Shoreline Change Analysis in New Washington, Aklan using Digital Shoreline Analysis System (DSAS)

Ainalyn Nerves[1], Francesca Deighl Rivera[1,2], Ariel Blanco[1,2], Yasmin Tirol[3], Kazuo Nadaoka[4]

[1] Department of Geodetic Engineering, University of the Philippines Diliman, Philippines - aanerves@gmail.com, frrivera@alum.up.edu.ph, acblanco@up.edu.ph
[2] Philippine Space Agency, Philippines - (deighl.rivera, ariel.blanco)@philsa.gov.ph
[3] Aklan State University, Philippines - yhptirol@asu.edu.ph
[4] School of Environment and Society, Tokyo Institute of Technology, Japan - knadaoka@gmail.com

Keywords: Shoreline, DSAS, Landsat, Aklan, Erosion, Accretion

Abstract

Shoreline changes are a critical indicator of coastal vulnerability, impacted by natural processes and human-induced factors such as climate change. This study investigates shoreline changes in New Washington, Aklan, Philippines, focusing on erosion and accretion patterns since 1985. With the use of satellite imagery, coupled with Remote Sensing and Geographical Information System (GIS) techniques, this study examines the spatio-temporal variability in erosion and accretion patterns. Through the Digital Shoreline Analysis System (DSAS), a quantitative analysis of shoreline change rates was conducted. Using four (4) DSAS change metrics such as Endpoint rate (EPR), Linear Regression Rate (LRR), Shoreline Change Envelope (SCE), and Net Movement Shoreline (NMS), it was identified that the shoreline change in Bakhawan Park area is due to its location being at the mouth of Aklan River. Most of New Washington’s shoreline experiences erosion with 0-1.46 m/yr from LRR, eroding at most 40m of sediments in thirty years; evident along areas of Brgy. Tambac and Poblacion. The largest shoreline deviation can be observed in the areas located near the mouth of Batan Bay with 153 meters since 1985.

1. Introduction

1.1. Background of the study

Shoreline changes are often attributed to erosion and accretion over the years. Coastal erosion, which is the physical reduction of landmass at the coast, results from the interaction of marine, fluvial, and landslide processes (Mentaschi et al., 2018). Specifically, the Philippines, particularly in the municipality of New Washington, Aklan, has been facing a recurring problem of flooding since 2008 due to climate change and global warming. An interview with a professor from Aklan State University (ASU)-New Washington revealed observations of sediment loss and erosion along the coastline of New Washington since the 1990s, based on satellite observations (Aguirre, 2023). Over time, New Washington faces the threat of forming unstable areas that, if ignored, can cause environmental and economic losses (Williams et al., 2017).

A study utilized existing traditional maps to identify historical changes in the shoreline of Lake Erie in Ohio (Li et al., 2001). Additionally, aerial photographs from specific periods were employed to analyze shoreline variations (Jeong et al., 2019). In this study, researchers used historical satellite images to analyze shoreline changes, employing both Remote Sensing (RS) and Geographical Information System (GIS) techniques. These methods were utilized to detect instances of shoreline accretion and erosion spanning the years 1985 to 2022.

This study aims to map and analyze shorelines and coastlines using satellite images and to determine the spatio-temporal variation of accretion and erosion rates. This analysis will enable concerned government agencies, NGOs, and researchers to implement improved coastal policies and initiatives aimed at preventing further degradation of shoreline conditions in the area. In addition to the New Washington, Aklan area, the study also includes Bakhawan Park, a mangrove forest located in Kalibo, Aklan, and Batan, Aklan, situated in the southern part of New Washington, to inspect the movement of sediments/sand from one place to another. Furthermore, through the utilization of the Digital Shoreline Analysis System (DSAS) in ArcMap, researchers quantitatively analyzed the rate of change.

2. Data and Methods

This study mainly utilized the use of multispectral imagery, specifically Landsat 5 TM for the years 1985 to 2012 and Lansat 8 OLI from 2013-2022. The main method used is the Digital Shoreline Analysis System (DSAS), a computer software used for calculating shoreline change. Shown below is the methodological framework used in the study.

