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Caspian rapid Sea level fluctuation and intensity of displacement of the shorelines in the Gorgan Bay and Miankaleh coast

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ABSTRACT

Displacement of coastlines under the influence of hydrodynamic factors and rising sea levels cause serious damage to economic, social and environmental infrastructure, and rapid fluctuations in the Caspian Sea water level since the twentieth century have created adverse conditions for the coastal environment. The main objective is to assess the severity of changes in the shores of Gorgan Bay and Miankaleh coast as protected environmental areas of wildlife sanctuaries and biosphere reserves during a period coinciding with the decrease of the Caspian Sea water level during the years 1995-2019. The morphological conditions of the coastlines of Gorgan Bay and Miankaleh coast were investigated by field observations and analysis of satellite images. A total of 10 study axes were selected around Gorgan Bay and Miankaleh and the intensity of shoreline movement by processing multi-time satellite images belonging to the years (1995-2019) in the GIS environment and with the help of digital software for coastal line analysis (DSAS), was calculated. Based on the shoreline movement, the study area was classified into three groups with shoreline changes (high, medium and low). The results show that the northeastern extremities of Miankaleh and the western extremity of Gorgan Bay have the highest coastline displacement and the central areas south of Gorgan Bay and the north-central part to the western part of Miankaleh coast have very little displacement. For comprehensive management of coastlines in the study area, focus on areas with high physical vulnerability is necessary and continuous control of quantitative and qualitative changes in coastal habitats affected by fluctuations in the water level of the Caspian Sea can reduce the existing challenges.

1. Introduction

Global warming and rising ocean water level during the Anthropocene have created the right conditions to increase the physical vulnerability of coastal areas, and large areas of the Earth's coast have been flooded and eroded [10]. The relocation of coastlines has a direct impact on various economic infrastructures such as commercial ports, fishing docks, thermal power plants and coastal tourism facilities [11, 34]. The Caspian Sea coast is no exception to this rule and has undergone serious changes and extensive environmental challenges due to fluctuations in sea level, which is sometimes more than a hundred times faster and sometimes in the opposite direction of the oceans [19, 25, 16]. Fluctuations in the water level of the Caspian Sea since the twentieth century have caused the deformation of coastal processes and the joint impact of the fluctuating phases of the Caspian Sea and human factors, conditions of sedimentation regime change, shoreline displacement and the development of erosion phenomena on the coast [17, 25, 6]. The economic consequences of a 250 cm increase in the Caspian Sea water level during the period 1978-1995 are estimated at more than $ 17 billion [24]. The rapid decline of the Caspian Sea water level during the periods 1930-1978 and 1995-2019 has led to major deformation of natural habitats, extinction of coastal wetlands and the impact of centralized economic capacity in coastal areas [21, 27]. Qara Baghaz Bay, as the largest reservoir on the eastern shore of the Caspian Sea and with very high environmental value, during the eighties of the twentieth century, due to the increasing decline in the water level of the Caspian Sea completely dried up and lost its wetland ecosystem services. The effect was to inflict great economic and social damage on the former Soviet government [24]. At present, about 30% of the area of Gorgan Bay and a large part of Miankaleh wetland has dried up due to the decrease of water level

