

Vegetation covers change and its impact on Barchan Dune morphology in Parangtritis Coast, Indonesia

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Abstract. Barchan dune is a peculiar type of dune that forms in wind corridors at the Inner Zone of Parangtritis Sand Dune. Their existence is increasingly threatened by land-use changes, especially vegetation coverage. This research illustrates the dynamics of vegetation cover change at the Inner Zone with the NDVI value approach using Sentinel-2 imagery. We also conduct field surveys to determine the actual condition of barchan dunes and compare it to previous morphology data. We only used the slip face height as a parameter of the barchan morphometric. The result showed that the vegetation coverage changed annually in different parts of the Inner Zone from 2015 until 2019. This vegetation covers controlled by restoration program in 2015 and 2016. The vegetation density on the transport zone more significantly affected the morphology of barchan than vegetation density which grow on the barchan body. Based on field data, mostly barchan dunes (10 barchans) experienced a decrease of slip face height than increased slip face height (4 barchans). All of the decreased barchans located in the middle of the Inner zone. The most decreased slip face height as low as 29.3 meters.

1 Introduction

Indonesia is a country with various Aeolian landforms. The most famous is a sand dune in the Parangtritis coast. Dune formed in Parangtritis, Kretek District, Bantul Regency Yogyakarta is unique because it forms a crescent moon (Shows in Figure 1) where this type of barchan is the only dune formation in Southeast Asia [1,2].

Dune formation is influenced by various factors one of which is the density of vegetation that can act as a wind barrier and reduce the rate of sand in the deflation process [3][4]. The effect of vegetation density can also be seen from several criteria for disturbance to dunes such as sand waves change, the appearance of deflation holes, and the formation of sediment erosion. Vegetation affects the dunes can be divided into two types: solitary vegetation and vegetation groups. Vegetation groups more take effect in inhibiting the transport rate of sand rather than solitary vegetation. Vegetation groups with more than 3 meters height and high density can stop the deflation process and make the surface of the dune flat. Solitary vegetation will make tongue sediment or cup deflation hole structure behind the vegetation [5].

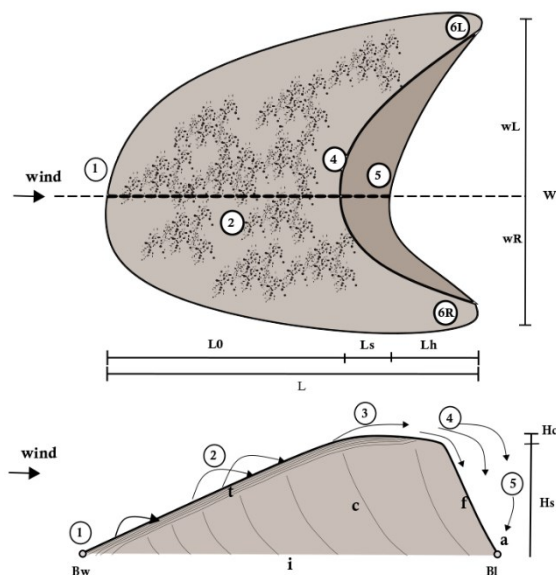


Fig. 1. Barchan dune morphology, morphometry, & structures. Morphology: (1) windward toe, (2) windward side, (3) crest, (4) brink, (5) slip face, (6) horns (L= left, R= right). Morphometric: L , length of barchan; L_0 , length from toe to the brink; L_s , length of slip face; L_h , length of horn; W , the width of barchan; w_L , the width of the left horn; w_R , the width of the right horn; H_c , the height of barchan; H_s , the height of the slip face; B_w , windward bottom; B_l , lee bottom. Structure: t , top set; c , tabular-planar cross bed set; f , foreset; a , apron deposits; i , interdune deposits. (Modified from [6])

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The morphology of dune in the study area is shown by the existence of various forms of dune type and with different morphometric conditions. The types of dune include elongated type, tongue type, transverse type, nebkha type, star type, linear type, and parabolic type [7]. Generally, there is 2 type of barchan dune, symmetric barchan, and asymmetric barchan. The difference is in the length of the horn, the symmetric barchan has relatively the same length while the asymmetric barchan has one longer horn. Barchan dune in the Parangtritis coast mostly has asymmetric morphology caused deflection of wind direction by vegetation [8]. This study only investigated morphological changes in barchan dune with slip face height parameter (H_s). Slip face is the backward side of the barchan with a steep slope [6]. Morphological, structure, and morphometric of barchan dune detailed in Figure 1.

