



Coastal Erosion Threat on the Kızılkumu Spit Geotourism Site (SW Turkey): Natural and Anthropogenic Factors

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Abstract

The uniqueness of the spits comes from their special coastal geomorphology. Spit's evolution is controlled by the fragile environmental conditions, the sediment input, long shore currents, wave, wind and river processes. The Kızılkumu Spit, one of the attractive examples (400 m long; 18–48 m wide) is located in an environmentally protected area in southwestern Turkey (Datça-Marmaris). Extending 50 cm below the sea as a red carpet, the spit with its distinctive appearance and mysterious history enhance the site's attractiveness which brings on the possible anthropogenic effects as overpopulation during summer tourism and the lower sediment influx from improper marine structure. This study characterizes the spit formation via recent and the past satellite images, geological and topographical maps to better figure out the protection pathways. Six locations were defined and twelve beach sediments in total were sampled. The particle size distribution by sieving together with micro-imaging the sediments are combined with the statistical analyses. Mode values from sieve analysis and the red-coloured sediments along the coast which are also visible on satellite images point out that the Kızılkumu Spit is fed from north (via Kocapınar Stream Delta and its coast) and east (via Bozeğri Brook). An uncontrolled sand-drawing from the coast, establishing the breakwaters to prevent the longshore currents and waves onto the coastal structures and experiencing walking along the spit, all cause the dispersion of the sediments and very intense erosion on the spit. The results of this study suggest that immediate protection measures (including spit-monitoring, prevention of sand drawing, limitation of daily tourist activities) should be taken for future sustainability of the Kızılkumu spit.

Keywords Kızılkumu · Spit · Beach sediment · Coastal erosion · Geotourism · SW Turkey

Introduction

Beach morphology is susceptible for the changes due to the wave and current actions together with the sediment flow from various sources: fluvial sediments, cliff and foreshore erosions, seafloor sediments and wind-blown sand (Oertel 1985; Bird 2008; Stanica and Ungureanu 2010; Otvos 2012; Petrakis et al. 2014). On the other hand, beaches are susceptible to gain shapes artificially due to human activities (Woodroffe 2002; Bird 2008; Stanica and Ungureanu 2010; Petrakis et al. 2014). Therefore, both the geological and the anthropogenic factors have great impacts on the coastal

regions (Alexandrakis et al. 2015). Coastal erosion is the loss of sediments relative to fixed reference line due to natural or anthropogenic effects (Van Der Weide et al. 2001; Alexandrakakis et al. 2010, 2015). Mediterranean region has been suffered from the coastal erosion at varying ratios (Alexandrakis et al. 2010). Besides the environmental impact (e.g. the reduction in the coastal biodiversity), the coastal erosion also threatens the local socio-economical life (including loss of land with economic worthy, and damage of coastal infrastructure) where the tourism plays key role for economy (Petrakis et al. 2014; Alexandrakakis et al. 2015). Additionally, Petrakis et al. (2014), IPCC (2014), Danladi et al. (2017) and several other studies emphasized that possible sea level rise threatens many of the coastlines and high wave energy beach zones. Furthermore, coastal erosion may affect the value of such landforms to be classified as geosite and/or geological heritage.

Due to the unique features of some beaches such as spits, it is highly important to conserve the appearances and

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sustainability (Wimbledon 1996; Kazancı 2010). Geomorphologically, one side of the spit, is connected to the mainland while the other side is open to the river mouth or sea (Ollerhead and Davidson-Arnott 1995; Dan et al. 2011; Thomas et al. 2014; Ekinçi and Doğaner 2016; Gül et al. 2019a). Their evolution can be controlled by the sea level fluctuation, coastal erosion, sediment supply, climate, wave action, tectonism, drainage area of the source river and human impact (Ollerhead and Davidson-Arnott 1995; Kumara et al. 2010; Nagarajan et al. 2015). They can be formed in various lengths and widths in different marine settings with the suitable environmental conditions, such as Curonian Spit (Lithuania-Baltic Sea, Jarmalavičius et al. 2012), Buctouche Spit (New Brunswick-Canada; Ollerhead and Davidson-Arnott 1995), East Cantabrian Estuaries (Oka Estuary-Spain; Monge-Ganuzas et al. 2015); Karnataka Coast (W India; Kumara et al. 2010), spit in the Baram river mouth (Eastern Malaysia, Nagarajan et al. 2015) and Çardak Spit (Çanakkale, Turkey, Kazancı 2013). South-western Turkey also hosts some special spit formations: the İztuzu Spit (Maktav et al. 1996; Gül et al. 2019a) and the Kızkumu Spit located in Marmaris town (Figs. 1 and 2; Atabey 2002; Ekinçi and Doğaner 2016).

Kızkumu Spit, which is relatively smaller, has a concave structure and seems like a red carpet on which the visitors can walk along and reach to the middle of the gulf (Fig. 1). Moreover, it has an ancient history about the formation of the spit, which attracts thousands of tourists. This region is located in the geoheritage list of Turkey (<https://www.jemirko.org.tr/download/envanter-listesi-detayli/?wpdmml=180>; access date: 10.09.2019). The pictures and characteristics of the Kızkumu Spit are presented in Facebook page of the UNESCO - Turkey (https://www.facebook.com/permalink.php?id=2255660554667220&story_fbid=2419571401609467; access date: 10.09.2019). The Kızkumu was announced as a 1st-grade natural site and the 3rd-grade archaeological site in 1996 (Ekinçi and Doğaner 2016). Moreover, several news mentioned that related administrations applied to UNESCO for registering Kızkumu to the list of the endangered natural heritage (<https://www.memurlar.net/haber/449829/kizkumu-nda-unesco-icin-calismalar-hizlandi.html>; access date: 10.09.2019). Numerous environmental actions were held by environmentalists in previous years (<http://marmariscevrecileridermegi.org/?s=kizkumu>; access date: 10.09.2019). Especially during the summer periods, not only for its ancient history but also the geological, geomorphological and archaeological features create intense visiting activities that certainly affect the depth and width of the spit.

Even though its unique form, only a few scientific researches were carried to better understand the geological development of the Kızkumu Spit (e.g. Atabey 2002; Ekinçi and Doğaner 2016). Since different models were proposed for the formation of the Kızkumu spit, additional studies are

necessary to form up the conservation patterns for its future sustainability. The precautions are vital to prevent the degradation of the sediment accumulation or a complete disappearance of the spit (Alexandrakis et al. 2015).

The main objective of this study is to understand the evolution and development of the Kızkumu Spit-sand tongue by characterizing the sediments, sediment transportation routes and the coastal variations. Besides natural factors (direction of the sediment input), the impact of anthropogenic effects (construction barriers to prevent the sediment transportation, over-use during the summer tourism) is also evaluated in this study.

Material and Methods

The study area is located in the southwest of Turkey. The oral communication with the local people and the previous studies emphasize that the spit area was above the sea level (Fig 2b); however, the recent topographical maps encounter the spit below the sea level (Fig. 2a).

Recent Google Earth images were studied in detail to understand the possible sediment transportation ways and the coastal variations. These images were also taken into consideration to determine the possible structural units that may actively affect the formation of spit (Google Earth 2017).