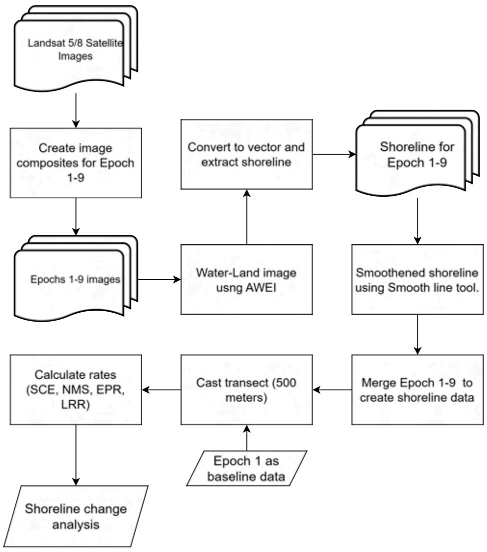


Figure 1. Methodological Framework

2.1. Study Area

New Washington, along with Kalibo and Batan, are coastal municipalities located in the northern part of Aklan Province in the Western Visayas Region, with a cumulative area of approximately 170 sq. km. Their total shoreline length, running from the mouth of the Aklan River to the coastal end of Batan, is approximately 48 km. Bakhawan Park (a mangrove sanctuary) and the estuaries of the Aklan River can be found in Kalibo, while enclosed estuaries and several small islands are located in New Washington. Batan hosts Batan Bay and Tinago Lake. Several water features and coastal resources can be found across these areas.

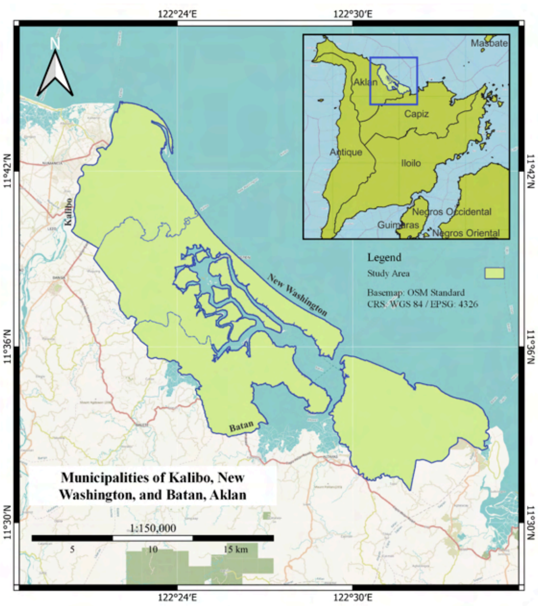


Figure 2. Study Area

2.3. Landsat 5/8 Satellite Image Acquisition

The study utilized the Landsat 5 TM (L5) and Landsat 8 OLI (L8) from the National Aeronautic and Space Administration (NASA) due to their historical availability and for the consistency of the study which has a spatial resolution of 30 meters (visible, NIR, SWIR) (U.S. Geological Survey, n.d.). In this study, we utilized the use of these bands for processing.

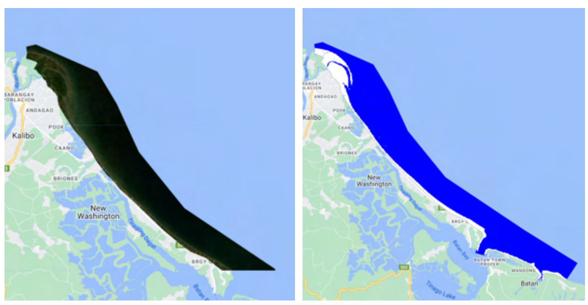
To further analyze the shoreline change in the area, the researchers divided the years into nine (9) epochs from 1985-2022. Shown in Table 1 are the division of epochs and their corresponding satellite image providers. A composite image using the mean of each epoch was acquired using Google Earth Engine.

Epoch	Year	Landsat
1	1985-1989	5
2	1990-1994	5
3	1995-1999	5
4	2000-2004	5
5	2005-2009	5
6	2010-2012	5
7	2013-2016	8
8	2017-2019	8
9	2020-2022	8

Table 1. Division of years per epoch and satellite image provider used.

