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Gorgan Bay environmental consequences due to the Caspian Sea rapid water level change

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ABSTRACT
The rapid Caspian Sea level fluctuations have caused unstable conditions for coastal areas during the 20st and 21st centuries, and have led to significant losses for economical and social infrastructure. The main objective of this study was to assess the impact of the Caspian Sea level fluctuations on the environment of the Gorgan Bay coasts, which is a large, shallow inlet at the extreme south-east corner of the Caspian Sea. So that, studying required documentations have made it possible to become acquainted with the geographical, geological and environmental conditions of Gorgan Bay. The morphological conditions of coastal lines and diversity of coastal habitats were also assessed in field observations. The geometric structure of coast, their sediment types and the physicochemical properties of soils belonging to coastal habitats were evaluated by determining three transects and nine study sites in the spring and summer 2017. Changes in the coastline of Gorgan Bay were also processed using Land-Sat satellite imagery from 1977, 1995 and 2017. The results exhibited that the environmental vulnerability of the Gorgan Bay coasts depends on the morphological conditions of coastal habitats and alterations in the Caspian Sea level. So that, the plant and animal communities located in the most end of western part of the Gorgan Bay have faced serious challenges during the current century due to the decrease in the Caspian Sea level. Connecting canals between the Bay and Sea will also lose their discharge capacity and the Gorgan Bay will completely be dried up due to this decline. Emergence of large mudflats with sedimentary composition of sandy silt, which has created a very good potential for occurrence of haze, and also replacing the drought ecosystem, instead of the aquatic one, are other environmental events which are expanding vastly in the coastal areas of the Gorgan Bay.

Key words: Caspian Sea, Coasts, Environment, Fluctuations, Gorgan Bay, Morphology.

INTRODUCTION
The Caspian Sea, as the world's largest closed lake, is very important in terms of water level fluctuations. The rate of changes in its water level is usually one hundred times more than the oceanic water fluctuations and sometimes this process is evident by comparing it with the ocean basins (Khoshravan & Vafaee 2016). The rapid reduction of the Caspian Sea level during 1930-1978, by 3 meters caused serious environmental challenges in its marginal areas such as the gulfs, some important islands and deltas, and the delta of Volga River (Kosarev & Kostianoy 2005). Furthermore, raised Caspian Sea level during 1978-1995, approximately 2.5 meters, caused flood and also destroyed and eroded large part of coastal areas (Kroonenberg *et al*. 2000) directly affecting the environmental conditions of the coastal areas. Gorgan Bay is an extremely important environmental area and has been considered as one of the nine Iranian biosphere reserves included in Ramsar Wetland Sites of Iran (Convention in 1975).

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Its area has 23 special habitats occupied by coastal-marine organisms in the form of single and multi-species communities (Nori-Balanji *et al.* 2012).

Many permanent and seasonal rivers from the southern and eastern parts of northern slopes of the Alborz Mountains, lead to the Gorgan Bay, of those, Gharesoo and Gorganrood, with an average annual discharge of half a billion cubic meters and sediment volume of 3.5 million tons per year, are the most important ones (Afshin 2004). The sediments of Gorgan Bay coasts are in the range of sand to clay in terms of aggregation. So that, at the mouth of Gorgan Bay, the sand ratio in sediments tend to be increased.

The average amounts of calcium carbonate and organic matter are 93% and 90%, respectively. In the Gulf of Gorgan, by decreasing the slope, the organic matter content is reduced, while calcium carbonate elevates (Lahijani *et al*. 2010). The hydrogeochemical study on the Gorgan Bay exhibited that the water flow entering from the Caspian Sea into the bay is very important in the chemical properties of water and sediment, while the impact of rivers in this case is negligible (Bashari 2014). The Gorgan Bay water compositions are in the range of the Sea water in terms of total dissolved solids (TDS) and also the main cations and anions ratio (Bashari 2014). Comparing the chemical compositions of river water with those of Gorgan Bay in the piper diagram displayed that the total ions dissolved in the bay are influenced by the Sea flow, but not by the rivers (Bashari 2014). The environment of Gorgan Bay is influenced by the Sea, adjacent rivers and the peninsula of Miankaleh. Gorgan Bay and Miankaleh Peninsula as well as Lapoo-Zaghmarz were registered as the Biosphere Reserves and the first international wetland complex respectively in the list of wetlands of international importance (the "Ramsar List" in 1975). In the division of wetlands in the Ramsar Convention (1975), Miankaleh Wetland and Gorgan Bay are classified as type “A”, i.e., permanent shallow waters. The diversity of macro fauna in Gorgan Bay was reported to be very low, and Annelida was the most frequent aquatic animal group (Taheri *et al.* 2012), reflecting the very high ecological value of the bay. Many studies have focused on the role of the Caspian Sea level fluctuations on the morphological formation of Gorgan Bay and Miankaleh Island. Abdollahi-Kakroodi *et al.* (2012) have studied the sediments in the coastal areas around the southeastern part of Gorgan Bay in the Bakho Kenareh region, concluding that the bay was still not formed, during the recent widespread expanding of the Caspian Sea, 2600 years ago (at the end of the Holocene) at altitude of -22 m. Furthermore, elevating the Caspian Sea water during the Little Ice Age led to the formation of a sedimentary terrace at -24 m below sea level in the peninsula of Miankaleh, and subsequently emerging Gorgan Bay (Khoshravan 2011; & Abdollahi-Kakroodi *et al*. 2012). Comparing the chemical composition of surface sediments with older ones in Gorgan Bay has displayed that they are more influenced by sediment yields due to the erosion of the catchment area of rivers leading to the Bay (Lahijani *et al*. 2010) and also the bay sediments are considered as intermediate carbonate and destructive environments. Furthermore, the rivers leading to the bay and deposits entering from the Caspian Sea play an important role in the provision of its sedimentary materials. Studies on the Gorgan Bay sediment chronology by Amini (2012) revealed that the sedimentation rate in the bay was on average 2.5 mm per year, during the Holocene period (10,000 years ago) up to now, and increased from east to west in Gorgan Bay. The results of studies conducted by the Iranian Ports and Maritime Organization in 2014 indicated that during the storms, the storm surge would increase the flow rate of the Caspian Sea into Gorgan Bay at the location of the Ashooradeh and Chopoghli channels.