in the Caspian Sea and its important coastal habitats have been destroyed [24]. Calculating the intensity of variability of coastlines in different regions of Gorgan Bay and Miankaleh coast from the decrease of Caspian Sea water level is the main question in this study. The average rate of decline of the Caspian Sea water level during 1995-2019 was about 6 cm per year and during the last 24 years, the Caspian Sea water level has decreased by 150 cm[24]. The quantitative and qualitative impact of wetland and sand environments around Gorgan Bay during the mentioned time is very different and with the process of wetland drying, terrestrial ecosystems have quickly replaced aquatic ecosystems [24]. Behavioral response of coastlines to sea level fluctuations depend to important natural criteria, such as: average shore slope, embankment width, type and texture of coastal sediments, rate of change in sea level, coastal landforms, intensity of tidal currents and the energy of the waves [23]. The rate of shoreline displacement in Gorgan Bay is also a function of the topography of the wetland bed and the dry coastal part and the highest intensity of shoreline shifts occurred in the western and northeastern regions of Gorgan Bay [24, 34]. Gorgan Bay is a suitable dynamic system for analyzing the impact of Caspian Sea water level fluctuations on the coastal environment [24]. A large part of the western part of Gorgan Bay dried up during the 1930s-1978 with the decrease of the Caspian Sea water level and today, again, similar hydromorphological conditions have occurred for Gorgan Bay [24, 34]. Gorgan Bay, under the Caspian Sea declining scenario, will move towards complete drought by 1402 due to the closure of its connection [34]. The high rate of sedimentation in the area of the communication channel between Gorgan Bay and the Caspian Sea has provided the conditions for changing the topography of the bed and the drying process [12, 7]. Fluctuations in the Caspian Sea level and its common hydrodynamic phenomena such as: riparian currents, wind turbines, density and fluvial flows of river waters have a very important role in the morphodynamic deformation of Gorgan Bay [30]. The growth of the Miankaleh sandy spit at the edge of the submerged depression parallel to the Great Mazandaran fault during the late Holocene period has created suitable conditions for the creation of Gorgan Bay [24]. Gorgan Bay has progressed to complete drought many times during the geological period, but the increasing oscillating phases of the Caspian Sea water level have created conditions for its regeneration and reconstruction [13]. Today, the use of digital shoreline analysis system(DSAS) software to calculate and statistically analyze the shoreline movement of the Earth's seas, in the GIS environment is widely used [11, 12, 36]. It is also possible to study the changes of the coastline of Sefidrood delta using satellite images [5] and to evaluate the changes of the coastline in the Caspian delta basin using the digital shoreline analysis system (DSAS) deltas: Haraz, Babolrood and Talar [34] pointed out in Iran. The results of studies on the displacement of the Sefidrud delta coastline have shown that coastal landforms have undergone significant changes over time due to fluctuations in the water level of the Caspian Sea [2, 4, 35, 20]. A study of shoreline changes in Gujarat and Arisa, India has shown that rising Indian Ocean water levels have caused shoreline shifts and the severity of erosion of coastal lowlands [27, 28]. A study of littoral processes of the Atlantic coast of the United States found that storm surges, along with rising Atlantic water levels, caused shoreline shifts and increased severity vulnerabilities in coastal areas [37].Changes in coastlines around the main ports in the north of the country during the period (2005-2012) were studied by the Ports and Maritime Organization (2008), [29], using Landsat satellite images and it was found that the shoreline displacement is a function of fluctuations in the Caspian Sea water level and processes of deposition. Due to the fact that so far, no comprehensive research has been conducted on the quantitative changes of the coastline of Gorgan Bay and Miankaleh coast during the phase of decreasing water level of the Caspian Sea. Therefore, the main purpose of this study is to calculate and statistically analyze the quantitative intensity of coastline movement in different regions of Gorgan Bay and Miankaleh coast. The intensity of changes in the coastline of Gorgan Bay, using statistical analysis, was assessed by processing multi-time satellite images in the software of digital shoreline analysis (DSAS) in the GIS environment.

2. Materials and methods

2.1. Study area

The Caspian Sea, as the largest lake on Earth, is located in the very important geopolitical region of Eurasia, and the five countries of Azerbaijan, Iran, Kazakhstan, Russia and Turkmenistan are the coastal countries around it (Figure 1). The Caspian Sea stretches along the Earth's meridian and is located between latitudes (07°, $47^{'}$ and 33°, $36^{'}$) north and longitudes (43°, $43^{'}$ and 53°, $54^{'}$) east. The sea is 1200 km long and its average width is 310 km. Its maximum and minimum widths are 435 and 196 km. The water level of the Caspian Sea is currently -28 meters lower than the water level of the Baltic Sea. Under this altitude level, the Caspian Sea surrounds about 7500 km and an area of more than 390,000 square kilometers. The change in the size of the Caspian Sea is a function of fluctuations in the water level of the Caspian Sea. The volume of water in the Caspian Sea is 78,000 cubic kilometers. Its average depth is 208 meters and its maximum depth is 1025 meters in the southern depression [14]. This large lake has no known tides and its average salinity is about one third of the ocean water salinity, (13 grams per liter), [22]. The salinity of the Caspian Sea water increases