2.3. Shoreline Extraction

Shoreline extraction plays a crucial role in this change analysis. Previous studies utilized Landsat-8 OLI imagery for coastline extraction, using the traditional water index method to extract the coastline directly from the original 30m Landsat-8 OLI multispectral image (Liu et al., 2017). In this study, the acquired satellite images underwent processing using geospatial techniques to extract the shoreline for each epoch. The Automated Water Extraction Index (AWEI) was computed, employing Otsu Thresholding to determine the optimal threshold for identifying water pixels in each image. This approach facilitated the detection of the delineation between the water body and land. Additionally, for consistency, inland water bodies and small islands were excluded from the study. Subsequently, the water-land images were converted into vector format, and their respective shorelines were extracted. Shown below are sample figures for the shoreline extraction; these methods were utilized using GEE.



(a) (b)

(c)

Figure 3. (a) Composite image for Epoch 7, (b) Water-land raster format, (c) Shoreline extraction after conversion of raster to vector.

2.4. Digital Shoreline Analysis System (DSAS) for Shoreline Processing

The Digital Shoreline Analysis System (DSAS) is a tool within Esri ArcGIS Desktop that enables users to calculate rate-of-change statistics from multiple historical shoreline positions. It provides an automated method for establishing measurement locations, performing rate calculations, and furnishing the statistical data necessary for assessing rate robustness (Digital Shoreline Analysis System (DSAS) Update | U.S. Geological Survey, n.d.). Studies have demonstrated that using DSAS allows for clear shoreline analysis as well as the calculation of average erosion and accretion rates for a study area. DSAS provides valuable information for the implementation of effective coastal zone management (Baig et al., 2020).

In this study, each generated shoreline was smoothed using the Smooth Line tool in ArcMap, with a smoothing tolerance of 0.001 decimal degrees as the default value. Insignificant lines were manually removed to enhance the comprehensiveness of the shoreline data. Epoch 1 was used as the baseline, and the shorelines for each subsequent epoch were merged into a single "shoreline data" set. The DSAS tool was used with its default settings. For the Cast Transect settings, a maximum search distance of 500 meters was used, which was sufficient to reach all shorelines for each epoch. DSAS generates transects that are cast perpendicular to the reference baseline (Epoch 1). It then measures the distance between the baseline and each shoreline intersection along a transect to generate the change metrics shown in Table 2.

Distance measurements	Shoreline Change Envelope **(SCE)** Net Shoreline Movement **(NSM)**
Statistics	End Point Rate **(EPR)** Linear Regression Rate **(LRR)** Weighted Linear Regression Rate **(WLR)**
Supplemental statistics for Linear and Weighted regression	Confidence Interval **(LCI/WCI)** Standard Error **(LSE/WSE)** R-squared **(LR2/WR2)**

Table 2. DSAS change metrics

In this study, we utilized Shoreline Change Envelope (SCE), Net Shoreline Movement (NSM), End Point Rate (EPR), and Linear Regression Rate (LRR) values. Positive values of EPR and LRR indicate accretion, while negative values indicate erosion. The SCE and NSM provide a general idea of how much the shorelines deviate from each other (Estrada et al., 2020). For a better understanding and detailed analysis, the shoreline was divided into segments based on observable inflection points—locations where the results indicated a change from erosion to accretion or vice versa.

Figure 4. Perpendicular transects along the shorelines per epoch.

2.5. River Course Extraction

A part of the Aklan River's course located in Kalibo and its estuaries was also extracted for every epoch to supplement the analysis of results from DSAS. To extract only the river course, the same method using AWEI was employed, utilizing Otsu Thresholding to determine the optimal threshold for identifying water pixels in each image (Figure 5).

Once all the river courses for all the epochs were extracted, change analysis was performed by measuring the total area per epoch using polygon shapefiles in Quantum Geographic Information System (QGIS) for convenience and ease of processing. Additionally, the difference in area between pairs of epochs (e.g., Epoch 1 to Epoch 2, etc.) was calculated to determine the change in total area, where negative values indicate erosion, and positive values indicate accretion.

(a) (b)

Figure 5. Snapshot of Water-Land raster of Kalibo-Aklan River Course for (a) Epoch 4 (2000-2004) and (b) Epoch 9 (2020-2022).

