Study of shoreline evolution under the influence of jetty construction: A case study of Karangsong Beach, Indramayu, Indonesia

U Abdurrahman\(^1\), H Park\(^{1,3}\), and T Suprijo\(^{1,2}\)

\(^1\)Research and Technology Dept., Korea-Indonesia, Marine Technology Cooperation Research Center
\(^2\)Faculty of Earth Sciences and Technology, Bandung Institute of Technology, Indonesia
\(^3\)Korea Institute of Ocean Science and Technology, Korea

Email: umarabd@mtcr.center

Abstract. Karangsong Beach, Indramayu located on the north coast of Java Island of Indonesia has been an important traditional small downstream river port for the fishermen who live in the Indramayu District area. This traditional port has been rehabilitated by construction of jetty in the period 2005 to 2007. The jetty construction affected coastal process, which was previously dominated by erosion turned into dominated by accretion. This study examines the process of shoreline evolution by calculating the sediment transport rate and analyzing the shoreline changes. The analysis began by extracting shoreline data from Google Earth images to provide a historical database of shoreline. The coastal process was then simulated using the coastline model Uniform Beach Sediment Transport Coastline (UNIBEST-CL) with waves and the longshore component of tidal currents as input and also calibrated using the shoreline database. The calibrated model was employed to simulate the annual conditions over a nine-year period, 2008-2017. The results show the sediment transport rate is dominated by the southeast direction. There is a significant difference in coastal processes between northern and southern regions, which is due to the presence of jetty. In the northern region, the sediment transport rate was blocked by the jetty so that this region is accreted. In the southern region, the supply of sediment from the north replaced by sediment supply from the river causes accretion yet smaller than the northern region.

1. Introduction
1.1. Background
The shoreline is a feature in a coastal ecosystem which is always in a dynamic state, in response to physical processes and anthropogenic influence. The environment and organisms can be negatively affected due to uncontrolled changes that occur in the coastal region. Due to its dynamic condition, it is crucial for coastal management and planning to know where the shoreline is, where it has been in the past, and where it is predicted to be in the future [1, 2].

One example of how important to research coastal dynamics is what occurs in Indramayu District, West Java Province, Indonesia. The Indramayu District area is known as the center of the fishing area of West Java because it contributes 63% of West Java Sea Fishery Production [3]. The amount of fresh marine fish production in this district continues to increase. In 2015 the amount of marine fish production in Indramayu District worth 136,091.48 tonnes, then increased in 2017 to 139,713.49 tonnes. This high production of fisheries is related to the influence of facilities in the region. One of them is the
construction of a jetty structure at the mouth of the Prajagumiwang River which began in 2005 in Indramayu District, specifically at Karangsong Beach, Karangsong Village, Indramayu Sub-District, Indramayu District [4].

The construction of this jetty is part of the solution of the sedimentation in the shipping lane on the Prajagumiwang River as a transportation route for ships that will land their catch at the Karangsong Fish Landing Base [5]. This sedimentation occurs due to the Prajagumiwang River as a tributary of the Cimanuk River which carries a large amount of sediment [6].

In addition to having an impact on local fishery activities, the construction of a jetty will have an impact on changing the sediment transport rate pattern on Karangsong Beach. Based on a study conducted by [7] in the period of 1942 – 2003, the coast in Indramayu District was dominated by erosion. Besides, based on the results of the analysis of height and wave period in Indramayu District in 1981 - 1985 by [8], Indramayu District is a zone dominated by erosion processes. The same thing is found in a study conducted by [9] which states that Indramayu District is dominated by an erosion process compared to other sub-districts in Indramayu District.

In understanding the coastal process in Karangsong Beach, this study uses a methodology that has not been used in previous studies. Shoreline changes in this area will be calculated and predicted using remote sensing technology and coastal modeling, respectively. This study aims to examine the pattern of shoreline changes at Karangsong Beach, Indramayu as a result of the jetty construction.

1.2. Karangsong Beach Indramayu

Karangsong Beach is located in Karangsong Village, Indramayu Sub-District, Indramayu District, West Java Province. This village is a coastal village located in the eastern region of the Indramayu District area with the topography being low and slope. Geographically, Karangsong Village is located between 108°19' - 108°22' E and 6°17' - 6°19' S. The air temperature in Indramayu District is classified as hot, ranging from 23 – 30 °C. Rainfall throughout 2017 was recorded at 1,610 mm with 141 rainy days and a daily average of 11.42 mm per rainy day [10]. Karangsong Beach is a relatively gently slope beach with beach material consisting of sand and mud. Specifically, based on visual observations, estimated significant wave height ranging between 30 – 40 cm, a period between 3 – 5 seconds with the direction of the wave from the northwest and east [5].

