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Caspian rapid Sea level fluctuation and intensity of shorelines displacement in the Gomishan Lagoon

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ABSTRACT

Coastal displacement due to hydrodynamic factors and changes in sea level has serious impacts on adjacent ecosystems, economic infrastructure, and human communities. Rapid fluctuations in the Caspian Sea level have created unstable conditions for coastal environments since the twentieth century. This study aims to evaluate the amount of shoreline displacement and Morpho- logical changes in the shoreline at the location of the Gomishan wetland between 1995 and 2019 and its impact on this international wetland. To this end, by processing Landsat satellite Images in the mentioned years using the Normalized Difference Water Index (NDWI), the water body was separated from non-water to extract the shoreline. The results show a significant displacement of the shoreline ranging from -136 to -1072 meters downstream of the Gorganrud River estuary in the southern region and a forward displacement of the shoreline inside the sea from 135 to 7781 meters, with most of the displacement occurring in the northern section. The studied area was classified into three groups based on the shoreline displacement (high, medium, and low). The results show that the northern part of the Gomishan wetland experienced the highest amount of shoreline displacement, and the amount of shoreline displacement gradually decreased in the central and southern regions. Additionally, the results show a significant relation with the period of decreasing the Caspian Sea level during the study period.

1. Introduction

The investigation of the impact of sea level fluctuations on coastal regions holds significant importance [1]. The Caspian Sea, which spans an area of 436,000 square kilometers, is recognized for its rapid water level changes [2]. Coastal Wetlands situated along the southern shores of this lake are considered to be one of the most crucial ecosystems in the region. During the late Holocene period, the growth of the sandy spit along the coastline of the Caspian Sea has created suitable conditions for the creation of Gomishan Lagoon [3].The Gomishan International Wetland, formerly encompassing an area of 177 square kilometers in 1995, played a vital role in the environmental landscape of the southeastern coast of the Caspian Sea. The stability and water depth of this lagoon were closely linked to fluctuations in the Caspian Sea's water level, according to Jeihouni et al. (2019). This site was once a completely natural coastal wetland along the Caspian Sea and provided vital support to numerous vulnerable bird species, with bird populations sometimes exceeding 150,000, as highlighted by [4].Gomishan Lagoon and Gorgan Bay have 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 [5,2].One of the most important distinctions between the Caspian Sea and other open seas lies in their varying sea level patterns. Specifically, While the Caspian Sea has experienced a decreasing and increasing trend, according to the obtained data, the water level of the open seas is continuously increasing [6].The Caspian experienced a notable ascent of 2.4 meters. Subsequently, from 1995 to 2019, its level declined by 1.5 meters (Figure 1).

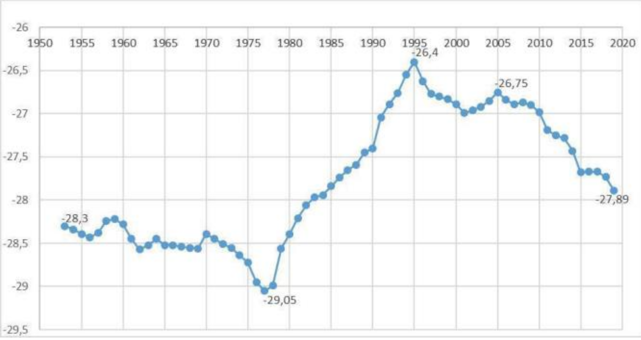

Figure 1. Caspian Sea levels with respect to the high sea level [7]

