Three Decades State of the Tombolo Related to Wind Climate (1985 to 2015): Case of Galesong Beach, Takalar Regency

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Abstract. Tombolo-shaped beach in Galesong District orientated westward is a nice morphology behind the detached Sanrobengi Island in front of mainland of Takalar Regency. Our main interest is formulated as the problem of how the tombolo whether is experiencing continual growth or retreated. This study aims to explain changes of shape and its area of the tombolo morphology for each five-year period along the shoreline based on the influence of wind directions. This study uses Google Earth Pro Image from 1985 to 2015 to map key changes of the shoreline, where the obtained data are analysed using ArcGIS 10.3. Wind data is obtained from the European Centre Medium-Term Weather Forecast (ECMWF) from 1985 to 2015 where the wind data is analysed using Ocean Data View, and WRPlot 5.3 is used to form wind rose diagrams. Shoreline of the tombolo is divided into six segments and studied into five-year periods from 1985 to 2015. The obtained results showed that the wind direction is enough to influence the change of shorelines in the area of the Tombolo. From 1985 to 2015, the dominant wind direction is from the West and Northwest. Overall changes are as follow, the area of tombolo is developed during the period of 1985 to 1995; while the area of tombolo is retreated in the period of 1995 to 2015.

1. Introduction
Study on shoreline change is needed for the purposes of coastal management. In order to put the management is in accordance with the natural tendency, accordingly the trend of shoreline change is of importance. Thereof, the anticipation and trend of shoreline changes are needed to be clearly defined first. Some methods of anticipating shoreline changes as described by partial differential equations (PDE) are published in various papers using analytic and/or numerical solutions based on the empirical orthogonal function (EOF) and one-line theory models. A comparison between solutions of PDE and maps of the real field can be used to correct the prediction by PDE. The maps of the real field should be provided in advance using the GIS (Geographic Information System) and remote sensing methods to see the change from the past to the recent trend.

Tombolo is an Italian word, comes from the Latin tumulus, which means mound sedimentation behind an island or breakwater. The island or breakwater became known as a bound island. Tombolo is also called sandy isthmus. The shoreline moves towards the island (or a separate breakwater) because the increase in the sediment on the cape of the island is due to wave energy so that the shallow water behind an island is reduced due to sand deposition [1].

The bending of orthogonal waves that occur behind the island is called wave diffraction, while the bending out of the island is called wave refraction. The area of diffracted waves is weaker than that of the area of refracted waves. This condition generates sediment transport from strong areas to the weaker which causes a tombolo formation. In other words, sediment transports are generated from both sides
toward the cape of a tombolo. Accordingly, when there are available sediment sources, the depositional area is known as an area of spit, will approach to the island as a tombolo [2].

Some studies have been done recently with respect to changes in the shoreline. The islands of Samalona, Barrang Caddi, and Bonetambung among many islands in Spermonde Archipelago in the platform of Makassar water have been experienced shoreline changes with respect to the direction of the wind [3]. Likewise, of that change in the islands, the shoreline changes in the mainland of Makassar also occur, such as along the Jeneberang river delta. This change has been investigated by taking into account the transport of sediments using sediment budgeting in cell sedimentation [4]. Other studies of shoreline change are along shoreline Mangarabombang, South Galesong using a One-line method [5], along shoreline Saddang River Delta.

Shoreline changes have been estimated in the Districts of Surat, Navsari, and Valsad along the Southern part of Gujarat Coast from 1990 to 2014. In order to understand is dynamic using the same method [6]. Other groups of Indian scholars tried to evaluate spatio-temporal variability and to forecast future shoreline position, and to remediate the coast along the Udupi Coast using remote sensing, GIS, and statistical methods for 98 years spanning to obtain a better understanding [7]. In line with studies in the Indian Coast, studies in several areas in South Sulawesi also conducted on coastal problems such as sedimentation and erosion which were completed using the Kraus’s equation [8].

The problem to be described is formulated as follows: how to understand the shoreline's and area's change of the tombolo in related mainly to the wind directions and speed. This study aims to find characteristic changes during three decades in tombolo morphology and land area for each five-year period along 1985 to 2015 period on Galesong Beach, Takalar Regency.

2. Methodology
This study is focused on the morphological change of tombolo located at Galesong Beach, Takalar Regency. The changes are analyzed to see trends and how the areas of shoreline changes during three decades from 1985 to 2015. These changes are calculated, graphed, and compared for each period of five years which is searched into six-segments, two segments in northern part and three segments in southern part, and one segment is behind the island of Sanrobengi as the cape of tombolo-shaped shoreline as depicted as a study area in Figure 1. Discussions on the growth of the tombolo are presented accordingly.

The data of the tombolo’s growth is acquired from Google Earth Pro Image of 1985 to 2015 to map the tombolo changes (shoreline and its land area). While the data of wind directions and speeds is acquired from European Centre for Medium-Range Weather Forecasts (ECMWF) for the wind data (1985 to 2015). ArcGIS software version 10.3 is used to map shoreline of Galesongs’s tombolo, Ocean Data View (ODV) version 5.1.1 is used to extract wind directions and wind speeds, and WRPlot View version 5.3 is used to provide wind data in wind rose diagrams.