along the north-south from the mouth of the Volga River with the combination of fresh water to the southern part of the Caspian Sea with the combination of brackish water. The Caspian Sea bed is divided along the north-south into three shallow northern areas, the middle Apsheron depression and the southern depression of Darband (Figure 1). The southern part of the Caspian Sea covers about 65% of the Caspian Sea water resources [22]. The deepest part of the Caspian Sea is its southern gorge, which overlooks the northern coast of Iran. Apsheron ridge with a depth of 160 to 180 meters separates the central part from the southern depression of the Caspian Sea. The morphological appearance of the coasts of the southern part of the Caspian Sea is mostly affected by the trend of the northern heights of Alborz. The average height of the Alborz mountains is about 2000 meters and from these heights about 62 main rivers flow to the Caspian Sea. The southern part of the Caspian Sea overlooks the northern coast of the country in the provinces of Golestan, Mazandaran and Gilan from the city of Gomishan in the southeastern tip to Astara in the extreme southwestern part. Specific climatic conditions of this region of the Caspian Sea with different distribution of temperature and precipitation have a direct impact on the formation and structural changes of coastal morphological features such as: coastal plains, sandy areas, mudflats, deltas, alluvial fans , fluvial plains and rivers along the coastline of the Caspian Sea and the geographical location of desert, coastal, forest, river and plain environments in different areas of the southern shores of the Caspian Sea depends on the long-term dominance of climatic factors[22]. Therefore, the climate of the southern coasts of the Caspian Sea is one of the most important criteria for shaping the structure of coastal morphology. Geological structure of northern Alborz mountains from Gorgan to Rasht and from Rezvanshahr to Astara with various stratigraphic characteristics and geodynamic performance of active faults such as: Mazandaran large fault, Lahijan fault and Astara fault play a very important role in creating morphological zones on the coasts South of the Caspian Sea and the hydrodynamic forces of the Caspian Sea (fluctuations in water level, waves and coastal currents) and hydraulic forces of rivers have caused coastal morphological effects. The southern coasts of the Caspian Sea extend from the southwestern tip (Astara port) to the southeastern tip (Gomishan coast) with a length of 890 km [29], (Figure 2). The length of the coastline in Mazandaran, Golestan and Gilan provinces is 487, 131 and 272 km, respectively [29]. The southern coasts of the Caspian Sea are divided into five morphological units based on the geometric structure of coastal areas and the type of coastal landforms [15]. coasts with steep slopes in the dry part in the western part of Mazandaran and northwest of Gilan with coarse-grained and gravel sandy sediments and very low slopes with silty to clay silty sediments in the southeastern extremity along the southern part of Gorgan Bay is located in the eastern part of the coast of Turkmen port and Gomishan. Low sandy beaches can also be seen in the area overlooking the coast of Astara. The southern coasts of the Caspian Sea, in terms of sediment morphodynamics are classified into types (reflective, dissipative and intermediate) [16] and are divided into categories (erosive, intermediate or equilibrium and active sedimentary) in terms of severity of erosive vulnerability [15]. Gorgan Bay is located in the easternmost part of the southern coasts of the Caspian Sea (Figure 1), [30]. This intercontinental depression is separated from the Caspian Sea by the Miankaleh sand spit and is connected to the Caspian Sea at the northeastern end by the Chapoqli and Ashooradeh communication channels (Figure 1). Gorgan Bay catchment area has an area of about 15,000 square kilometers and includes mountainous areas, foothills and coastal plains [24]. Numerous permanent and seasonal rivers from the southern and eastern part overlooking the northern slopes of Alborz lead to Gorgan Bay, of which Qarasu and Gorgan rivers, with a total average annual discharge of half a billion cubic meters and a volume of sediment of 3.5 million Tons per year are the most important of them [1]. The results of the hydrogeochemical study of Gorgan Bay have shown that the amount of water entering the Caspian Sea to Gorgan Bay has a very important role in the chemical properties of water and sediment in Gorgan Bay and the impact of rivers is very small [6]. The environment of Gorgan Bay is affected by the Caspian Sea, the rivers leading to it and the Miankaleh Peninsula. Gorgan Bay was registered in 1975 along with Miankaleh and Lapoo Zaghmarz wetlands as a biosphere reserve in the first international wetland complex of the world in the list of wetlands of Ramsar Convention. In the classification of wetlands in the Ramsar Convention (1975), [7]. Miankaleh wetland and Gorgan Bay are considered as type A or permanent shallow sea waters. This area includes a collection of valuable ecosystems and sensitive and vulnerable habitats, as well as beautiful landscapes and natural tourist attractions. Therefore, Gorgan Bay has a very high environmental value.