Coastal displacement has a direct impact on various economic infrastructures, including commercial ports, fishing docks, thermal power plants, and coastal tourism facilities [8,9], and with time, heavy damages are caused by the hydrodynamic erosion factors of the sea (coastal currents and waves) and sea level fluctuations have affected them [10]. 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[11,12,13].Since the twentieth-century Fluctuations in the water level of the Caspian Sea 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 [14,12,15].The economic consequences 250 cm increase in the Caspian Sea water level during the period 1978-1995 are estimated at more than $ 17 billion [16].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 Lagoons, and the impact of centralized economic capacity in coastal areas [17,12]. As the largest reservoir on the eastern shore of the Caspian Sea and with a very high ecological value, Gara Baghaz Bay completely dried up during the eighties of the twentieth century, due to the increasing decline in the water level of the Caspian Sea and losing its lagoon ecosystem services. As a result, many economic and social damages were inflicted on the former Soviet government [16]. At present, about 30% of the area of Gorgan Bay and a large part of Miankaleh Lagoon has dried up due to the decrease in water level in the Caspian Sea, and its important coastal habitats have been destroyed [16].The shoreline is the physical boundary between land and water and due to its dynamic nature, it changes continuously over time [18,19,20].As a result, maps illustrating changes in shoreline and coastal areas are critical in coastal hazard assessment [21].The main purpose of this research is to calculate the intensity of variability of shorelines in different regions of Gomishan coastal Lagoon with specific emphasis on the effects exerted by a reduction in water levels within the Caspian Sea between 1995 and 2019. In this research, to achieve this goal, the processing of Landsat satellite Images in 1995 and 2019 was used to calculate the amount of movement and change of the beach morphology by extracting the shorelines in these years. The coastal habitats of Gomishan Lagoon, Gorgan Bay, and Miankala Lagoon possess a significant conservation value [15]. Furthermore, it is worth noting that Gomishan International Lagoon has been recognized as a biosphere reserve and Life Sanctuary by the Ramsar Convention ,and having been registered in 1975 [22]. The expansion of coastal plants along the coast of the Caspian Sea and the coast of Gorgan Bay and Gomishan Lagoon with high diversity and species richness has led to the creation of important habitats including salt marshes, salt marshes and freshwater along with sandy grasslands and forests. Pomegranate and Gaz shrubs are highly sensitive and physically vulnerable to changes in the water level of the Caspian Sea [15,13]. In addition, the importance of the eastern and southeastern parts of Gorgan Bay, such as Bandar Turkmen and Bandar Gaz, is very high in tourism and fishing activities, and the safe connection of Gorgan Bay and the Caspian Sea is considered an important strategic criterion for the protection of economic, social and environmental infrastructure [11,23].The water level of the Caspian Sea increased by 250 cm during the years 1978-1995 and caused the destruction of a large area of habitats belonging to the terrestrial ecosystems of the Caspian Sea (Gomishan Lagoon and Gorgan Bay) and instead, the Miankala coastal Lagoon and Gorgan Bay added [13]. The decrease in the water level of the Caspian Sea by 150 cm since 1995 caused the drying of a large part of the western end of the Gorgan Bay and the northeastern part of the Miankala Lagoon, and as a result, the coastal Lagoons of Miankala and Gomishan dried up and more than 30% decreased from the area of Gorgan Bay [20].Satellite data and remote sensing techniques make it possible to identify and monitor various features of the Earth's surface. Therefore, they identify a wide range of ecological and environmental components [24,25,26,27].As a result, numerous studies have been undertaken using remote sensing and geographic information systems to investigate the transformations in shorelines and their influence on coastal wetland ecosystems.Domazetović et al., 2021 used NDWI to extract the shoreline [28]. Alcaras et al., (2020), also evaluated the function of NDWI as favorable for this purpose [29], and Saeed and Fatima, 2016 extracted the beaches of Dubai by using NDWI. Qureshi et al.,(2020),evaluated the ecological changes in Gomishan wetland by using remote sensing. They reported the most important factor that naturally affects the surface ecological characteristics of Gomishan Lagoon is the fluctuation of the Caspian Sea water level, which leads to the decrease and increase of the water level of the Lagoon [30]. The result of Jeihouni et al., (2019), also emphasizes the direct impact of the Caspian Sea water level on Gomishan Lagoon [2]. Khoshravan et al., (2022), using remote sensing and GIS, investigated the intensity of changes in the shorelines of the Caspian Sea coast in the area of the coast of Sefidroud Delta and Gorgan Bay [31].Ghaderi and Rahbani, (2020), analyzed the changes in Bandar Abbas shoreline using remote sensing and GIS [32].

2. Research method

2.1 Study area

Gomishan Wetland is located in the extreme southern part of the eastern coast of the Caspian Sea, along the western border of the Turkmen Steppe plains. It covers a vast area of 17,700 hectares and is situated at a depth of 27 meters below the level of the open sea. The wetland's coordinates are 37° 09´ to 37° 20´ N and 53° 54´ to 53° 58´E f. It takes on the form of a relatively narrow strip running along the southeastern shores of the Caspian Sea in a north-south direction as shown in Figure 2.