Figure 1. Map of the study area

In the 1950s, local people used accreted land for the construction of shrimp and milkfish ponds around the coastal area until the 1990s. This development was not accompanied by consideration for the carrying capacity and sustainability of the ecosystem, especially mangroves, which were originally
abundant in Karangsong Village. This imbalance causes Karangsong Village to experience continuous erosion problems [1].

In 2005 – 2007, the construction of a jetty on Karangsong Beach was carried out to overcome the problem of erosion and sedimentation in the shipping lane to PPI Karangsong [4,5]. After the construction of the jetty at Karangsong Beach, mangrove planting was also carried out which began in 2008 – 2016 [11]. The construction of the jetty caused Karangsong Beach to experience a quite large accretion, an increase in the beach area of 297,136 m², and an increase in the shoreline reaching 13,897 m [11]. Meanwhile, the sedimentation of shipping lanes to PPI Karangsong still occurs. The problem of sedimentation in the shipping channel is minimized by periodic dredging every 1-2 weeks. This is triggered by the geological conditions in the upstream area which are composed of volcanic rocks that have not been completely consolidated [13, 14, 15, 7].

2. Methodology
2.1. Shoreline Changes Calculation
Shoreline changes analysis was performed using the USGS Digital Shoreline Analysis System (DSAS) version 5.0, which is a toolbox in the ArcGIS software. Shoreline change is calculated based on the distance perpendicular to a baseline. The baseline is made in such a way that its direction is parallel to all involved shorelines. At the baseline, several transects were formed in a perpendicular direction to the line. This transect is used to calculate the distance between the baseline and the shoreline.

Shoreline changes statistical parameters that are generally used to analyze are Shoreline Change Envelope (SCE), Net Shoreline Movement (NSM), End Point Rate (EPR), and LRR (Linear Regression Rate). The SCE and NSM values will show how much changes (in distance) have occurred and also indicated how dynamic an area is. Meanwhile, the EPR and LRR values will indicate the rate of change, positive values represent shoreline movement toward the sea (accretion), whereas negative values represent erosion. EPR is calculated by dividing the distance between the oldest and the most recent shoreline (NSM) by the time elapsed in between. LRR shows the shoreline change rate based on fitting a least square regression to all distance – baseline of shoreline. LRR is considered the most robust quantitative method when there is limited shoreline data and most often used in defining the shoreline changes rate [16].

2.2. Remote Sensing Analysis
Remote sensing is the process of detecting and monitoring a characteristic of a certain area at a certain distance by measuring the value of its reflection and radiation emission [16]. The use of image data in shoreline change analysis has several advantages compared to conventional surveys, including that it can be applied to monitor shoreline changes more effectively and efficiently in terms of time and cost use [18, 19, 20]. One platform that provides image data is Google Earth which has been used in several studies [19, 21, 22, 18].

The shoreline data from the Google Earth platform is obtained from the Historical Imagery tool. The shoreline is obtained based on the most commonly used shoreline indicator, namely the High Water Line (HWL) [2]. The shoreline from Google Earth is obtained by using manual digitization. The eye altitude while digitizing the shoreline is kept constant of 80-100 m. One of the accuracy factors of this method is the interpreter’s ability to delineate shorelines [23, 24]. The Google Earth errors which come from georeferencing errors, platform-oriented errors, and error due to the zenith angle in this study is considered not to have a significant effect and not taken into account. The manual digitization error is estimated by digitizing the image twice and calculating the difference in the distance as a digitizing error by using SCE parameters. The mean of SCE value on the twice digitized shoreline will be used as the digitization error. Meanwhile, the tidal error was estimated by calculating the daily tidal run-up range on the image day by using tidal range predicted from TMD (Tidal Model Driver) and beach slope [18, 25].

