Preliminary Investigation of Shoreline Response in San Juan, La Union, Philippines

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Abstract: Coastal erosion has been affected by environmental factors and human development. The investigation of the coastal erosion in San Juan, La Union covers the analysis and quantitative data that can be applied to protect the coastal community, to minimize economic losses, and to plan for the improvement of coastal process response. The main objective of this study was to investigate the shoreline response based on the extent of the coastal erosion problem of the 5.36 km - coastline of San Juan La Union and predict the long-term erosion pattern and shoreline change. The characteristics of the triggering factors of coastal erosion were evaluated during normal and extreme weather conditions. The areas along the coastline were characterized whether it experienced dominant deposition or erosion. Changes in shoreline position were assessed to predict future shoreline change scenarios. Sediment transport analysis was conducted by using the Kamphuis Formula and the CERC Formula. For Kamphuis, it was found that the beach slope had a significant effect on the amount of sediment transport rate. The values for normal conditions range from 9969 to 70857 $m^3/year$ while extreme conditions range from 202,703.99 to 10,640,468.54 $m^3/year$. For CERC, it was found that all were having the same value per month. The values for normal conditions range from 43215 to 158819 $m^3/year$ while extreme conditions range from 1,535,746,276 to 51,912,451,224 $m^3/year$. The shoreline positioning analysis showed that the southern region of the study area was dominated by erosion and the central to northern regions were dominated by deposition. The 1985 to 2020 shoreline change indicated an average movement of shoreline at 57.036 cm/yr and at 51.903 cm/yr characterized by recession and advancement, respectively. Furthermore, the shoreline prediction analysis reveals that the rate of displacement from 2020-2050 is 131.56 cm/yr and 173.04 cm/yr showing deposition and erosion patterns, respectively.

Key Words: Shoreline Response and Change; Coastal Erosion; Hydrodynamic Factors; Sediment Transport; Littoral Net Balance

1. INTRODUCTION

The coastal area serves as a shelter, an economic source, tourism, and historical and cultural knowledge. People live near the shoreline because the idea of living near the sea provides easy access to all kinds of food. The beauty and ambiance of coastal areas result in people flocking the coasts, therefore increasing the tourism of the coastal areas. Coastal erosion is a natural and complex process that occurs daily. The complex process of coastal erosion results in the transportation of sediments that takes it away or deposits it to the coast. It is only when the net balance of silt being eroded surpasses silt being deposited is when coastal erosion poses a threat to the community. The main impact of coastal erosion is the loss of land that increases the setback for the construction of man-made structures. The degree of the impact of coastal erosion varies depending on the different factors. A receding coastline of 1 m/year may be insignificant compared to the rate of 20 m/year, but 1 m/year is still a significant value over the long term as the coast would recede 100 meters from the original coastline within a hundred years. According to Lewis and Bird (2014), "Erosion can be temporary, reversed by a following period of deposition, or long-term, resulting in a net retreat of the coastline (recession). The retreat of the coastline can be traced by comparing dated sequences of maps and charts, or air and ground photographs.". Coastal erosion is a key factor that should be considered since it can affect multiple aspects such as safety and protection of the communities, infrastructure, preservation of the coastal environment and economic activities.

La Union is known as the surfing capital of the Northern Part of the Philippines. According to the Provincial Government of La Union, "La Union capitalizes on the surfing activity in San Juan as it draws an increasing number of tourist arrivals through the years. As of 2015, tourist arrivals posted 392,477 individuals with an average length of stay of 1.3 days and an average occupancy rate of 31.46%." The causes of coastal erosion in the Philippines could be factored into the natural factors. Examples of these natural factors include the switching of the flow of water from a source, mass wasting, return to normal sedimentary rates of soil from a geographical event. As population and investments in infrastructures steadily grow along with rapid urbanization and expansion, coastal communities become more and more at risk or vulnerable to coastal hazards such as tsunamis, storm surges, and erosion: the latter being the most widespread and persistent in the past several decades (Berdin, Remotigue, Zamora, & Yacat, 2004). Due to the increasing number of tourists and other factors related to coastal erosion, the local government has initiated measures to prevent coastal erosion. The existing government interventions include the planting of vegetation, coastal protection infrastructure, and disaster relief operations and assistance. According to Bayani, M. Dorado, and R. Dorado (2009), "Along the Ilocanos Norte, Ilocanos Sur, and Catbangen coast, local barangay officials have undertaken initiatives to prevent coastal erosion by means of soft protection or vegetation. In particular, they have planted coconut along the shoreline to help stabilize the beaches and prevent coastal erosion.

San Juan, La Union, is part of the San Fernando Bay which has been experiencing constant coastal erosion throughout the years. The figure below shows the coastline of San Juan La Union.

