http://www.moderntechno.de/index.php/meit/article/view/ge3-023
DOI: 10.30890/2567-5273.2018-03-01-023

УДК: 556.54:627.4+528

SHORELINE CHANGES IN THE CASPIAN SEA SOUTHERN COAST
ИЗМЕНЕНИЯ БЕРЕГОВОЙ ЛИНИИ НА ЮЖНОМ ПОБЕРЕЖЬЕ КАСПИЙСКОГО МОРЯ

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Abstract. *The natural conditions of the southern coast of the Caspian Sea that affect the changes in the shoreline of the territory between the mouth areas of the Kharaz and Neka rivers are considered. The main attention is paid to fluctuations in sea level in recent decades, sea currents and sediment transport along the coast, as well as intensification of economic activity. With the use of the cartographic service "Google Earth", the parameters of the changes in the shoreline for the period 2004-2017, which influence the prospects for the development of this territory, have been determined approximately.*

Keywords: *coastline, the Caspian Sea, cartographic service.*

Introduction. The regulation of the river flow by reservoirs and the increasing use of water in the economy cause a reduction in the inflow of water and sediment into the mouth of the rivers**.** And this serves as a powerful factor in changing the water regime of delta landscapes and, in general, the hydrological and morphological processes in them [7, 14]. As a result, the interaction of deltaic landscapes and water masses of seas, into which these rivers flow, changes [15]. Such interaction takes on special features in the mouths of the rivers of the Caspian Sea, the level of which is dramatically changing [5], especially in recent decades [9].

The subject and method of research. The basin of the Caspian Sea is a vast drainless depression. The largest river in Europe, the Volga, as well as numerous large and small rivers, among which the largest (in terms of runoff) are the Kura, the Ural, Terek, Sulak, flows into this sea. With a large meridional length of the sea basin, the natural conditions in it are diverse - from a moderate climatic belt in the north to a subtropical one - on the southern coast, where the study area is located (Fig.1). This area is geomorphologically a relatively narrow coastal plain between the Alborz mountain ridge and the sea, reformed by the Caspian transgressions and fluvial deposits of the local Kharaz, Babol, Talar, Tajan, Neka rivers and temporary streams (Fig. 3). Small rivers, flowing from the southern slopes of the Iranian coast, usually have simple mouths, sensitive to the impact of natural and anthropogenic factors [16]. Sometimes they form ephemeral deltas, destroyed later by waves and alongshore currents. The territory of the Sefidrud and Gorgan deltas, as well as the narrow seaside strip between the rivers Sefidrud and Kharaz in this article is not considered. Of the total catchment area of the Caspian Sea rivers basin, 3.05 million km^2, including the catchments of rivers, of which water does not now flow into the sea [3, 9], the area of basins of Iranian rivers ranges from 166,800 km^2 [5] to 185 thousand km^2 [6, 16]. At the same time, the largest areas fall just on the Sefidrud

(75.2 thousand km^2) and Atrek basins - (35.7 thousand km^2), and the area of river basins between Sefidrud and Atrek is only 48.9 thousand km^2 [1]. The total water flow to the Caspian Sea is estimated in the range of 268-332 km^3 / year [9], and on average for the 20th century - about 300 km^3 / year. For a more modern period (1978-2008), the runoff of all the basin rivers was 308 km^3 / year [8]. The natural flow of water from the Iranian rivers (Fig. 1, Table 1) to the Caspian Sea is estimated at 16.6 km^3 / year, and modern - at 10.4 km^3 / year, that is, the reduction of runoff under the influence of economic activity exceeds 6 km^3 / year. The sediment flow in the beginning of the 21st century is estimated at more than 40 million tons per year [2, 6, 16, 17].

Most of the Iranian rivers are regulated by reservoirs, including those flowing into the explored territory of the Kharaz, Tajan, and Gorgan rivers. At the same time, the construction of new reservoirs continues. In the river basins of this region there are also many small earth dams known as "sals" [13, 16, 18]. The coastal plain north of the Elburs mountain range is densely populated, agriculture is developed here, with cultivation rice, cotton, vegetables under irrigation. The average air temperature here in winter is above 0°C, in summer - more than 24°C, and the amount of precipitation is about 1000 mm. The loss of rivers water flow to irrigation accounts for about 40% of all runoff losses. For the same reason, the sediment runoff decreases by 10-40% [6, 9]. These deposits accumulate in reservoirs and in fields and, accordingly, do not enter the estuarine areas of rivers and do not take part in the interaction of landscapes and water masses of the sea as one of the most important factors in the coastal plain formation. On the other hand, the state of its landscapes is influenced by currents in the sea, wave action, wind-surges. But the greatest influence of the sea is determined by long-term fluctuations in the level of the Caspian Sea.

