Civil Engineering Dimension
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Monitoring and Analysis of Coastline Changes in the Coastal Area of Bali Island, Indonesia

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DOI: https://doi.org/10.9744/ced.26.1.32-50

Article Info:
Submitted: Oct 12, 2023
Reviewed: Jan 30, 2024
Accepted: Feb 07, 2024

Keywords:
coastline,
Bali Island,
field survey,
remote sensing.

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Abstract

Erosion and accretion occuring in coastal areas are indications of changes in the coastline's position. The beach areas in Bali have high economic value as tourist attractions; yet, the condition of the beaches in several places on the island is very concerning. Monitoring shoreline changes can be accomplished using remote sensing technology which is more efficient than the conventional methods. This paper describes the results of changes in the coastline from 2014 to 2021 with remote sensing for all coastal areas of the island of Bali surveyed in the field. This research has successfully detected changes in coastlines throughout the coastal areas of Bali Island by remote sensing method and verified by field survey. The survey results also show that remote sensing method has met the survey from previous studies specifically in Gianyar Regency and Jembrana Regency. Hence, it is applicable for further use in other areas.

Introduction

The problem of coastal areas in Indonesia is one of the environmental issues that needs serious attention. Many infrastructures and cities were built in coastal areas. Therefore, environmental conditions in coastal areas should always be monitored and maintained. One factor of the level of damage to coastal areas is shown from the damage to the coast due to abrasion. This can be seen from changes in the coastline that occurred in an area. Coastline changes or often called coastline evolution occur on a scale of seconds to millions of years [1–4]. Coastline changes consist of abrasion and accretion phenomena. The abrasion and accretion processes result in unbalanced coastal conditions and have an impact on damage to coastal areas [5,6].

Abrasion is the process of coastal erosion by destructive ocean waves and ocean currents. The abrasion process could damage infrastructure in coastal areas, such as access roads, bridges, and buildings around the coast (houses, factories, port facilities), rice fields, pond areas, and beach recreation areas [7–10]. Coastal accretion is a change in the coastline towards the open sea due to the process of sedimentation from land or river mouths on the coast. This accretion process can occur due to sedimentation resulting from land clearing (land conversion), high volumes of fresh water runoff due to high rainfall, and the transport of sediment from river bodies to the sea. On the other hand,

Note : Discussion is expected before July, 1st 2024, and will be published in the "Civil Engineering Dimension", volume 26, number 2, September 2024.
ISSN : 1410-9530 print / 1979-570X online
Published by : **Petra Christian University**

a prolonged coastal accretion process (from thousands to millions of years) can also cause sedimentation to spread evenly over a certain area, giving rise to a new land in the form of a delta or raised land. Coastal accretion processes usually occur in coastal waters where there are many river mouths and have small sea wave energy [11].

Monitoring changes in coastlines can be done by direct field surveys. However, because coastal areas are well-known with large and elongated areas, direct field surveys are very inefficient (requires high costs and requires a long time). One very efficient method for monitoring coastline changes is by utilizing remote sensing method [12–29]. Research on monitoring shoreline changes as a whole in the coastal areas of Bali Island using Synthetic-Aperture Radar (SAR) imagery has been conducted in several research [30,31]. This research enables the provision of information about changes in coastlines spatially and temporally along the coastal areas of the island of Bali. Research on shoreline changes, especially in several coastal areas of the island of Bali, has also been carried out previously by several papers [32–37]. The type of image used is an optical image. Meanwhile, the use of SAR imagery was carried out in other papers [38,39] where the location is on the Southeast Coast of Bali Island (Coast of Gianyar Regency and Klungkung Regency). By knowing the changing conditions of the coastline along the coastal areas of Bali Island, an evaluation of beach conditions can be carried out. The results of this research serve as a reference for prioritizing maintenance efforts on impaired beaches and maximizing the development of potential beaches. This research is significant to be executed immediately because obtaining the earliest data on changes in coastlines may prompt consideration of rapid mitigation actions. The results of mapping changes in coastlines in the coastal areas of Bali Island will be described in detail in this research and the results of the field survey are presented as validation of the remote sensing analysis results.

Method

The research location is carried out along the coastal area of the Bali Island by dividing up into several regions as shown in Figure 1. The figure is downloaded from Satellite Sentinel-1 A&B with the link (https://esar-ds.eo.esa.int/oads/access/collection/ASA_IMP_1P) in period of 2014 to 2021. There are eight regencies and one city in Bali Island. After downloading the SAR imagery, it continues with pre-processing SAR imagery, analyzing the quality of image polarization, image thresholding, extracting coastline, coastline change detection, validation and accuracy testing [40].

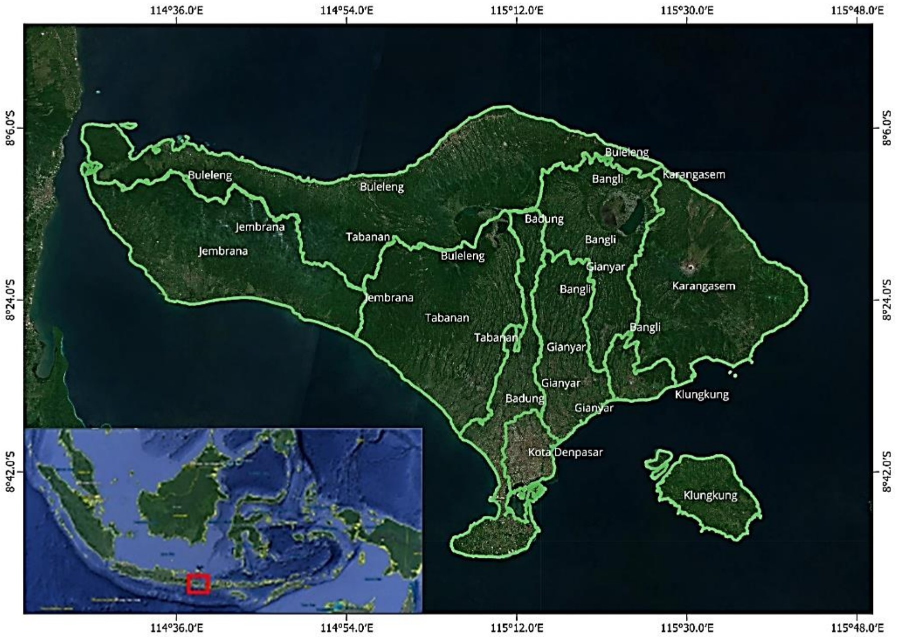


Figure 1. Maps of Research Area

Coastline Change Analysis during 2014 – 2021 with Digital Shoreline Analysis System (DSAS) Software

Several steps involved in the process of analysis with Digital Shoreline Analysis System (DSAS) applications [41–43] are as follows.

Determination of the Reference Line or Baseline

The process of determining the reference line (baseline) is a vital step in the analysis of DSAS applications. This baseline is used as the main reference to measure shoreline changes every year. This process is carried out by creating a "buffer" of all shoreline extraction results. DSAS would determine the best baseline for all shoreline data. Figure 2 shows an example of the process for making a baseline (reference line) from coastline data in 2014 and 2021. The baseline line is shown by the white line and the red line indicated the coastline in 2021 and blue line indicated the coastline in 2014.

Figure 2. Example of a Baseline (Reference Line) Making Process from Coastline Data for 2014 and 2021

Determination of the Shorelines to be Analyzed

During the baseline development process, each year's coastline data is stored separately in shapefile (.shp) format. Based on the year of data, there should be more than one coastline data for comparation of each data. Afterward, the process of merging all shapefiles must be carried out into one shapefile and named shorelines.shp as shown in Figure 3.

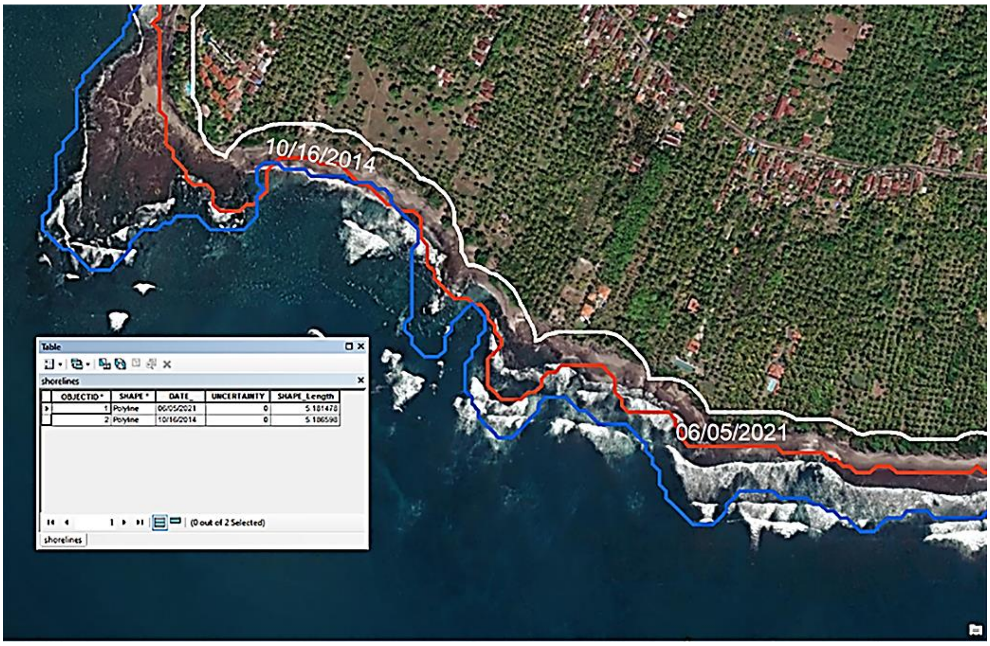


Figure 3. Example of Combining Several Coastlines from Different Years in One Shapefile (Shorelines.shp)

Conducting Parameter Settings (Baselines and Shorelines)

The aim of this process is to determine the parameters of the DSAS application. These parameters would be used further for analysis and calculations. Figure 4 is an example for determining the baseline parameters, which include the baseline layer and orientation. Figure 5 shows how to determine the shorelines parameters. Figure 6 explains the metadata parameters such as user general information, research purpose and contact information.

