Geospatial Technologies Applications in Seawall Feasibility Study

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Abstract:

Geospatial technologies have revolutionized the way we approach the feasibility study of critical infrastructure projects such as seawalls. Seawalls are essential structures that protect coastal communities from erosion, storm surges, and rising sea levels. At present three coastal municipalities of Camarines Sur in the Philippines are at risk of being exposed to coastal erosion, occurrence of storm surge, coastal flooding and tsunami to name some problems. The objective of this paper is to highlight the benefits and relevance of geospatial technology applications in the different aspects of the seawall feasibility study. In the absence of geospatial technology, engineers and environmental scientists must rely on physical visits to the potential seawall construction sites, conducting a visual inspection of the coastline and noting key features. While a conventional feasibility study can provide insights, it will probably be less accurate and efficient than one conducted with geospatial technologies. With the use of GIS, remote sensing, simulation and modelling, project planners can make informed decisions about the most appropriate sites. The identification of the most suitable locations and priority areas for seawall construction help reduce cost of construction, resulting in 45 segments with an aggregate length of 21 km instead of the full 45 km coastline. It also helps in assessing environmental impacts, real-time monitoring using GPS and drones, and even in the assessment of seawall's performance after construction. Parcellary survey and land valuation works is responsible for the acquisition of lots along the seawall footprint, identifying affected lots within the right of way limits and segregate them for the purpose of registering them in favor of the government. Global positioning system in real time kinematics mode is used for the conduct of parcellary survey. In conclusion, geospatial technologies are indispensable for seawall projects from site selection to construction, maintenance and monitoring.

Keywords: geospatial technology, right of way, seawall feasibility study

Introduction

Geospatial technologies is a term used to describe the range of modern tools used to capture, analyze, manage, and visualize data related to the Earth's surface and its features. These technologies include Global Navigation Satellite Systems (GNSS) or in particular Global Positioning System (GPS), Geographic Information Systems (GIS), Remote Sensing, and even social media location tagging. They have become a critical tool in the construction sector by helping construction professionals locate and track construction sites, monitor work progress, and identify potential risk.

Geospatial technologies have proven to be an effective tool for collecting accurate geospatial data in near real time (Mallela et al, 2018) for the inspection of highway construction projects. The construction life cycle is composed of several phases such as design, operation, and management. These phases are in constant evolution due to process innovation (Mattana et al, 2019). Esri India Technologies Ltd, an end-to-end GIS solutions provider, highlighted the benefits of utilizing drones and GIS technologies in mapping construction sites and assets, helping in inventory management.

An article by Matt Sharon (2023) discovered from a survey conducted that 65% of construction professionals believe that geospatial technology will be essential for sustainable infrastructure projects in the future. It has also been reported that the use of geospatial technology can save up to 20% on the cost of infrastructure projects. Construction companies and individual contractors rely on geospatial analytics to manage their projects and improve efficiency. These tools can also help contractors and construction companies save time and money by automating tasks and organizing data.

Geospatial technologies have revolutionized the way we approach the feasibility study of critical infrastructure projects such as seawalls. Seawalls are essential structures that protect coastal communities from erosion, storm surges, and rising sea levels. Although seawalls are a form of structural defense to control shoreline erosion, in many cases they are observed to aggravate the problem. According to Jayappa et al. (2003), seawalls damage beaches more rapidly than beach groins. Several researchers have studied the effects of seawalls constructed along the different coastal regions of India (Hegde, 2010, Kumar and Ravinesh, 2011). In most of the literature, it is indicated that seawalls have either underperformed or failed in the protecting the affected coastline. Hence, the need to evaluate the actual performance of the seawall after construction.

