COASTLINE CHANGE ANALYSIS ON BALI ISLAND USING SENTINEL-1 SATELLITE IMAGERY

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Abstract. Bali is well-known as a popular tourism location for both local and foreign tourists. There are nine areas designated for tourism, eight of which are coastal. However, due to coastal erosion, the coastline of Bali is changing every year. The purpose of this study is to determine the changes that took place between 2015 and 2020 using Sentinel-1 satellite imagery. The study was conducted along the coastline of Bali Island at coordinates 08° 53' 35.5648" S, 114° 24' 41.8359" E and 08° 00' 46.7865" S, 115° 44' 17.5928" E. The coastlines were identified using the Otsu image thresholding method and linear tidal correction was performed. The coastline change analysis was made using the transect method. Ground truths were conducted in representative areas where major changes had occurred, either as a result of abrasion or accretion. According to the Sentinel-1 analysis, the coastline changes in Bali during the period 2015 – 2020 were mainly caused by abrasion, apart from at Buleleng, which were generally caused by accretion. Abrasion in Bali is dominantly affected by strong currents and high waves meanwhile accretion which having weak currents and low waves was more affected by human factor such as the construction in this study area.

Keywords: *Bali, coastline change, Sentinel-1, abrasion, accretion*

1 INTRODUCTION

Bali is well-known as a popular tourism destination for both local and foreign tourists. Each region of Bali Province has coastal areas, apart from Bangli Regency. Bali Province Regulation No. 3 of 2020 designated nine areas for tourism, with eight of them being coastal. These areas increase regional income and the economy of the surrounding society. However, development activities in coastal areas will have a negative impact on the coastal environment, including pollution and environmental damage, as well as excessive use of natural coastal resources (Holden, 2016; Pramudyanto, 2014).

Due to coastal erosion, the coastline of Bali is changing every year. PEMSEA and Bali PMO (2004) reported that Bali's coastline was eroded by approximately 51.5 kilometers out of 480 kilometers in 1987 and further increased to 64.85 kilometers in 1997. Damanik (2015) adds that in the three years from 2010 to 2013, Bali's coastline increased by 123 kilometers due to erosion, from 470 kilometers to 593 kilometers.

This phenomenon indicates the importance of study of the coastline changes in Bali, especially because almost all the coastal areas on the island are designated for tourism. The use of remote sensing technology is an objective method for the detection of coastline change, and can be performed automatically or semi-automatically, with wide spatial and temporal coverage (Li, Di, & Ma, 2003; Sui, Wang, Yang, & Wang, 2020; Zollini et al., 2020). SAR (Synthetic Aperture Radar) is a remote sensing technology with active sensors, as opposed to optical satellites with passive sensors (Herndon, Meyer, Flores, Cherrington, & Kucera, 2020). Compared with optical images, those from SAR have

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many advantages. They can be acquired during the day or night and are cloud-free (Erteza, 1998). Sentinel-1 is an example of an open source high-resolution SAR satellite, whose applications include maritime surveys (European Space Agency [ESA], 2012).

Studies on coastline change have been conducted in several regions of Bali using optical satellite imagery (Aryastana, Ardantha, Nugraha, & Candrayana, 2017; Aryastana, Ardantha, Rahadiani, & Candrayana, 2018; Aryastana, Eryani, & Candrayana, 2016; Suniada, 2015). In addition, a study of coastline change using SAR satellite imagery was conducted by Artama, Gede, Karang, and Putra (2019) in Gianyar and Klungkung Regency using Sentinel-1 and ALOS PALSAR imagery. Their study is a reference for analysing coastline changes using SAR images throughout Bali.

The purpose of this study is to determine coastline changes in Bali between 2015 and 2020 using Sentinel-1 satellite imagery.

2 MATERIALS AND METHODOLOGY

2.1 Location and Data

The study was conducted along the coastline of Bali Island at coordinates 08° 53' 35.5648" S, 114° 24' 41.8359" E and 08° 00' 46.7865" S, 115° 44' 17.5928" E (Figure 2-1). The data used were Sentinel-1 satellite images of 2015 and 2020 obtained from Sentinel Australasia Regional Access [SARA], with a spatial resolution of 10 m. As the area of one Sentinel-1 scene does not cover the whole area of Bali, it is necessary to combine two scenes with adjacent periods using mosaic method. For comparison, Landsat optical images with a spatial resolution of 30 m obtained from USGS Earth Explorer covering the same period were also used in the representative areas .