2.3. Shoreline model
Shoreline changes prediction is carried out using the Uniform Beach Sediment Transport (UNIBEST-CL) model developed by WL DELFT HYDRAULICS. This model consists of two main models,
UNIBEST-LT and UNIBEST-CL. UNIBEST-LT is used to calculate the amount of longshore currents and coastal sediment transports induced by tides and waves. This model transforms offshore waves towards the shore by considering the processes of refraction, shoaling, and breaking. Meanwhile, UNIBEST-CL is used to calculate shoreline changes due to longshore sediment transport gradients based on the results of calculations from UNIBEST-LT. The basic equation describing the longshore current distribution is the momentum equation alongshore shows in equation (1). The result of this equation, the longshore current velocity, is then used to calculate the sediment transport rate using various formula options provided in the UNIBEST-CL [26].

\[
\frac{d}{dy}S_{yx} + \rho g \frac{dh_0}{dx} + \rho \frac{g}{C^2} V |V| = 0
\]

\[S_{yx} = \text{radiation stress component in the perpendicular plane of the y-axis (cross-shore)}\]
\[\rho = \text{fluid density (kg m}^{-3}\text{)}\]
\[g = \text{gravitational acceleration (9.8 m s}^{-2}\text{)}\]
\[h_0 = \text{tidal elevation (m)}\]
\[x = \text{shoreline position in the longshore direction (m)}\]
\[C = \text{Chezy friction coefficient (m}^{1/2}\text{s}^{-1})\]
\[V = \text{longshore current velocity (m s}^{-1}\text{)}\]

Sediment transport rates and shoreline changes simulated with the UNIBEST-CL model were carried out from 1 June 2008 - 1 June 2017 and divided into 9 parts of the simulation, each with a duration of one year.

The sediment transport rate formula in the UNIBEST-CL model chosen in this study is the van Rijn formula (1992) in [26]. In addition, the calculation of the bedload sediment transport rate as a sediment supply from rivers is carried out separately using the approach of Schoklitsch (1943) in [27]. This approach generally requires information on river dimensions, river hydrodynamic information, and river sediment characteristics. The river dimension information required is river width, current velocity, depth, and bottom slope. Information required for river sediment characteristics includes the density value of the bed load material and the grain size distribution of the sediment [27]. River dimensions and river sediment characteristics were obtained from field survey results. The river discharge data is obtained from the Prajagumiwang River Hydrology Report, BBWS Cimanuk-Cisanggarung in 2016. The discharge value is assumed not to change year by year, so the same value is used for all parts of the simulation.

2.3.1. Input data and scenario
The UNIBEST-CL model requires input data including beach profile, sediment characteristics, wave information, tidal information, and initial shoreline.

Depth profile data uses a combination of bathymetry data survey results from [5] and BATNAS (National Bathymetry) data from [28], is shown in Figure 2.

![Figure 2. Cross-shore profile used in this study](image-url)
Wave information including significant wave height, period, direction, and total duration in hours along the simulation duration is obtained from the results of the [29] ERA-Interim dataset with a spatial grid resolution of \(0.125\degree \times 0.125\degree\) and a temporal resolution of 6 hours for the entire duration of the simulation. The tidal information obtained from the TMD model includes the elevation, the tidal longshore current component velocity, and the percentage of occurrence during the simulation duration. The initial shoreline uses digitized images from Google Earth from 2008 which were also used in the remote sensing analysis. The data collection points for these two parameters are at \(6\degree18'50"\ S\) and \(108\degree27'15"\ E\). The initial shoreline uses the results of digitizing images from Google Earth in 2008 which are also used in the analysis of shoreline changes using the remote sensing method.

Karangsong Beach which has a length of about 6 km is divided into several segments with a distance between segments of about 50 m. Each of these segments is a spatial grid used in the UNIBEST-CL model. Placement of the global climate (input for the model contains wave and tidal information) at \(6\degree16'6.25"\ S\) and \(108\degree24'42.85"\ E\) was carried out. Simulations of coastal sediment transport rates and shoreline changes using the UNIBEST-CL model were carried out along Karangsong Beach based on sediment transport rate gradients. The spatial arrangement of the UNIBEST-CL model in this simulation is shown in Figure 3.

![Figure 3](image)

**Figure 3.** The spatial arrangement of the DSAS method (right, the distance between transect is 50m) and the spatial arrangement of the UNIBEST-CL model (left)

In this study, the modification of the southern jetty arrangement was carried out by adjusting the jetty type to be semipermeable, which means that the jetty can release some of the sediment passing through. The type of jetty is set by determining the percentage of blocking on the jetty. After doing several experiments, the optimal blocking percentage for the jetty is 50%. An illustration of this modification is shown in Figure 4.

![Figure 4](image)

**Figure 4.** Jetty modification illustration. Normal condition (left), conditions by including river sediment supply (center), and conditions by setting the jetty to be semipermeable type (right)

2.3.2. Shoreline validation method

Validation of the simulated shoreline is done by comparing the simulation results of the UNIBEST-CL model with the shoreline obtained from digitized shoreline data from Google Earth. Quantitative
validation was carried out using statistical parameters, Correlation Coefficient (CC), bias, and Root Mean Square Error (RMSE).