Literature Review

Geospatial technologies can be used to select the most sustainable site for a new infrastructure project (Matt Sharon, 2023). The integrated model of GIS and Building Information Model (BIM) are used to seamlessly transfer data among the different stages of design and construction. BIM and GIS can be used to construct infrastructure projects more efficiently and sustainably. This is because the integrated model can be used to track the progress of the project, identify potential problems, make changes as needed, and assess the environmental impact of different sites, particularly in coastal areas. The increasing use of spatial data and GIS by organizations and researchers is a valuable tool to help solve the planning and management issues in the coastal zone.

The assessment of changing rate of shoreline is very important for researcher, planner and developer for development of new plans, hazard assessment and zoning, erosion and accretion studies, and sediment budgets (Zuzek et al. 2003). Samantha and Paul (2016) used remote sensing and GIS techniques for the geospatial analysis of shoreline and land use/land cover changes. Balaji, R. et al (2017) used remote sensing techniques to understand the shoreline change dynamics and the effect of seawall construction in Fansa, India. Li et al (1998) developed a coastal GIS to support a modernized shoreline monitoring and management in Malaysia. Yu et al (2001) presented a design model of hydro-project management based on GIS, and the model is used to develop information system of the seawall management of Zhejiang, China which has been proven to be valid and practical.

Objectives and Significance of the Study

In the absence of geospatial technology, engineers and environmental scientists must rely on physical visits to the potential seawall construction sites, conducting a visual inspection of the coastline and noting key features. While a conventional feasibility study can provide insights, it will probably be less accurate and efficient than one conducted with geospatial technologies.

The objective of this paper is to highlight the benefits and relevance of geospatial technology applications in the different phases of the seawall feasibility and detailed engineering design study. One primary concern of the project is determining the financial viability of the proposed flood and seacoast protection, focusing on the Right-of-Way (ROW) cost of the seawall project. The outputs will be used by the Department of Public Works and Highways (DPWH) for the effective management of its limited resources.

Study Area

The study area is located in the municipalities of Minalabac, Pasacao and San Fernando in the province of Camarines Sur, which is geographically located in the central part of the Bicol peninsula and forms the southeastern part of Luzon island. The three coastal municipalities are on the southwestern portion of the province and bounded on the west by the Ragay Gulf. Some of the problems identified in the municipalities are coastal erosion, occurrence of storm surge, coastal flooding and tsunami. Location map of the proposed seawall alignment is presented in Figure 1 below.

Figure 1. Map of Minalabac, Pasacao and San Fernando in Camarines Sur

Methodology

Available data, studies and documents regarding the coastal hazards along the proposed alignment such as coastal erosion, tsunami, high tide, and others will be compiled and reviewed to determine their adequacy and appropriateness. This will effectively reduce the amount of data to be collected from the field and decide on the strategic procedures to gather the remaining necessary data. The team must conduct a reconnaissance survey prior to actual fieldwork in order to assess the actual ground condition, safety, and security situation of the area to determine the optimal manner of doing the fieldwork. The reconnaissance survey will provide idea on any challenges or issues that may arise during the conduct of the actual survey works. Seven (7) major steps are needed to accomplish this study. The general process flow is shown in Figure 2 below.