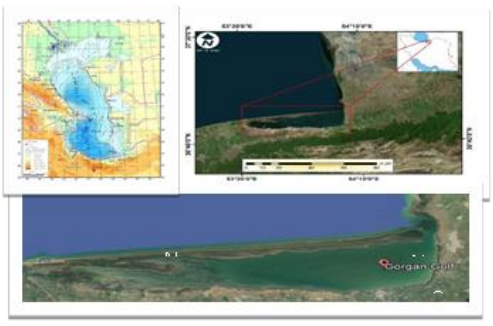

Figure 1. Geographical position of the Caspian Sea, Gorgan Bay, Miankaleh coast and measuring axes (West Miankaleh: MG, Miankaleh West: WM, Miankaleh Central: CM,

Miankaleh: EM, Gorgan Bay Northwest: NWG, Gorgan Northeast: NEG, Turkmen Port: TP, Gaz port: GP, South Central Region of Gorgan Bay: SCG, Southwest Region of Gorgan Bay: SWG).

2.2. Research method

This research has been done by the method of documentary studies and software analysis. At first, the necessary acquaintance with the characteristics of natural geography and morphology of the study area was done by reviewing scientific documents, including: specialized reports, research articles, thematic maps. Then, by initial processing of existing satellite images through Google Earth software (Google Earth Pro, 2020), the morphological appearance of the coast was examined and 10 measuring axes were selected based on the criteria of diversity of coastlines and landforms located in them (Figure 1). The rate of change of Caspian coastlines along transects with a distance of 100 meters in the software of digital shoreline analysis system (DSAS) and Landsat multi-time satellite images (TM and LOI sensors) with a spatial resolution of 30 meters in GIS environment with the help of software (Arc-Map) version 10.6.1 belonging to ESRI company in the years 1995-2019 along the 10-axis shoreline in Gorgan Bay was analyzed (Figure 2). The shoreline displacement was calculated in the GIS software environment, and multi-time images of Landsat satellite sensors from 1995 and 2019 were processed based on the data in band (5) which is close to the infrared spectrum (NIR), and the boundary between the dry coast and the shallow part of the sea was separated and the coastline was drawn (Figure 2). Then, the amount of shoreline movement in the above-mentioned time period (NSM) and its annual average (EPR) compared to the baseline in the software environment of digital shoreline analysis system(DSAS) and with the help of transect module at distances of 100 meters, was drawn and calculated. All numerical data were processed in the form of data tables in Microsoft Excel software environment and curves and graphs related to the shoreline displacement were generated (Figure 2) and finally by summarizing the results, the research objectives were achieved.

3. Results

3.1. Changing the coastline in the northwestern part of Miankaleh

The average rate of positive displacement of the shoreline or retreat of the Caspian Sea water in the northwestern part of Miankaleh coast during the period of 24 years between 1995-2019 is equal to 127 meters (Table 1), which averages 5 meters per year, sand embankment width in this area has increased (Table 2). The maximum shoreline movement is 166 meters and the minimum is 74 meters (Table 1). shoreline changes in this part of the study area are uniform and the change threshold is between 3 to 7 meters per year (Table 2).