3. Results and Discussion

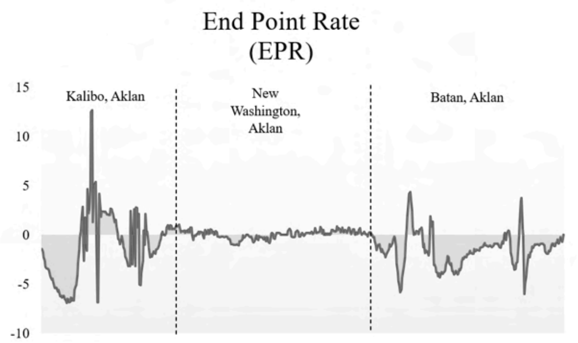
3.1. Shoreline Analysis

Figures 6 to 9 show the graphs representing the values generated from DSAS for each change metric. In total, 895 transect lines were generated as input to DSAS (represented on the x-axis), producing the same number of observations for each metric used. These graphs are divided into the shorelines of the three municipalities included in the study area. Some dramatic inflections and fluctuations from high accretion to high erosion (or vice versa) are mostly attributed to the sudden erosion or accretion of sand spits, which are primarily located north of Kalibo, Aklan.

3.1.1. End Point Rate and Linear Regression Rate

As mentioned, the End Point Rate (EPR) and Linear Regression Rate (LRR) provide information on the nature of sedimentation, indicating erosion for negative values and accretion for positive values. Figure 6 illustrates the EPR and LRR values per transect. The municipality of Kalibo showed the highest fluctuation across the included shoreline, which can be attributed to its direct proximity to the estuaries of the Aklan River and the presence of the Bakhawan (Mangrove) Park, with its highest approximate rate of 12.67 m/yr. Additionally, sediments are continuously deposited towards the sea, specifically northeast of Bakhawan Park, feeding the sand spits (see Figure 11), which causes fluctuations in values within each transect, with a rate of 6 m/yr.

The third part of the graph in Figure 6 includes the southernmost edge of the New Washington shore and the northernmost part of Batan, Aklan. Most of these areas experience erosion, with an end-point rate of 4.3 m/yr and a linear regression rate of 5.91 m/yr. Located between these areas is Batan Bay, where a port is also present; thus, the continuous erosion along the shoreline can be attributed to the flow of water into the bay.



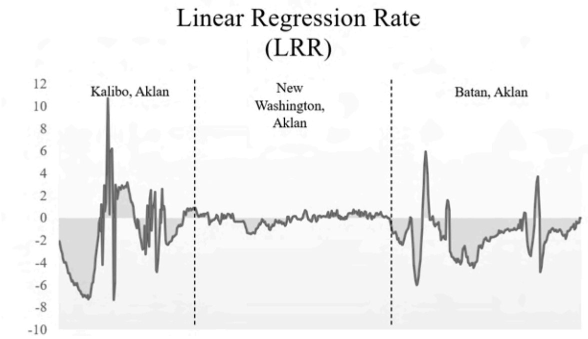


Figure 6. End Point Rate (EPR) and Linear Regression Rate (LRR) results

Moreover, most of the shoreline along New Washington shows a linear trend, except for the area near ASU-New Washington and a local resort, Sampaguita Garden Resort, where a faster rate of erosion (approximately 1.46 m/yr) is visualized as a sudden dip in the chart in Figure 7. This poses a danger to the area and must be continuously monitored.

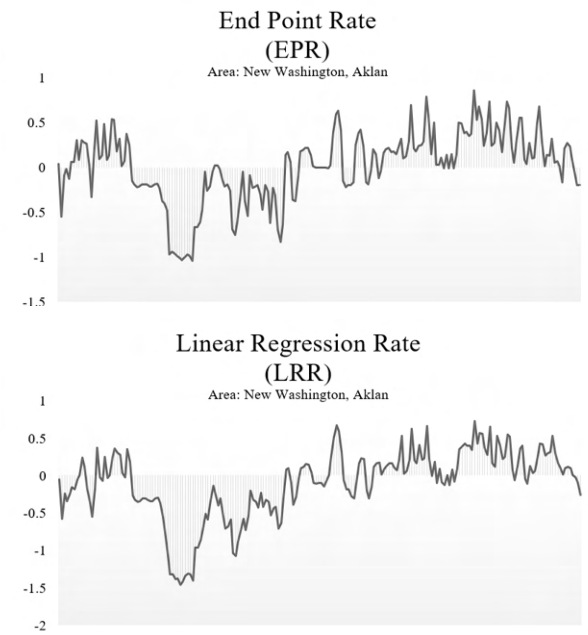


Figure 7. End Point Rate (EPR) and Linear Regression Rate (LRR) results for New Washington, Aklan