Creating Transects and Performing Statistical Calculations

After all parameters have been set up, then the transect can be determined. The transect is a line perpendicular to the baseline and assists in measuring the shoreline changes from the baseline. The process and parameter settings for making a transect are shown in Figure 7, which include the casting and define the spacing distance. Results of making a transect are shown in Figure 8. The completed transect is shown in green line, and it measures the shoreline changes between the baseline (white line), 2021 coastline (red line) and 2014 coastline (blue line).

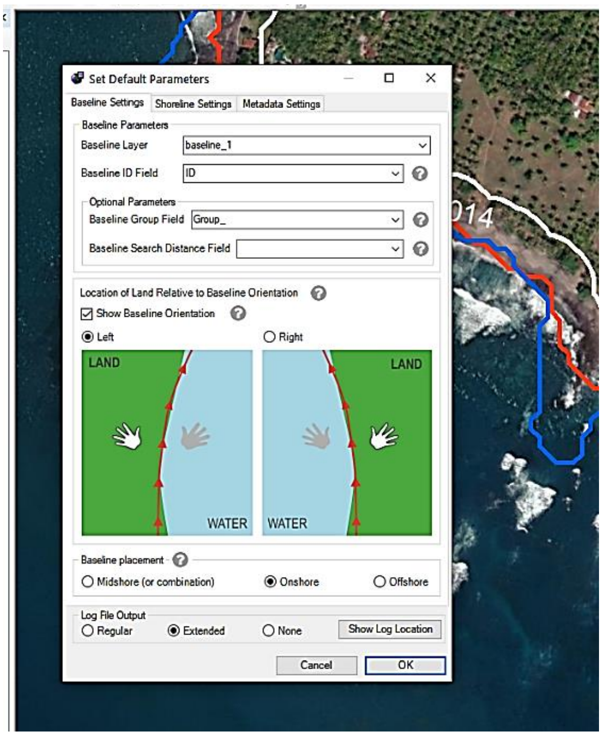


Figure 4. Determine Parameters for Baseline in DSAS Software

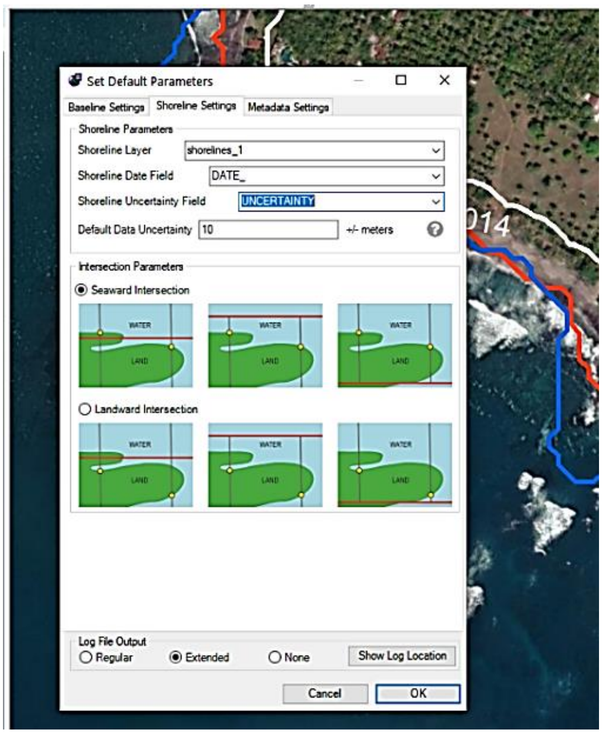


Figure 5. Determine Parameters for Shorelines in DSAS Software

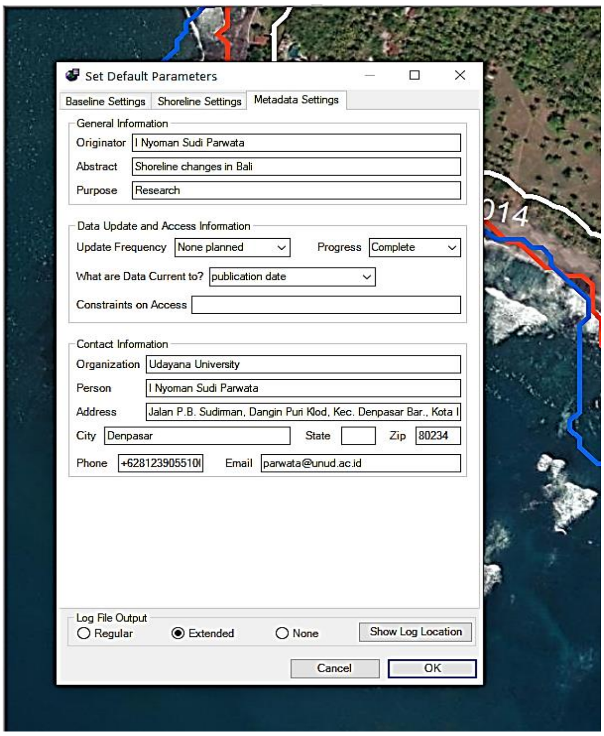


Figure 6. Determine Parameters for Metadata (user information and research topics) in DSAS software

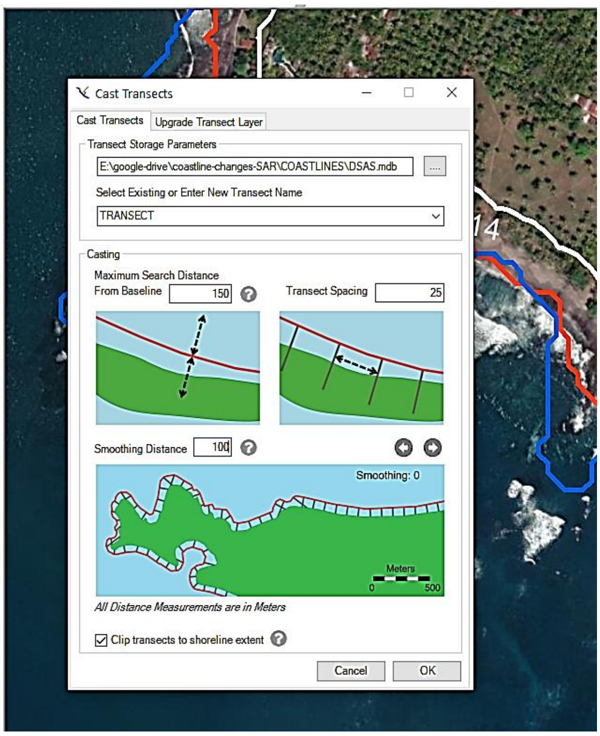


Figure 7. Process and Parameter Settings of Creating Transects

Figure 8. Results of Making a Transect (Green Line)

Results and Discussion

Based on the DSAS application result, changes in coastlines from 2014-2021 for the entire Bali Island are shown in Figure 9 [14]. Abrasion is indicated by color and negative values as follows: green (0 to -10m), yellow (-10 to -20m), orange (-20 to -30m) and red (more than -40m). While accretion is indicated by a positive value, with the following colors and values: light blue (0 to 10m), blue (10 to 20m), and dark blue (more than 30m). Explanation of the coastline changes in each region is described in several paragraphs below in more detail.

The field survey was conducted in five regencies in Bali, including: Buleleng Regency, Klungkung Regency, Gianyar Regency, Badung Regency and Jembrana Regency. Surveys were carried out in areas that revealed coastal damage (either abrasion or accretion) from the Sentinel-1 imagery. Results of the survey and observation on the field verify that the results of coastline changes by using Sentinel-1 imagery have an agreement of abrasion and accretion occurrence in shoreline of Bali Island.