Barchan dune can be damaged by human activities such as agriculture and tourism [4][9][10]. Many dunes experienced a transition from barchan to parabolic types accompanied by additional vegetation. The transition of barchan to parabolic dunes due to slow winds speed around the barchan dunes. This slower wind then decreased surface erosion or deposition towards the slip face. Then, barchan dunes will lose their equilibrium and changed the formation of slope from convex to concave [11][12].

The dynamics of changes in vegetation density were due to forestry activities in the coastal area. The coastal forestry activity took place from the 1980s by the Department of Agriculture and Forestry (Dispertahut) of the Bantul Regency. Then around 2011 with the Coastal Forest Making Program [3]. The activity is supported by the surrounding community because the program can provide direct benefit value for firewood production. The growth of these trees in the duneland also encourages the community to utilize the duneland for agricultural activities. Conservation activities started at the end of 2015 using a combined top-down and bottom-up approach. Dune restoration was carried out at the end of 2016. Forest, building and fishpond are relocated[13]. After that, the restoration program got stuck because the government does not seem to have a long-term plan.

2 Methods

2.1 Research Location

This research located in Inner Zone of Barchan Sand Dunes Parangtritis, Bantul Regency, DI Yogyakarta, Indonesia. Dune inner zone is an area of around 141.1 Ha which should be free from buildings and plants. Barchan dune was only formed in the wind corridor about 53.4 Ha area in the Inner Zone of Parangtritis Coast [3]. This area is a zone of active dune formation. Based on barchan distribution (Shows in Figure 2), the wind corridor has NW-SE orientation following the Baturagung scarp.

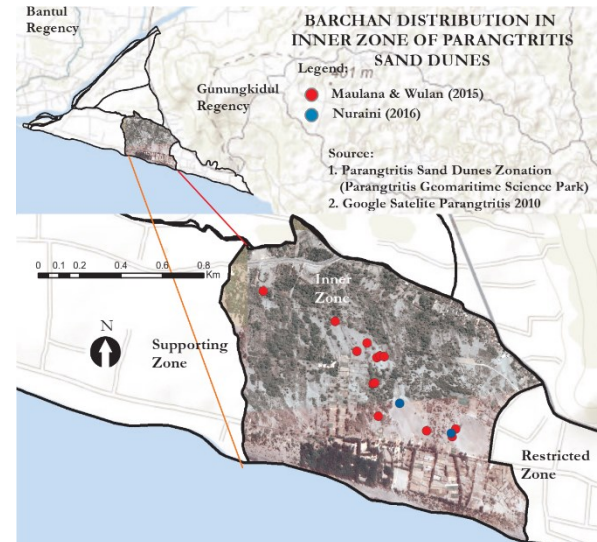


Fig. 2. Barchan dunes distribution in Inner Zone of Parangtritis coast. Barchan dune identified using UAV by Maulana & Wulan in 2015 (red dots). Barchan dune identified during a field survey by Nuraini in 2016 (blue dots).

2.2 Data Processing

2.2.1 Barchan Distribution Data

Morphometric data of barchan dune was used to identify morphology changes due to changes in vegetation density around the barchan dune. Morphology data of barchan dune in the Inner Zone of Parangtritis has been published by [8] and [5]. That morphometric data required validation to know the transformation of barchan dune with re-measuring parameters on every barchan dune. This research used slip face height. Morphometric changes between previous data and field survey data classified appropriate Table 1 below.

Table 1. Dunes changes classification.

Range (meter)	Class
$-2.0 < \Delta < 2.0$	Not change (NC)
$-6.0 < \Delta < -2.1$ or $2.1 < \Delta < 6.0$	Slightly changed (SC)
$\Delta < -6.1$ or $\Delta > 6.1$	Changed (C)

Note: (-) to decrease dune parameters

2.2.2 Image Data

Vegetation covers change analysis used Sentinel-2 L1C image from the European Space Agency (ESA) with data acquisition from 2015 until 2019. The selected image data has no cloud covers or minimum cloud cover conditions to minimize errors due to atmospheric disruptors (during the dry season: Apr-Oct). This image has a temporal resolution about 2-5 days and spatial resolution up to 10 meters in band 4 (Red) and band 8 (Near Infra-Red) [14].