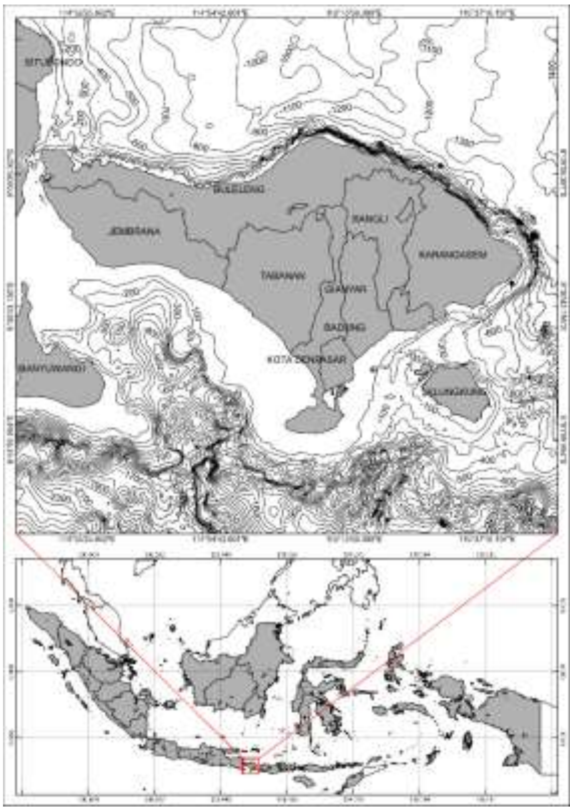


Figure 2-1: Maps of the study site

Other supporting data used included current, wave, and tide predictions and the data elevation model (DEM). Current and wave data were obtained from the Copernicus Marine Environment Monitoring Service [CMEMS], with a 1/12°×1/12° spatial resolution and annual mean temporal resolution. The tide predictions with a one hour time resolution were obtained from BIG Online Tide Prediction, at several representative points according to the acquisition time of the satellite images. DEM SRTM HGT (Shuttle Radar Topography Mission Height) with a resolution of 1 arc second was obtained from B-Open Solutions. Tide prediction and beach slope (obtained from DEM data) were used to perform tidal correction on the coastlines which were extracted from satellite images.

2.2 Methods

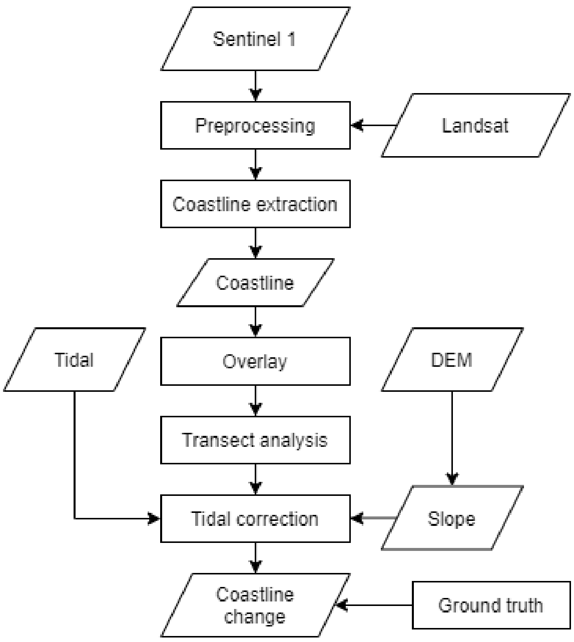


Figure 2-2: Research flowchart

The coastline extraction method from the Sentinel-1 images included preprocessing, segmentation and vectorisation. SeNtinel Application Platform (SNAP) software was used to preprocess the Sentinel-1 images in order to obtain radiometrically- and geometrically- corrected images for better interpretation. Mosaicking of the Sentinel-1 data was performed in order to cover the whole area. The choice of VH polarisation and the conversion of decibel bands were the main factors that ensured that the SAR images had a clearer contrast between land and sea features (Truckenbrodt et al., 2019; Zollini et al., 2020).

The next step was segmentation, which aimed to separate land and sea as represented by binary images using the Otsu image thresholding method (Otsu, 1979). In the final step, vectorisation was performed to obtain the coastline features in the form of vector data. The coastline extraction method on the Landsat images was conducted using the NDVI (Normalized Difference Vegetation Index) and Tasseled Cap transformation method (Kauth & Thomas, 1976).