3.1.2. Net Shoreline Movement (NSM) and Shoreline Change Envelope (SCE)

NSM and SCE provide information on how much the shoreline has changed from the baseline. A general observation was determined in the northernmost part of the shoreline data, due to the fast and massive growth of Bakhawan Park, a mangrove sanctuary, in Kalibo, as measured by the transects created, which caused noisy parameter values. These noise or fluctuations may be attributed to the disturbed sediment movement caused by the mangrove sanctuary and discharge from Aklan River. Nevertheless, both NSM and SCE indicate that from the baseline, i.e., Epoch 1, the shoreline movement extends up to

190 meters in Kalibo, Aklan, primarily due to the aforementioned significant growth of the mangrove sanctuary. However, erosion is also evident in the area, with approximately 250 meters of eroded land area near the estuaries of the Aklan River. Additionally, the area of Batan, Aklan, has also experienced accretion over the years, with 153 meters gained since 1985. This can be justified by the establishment of recreational and residential areas near the shore.

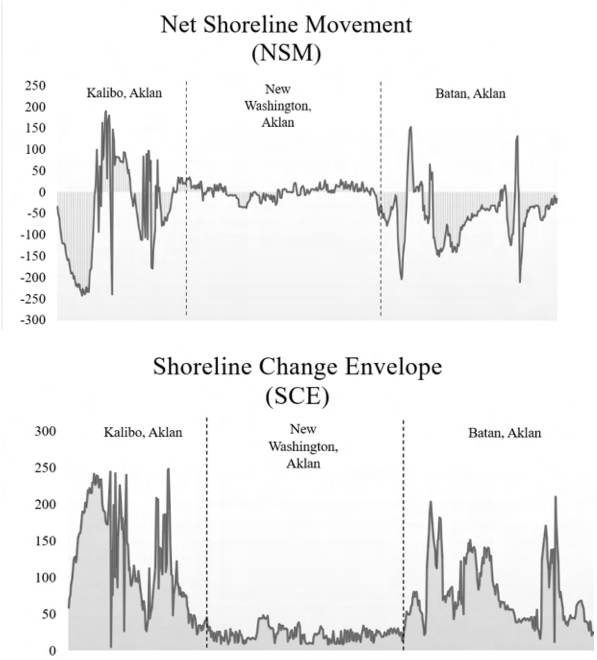


Figure 8. Net Shoreline Movement (NSM) and Shoreline Change Envelope (SCE) results

However, zooming into New Washington, we can observe in both the graphs of NSM and SCE that the same area with the highest rate of erosion has eroded up to 40m in 32 years, specifically in Barangay Tambac, Barangay Poblacion, and near Aklan State University. The continuous erosion in this area may pose risks to establishments and residents nearby. Additionally, there is an accumulation of coastal sediments extending from the shoreline in areas near Barangay Ochando.

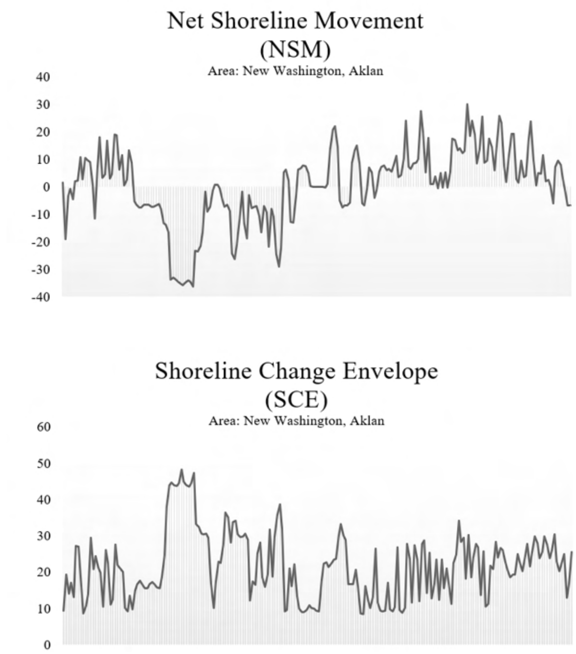
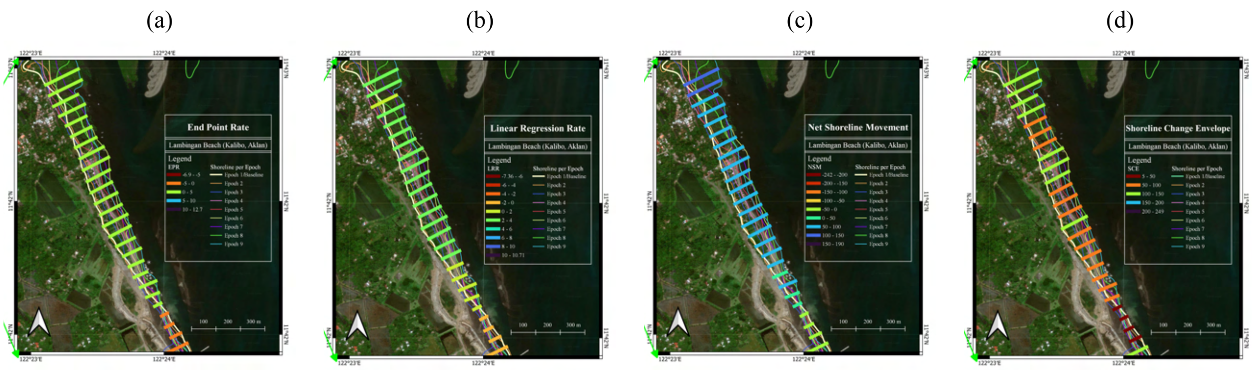