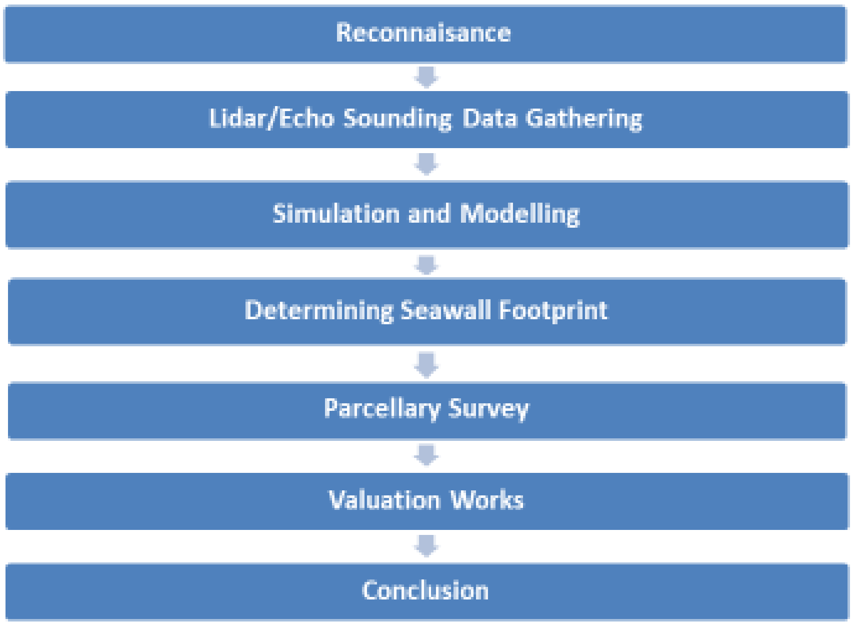

Figure 2. General Process Flow of the Study

A control survey must be conducted to establish a network of horizontal and vertical monuments that serve as a reference framework for initiating other surveys. This will serve as the reference for the lidar and echo sounding data gathering. The GPS survey team use a Spectra SP60 dual frequency GNSS receiver to determining the horizontal and vertical position of control points. Horizontal position is referenced from the standard reference system of the National Mapping and Resource Information Authority (NAMRIA) or existing horizontal references on the project site. Elevation or vertical position is referenced from the nearest existing benchmark.

Topographic survey data gathering is done on the project area using aerial lidar survey. A lightweight laser scanner, the RIEGL VUX-240, is utilized to obtain a 3-dimensional ground elevation data gathered at a rate of 1.5 million of points per second. The bathymetric survey is conducted with a multibeam echosounder (MBES) and single beam echosounder (SBES). Survey equipment is capable to measure depths of at least 100 mters with a resolution of no less than 0.01 meter.

Simulation modelling is the process of creating and analysing a digital prototype of a physical model to predict its performance in the real world. Using the data from lidar and echosounder, a flood model is generated for flood risk management and risk reduction. This helps minimise the loss and damage caused by floods by knowing what areas have high exposure to flood risk and choose to build important infrastructure like seawall. The output will determine the optimum location of the seawall and indicate the affected lots. These lots will be the subject of a parcellary survey and appraisal works to determine the approximate cost of the right-of-way acquisition. They will be segregated for the purpose of registering them in favor of the government.

Results and Discussion

The Riegl VUX-240 LiDAR scanner is mounted on the Cessna 172P plane with a metal bracket to conduct the lidar mapping. The aircraft flies at a maximum of 600 meters from the ground (if allowed by the terrain) to make sure that all features on the ground are clearly visible. The Seabat T50R (multibeam echo sounder) is mounted on a boat to measure deep water level and leveling rod for shallow water level with the aid of dual frequency real time kinematic positioning. A clear sky is required during the survey to make sure that a good reception of satellite signal is received by the GPS equipment which is subscribed to Trimble RTX. A real time GPS correction with the error of 0.02 meter horizontal and 0.05 meter vertical is fed into the Hypack software, together with the heave, pitch, roll and yaw corrections from its internal IMU. The resulting data in the Hypack software are corrected in real time for position and elevation of the sea floor. Geoid correction is likewise incorporated in the software. Photos of the lidar and echosounder with the platforms used during data acquisition is shown in Figure 3 and Figure 4.