The results of parallel calibration studies in the Caspian Sea and Gorgan Bay have exhibited that in the storm events, the water flows from the sea into the bay and a large amount of the sea water enters the bay in a short time (Ports & Maritime Organization 2014). The results of simulation studies on the drying process of Gorgan Bay under fluctuating scenarios with a decay rate of 5 cm per year display that the main waterway of the bay with the sea will be completely blocked by 2023, so that, the Chopoghli and Ashooradeh channels will no longer be able to supply water to the bay (Sharbati & Ghanghermeh 2015). Hydrological studies exhibited that the average annual rainfall in Gorgan Bay is about 500 mm per year, while the average annual evaporation rate is 1500 mm. Therefore, without considering the discharge of the inflowing rivers, the bay level is reduced by 1 meter per year, hence by blocking the waterways, the bay will completely be dried up within three years (Ports & Maritime Organization 2014). The satellite images revealed that the water exchange volume between the bay and the sea is adjusted based on the sea level. Thus, once the sea level was lower than 28 m, the connection between the bay and the sea was completely cut off, while once the sea level was above 26 m, the Khoozini channel was united to the other connecting channels and water exchanges increased (Nazarali *et al*. 2014).

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Gorgan Bay, along with Miankaleh Peninsula, is one of the ten Iranian national reserves that has been studied ecologically for many occasions (Ejtehadi *et al*. 2003; Shokri *et al*. 2004; Ejtehadi *et al*. 2005; Asri *et al*. 2007; Sharifnia *et al*. 2007; Tamartash *et al*. 2009; Vahedi & Yasari 2011). Taxonomy of the bay vegetation and also describing its main habitats, classifying ecological species groups, assessing the relationship between vegetation diversity and various ecological factors as well as determining the most important environmental parameters affecting their establishment in the coastal area of Miankaleh Peninsula and Ashoordeh channel were reported by Saeidi *et al*. (2014). However, the impact of the Caspian Sea level fluctuations has not yet been studied on the Gorgan coastal environment. Therefore, the main objectives of this study were to assess the relationship between the morphology of coastal areas by defining the most important habitats in the bay and also to assess how its dynamic environment alters due to the fluctuations in the surface level of the Caspian Sea in order to be used for predicting the further circumstances.

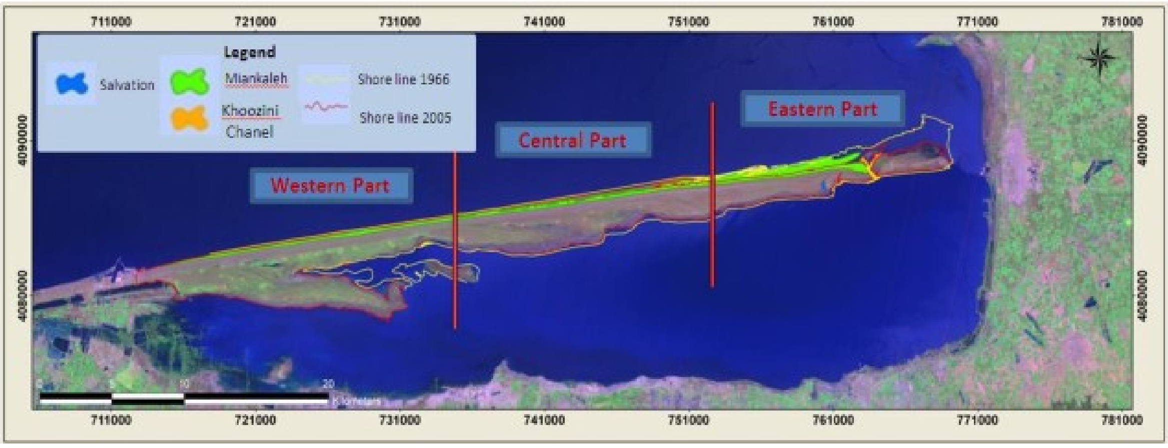

Fig. 1. Classification of the study area in the Gorgan Bay.

MATERIALS AND METHODS

The Gulf of Gorgan, also known as Gorgan Bay, is the largest bay in the Caspian Sea. It is located at the south-eastern coasts of the sea beside Gorgan City in Iran (36°48′- 36°55′ N, 53°25′- 54°02′E). The bay is 54 km in length, about 12 km in maximum width, 360 km^2 in surface area and 2.5 m in maximum depth (Ports & Maritime Organization 2014). It is separated from the Caspian Sea by the Miankaleh spit linking to the sea by the Chopoghli and Ashooradeh connection channels at the most northeast (Fig. 1). Its catchment area is about 15,000 Km^2 and includes mountainous, piedmont and coastal plain areas (Lahijani *et al*. 2010). The study area includes a collection of valuable ecosystems and vulnerable habitats as well as beautiful landscapes and natural tourist attractions.

In this study, the natural, environmental and morphological conditions of Gorgan Bay have been investigated by collecting new data from literature since 1978. Then, the most important morphological features were identified along with important coastal ecosystems by conducting field observations around the coastal areas of the bay. By dividing the study area into three parts including eastern, central and western ones, and by selecting three transects, geometric structure of the coast, coastal sediments, their habitats and the length of the vegetation area were sampled and evaluated (Fig. 1). A total of nine distinct coastal habitats were identified. Soil samples were collected from a depth of 20 cm and their physicochemical characteristics were analyzed in the Research Laboratory of Water and Soil (Babol, Iran). Soil texture (clay, silt and sand), organic matter and calcium carbonate rates (%), pH and electrical conductivity were determined according to the ISRIC (1986) and Page *et al*. (1982). The most important criteria studied in field operations include: identification of the morphological side effects of coastal areas, the environmental impact of fluctuations in the Caspian Sea water level, the physical response of coastal habitats to the alterations in the bay water level and identification of the most important environmental challenges, which were carried out using assessment of historical aerial photographs and ground observations. Also, satellite images (Land-Sat, TM images) were compared over three periods of 1978, 1995 and 2017 (https://gisgeography.com/usgs-earth-explorer-download-free-landsat-imagery), which coincided with alterations in the sea water level, and the changes in the coastal lines of the bay. In order to

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evaluate the statistical variation of soil properties and other environmental variables, one-way analysis of variance (ANOVA, SPSS software, v.20) was used. The analyses were run both among the transects and different zones. These changes were also examined using the principal component analysis (PCA) technique in the CANOCO 4.5 software.