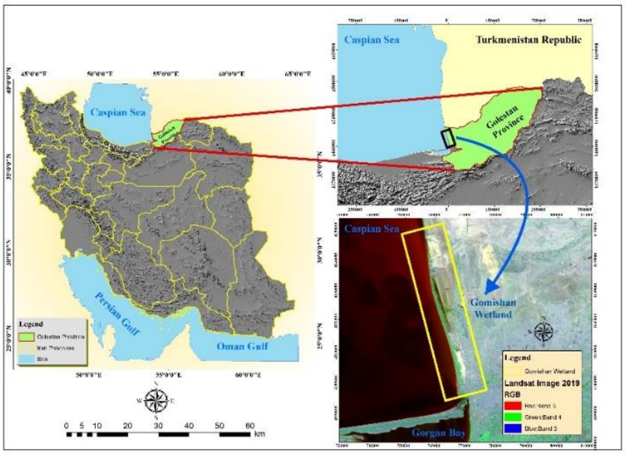

Figure 2. Study area

2.2. Methodology

In the present study, geometric correction, radiometric and atmospheric corrections were initially performed to determine the shoreline changes using Landsat, colour composite of 5,4,3 bands for the Image of 1995 and 6,5,4 bands for the Image of 2019 was created. Furthermore, NDWI (Normalized Difference Water Index) was used to separate the water body from non-water.NDWI is used for monitoring changes related to water content in water bodies. Since water bodies strongly absorb light in the visible to near-infrared range of the electromagnetic spectrum, NDWI uses bands in the green and near-infrared range to highlight water bodies. NDWI can effectively increase information related to water in most cases. It is sensitive to natural surfaces and leads to an overestimation of water. Water bodies with low reflectance are only reflected in the visible part of the electromagnetic spectrum In their liquid state, water bodies usually have high reflectance in the blue spectrum (0.4-0.5 micrometers) compared to the green (0.5-0.6 micrometers) and red (0.6-0.7 micrometers) spectra. Values greater than 0.5 are usually associated with water. Vegetation cover usually has much smaller values and man-made areas have values between zero and 0.2. NDWI was developed by McFeeters in 1996 to enhance water-related features of developed landscapes. This index uses near-infrared (NIR) and shortwave infrared (SWIR) bands [34,35,36].NDWI could be calculated by using Eq.(1):

$$NDWI=\frac{Green-NIR}{Green+NIR} \qquad (1)$$

where in Eq.(1) $Green$ and NIR represent the respective reflectance values of green light and near-infrared light. Following the extraction of shorelines from satellite Imagery for the purpose of calculating shoreline displacement, the shoreline in 1995 was selected as the baseline, and 92 transects were drawn from it to the shoreline in 2019. The Digital Shoreline Analysis System (DSAS) was used to perform computations for shoreline rates of change. DSAS is one of the reliable tools for quantifying the rate of shoreline changes during a particular period, which was developed by USGS and has been used in many similar projects during the last two decades [33]. This methodology facilitated the determination of both the displacement and morphological changes of the shoreline. Moreover, in order to estimate the extent of erosion and sedimentation within the Gorganrud River estuary, the shorelines from the various studied years were connected. Subsequently, by analyzing the eroded and sedimented areas, their respective surface areas were calculated (Figure3).