Figure 3. Lidar Equipment and Cessna Plane

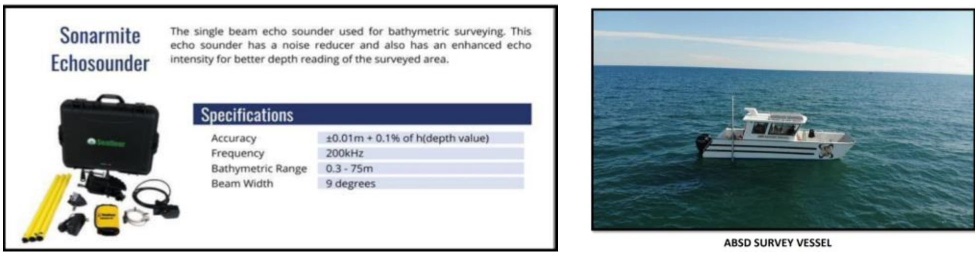

Figure 4. Echosounder Equipment and Boat

Lidar data is initially collected as a “point cloud” of individual points reflected from everything on the surface, including structures and vegetation. To produce a “bare earth” Digital Terrain Model (DTM), structures and vegetation are stripped away. From the DTM, the contours are derived, according to the contour interval defined by the particular component user of the project. A sample merged DTM is shown in Figure 5 below, indicating elevations on both land and water.

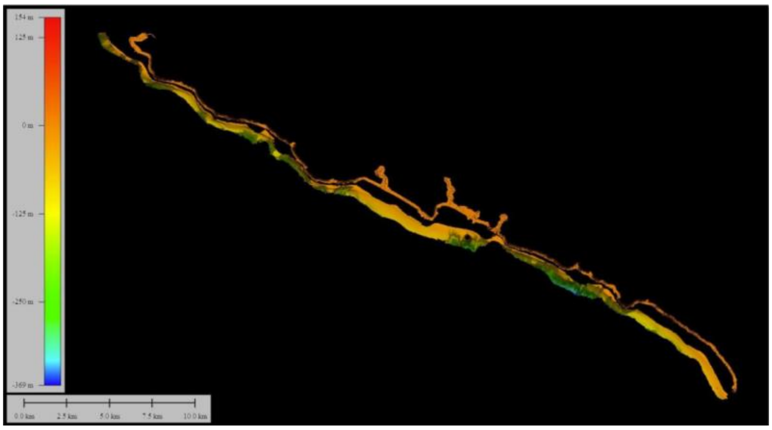

Figure 5. A Sample Merged Digital Terrain Model (DTM)

Ground Validation after the data acquisition of the lidar data is required, to check for the accuracy of derived location coordinates. Elevation of features easily found on the ground such as marks on roads, manholes or bridges are compared versus the elevation of the point cloud. The features chosen must have the following characteristics:

- free from vegetation to make sure that the point cloud being compared is correct
- point under an open sky and not under a tree canopy for good satellite reception
- point is in a flat surface not prone to disturbance or tampering
- the set of points are strategically distributed over the project area.

Having validated the DTM, numerical modeling follows. It is a technique where the physical environment of the shoreline can be investigated using computer technology. With additional data needed including shoreline, size of grain, wave data, tidal data and the effects of wind as well, data for numerical modeling is organized in GIS and provided to the modeling system. Various scenarios are tested based on exposure (1 house per 500 meters & 1 house per 200 meters) and based on inundation (1 meter & 0.5 meter). Along with the proposed TOR alignment, these 4 schemes were explored for the alignment of the seawall. It should be noted that the alignments based on inundation are bounded by the longest alignment based on exposure. Inundation was not checked for areas with no visible houses, Google Earth as of 2017. The plot of the TOR alignment, along with the 4 other alignments are shown in Figure 6 below.

Figure 6. Alignment Schemes (TOR & 4 others) for the Entire Project Coastline

Table 1 below summarizes the lengths of each alignment with respect to each municipality. All of the alignments are longer than the TOR alignment. Pasacao has the longest length for all the alignments due to its long coastline. From the 4 alignments, 2 alignments schemes were generated by combining the alignment based on exposure with an alignment based on inundation.