For the present study, twelve loose samples of both coarse and fine-grained sediments were collected from six different locations during the field studies in order to determine the sediment type and grain size variations (Fig. 3a, b). After surveying the whole Kızkumu Spit, sample 2 was taken from the closest point to the mainland (Fig 3b). Samples 1, 4, 5 and 6 were taken from the northern feeding area—delta and the coast of the Kocapınar Stream (Figs. 4 and 5a, b, c). Sample 3 was taken from the eastern feeding area—delta and the coast of the Bozeğri Stream (Figs. 3a and 4). Sieve analyses of 6 samples (115–1905 g) were performed by using the standard sieves (31.5 mm–16 mm–4 mm–2 mm–1 mm–500 µm–250 µm–125 µm–62 µm-pan; Figs. 6 and 7). The frequency ratios (Fig. 6a), cumulative retained percentages (Fig. 6b) and the cumulative passing percentages (Fig. 6c), classification of sediments and their statistical evaluations (including sorting, mode, skewness, kurtosis) were made according to Folk (1974) and presented in Table 1. The compositional variations of the sediments were evaluated according to the mode values under microscope to define the grains and their provenances (Fig. 8).

Geology and Geomorphology of the Kızkumu and Its Surrounding

The Kızkumu and its surrounding region contain the Lycian Nappe Units and its Quaternary cover (Şenel and Bilgin 1997). The oldest geologic unit is the Çövenliyaıyla volcanics

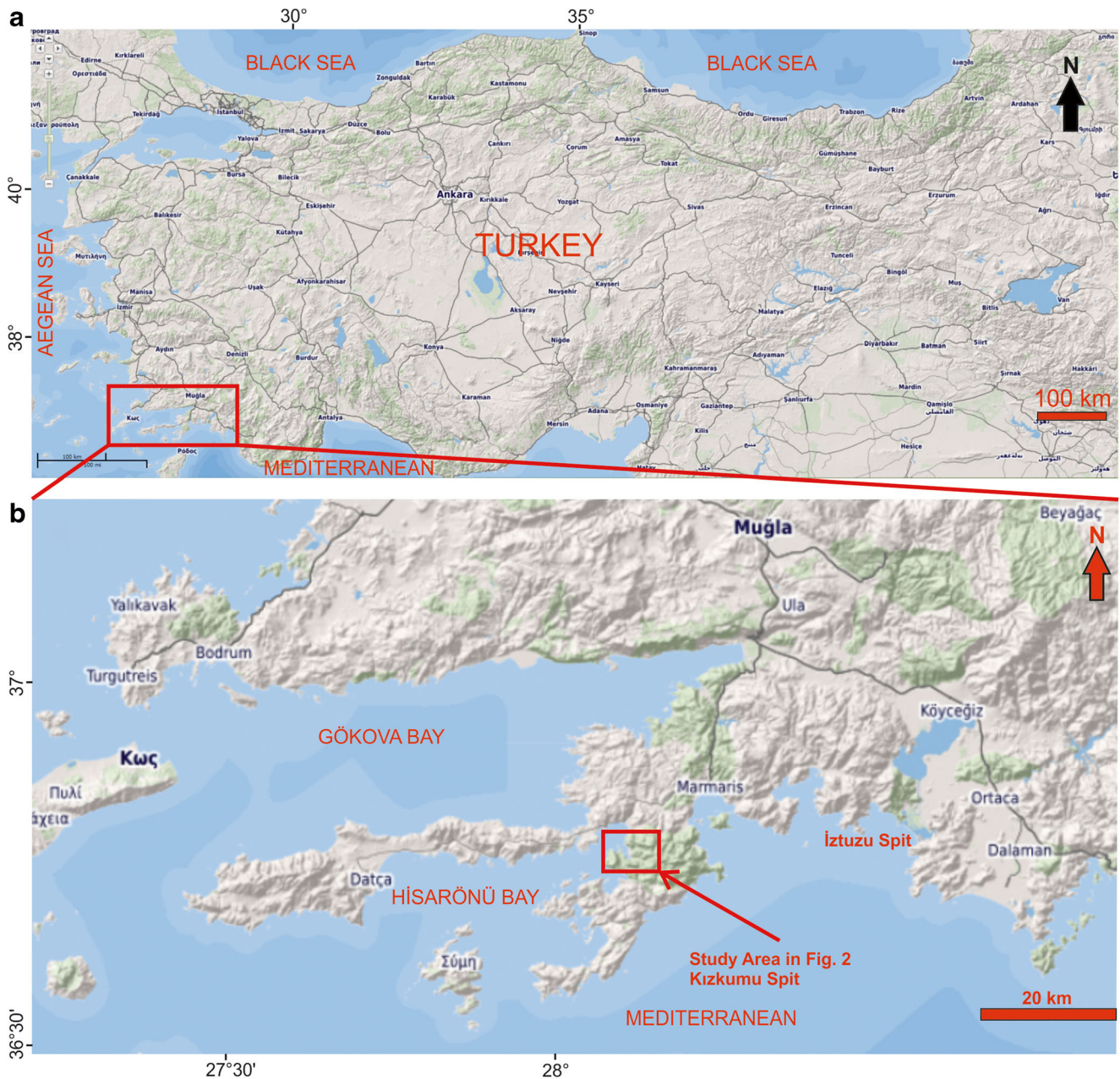


Fig. 1 **a** The location of the Kızkumu Spit in SW Turkey. **b** The location of the spit area and the protected zone of the Hisarönü Bay (maps obtained from the <http://yerbilimleri.mta.gov.tr/anasayfa.aspx>; access date: 30.04.2019)

composed of green-red spilite, basalt, green tuff, tuffite, locally radiolarite, chert and limestones (Middle-Upper Triassic; T-2-a; Fig. 2b). The Orhaniye Formation contains the Jurassic-Cretaceous grey-beige-cream-yellow-pink-red-coloured micrite and chert with calciturbidites (Jk-17-a). Bedded cherty member (Jk-14-a) forms the upper part of the Orhaniye Formation, including thin-medium bedded red, reddish brown, locally grey-green-blue-coloured radiolarite, chert and shale (Fig. 2b; Şenel and Bilgin 1997). The Kızılcaadağ melange contains the Cretaceous harzburgite, dunite, serpentinite, serpentized harzburgite, dunite (Mz-k2s;

Upper Senonian) in matrix and olistostrome including the Jurassic-Cretaceous cherty limestone (Jk-8-a) blocks (Fig. 2b). These older units were uncomfortably overlain by the Quaternary alluvium (Q-21-k).

