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Morphological changes in the southern coasts of the Caspian Sea using remote sensing and GIS

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ABSTRACT

Coastal areas are continuously under the regional changing and interaction of land-sea resulting in the short and long terms deformation. Study of beach morphology has been one of the most important issues in coastal engineering research projects. Managing and controlling the shoreline changes and behavior are essential for all marine projects and integrated coastal zone management policy in such environments. In the present study, Guilan Province region was selected and an analysis of the coastal zone behavior was carried out based on the available satellite images. According to results, we estimated the bed level changes and also submerged area, resulting from a rise in sea level at different locations in the study area (from Anzali Port to Boujagh National Park) and compared them with those obtained from the satellite images. The results were presented graphically and changes in shorelines were estimated using ETM+ sensors and OLI images from 2002 to 2013 which can be used for site selection and design of marine structures and establishing a data base for the coastal zone in the study region. Laplacian filter was applied to satellite images to establish the shoreline and to clarify the effect of ports and coastal structures constructed in the study region on beach and shoreline morphological changes. This study is a combination of remote sensing and GIS systems with field surveys on the ground. The innovation of this work is the application of Laplacian filter for shoreline detection and estimation of the sediment deposition area by calculating the distance between the observed shorelines. This will lead to the better understanding of the effect of coastal structures on the beach morphology using satellite images. The results show the remarkable changes occurred in the shoreline due to the environmental and human-based effects during the eleven years period. The present study can be considered as a contribution to the existing knowledge of the coastal process in the study area and referred to as a basis for the future coastal research projects.

Key words: Caspian Sea, change detection, coastline, GIS, laplacian filter, remote sensing.

INTRODUCTION

Coastal areas are known as important features on the earth's environment. Investigation of the coastal zone dynamics has received much attention nowadays, particularly due to the population residing in the coastal area and the global venation of water level in the oceans. Because the water level in large basins is one of the main elements in controlling their dynamic behavior, such investigation can greatly affect the human communities residing within coastal areas. Therefore, any study

related to the water level fluctuation and its effect on coastal morphology can be of great importance to establish a solid-based background for environmental and engineering projects located in coastal areas.

The Caspian Sea is the largest enclosed body of water in the Earth by a surface area of 372000 square kilometers and a volume of 78200 cubic kilometers. The lake accounts for 40% to 44% of the total lacustrine waters of the world. It has a maximum depth of about 1025 meters. It is divided into three distinct physical regions including northern, middle and southern Caspian. The southern Caspian is the deepest, with a depth over 1000 meters and account for 66% of the total water volume (Firoozfar *et al.* 2001).

The Guilan Province is located in the southern coast of the Caspian Sea where the existence of the Sefidroud delta and Anzali Port make this area very important (Fig. 1). The coastal zone in this area is mainly formed and covered by sand, which is the main reason for rapid changes in coastal morphology (Firoozfar *et al.* 2001). Therefore, the remote sensing technology which is a very powerful tool in monitoring and change detection process, can be used and applied in this area for detecting changes in coastal areas within time intervals with a reasonable level of accuracy.

The effects of sea level rise on coastal morphology covering the current study area have been investigated by different researches as reported by Short (1999). The results of the measurements on the southern coastlines of the Caspian Sea especially the Anzali region shows a parabolic behavior of sandy coasts in this region which is compatible with the Dean's equilibrium profile (Dean 1991). Sea level rise which cause the variation of equilibrium beach profiles is one of the most important issues on coastal engineering projects. Investigation of sea level rise conditions and its impacts such as beach drowning, ruining farm lands, destructive environmental effects, are the factors which should be considered by governments dealing with these subjects. Some of the factors which cause the sea level rise are atmospheric such as rain fall, climate changes and tectonic movements (Nairnand Southgate 1993). The dramatic sea level rise of the Caspian Sea (about 2.25 meters since 1978) has caused serious concern to all five surrounding countries. Flooding over the coastal zone has ruined buildings and structures such as roads, beaches, and farm lands. Moreover, sea level rise may cause changes in: beach morphology, hydro chemical regimes of river mouths, sediment depositions, and groundwater characteristic. It is very important to prepare a coordinated work plan on joint activities of the Caspian Sea littoral countries to tackle its level rise problems. The assessment of the role of various factors in sea level changes is essential to be able to develop predictive models (Haghani & Leroy 2016).