RESULTS

Assessment of changes in coast lines of Gorgan Bay using satellite images

The results of the comparison of satellite images between 1977 and 1995 and 2017 indicate that from 1995 to 2017, when the Caspian Sea level was reduced by 140 cm, about 20% of the Gorgan Bay was completely dried up (Fig. 2). However, in 1977 compared to 1930 by a 3-meter reduction in the sea level, about 40% of the bay area was completely dried (Fig. 2). The comparison of obtained results from the past aerial photograph interpretations has exhibited that the connective channels of the bay (Khoozini, Ashooradeh & Chopoghli) had completely dried out and lost their functionality in 1978, and the bay reached its minimum level. In other words, the current circumstance was experienced before, but the bay hydrologic condition was reversed during 1978-1995 due to the sea water level increment, hence the Chopoghli and Ashooradeh channels were connected to the sea again at 1986, while Khoozini was again joint to the sea at 1998. It was continued up to 2011, while from 2012 till now, the rapid shrinkage of the sea water level has caused the severe drought of the bay and again the connective functionality of all three waterways have been lost. The evaluation of satellite images in 2016 has illustrated that the vast parts of western area of the bay has been completely dried out, hence the Ashooradeh and Chopoghli channels were fully closed. The Gorgan Bay area is now reduced up to 360 km^2, while it was about 450 km^2, before drought. Therefore, the effect of the Caspian Sea fluctuations on the alterations in the bay water territory confirmed based on the evidence obtained from satellite imagery.

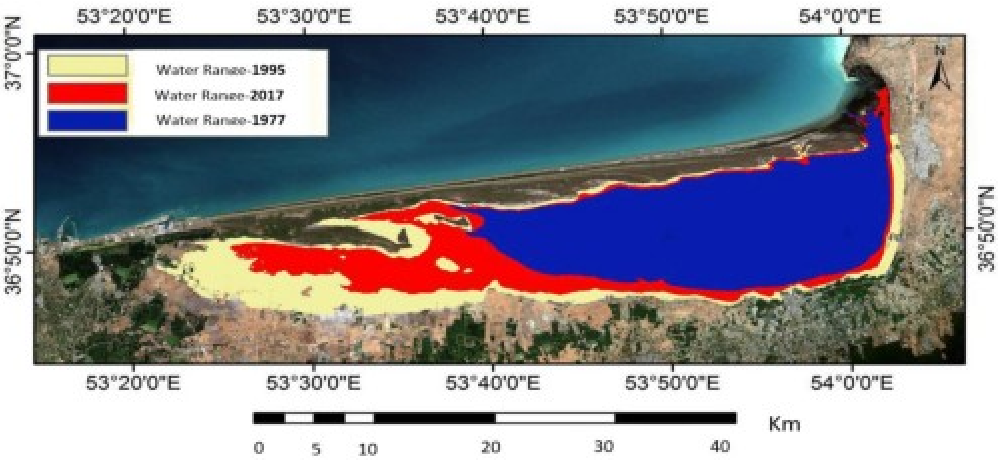

Fig. 2. Comparison of Gorgan Bay area alterations using satellite images google earth.

Coastal habitats around Gorgan Bay

In general, based on field studies and observations on the studied area, following coastal habitats were identified due to the influence of the Caspian Sea level fluctuations which occurred since 1930 (-28 to -26 m):

Mud flats free from vegetation

Mudflats are located near the water withdrawal zone of Gorgan Bay and Miankaleh Wetland (Fig. 3-C). High salinity has caused the dry vegetation not to grow in this area. Its sedimentary deposits include silty clays containing sandy elements and shell of tiny aquatic gastropod. These sedimentary terrains are extended in very low-gradient marginal areas of the bay, and usually the complete drying out of these mud surfaces provides stormy winds with the conditions for the appearance of haze. There are usually remnants of green algae and many halophytes such as *Ruppia maritima*. The characteristics of these zones are pitted organic materials on the coastal dry section.

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***Salicornia* saltmarshes**

Salicornia europaea characterizes mostly as mono dominant in many salt marshes surrounding the bay usually with a short distance from the coastline of Gorgan Bay. The slope of the coastal area is very mild, and the sediment consists of silty sand with clay materials, which are very fine grains (Fig. 3-A), with PH 8.88, and usually in the vicinity, there are shell remnants of mollusks such as gastropod. The electrical conductivity of the soil is 21.2 mho per cm. The other most important dominant species of this habitat are: *Aeluropus lagopoides, Aeluropus littoralis, Frankenia hirsuta, Limonium meyeri and Suaeda heterophylla. S. europaea* with the highest resistance to salinity and flooding is the first vegetative area on the bay coast.

Brackish marsh contains *Juncus*

This brackish marsh biozone is usually located with a specific border alongside toward the dry terraces of the bay's coast, at higher terraces alongside the marsh *Salicornia* (Fig. 3-B). Other most important dominant species of this habitat include *Carex extensa*, *Cyperus odoratus* subsp. *Transcaucasicus*, *Eleocharis caduca* and *Schoenus nigricans*. The sediments of this marsh are of fine to medium grains sands, contain relatively coarse shell of mollusks. Acidity of soil in this area is 8.47 and the electrical conductivity of the soil is 0.79 mho per cm. Usually, this zone has a wide range of width depending on the slope of the coastal area of the bay and it is usually morphologically located with a topographic prominence over the bay's coastline.

Sand farms containing the remnants of *Tamarix*

The *Tamarix* habitat is concentrated in the most end of western part of the northern section of Gorgan Bay. A large part of the natural habitat of this plant index has been eliminated due to the last rise of the Caspian Sea level in 1995, and the remains of the stems and roots of the plant have paved the coastal area to 25 m in width. In the sediments deposited in this habitat, a thin horizon of black soils mixed with sand material is observed (Fig. 3-D). *Tamarix ramosissima* is the dominant species in the group, and is seen as large and small masses in the shrubbery of the *Artemisia scoparia* and *Juncus littoralis.* In these areas, underground water climbs to the surface of the soil and causes salinity of the soil. *Hordeum marinum, Petrorhagia prolifera*, *Centaurium spicatum* and *Tamarix szowitsiana* are other dominant species of this habitat.

***Punica* sand farms**

In this area, the distance from the coastal area decreases the effects of salinity and in also due to rainfall and sweet underground water, special species such as *Punica granatum*، *Rhamnus pallasii* and *Rubus sanctus* grown in this area. *Campanula rapunculus*, *Convolvulus cantabrica*, *Lithospermum officinale* and *Rumex tuberosus* are other dominant species of this habitat. The density and abundance of these plants prevent the erosion of sediments and causes the stabilization of them. Its sedimentary deposits include silty clays with the pH equals to 8.24 and the electrical conductivity is 0.78 mho per cm.