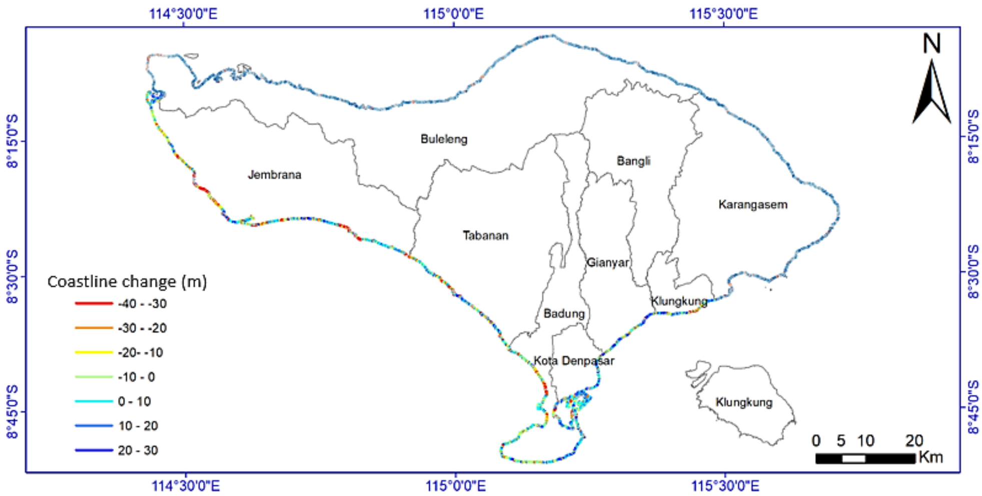
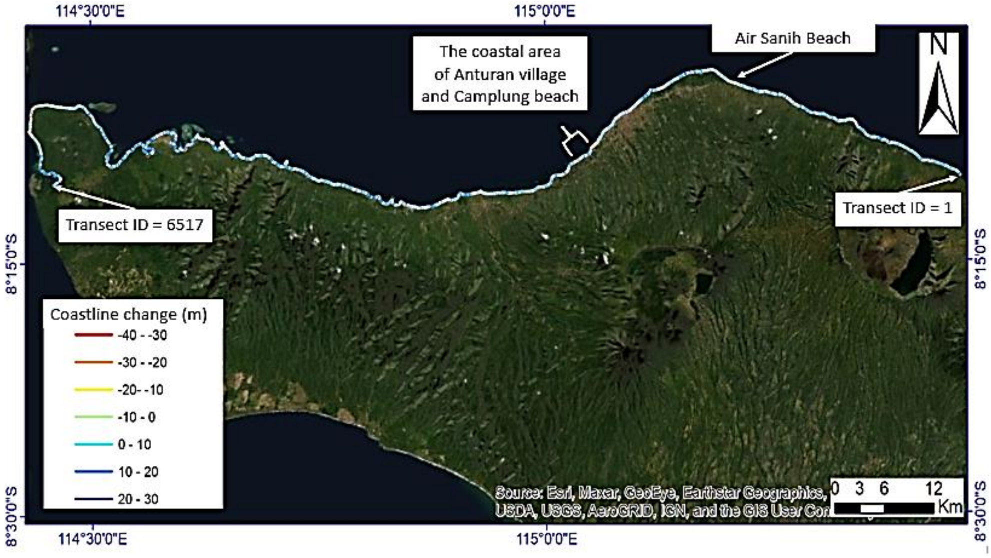


Figure 9. Results of Coastline Changes from 2014-2021

Buleleng Regency

Buleleng Regency is the region in the northern side of Bali that has the longest coastline in the island. The results of this research show that changes in coastline conditions are relatively small compared to other regencies in Bali. However, the beaches with the worst abrasion are in the Anturan Village area and along Camplung Beach. The rate of abrasion occurring at this location is more than -5 m/year with a length of around 3,245 meters. In other locations, abrasion also occurs, notebly on Air Sanih Beach with an abrasion rate of 5-10 m/year on a length of 977 m. The results in Buleleng Regency are shown in Figure 10. The graph in Figure 10(b) is the result plot of Figure 10a with the x-axis based on location of Transect ID = 1 to 6517. The y-axis indicates the value of abrasion (negative value) or accretion (positive value) on each transect with distance of 25 meter.

Anturan Village and Camplung Beach location are indicated between Transect ID = 2200 to 2400. The documentation of the field survey conducted on the beach in Anturan Village is shown in Figure 11. On this beach, abrasion is dominant and has eroded several tree roots structures on the beach. The Buleleng regency government seems to have started building revetments to prevent erosion from getting worse. This was proven when the survey team came to the area and observed the process of building revetments and concrete pavement.



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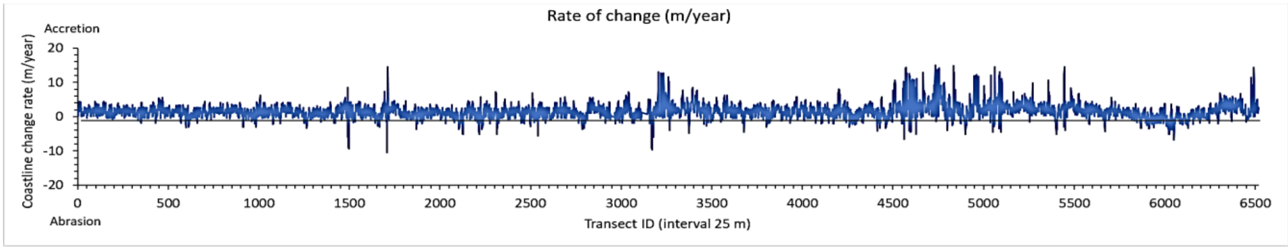

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Figure 80. (a) Results of Changes in Coastline (m), and (b) Rate of Change in Coastline (m/year) in Buleleng Regency from 2014-2021

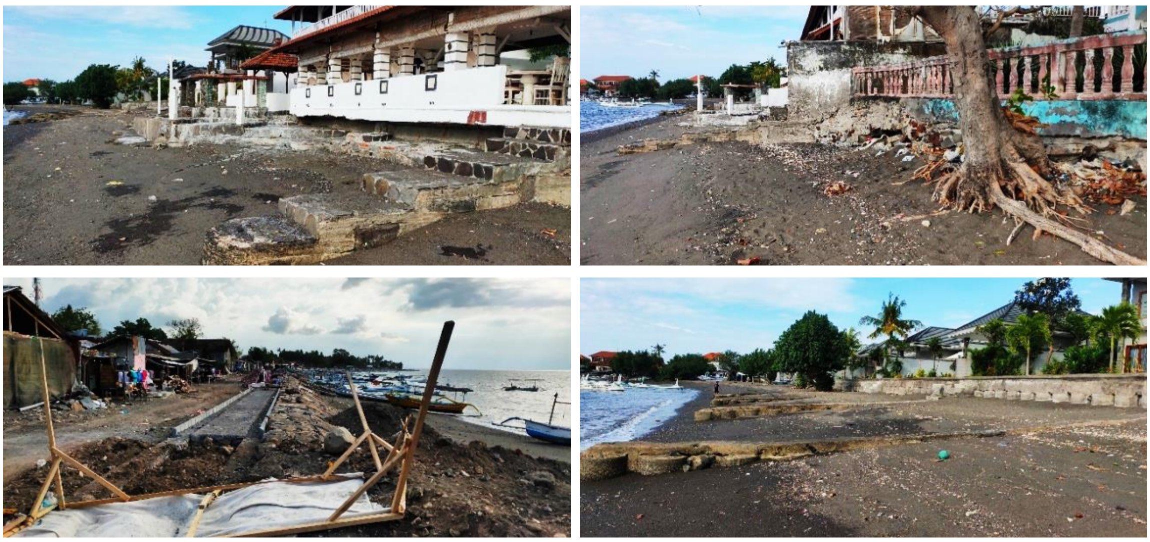


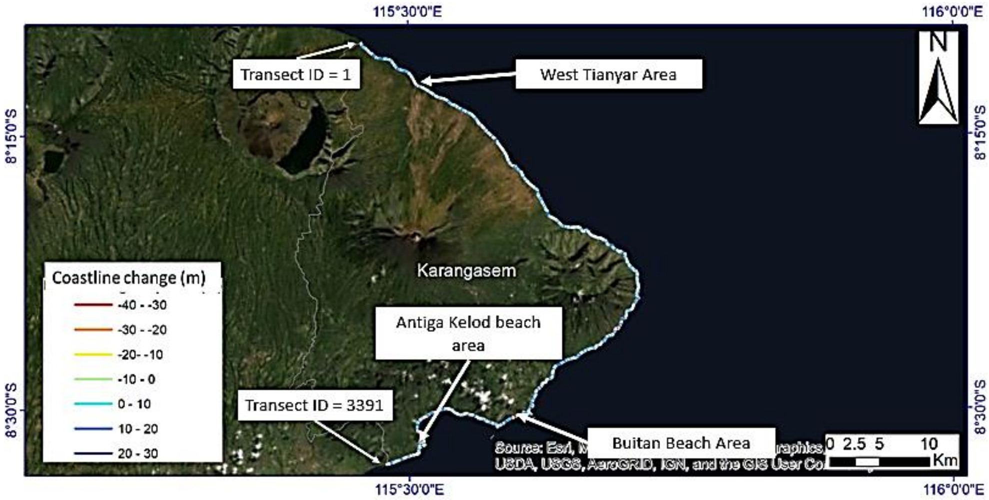
Figure 11. Coastline Survey in Anturan Village, Singaraja, Buleleng Regency

Furthermore, the conditions at Camplung Beach are shown in Figure 12. Information about abrasion at Camplung Beach has long been reported by the local community. This can be seen from the team's survey results which show abrasion conditions at various points on the coast. Monitoring by the research team points out that there are no signs of beach improvements being carried out by the government.

Figure 12. Coastline Survey in Camplung Beach, Singaraja, Buleleng Regency

Karangasem Regency

The results in Karangasem Regency are shown in Figure 13. Beach erosion in Karangasem Regency occured in the West Tianyar Coastal Area (Transect ID 245-300) with an abrasion rate of 5 m/year over a length of 1,440 meters, in the Buitan Village Coastal Area (Transect ID 2800-2848) with an abrasion rate of 5-10 m/year over a length of around 1,200 meters, and in the coastal area of Antiga Kelod Village (Transect ID 3140-3186) with abrasion rate 5-10 m/year with a length of 1,143 meters.