The direction and speed of the wind over the sea is very variable in space and time. In winter and autumn, the north and north-east winds prevail in the southern part of the sea, and in the spring and summer the frequency of south-eastern directions increases [9]. The general features of the currents in the sea, according to [10-12, 17], are shown in Fig.2. They show that along the southern coast predominate flows, which transport sediment from west to east. An example of such a transfer of suspended sediments along the entire southern coast is visible on the Terra satellite image for June 10, 2015.

Table 1.

Characteristics of the rivers of the southeastern coast [2]

River	Length, km	Area of the basin, thousand km^2	Flow	
			Water, km^3 / year	Suspended sediment, million tons / year
Kharaz	185	4,10	1,07	2,37
Talar	150	2,85	0,32	1,12
Babol	170	1,50	0,49	0,44
Tajan	192	4,00	0,42	0,38
Neca	180	3,00	0,15	0,42
Gorganrud	350	12,6	0,41	3,08

Among the main factors affecting the dynamics of the shores include wave action in the conditions of the non-tidal Caspian Sea [9]. It is the wave action that destroys the banks of the deltas and involves the products of erosion in the longshore sediment flows. The height of the waves near the deep southern coast can reach 10-11 m, decreasing to the more shallow south-west coastline [4].

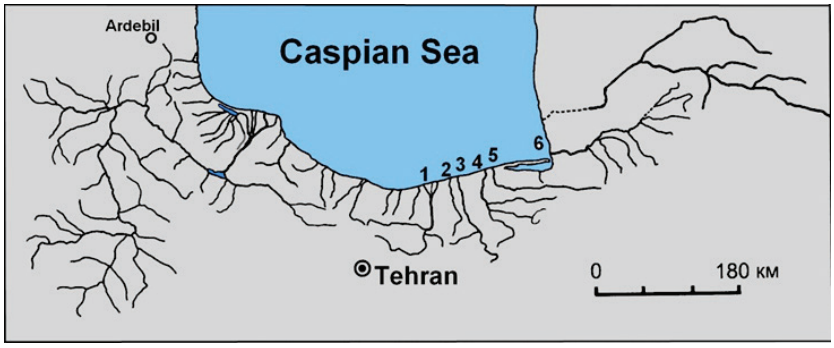

Fig.1. The rivers of the region are: *1 - Kharaz, 2 - Talar, 3 - Babol, 4 - Tajan, 5 - Neka, 6 - Gorganrud [9]*

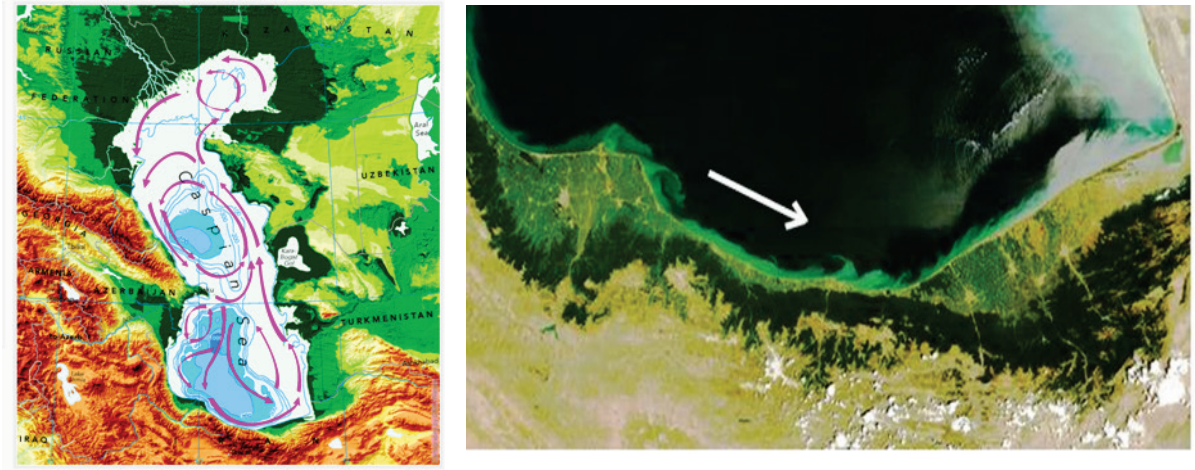

Fig.2. Direction of currents in the Caspian Sea [15] (left) and sediment transport along the southern coast (Terra, 10.06.2015)