Physical and chemical properties of coastal soils of Gorgan Bay

Comparison of coastal soil texture in terms of percentage of sand, silt and clay particles exhibited that the coastal habitat soils of Gorgan Bay varies between sand, silty sand and loam. In the most end of western part of the bay, in very shallow wetland area, sediments contain 54% sand, 34% silt and 12% clay and are classified as the loam soil group (Table 1).

By increasing the distance from the coast line toward the land, soil aggregation has increased and the sandy matter rate (%) has elevated in the *Salicornia* and *Juncus* plant habitats (Table 1). The soils of the middle part of Gorgan coastline in the *Juncus* brackish habitat contained much more fine-grained granular materials than western part (Fig. 4), and there was a good gradient affinity between the *Juncus* habitat soils of the eastern and western parts of the bay (Fig. 4).

The sandy substances rate (%) of soil for *Punica granatum* and *Tamarix* plants was higher than 75%, while there was a small amount of silt and clay particles in the soil texture (Table 1). Therefore, the coastal soils of the bay in different habitats were divided into three groups including 1) very fine silty grains containing sandy particles, 2) coarse gravel sand containing particles of silt and clay, and 3) sands free of fine grain material (Fig. 4). There is a great deal of adaptation between coastal habitats and the texture of their covering soils.

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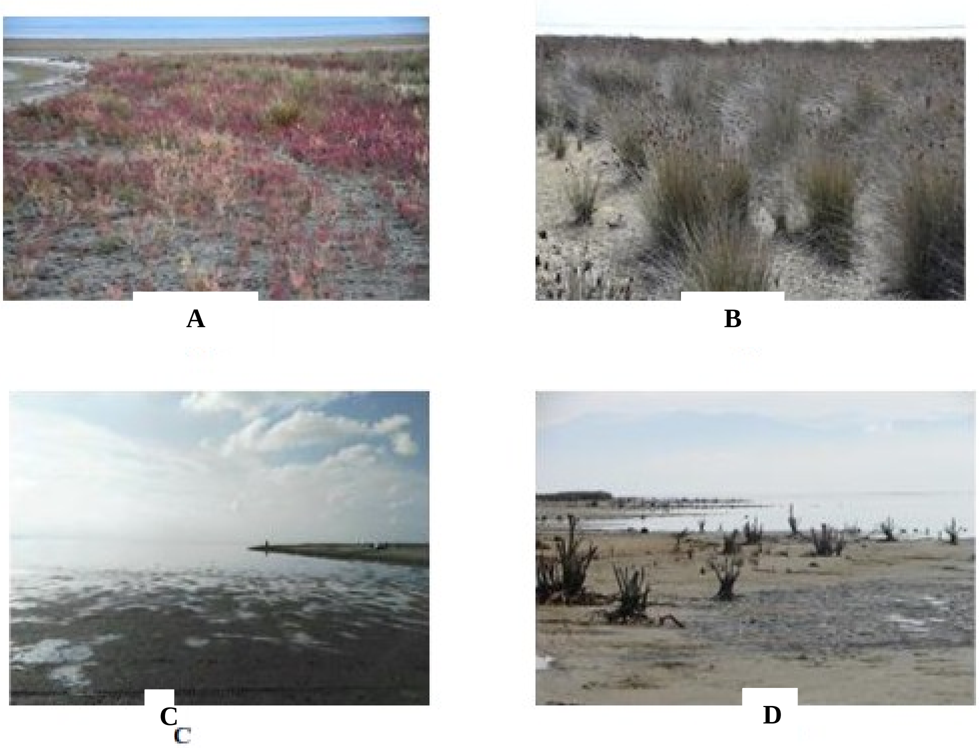

Fig. 3. The most important vegetation habitats of the Gorgan Bay coast.
(A. *Salicornia* Salt marsh, B. *Juncus* Brackish marsh, C. Mud flat, D. *Tamarix* sandstone)

Table 1. Physicochemical characteristics of Gorgan Bay coastal soils.

Calcium carbonate (%)	Electrical conductivity (μmho/cm)	Acidity pH	Organic carbon (%)	Soil type	Clay (%)	Silt (%)	Sand (%)	Station	Sample Lable	Study axis
39	18.24	8.56	1.813	Loam	12	34	54	Wetland	1	Western part
41	22.9	8.58	1.891	Silty sand	16	17	67	Mud flats	2	
45.5	21.2	8.88	0.585	Silty sand	10	3	87	*Salicornia* Saltmarshes	3	
47.5	0.79	8.47	0.37	Sand	6	1	93	Brackish marsh Juncus	4	
42.5	0.78	8.24	2.847	Silty sand	6	14	80	Punica sandstones	5	
47	18.5	8.9	2.281	Silty sand	12	12	76	*Tamarix*sandstones	6	Central Part
44.5	3.04	8.21	3.432	Silty sand	8	14	78	Brackish marsh Juncus	7	
46	17.8	8.59	2.418	Loam	20	46	34	Wetland	8	Eastern part
47	9.3	8.61	0.37	Sand	6	0	94	Juncus sandstones	9	

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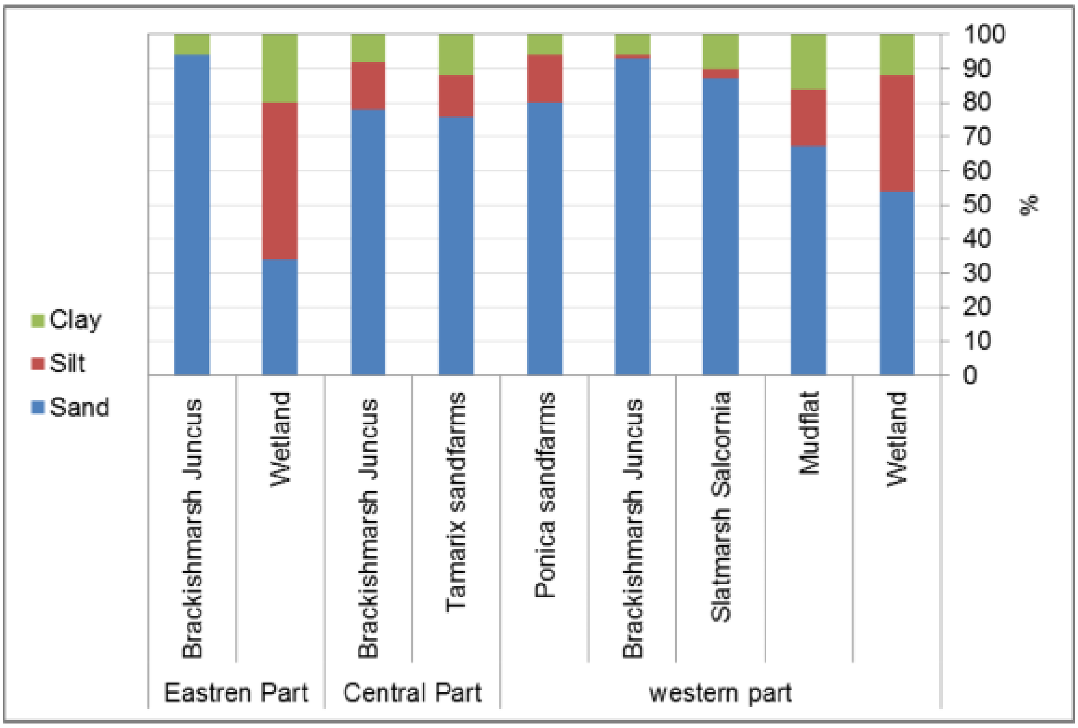