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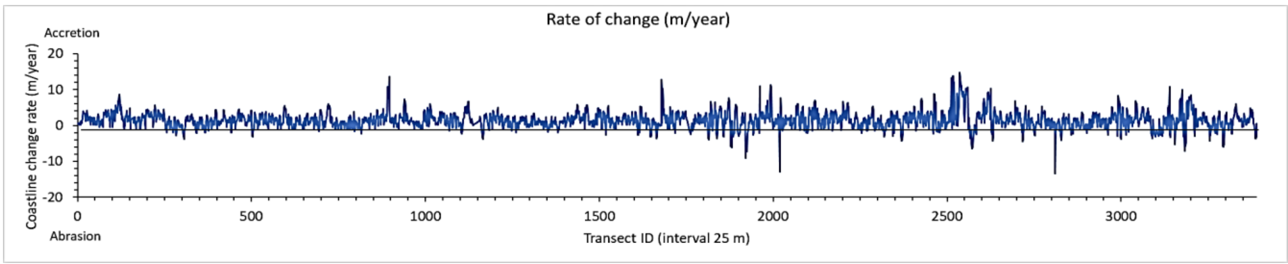

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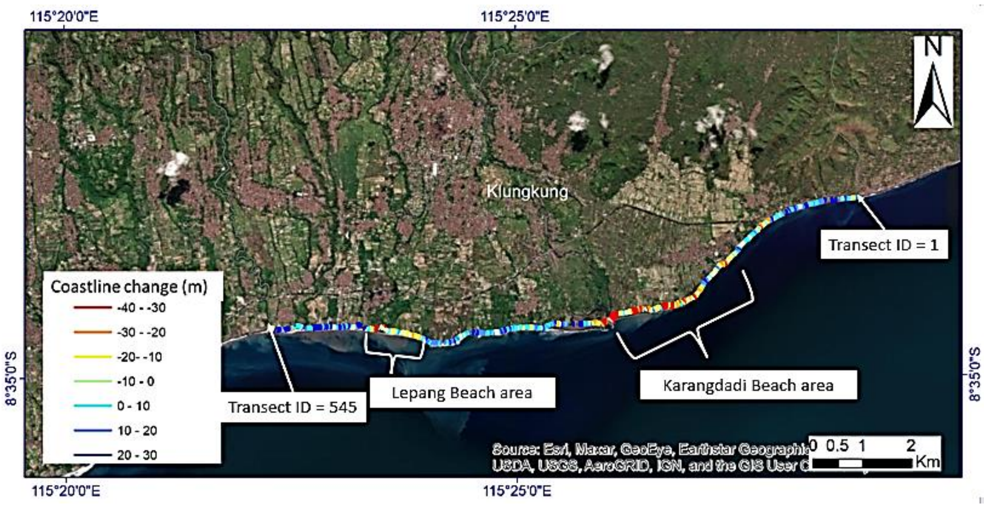
Figure 13. (a) Results of Changes in Coastline (m), and (b) Rate of Change in Coastline (m/year) in Karangasem Regency from 2014-2021

Klungkung Regency

Klungkung Regency has the shortest coastline compared to other regencies in Bali. Nevertheless, the level of coastal damage due to abrasion in this regency is severe. The results in Klungkung Regency are shown in Figure 14. The results of this research show that abrasion occurred on Karangdadi Beach (east of Kusamba Harbour) in Transect ID 125-260. The rate of abrasion that occurs at this location is around 5-15 m/year with a length of more than 3,345 meters. Abrasion also occurs on Lepang beach (Transect ID 410-458) and its surroundings at 5-10 m/year along the length of 1,167 meters.



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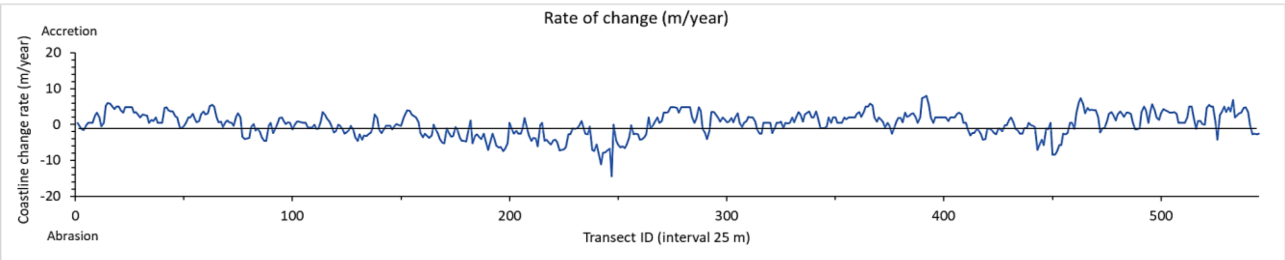

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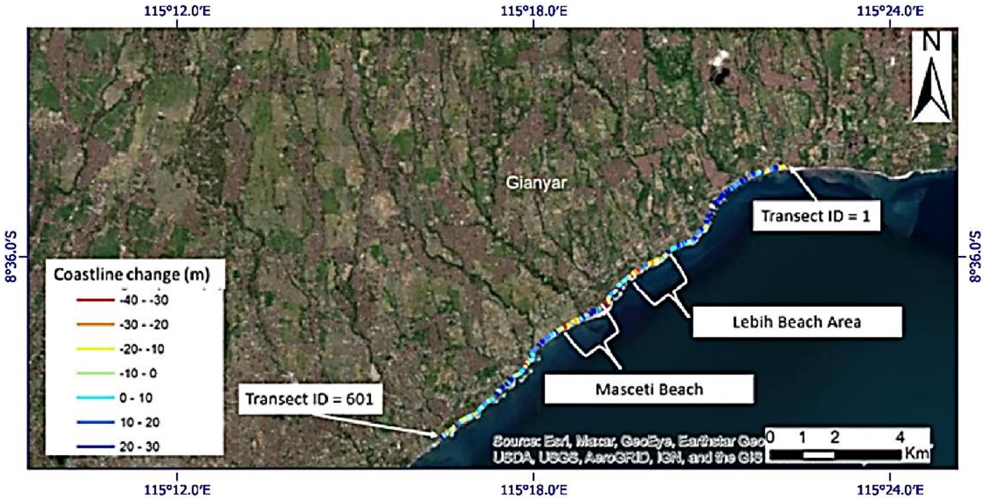
Figure 14. (a) Results of Changes in Coastline (m), and (b) Rate of Change in Coastline (m/year) in Klungkung Regency from 2014-2021

Figure 15. Coastline Survey in Kusamba Beach, Klungkung Regency

The survey location in Klungkung Regency is situated in the eastern part of Kusamba Harbour. The unique condition of this beach is shown by the results of the Sentinel-1 image which identifies the coastline is moving towards land (abrasion). Conversely, field surveys pointed out sedimentation that has covered half the height of local buildings and temples as shown in Figure 15. This is possibly caused by waves heading towards land and carrying sand material.

Gianyar Regency

The results in Gianyar Regency are shown in Figure 16. The worst beach erosion in Gianyar Regency occurred in Lebih Beach area and the surrounding coastal areas (Transect ID 200-288) with abrasion lines reaching 5-10 m/year with a length of around 2,190 meters. Abrasion also occurs in Masceti Beach area and its surroundings (Transect ID 300-374) with an abrasion rate of more than 5 m/year with a length of 1,850 meters. Previous study in Lebih Beach has been done with the results of abrasion rate between 2009-2015 by SPOT satellite is around 3.9 m/year [44]. By comparing the previous study with the results of this research, it is clear that Lebih Beach's coastline is experiencing abrasion.



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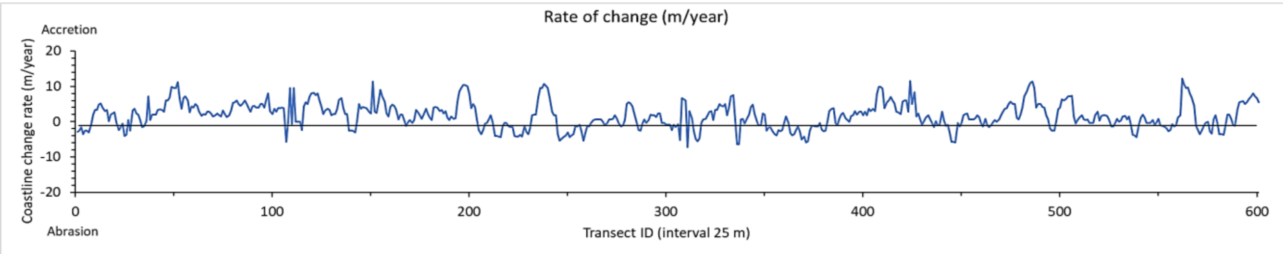


(b)

Figure 16. (a) Results of Changes in Coastline (m), and (b) Rate of Change in Coastline (m/year) in Gianyar Regency from 2014-2021

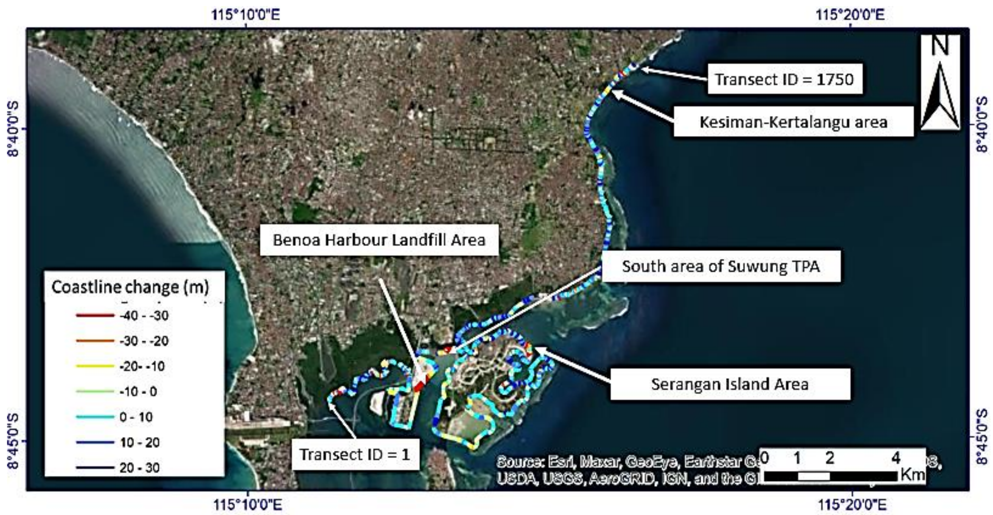
Figure 17. Coastline Survey in Lebih Beach, Gianyar Regency and Its Surroundings

The field survey in Gianyar Regency was focused on Lebih Beach and its surroundings. The research team found that the local government has long taken action to deal with abrasion disasters by constructing coastal protection structures and pavements. However, due to the strong waves on this beach, there was serious damage to the building (Figure 17).