Table 1. Summary of the Length for Each Alignment per Municipality

Municipality	Alignment				
	TOR	Based on Exposure (1 house per 500m)	Based on exposure (1 house per 200m)	Based on inundation (>0.5m)	Based on inundation (>1m)
Pasacao	15.1	20.7	18.8	20.2	15.2
San Fernando	4.5	5.8	5.6	3.6	2.1
Minalabac	6.1	6.1	6.1	4.8	1.7
Total	25.7	32.6	30.5	28.6	19.0

Scheme 1 is based on the longer 1h500 exposure and the less stringent 0.5m inundation. Scheme 2 on the other hand is based on 1h200 exposure and 1m inundation. Scheme 2 is the recommended seawall alignment scheme due to its shorter total length. Table 2 summarizes the segment lengths per municipality and barangay for Scheme 2. There is a total of 45 segments, segment 14 in Caranan, Pasacao being the longest with a length of 1479m while segment 5 in Dalupaon, Pasacao is the shortest with a length of 41m. The index map of these 45 segments of the seawall alignment is shown in Figure 7 below, with GoogleEarth satellite image as background.

Table 2. Summary of Segment Lengths per Municipality and Barangay (Scheme 2)

Segment	Municipality	Barangay	Length (m)
1	Pasacao	Tinalmud	345
2	Pasacao	Tinalmud	649
3	Pasacao	Tinalmud/Dalupaon	654
4	Pasacao	Dalupaon	128
5	Pasacao	Dalupaon	41
6	Pasacao	Dalupaon	1163
7	Pasacao	Dalupaon	902
8	Pasacao	Dalupaon	170
9	Pasacao	Dalupaon	164
10	Pasacao	Dalupaon	247
11	Pasacao	Caranan	172
12	Pasacao	Caranan	515
13	Pasacao	Caranan	58
14	Pasacao	Caranan	1479
15	Pasacao	Caranan	511
16	Pasacao	Caranan	224
17	Pasacao	Caranan/Santa Rosa Del Sur	161
18	Pasacao	Santa Rosa Del Sur	171
19	Pasacao	Santa Rosa Del Sur	127
20	Pasacao	Santa Rosa Del Sur	134
21	Pasacao	San Cirillo	254
22	Pasacao	San Cirillo	122
23	Pasacao	Balogo	744
24	Pasacao	Balogo	623
25	Pasacao	Balogo	889
26	Pasacao	Balogo	274
27	Pasacao	Balogo/Bical	182
28	San Fernando	Bical	1116
29	San Fernando	Bical	638
30	San Fernando	Gnaran	679
31	San Fernando	Pinamasagan	530
32	San Fernando	Pinamasagan	430
33	San Fernando	Pinamasagan/Cotmo	113
34	San Fernando	Cotmo	513
35	San Fernando	Cotmo	105
36	San Fernando	Cotmo	200
37	San Fernando	Cotmo	123
38	Minalabac	Bagolatao	1364
39	Minalabac	San Antonio	547
40	Minalabac	Salingogon	209
41	Minalabac	Salingogon	1443
42	Minalabac	Hamoraon	260

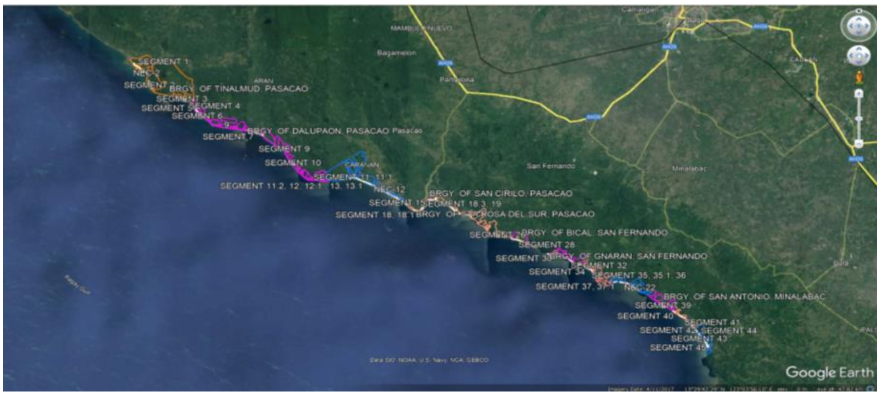

Figure 7. Index Map of the 45 Segments of the Seawall Alignment on GoogleEarth Satellite Image

The footprints of the 45 segments of the proposed seawall indicates the location of affected lots. Research of all relevant information pertaining to these lots, tax declarations, titles, maps of military reservation, cadastral maps, tax maps, maps of protected areas, maps for areas of agrarian reform beneficiaries and areas of Indigenous People is accomplished.