Fig. 4. Soil texture characteristics of Gorgan Bay Coastal.

In the nine coastal habitats of the bay the organic matter contents in sandy soils planted by *Tamarix*, *Punica* and *Juncus* were much higher than in the other soils (Fig. 5). This is a sign of the appropriate time for soil grinding in the abovementioned habitats (Table 1). The organic matter content in the shallow wetland area of the bay was also higher than in the other areas. Pythagoristic conditions due to reduction of the bay water level have increased the organic matter rate in the soil (Table 1). The abundance of organic matter in the sandy habitat of the *Juncus* was the lowest among the coastline of the bay (Fig. 5).

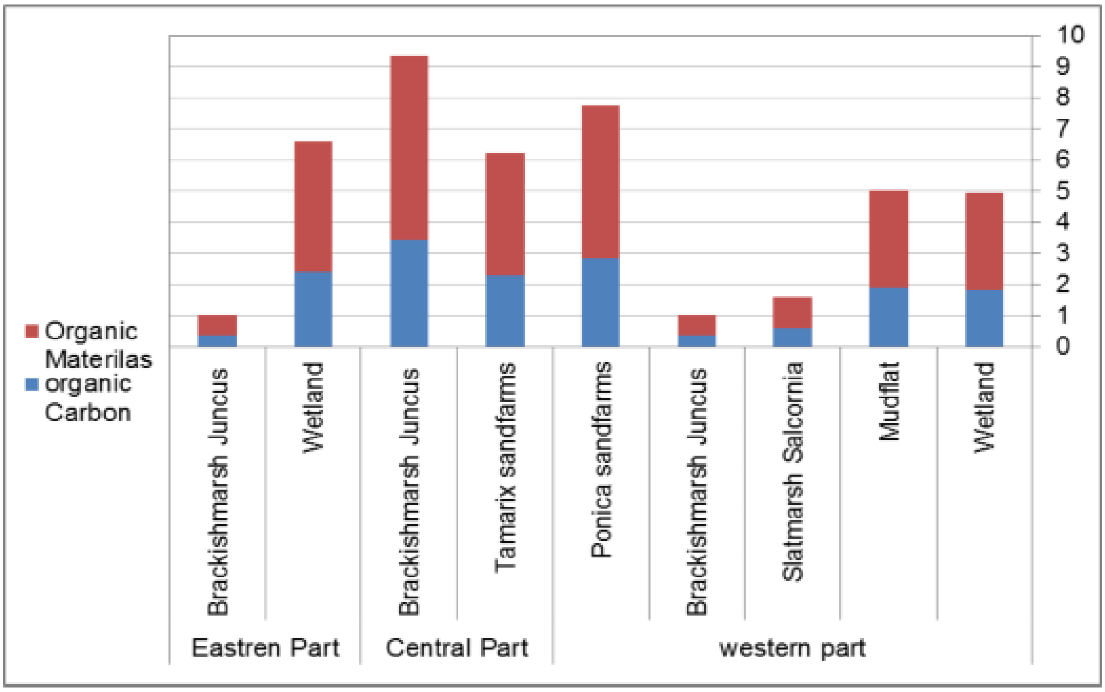

Fig. 5. The abundance of organic matter in the coastal soils of the Gorgan Bay.

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The results exhibited that all coastal soils taken from the studied area have a similar amount of calcium carbonate, and also have a chemical similarity (Fig. 6). However, calcium carbonate content in wetland sediments was lower than in the other sedimentary environments. In fact, the abundance of mollusks lime shellfish in the sediments results in an increase in the amount of calcium carbonate present in the coastal soil.

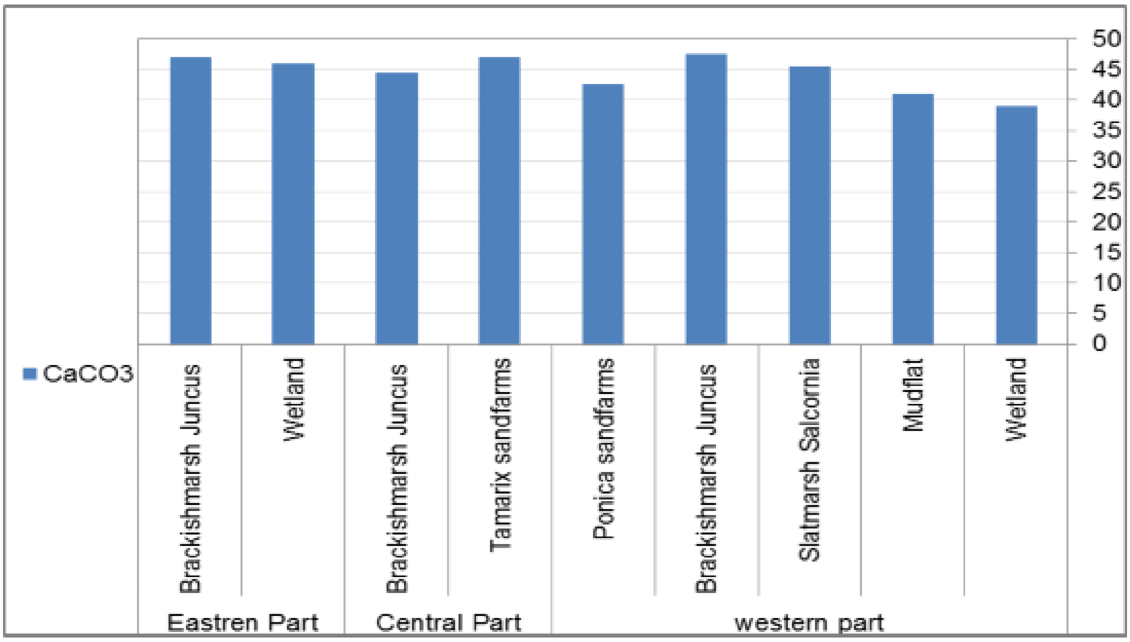

Fig. 6. The abundance of calcium carbonate in coastal soils of Gorgan Bay.