The research team also discovered that the Bench Mark (BM) in the Bali-Penida river area had collapsed due to abrasion, as shown in Figure 18. This proves that the waves that caused the abrasion were very strong. Of course, the BM structure cannot be used as a benchmark anymore because the position and slope have changed.

Figure 18. The Condition of the Bench Mark (BM) belonging to the Bali-Penida River Area had Collapsed due to Abrasion

Denpasar City



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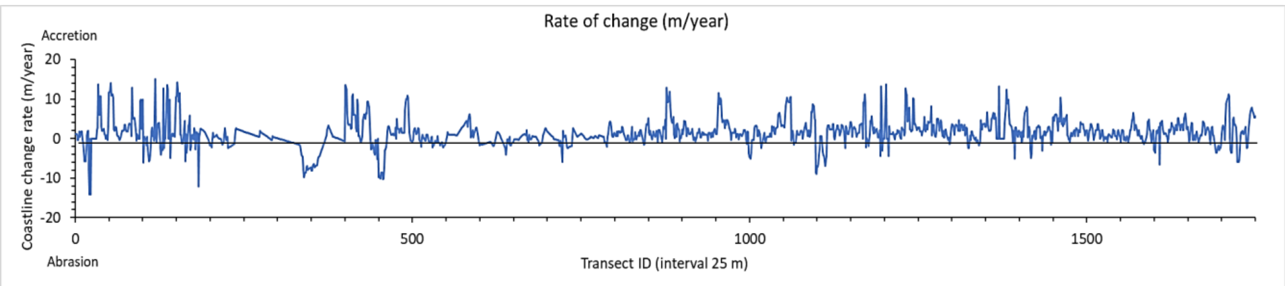

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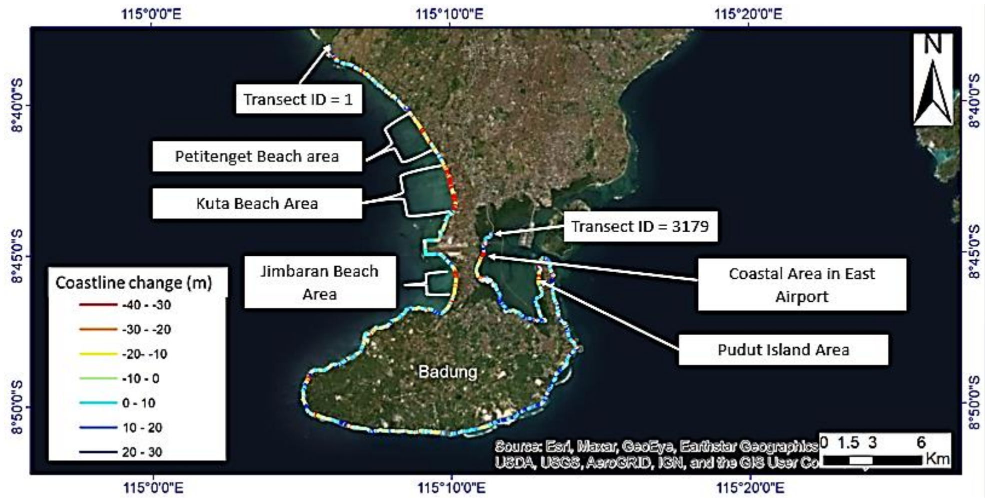
Figure 19. (a) Results of Changes in Coastline (m), and (b) Rate of Change in Coastline (m/year) in Denpasar City from 2014-2021

The coastline of Denpasar City, especially in the Serangan Island area, is quite complicated. The results in Denpasar City are shown in Figure 19. Abrasion occurred in the Kesiman-Kertalangu area (Transect ID 1600-1653) with an abrasion rate of more than 5 m/year over a length of 1,320 meters. To the south of the Suwung landfill site (Transect ID 450-468), abrasion occurs at around 5-10 m/year with a length of 445 meters. Abrasion also occurs in the Serangan Island area (Transect ID 1100-1116) with an abrasion rate of around 5-10 m/year with a length of 405 meters. This research also found abrasion in the landfill area before the entrance to Benoa Harbour (Transect ID 170-200). The abrasion rate in this area is around 5-10 m/year with a length of 716 meters.

Badung Regency

Badung Regency has several beach areas which is well-known to be tourist destinations. The results in Badung Regency are shown in Figure 20. Beach erosion in Badung Regency occurs on Petitenget Beach (Transect ID 200-279) occurs at a rate of 5-10 m/year with a length of 1,971 meters. Abrasion at Kuta Beach (Transect ID 475-600) with an abrasion rate reaching more than 10-15 m/year with a length of 3,125 meters. Abrasion also occurs in the Jimbaran - Kedonganan Beach area (Transect ID 800-900) at a rate of 5-10 m/year along a length of 2,501 meters. On the east coast of Ngurah Rai Airport (Transect ID 3000-3030), abrasion occurred at a rate of around 5-10 meters with a length of 746 meters. Another location is Pudut Island (Transect ID 2400-2448), this area has long been reported to experience abrasion, and this research recorded an abrasion rate of more than 5 m/year with a length of 1,182 meters.



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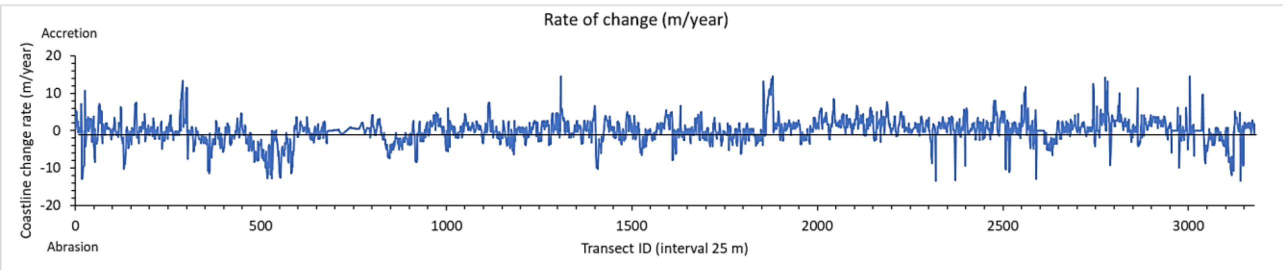

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Figure 20. (a) Results of Changes in Coastline (m), and (b) Rate of Change in Coastline (m/year) in Badung Regency from 2014-2021

Utilizing drone for coastal surveying is also feasible to be done to be compared with remote sensing [45]. Field surveys at Petitenget Beach were also conducted utilizing drones in 2021. Mapping using a DJI Phantom 4 Pro drone and five ground control points (GCPs) which were evenly distributed along the coastline. The results of coastline extraction using a drone are shown in Figure 21. The yellow line is the result of coastline extraction using a drone. The red line is the 2021 coastline obtained from Sentinel-1 imagery. The blue line is the 2014 coastline obtained from Sentinel-1 imagery. Overall, the coastline analysis obtained from Sentinel-1 imagery in 2021 (red line) is almost inline as the coastline field survey obtained using drones (yellow line) in the same year. The coastline changes from 2014 to 2021 are indicated by the distance of blue line to the red line or yellow line. This shows that the Sentinel-1 image results are applicable for the use in this research to give information on coastline changes in Bali.