Normalized Difference Vegetation Index (NDVI) is a comparison between the reflectance value of red band with near-infrared which is normalized because of the

reflection of land cover like vegetation. This data can be used to estimate the density of green areas on the surface of the earth [15]. Normalized Difference Vegetation Index (NDVI) is measured by the following formula:

$$NDVI = (NIR - VIS) / (NIR + VIS) \quad (1)$$

The near-infrared band (NIR) on Sentinel-2 is band 8 and the red band (VIS) is band 4. Plants with dense, healthy, and green leafy will absorb more red bands (VIS) and reflect more near-infrared bands (NIR) so that the NDVI value is high close to 1.0. We used ENVI to determine the value of NDVI in each image. We also make a classification of NDVI value following Table 2.

Table 2. NDVI value classification for vegetation density

NDVI Value	Vegetation Class
-1.00 - 0.00	No vegetation (ND)
0.01 - 0.30	Slightly density (SD)
0.31 - 0.60	Moderately density (MD)
0.61 - 1.00	Highly density (HD)

Source: Modified from [16]

2.3 Workflow

The research includes pre-survey work, field survey, and data processing & analysis. The detailed workflow of this research can be seen in Figure 3.

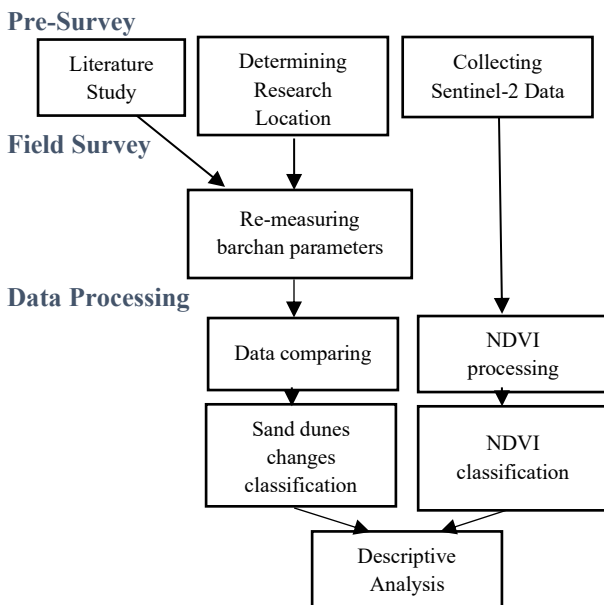


Fig. 3. The workflow of the research

3 Results and Discussions

3.1 Vegetation covers change

Vegetation covers in the Inner zone shown in Figure 4. Vegetation covers in 2015 the majority has a slight vegetation density. There is a moderate to a high density

of vegetation in the northern part (area B). Areas that are not covered with vegetation are in a large dune near Parangkusumo beach (area C). This dune until now used as a tourist attraction that is quite popular with the sunflower park and the sandboarding in the slip face part of the sand dune. There is 5 barchan in this area, barchan no. 1, 2, 3A, 3B, and 6B. At the end of 2015, Yogyakarta Province & Bantul Regency Government, Badan Informasi Geospasial, Universitas Gadjah Mada, supported by the Ministry of Research, Technology and Higher Education set up a marker “tetenger” at the Inner zone, which initiating barchan dune restoration [13].

In 2016, vegetation in Parangtritis dune was dominated by high and medium density especially in the western (area A), northern (area B), and southern part (area D). The area that originally had a slight vegetation density turned into a high density. Previous research in 2016 revealed that there is high vegetation distribution based on the planting period. The western part (area A) planted with a high density of *Casuarina equisetifolia* and *Acacia mangium* with 3 meters high and tight canopy. The northern part (area B) planted with moderately to a high density of *Casuarina equisetifolia* and *Acacia mangium* with variation in height between 1-4 meters. The southern part (area D) planted dominantly with moderately to a high density of *Casuarina equisetifolia* [5]. Restoration activities such as the translocation of buildings & fishponds also clearing vegetation was implemented at the end of 2016 [17].