The parcellary survey work is undertaken in accordance with the common surveying and mapping requirements and specifications stipulated in the Manual for Land Surveys in the Philippines. Actual ground survey is conducted using GNSS (base and rover) RTK receiver, determining position (Northing, Easting and Elevation) with an uncertainty of a few millimeters. GCP's including BLLM's, MBM's, BBM's and other primary control points along and near the stretch of the project site is observed. The features of the land, centerline of the National Road, actual boundaries, corner monuments of every affected lot, actual land owners or occupants, improvements, buildings and trees found are observed and properly documented. Table 3 shows all lots affected by the seawall alignment.

Table 3. Subject Properties for the Compulsory Acquisitions of IROW

SUBJECT PROPERTIES FOR THE COMPULSARY ACQUISITIONS OF ROAD RIGHT-OF-WAY (RROW)-CAMSUR SEAWALL ALIGNMENT PROJECT							
MUNICIPALITY	BARANGAY	SEGMENT No. of Segments per Barangay		No. of Affected Lots/Claimants	Cadastral Area (sq.m.)	Remaining Area (sq.m.)	Area of Seawall ROW (sq.m.)
PASACAO							
	Tinalmud	4	1 to 4	7	2,242,251	2,183,295	58,956
	Dalupaon	6	5 to 10	16	1,271,169	1,199,432	71,737
	Caranan	6	11 to 16	15	900,937	858,707	44,398
	Sta. Rosa del Sur	4	17 to 20	16	110,855	89,381	21,474
	San Cirilo	2	21 to 22	87	*	*	19,844
	Balogo	5	23 to 27	63	993,908	921,579	72,329
	TOTAL	**27**		**204**	**5,519,120**	**5,252,394**	**288,738**
SAN FERNANDO							
	Bical	2	28 to 29	43	434,527	296,279	177,198
	Gnaran	1	30	16	*	38,655	4,277
	Pinamasagan	3	31 to 33	6	379,581	374,453	5,128
	Cotmo	3	34 to 36	6	282,516	269,908	12,608
	TOTAL	**9**		**71**	**1,096,624**	**979,295**	**199,211**
MINALABAC							
	Bagolatao	2	37 to 38	35	550,769	534,050	16,719
	San Antonio	1	39	5	217,237	204,904	11,485
	Salingogon	2	40 to 41	36	88,906	62,852	26,054
	Hamoraon	4	42 to 45	28	403,979	368,494	31,006
	TOTAL	**9**		**104**	**1,260,891**	**1,170,300**	**85,264**
GRAND TOTAL		**45**		**379**	**7,876,635**	**7,401,989**	**573,213**

The project traverses through six (6) barangays of the Municipality of Pasacao, Camarines Sur namely, Barangays Tinalmud, Dalupaon, Caranan, Sta. Rosa Del Sur, San Cirilo, and Balogo. In this municipality, twenty-seven (27) segments of the seawall project can be found. There are 204 identified affected claimants and that out of the 5,519120 sqm. cadastral area, 5,252,394 sqm. is the remaining area and that 288,738 sqm. is the area of seawall ROW. Four (4) segments are within Barangay Tinalmud, particularly, Segments 1-4. There are seven (7) identified affected lots or claimants, and that out of the 2,242,251 sqm. cadastral area, 2,183,295 sqm. is the remaining area and the area of seawall ROW is 58,956 sqm. Details for the other barangays are correspondingly tabulated and presented.