The transect method was employed to analyse the coastline changes (Vos, Splinter, Harley, Simmons, & Turner, 2019). The 200 m transect (100 m landward and 100 m seaward) along the border of Bali Island had a distance of 100 m between the transects. Prior to calculating the coastline changes, the length of each coastline was calculated from the tip of the transect perpendicular offshore. The distance between the oldest and the youngest coastlines for each transect was calculated. The rate of coastline change was calculated by dividing the distance of coastline change by the elapsed time between the oldest and most recent coastline (Himmelstoss, Henderson, Kratzmann, & Farris, 2018). The categories of coastline change rates are shown in Table 2-1.

Linear tidal correction was performed to adjust the extracted coastline to the reference elevation. Linear tidal correction used tide and beach slope with the following formula:

$$\Delta x = \frac{z_{ref} - z_{lw}}{m} \qquad (2-1)$$

where Δx is coastline correction; z_{ref} is the reference elevation (e.g. 0 m above sea level); z_{lw} is the sea level (tides); and m is the beach slope (Vos et al., 2019).

Ground truths were conducted to compare the results of the satellite image analysis with the actual conditions. The ground truth methods used were surveys and interviews. Ground surveys were conducted in areas where the coastline changes were significant, based on the categories in Table 2-1.

Tabel 2-1 Coastline change rate categories (Setyandito & Triyanto, 2007)

Coastline change rate (m/year)	Category
> -10	Very heavy abrasion
-10 - -5	Heavy abrasion
-5 - -2	Moderate abrasion
-2 - 0	Light abrasion
0 - 2	Light accretion
2 - 5	Moderate accretion

Coastline change rate (m/year)	Category
5 - 10	Heavy accretion
> 10	Very heavy accretion

3 RESULTS AND DISCUSSION

The current velocity in the study area was 0.005 – 1.448 m/s in 2015 and 0.001 – 1.297 m/s in 2020. Significant wave height was 0.217 – 1.845 m in 2015 and 0.216 – 1.954 m in 2020. Figure 3-1 shows that current velocity was higher in the strait area. Apart from that in the Indian ocean, the significant wave height was also higher around the strait area, as shown in Figure 3-2.

According to Harahap (1999), current velocity in the study area is divided into four categories, namely slow (0 – 0.25 m/s), medium (0.25 – 0.5 m/s), fast (0.5 – 1 m/s) and very fast (> 1 m/s). Based on Badan Meteorologi Klimatologi dan Geofisika [BMKG], wave height is divided into seven categories: calm (0.1 – 0.5 m), low (0.5 – 1.25 m), medium (1.25 – 2.5 m), high (2.5 – 4 m), very high (4 – 6 m), extreme (6 – 9 m) and very extreme (9 – 14 m).