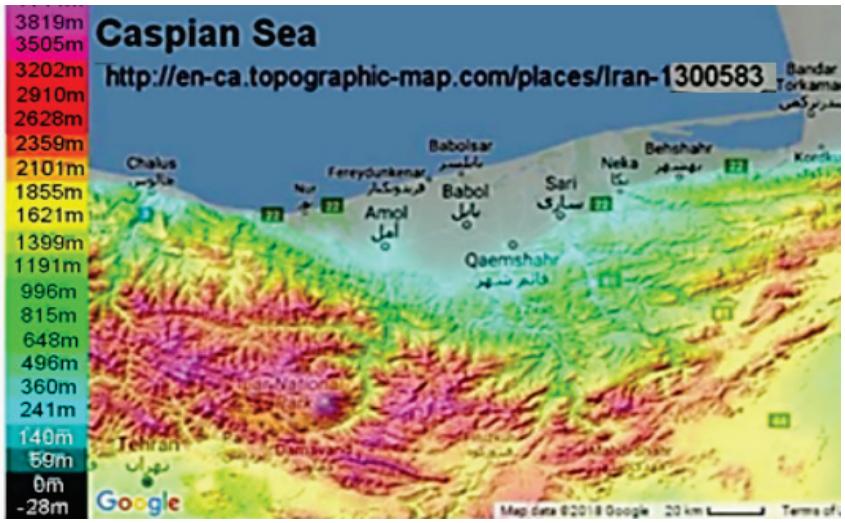

Fig.3. Relief of the southern coast of the Caspian Sea

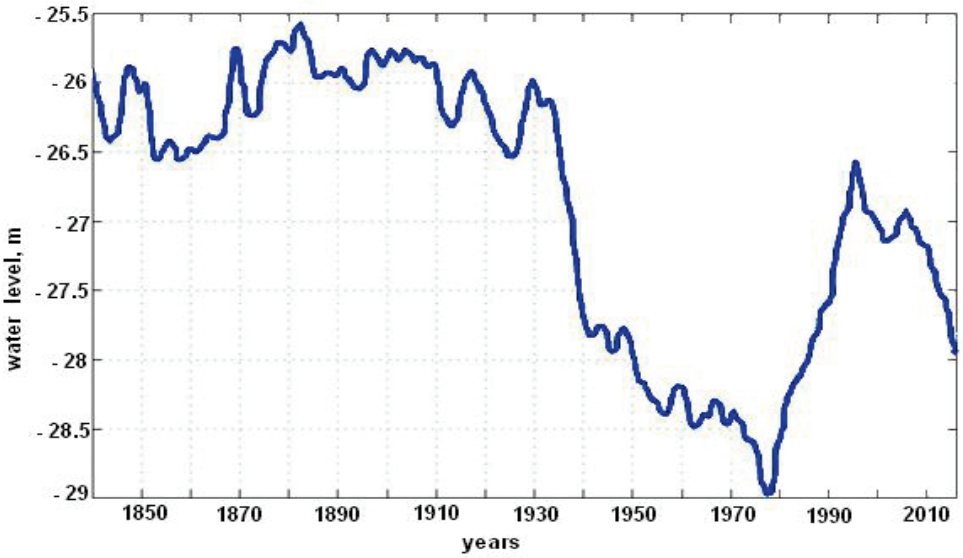

Fig.4. Fluctuations in the water level in the Caspian Sea [10]

An important factor in impact the reformation of the coastal plain shores is also the wind-surges phenomena. On the relatively deep coast of the Southern Caspian, these phenomena are incomparably weaker than in the shallow northern part of the sea. Usually they do not exceed 0.5 m. And, of course, the greatest impact on the coast is caused by fluctuations in sea level in the long-term aspect. As is known, in the period from 1930 to 1977 there was a fairly rapid decrease in the level of the Caspian Sea by more than 3 m [10].