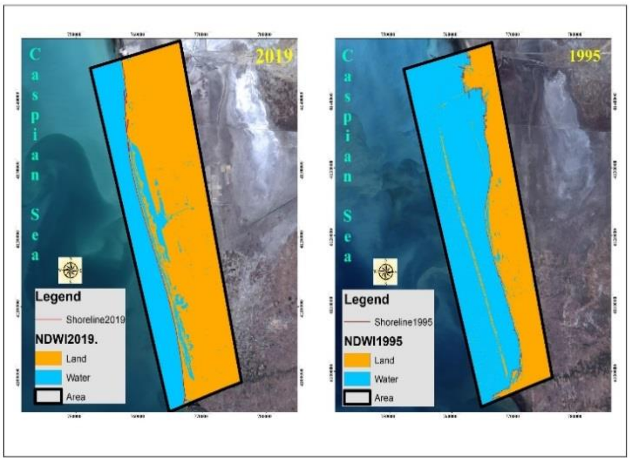

Figure 3. Shoreline extraction based on applications of NDWI, 1995&2019

3. Results

The results of satellite image processing using NDWI indicate a significant displacement and morphological changes of the southeastern shoreline of the Caspian Sea in the Gomishan Wetland area, which has led to the degradation of this valuable ecosystem. The analysis of shoreline extraction in 1995 and 2019 shows that the rate of shoreline changes in the study area is not uniform, and the displacement of the shoreline increases from south to north between the Turkmen port and Gomishan, with the exception of the Gorgan River estuary area, where shoreline regression of (-136 to -1072) meters is observed in the Khajeh Nafas region. The maximum shoreline displacement of 7.8 kilometers occurred in the northern part of the Gomishan Wetland, with a length of 7781 meters. According to the leveling data (Figure 1). The decrease in the water level of the Caspian Sea has been the main factor in recent years, leading to the drying out of the water body and shoreline of this coastal wetland. (Figure 4) depicts the amount of shoreline displacement in the study period, and (Figure 5) represents the number of changes based on the south-to-north transects drawn in the study area. The results of the field observations show that the Gomishan Lagoon has completely dried up, and its aquatic environment has turned into muddy areas (Figure 6). Over time, the growth of Salicornia Europa species on these muddy sediments has transformed the environment into a salt marsh (Figure 7). The change from a lagoon sedimentary environment to mudflats and salt marshes has led to the deposition of different sedimentary facies over the coastal landforms.

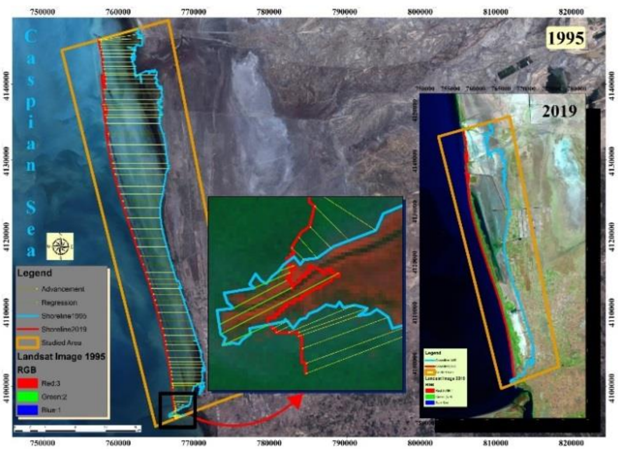

Figure4. The displacement of the shoreline of Gomishan Wetland , 1995 & 2019

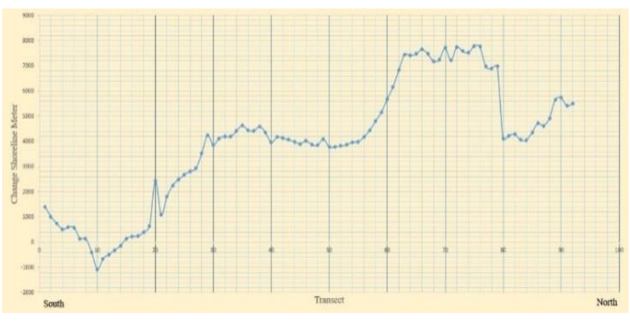

Figure5. The displacement of the shoreline of Gomishan Wetland from 1995 to 2019

landforms. The drying up of the lagoon has resulted in the development of mud cracks in the silt-clay sediments of the past sedimentary environment. These mud cracks provide a substrate for the growth of Salicornia plants, which are adapted to dry and salty environments (Figure 7). The transition from aquatic ecosystems to land, coupled with the growth of coastal vegetation, has paved the way for domestic animals to graze. As a result, the fishing practices that were once common in this area have given way to animal husbandry (as shown in Figure 7). Field observations indicate that the sedimentary environment changes from mudflats to sandbanks when moving from east to west along the edge of the Caspian Sea (Figure 8). Additionally, (Figure 9) shows the surveyed data points.

4. Discussion

As stated in the results of this study, a significant difference in the rate of coastline retreat and advance is observed along the studied area, resulting in imbalanced morphological changes in different sections of the coast. As evident from the satellite image processing maps for 1995 and 2019, the coastline displacement shows an increasing trend from south to north, which may be due to a decrease in the slope of the northern coast in the studied area [37]. In addition, two influential factors have increased the rate of coastline advance: the Gorganrud River mouth carrying annual sediment and the sandy barrier of Bay Gorgan acting as a dam that reduces the force of coastal currents, has increased the rate of coastline advance in the southern section within the sea. The average rate of decline of the Caspian Sea water level during 1995-2019 was about 6 cm, and the water level of the Caspian Sea has decreased by 150 cm in the last 24 years [16]. The quantitative and qualitative impact of wetland and sand environments around Gorgan Bay during the mentioned time are very different, and with the process of wetland drying, terrestrial ecosystems have quickly replaced aquatic ecosystems [16]. The behavioral response of coastlines to sea level fluctuations depends on important natural criteria such as average shore slope, embankment width, type and texture of coastal sediments, rate of change in sea level, coastal landforms, the intensity of tidal currents, and the energy of the waves [38]. The rate of shoreline displacement in Gorgan Bay is also a function of the topography of the wetland bed and the dry coastal area, where the highest intensity of shoreline shifts occurred in the western and northeastern regions of Gorgan Bay [16, 8]. Gorgan