Figure 1.1 Coastline of San Juan, La Union (Google Map, 2020)

Due to the effects of the environmental factors and human activities, the people living in those coastal communities are affected by the short-term and long-term effects of coastal erosion. San Juan, La Union, is an upcoming tourist destination spot for surfers and tourists. The investigation of the coastal erosion in San Juan, La Union will provide measurements that can be applied to protect the community and its activities, to minimize economic losses, and to plan for the improvement of response.

2. METHODOLOGY

2.1 Wind Hindcasting

According to Barua (2005), "Wave hindcasts refer to the predictions of wind waves on the water surface for a past event. Wave nowcasts and forecasts similarly refer to the predictions in real time and in the future, respectively". With the wind data obtained from online sources, as well as from Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), a relationship can be established between the wind data and wave characteristics.

2.2 Sediment Transport Analysis

The displacement of sediments was computed through different numerical formulas. These numerical formulas include Kamphuis 1991 Formula and CERC Formula. The Kamphuis formula, equation 1, takes into account parameters such as wave breaker direction, wave breaker height, bed slope, sediment grain size, effect of swells. The CERC formula, equation 2, was applied along with models to estimate the sediment transport rate in different zones. The analysis begins by determining the wave current and readjustment of the variables under the model. Then, the conditions of the wave were designed to simulate longshore transport.

$$Q_{vol} = (6.4x10^4)(H_{sbr})^2\,(T_{op})^{1.5}\,(m_b)^{0.75}\,(D_{50})^{-0.25} sin^{0.6}(2\theta_{br})$$

(Eq. 1)

Where:

Q_{vol} = total longshore transport rate, m^3/year

H_{sbr} = Height of breaker wave

T_{op} = Peak Wave Period, Seconds

m_b = Slope of Beach, Meters

$$m_b = \frac{\text{Average Depth}}{500\text{ m}} \text{ (with reference to mean sea level)}$$

D_{50} = Mean Grain Size, Millimeters

θ_{br} = Break Wave Angle, θ

$$Q = (2.9x10^6)(H_{sb}^{\frac{5}{2}})(\sin(\theta_b)) \quad \text{(Eq.2)}$$

Where:

Q = Submerged total longshore transport rate, m^3/year

H_b = Significant wave height at breaking, meters

θ_b = Breaker Wave Angle, θ

2.3 Data Collection and Gathering

This qualitative research method made use of published reports/studies from the following: the thesis of Anca et al. (2017) regarding Investigation on the Longshore Sediment Transport Mechanism along San Fernando Bay La Union, the study of Berdin et al. (2004) regarding Coastal Erosion Vulnerability, and the research of Dorado et al. (2009) regarding Economic Vulnerability and Possible Adaptation to Coastal Erosion in San Fernando City Philippines. Meanwhile, the secondary data collected by the researchers included wind and tide data. These data were recorded by the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). Additionally, data such as the satellite maps and aerial photographs of the specific coastline stretch were obtained through the National Mapping and Resource Information Authority (NAMRIA) and softwares such as Google Earth Engine. GIS Mapping software was utilized to analyze the collected geographic map data. The data were then interpreted through statistical methods by forming a correlation between factors and establishing the coastal erosion trends and patterns.

3. RESULTS AND DISCUSSION

From the accessed data of NAMRIA, Figure 3.1 shows the tide data with respect to the mean lower low water (MLLW) for years 2010 to 2020 in Curimao Tide Station (Ilocos Norte). The tide data were on a per hour basis for each day so the researchers used the minimum, maximum, and average values for each day. With the given data, the researchers found that the tide elevation usually increases from June to September then decreases back to its normal tide height. The recorded tide heights from these months were usually the highest and can reach up to greater than 200 cm and the highest recorded height was 238 cm. The lowest tide heights for the on the other hand were lower than 100 cm and the lowest recorded height was 70 cm. The average tide height was near the 150 cm mark.

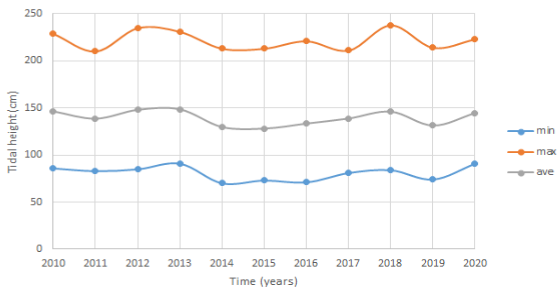

Figure 3.1 Tide Data for Years 2010-2020 (NAMRIA)

With the wind data accessed from PAGASA and researchers' use of wind hindcasting method for wave height and maximum time of wave, Figure 3.2 represents the yearly sediment transport rate of both Kamphuis and CERC Formula for normal conditions. The values obtained from using the CERC formula had higher values compared to the values obtained from Kamphuis Formula. The percent difference between the two equations would range between 239 to 261 percent. This is caused by the CERC formula which can sometimes overestimate/underestimate the sediment transport rates due to the K coefficient. The K coefficient is used as a calibration tool obtained from the experimental setup of the beach. Both follow the same trend, having an increasing value of sediment transport from 2000 to 2015 and decreasing in the year 2019. The upward trend could be used to predict the future sediment transport rate.