The distribution of these geological units may be responsible for the recent morphology of the Orhaniye-Hisarönü District and the bottom configuration of the marine environment. The valley of the Kocapınar Stream is surrounded by the hill with a maximum height of 800 m. Northern part of the valley includes the higher hills and ridges. Their heights are decreasing towards the sea down to the west. The stream ends with nearly flat

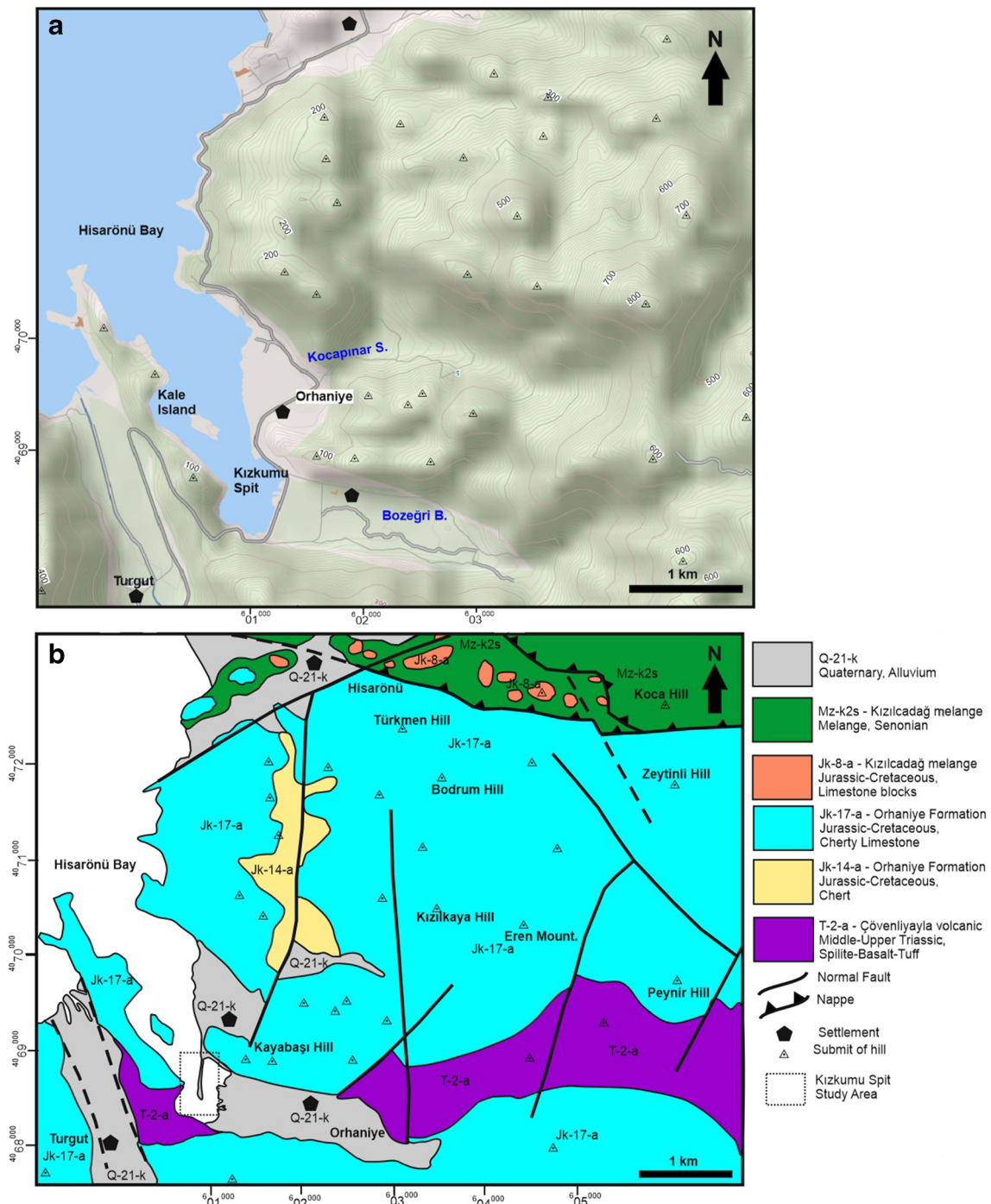
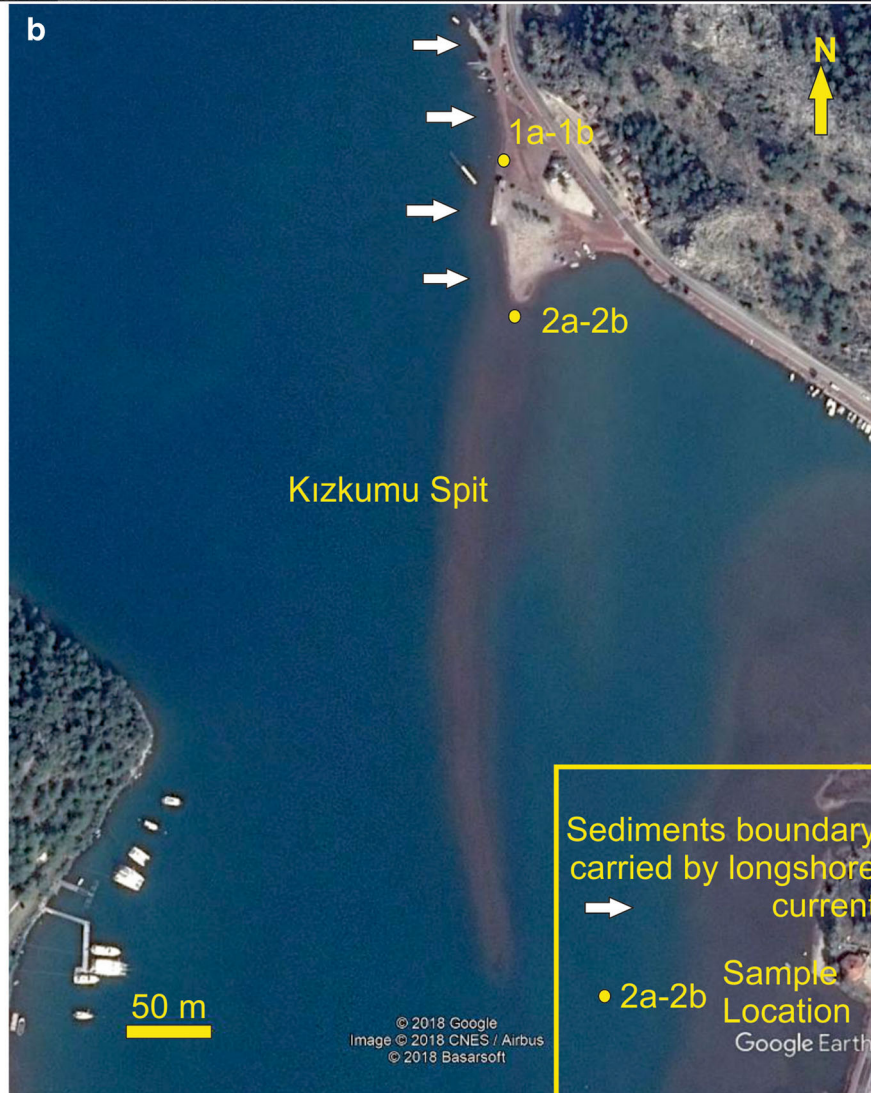
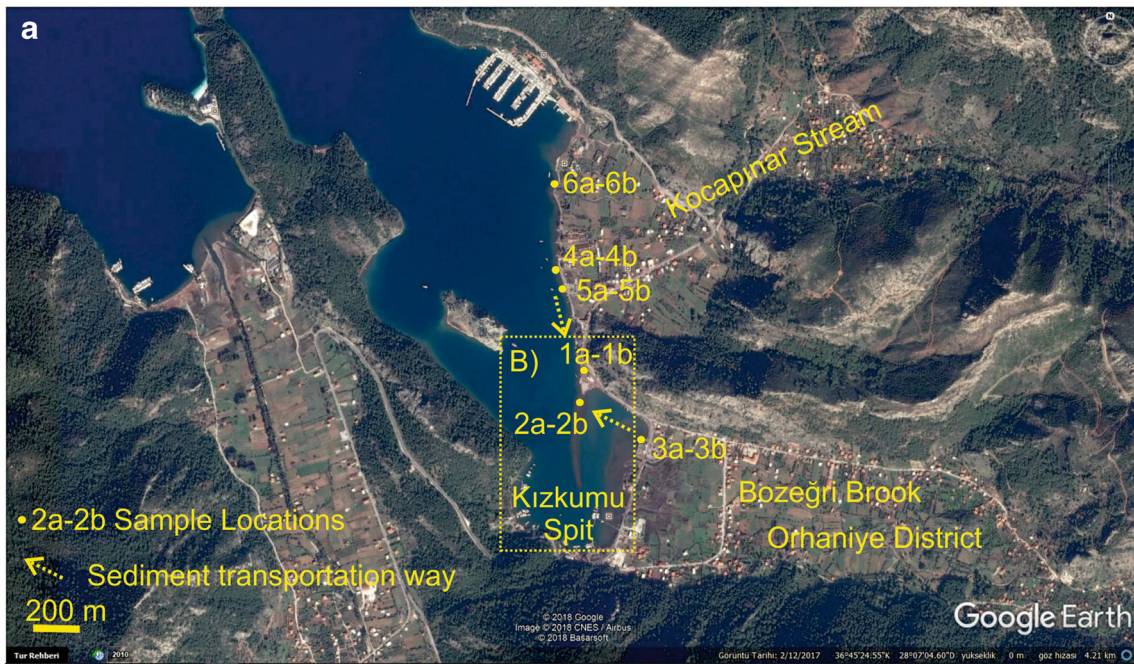