2.4. Field survey
In this study, a field data survey was carried out which includes a sampling of coastal and river sediments and measuring the tidal run-up range against time due to tidal effect. After obtaining the sediment sample, a sieve analysis was carried out to obtain the value of the grain size distribution of the sediment, so that the dominance of the sediment type in the Karangsong Beach and Prajagumiwang River areas could be determined. Measurement of the run-up distance and the tidal elevation are required to calculate the beach slope. The beach slope is calculated by dividing the value of the difference in tidal elevation with the difference in tidal run-up at two different times. The run-up distance is obtained by measuring the distance from a benchmark to the HWL position and is carried out at several observation times. Meanwhile, the tidal elevation value is determined based on data from TMD. An illustration of the calculation of the beach slope is shown in Figure 5.

![Figure 5. Illustration of beach slope calculation based on tidal run-up range](image)

3. Result and Discussion
3.1. Field survey result
The grain size distribution of the sediments in the Karangsong Beach area is dominated by grain sizes of 0.1 - 0.2 mm. This grain size value is based on the Udden-Wentworth Scale [30], which corresponds to the type of sand, fine sand, and very fine sand. Based on Figure 6, the value of the $D_{50}$ sediment grain size distribution in Karangsong Beach in the northern region is 0.130 mm while in the southern area it is 0.090 mm. This value indicates that the type of sediment at Karangsong Beach is fine sand for the northern region and very fine sand for the southern area. Meanwhile, on the Prajagumiwang River the value of the $D_{50}$ sediment size distribution is 0.210 mm indicating the fine sand sediment type.

![Figure 6. The cumulative distribution of sediment grain sizes in Karangsong Beach in the north (left), the south (center), and the river (right)](image)
Table 1. The result of uncertainty calculation for image data from Google Earth (unit in m)

| Time         | 2008-06-01 | 2009-06-24 | 2013-08-01 | 2014-10-31 | 2015-05-24 | 2016-07-12 | 2017-06-02 |
|--------------|------------|------------|------------|------------|------------|------------|------------|
| Source       | Digital Globe, NASA | Digital Globe, NASA | CNES/ Airbus | CNES/ Airbus | Digital Globe, NASA | Digital Globe, NASA | Digital Globe, NASA |
| Daily Tidal Range | 0.62      | 0.38      | 0.55      | 0.43      | 0.44      | 0.52      | 0.59      |
| Tidal Error  | 18.84     | 11.49     | 16.78     | 12.99     | 13.46     | 15.75     | 17.84     |
| Digitization error | 1.25      | 1.39      | 2.69      | 1.53      | 1.43      | 1.65      | 1.40      |
| Total Error  | 20.10     | 12.88     | 19.47     | 14.53     | 14.89     | 17.39     | 19.24     |

Apart from getting the grain size distribution of the sediments, the run-up distance was also measured. This run-up distance measurement is used to obtain the value of the beach slope at Karangsong Beach. In the northern region, the slope of the coast is 0.0359, while in the southern area the slope of the coast is 0.0309, then the average slope of the beach at Karangsong Beach is 0.0325. This beach slope value is used to determine the amount of uncertainty of the shoreline based on image data from Google Earth caused by the tidal effect.

3.2. Wave and tidal conditions
Data is taken at the closest point to Karangsong Beach where wave data is available. This data is located at a distance of about 5 km and has a depth of about 10 m. Wave parameters analyzed are significant wave height, average wave period, and average wave direction.

The tidal data used in this study were obtained from TMD. The data is taken at the closest point to Karangsong Beach. The point is about 15 km away and has a depth of 83.6 m. The available tidal current velocity from the TMD needs to be projected in advance against the direction of the shoreline. The projection of the shoreline is needed so that the tidal current velocity obtained shows the direction parallel to the coast (longshore current) and perpendicular to the coast (cross-shore current). In this study, the tidal current velocity used is only longshore because the current component is considered a component that contributes significantly to the longshore sediment transport rate.