During this period there was an intensive development of the coastal plain, the development of infrastructure, the construction of industrial enterprises and housing. And from 1978 to 1995 there was an increase in the average annual sea level of 2 m 35 cm, although by this time the withdrawal of the runoff for household needs, which began in the first half of the last century, increased. And this required active protection of the coast from flooding, wave activity and alongshore currents, which is clearly visible on large-scale maps of Google Earth and in Fig. 5. Over the next 20 years [10], the level of the Caspian Sea decreased again (Fig.4), revealing a beach stony-sandy strip extending eastward (towards the Khalij-e Gorgan Bay), where sand deposits prevail.

The methodology for assessing changes in the shoreline of the southern coast of the Caspian Sea provides the use of data from the cartographic service "Google Earth". Mapping maps for different dates using the so-called "historical ruler" ("image in time") allows us to determine the change in the parameters of the object under study for different years (from the existing database of this cartographic service). Naturally, the obtained data are approximate because of inaccuracies in reading the indications of the cartographic service at different scales of the maps. In addition, in the databases of the "Google Earth" service there are cartographic materials for different years for different parts of the investigated objects, which also reduce the accuracy of determining the spatial changes of the object.

Fig.5. Types of southern coast:

1 – Western part
https://lh5.googleusercontent.com/p/AF1QipPtdeTcFAGDT6LUOn15ca6454hfy3yCqh1oLBoH=rp,
2 - the middle part
https://lh6.googleusercontent.com/proxy/1Gfw6zYtsUy2hPcbrWBhPXYAQTXl7PiKFpCQzFrLEp00365YWKMxLz2zBW6Xs-jgB1orqJ5rPPkZmB8kbMkDo5vO1xldehc=rp,
3 - eastern part
https://cdn2.360cities.net/pano/mohammadreza/00362554_1And2more-tonemapped-Panorama4-5-jpg/mercetor/4.jpg
4 - protection of port facilities
https://cdn2.360cities.net/pano/mohammadreza/00362554_ 1And2more-tonemapped-Panorama4-5-jpg/mercetor/4.jpg

Fig.6. Points of measurement of the dynamics of the shoreline

Results and discussion. Considering the considerable length of the investigated part of the southern coast, which is more than 180 km from the town of Nur in the west to the town of Bandar-Torkemane in the east, 7 points of changes observation in the shoreline were selected (Fig. 6). At the same time it was taken into account the nature of the relief - the reduction of the territory in the eastern direction. The initial years of measurements were chosen from the available information on the mapping

service "Google Earth" (from 2004 to 2011), and the deadline - 2017 (except point 7, where the information was available only for 2016). The estimation of changes in the shoreline of the coastal plain with a decrease in sea level over the indicated period is shown in Table 2, according to the "historical ruler" ("image in time") of the Google Earth service.

Table 2.

Changing the shoreline according to Google Earth, m

Measurement point number	Years of measurement	Distance from the reference frame, m	Change in coastline, m	The rate of change, m / year
1	2017/2011	277/255	+ 22	3,7
2	2017/2007	232/231	+ 1	0,1
3	2017/2007	723/712	+ 11	1,1
4	2017/2006	709/643	+ 66	6,0
5	2017/2004	442/305	+ 137	10,5
6	2017/2004	1282/1212	+ 70	5,4
7	2016/2004	1654/1575	+ 121	10,1