Bay and Gomishan Lagoon are suitable dynamic systems for analyzing the impact of Caspian Sea water level fluctuations on the environment of coastal areas [16]. In the past, Gomishan Lagoon was completely dried up due to the decrease in the water level of the Caspian Sea between the 1930s-1978, and now, similar hydro morphological conditions have occurred for Gorgan Bay [16, 8]. The forecast shows that under the scenario of decreasing Caspian Sea fluctuations, Gorgan Bay will move towards complete drought by 2023 due to the closure of its connection [39]. Studies by Khoshrovan et al. in 2019 have shown that changes in the water level of the Caspian Sea affect the extent of variation in the coastal habitats of Gorgan Bay.The sandy beaches of the southeastern margin of the

Figure 6. Landform formation of mud flats on the dry bed of Gomishan lagoon and the development of mud cracks on them

Figure 7. Landform change of mud flats to salt marsh with the growth of Salicornia plant on the mud bed left over from Gomishan Lagoon

Figure 8. Change of the sedimentary environment of mud flats to sand tongue on the edge of the Caspian Sea coastline in the western part of Gomishan Lagoon

Figure 9. Illustrate the plotted points, salt flats, and dried-up environments.

Caspian Sea along the northeastern part of the Miankala Lagoon and the shallow marshes at the western end of Gorgan Bay have experienced the greatest changes between 1995-2019 [13]. During this time, the most important ecological events in Gorgan Bay and Miankala Lagoon were the conversion of coastal lagoons to salt marshes and the change of aquatic ecosystems to dry land [13].The fluctuations in the water level of the Caspian Sea also affect the extent of Gomishan Lagoon. Over the last three decades, a large area of Gomishan Lagoon has dried up, leaving only narrow marshes and salt marshes in some places. In 1994, Gomishan Lagoon was about 171 square kilometers in size, but by 2014, its area had decreased to 58 square kilometers, and it completely dried up in 2015 [2]. Previous studies have shown that seasonal changes in the water level of the Caspian Sea directly affect the hydrological regime of Gomishan Lagoon. For example, from January to July 2000, the area of Gomishan Lagoon increased from 130 to 165 square kilometers, equivalent to 35 square kilometers [2].The rapid changes in the sea level of the Caspian Sea have significant impacts on the coastal lagoons located in the southeastern part of the sea [30]. This research confirms that the amount of coastline variability in the studied area is very different, and the physical vulnerability of Gomishan coastal Lagoon depends on the geometric structure of its beach. The northern region of Gomishan has experienced high levels of drought and coastline displacement, while the central and southern parts have been less sensitive to changes in water level.The rapid displacement of coastlines in the northern part of Gomishan has caused the disappearance of suitable conditions for the entry of Caspian Sea water into the Lagoon, resulting in its complete drying since 1995. Field observations show that the decrease in the water level of the Caspian Sea has caused the formation of clay flats (Figure 6) and salt marsh landforms (Figure 7). The Salicornia plants gradually cover the bed of the mud flats, leading to a change in the landform from mud flats to salt marsh. With the extensive growth of plants adapted to the dry and salty environment, the area has become suitable for livestock grazing, which the natives of the region use effectively. Coastal sediments along the east-to-west direction change from very fine-grained facies of clayey silt belonging to mud flats to coastal sands, and the border between them is clearly defined (Figure 7). The rapid rate of shoreline displacement in the northern part of Gomishan Lagoon leads to a significant reduction in water column depth in communication channels, preventing the proper exchange of water between the Caspian Sea and Gomishan Lagoon. This causes many environmental problems in the southeastern region of the Caspian Sea.Based on a comparison of shoreline displacement between 1995 and 2019, the study area can be classified into three groups. The first group is characterized by the highest degree of shoreline displacement and encompasses the coastal region in the northern portion of the Gomishan Lagoon, within the timeframe of the research conducted (1995-2019), alterations to the shoreline in this area ranged from 4051.9 to 7781 meters. The second classification pertains to the coastal area situated in the central portion of Gomishan, where the degree of shoreline displacement from 1995 to 2019 was observed to be between 3782 and 6160.5 meters. Finally, the third group includes the shoreline in the southern portion of Gomishan up to Bandar Turkman with a shoreline change equivalent to that of 2205 meters during the study period.However, it should be noted that the only exception observed in the studied area pertains to the displacement of the Gorgan River mouth coastline, which shows a retreat of (-1072) meters towards the coast during the timeframe of the study (Figure 10). Furthermore, at the estuary of Gorganrud River, we observe erosion and sedimentation resulting from the collision of river flow with sea currents. Figure 10 and Table 1 illustrate the amounts of coastal erosion and sedimentation at the mouth of Gorganrud River.