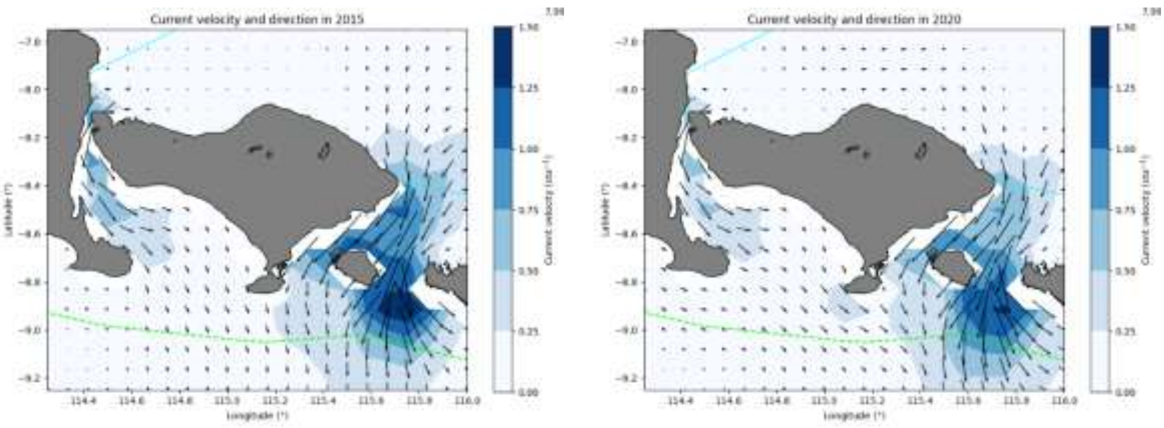


Figure 3-1: Current velocity and direction in 2015 and 2020

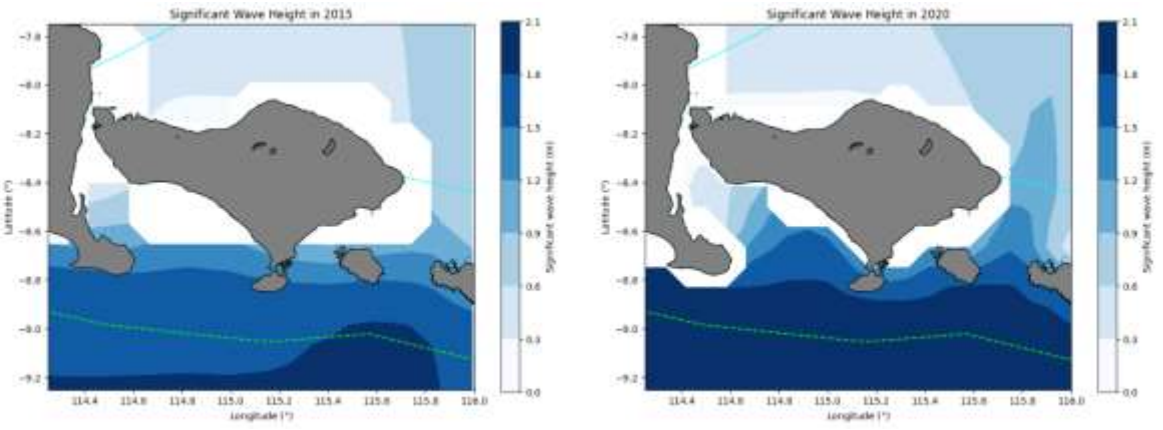


Figure 3-2: Significant Wave Height in 2015 and 2020

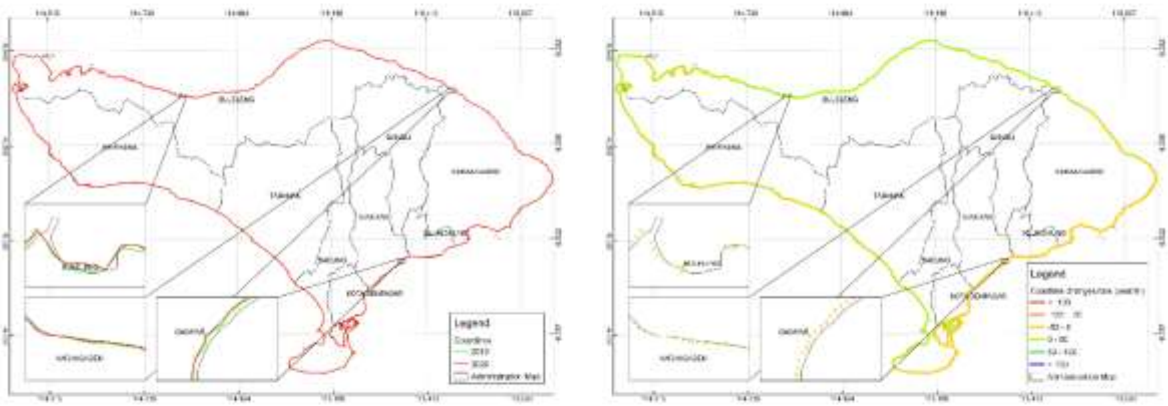
The outputs of the coastline extraction in each period are shown in Figure 3-3a. In addition, the results of the coastline change analysis using Sentinel 1 from 2015 to 2020 are shown in Figure 3-3b, which indicates different coastline change phenomena in each region in Bali. Green depicts the accretion phenomenon, while abrasion is depicted by orange. The northern region of Bali is dominated by accretion, while abrasion mostly occurs in the southern and eastern regions.

Table 3-1 shows that Buleleng is the only area affected by accretion, with a distance and rate of coastline change of 9.97 m and 1.99 m/year respectively. The area most affected by abrasion is

Gianyar, where the distance of coastline change is -40.80 m, with a rate of -8.16 m/year.