Fig. 2 **a** Topographical view of the Kızkumu Spit area (map obtained from the <http://yerbilimleri.mta.gov.tr/anasayfa.aspx>; access date: 09.01.2020). **b** Geological map of the study area (modified from Şenel and Bilgin 1997; <http://yerbilimleri.mta.gov.tr/anasayfa.aspx>; access date: 09.01.2020)

topography of the Kocapınar delta. The Bozeğri Brook is located in the south eastern side of the study area. The valley of this brook is surrounded by the hill of maximum 600-m height, which decreases towards the west. The Bozeğri Brook valley is filled with an elongated delta. The weathered fragments from Çövenliayla volcanic units and Orhaniye Formation have been transported initially to the valleys of the Kocapınar Stream and

Bozeğri Brooks. Afterwards, these sediments have been carried to the delta and the coastal areas (Fig. 2).

Fig. 3 **a** The Google Earth image showing the sampling locations in the vicinity of the Kızkumu Spit. **b** The Google Earth image of the Kızkumu Spit with white arrow showing the red-coloured sediment movement boundary (Google Earth 2017)



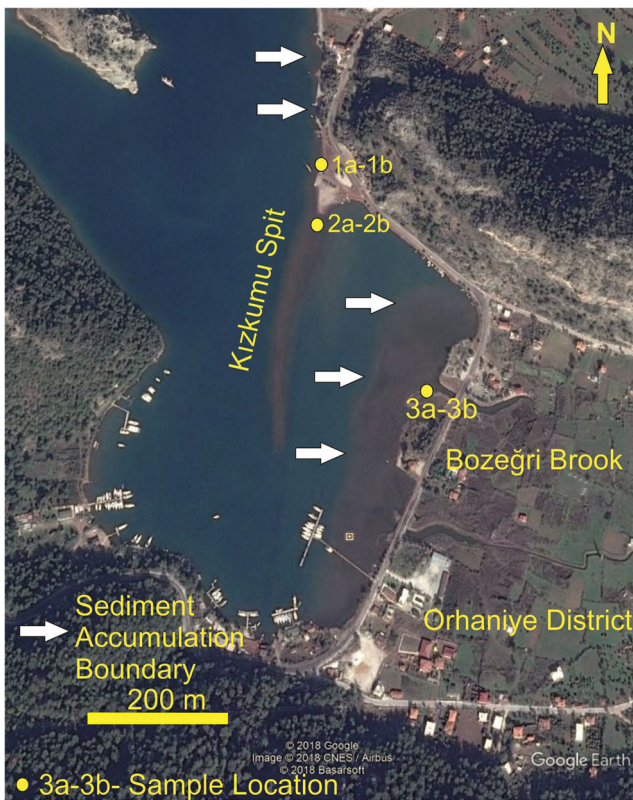


Fig. 4 The Google Earth image of the east of the Kızkumu Spit with white arrow showing the red-coloured sediment distribution from Bozeğri Stream (Google Earth 2017)

Characteristics of the Kızkumu Spit

Ancient History

The Bybassos (B.C. 7th–6th century) ancient city located in and around the Kızkumu Spit includes ruins of the Early

Hellenistic and Byzantium church, farm, agricultural terrace, settlements, temple, port, wall, ceramics and amphora (Held et al. 2007, 2009, 2011). The Kızkumu Spit has an old story linked with the Bybassos ancient city. Long time ago, the King of Bybassos lived with his beautiful daughter on the shores of today’s Orhaniye Village. The princess fell in love with a poor fisherman. Every night, these secret lovers communicating with the lights of their lanterns. When the King learnt about this love, the king sent his soldiers to capture the fisherman. During the ambush, Princess rushed towards the sea. The sand poured from her skirt created a long narrow road for her; however, before reaching to the fisherman, she was hit by the arrow. Her blood gave the red colour to the sand. The poor fisherman took the princess to the boat and was lost in the sea. According to some others, the Bybassos was invaded by pirates and the king was killed. One night, when she was escaping with sand filled skirt, in each step she, sprinkled with a bunch of sand to the sea. The sand was accumulated on the floor where she walked through and elongated like a road. However, when the sand was all gone, she got drowned (<http://www.routemarmaris.com/mobil/MShowDetail.aspx?MenuId=2898>; <http://www.muglakulturizm.gov.tr/TR-158180/orhaniye%2D%2Dkizkumu.html> access date 30.04.2019).