Due to the rapid Caspian Sea level changes which has been observed during the last century, it is absolutely essential to provide a data-base for each coastal zone. One of the most important zones of the southern Caspian coastlines is the north of Iran.

Recently, Investigation of coastal change detection using remote sensing has been performed and reported by different researchers. Alesheikh *et al.* (2007) examined current methods of coastline change detection using satellite images and proposed a new procedure based on a combination of histogram thresholding and band ratio techniques. Muthukumarasamy *et al.* (2013) applied the remote sensing method to a particular coast in India demonstrating the erosion and accretion areas in that region. In another recent work, Gutierres & Teodoro (2015) studied the beach hydromorphology using remote sensing analysis of a coast in Portugal indicating the capability of remote sensing techniques to assess the coastline behavior. Also, Kannan *et al.* (2016) studied the shoreline changes of Nellore district in Andhra Pradesh coast in India, as well as the quantity of the erosion and accretion rate using multi-temporal resolution satellite data (TM & LISS III, IV) and geographic Information system

(GIS) for a period of 25 years from 1989 to 2015 (Afsoos Biria *et al*. 2014 and Bird 2000).

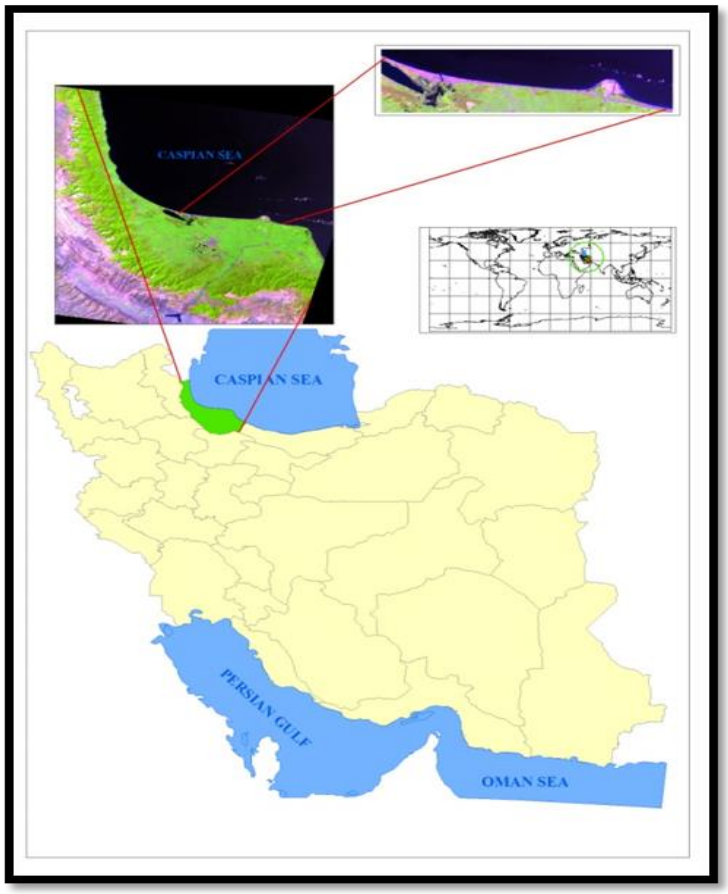


Fig. 1. Location of the study area.

Data and Modelling

Prediction of coastal morphological changes as sea level fluctuates is not easy due to a number of difficulties. On one hand, predictive models are not being reliably generated due to lack of knowledge of the interaction between coasts and energy sources. On the other hand, a model which is developed to forecast the behavior of a particular coast cannot be applied to another because natural processes depend on coastal features which differ from one coast to another. Fig. 2 shows the Bruun's first theory about beach profile geometry (Bruun 1962). Later in 1962 Bruun proposed that the equilibrium beach profile does not change in response to sea level variations (Bruun Rule). In his view, in the case of sea level changes only a given volume of sand will move from the upper part of the profile and this volume will lie over the lower part of the profile. the accumulated volume is equal to the eroded volume (Bruun 1962). Based on the Bruun Rule, since the shore normal geometry of beaches remains unchanged under sea level rise conditions, the amount of shoreline retreat can be calculated if the amplitude of sea level rise and the form of the original profile are known. This is a geometric model and can be applied if assumed geometric rules are valid.

Fig. 3 shows the Caspian Sea level rise history for a period of 64 years based on the report from the Ports and Marine Administrations of Guilan Province, 2015.

