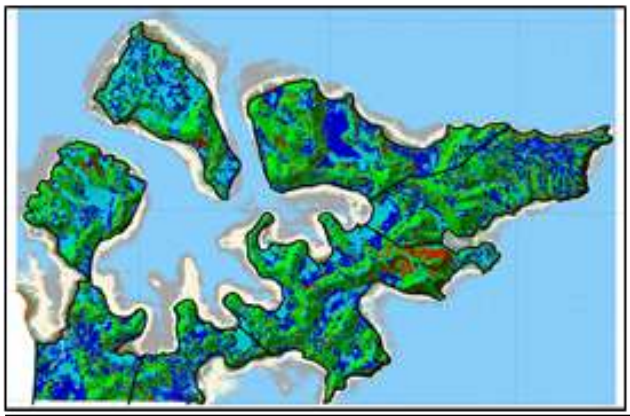


Figure 11. Vulnerability Map of Puerto Galera Bay

Landslide and Soil Erosion

Spatial rendition or maps of these factors were reclassified using their corresponding indices. Using a GIS program, these parameters were spatially computed to come up with the final vulnerability map of the bay as displayed in the framework seen in **Figure 11**.

In terms of landslide and soil erosion, highly critical areas in the Bay are located in its coastal perimeter, along headlands and promontories or sides of mountain ridges. This is seen as red areas in **Figure 11** (reclassified slope and Landuse Maps). This also corresponds to areas that are within 50 percent and above slopes that are mostly vertical cliffs facing coastal waters (**Figure 12**). Areas with mild slopes of 0-8 percent are mostly residential communities and tourist zones.

Figure 12 Promontories and cliffs with very steep slopes around the bay are very susceptible to landslides and mass soil movements. Photos show landslide occurrences especially during strong typhoons.

The enclosed water of Puerto Galera Bay is formed by surrounding narrow land strips and promontories jutting within and outside its boundaries. The beach and, coast areas are usually backed dropped by cliffs and near vertical slopes as seen in the 3-D rendition of the Bay extracted from the 1:10,000 topographic map draped with the 2015 Google imagery (**Figure 13**). In this type of land formation has narrow transition phases between each ecosystem from upland to mangroves to beach and finally to the marine environments. The created landscapes are fragile and vulnerable environments wherein activities in the uplands will l have an adverse and telling effect in its lower ecosystems due to the shortness in distances and steepness of slopes between its land use phases. Large vegetation clearing in the upland can create accelerated erosion and sedimentation of coastal waters that will directly impact into the seagrass and coral communities. This situation is seen in the 2006 satellite images of the Bay where large land tract clearing for commercial development results in heavy siltation of coastal waters around the immediate vicinities (**Figure 14**)

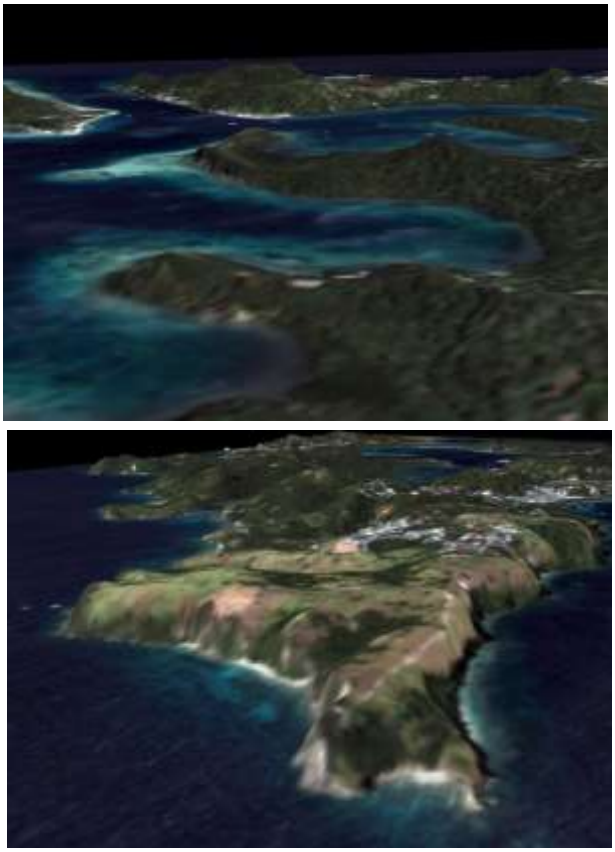


Figure 13 3-D Landscape of Puerto Galera Bay draped with the 2015 Google imagery

Figure 14 Google imageries of coves inside the bay showing heavy sedimentation due to developments in the upper areas.