Morphology

The measurements on the Google Earth image show that the Kızkumu spit has a slightly curved structure, 400 m length. The red-coloured sediment distribution at the open sea end is 18 m wide and the attached landside is 47–48 m wide (Fig. 3a, b). While Atabey (2002) states that the Kızkumu spit is

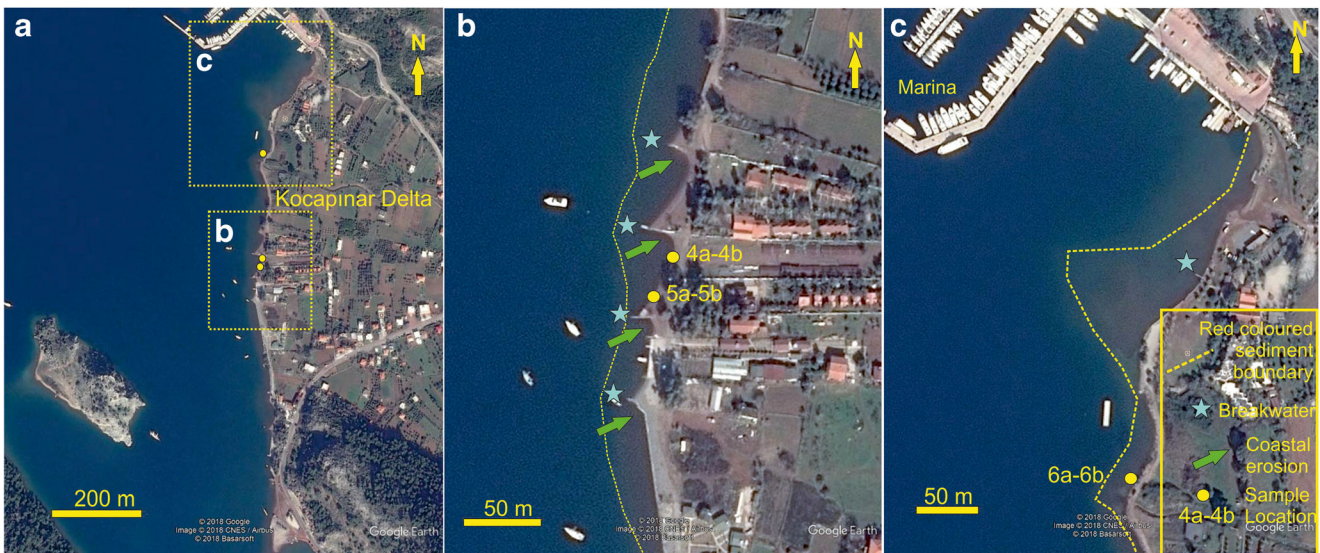


Fig. 5 The Google Earth images of **a** the north of the Kızkumu Spit and the coastal side of the Kocapinar Delta. **b** The locations of the Samples 4 and 5 (dashed line shows the red-coloured mobile sediment boundary;

green arrows point out the coastal erosion due to breakwaters. **c** the location of Samples 6 (dashed line shows the red-coloured mobile sediment boundary) (Google Earth 2017)

375 m long and 5–15 m wide and 20–50 cm below the water, Ekinçi and Doğaner (2016) indicates that the Kızkumu Spit is 10–30 m wide and 420 m long. Short-term variations of the wind and wave directions (mainly NW to SE) result in curved or hook morphology of the spit (Ekinçi and Doğaner 2016). Seawater depth is 7.5 m at the end of the open sea side and it is 2.5 m in the lagoon between the spit and Bozeğri Brook mouth (Atabey 2002). Lagoon includes silt- and clay-sized sediments at the bottom and is covered by reed towards the Bozeğri Stream mouth. The stream mouth also contains small sand islands (Atabey 2002). In addition, salt marsh and estuary were defined at the Bozeğri Stream mouth (Ekinçi and Doğaner 2016). Sea is deepening towards the Kale Island (western offshore of the spit) from 13 to 20 m (Atabey 2002). Ekinçi and Doğaner (2016) identified that the bathymetry of the Kızkumu Spit is up to 5 m in the offshore side of the Kocapınar Delta. Wavelengths in the study area were determined as 1.25 m (Ekinçi and Doğaner 2016). Those WNW- to ESE-directed waves led to the formation NW- to SE-directed longshore currents. Changing of wave refraction and the interruption of the longshore currents due to coastal structures (breakwater etc.) cause the coastal erosion and newly formed small sediment accumulations in the Kocapınar Stream Delta.

Sediment, Deposition and Feeder System

Samples 2a and 2b, obtained from the Kızkumu, are poorly sorted, platykurtic, sandy gravel (Table 1). Average grain size of the Sample 2a is ($-1.6 \text{ } \phi$) and Sample 2b is ($-1.6 \text{ } \phi$) (Fig. 6d; Table 1). Both samples have Mode 1 in $-2.0 \text{ } \phi$ (4 mm), Sample 2a also has second mode value Mode 2 ($-2.0 \text{ } \phi$) (1 mm) (Fig. 6e; Table 1). Sample 3 (from the Bozeğri Brook), classified as sandy gravel, while average grain size of it is smaller than the Kızkumu samples 2a and 2b. Sample 1 (sandy gravel) grain size is smaller than the Kızkumu samples (from southern part of the Kocapınar Stream Delta). Samples 4 and 5 (from central part of the Kocapınar Stream Delta) generally include gravelly slightly gravelly sand, and Sample 6 (from northern part of the Kocapınar Stream Delta) is classified as sandy gravel (Table 1).

Figures 7 and 8 present detailed views of the coarse- and fine-grained mode values, respectively. Coarse-grained mode section of Sample 2 mainly contains black-coloured volcanic rock fragments, reddish brown-coloured chert and, to a lesser extent, white-coloured limestone fragment-bearing gravels. Sample 3 from east of the Kızkumu spit also has a similar composition; however, the limestone fragments are in relatively low ratio. Samples 1, 5 and 6 from north of the Kızkumu spit have higher ratios of limestone fragments (Fig. 7).

Finer-grained mode section of Sample 2 contains red-coloured radiolarite, black-brown-green-coloured volcanic rock fragments and red-white-coloured limestone fragment-

bearing sands. Sample 3 contains generally dark-coloured (black-green) volcanic rock fragment-bearing sands. However, Samples 1, 4, 5 and 6 contain mostly red-coloured sediments including chert, radiolarite and limestone fragment-bearing sands (Fig. 8).