Table 1. The area of erosion and sedimentation in the estuary of Gorganrood River between 1995 and 2019

Characteristic	Value
Sedimentation	37.4 [*ha*]
Erosion	25.1 [*ha*]

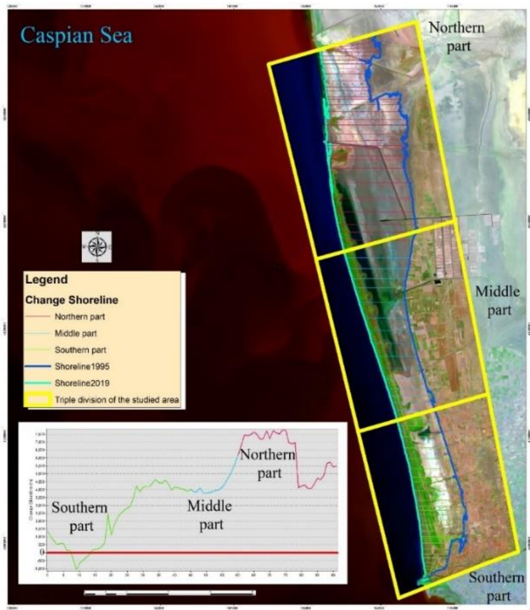

Figure 10. shoreline displacement measurement in the southern, central, and northern regions.

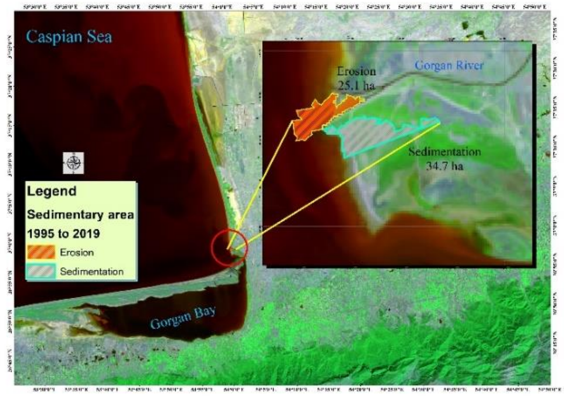

Figure 11. Spatial location of erosion and sedimentation at the mouth of Gorganrud River from 1995 to 2019

5. Conclusions

The study of the displacement of coastlines is conducted to determine the physical vulnerability of sea coasts and their catchments. The different responses of coastlines to sea level fluctuations are good natural indicators for evaluating the variability of habitats and the shape of physical parameters of coastal areas. The high level of sedimentation in 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 [23]. The results of this research indicate that the different coastal areas of Gomishan Lagoon have shown different morphological behaviors under the influence of the Caspian Sea water level decrease, and the intensity of the variability of the coastlines was a function of the geometric structure of the beach and the rate of Caspian Sea water level decrease. The drying up of Gomishan Lagoon caused the formation of coastal landforms such as mud flats and salt marshes in a large area of the region. The northern part of the Gomishan Lagoon experienced the highest degree of shoreline displacement during the period of 1995-2019. As a result, the Lagoon and coastal marshes have completely dried up, resulting in a shift from aquatic to dry ecosystems. The results of this research are used for comprehensive conservation management programs aimed at restoring and improving the ecological conditions of Gomishan Lagoon. For the comprehensive management of the studied area's coastlines, it is necessary to focus on areas with severe physical vulnerability resulting from the decrease in the water level of the Caspian Sea. Continuous control of the rate of quantitative and qualitative changes in the coastal habitats affected by the fluctuations of the water level of the Caspian Sea can reduce environmental challenges in existing coastal Lagoons. The effectiveness of remote sensing techniques, such as the NDWI index, for coastal studies has been confirmed, particularly regarding the extraction of coastlines for studying morphological changes. These techniques have proven to be highly effective in analyzing and monitoring coastal regions, providing valuable insights into the changes that occur over time.

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