Figure 9. Net Shoreline Movement (NSM) and Shoreline Change Envelope (SCE) results for New Washington, Aklan

3.1.3. Resulting Maps

The part of the shoreline depicted in Figure 10 is located in Banga, New Washington, where the area is predominantly built-up, mostly residential. Most of the area has experienced moderate erosion, ranging from -3.7 to 0 meters per year. This erosion may be caused by the movements of the waves and also signifies a steep coastal shelf. It's important to note that a specific area along the shoreline showed a larger value of erosion compared to the rest of the mapped area in Figure 10. The smallest value calculated for NSM was approximately 1 meter eroding, while the largest NSM is around 35 meters eroding, observed in the same place. Therefore, this area requires monitoring as it may continue to erode, affecting the residential and built-up areas near the shoreline.



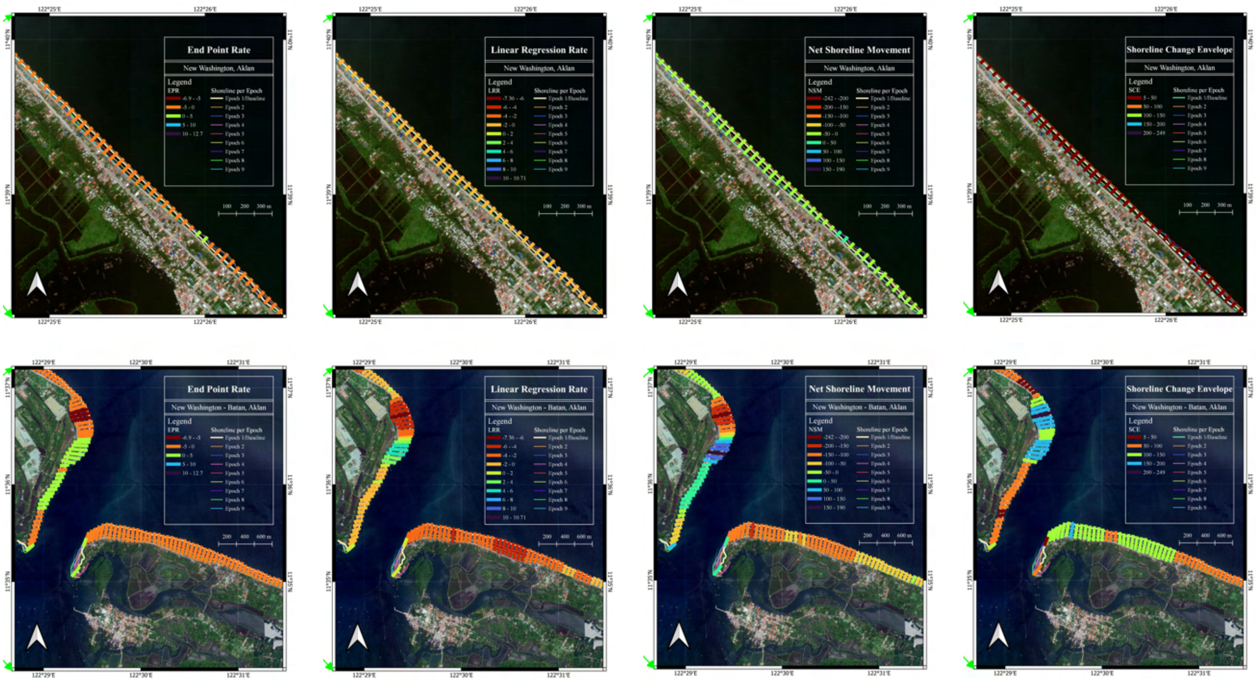


Figure 10. (a) EPR, (b) LRR, (c) NSM, and (d) SCE Maps of selected areas

3.2. River Course Change Analysis

One of the possible reasons for the large shoreline change in Kalibo, Aklan is its proximity to the Aklan River's estuaries. It is evident in Figure 11, that the left stream (a) of the river has been closed possibly because of either accretion or weak current flow among others. This caused a streamlining of the river into one stream flowing north and out to the coast, carrying more sediments and thus continuously extending the sand spit (b) (identified in the study as part of the shoreline) around Bakhawan Park.