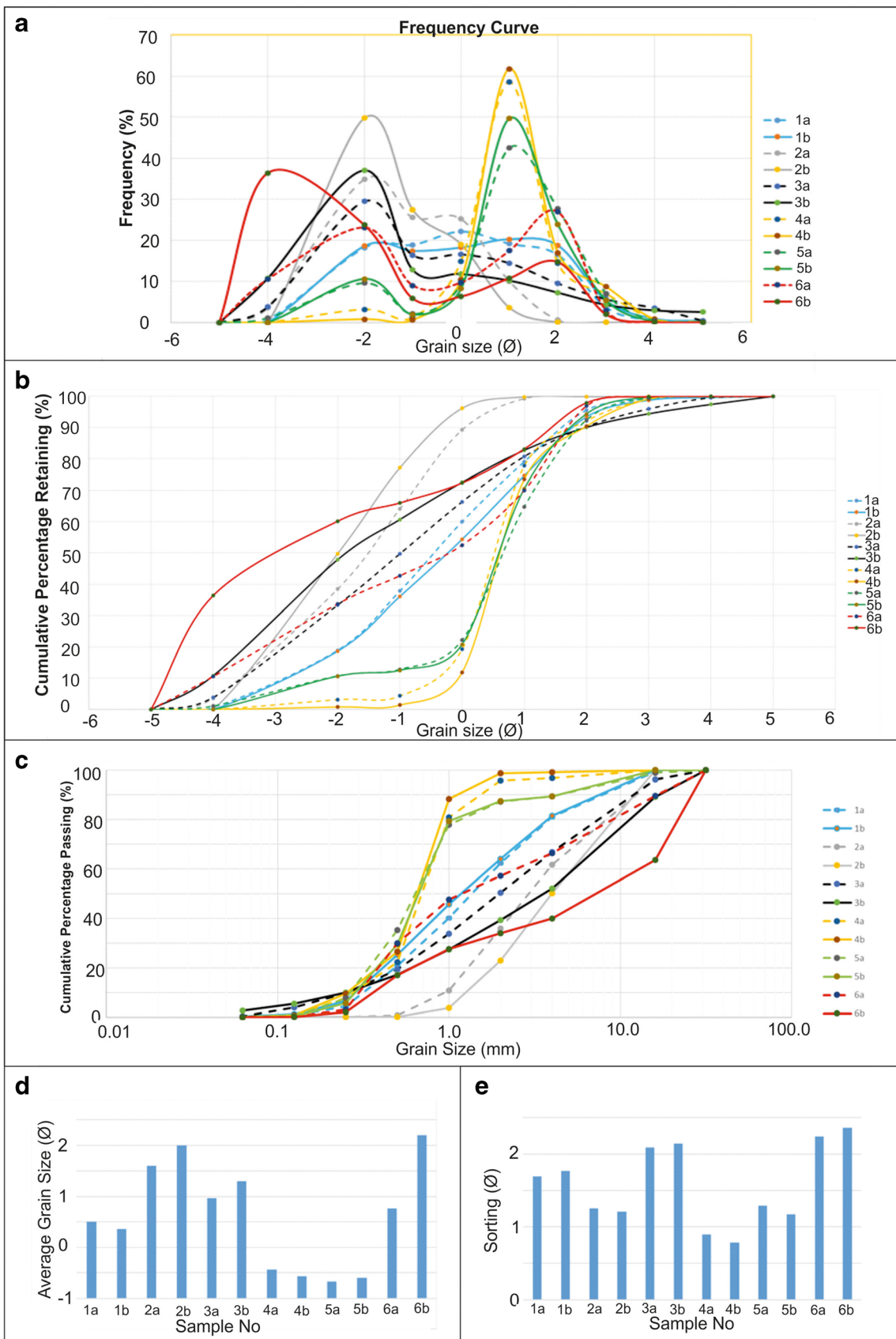
Considering the type of sediment and related grain size of the Kızkumu Spit, source sediments of the spit must be transported from both Delta of the Kocapınar Streams and Bozeğri Brook. Coarse-grained volcanic rock gravels of the spit were transported from the eastern side, while limestone gravels mostly were transported from the northern part. Fine-grained volcanic sands can be transported more or less from both sources, while limestone sands were mostly transported from the northern part.

Similarly, Atabey (2002) and Ekinçi and Doğaner (2016) reported that the Kızkumu Spit contains radiolarite, chert, limestone fragments bearing angular-subrounded, brown, yellow, red gravels and sands. Atabey (2002) also suggested that these sediments derived from the Bozeğri Stream, which could be dispersed to 250 m towards the open sea, and after, NW to SE oriented sea waves carry the sediments to the SE and lead to the formation of the Kızkumu. However, Ekinçi and Doğaner (2016) proposed that the sediments of the Kocapınar Stream Delta are carried by the longshore currents: wind and wave actions from NW to SE lead to formation of the Kızkumu Spit. Moreover, Ekinçi and Doğaner (2016) stated that the Kocapınar Stream reaches to maximum discharge during the rainy spring season; therefore, wave actions and sediment transportations due to decreasing of the capacity of longshore currents were the least intense during this period limiting the development of the spit.

Discussion

The results of the sieve and images analyses point out that the Kızkumu Spit has been fed from both north and east directions. Dark-coloured volcanic rock fragments are mainly derived from the eastern Bozeğri Brook, while white-red-coloured limestone and red-coloured chert fragments are mainly derived from the northern Kocapınar Stream Delta (Figs. 7 and 8). However, the Kızkumu Spit sample (Sample 2) has relatively more gravel-sized sediments. Only a few samples (Sample 6B and Sample 3B) have gravel ratio values similar to Kızkumu Spit. Relatively low ratio of gravel-sized sediments may be because of sampling and/or decreasing of wave and longshore current effects to the spit. Additionally, finer-grained sediments may be winnowed by the waves and/or initially dispersed due to tourism activities and later winnowed, which at the end causes the dominance of the coarser sediments of the Kızkumu Spit.

The general view of the Kızkumu Spit shows that the spit is covered by marine water (Fig. 9). However, several sources



◀ **Fig. 6** Graphics showing the **a** frequency curves of the samples based on the results of the sieve analysis. **b** Cumulative weight retaining percentage (%) versus grain size (ϕ). **c** Cumulative weight passing percentage (%) versus Grain size (mm). **d** Average grain size (ϕ) versus Sample no. **e** Sorting (ϕ) versus Sample no.

topographical map printed in 1996 by General Commander of Mapping: beach in geological map (Fig. 2b; Şenel and Bilgin 1997). Local residents also reported that the Kızkumu Spit was above the sea level during the 1980s. They also mentioned that the significant quantity of the sediment was used for the construction purposes. Sand extraction drawing from the delta and the coast for the construction affected the

mentioned that this region was mapped above sea level in 1/25000 scaled topographical maps of 1963 and 1/25000 scaled

Fig. 7 Macro-views of the selected samples in a grain size of 4 mm



Table 1 Statistical parameters of the sieve analysis, and the classification of the sediments according to Folk (1974)