Figure 7. Time series graph of wave significant wave height (top-left), wave period (top-right), and wave direction (bottom)
3.3. Shoreline changes analysis

In this study, the same approach was used in calculating the bedload sediment transport rate by the discharge approach by Schoklitsch (1943) in [27]. Based on the calculation results, the Parajagumiwang River has an average discharge value of 0.142 m³·s⁻¹ and an average river current velocity of only 0.003 m³·s⁻¹. Based on the estimates made, the value of the bottom sediment transport rate from the Prajagumiwang River has a value of 0.024 kg·m⁻¹·s⁻¹ or is equal to 9,028.77 kg·m⁻¹·s⁻¹. This value is then used as input in the simulation of the sediment transport rate.

![Figure 8](image8.png)

**Figure 8.** Comparison of the tidal current of the original data and projected (left) and bivariate diagram of tidal current longshore component and tidal elevation between 2008 – 2017 (right)

Longshore sediment transport rates in 2008 - 2016 that have been obtained from the simulation results are shown in Figure 10. Based on this figure, it can be seen that all sediment transport rates are positive. This means that all sediment transport rates are to the southeast.

![Figure 9](image9.png)

**Figure 9.** The river discharge and current velocity of the Prajagumiwang river in 2016

Longshore sediment transport rates in 2008 - 2016 that have been obtained from the simulation results are shown in Figure 10. Based on this figure, it can be seen that all sediment transport rates are positive. This means that all sediment transport rates are to the southeast.

![Figure 10](image10.png)

**Figure 10.** Longshore sediment transport rate between 2008 and 2016

There is a significant difference in the value of sediment transport rates in the northern and southern area of Karangsong Beach. The value of sediment transport rates in the northern region is more varied spatially and temporally, while in the southern area it shows a less varied. This indicates that in the
northern region the sediment transport rate is more dynamic than in the south and implies that changes in the shoreline will also be more dynamic.

In general, the difference between the simulated shoreline and the digitization of Google Earth is the detail of the shoreline that cannot be depicted well in the simulation results. This can be seen clearly on the shoreline of 2008, 2009, and 2016, especially in the northern region of Karangsong Beach. Apart from the condition of the shoreline in the northern region which contains more complex shapes that cannot be well depicted by the model, the dynamics of changes in the shoreline in the northern region are also greater than in the southern area. Another significant difference is that the southern area, which is located close to the jetty, shows that the dominant shoreline is too eroded compared to the condition of the shoreline as a result of Google Earth.

Figure 11. Shoreline comparison from UNIBEST-CL (left) and Google Earth (right)

Figure 12 shows a shoreline validation for all years, 2009 - 2017. The uncertainty value chosen is the average uncertainty value for 2009 - 2017 on image data from Google Earth caused by errors due to tidal effect and manual digitization. The correlation for the whole year shows a fairly good value of 0.93, indicating a good match between the simulated shoreline and digitization of Google Earth.
The LRR statistical parameter is the value obtained based on the linear regression of all available shoreline data. The LRR comparison between Google Earth and UNIBEST-CL has fairly good suitability, this means that the model results can represent the actual conditions.

4. Conclusions

The value of sediment transport rates at Karangsong Beach is influenced by factors of waves and tidal currents. Waves on Karangsong Beach, Indramayu are dominated by waves which come from the north with wave periods of 4 - 5 seconds, and significant wave heights of 0.5 - 1 m. The velocity magnitude of the longshore current component of the tidal current at Karangsong Beach Indramayu is 0.088 m·s\(^{-1}\) and only 20% of the cross-shore component.

The sediment transport rate at Karangsong Beach is dominated by the sediment transport rate that leads to the southeast, both in the north and south region. As a result of this sediment transport rate that leads to the southeast, in the northern region, the sediment tends to accumulate on the jetty side, and in the southern area, the river provides a significant supply of sediment load at the sediment transport rate which also leads south.

Based on the analysis of sediment transport rates and shoreline changes, Karangsong Beach has experienced significant changes in characteristics due to the construction of the jetty. After the construction of the jetty, Karangsong Beach tends to experience accretion. Then over time, changes in the shoreline at Karangsong Beach show fluctuating values but getting smaller from time to time.