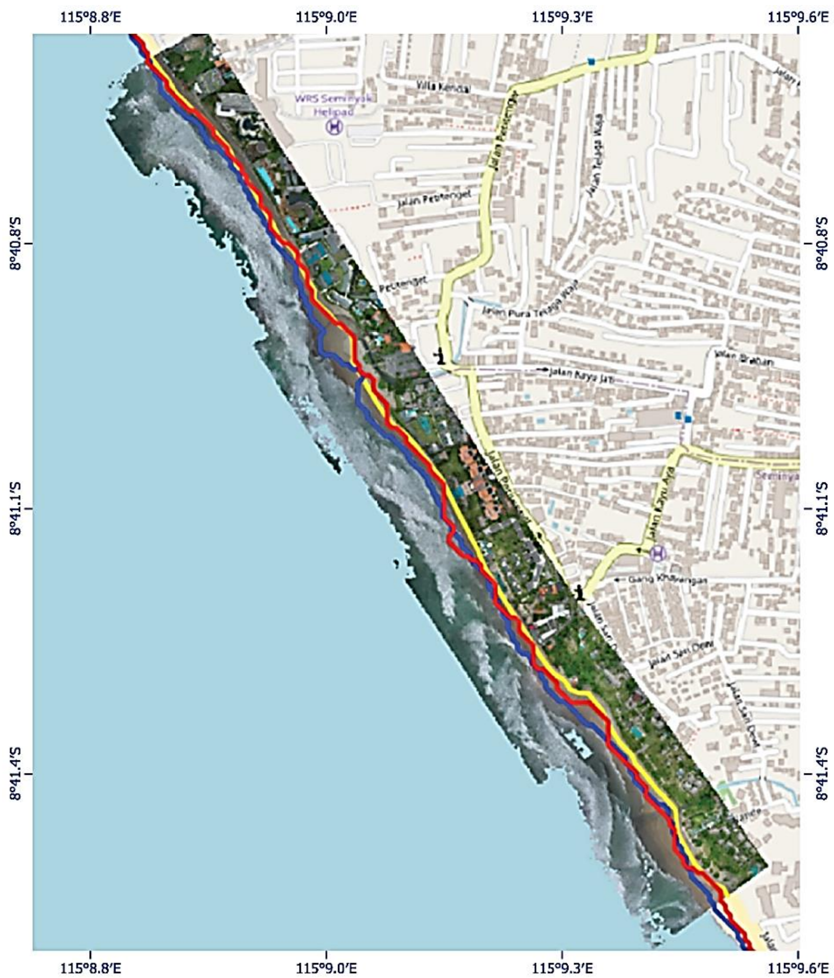


Figure 21. Results of Coastline Extraction using Drones (yellow line), 2021 Coastline (red line) and 2014 Coastline (blue line) in Petitenget Beach, Badung Regency

When data collection was carried out using drones, the research team also observed the Petitenget beach conditions in the field. There are several signs indicating abrasion on this beach as shown in Figure 22.

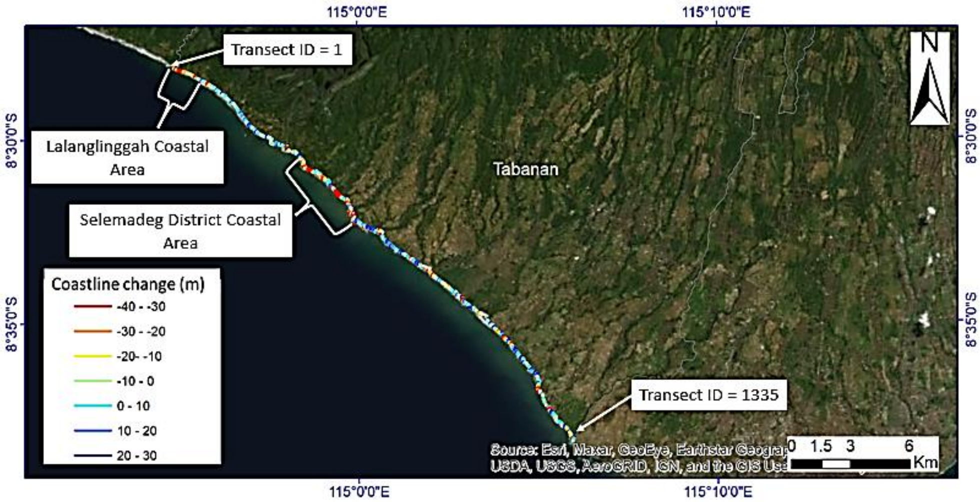
Figure 22. Coastline Survey in Petitenget Beach, Badung Regency and Survey Team Documentation

Initially, the research team was planning a drone survey to be carried out on Kuta beach. However, after checking the drone track, the team found that Kuta beach was included in the Aviation Security Area. This area is an area that is prohibited for flying drones. Thus, the drone survey was moved to Petitenget beach. On the other hand, the research team made direct observations and found evidence of abrasion and accretion on Kuta Beach as shown in Figure 23.

Figure 23. Coastline Survey in Kuta Beach, Badung Regency

Tabanan Regency

The results in Tabanan Regency are shown in Figure 24. Beach erosion in Tabanan Regency predominantly occurs in areas along the coast of Selemadeg, East Selemadeg and surrounding areas (Transect ID 375-542). The abrasion rate in these areas reaches 10-15 m/year, with a total length of around 4,167 meters. In another area, namely the Lalanglinggah coastal area (West Selemadeg) with Transect ID from 0-52, abrasion occurs at a rate of 5-10 m/year with a length of 1,293 meters.



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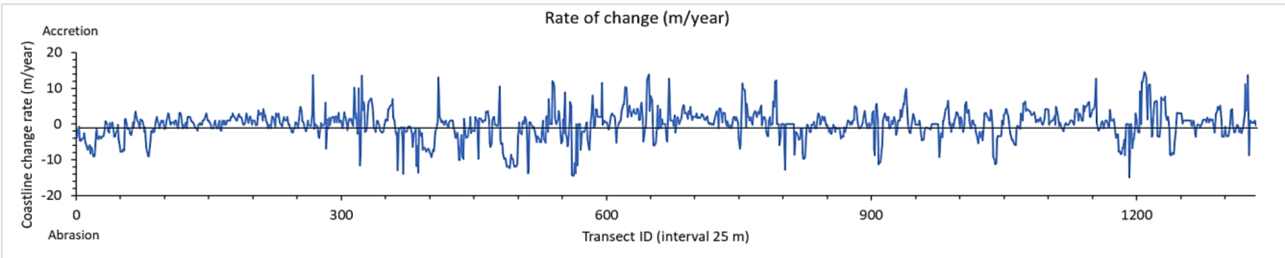


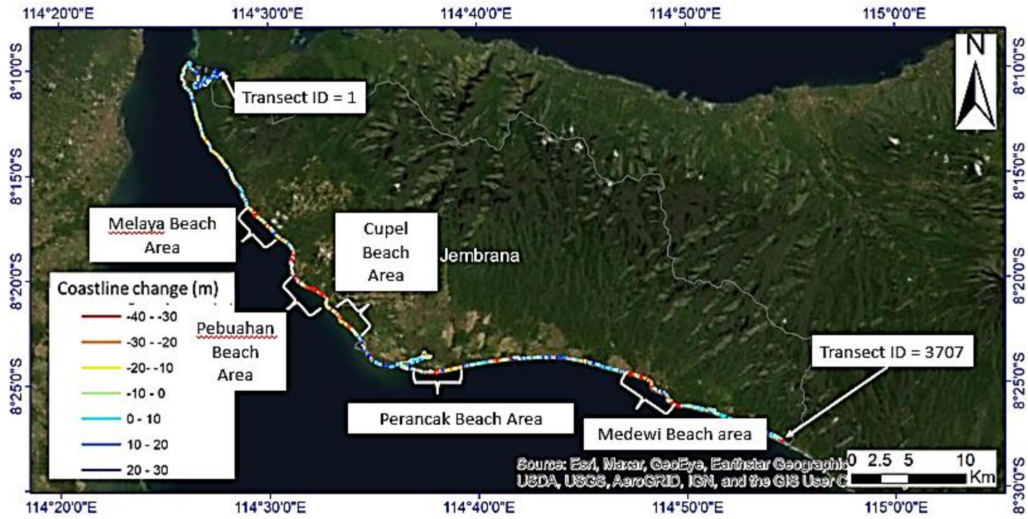
(b)

Figure 24. (a) Results of Changes in Coastline (m), and (b) Rate of Change in Coastline (m/year) in Tabanan Regency from 2014-2021

Jembrana Regency

The results in Jembrana Regency are shown in Figure 25. The worst abrasion in Jembrana Regency occurred in the coastal area of Melaya Beach (Transect ID 700-785), abrasion occurs at a rate of more than 5 m/year with a length of around 2,129 meters. In the coastal area of Pebuahan, Banyubiru District (Transect ID 1000-1228). The rate of abrasion in this area reaches 10-15 m/year with a length of 5,694 meters. Abrasion also occurs in the Cupel Beach area (Transect ID 1350-1462) at a rate of 5-15 m/year along a length of 2,814 meters. Abrasion also occured along a 3,105-meter stretch in the Perancak Beach area (Transect ID 2250-2375) at a rate of around 5-10 m/year. Nearby Medewi Beach (Transect ID 3050-3295), abrasion occurs at a rate of more than 10 m/year along 6,107 meters.

Previous studies in Jembrana Regency shows that coastline changes are occurred in several beaches in Jembrana, where the research results in this paper has an agreement with the previous study [34,46].