Implementation of the restoration program in 2016 has reduced the density of vegetation in the dune in 2017. Changes in vegetation density in the Inner zone in 2017, 2018, and 2019 had only slightly changed so that the illustrations look similar. In 2017, in the western part (area A) the high vegetation density changes to moderate density, in the southern part the medium vegetation density changes to slightly vegetation density. In 2018, there was an increase in vegetation density in some small parts, such as northern (area B) and central (area B) part. In 2019, most areas with high and medium density have decreased density to medium density and slight density. This phenomenon occurs in almost all areas of the Inner zone. Slightly vegetation density dominates the east part. In the southern part (area D) there is still a high-density area which is a tight canopy of *Casuarina equisetifolia* at Cemarasewu beach.

Qualitative observations were also made during a field survey to identify vegetation distribution patterns based on their type. The western part (area A) has a high-density group of *Acacia mangium* and lots of dried bushes. The northern part (area B) has many variations between *Casuarina equisetifolia*, *Acacia mangium*, also we found a lot of agricultural lands planted with chili and eggplant. The central part (area C) has two blocks of vegetation, one is a block of *Casuarina equisetifolia* and the other one is a block of *Acacia mangium*. In the southern part, there are high-density groups of *Casuarina equisetifolia* at Cemarasewu beach and moderately density at Parangkusumo beach.

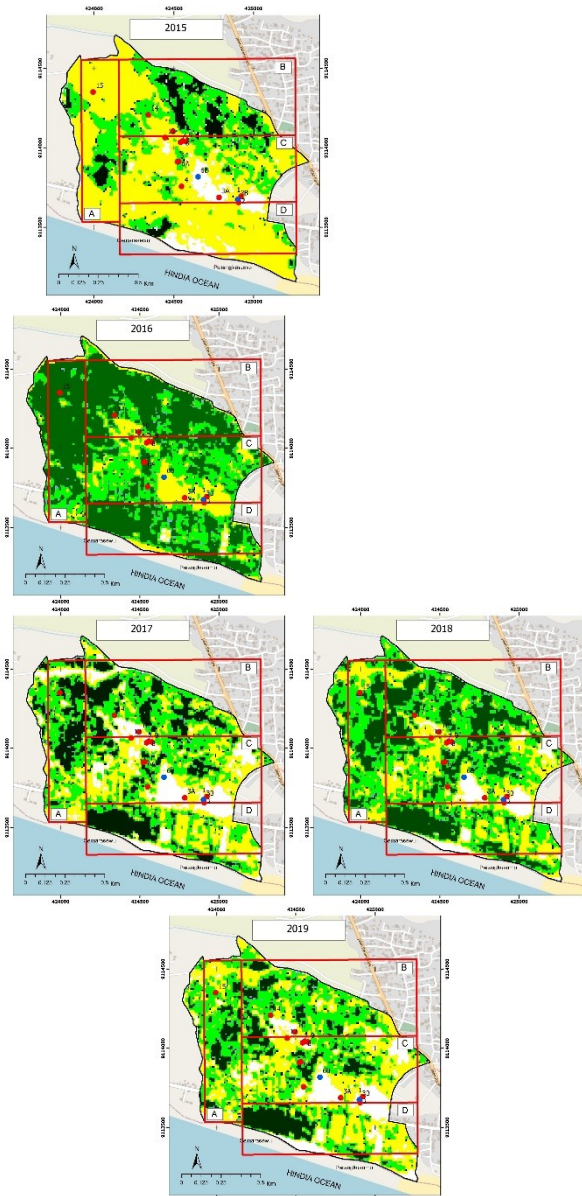


Fig. 4. The vegetation covers changed in Inner Zone. White areas illustrate no vegetation cover, yellow areas slightly density, green areas moderately density, and dark green areas high density.

3.2 NDVI measurement

In general, the tendency of NDVI values in a dune is determined by the image used. Sentinel imagery taken in 2016 has the highest average NDVI values compared to 2015, 2017, 2018, and 2019 imagery. Sentinel imagery in 2017, 2018, and 2019 has fluctuated, while Sentinel in 2015 had the lowest NDVI value for each dune (Shows in Table 3).

Each barchan dune had a different response for NDVI value. We focused on barchan no. 5, 6A, and 15 which has a high-density period in a different year. Barchan no. 5 and 6A located in a contiguous area. Barchan no. 5 has a high-density condition for 4 years with NDVI value around 0.62-0.73 (Figure 5). Barchan no. 6A has a high-density condition (0.61) in 2018. In this location, there are blocks of *Casuarina equisetifolia* and a lot of bushes on the surface. The high value of NDVI can be caused by

these bushes coverage. Barchan no. 5 and 6A prone to severe damage due to wind speed to the west and northwest is blocked by vegetation group.