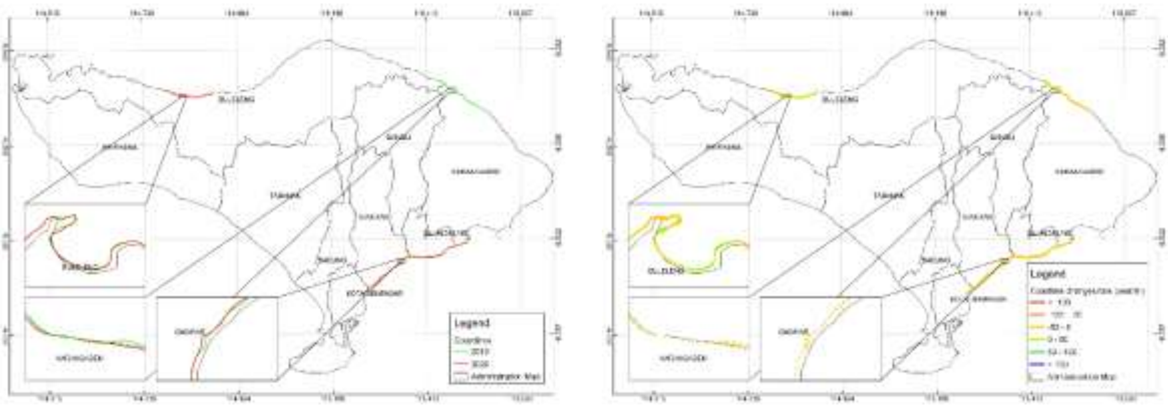
For comparison, coastline change analysis was also conducted using Landsat for the same period in Gianyar, Karangasem, and Buleleng. The overlay of coastline extraction each year and the rate of coastline changes are shown in Figure 3-4a and Figure 3-4b respectively. The results are given in Table 3-2.

Based on Sentinel-1 and Landsat analysis, the coastlines in both Gianyar and Karangasem are affected by abrasion, which is mostly caused by natural factors (Hariyanto, Mukhtar, & Pribadi, 2018; Suarna, 2019). As shown in Figures 3-1 and 3-2, current velocity and wave height in these two areas are both high. Karangasem and Gianyar face the Lombok Strait, which has high oceanographic factors due to its minimal sill, which hampers the transportation of water mass through it (Karang, Nishio, Mitnik, & Osawa, 2012).



(a) (b)

Figure 3-3: Maps of Bali coastline change using Sentinel-1: a) overlay per year, b) coastline change rate.



(a) (b)

Figure 3-4: Maps of Bali coastline change using Landsat: a) overlay per year, b) coastline change rate.

Artama et al. (2019) report relatively similar results for the period 2007 – 2018, showing that in general the coastline of Gianyar was changed due to abrasion. The same phenomenon also dominated the coastline change in Karangasem, as reported by Aryastana et al. (2018) whose study was conducted in the period of 2009 – 2015.

Similar results were also obtained using either Sentinel-1 or Landsat in Buleleng, with coastline change dominated by accretion. Wicaksono and Winastuti (2020) also conducted coastline change analysis in Buleleng between 2000 and 2019 using a combination of Landsat 5, Landsat 7, Landsat 8, Sentinel-2A and SPOT-7. They reported that the coastline of Buleleng was dominated by accretion, with a total addition of 875 m, although in some areas there was massive abrasion. As reported by Indrawan, Damayanti, and Rustanto (2019), abrasion in some areas in Buleleng is mainly caused by natural factors, such as wind, currents and waves, with accretion mainly caused by human factors, such as coastal reclamation. Based on Figures 3-1 and 3-2, current velocity and wave height were not very high. Therefore, abrasion was not the dominant factor in Buleleng.