5. References

[1] Boak EH and Turner IL 2005 Shoreline Definition and Detection: A Review Journal of Coastal Research 21 688-703
[2] Toure S Diop O Kpalma K and Maiga AS 2019 Shoreline Detection using Optical Remote Sensing: A Review International Journal of Geo-Information 8 75
[3] Central Bureau of Statistics, Indramayu District 2017 Kabupaten Indramayu Dalam Angka 2017 BPS Kabupaten Indramayu
[4] PT Yasa Patria Perkasa 2016 (www.yasapatriaperkasa.co.id/projects/proyek-pembangunan-jetty-muara-sungai-prajagumiwang-karangsong-kabupaten-indramayu-tahap-ii/135/2016/05/31)
[5] Fisheries and Maritime Affairs Dept., Indramayu District 2003 Pekerjaan Penyusunan Studi Kelayakan PPI Karangsong Kabupaten Indramayu Tahun Anggaran 2003, Laporan Final (Indonesia: Indramayu District Government)
[6] Sodikin 2011 Karakteristik dan Pemanfaatan Sumberdaya Pesisir dan Laut di Kawasan Pantai Kabupaten Indramayu Gea 11 200-208
[7] Kurnio H Naibaho T and Mustafa MA 2010 Karakteristik Pantai Indramayu Keterkaitannya dengan Keberadaan Gas Biogenik Geo Resources, JSDG 20 33-40
[8] Ilahude D and Usman E 2009 Pendekatan Secara Empirik terhadap Gejala Perubahan Garis Pantai Daerah Indramayu dan Sekitarnya Jurnal Geologi Kelautan 7 99-110
[9] Prawiradisastra S 2003 Permasalahan Abrasi di Wilayah Pesisir Kabupaten Indramayu Alami 8 42-46
[10] Central Bureau of Statistics, Indramayu District 2018 Kabupaten Indramayu Dalam Angka 2018 BPS Kabupaten Indramayu
[11] Oni 2018 Success Story Rehabilitasi Ekosistem Mangrove di Pantai Karangsong Kabupaten Indramayu Tesis Master’s thesis (Indonesia: Institut Pertanian Bogor)
[12] Abdurrahman U 2018 Studi Perubahan Morfologi Pantai, Studi Kasus: Pantai Karangsong, Kabupaten Indramayu Jurnal Oseanografi 6 10-21
[13] Afriza L Kartika T and Riyanti A 2017 Pengembangan Ekowisata Berbasis Masyarakat (Community Based Ecotourism) dalam Rangka Mengentaskan Kemiskinan di Desa Karangsong, Kabupaten Indramayu Jurnal Sains Terapan Pariwisata 3 20-34
[14] Thieler ER Himmelstoss EA Zichichi JL and Ergul A 2017 Digital Shoreline Analisis System (DSAS) version 4.0 – ArcGIS extension for calculating shoreline change (ver. 4.4 July 2017) U.S. Geological Survey Open – File Report 2008-1278
[15] Malarvizhi K Kumar SV and Porchelvan P 2016 Use of High Resolution Google Earth Satellite Imagery in Landuse Map Preparation for Urban Related Applications International Conference on Emerging Trends in Engineering, Science and Technology (ICETEST - 2015) 1835-42
[16] Hendriyono W Wibowo M Al Hakim B and Istiyanto D C 2015 Modeling of Sediment Transport Affecting the Coastline Changes due to Infrastructures in Batang-Central Java Procedia Earth and Planetary Science 14 166-178
[17] Achiari H Wulandari N Yustiani YM and Harlan D 2015 Study Erosion and Coastal Destruction at Pondok Bali North Coast West Java of Indonesia International Journal of Management and Applied Science 1 317-320
[18] El Kafrawy SB Basiouny ME Ghanem EA and Taha AS 2017 Performance Evaluation of Shoreline Extraction Methods Based on Remote Sensing Data Journal of Geography Environment and Earth Science International 11 1-18
[19] Goncalves RM Saleem A Queiroz HAA and Awange JL 2019 A fuzzy model integrating shoreline changes, NDVI and settlement influences for coastal zone human impact classification Applied Geography 113
[20] Padman L 2005 Tidal Model Drivel (TMD) Manual (Seattle: Earth and Space Research Institute)
[21] Deltas 2011 UNIBEST-CL+ Manual (Netherlands: Deltas)
[22] Yang CT 1996 Sediment Transport: Theory and Practice (Singapore: The McGraw-Hill Companies, Inc)
[23] Geospatial Information Agency 2019 (http://tides.big.go.id/)
Acknowledgments

This research was a part of the project titled “Marine Science & Technology Cooperation between Korea and Indonesia (20180319)” funded by the Ministry of Oceans and Fisheries, Korea. The licensed UNIBEST-CL software is used courtesy of the Coastal Research and Development Center, Ministry of Public Works and Public Housing, Indonesia.

[29] European Centre for Medium-Range Weather Forecasts (ECMWF) 2019 (https://apps.ecmwf.int/)
[30] Lewis DW and McConchie D 1994 Analytical Sedimentology (London: Chapman & Hall)