Table 3. Barchan dunes NDVI value classification

No	X	Y	NDVI Classification				
			2015	2016	2017	2018	2019
1	424924	9113695	ND	SD	ND	ND	ND
2	424907	9113656	ND	SD	ND	ND	ND
3A	424784	9113688	ND	SD	ND	SD	ND
4	424550	9113757	SD	MD	SD	MD	SD
5	424524	9113911	MD	HD	HD	HD	HD
6A	424532	9113914	SD	MD	MD	HD	SD
7	424543	9114035	SD	SD	ND	SD	ND
8	424558	9114043	ND	SD	ND	ND	ND
9	424578	9114040	SD	SD	ND	ND	ND
10	424496	9114103	SD	SD	ND	SD	ND
14	424340	9114207	MD	MD	SD	MD	SD
15	423994	9114350	SD	HD	MD	MD	MD
12	424446	9114064	MD	MD	MD	MD	SD
3B	424902	9113675		SD	ND	ND	ND
6B	424653	9113817		SD	ND	ND	ND

Source: Data processing, 2019

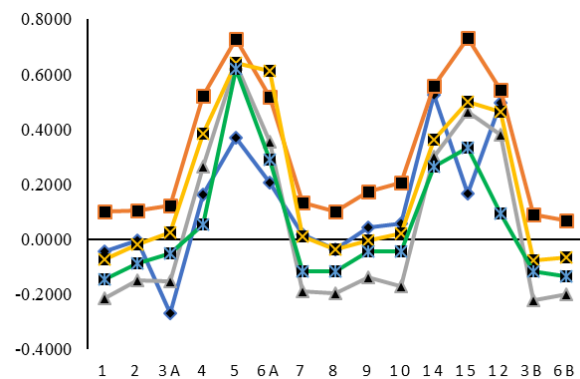


Fig. 5. NDVI value on each barchan in 2015 (blue line), 2016 (orange line), 2017 (grey line), 2018 (yellow line), & 2019 (green line).

Barchan no. 15 located in the western part (area A) and the location is far from another barchan. This barchan has a high-density condition in 2016 and after that has a moderate density of vegetation. During the field survey, this barchan has a lot of dried bushes and *Acacia mangium* in the windward toe. There are chili plantations in the slip face area and a cattle beside of this barchan (Shows in Figure 6). The high density of *Acacia mangium* is on the east side. The wind that brings sand can be trapped there.

Bushes coverage in the barchan dunes surface gave a different response to NDVI value. Healthy bushes will make a higher value of NDVI than dried bushes. So, healthy bushes cover in barchan no. 5 identified to high

density while dried bushes cover in barchan no. 15 identified to moderate density. That's facts that made uncertainty in determining vegetation density using NDVI. Vegetation density analysis using NDVI requires field validation.



Fig. 6. Slip face of barchan no. 15 fully with dried bushes. (Photo by Agatha Andriantari, 2019)

3.3. Morphometry of Barchan dune

Based on field survey data, 3 barchan dunes classified to changes (C), 4 barchan dunes classified to slight changes (SC), and 8 barchan dunes classified to not changes (NC). Detail morphometric changes showed in Table 4.

Table 4. Slip face height changes classification

No	X	Y	Slip Face Height in 2015 (meter)	Slip Face Height in 2019 (meter)	Slip Face Height Changes (meter)	Class
1	424924	9113695	5	4.88	-0.12	NC
2	424907	9113656	3.4	2.7	-0.7	NC
3A	424784	9113688	1.5	2.6	1.1	NC
4	424550	9113757	15	8.15	-6.85	C
5	424524	9113911	9	4.4	-4.6	SC
6A	424532	9113914	8	3.54	-4.46	SC
7	424543	9114035	1.5	2.5	1	NC
8	424558	9114043	0.7	0.7	0	NC
9	424578	9114040	15	6.9	-8.1	C
10	424496	9114103	7	5.9	-1.1	NC
14	424340	9114207	32	2.7	-29.3	C
15	423994	9114350	12	9.4	-2.6	SC
12	424446	9114064	5	2.71	-2.29	SC
3B	424902	9113675	3	3.4	0.4	NC
6B	424653	9113817	2	2.2	0.2	NC