Sample no	Statistical parameters														Grain size percentage (%)										
	Median (ϕ)	Average grain size (ϕ)	Sorting (ϕ)	Skewness (ϕ)	Kurtosis (ϕ)	Mode 1	Mode 2	CG	MG	FG	Gr	VCS	CS	MS	FS	VFS	Gravel	Sand	Mud	Folk (1974) class					
1a	-0.4	-0.5	1.7	PS	-0.10	NS	0.96	MK	0.0	0.7	9.3	8.9	18.9	22.1	19.2	16.5	3.6	0.5	37.8	61.9	0.3	sG			
1b	-0.2	-0.4	1.8	PS	-0.14	NS	0.92	MK	-2.0	1.0	0.0	10.0	8.6	17.4	18.3	20.3	18.8	5.3	0.9	36.1	63.6	0.4	sG		
2a	-1.3	-1.6	1.3	PS	-0.40	SCS	0.68	PK	-2.0	0.0	3.6	16.4	18.4	25.6	25.2	10.0	0.6	0.0	0.0	64.1	35.9	0.0	sG		
2b	-2	-2.0	1.2	PS	0.04	NS	0.84	PK	-2.0	0.0	0.0	24.0	25.8	27.4	19.0	3.6	0.1	0.0	0.0	77.2	22.8	0.0	sG		
3a	-1	-1.0	2.1	VPS	0.08	NS	0.89	PK	-2.0	0.0	3.8	14.2	15.3	16.4	16.6	14.5	9.5	5.7	3.5	49.7	49.9	0.4	sG		
3b	-1.8	-1.3	2.1	VPS	0.33	SFS	0.78	PK	-2.0	0.0	10.8	19.2	17.9	12.8	11.9	10.2	7.3	4.3	3.0	60.7	36.7	2.6	sG		
4a	0.5	0.4	0.9	MoS	-0.02	NS	1.69	VLK	1.0	0.0	0.0	1.0	2.1	1.2	14.9	58.5	14.4	7.0	0.7	4.3	95.6	0.1	(g)S		
4b	0.6	0.6	0.8	MoS	0.13	FS	1.38	LK	1.0	0.0	0.0	0.0	0.8	0.6	10.4	61.7	16.9	8.7	0.8	1.4	98.5	0.1	(g)S		
5a	0.7	0.7	1.3	PS	-0.25	CS	1.58	VLK	-2.0	1.0	1.1	3.9	5.7	2.1	9.4	42.5	27.7	7.0	0.4	12.8	87.1	0.1	gS		
5b	0.6	0.6	1.2	PS	-0.21	CS	1.74	VLK	-2.0	1.0	0.0	5.0	5.6	1.9	8.3	49.7	23.9	5.4	0.2	12.5	87.5	0.0	gS		
6a	-0.2	-0.8	2.2	VPS	-0.34	SCS	0.66	VPK	-2.0	2.0	10.6	11.4	11.7	9.0	9.8	17.5	26.9	2.9	0.2	42.7	57.3	0.0	sG		
6b	-3	-2.2	2.4	VPS	0.44	SFS	0.58	VPK	-4.0	2.0	36.4	11.6	12.1	5.8	6.4	10.8	14.8	2.0	0.1	66.0	34.0	0.0	sG		

Sorting: VPS very poorly sorted, PS poorly sorted, MoS moderately sorted, WS well sorted, VWS very well sorted. Skewness: SFS strongly fine skewed, FS fine skewed, S symmetric, CS coarse skewed, SCS very coarse skewed. Kurtosis: VPK very platykurtic, PK platykurtic, MK mesokurtic, LK leptokurtic, VLK very leptokurtic. CG coarse gravel, MG medium gravel, FG fine gravel, VCS very coarse sand, MS medium sand, VFS very fine sand, sG: sandy gravel, gS gravelly sand; (g)S slightly gravelly sand; FS% fine skewed; CS% coarse skewed

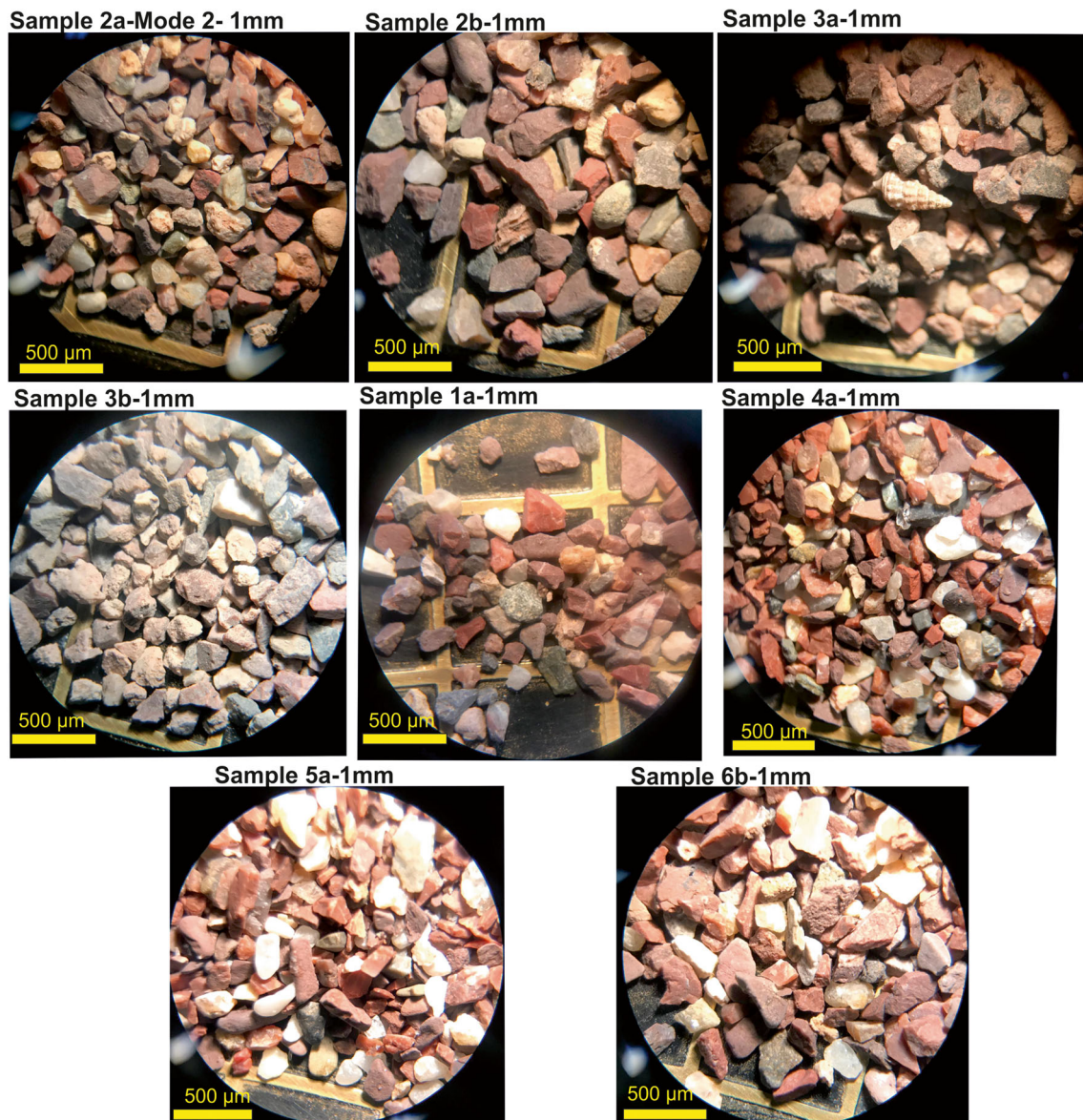


Fig. 8 Micro-views of the selected samples in a grain size 1 mm

sediment input to the spit (Ekinci and Doğaner 2016). A range of 20–50-cm seawater cover on the spit due to spreading sediments by touristic walking especially during the summer time was reported by Atabey (2002). The local divers stated that 50 cm–1 m below the sea surface, thick unconsolidated sediments and rocky (possibly older rocks of limestone and volcanics) surface were detected. The limited sediment accumulation may develop due to structural distribution of the rocky surface at the base. This thin sediment accumulation of the Kızkumu Spit requires very urgent protective measures.