Acidity and electrical conductivity of coastal soils of existing habitats in the bay are subjected to the influence of wetland brackish water in soil texture. The results of coastal soil analyses exhibited that the soil electrical conductivity is higher in wetlands, the mud flats and salt marsh *Salicornia* and *Tamarix* and farms, than in the other areas (Fig. 7). The electrical conductivity of soil in the sand sediments belonging to the *Jancus* habitat had the lowest value (Fig. 7). However, soil acidity in all samples followed up a constant value and had an alkaline characteristic (Fig. 7).

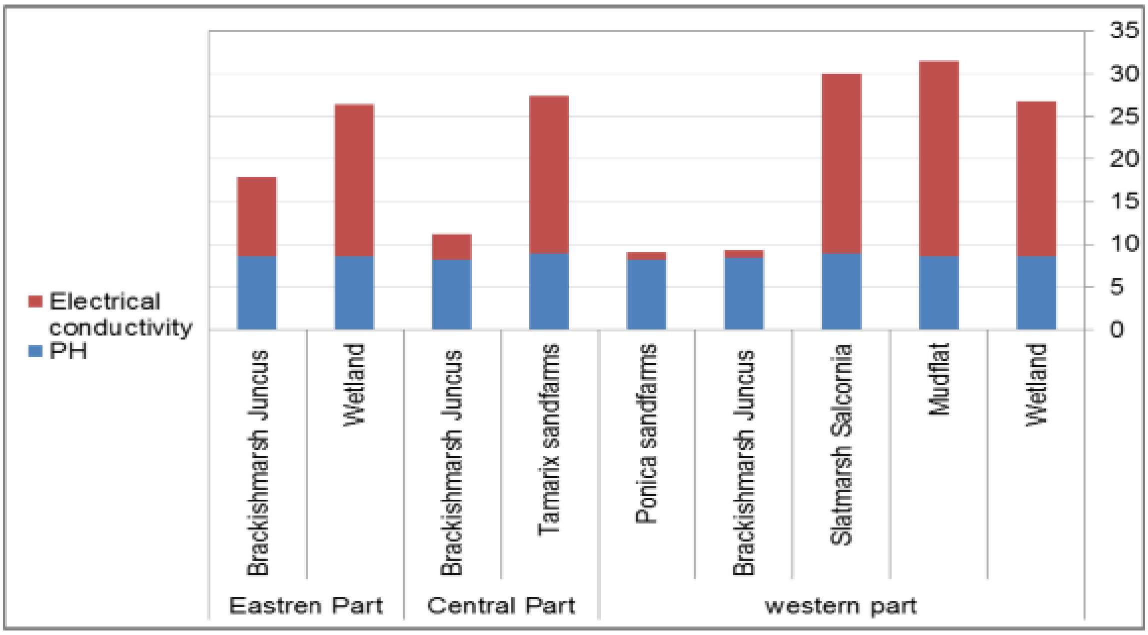

Fig. 7. Acidity and electrical conductivity changes in coastal soils of Gorgan Bay.

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Single-variable and multi-variable statistics to evaluate alterations in coverage zones

Based on the PCA model, various coating zones shown in various colors (Fig. 8) can be distinguishable along the ecological gradient of electrical conductivity and soil texture type. This indicates the separation of these zones based on these two ecological parameters. On the other hand, the shrubbery coverage zone was more separable than the other ones due to containing the organic matter. The axial values of the first two axes of this analysis were 0.9868 and 0.024, respectively, which justifies and interprets 99.2% of the variations between the studied sites independently. Furthermore, based on ANOVA test, the soil characteristics, distance from seawater and elevation of terraces exhibited a statistically significant difference between the coverage zones ($p < 0.05$), but these features did not vary significantly between terraces other than lime.

Table 2. Analysis of variance (One-Way ANOVA) of studied soil variables and other related variables among different transects. The significance level (bold items) is $p < 0.05$.

		Sum of Squares	df	Mean Square	F	Sig.
Sand	Between Groups	1630.361	2	815.181	1.944	0.186
	Within Groups	5032.972	12	419.414		
	Total	6663.333	14			
Silt	Between Groups	1005.428	2	502.714	1.894	0.193
	Within Groups	3184.306	12	265.359		
	Total	4189.733	14			
Clay	Between Groups	75.178	2	37.589	1.192	0.337
	Within Groups	378.556	12	31.546		
	Total	453.733	14			
OM	Between Groups	14.646	2	7.323	3.012	0.087
	Within Groups	29.174	12	2.431		
	Total	43.820	14			
pH	Between Groups	0.047	2	0.024	0.456	0.644
	Within Groups	0.618	12	0.051		
	Total	0.665	14			
EC	Between Groups	360.120	2	180.060	1.534	0.255
	Within Groups	1408.517	12	117.376		
	Total	1768.637	14			
$CaCO_3$	Between Groups	124.188	2	62.094	3.786	0.053
	Within Groups	196.813	12	16.401		
	Total	321.000	14			

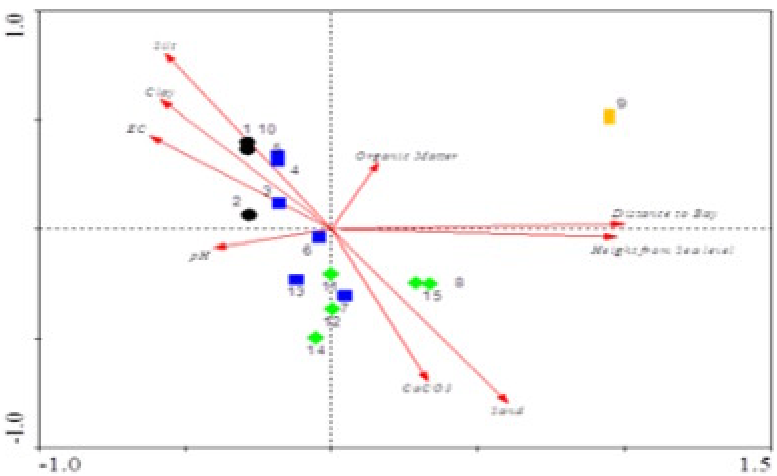

Fig. 8. PCA analyses on soil samples from different vegetation zones. Black: vegetation zone 1; Blue: vegetation zone 2; Green: vegetation zone 3; Brown: vegetation zone 4.