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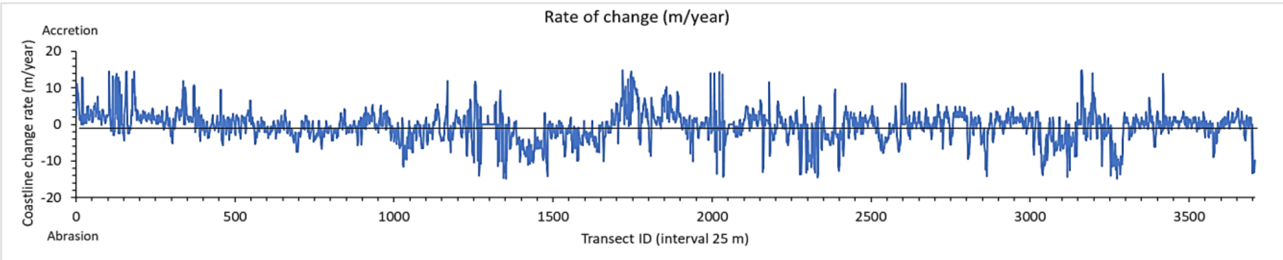

(b)

Figure 25. (a) Results of Changes in Coastline (m), and (b) Rate of Change in Coastline (m/year) in Jembrana Regency from 2014-2021

In addition to the result in Figure 25, the results of the field survey at Pengambengan Fish Harbour Beach (Transect ID 1650-1900) showed that there was large sedimentation in the east of the harbor (Figure 26). Most likely this sedimentation is the effect of long-term construction on the harbour shoreline. It is likely that the sand which caused this sedimentation came from the river estuary to the east of the port. From the surrounding information, this embankment was built to overcome the sedimentation process that occurs in the fishing boat harbour.

Figure 26. Coastline Survey on The Beach of Pengambengan Fish Harbour, Jembrana Regency

Severe coastal abrasion occurred along Pebuahan Beach. Numerous sections of road were damaged due to this abrasion. Moreover, there were traces of buildings that have been eroded by abrasion and the only structure left was basic construction of the building (Figure 27). There is a high possibility that this abrasion occurred due to the construction of embankments at the Pengambengan fish harbour. Sand material collected on the east coast of Pengambengan harbour should be able to reach Pebuahan Beach if the embankment is not built.

Figure 27. Coastline Survey in Pebuahan Beach, Jembrana Regency

For the coastline extraction results in Jembrana Regency, a validation test was carried out with reference data from Landsat 8 results [44]. The comparison results in Figure 28 point out that the two coastlines in general is in a good agreement to define the coastline area. There are some differences at several points, which is most likely due to differences in spatial resolution between Sentinel-1 and Landsat 8 data [47–52].

Figure 28. Comparison Results of SAR and Landsat Coastlines in 2019. Landsat Results were Obtained from [44]

Conclusions

From this research, DSAS result has been done to monitor and analyses the coastline changes in Bali Island and verified by field survey. The conclusions obtained from this research include:

1. This research has succeeded in detecting changes in coastlines throughout the coastal areas of Bali island by utilizing Synthetic Aperture Radar (SAR) remote sensing technology and Digital Shoreline Analysis System (DSAS) from 2014-2021.
2. The SAR image used comes from the Sentinel-1 satellite which has a resolution of 15x15 meters.
3. Field surveys confirmed the results of coastline extraction from Sentinel-1 imagery, where abrasion and accretion was found on several beaches in Bali. Previous studies in Gianyar Regency and Jembrana Regency also confirmed these findings.
4. Validation results using drone data show that the coastline extraction results from Sentinel-1 imagery are in agreement with the DSAS result and field survey to the location.

In this research, Sentinel-1 imagery with a resolution of 15x15 meters was used, which has shortage on less detailed coastlines, especially on beaches with winding coastlines. In the future as a recommendation, future research can be conducted with better resolution for data accuracy. One of the options is data from ALOS-2 with a resolution of 3x3 meters. However, this data would need cost for access fee. Therefore, it is necessary to establish cooperation in the field of coastline change research to obtain ALOS-2 data. In addition to the coastline condition, some of the damaged beaches have been or are currently being repaired by the government. However, there are also beaches that have been repaired but are damaged again due to strong waves.

Acknowledgments

The author would like to thank Research and Community Service (LPPM UNUD) for funding this research with contract number B/96-224/UN14.4. A/PT.01.05/2021, May 1, 2021. The author also would like to thank the European Space Agency (ESA) for providing free Sentinel-1 imagery through Takahiro Osawa from Yamaguchi University and I Nyoman Sudi Parwata from CReSOS.

References

1. Li, K., Zhang, L., Chen, B., Zuo, J., Yang, F., and Li, L., Analysis of China's Coastline Changes during 1990–2020, *Remote Sensing*, *15*(4), 2023, p. 981. https://doi.org/10.3390/rs15040981
2. Murray, J., Adam, E., Woodborne, S., Miller, D., Xulu, S., and Evans, M., Monitoring Shoreline Changes along the Southwestern Coast of South Africa from 1937 to 2020 using Varied Remote Sensing Data and Approaches, *Remote Sensing*, *15*(2), 2023, p. 317. https://doi.org/10.3390/rs15020317
3. Wang, X., Yan, F., and Su, F., Changes in Coastline and Coastal Reclamation in the Three Most Developed Areas of China, 1980–2018, *Ocean & Coastal Management*, *204*, 2021. https://doi.org/10.1016/j.ocecoaman.2021.105542
4. Alharthi, A., El-Sheikh, M.A., Elhag, M., Alatar, A.A., Abbadi, G.A., Abdel-Salam, E,M., et al., Remote Sensing of 10 Years Changes in the Vegetation Cover of the Northwestern Coastal Land of Red Sea, Saudi Arabia, *Saudi Journal of Biological Sciences*, *27*(11), 2020, pp. 3169–3179. https://doi.org/10.1016/j.sjbs.2020.07.021
5. Kuleli, T., Quantitative Analysis of Shoreline Changes at the Mediterranean Coast in Turkey, *Environmental Monitoring and Assessment*, *167*, 2010, pp. 387–397. https://doi.org/10.1007/s10661-009-1057-8
6. Hidayati, N., *Dinamika Pantai*, Malang, UB Press, 2017.
7. Hermawan, S., Implementation of Decision Support System for Integrated Coastal Zone Management of Sustainable Mariculture Development Industry in Indonesia, *Civil Engineering Dimension*, *18*(2), 2016, pp. 117–126. https://doi.org/10.9744/ced.18.2.117-126
8. Balakrishnan, P., Abulibdeh, A., and Kabir, T.A.K., Assessment of the Impact of Anthropogenic Evolution and Natural Processes on Shoreline Dynamics using Multi-Temporal Satellite Images and Statistical Analysis, *Water*, *15*(8), 2023, p. 1440. https://doi.org/10.3390/w15081440
9. Pranoto, S., Prediksi Perubahan Garis Pantai Menggunakan Model Genesis, *Berkala Ilmu Teknik Keairan*, *13*(3), 2007, pp. 145–154.
10. Li, R., Liu, J.K., and Felus, Y., Spatial Modeling and Analysis for Shoreline Change Detection and Coastal Erosion Monitoring, *Marine Geodesy*, *24*(1), 2001, pp. 1–12.
11. Istiqomah, F., Sasmito, B, and Amarrohman, F., Pemantauan Perubahan Garis Pantai Menggunakan Aplikasi Digital Shoreline Anaysis System (DSAS) Studi Kasus: Pesisir Kabupaten Demak, *Jurnal Geodesi Undip*, *5*(1),