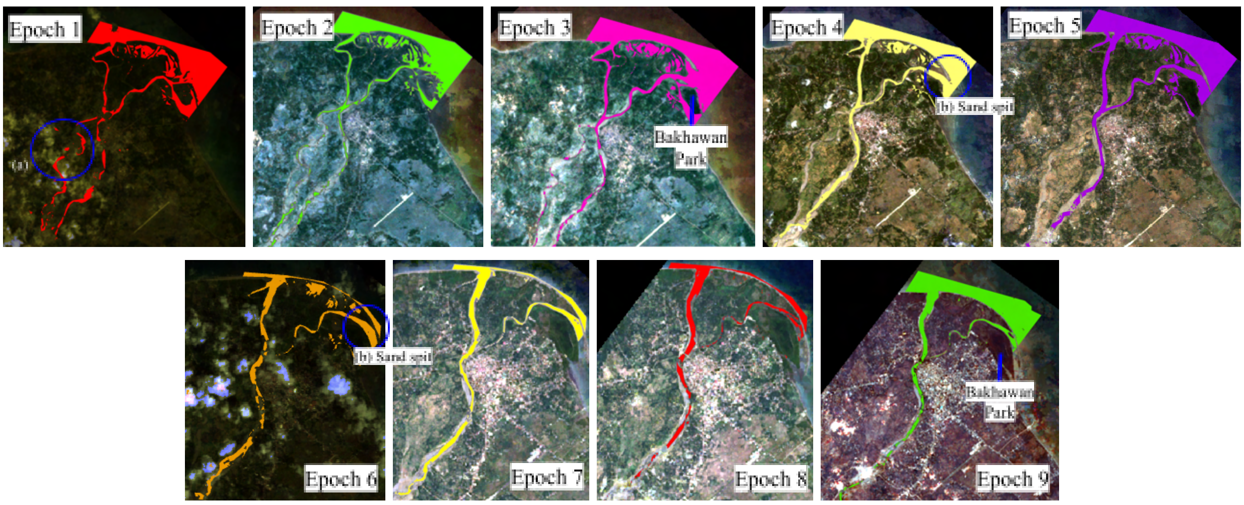


Figure 11. River Course over the Epoch. (From left to right: Epoch 1 to 9)

3.3. Government and Non-Governmental Organizations (NGOs) Discussions

Through capacity-building and educational events, this study successfully achieved its objectives of raising awareness about the concurrent issues of erosion and accretion in New Washington, Aklan. The study was presented at the InMSEA: Integrated Network-based Management for Southeast Asia coasts, with participants from various State Universities and Colleges, including Aklan State University, Bohol Island State University, Samar State University, Eastern Samar State University, Southern Leyte State University, Mindanao State University-Naawan, UP Tacloban, UPVTC Biological Society, as well as representatives from NGOs and concerned government agencies such as Guiuan Development Foundation, Inc., DOST-PCIEERD, LGU Balangiga, and LGU Lawaan. This event served as a platform for sharing insights and findings from the study, aiming to facilitate discussions and collaborations among stakeholders.

Furthermore, the study was also discussed at the 2nd National Panel of Technical Experts' Policy Forum at the Southern Luzon State University, which focused on the navigation of flooding's impact on climate change, food security, and disaster response in the Philippines.