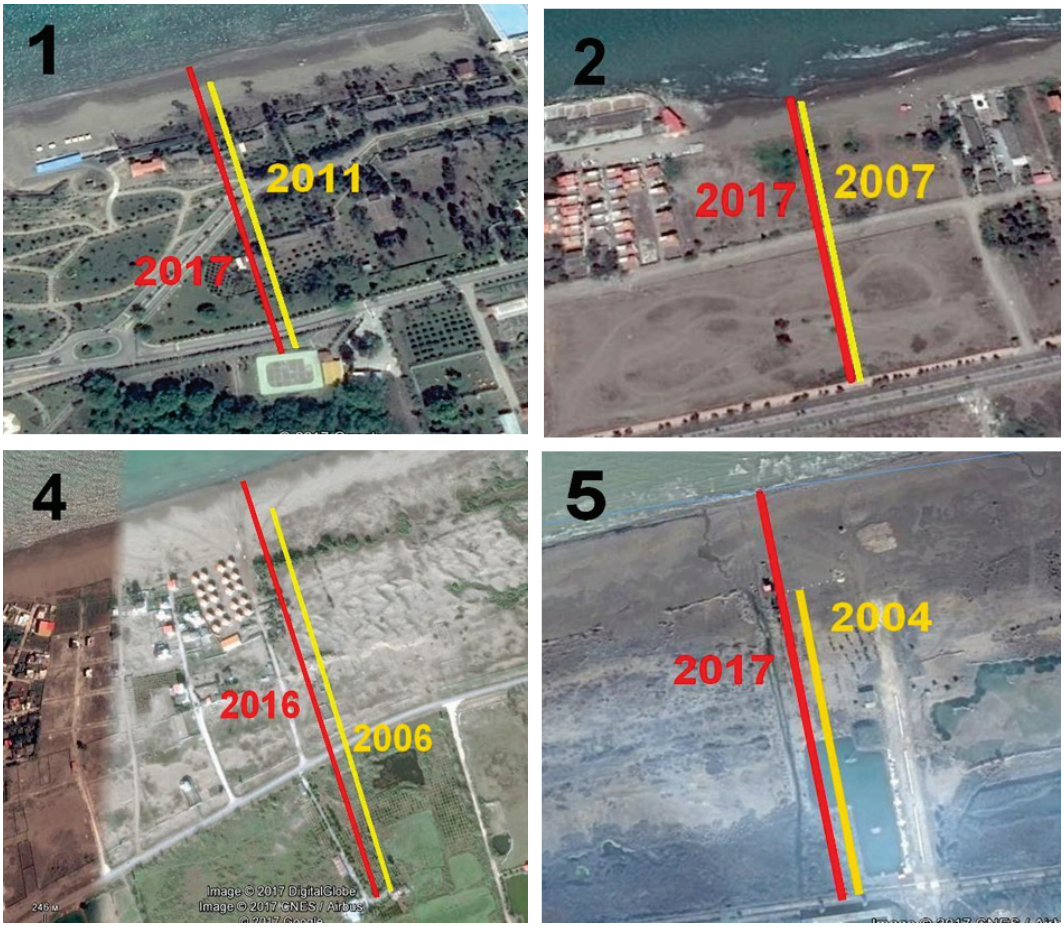

Fig.7. Examples of deviation of the coastline in points 1,2,4,5.

The most characteristic points (1, 2, 4, 5), reflecting different values of the coastline deviation of the southern coast, are shown in Fig.7. On the whole, the obtained data show (despite their approximate value) that the rate of sea retreat in the

western part of this territory was from 0.1 to 3.7 m / year, and in the east - from 5.4 to 10.5 m / year. In the lowest part of the coast (point 5) the sea retreated by 137 m during the period 2004-2017. Over a longer period, reflecting the phase of the greatest decline in sea level (1978) and its maximum rise (1995), an assessment of the changes in the shoreline will be made based on Landsat satellite images.

The conclusion. Changes in the shoreline of the southern coast of the Caspian Sea in the area between the estuarine areas of the Kharaz and Neka rivers in recent decades are caused by fluctuations in its level, intense wave activity, alongshore currents transporting sediments mainly from west to east, as well as by active economic activity**.** The regulation of the rivers flow by reservoirs and the withdrawal of water for irrigation and water supply led to a decrease in the flow of water and sediment to the mouths of local rivers and to an increase in the erosion of shores by the sea in unprotected areas**.** At the same time, measures to protect the shores, especially in the western and central parts of this territory, intensive construction of infrastructure facilities, expansion of settlements and development of the coast for economic activities contributes to the weakening of erosion processes. Analysis of changes in the shoreline in the phase of sea level reduction is performed according to the mapping service "Google Earth" for the period 2004-2017. According to these data, the sea retreated in the area to a distance of one meter in the western part of this territory to 137 m in the east. At the same time, the sea retreat rate was 0.1 to 10.5 m per year.

Acknowledgment: This study was made possible in part by NASA's Land Cover and Land Use Change (LCLUC) Program (Grant # NNX15AK66G).

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Аннотация. *Рассмотрены природные условия южного побережья Каспийского моря, которые влияют на изменения береговой линии на участке между устьями рек Хараз и Нека. Основное внимание уделено изменениям уровня моря за последние десятилетия, морским течениям, вдольбереговому движению наносов, а также интенсификации хозяйственной деятельности. С использованием картографического сервиса «Планета Земля» приближенно определены изменения береговой линии за период 2004-2017 гг., которые влияют на перспективы развития этой территории.*

Ключевые слова: *береговая линия, Каспийское море, картографический сервис «Планета Земля».*