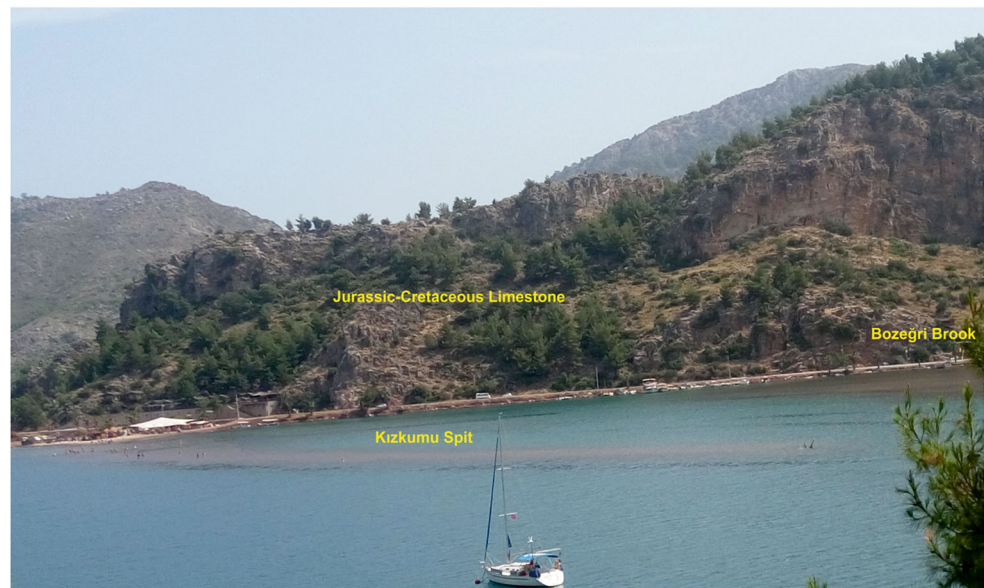
Google Earth image shows that there is no sediment activity through the Kocapınar Stream Delta to prevent longshore currents after the marina construction (Fig. 5). In addition, small docks or breakwaters (at least five) prevent the sediment movement. Depending on the change in the wave direction, southern parts of the breakwaters are under the effects of the

coastal erosion; northern parts act as sediment accumulation area. Dashed line of the red-coloured mobile sediment boundary is observed very close to breakwater; therefore, sediment input to the Kızkumu Spit has probably been cut via breakwaters (Fig. 5b).

Ekinci and Doğaner (2016) defined that the marina (Fig. 5c) and docks create important obstacles for the longshore currents and sediment transportation to the spit. It is also suggested by the same studies that the destruction of Poseidon type seaweed and marina on the sediment transportation way create pressure on spit development. Kumara et al. (2010) also pointed the importance of the sediment source land-based factors for spit development.

Anthropogenic activities including construction (piers-marina-breakwater, hotel), tourism activities (boat, walking etc.) together with the longshore currents and the sediment input

Fig. 9 Photograph showing the general view of the Kızkumu Spit, Jurassic-Cretaceous limestone and Bozeğri Brook



control the evolution of the Kızkumu Spit. Ekinci and Doğaner (2016) and Atabey (2002) offered some preservation methods including new tourism activities, limiting the number of visitors and coastal construction. However, additional precautions must be taken into consideration along the longshore current and also drainage area of the Kocapınar and Bozeğri Streams. The coast and the drainage area that hinder the sediment transportation must be prevented. Sustainability of the sediment supply from both directions has vital importance for the long duration of the Kızkumu spit. Possible sea level rises due to global warming (IPCC 2014) may also threaten this region. Additional sea level risings increase the water body thickness on the spit, hence the spit may totally be under water. Therefore, the areal distribution of the Kızkumu Spit, especially the sediment dispersal, must be monitored; if necessary, sand dispersion preventive methods (fence, net etc.) should be applied.

SW Anatolia mainly includes rocky coasts due to the tectonic development and the lithology of the host rock (e.g. Gül et al. 2017, 2019b). Western part of Turkey hosts some important spit evolutions such as in Çanakkale (Kazancı 2013), Büyük Menderes River Mouth (Erol 1996, 1997), Ölüdeniz, Dalaman, Güllük, Sasalı, Aliğa and Dikili determined from Google Earth images. Two spits have been well documented in Muğla coast: the İztuzu Spit (Maktav et al. 1996; Brückner 1997; Gül et al. 2019a) and Kızkumu Spit (Atabey 2002; Ekinci and Doğaner 2016). Special environmental conditions including river mouth, sediment input, wave-wind directions and long shore currents were all responsible for their formation (Maktav et al. 1996; Brückner 1997; Atabey 2002; Ekinci and Doğaner 2016; Gül et al. 2019a). Main beach of the İztuzu Spit is around 56 ha, and mainly includes well-sorted sand size sediments with benthic foraminifera and ostracod fossil shell on the surface (Maktav et al. 1996; Gül et al. 2019a). The

open edge of İztuzu Spit is limited by the Dalyan River Mouth, and this spit also acts as a breeding area for the loggerehead-*Caretta caretta* turtle (Maktav et al. 1996). Moreover, the İztuzu Spit has been affected by the human interactions due to improper pier constructions (Gül et al. 2019a). The Kızkumu Spit only covers 0.92 ha, and mainly includes coarser gravel-sized sediments, and open edge limited by the sea. The historical relation of the Kızkumu spit is increasing the attraction of the region. The direct human impact on the Kızkumu Spit is stronger than the İztuzu Spit. In addition, location of the Kızkumu Spit may have been controlled by the bottom topography, and its evolution requires more specific combination of wave-wind action, sediment input and longshore current.

Spit areas are among the most spectacular landscapes around the world (Povilanskas et al. 2016) with unique morphologies and complex evolution patterns. These unique landforms are very sensitive to the environmental conditions; therefore, any change in the natural processes as well as the human interventions could possibly deteriorate this delicate environment. If the landform is very restricted in a narrow zone like the Kızkumu Spit, it is inevitable to lose it forever.

Conclusion

The Kızkumu Spit is one of the unique spits of SW Turkey with its attractive historical story and environmental beauty. This small spit is only 400 m long and 18–48 wide.

- The Kızkumu Spit has been formed by the two river sediments transported by the longshore currents. In addition, bottom topography, wave and wind actions control the spit formation.

- Furthermore, large (marina) and small (breakwater) coastal structures prevent the excess wave effects and change the direction of waves and longshore currents. Thus, disintegration of the deltaic sediments is decreasing. Small-scaled coastal erosions were also detected in one side of these structures, while the sediments were entrapped on the other side of the spit. Therefore, the amount of the sediments flowing towards the Kızkumu is reduced.
- Excess tourism activities (including walking on the spit, marine vehicle usages) cause the dispersion of sediment on the Kızkumu Spit. The marine water depth (recently varies between 20 and 50 cm) on the spit is increasing; therefore, wave action is enhancing. This situation leads winnowing of the fine-grained sediments and accumulation of much coarser sediments on the spit. These inter-supporting processes accelerate inevitable adverse effects on the evolution of the spit.
- If the conservation pathway is not drawn soon, this unique geological formation could be irreversibly damaged and the spit formation might be totally lost. Extinction of such a peculiar geoheritage may threaten the local summer tourism and the socio-economical life of the region.

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