Source: Data processing, 2019

The distribution of morphological changes on barchan dunes can be seen in Figure 7. Barchan with a changed class (slip face decreased more than 6.1 meters) located in the middle of the Inner zone. Barchan no. 14 became the

biggest decline with 29.3 meters. NDVI value of this barchan along 2015-2019 between slight density to moderate density. That vegetation density compared with vegetation density on barchan no. 5 with high-density vegetation along 2016-2019. Barchan no. 5 only decreased by 4.6 meters (slightly changed class). We assume that vegetation density on transport zone (Shows in the red highlighted area in Figure 7) controlled that morphology changes. Therefore, vegetation density on the transport zone more significantly affects the morphology of barchan than vegetation density which grows on the windward side and slip face.

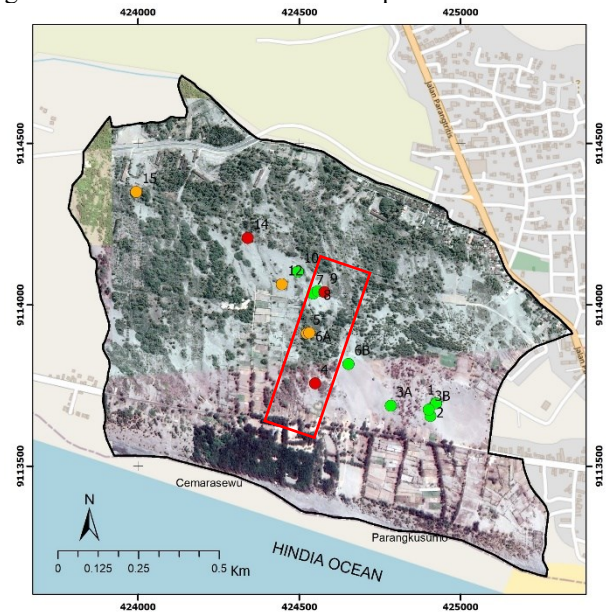


Fig. 7. Slip face height changes in the Inner Zone of the Parangtritis coastal area. Green dots represent barchan with no changes, while orange dots for barchan with slightly changed, and red dots for barchan with changed class.

Barchan no. 4 and no. 9 which located in this highlighted area also has changed class (C) with decreased by 6.85 meters and 8.1 meters. Vegetation cover in this area monitored grown since 2015. The red highlighted area located in the transport zone based on micro-zonation of the Inner zone by [4]. We recommend clearing dense vegetation in this highlighted area. This zone should be free from anthropogenic activities such as fishpond, settlement, cattle, and agriculture. Indigenous vegetation such as *Siwalan* (*Borassus flabellifer*) allowed growing in this zone. However, the density of indigenous vegetation must also be considered.

Although many barchans experience a decrease in slip face height, about 26.7% (4 barchans) have increased slip face height. Most of the barchans are on the main dune near Parangkusumo beach. This area was relatively free from dense vegetation. This area received sand transport from the foredune with dominantly creeping sand movement [18]. Sand movement characteristics controlled by vegetation cover also wind speed. A disturbance between foredune and main dune is tourism development and settlement near Parangtritis beach.

Barchan no. 11 and 13 cannot be identified again in the field survey. This barchan located near barchan no. 12 and is in the active track of the jeep. We only saw the dune

plains here. These deformations were most likely caused by the jeeps that acted as tourism object of Parangtritis, proven further by the tire trails left by the jeeps (Shows in Figure 8).



Fig. 8. The tire trails left by the jeeps had flattened barchan No. 11 and 13 around barchan no. 12 location. Photo by Agatha Andriantari, 2019.

4 Conclusion

The vegetation covers dynamics measured through the NDVI approach showed that barchan dunes have a quite similar annual NDVI value. Generally, the NDVI value tendency of a dune is being affected by imageries used as a source. NDVI value is not only influenced by the density of vegetation but also vegetation conditions. So, field validation needed to analyze vegetation density. Morphology of barchan dunes significantly affected by vegetation density in the transport zone. We recommend clearing and monitoring this zone from dense vegetation. There are 10 barchans (66.7%) that have decreased slip face height and 4 barchans (26.7%) have increased slip face height. The most significant decrease of slip face height occurred on barchan no. 14 with decreased as far as 29.3 meters.

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