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Table 3. Analysis of variance (One-Way ANOVA) of studied soil variables and other related variables among four vegetation zones. The significance level (bold items) is $p < 0.05$.

		Sum of Squares	df	Mean Square	F	Sig.
Sand	Between Groups	4704.367	3	1568.122	8.805	0.003
	Within Groups	1958.967	11	178.088		
	Total	6663.333	14			
Silt	Between Groups	2928.533	3	976.178	8.514	0.003
	Within Groups	1261.200	11	114.655		
	Total	4189.733	14			
Clay	Between Groups	271.033	3	90.344	5.439	0.015
	Within Groups	182.700	11	16.609		
	Total	453.733	14			
OM	Between Groups	8.982	3	2.994	0.945	0.452
	Within Groups	34.838	11	3.167		
	Total	43.820	14			
pH	Between Groups	0.375	3	0.125	4.740	0.023
	Within Groups	0.290	11	0.026		
	Total	0.665	14			
EC	Between Groups	1508.423	3	502.808	21.255	0.000
	Within Groups	260.214	11	23.656		
	Total	1768.637	14			
$CaCO_3$	Between Groups	129.200	3	43.067	2.470	0.116
	Within Groups	191.800	11	17.436		
	Total	321.000	14			

DISCUSSION

The environment of Gorgan Bay has been affected by the fluctuations of the Caspian Sea, and its dynamic coastal habitats have undergone major alterations over time. The level fluctuations of the sea have continued, since the time of the development in the Pliocene period, in form of a long-term (multi-year), medium-term (several hundred years), short-term (decades-long) and very short-term (many hours or days or months) (Kazanci *et al*. 2004). According to the calculations made by environmental economists, the ecosystem value of the planet is estimated at $ 33 trillion annually, with wetland ecosystems of about $ 5 trillion (Safaeeyan *et al*. 2002), which means that the lagoons have a lot of economic value in terms of environmental performance. Miankaleh wetland and Gorgan Bay along with Gomishan lagoon are considered as a complex collection of biological reserves on the planet. The presence of various valuable animals, sturgeons, migratory birds and diverse vegetable communities have led to the formation of a very important reservoir of genetic resources in the area, and also, Miankaleh Peninsula is a suitable barrier to prevent the erosion of the coastal areas of the southern Gorgan Bay. Annual large volumes of nutrients and organic substances reach to the bay through the rivers and the Caspian Sea and their sediments provide favorable conditions for the formation and development of coastal habitats. The results of field observations showed that the behavior of different habitats in the coastal areas of the bay is accompanied by significant changes associated with influence of the hydrologic behavior of the sea. The increase in the level of the sea during 1978-1995 by 250 cm led to the advent of the bay waters in coastal areas, hence the beaches exhibited different physical response depending on the geometric and morphological conditions. The shores of the most end of western part of the bay, once inhabited by the *Tamarix*, *Salicornia* marshes, and the brackish marsh contained *Juncus*, were affected by the influence of the brackish water of the bay and many terrestrial organisms were destroyed (Fig. 9).

In the wake of the widespread water retrogression of Gorgan Bay between 1930 and 1978 as well as between 1995 and 2017, once water levels were reduced by 300 and 140 cm, respectively, the aquatic organisms, including submerged aquatic plants and algae, with aquatic invertebrates disappeared and terrestrial ecosystems replaced in wetland areas. The results of the satellite images exhibit that water retrogression during the two

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aforementioned time intervals, led to 40% and 20% reduction in the bay area and the water exchange capacity between the bay and the sea was eliminated (Fig. 1). Therefore, the environment of the bay and its habitats are subjected to the surface water level fluctuations of the Caspian Sea. Reduction of the level of the sea has led to the destruction of some mollusks and benthos habitats (Khoshravan *et al*. 2013). The imbalance in the hydrologic level of the bay causes a lot of pressure on the environmental indicators and the loss of a large number of different species of living organisms. As shown in the results, the presence of different habitats from *Salicornia* Salt marshs, *Juncus* Brackish marsh and *Tamarix* and *Punica* shrub lands, at the margin of the coastline of the bay have increased the environmental importance of the bay. The species and composition of the coastal habitats soils vary according to the geometric features of the coast (slope and distance to the coastline). So that, the high water salinity leads to the loss of coastal xerophyte plants. At the moment, reducing the bay level in the most end of western part has provided circumstances for the formation of sandy areas containing fine-grained silty sediments. These coastal areas are very suitable focal points for the emergence of haze. The influence of *Salicornia* on the margin of the its coastline altered the ecological function of the bay, leading to consequent dryness of aquatic ecosystems. The results exhibited that the optimum level for the hydrological stability of the bay is -26 meters. If the sea water level is lower than -28 m, the bay will go towards full drying. At present, the presence of sedimentary terraces at a -26 m level is a good indication of the increase in the its level in 1995. Thereafter, its coastline retreated and its displacement rate in the western part exceeded 20 kilometers. Chopoghli and Ashooradeh connecting channels greatly lost their ability to transport the sea water to the bay, and by a further 50 cm reduction in the sea level, at -28.5 m, these ways will be completely blocked. Under these circumstances, Gorgan Bay will completely be dried up to 2025 according to the forecasting models (Sharbati & Ghanghormeh 2015).