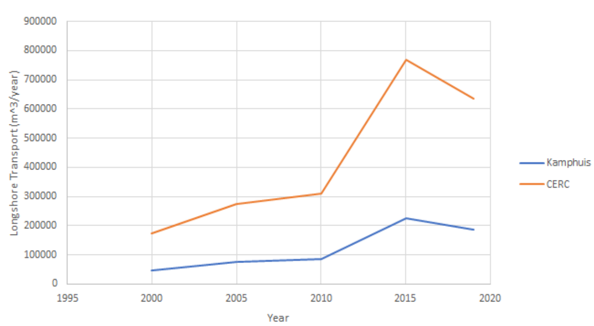

Figure 3.2 Comparison between Kamphuis and CERC Formula (Normal Conditions)

With the results obtained from the application of the Kamphuis and CERC formulas to predict the future sediment transport rates, a trendline was acquired. This was done by finding a relationship between the values obtained from the sediment transport rates using the Kamphuis and CERC formula and forming a trendline. In analyzing the trendline, it was found that the best formula which had the highest coefficient of determination was the polynomial. Figure 5.2.4.1 shows the trendline equation with the corresponding coefficient of determination from 2000 until 2050. It can be seen that the trend of sediment transport rate is increasing exponentially throughout the years until the year 2050. The culmination of this explanation is seen in Figure 3.3.

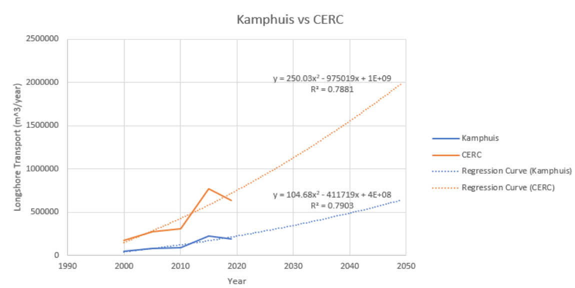

Figure 3.3 Prediction of Sediment Transport Rates projected to year 2050

The change in shoreline position over a time scale period would generate either a deposition scenario or an erosion scenario. It was important to note that even though the net change of area would be determined as deposition or erosion, both processes still occur within the study area. Table 3.1 shows that the years from 1985 to 2005 yielded to an erosion change of the area. Meanwhile, the other time periods (2005-2010, 2010-2015, and 2015-2020) resulted to deposition in littoral net balance. Overall, the net change throughout the years was deposition throughout the study area.

Table 3.1 Summary of change in area for the different time periods

Year 1	Year 2	Characteristic	Change in Area (m^2/year)
1985	2005	Erosion	-4970.04
2005	2010	Deposition	10000.79
Year 1	Year 2	Characteristic	Change in Area (m^2/year)
2010	2015	Deposition	16168.69
2015	2020	Deposition	2030.03
		Total	23229.47

With the transects established and by computing the perpendicular distance for every interval of 50 meters across the shoreline for each time period with the use of QGIS, the estimated scenarios for future shoreline shape were found. The first scenario for prediction (Figure 3.4) was to obtain the linear rate of displacement and project it over the deposition and erosion area of shoreline change from 2015 to 2020. The second scenario (Figure 3.5) for prediction was to obtain the best fit line from the graphed rate of displacement in terms of erosion and deposition and project the shoreline displacement in terms of the areas of deposition and erosion from the change in shoreline from 1985 to 2020. In Figure 5.5.3, the year 1985 was set as the origin. The best fit line from the formed respective trendlines for deposition and erosion was then projected to forecast the scenarios for 2030, 2040, and 2050. The rate of displacement in terms of deposition for the year 2030, 2040, 2050, with reference to the year 2020 was approximately 495.754 cm per year, 563.98 cm per year, and 632.206 cm per year respectively. The rate of displacement in terms of erosion for the year 2030, 2040, 2050, with reference to year 2020 was approximately 268.954 cm per year, 286.922 cm per year, and 304.89 cm per year respectively.