There are only a few areas that are highly critical in terms of land use and vegetation cover. This means that generally, the bay has a good vegetation and land use cover (**Figure 15**). As seen in land use map, beach and secondary forests still abound in the bay, this is represented by the yellow and cyan colors in the reclassified land use/vegetation map. Critical areas represented by the red colors are residential and bare areas mostly located in Poblacion, Sabang and Palangan.. Critical areas can also be found in San Antonio, Sto Niño and Sinandigan but these are in spot areas only.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Coastal areas present difficult management and land use situations. They are extremely attractive to urban development due to their open vistas, recreational potentials and easy access to the sea with its varied resource and livelihood alternatives. These areas however are fragile environments where land use/vegetation, slopes and biological and physical resources are so delicately balanced that only a slight alteration in one environment can lead to a chain of negative impacts.

As a coastal area, Puerto Galera plays a very important role, locally as a venue for economic and tourism activities as well as a main livelihood source, Internationally, it is a very important marine and coastal biodiversity hotspot and with its natural land structure that encloses a Bay, it ideally serves as a harbor and coastal protection land structure. Its preservation and sustainable use therefore benefits all sectors spanning not only the past but future generations as well.

Based on the vulnerability assessment that was done, there are various biophysical concerns that urgently need to be addressed concerning its conservation and protection, if the Bay is to continue to serve in its various purposes. These concerns include conservation and protection measures addressing landslide and erosion, anthropogenic pollution, coastal degradation and depletion of marine resources. In managing well, the Bay's resources, regulated urbanization is highly recommended and planning for is protection and conservation is of high priority.

Landslide and soil erosion measures

Highly vulnerable areas to landslide and erosion should be placed under strict protection areas with a buffer zone where no adverse development activities should be initiated. Large tract clearing of land for construction and vegetation clearing around the Bay can cause heavy siltation i sedimentation of coastal waters that can be detrimental to ecosystems like mangroves, seagrasses and corals. In the advent of climate change where heavy rainfall and strong typhoons is the norm, vulnerability of the bay to landslides has been heightened. This calls for heightened protection measures and the present land use and vegetation pattern should be maintained if not enhanced to serve as check for erosion and landslides caused by upland degradation. This will involve the conservation of the upland to coastal continuum composed as secondary and molave beach forests in the upland portions, beach forests in the mid sections and mangroves nearest it coastal waters. Land use planning should incorporate the maintenance and strict adherence to this land use and vegetative patterns.

Mitigation measures pertaining to urbanization

Coastal areas are very appealing to land use changes favoring urbanization, They, are however not suitable for development and are particularly best left as open spaces, special easements or nature reserves. This is very true for Puerto Galera which is highly exposed to the open sea with its strong winds and tidal currents. Development of these sites especially sea cliffs and backshore slopes expose these areas to erosion due to high wave and wind velocities and slope instabilities.

Puerto Galera Bay has reached if not exceeded its land capabilities in terms of urbanization since gently sloping lands appropriate for this purpose are already used as tourist spots and built-up areas. Congestion is evident in the fast encroachment of urbanization to unsuitable areas with very steep slopes and vegetated areas intended to protect the land.

Urban areas are often built of materials that negatively impact the environment especially thermally and hydrologically. Their structural forms and geomorphology are atypical to most landscapes. Uncontrolled urbanization is therefore not suitable for the Bay. Building heights and dimensions should not burden the land, aggravate the environment, and visually impair the natural beauty of the landscape.

Latest satellite imagery in **Figure 15** shows that aside from sedimentation, other human impacts include scouring of shallow coral reef areas done by bancas docking around the Bay. Local legislation should also cover laws that would prevent or minimize anthropogenic impacts.