The goal of these engagements was to enhance understanding and awareness of the potential risks and threats posed by shoreline changes, empowering participants to advocate for appropriate environmental initiatives and policies. This study enabled concerned offices to prioritize the need for monitoring and disaster risk reduction planning and to specify various factors that aggravate the behavior of sediments along the municipalities' coasts.

4. Conclusion

Based on the analysis using four Dynamic Shoreline Analysis System (DSAS) change metrics - End Point Rate (EPR), Linear Regression Rate (LRR), Shoreline Change Envelope (SCE), and Net Movement Shoreline (NMS) - it becomes evident that the shoreline changes in the Bakhawan Park areas are primarily influenced by its location at the mouth of the Aklan River. This had significant effects on the trend of erosion along the shoreline of New Washington with erosion rates ranging from 0 to 1.46 meters per year, as determined by LRR. This erosion has resulted in the gradual loss of up to 40 meters of sediment over thirty years, particularly pronounced in areas such as Brgy. Tambac and Poblacion. Furthermore, the most substantial deviation in shoreline position has been observed in regions near the mouth of Batan Bay, exhibiting a notable shift of 153 meters since 1985. Hence, this stresses the need for practical plans and actions to deal with the problems caused by changes in the shoreline. This is crucial for protecting New Washington's coastal areas and the people who live there from potential dangers in the future. However, it's important to note that this study's limitations include the effects of wind, waves, rainfall, and elevation data. Hence, this suggests further improvement moving forward.

Acknowledgment

This research was made possible with the help of the Upgrading and Promoting the Comprehensive Assessment and Conservation of Blue Carbon Ecosystems and their Services in the Coral Triangle (UPBlueCARES) Project implemented by the Environmental Systems Applications of Geomatics Engineering (EnviSAGE) Research Laboratory of the Department of Geodetic Engineering and funded by the University of the Philippines.

We extend our gratitude to our advisers, Dr. Ariel Blanco, Dr. Yasmin Tirol, and Prof. Kazuo Nadaoka for contributing their knowledge to this research.

References

Aguirre, J. (2023). Aklan researcher warns of flood risks due to mangroves project. RAPPLER. https://www.rappler.com/nation/visayas/aklan-researcher-warns-of-flood-risks-due-to-mangroves-project/

Baig, M. R. I., Ahmad, I. A., Shahfahad, Tayyab, M., & Rahman, A. (2020). Analysis of shoreline changes in Vishakhapatnam coastal tract of Andhra Pradesh, India: an application of digital shoreline analysis system (DSAS). Annals of GIS, 26(4), 361–376. https://doi.org/10.1080/19475683.2020.1815839

Digital Shoreline Analysis System (DSAS) | U.S. Geological Survey. (2021, November 19). https://www.usgs.gov/centers/whcmsc/science/digital-shoreline-analysis-system-dsas#overview

Estrada, J., & Visitacion, M. R. (2020). Analysis Of Black Sand Mining-Induced Coastal Erosion Along The Northern Coastline Of Cagayan, Philippines Using Gis And Remote Sensing Techniques (thesis). College of Engineering, University of Philippines Diliman, Quezon City.

Jeong, H. Y. (2019). A study on Changes in Coastal erosion environment by Time Series Coastal Detection Using GIS.

Journal of Coastal Research, 91(sp1), 331. https://doi.org/10.2112/si91-067.1

Li, J. L. R. (2001). Spatial modeling and analysis for shoreline change detection and coastal erosion monitoring. Marine Geodesy, 24(1), 1–12. https://doi.org/10.1080/01490410121502

Liu Y, Wang X, Ling F, Xu S, Wang C., (2017): Analysis of Coastline Extraction from Landsat-8 OLI Imagery. Water.; 9(11):816. https://doi.org/10.3390/w9110816

Mentaschi, L., M.I. Vousdoukas, J. Pekel, E. Voukouvalas and L. Feyen, (2018). Global long-term observations of coastal erosion and accretion. Scientific Reports, 8:12876.

What are the band designations for the Landsat satellites? | U.S. Geological Survey. (2024, March 19). https://www.usgs.gov/faqs/what-are-band-designations-landsat-satellites

Williams, A. T., Rangel-Buitrago, N., Pranzini, E., & Anfuso, G. (2017). The management of coastal erosion. Ocean & Coastal Management, 156, 4–20. https://doi.org/10.1016/j.ocecoaman.2017.03.0