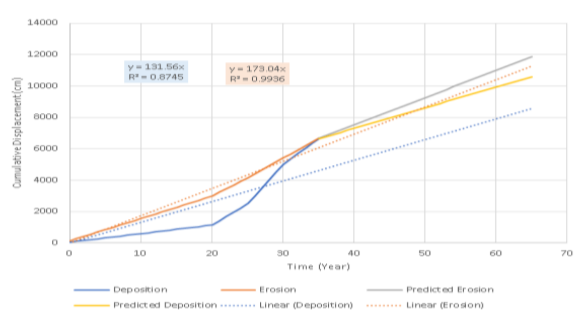

Figure 3.4 First Scenario: Linear Rate of Displacement to Predict Shoreline Shape in 2030, 2040, and 2050

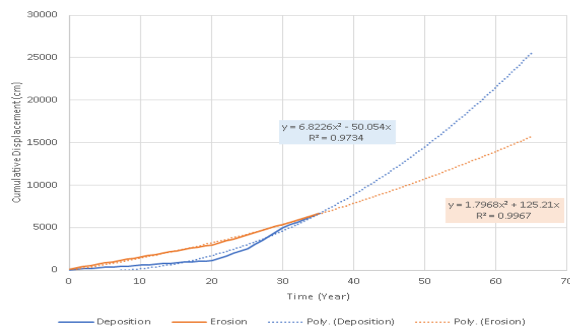

Figure 3.5 First Scenario: Linear Rate of Displacement to Predict Shoreline Shape in 2030, 2040, and 2050

4. CONCLUSIONS

The research revealed the state of the coastline and produced future scenarios of the coastline which may be used as one of the coastline management strategies in the coastline stretch. The prevailing wind direction is northwards therefore the prevailing direction of the sediments is also northwards. The average wave height in the year 2010 was around 0.1 meters while in the year 2015, it rose to 0.211 meters. This signified that a greater amount of wave energy would impact the shorelines, although the amount of wave energy is insufficient to translate to erosion. For the tidal height data, it is seen that the tidal height values were low from the first half of the year, but it rose during July to September, and decreased again during October to December.

For the longshore sediment transport rate, the Kamphuis and CERC formulas were used. For the Kamphuis formula, it was found that the beach slope had a significant effect on the amount of sediment transport rate when using the Kamphuis formula. The values of sediment transport were increasing for each transect established. Transect 1 has an average beach slope of 0.15 while transect 4 has an average beach slope of 0.26. For the CERC formula, it was found that all were having the same value per month. The reason for this is due to the parameters that were used for the formula. The breaking wave height and the breaking wave angle were the same for each month. This caused the values for the CERC formula to be the same. In comparing both formulas, both follow the same trend for the years 2000 to 2019 which is increasing. There was a significant difference between the two values ranging from 239-261% because the CERC formula requires further calibration of the coefficient, K. For significant finding of the longshore sediment transport for normal and extreme conditions, it was found that the amount of sediment transport for extreme condition was significantly larger than the normal condition. This was due to the strength of the wind that generated higher waves and stronger current triggering the transport of sediment.

Through analyzing the georeferenced satellite images from different years in QGIS, the critical areas of erosion and deposition were identified for each time period. It showed that the southern region of the study area was dominated by erosion and the central to northern regions were dominated by deposition. From the year 1985 to 2005, the areas dominant for deposition and erosion were Section 7 and Section 11. From the year 2005 to 2010, the areas dominant for deposition and erosion were Section 13 and Section 12, respectively. From 2010 to 2015, the areas dominant for deposition and erosion were Section 7 and Section 2, respectively. Lastly, from 2015 to 2020, the areas dominant for deposition and erosion were Section 10 and Section 11, respectively.

In terms of shoreline prediction, the perpendicular distance between each time period was measured for every 50 meters across the shoreline. The trendlines were used to predict the shape and position of the shoreline in the years 2030, 2040, and 2050. From the linear trendline, the shoreline displacement in terms of deposition was 131.56 cm per year while the shoreline displacement in terms of erosion was 173.04 cm per year. As it was a linear trendline, the rate of displacement remained the same throughout the future years. As for the polynomial trendline, each significant year had a different rate of displacement. In the years 2030, 2040, and 2050, the shoreline displacements in terms of deposition were 495.754 cm/year, 563.98 cm/year, and 632.206 cm/year, respectively. In the years 2030, 2040, and 2050, the shoreline displacements in terms of erosion were 268.954 cm/year, 286.922 cm/year, and 304.89 cm/year, respectively. Despite the polynomial trendline being the best fit line between the two, the shoreline displacement reaching up to 6.3 m a year was considered very large and had to be reconsidered for the prediction of shoreline prediction. A coastal management plan can then be formulated by the local government based on the identified areas that are under risk of shoreline responses (recession or advancement) to ensure a sustainable safe and protected coastal community.

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