Data from Google Earth Pro was processed using ArcGIS 10.3 to map shorelines and its land area changes commencing from 1985 up to the end of 2015. Mapping was divided into six segments and six periods. The first period began from 1985 to 1990. Then each period was mapped every five years until the end of year 2015.

As for wind data, the downloaded data is filtered according to the study area using ODV (Ocean Data View) application, and the obtained data in ODV is submitted in the format of Network Common Data Form (NetCDF). Then the ODV data is expressed into time data: year, month, date and time and wind direction and speed in Excel format. While directions and speeds of wind are determined using the WRPlot View application. The frequency distribution of wind directions in the area is outlined by producing wind roses [9]. The next step is making wind diagrams for every five years.
3. Result and Discussion

The results of the study are as follows. The positive and negative growth of land areas and its shoreline change for six segments are calculated and presented for every five-year period as depicted in Table 1. The positive value of the growth of land area means that the land area is undergoing sedimentation and its shoreline develops. While the negative value means that the land area is undergoing erosion and its shoreline retreats.

| Years          | Segment (m²) | Total  |
|----------------|--------------|--------|
|                | 1            | 2      | 3      | 4      | 5      | 6      |       |
| 1985-1990      | 14471.13     | 19260.21 | -389.56 | -7422.06 | -16357.20 | -5716.41 | 3846.12 |
| 1990-1995      | -7709.89     | -11347.38 | 10572.84 | 23623.43 | 28023.39 | 14503.19 | 57665.58 |
| 1995-2000      | -9557.80     | -12890.63 | -15637.80 | 3779.66 | -35481.66 | -18498.91 | -88287.14 |
| 2000-2005      | -2350.84     | 7097.36 | -27787.78 | -14688.74 | 2689.02 | 700.66 | -34340.33 |
| 2005-2010      | -17517.30    | -18872.43 | 9827.54 | -49344.73 | -12694.90 | -10096.52 | -99508.34 |
| 2010-2015      | -3221.09     | 29161.04 | -9149.60 | -2019.98 | -12136.00 | -6167.30 | -3532.92 |
| Total          | -25885.79    | 12408.18 | -32564.36 | -46072.42 | -45957.34 | -26085.30 |
In the period of 1985 to 1990 the trend can be seen that segments 1 and 2 are experiencing sedimentation. While segments 3 to 6 are experienced an erosion process. In total, during the period of 1985 to 1990, the land area of tombolo experienced an increase in area. As for the period of 1990 to 1995, the opposite trend occurred compared to the previous period. In segments 1 and 2 are marked negatively indicating that the land areas are reduced and its shoreline retreats. While in segments 3 to 6, the land areas develop, consequently its shoreline also develops. In total, during the period of 1990 to 1995, the land area of tombolo develops.

In the period of 1995 to 2000, the land area of tombolo experienced an increase only in segment 4, while the rest segments 1, 2, 3, 5 and 6 show negative value which indicated that land area of tombolo suffered retreat. Whereas in the period of 2000 to 2005, segments 1, 3 and 4 show negative value and the rest segments 2, 5, and 6 are positive, indicating that the land area of tombolo experienced an increase in area. But totally, in the period of 1995 to 2000 and in the period of 2000 to 2005, the tombolo experienced a reducing area.

In period of 2005 to 2010, from all segments, only segment 3 experienced an increase in area. The other segments have negative values which indicate that the land area of tombolo is experiencing a reducing area. Similar to the later period, in the period of 2010 to 2015, only segment 2 has positive value. Other segments are negative. In total, from the period of 2005 to 2010 until the period of 2010 to 2015, the land area of tombolo also experienced a reducing area.

Figure 2 shows that overall upward histograms are lesser than downward histograms, it means that the land area of tombolo is experiencing a reducing area for three decades. The biggest increase in the land area of tombolo occurred in 2010-2015, specifically in segment 2. The area in this segment reached 29161.04 m$^2$, it means that in this segment considerably develops during this period. While the largest decrease in the land area of tombolo occurred in 2005-2010, specifically in segment 4. The area in this segment suffered the land loss is about 49344.73 m$^2$. Figure 2 also encodes natural signals which inform us that the sediment resource to form the land area of tombolo is experiencing a decreasing trend during this three decades, while the natural forces generated by wind forces relatively remain the same directions and speeds. The next question which is relevant to ask is to where the sediment is transported? The logical answer is might be in an offshore ward. The hypothetical mechanism is due to longshore transport the sediment is transported to the land area of tombolo and distributed by cross-shore transport to the offshore.