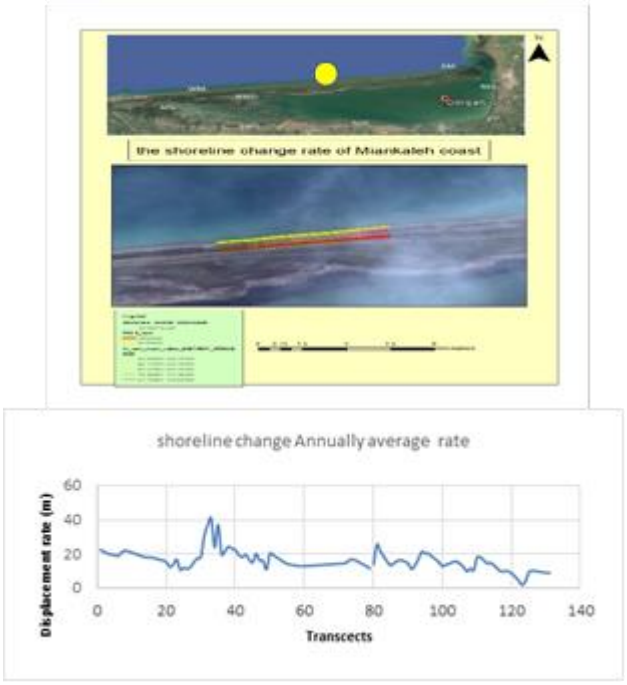

Figure 2. Drawing and comparing the coastline of the study area in the software of the GIS and with the help of ancillary software Digital Analysis of Coastlines (DSAS)

3.2. Changing the coastline in the north-central area of Miankaleh

The average positive displacement of the Caspian Sea shoreline or water retreat in the northwestern part of the Miankaleh coast during the 24-year period between 1995-2019 is 476 meters (Table 1), which averages 20 meters per year, the width of the sand embankment in this area has increased (Table 2). The maximum shoreline movement is 550 meters and the minimum is 434 meters (Table 1). Coastline changes in this part of the study area are uniform and the change threshold is between 18 to 23 meters per year (Table 2).

3.3. Changing the coastline in the northeastern part of Miankaleh

The average positive displacement of the Caspian Sea shoreline or water retreat in the northwestern part of the Miankaleh coast during the 24-year period between 1995-2019 is equal to 1626 meters (Table 1), which averages 68 meters per year, the width of the sand embankment in this area has increased (Table 2). The maximum shoreline movement is 2777 meters and the minimum is 1137 meters (Table 1). The shoreline changes in this part of the study area are very large and the change threshold is between 47 to 116 meters per year (Table 2).

3.4. Changing the coastline in the northeastern part of Gorgan Bay

The average positive displacement of the Caspian Sea shoreline or water retreat in the northwestern part of the

Miankaleh coast during the 24-year period between 1995-2019 is equal to 242 meters (Table 1), which averages 10 meters per year, the width of the sand embankment in this area has increased (Table 2). The maximum shoreline movement is 519 meters and the minimum is 57 meters (Table 1). Coastline changes in this part of the study area are moderate and the change threshold is between 2 to 22 meters per year (Table 2).

3.5. Changing the coastline in the northwestern part of Gorgan Bay

The average positive displacement of the Caspian Sea shoreline or water retreat in the northwestern part of the Miankaleh coast during the 24-year period between 1995-2019 is equal to 381 meters (Table 1), which averages 16 meters per year, the width of the sand embankment in this area has increased (Table 2). The maximum shoreline movement is 982 meters and the minimum is 41 meters (Table 1). The shoreline changes in this part of the study area are large and the change threshold is between 2 to 41 meters per year (Table 2).

3.6. Changing the coastline in the Turkmen port area

The average positive displacement of the Caspian Sea shoreline or water retreat in the northwestern part of the Miankaleh coast during the 24-year period between 1995-2019 is equal to 1058 meters (Table 1), which averages 44 meters per year, the width of the sand embankment in this area has increased (Table 2). The maximum shoreline movement is 1262 meters and the minimum is 729 meters (Table 1). Coastline changes in this part of the study area are very large and the change threshold is between 30 to 52 meters per year (Table 2).