The staking-out of corner monuments is done after the conduct of the actual ground survey. Corner monuments are re-established on corners appearing on the Certificate Titles or Land Technical Descriptions of every affected lot, including the corner boundary of seawall as indicated in the detailed seawall design plan. The corner monuments recovered and observed using RTK are evaluated and compared to the Certificate Titles or Land Technical Descriptions and if found to be within the allowable error as prescribed by the Manual of Land Surveys, then it will be used as a Common Point Reference. The setting of cylindrical concrete monument is done simultaneously after the conduct of the Stake-out Survey.

In valuation, standards must be followed because they ensure the safety, quality and reliability of products and services. The International Valuation Standards (IVS) are standards for undertaking valuation assignments using generally recognized concepts and principles that promote transparency and consistency in valuation practice. The market value of a home is often referred to as the fair market value. Fair market value in real estate is the determined price that a property will sell for in an open market. The project affected lots, the structures or improvements on the lots and parts of the area that will be affected by ROW of the project are determined. These structures or improvements include, among others, houses, buildings, churches, schools, health centers, roads, public and private utilities, trees, crops and other structures affected. Table 4 shows the summary of land areas, structures and trees inside the project right-of-way and the corresponding market values.

Table 4. Summary of Land Areas, Structures and Trees Inside ROW and Their Values

MUNICIPALITY	LAND VALUES (Php)	VALUE ON IMPROVEMENT (Php)	VALUE ON TREES (Php)	TOTAL VALUES ON LAND, IMPROVEMENT AND TREES (Php)
PASACAO				
Tinalmud	4,356,480.00	6,971,601.84	5,830,000.00	17,158,081.84
Dinalupaon	35,642,700.00	26,795,579.82	5,355,000.00	67,793,279.82
Caranan	20,948,200.00	30,323,004.17	1,700,000.00	52,971,204.17
Santa Rosa del Sur	93,403,780.00	42,595,334.24	580,000.00	136,579,114.24
San Cirilo	53,578,800.00	25,954,884.01	20,000.00	79,553,684.01
Balogo	134,327,860.00	81,827,440.58	2,990,000.00	219,145,300.58
TOTAL	**342,257,820.00**	**214,467,844.66**	**16,475,000.00**	**573,200,664.66**
SAN FERNANDO				
Bical	42,168,280.00	7,054,587.33	1,450,000.00	50,672,867.33
Gñaran	4,511,360.00	4,201,128.85	60,000.00	8,772,488.85
Pinamasagan	1,313,620.00	1,280,350.00	710,000.00	3,303,970.00
Cotmo	5,604,650.00	10,618,130.00	1,470,000.00	17,692,780.00
TOTAL	**53,597,910.00**	**23,154,196.18**	**3,690,000.00**	**80,442,106.18**
MINALABAC				
Bagolatao	12,989,024.00	21,177,342.62	1,428,000.00	35,594,366.62
San Antonio	11,751,300.00	11,387,946.37	901,500.00	24,040,746.37
Salingogon	45,602,108.00	35,528,588.31	2,483,000.00	83,613,696.31
Hamoraon	22,236,705.00	59,845,016.13	2,937,000.00	85,018,721.13
TOTAL	**92,579,137.00**	**127,938,893.43**	**7,749,500.00**	**228,267,530.43**
OVERALL TOTAL	**488,434,867.00**	**365,560,934.27**	**27,914,500.00**	**881,910,301.27**

Conclusion

Geospatial technologies have revolutionized the way we approach the feasibility study and detailed engineering design of critical infrastructure projects. They are indispensable for seawall projects from site selection to construction, maintenance and monitoring.

With the use of geospatial technologies, valuation work is facilitated. This study found the total land area of the seawall project right-of-way to be 573,213 m² with land value of Php 488,434,867. Considering other assets such as houses, trees and other structures the total compensation value is Php 881,910,000. This figure estimates the Right- of-Way acquisition cost and will be used by the DPWH for the effective management of its limited resources.

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