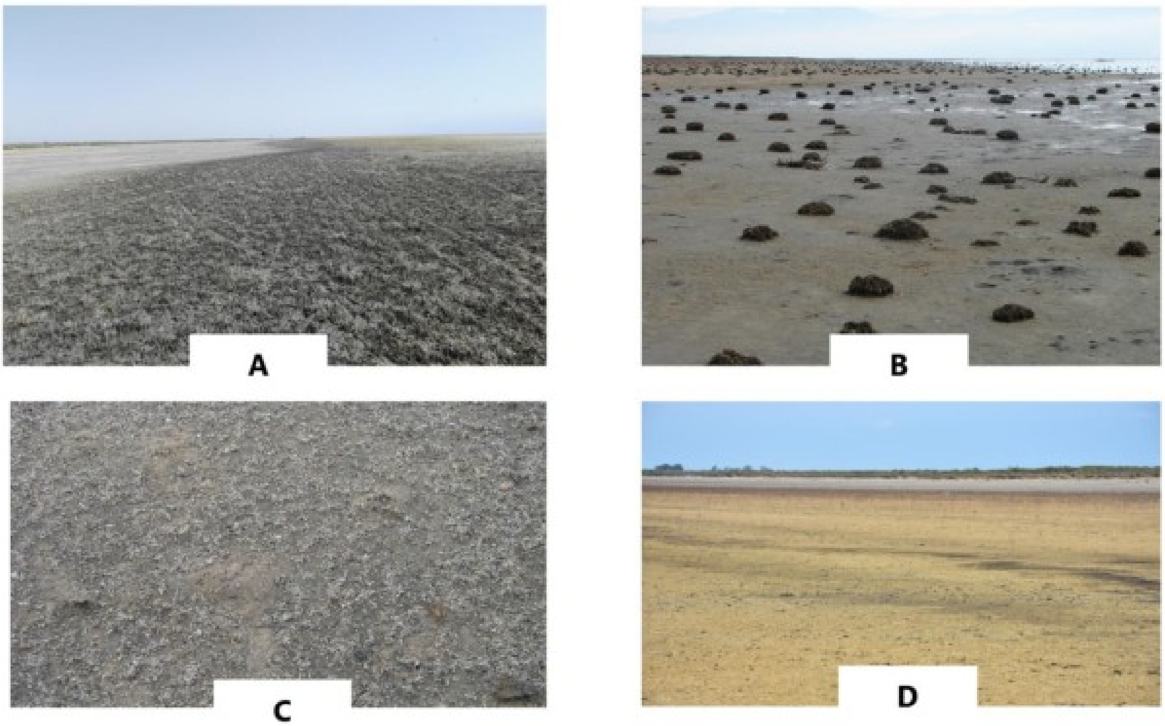

Fig. 9. The effect of fluctuations in the level of Gorgan Bay on coastal habitats (A) drying *Salicornia*; B) drying the *Juncus*; C) destroying aquatic molluscs; D) destroying algae and aquatic plants;

The results of this study indicate that soil properties are the most important factors determining the identity of vegetation and their changes along the transects. Small alterations in the electrical conductivity and soil texture as well as the distance between the terraces from the level of the bay, caused rapid changes in the coating, which have been observed in previous studies (Asri *et al*. 2007; Saeidi Mehrvarz *et al*. 2013).

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CONCLUSION

According to this study, it was revealed that the Gorgan Bay environment and its coastal habitats are affected by fluctuations in the Caspian Sea surface level. During the years 1930-2018, alterations in the sea level in two major recuperations between 1930-1978 and 1995 till now, and a progressive interval during 1978-1995 have made a special circumstance for the bay environmentally. The loss of the habitat of *Salicornia* salt marshes, *Juncus* brackish marsh land, *Tamarix* and *Punica* sand farms at a level above -27 m and the elimination of aquatic organisms have usually occurred with a decreased water level of the bay, including invertebrates (gastropods and bivalvia), phytoplankton (green algae) and charophites plants such as *Rupiah*. At present, the development of large mudflats with sedimentary composition of sandy silt has created a very good potential for occurrence of haze in the most end of its western part, and if the sea level continues to drop, connecting waterways lose their discharge capacity, hence the bay will completely dry up within three years. It seems that in view of the present remnants of *Tamarix* communities in the region and the relative tolerance of these plants to their growth in wet and dry environments, following the reduction of the sea level and the withdrawal of Gorgan Bay waters, these shrub communities will replace the *Salicornia* community in the future and forests of *Tamarix* will be created in the western and northern strips of Gorgan Gulf. On the other hand, the penetration of sandy sediments and the washing of surface salts in dry areas will also result in the formation of developed *Jancus* communities or even pomegranates. Based on field observations, a combination of *Juncus - Tamarix* communities is the most likely further coverage in the dry areas of Miankaleh. Although the situation will increase the biodiversity of dry and sensitive species in the coastal strip of the bay, it is considered to be a loss totally due to the disappearance of the aquatic ecosystem and the various aquatic biotopes (phytoplankton and animals) associated with it.

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نوسانات سطح تراز آب دریای کاسپین و پیامدهای محیط زیستی آن بر خلیج گرگان

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چکیده

افزایش میزان گازهای گلخانه‌ای در جو کره زمین طی دو قرن گذشته موجب بالا رفتن درجه حرارت زمین شده است و عکس العمل آب شناختی دریاچه‌ها و ذخایر آبی وابسته به آنها به صورت توسعه فرایند خشک‌زائی بوده است. خلیج گرگان در حاشیه جنوب شرقی دریای کاسپین نیز از این قاعده مستثنی نبوده و متاسفانه با کاهش سطح تراز آب دریای کاسپین سطح وسیعی از آن دچار خشک‌زایی شده است. در این مقاله معرفی راهکارهای مناسب برای برون‌رفت از شرایط موجود در راستای سازگاری با گرمایش کره زمین به عنوان هدف اصلی تحقیق محسوب می‌شود. با مطالعه مستندات علمی موجود، بازدیدهای میدانی، مطالعه رخساره‌های رسوبی و آنالیز محیط رسوبگذاری، شرایط تشکیل خلیج گرگان و تغییرات مورفودینامیکی آن بازسازی گردید. تفسیر تصاویر ماهواره‌ای دوره‌ای، نحوه تغییر شکل مورفولوژیک خلیج گرگان در دوره‌های نوسانی مختلف را مشخص کرد. در نهایت با تعیین میزان تاثیرپذیری خلیج مزبور نسبت به تغییر سطح تراز آب دریای کاسپین و پدیده‌های هیدرودینامیک رایج در منطقه مورد مطالعه، راهکارهای موثر برای سامان‌دهی و نجات خلیج گرگان از خطر خشک‌زایی معرفی شد. نتایج تحقیق نشان می‌دهد که تطابق اقدامات مهندسی با قابلیت‌های طبیعی خلیج گرگان بهترین راه برای ثبات هیدرولوژیک آن است و لایروبی دهانه‌های قدیمی آن در برنامه‌های دراز مدت نمی‌تواند پاسخگوی تعادل بخشی مناسب آب شناختی خلیج مزبور واقع شود.

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