3.7. Changing the coastline in the area of Gaz port

The average rate of positive displacement of the shoreline or retreat of the Caspian Sea water in the northwestern part of Miankaleh coast during the period of 24 years between 1995-2019 is equal to 654 meters (Table 1), which averages 27 meters per year, sand embankment width in this area has increased (Table 2). The maximum shoreline movement is 1288 meters and the minimum is zero meters (Table 1). Coastline changes in this part of the study area are large and the change threshold is between zero and 54 meters per year (Table 2).

3.8. Changing the coastline in the south-central area of Gorgan Bay

The average positive displacement of the shoreline or retreat of the Caspian Sea water in the northwestern part of Miankaleh coast during the period of 24 years between 1995-2019 is equal to 526 meters (Table 1), which averages 22 meters per year, the width of the sand embankment in this area has increased (Table 2). The maximum shoreline movement is 1028 meters and the minimum is 186 meters (Table 1). Coastline changes in this part of the study area are low to moderate and the change threshold is between 8 to 43 meters per year (Table 2).

3.9. Changing the coastline in the southwestern part of Gorgan Bay

The average positive displacement of the Caspian Sea shoreline or water retreat in the northwestern part of the Miankaleh coast during the 24-year period between 1995-2019 is equal to 1507 meters (Table 1), which averages 63 meters per year, the width of the sand embankment in this area has increased (Table 2). The maximum shoreline movement is 2988 meters and the minimum is 599 meters (Table 1). Coastline changes in this part of the study area are very large and the change threshold is between 25 to 125 meters per year (Table 2).

3.10. Changing the coastline in the Northwesternmost region of Gorgan Bay

The average rate of positive displacement of the shoreline or retreat of the Caspian Sea water in the northwestern part of Miankaleh coast during the period of 24 years between 1995-2019 is equal to 1846 meters (Table 1), which averages 77 meters per year, the width of the sand embankment in this area is enlarged (Table 2). The maximum shoreline movement is 5200 meters and the minimum is 341 meters (Table 1). The shoreline changes in this part of the study area are very large and the change threshold is between 14 to 216 meters per year (Table 2).

Table 1. The shoreline displacement rate of Gorgan Bay and Miankaleh coast during the period 1995-2019

No	Region Code	Average (m)	Maximum (m)	Minimum (m)
1	EM	1626	2777	1137
2	WM	127	166	74
3	CM	476	550	434
4	TP	1058	1263	730
5	GP	654	1288	0
6	NEG	242	519	57
7	NWG	381	982	41
8	SCG	526	1028	186
9	SWG	1507	2988	599
10	MG	1846	5200	341

Table 2. The annually average shoreline displacement rate of Gorgan Bay and Miankaleh coast

No	Region code	Average (m)	Maximum (m)	Minimum (m)
1	EM	68	116	47
2	WM	5	7	3
3	CM	20	23	18
4	TP	44	53	30
5	GP	27	54	0
6	NEG	10	22	2
7	NWG	16	41	2
8	SCG	22	43	8
9	SWG	63	125	25
10	MG	77	216	14

3.11. Comparison of coastline changes in the study area

Comparison of the average rate of shoreline changes over a 24-year period between 1995-2019 shows that the highest shoreline shifts in the westernmost region of Gorgan Bay, northeast coast of Miankaleh and southwest of Gorgan Bay at 1846, 1626, and 1507 meters respectively occurred (Figure 3). The coastline of Turkmen port (1058 m) and Gaz port (654 m) has been determined (Figure 3). The lowest shoreline movement rates are in the west of Miankaleh (127 m), northeast of Gorgan Bay (242 m), northwest of Gorgan Bay (381 m), north-central Miankaleh (476 m) and south-central Gorgan Bay (526 m), respectively (Figure 3).

Comparison of the average annual shoreline movement in the 10 axes measured around Gorgan Bay and Miankaleh coast shows that the highest annual shifts are to the western extremities of Gorgan Bay (77 m), northeast of Miankaleh (68 m), southwest of Gorgan Bay (63 m), Turkmen port (44 m), and Gaz port (27 m) (Figure 4). The lowest annual shoreline movements are in the western regions of Miankaleh (5 m), northeast of Gorgan Bay (10 m), northwest of Gorgan Bay (16 m), north-central region of Miankaleh (20 m) and south-central Gorgan Bay (22 m) (Figure 4).