Local legislations and ordinances

Protection and conservations measures should not only be at the national level. Local legislation and ordinances will be more effective since this will involve on-site protection measures. For example, regulation and control of tourist activities in critical marine areas should be a local legislation. Local legislation should also include establishment of Marine Protected Areas (MPAs) where effectiveness also concerns the involvement local communities. Provisions for IEC and alternative livelihood is also needed.

Protection and conservation of coastal and marine resources

If true conservation and protection measures are to be applied, Puerto Galera Bay should be declared as a Marine Reservation with strict protection measures implemented. In fact under national laws, the Bay has been declared as such but its actual implementation is not fully realized. This can however be done if there is the political will to do it thru programs that will address massive IEC needs and provisions for alternative livelihood provided to affected and marginalized sectors. Access by tourists to the Bay can be implemented but on controlled and highly monitored levels. No entry zones should however be implemented especially in strict buffer zone areas.

Figure 15. Goggle imageries in 3D landscape show the scouring effects of boats and bancas (shown in orange insets) on the shallow and deep coral portions of the coastal areas in Sabang and San Antonio.

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ANNEXES (Vulnerability Indices for soil and geology)

Vulnerability ratings for soil types (Ecosystems Research and Development Bureau Indices)

SOIL TYPE	Code	Vulnerability Rating	
		Value	Vulnerability
Pellusterts w/ Udalfs, Udorthents and Tropepts	V1b	1	Very Low
Tropudults w/Tropudalfs Tropeps & Oxisols	U1a	5	Very High
Tropaquepts w/ Entropepts	l2a	1	Very Low
Mountain soils w/ Entisols, Enceptisols, Ultisols and Alfisols w/ Thermic Hyperthermic and Isohyperthermic Temperature Regimes	X1	5	Very High
Tropaquepts w/ Hydraquents	F1b	0	
Tropopsamments w/Troporthents	E2a	2	Low
Tropudalfs w/ Tropepts	E1a	3	Moderate
Entropepts w/ Dystropepts	l3a	4	High
Tropudalfs w/ Tropepts	A1a	3	Moderate
Acrorthox w/ Tropudulfs	O1a	3	Moderate
Eutrandepts w/ Eutropepts	I1a	2	Low
Chromusterts w/ Udalfs, Udorthents and Tropepts	V1a	2	Low

DESCRIPTION	Symbol	Vulnerability Rating	
		Value	Vulnerability
Recent	R	5	Very High
Quarternary	QAV	5	Very High
Plioliocene-Quarternary	QVP	5	Very High
Pliocene-Quarternary	QV	1	Very Low
Pliocene-Pleistocene	N3+Q1	4	High
Upper Miocene-Pliocene	IN2	1	Very Low
(Igneous Rock)		4	High
Upper Miocene-Pliocene	N2	2	Low
	IN1	4	High
Oligocene-Miocene	SN1	1	Very Low
Oligocene-Miocene	Pgl		
Paleocene (Sedimentary &	lPgl		
Metamorphic Rocks)		4	High
Paleocene(?)-Eocene	SPgl		
(Igneous Rock)		1	Very Low
Paleocene-Eocene	lK		
(Sedimen		1	Very Low
tary & Metamorphic	UC	1	Very Low
Rock)	Nl	3	Moderate
Cretaceous-Paleocene	SPg2		
(Igneous Rock)		1	Very Low
Cretaceous-Paleogene	lPg2	1	Very Low
Neogene (Igneous	PJl	1	Very Low
Rock)	BC2		
Oligocene (Sedimentary		1	Very Low
&	BC1		
Metamorphic Rocks)		1	Very Low
Oligocene (Igneous	SK	2	Low
Rock)	UV	2	Low
Pre-Jurassic (?)	KPgl		
Basement Complex		2	Low
(Pre-	KPgl2		
Jurasic)		4	High
Basement Complex	N3	3	Moderate
(Pre-	SN2		
Jurasic)			
Cretaceous			
Undifferentiated			
Undifferentiated			
(Sedimentary			
& Metamorphic			
Rocks)			
Undifferentiated			
(Igneous			
Rocks)			
Pliocene Sediments			
Pliocene Marine			
Sediments			