Figure 3 shows the wind rose diagram in the period of 1985 to 1990, we believe that the wind direction and speed are associated with changes in the area of the study. The direction of the dominant wind from the west and followed from the northwest and southwest, as for the mainland of tombolo is orientated westward. The main resource of sediment might come from the river mouth of Jeneberang River in the northern part and comes from the river mouth of Sungai Papa in the southern part. During
During this period, an increase in the land area of tombolo occurred in segments 1 and 2, but segments 3, 4, 5, and 6 have retreated. During this period, the position of the cape, segment 3, is stable. The growth area of segments 1 and 2 is bigger than that of the reducing area of segments 4, 5, and 6.

**Figure 3.** Related wind directions and speeds in the period of 1985 to 1990

**Figure 4.** Related wind directions and speeds in the period of 1990 to 1995

**Figure 5.** Related wind directions and speeds in the period of 1990 to 1995

*Figure 4* shows the wind rose diagram in the period of 1990 to 1995. The dominant wind direction in this period is from the west, followed from the northwest and southwest. This trend is on the contrary.
to the previous period. In this period, segments 1 and 2 experienced erosion, while segments 3, 4, 5, and 6 experienced accretions, and the position of the cape also eroded. The eroded area of segments 1 and 2 is lesser than that of the growth area of segments 3, 4, 5, and 6. 

**Figure 5** shows the wind rose diagram in the period of 1995 to 2000. The dominant wind direction and speed is from the west and followed from southwest and northwest. All segments are eroded, except for segment 4 in the position next to the cape of tombolo. Overall processes make the land area of the tombolo experienced a reducing area.

**Figure 6** shows the wind rose diagram in the period of 2000 to 2005. The dominant wind direction is mostly from the west followed from the northwest and southwest. Due to the strong wind from the west, segments 1, 3, and 4 experienced erosion. As a balance to this transport in vicinities, segments 2, 5, and 6 experienced accretions. Overall processes make the land area of the tombolo experiencing a reducing area. **Figure 7** shows the wind rose diagram in the period of 2005 to 2010. The dominant wind direction is mostly from the west and followed from the northwest. Due to the strong wind from the west, the land area of tombolo experienced an increase in segment 3, but the rest segments retreat. Another factor is owing to the new coastal structure as a fishing port located in segment 3 caused an increase in accretion. But overall processes make the land area of the tombolo being reduced.

**Figure 8** shows the wind rose in the period of 2010 to 2015. The dominant wind direction is from the west and followed from northwest and southwest. Segment 2 experienced a broad increase, while the rest segments retreat. The growth of the land area of the tombolo in segment 2 reached 29161.04 m$^2$. In this period, the cape of the tombolo (segment 3) also experienced a reducing area. Overall processes make the land area of the tombolo being reduced. **Figure 8** shows the wind rose in the period of 2010 to 2015. The dominant wind direction is from the west and followed from northwest and southwest.
Segment 2 experienced a broad increase, while the rest segments retreat. The growth of the land area of the tombolo in segment 2 reached 29161.04 m². In this period, the cape of the tombolo (segment 3) also experienced a reducing area. Overall processes make the land area of the tombolo being reduced.

**Figure 8.** Related wind direction from 2005 to 2010

**Figure 9 (a) and (b)** show that the land area of the tombolo in the period of 1985 to 1995 experienced a growth area achieving 61511.7 m². **Figure 9 (c)** shows the land area of the tombolo experienced a reducing area achieving 88287.14 m² during the period of 1995 to 2000. Overall processes during the period of 1985 to 2000 make the land area of the tombolo a reducing area. During the last five years, from 1995 to 2000, the land area of the tombolo is being reduced. It could be by the reason of reducing sediment sources mainly from Jeneberang River. **Figure 10 (a), (b) and (c)** show that the land area of the tombolo in the period of 2000 to 2015 experienced a reducing area, respectively 34340.33 m², 99508.34 m², and 3532.92 m² in each five years period. The interesting fact to be studied is there a decreasing amount of eroded area. This fact can generate a question, that how is the trend to appear in the next five years? Of course, this question should be studied first before we raise the answer.

**Figure 9.** Tombolo’s area change from 1985 to 2000
4. Conclusion
The conclusion of this study is that there is a pattern of shoreline changes for every five-year period from 1985 to 2015 at Galesong Beach. Overall processes make the land area of the tombolo is experiencing a reduced area. The change in coastline should be influenced by the directions and speeds of the wind and might be by a reducing sediment source from Jeneberang river, and other tidal creeks in the beach of mainland Takalar Regency. Another reason might be by a set of coastal structure in the cape of the tombolo as a fishing port commencing in the year of 2007.

The dominant wind directions and speeds remain the same generally during this three decades, mainly the wind blows from the west and followed from the northwest and the southwest with the highest record of speed is about 11 m/s. Significantly reducing the land area of the tombolo is commencing from the year of 1995.

The directions of the dominant wind are from the west and northwest which are enough to influence the change of the land area of the tombolo. This can be used as important information for local communities in an effort to prevent coastal erosion continuously. To preserve the island of Sanrobengi which is completed by fringing reef is of importance to prevent the existing shoreline from being eroded. Further studies are badly needed to have a deep understanding of the future existence of the tombolo.

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