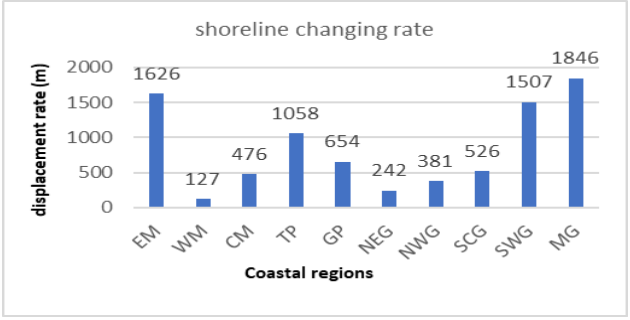

Figure 3. Comparison of the average amount of changes in the shoreline of Gorgan Bay and Miankaleh during the period 1995-2019

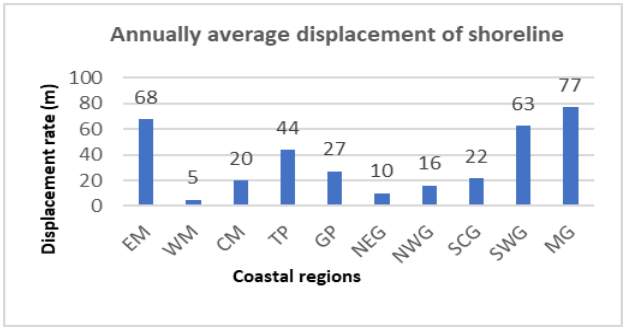

Figure 4. Comparison of the average annual changes of the coastline of Gorgan Bay and Miankaleh during the period 1995-2019

Reduction of the Caspian Sea water level by 150 cm since 1995 has caused a large part of the western extremity of Gorgan Bay and the northeastern part of Miankaleh Wetland to dry up, resulting in the drying of Miankaleh and Gomishan coastal wetlands and decreased more than 30 percent from the area of Gorgan Bay [19]. The results of studies have shown that the rate of variability of Gorgan Bay coastal habitats is subject to changes in the water level of the Caspian Sea and sandy shores of the southeastern Caspian Sea along the northeastern part of Miankaleh wetland and shallow lagoons. The western tip of Gorgan Bay had the most changes during 1995-2019 [19]. Changing the aquatic ecosystem to land and changing the cover of coastal wetlands to saline and brackish marshes are the most important ecological events of Gorgan Bay and Miankaleh wetland during the Caspian Sea water retreat during 1995-2019 [٢٠]. The quantitative variability of coastlines in different coastal areas of Gorgan Bay and Miankaleh wetland is very different and the severity of physical vulnerability of coastlines in the study area depends on the geometric structure of the coast [20]. The rate of drought and coastal shifts in the northeastern regions of Miankaleh and the western end of Gorgan Bay is very high (Figures 3 and 4). The mild topography of the shallow and dry coastal part has caused the behavioral reaction of coastal wetlands to be very severe against the decrease of the Caspian Sea water level, and the drying of coastal wetlands, the growth of sandy islands and the formation of mudflats are signs of natural coastal reaction. Instead, the sensitivity of the coastal areas of the western and central part of the north of Miankaleh wetland, the northeastern and south-central part of Gorgan Bay to the reduction of the Caspian Sea water level is very low (Figures 3 and 4). Rapid shifting of the coastline of the eastern and southeastern parts of Gorgan Bay has reduced the efficiency of water traffic in these areas and an important part of the wooden piers of Turkmen and Gaz ports has been taken out of water [10]. Currently, the possibility of sea traffic between the Caspian Sea and the Gulf of Gorgan has become very difficult and only through the Ashooradeh communication channel, the transportation of small