2016, pp. 78–89.
12. Tsiakos, C.A.D. and Chalkias, C., Use of Machine Learning and Remote Sensing Techniques for Shoreline Monitoring: A Review of Recent Literature, *Applied Sciences*, *13*(5), 2023, p. 3268. https://doi.org/10.3390/app13053268
13. Sun, W., Chen, C., Liu, W., Yang, G., Meng, X., Wang, L., et al., Coastline Extraction using Remote Sensing: A Review, *GIScience & Remote Sensing*, *60*(1), 2023
14. Yasir, M., Sheng, H., Fan, H., Nazir, S., Niang, A.J., Salauddin, M., et al., Automatic Coastline Extraction and Changes Analysis using Remote Sensing and GIS Technology, *IEEE Access*, *8*, 2020, pp. 180156–180170.
15. Matin, N. and Hasan, G.M.J., A Quantitative Analysis of Shoreline Changes along the Coast of Bangladesh using Remote Sensing and GIS Techniques, *Catena*, 201, 2021. https://doi.org/10.1016/j.catena.2021.105185
16. Parthasarathy, K.S.S. and Deka, P.C., Remote Sensing and GIS Application in Assessment of Coastal Vulnerability and Shoreline Changes: A Review, *ISH Journal of Hydraulic Engineering*, *27*(sup1), 2021, pp. 588–600.
17. Elkafrawy, S.B., Basheer, M.A., Mohamed, H.M., and Naguib, D.M., Applications of Remote Sensing and GIS Techniques to Evaluate the Effectiveness of Coastal Structures along Burullus Headland-Eastern Nile Delta, Egypt, *The Egyptian Journal of Remote Sensing and Space Science*, *24*(2), 2021, pp. 247–254. https://doi.org/10.1016/j.ejrs.2020.01.002
18. Kaya, İ.A. and Görgün, E.K., Land Use and Land Cover Change Monitoring in Bandırma (Turkey) using Remote Sensing and Geographic Information Systems, *Environmental Monitoring and Assessment*, *192*(430), 2020. https://doi.org/10.1007/s10661-020-08411-1
19. Maurya, K., Mahajan, S., and Chaube, N., Remote Sensing Techniques: Mapping and Monitoring of Mangrove Ecosystem—A Review, *Complex and Intelligent System*, *7*, 2021, pp. 2797–2818. https://doi.org/10.1007/s40747-021-00457-z
20. Ghosh, M.K., Kumar, L., and Roy, C., Monitoring the Coastline Change of Hatiya Island in Bangladesh using Remote Sensing Techniques, *ISPRS Journal of Photogrammetry and Remote Sensing*, *101*, 2015, pp. 137–144. https://doi.org/10.1016/j.isprsjprs.2014.12.009
21. Umar, Z., Akib, W.A.A.W.M., and Ahmad, A., Monitoring Shoreline Change using Remote Sensing and GIS: A Case Study of Padang Coastal Area, Indonesia, In: *IEEE 9th International Colloquium on Signal Processing and its Applications*, Kuala Lumpur, Malaysia, 2013, pp. 280–284.
22. Pattipawaej, O.C. and Oktaviani, K., Analysis of Shoreline Changes in Yogyakarta Coastal Areas using Remote Sensing Method, *IOP Conference Series: Earth and Environmental Science*, 2023, p. 1134.
23. Konuk, N. and Ergun, O.N., Monitoring the Coastal Changes in Samsun, Turkey, *Kent Akademisi*, *16*(2), 2023, pp. 1003–1016. https://doi.org/10.35674/kent.1115909
24. Silva, A.N. and Lira, C.P., Editorial on Remote Sensing Application in Coastal Geomorphology and Processes, *Remote Sensing*, *15*(9), 2023, p. 2396. https://doi.org/10.3390/rs15092396
25. Mohsen, I.A.S.A., Bekiet, M.H., AbuBakr, M., and Khatita, A.A.M., Monitoring Shoreline Changes in the Northern Suez Canal Zone using Remote Sensing and GIS Applications, *Bulletin of Faculty of Science*, *2023*(2), 2023, pp. 134–146.
26. Ennouali, Z., Fannassi, Y., Benmohammadi, A., Al-Mutiry, M., and Masria, A., Shoreline Change Detection along North Sebou–Moulay Bousselham, based on Remote Sensing Analysis, *Regional Studies of Marine Science*, *62*, 2023.
27. Zollini, S., Dominici, D., Alicandro, M., Cuevas-González, M., Angelats, E., Ribas, F., et al., New Methodology for Shoreline Extraction using Optical and Radar (SAR) Satellite Imagery, *Journal of Marine Science and Engineering*, *11*(3), 2023, p. 627. https://doi.org/10.3390/jmse11030627
28. Shamsuzzoha, M. and Ahamed, T., Shoreline Change Assessment in the Coastal Region of Bangladesh Delta using Tasseled Cap Transformation from Satellite Remote Sensing Dataset, *Remote Sensing*, *15*(2), 2023, p. 295. https://doi.org/10.3390/rs15020295
29. Apostolopoulos, D. and Nikolakopoulos, K., A Review and Meta-analysis of Remote Sensing Data, GIS Methods, Materials and Indices used for Monitoring the Coastline Evolution over the Last Twenty Years, *European Journal of Remote Sensing*, *54*(1), 2021, pp. 240–65.
30. Pujianiki, N.N., Parwata, I.N.S., and Osawa, T., A New Simple Procedure for Extracting Coastline from SAR Image based on Low Pass Filter and Edge Detection Algorithm, *Lontar Komputer: Jurnal Ilmiah Teknologi Informasi*, *12*(3), 2021, pp. 175–185. https://doi.org/10.24843/LKJITI.2021.v12.i03.p05
31. Pujianiki, N.N., Coastline Changes Monitoring Induced by Man-made Structures using Synthetic Aperture Radar: A New Simple Approach, In: *4th International Conference on Civil and Environmental Engineering*,

2022.

32. Putra, A., Husrin, S., and Ridwan, N.N.H., Analisa Perubahan Garis Pantai di Pesisir Timur Laut Bali dengan Menggunakan Dataset Penginderaan Jauh Studi Kasus Lokasi Situs Kapal USAT Liberty, Tulamben, In: *Seminar Nasional Kelautan*, 2014, p. 143–159.
33. Hariyanto, T., Mukhtar, M.K., and Pribadi, C.B., Evaluasi Perubahan Garis Pantai Akibat Abrasi Dengan Citra Satelit Multitemporal (Studi Kasus: Pesisir Kabupaten Gianyar, Bali), *Geoid*, *14*(1), 2018, p. 66. https://doi.org/10.12962/j24423998.v14i1.3822
34. Istiqomah, M.F., *Analisis Perubahan Garis Pantai Kabupaten Jembrana dengan Menggunakan Citra Satelit Landsat 8*, UIN Syarif Hidayatullah Jakarta, 2017.
35. Amfa, M., Awaluddin, M., and Amarrohman, F., Analisis Pengaruh Perubahan Garis Pantai Terhadap Batas Pengelolaan Wilayah Laut Provinsi Jawa Timur dan Provinsi Bali di Selat Bali, *Jurnal Geodesi Undip*, *6*(4), 2017, pp. 342–350.
36. Nugraha, I.N.J., Karang, I.W.G.A, and Dharma, I.G.B.S., Studi Laju Perubahan Garis Pantai di Pesisir Tenggara Bali Menggunakan Citra Satelit Landsat (Studi Kasus Kabupaten Gianyar dan Klungkung), *Journal of Marine and Aquatis Sciences*, *3*(2), 2017, p. 204. https://doi.org/10.24843/jmas.2017.v3.i02.204-214
37. Suniada, I., Deteksi Perubahan Garis Pantai di Kabupaten Jembrana Bali dengan Menggunakan Teknologi Penginderaan Jauh, *Jurnal Kelautan Nasional, 10*, 2015, pp. 13–20.
38. Dayanti, M.A.R, *Analisis Perubahan Garis Pantai Menggunakan Software Digital Shoreline Analysis System (DSAS) di Pantai Saba Kabupaten Gianyar Bali*, Institut Teknologi Bandung, 2022.
39. Artama, K.D., Karang, I.G.W.A., and Putra, N.G., Deteksi Perubahan Garis Pantai Menggunakan Citra Synthetic Aperture Radar (SAR) di Pesisir Tenggara Bali (Kabupaten Gianyar dan Klungkung), *Journal of Marine and Aquatic Sciences, 5*(2), 2019, pp. 278–288. https://doi.org/10.24843/jmas.2019.v05.i02.p16
40. Pujianiki, N.N., Pemetaan Garis Pantai di Wilayah Pesisir Pulau Bali dengan Citra Synthetic Aperture Radar, In: *Konferensi Nasional Teknik Sipil 16*, 2022.
41. Hossen, M.F. and Sultana, N., Shoreline Change Detection using DSAS Technique: Case of Saint Martin Island, Bangladesh, *Remote Sensing Applications: Society and Environment*, *30*, 2023. https://doi.org/10.1016/j.rsase.2023.100943
42. Muskananfola, M.R., Supriharyono, and Febrianto, S., Spatio-temporal Analysis of Shoreline Change along the Coast of Sayung Demak, Indonesia using Digital Shoreline Analysis System, *Regional Studies in Marine Science*, *34*, 2020. https://doi.org/10.1016/j.rsma.2020.101060
43. Baig, M.R.I., Ahmad, I.A., Shahfahad, Tayyab, M., and Rahman, A., 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), 2020, pp. 361–376.
44. Aryastana, P., Eryani, I.G.A.P., and Candrayana, K.W., Perubahan Garis Pantai dengan Citra Satelit di Kabupaten Gianyar, *PADURAKSA*, *5*(2), 2016.
45. Casella, E., Drechsel, J., Winter, C., Benninghoff, M., and Rovere, A., Accuracy of Sand Beach Topography Surveying by Drones and Photogrammetry, *Geo-Marine Letters*, *40*, 2020, pp. 255–268. https://doi.org/10.1007/s00367-020-00638-8
46. Hasan, W., *Analisis Perubahan Garis Pantai Berbasis Citra Satelit Landsat di Pantai Pebuahan Kabupaten Jembrana*, Universitas Udayana, 2021.
47. Mitri, G., Nader, M., Dagher, M.A., and Gebrael, K., Investigating the Performance of Sentinel-2A and Landsat 8 Imagery in Mapping Shoreline Changes, *Journal of Coastal Conservation*, *24*(40), 2020. https://doi.org/10.1007/s11852-020-00758-4
48. Parida, B. and Kumar, P., Mapping and Dynamic Analysis of Mangrove Forest during 2009–2019 using Landsat–5 and Sentinel–2 Satellite Data along Odisha Coast, *Tropical Ecology*, *61*, 2020, pp. 538–549. https://doi.org/10.1007/s42965-020-00112-7
49. Wang, X., Xiao, X., Zou, Z., Hou, L., Qin, Y., Dong, J., et al., Mapping Coastal Wetlands of China using Time Series Landsat Images in 2018 and Google Earth Engine, *ISPRS Journal of Photogrammetry and Remote Sensing*, *163*, 2020, pp. 312–326. https://doi.org/10.1016/j.isprsjprs.2020.03.014
50. Ottinger, M., Bachofer, F., Huth, J., and Kuenzer, C., Mapping Aquaculture Ponds for the Coastal Zone of Asia with Sentinel-1 and Sentinel-2 Time Series, *Remote Sensing*, *14*(1), 2022, 153. https://doi.org/10.3390/rs14010153
51. Chen, H., Chen, C., Zhang, Z., Lu, C., Wang, L., He, X., et al., Changes of the Spatial and Temporal Characteristics of Land-use Landscape Patterns using Multi-temporal Landsat Satellite Data: A Case Study of Zhoushan Island, China, *Ocean & Coastal Management*, *213*, 2021. https://doi.org/10.1016/j.ocecoaman.2021.105842

52. Ekercin, S., Coastline Change Assessment at the Aegean Sea Coasts in Turkey using Multitemporal Landsat Imagery, *Journal of Coastal Research*, *23*(3), 2007, pp. 691–698. https://doi.org/10.2112/04-0398.1