Table 3-1: Average coastline change based on Sentinel-1 for each region

Region	Average Coastline Change Distance (m)	Average Coastline Change Rate (m/year)	Category
Jembrana	-4.99	-1.00	Light abrasion
Tabanan	-7.69	-1.54	Light abrasion
Badung	-11.04	-2.21	Moderate abrasion
Gianyar	-40.80	-8.16	Heavy abrasion
Klungkung	-39.66	-7.93	Heavy abrasion
Bangli	-	-	-
Karangasem	-19.64	-3.93	Moderate abrasion
Buleleng	9.97	1.99	Light accretion
Denpasar	-32.67	-6.53	Heavy abrasion

Table 3-2: Average coastline change based on Landsat in Gianyar, Karangasem and Buleleng

Region	Average Coastline Change Distance (m)	Average Coastline Change Rate (m/year)	Category
Gianyar	-46.27	-11.12	Very heavy abrasion
Karangasem	-26.00	-6.25	Heavy abrasion
Buleleng	15.85	0.64	Light accretion

For validation, ground truths were conducted in Gianyar, Karangasem and Buleleng. A total of six survey points were employed: two in Gianyar, one in Karangasem, and three in Buleleng. Table 3-3 gives detailed information of the coordinate points in each area.

Point 1 was located west of Lebih Beach, Gianyar and was characterised as a sandy beach (Figure 3-5a). According to interview with local fisherman, there were frequent abrasions on Lebih Beach from the 1980s to the 2000s. As preventive action, an embankment was built along the coastal area. Point 2 was located west of Siyut Beach, Gianyar. This had similar conditions to Point 1 (Figure 3-5b), but in this case the Jeh Jinah river was the cause of abrasion. Point 3 was located at Sukalegawa Beach, Karangasem. This was characterised as a rocky beach (Figure 3-5c) and used to be a base for local fishermen from the 1990s to the 2000s. When the coastal conditions were not severely eroded, it was also used as a salt pond area. According to the ground truth, there were high waves at all three sites.

Three survey points in Buleleng Regency were Celukan Bawang Port, Tonasa Cement Factory and Penyabangan Beach (Figure 3-6). Points 1 and 2 were located in Celukan Bawang Port. Celukan Bawang is the port which is organized by Pelindo 3. The interview in Celukan Bawang Port was conducted with an employee of Pelindo 3, while that in Penyabangan Beach was conducted with the owner of the pond around the survey site. Based on the results of the interview with the Pelindo 3 employee, there has been abrasion around Celukan Bawang Port, but this has stopped because of the construction of the port. In addition, there has been accretion around Tonasa Cement Factory, that has occurred due to the construction of the factory itself. The interview with the pond owner revealed that there was a temple called Pura Penyabangan which had to be moved three times due to the abrasion of Penyabangan Beach. Despite the abrasion, local residents have been reconstructing the area since 2015, so the data analysis from 2015 – 2020 shows that the area has changed into one of accretion.

Table 3-3: Ground truth coordinate points

No.	Region	Latitude	Longitude	Figure
1.	Gianyar	8°35'4.08"LS	115°21'8.50"BT	Figure 3-5a
2.	Gianyar	8°34'36.23"LS	115°21'45.23"BT	Figure 3-5b
3.	Karangasem	8°10'50.14"LS	115°28'32.04"BT	Figure 3-5c
4.	Buleleng	8°11'24.53"LS	114°49'54.17"BT	Figure 3-6a
5.	Buleleng	8°11'32.41"LS	114°50'22.95"BT	Figure 3-6b
6.	Buleleng	8° 9'37.04"LS	114°44'1.53"BT	Figure 3-6c

(a) (b) (c)

Figure 3-5: Survey points: a) Point 1, located west of Lebih Beach, Gianyar; b) Point 2, located west of Siyut Beach, Gianyar; c) Point 3, located at Sukalegawa Beach, Karangasem

(a) (b) (c)

Figure 3-6: Survey points: a) Point 1, located at Celukan Bawang Port; b) Point 2, located north of Tonasa Cement Factory; c) Point 3, located at Penyabangan Beach

4 CONCLUSION

According to the Sentinel-1 analysis, the coastline changes on Bali Island during the period 2015 – 2020 were dominated by abrasion, apart from Buleleng, which was generally dominated by accretion. Based on the study, strong currents and high waves were the dominant causes of abrasion meanwhile accretion which having weak currents and low waves was more affected by human factors such as the construction in this study area.

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AUTHORS CONTRIBUTION

Suhendra, Christopher Ari Setiawan and Teja Arief Wibawa conceived and designed the analysis. Suhendra and Christopher Ari Setiawan collected the data or analysis tools, developed the theory, and performed the analysis. Teja Arief Wibawa and Berta Berlian Borneo verified the analytical methods. Suhendra and Christopher Ari Setiawan wrote the paper. All authors discussed the results and contributed to the final manuscript.

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