boats is possible [19, 29, 30] According to the predictions made until 1402, with the decrease of the Caspian Sea water level, Ashuradeh canal will lose its navigation capability and Gorgan Bay will move towards complete drying [32]. The results of this study show that the coastal habitats of the westernmost part of Gorgan Bay and the northeastern part of Miankaleh wetland are changing at an average annual speed of 77 and 68 meters, respectively, and the distance between the shoreline of Turkmen and Gaz ports from the water level of Gorgan Bay is Annually, respectively, increases by 44 and 27 meters (Figure 4). Very high annual shifting speed of the shoreline in the northeastern part of Miankaleh wetland at the rate of 68 meters per year causes a sharp drop in water depth in communication channels and lack of proper exchange of Caspian Sea water with Gorgan Bay. Gorgan bay will be destroyed by the Caspian Sea by 1405 and many environmental problems will occur in the southeastern region of the Caspian Sea. Based on the comparison of the average annual speed of shoreline movement, the study area can be classified into three groups. The first group, which includes coastal areas: northeast of Miankaleh, western and southwestern extremities of Gorgan Bay and Turkmen port, has the highest coastline movement and the threshold of annual shoreline changes in there is between (44-77 meters) per year (Figure 4). The second group includes coastal areas: Gaz port, south-central part of Gorgan Bay, north-central part of Miankaleh, and northwest of Gorgan Bay, and the annual shoreline movement in these areas is moderate and between (16-27 meters) per year (Figure 4). And the third group includes: the northeastern coastal areas of Gorgan Bay overlooking the southern part of Ashooradeh Island and the northwestern part of Miankaleh, where the annual shoreline changes between (5-10 meters) per year (Figure 4). Therefore, the implementation of management programs for the ecological reconstruction of Gorgan Bay and Miankaleh Wetland should be done based on the intensity of shoreline displacement and the western extremities of Gorgan Bay and the northeastern part of Miankaleh Wetland, which have the highest shoreline displacement, are a high priority which they have to organize.

4. Discussion

The conservation value of the coastal habitats of Gorgan Bay and Miankaleh Wetland is very high [31] and Miankaleh International Wetland was registered as a biosphere reserve and sanctuary by the Ramsar Convention in 1975 [7]. The spread of coastal plants along the Caspian Sea coast and on the shores of Gorgan Bay with high species diversity and richness, has led to important habitats including saline marshes, brackish marshes and freshwater along with sandy meadows and pomegranate shrub forests are highly sensitive to physical changes in the water level of the Caspian Sea and the Gulf of Gorgan [31, 18]. Meanwhile, the importance of the eastern and southeastern ports of Gorgan Bay, such as Turkmen port and Gaz port, is very high in tourism and fishing activities, and the safe connection of Gorgan Bay and the Caspian Sea is an important strategic criterion for protecting economic, social and environmental infrastructure [10, 19]. The fluctuation of the Caspian Sea during the years 1978-1995 with an increase of 250 cm had caused the destruction of a large area of habitats belonging to the land ecosystems of the

5. Conclusion

The study of shoreline displacement is done to determine the severity of physical vulnerability of coasts and their catchments. The different responses of shorelines to sea level fluctuations are a good natural indicator for assessing the variability of habitats and the deformation of physical criteria of coastal areas. The results of this study showed that different coastal areas of Gorgan Bay and Miankaleh wetland show different morphological behavior under the influence of decreasing water level in the Caspian Sea. The western extremities of Gorgan Bay and the northeast of Miankaleh Wetland had the highest shoreline displacement during the period 1995-2019, and as a result, a large part of Miankaleh Wetland and coastal swamps has dried up and aquatic ecosystems have changed their nature to land. The results of this study are used for comprehensive conservation management programs to rehabilitate and rebuild the ecological conditions of Gorgan Bay and create a safe and stable connection for water connection between the Caspian Sea and Gorgan Bay in areas where the shoreline movement rate is low such as: the central to the western part of Miankaleh coast seems to be mandatory. For comprehensive management of coastlines in the study area, focus on areas with high physical vulnerability is necessary and continuous control of quantitative and qualitative changes in coastal habitats affected by fluctuations in the water level of the Caspian Sea can reduce the existing challenges.

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