Recently, the Integrated coastal zone management (ICZM) procedure is carried out in the southern coasts of the Caspian Sea (Pak & Farajzadeh 2007). The main aim of this research is to identify the coastal problems and minimizing the impacts of different affecting factors on the coastal environment. The important factors affecting the shoreline

changes can be categorized into the two main groups of natural-based and human-based elements. According to Winarso & Budhiman (2001), coastal zone monitoring is an important task in sustainable development and environmental protection. For coastal zone monitoring, coastline detection in various times is essential. Coastline is one of the most important linear features on the earth's surface, which has a dynamic nature.

The present study emphasis on the two factors which are believed to have the remarkable effect on coastal changes named as current pattern and sea level regional changing as well as construction of ports or coastal structures. Remote sensing is used to detect the changes and help to manage and predict the behavior of the selected coasts.

Fig. 4 shows some samples of the selected targets in the study area. The coasts are mainly made of the sand, hence the intrusion of sea water inside the shorelines is clear. Also, Fig. 5 shows the typical coasts of the Anzali Trade-Industrial Free Zone which clearly indicates the effect of sea level drawdown and the resulting sedimentation in the shore.

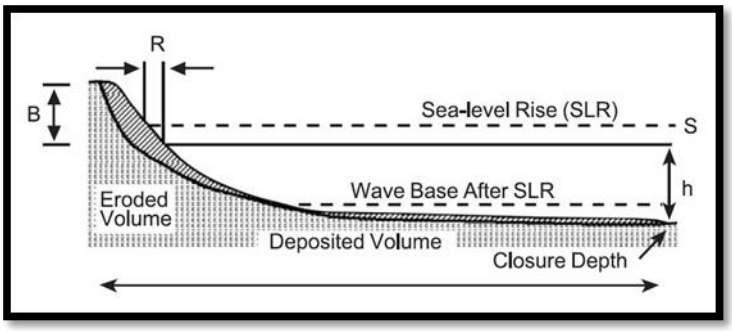


Fig. 2. Shoreline erosion under rising sea level conditions, the Bruun Rule (Bruun, 1962).

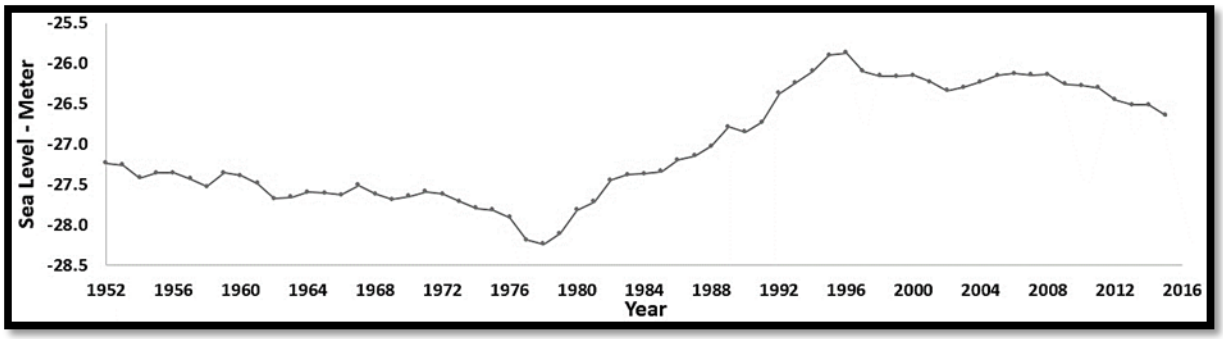


Fig. 3. Sixty years of the Caspian Sea level changes according to the high seas level (Ports and Marine Administrations of Guilan Province, 2015).

Fig. 4. Samples of the coasts which are located in the Southern Caspian Sea.

Fig. 5. Typical coasts of the Constructed Trade-Industrial Free Zone (Photos are taken by authors).

MATERIALS AND METHODS

Study Area

This study uses remote measurement and Landsat +ETM8 and OLI satellite images to analyze the southern coast of the Caspian Sea in an eleven years period between 2002 and 2013.

The length of coastline in the studied region is about 75 kilometers which is extended, from the north of the Anzali Wetland to Boujagh National Park (Fig. 6). The importance of this region is due to the existence of Anzali and Boujagh wetlands which are the Middle East largest ground-water parks as well as the existence of the largest port in southern coast of the Caspian Sea and also Anzali Trade-Industrial Free Zone in the study area (Haghani & Leroy 2016).

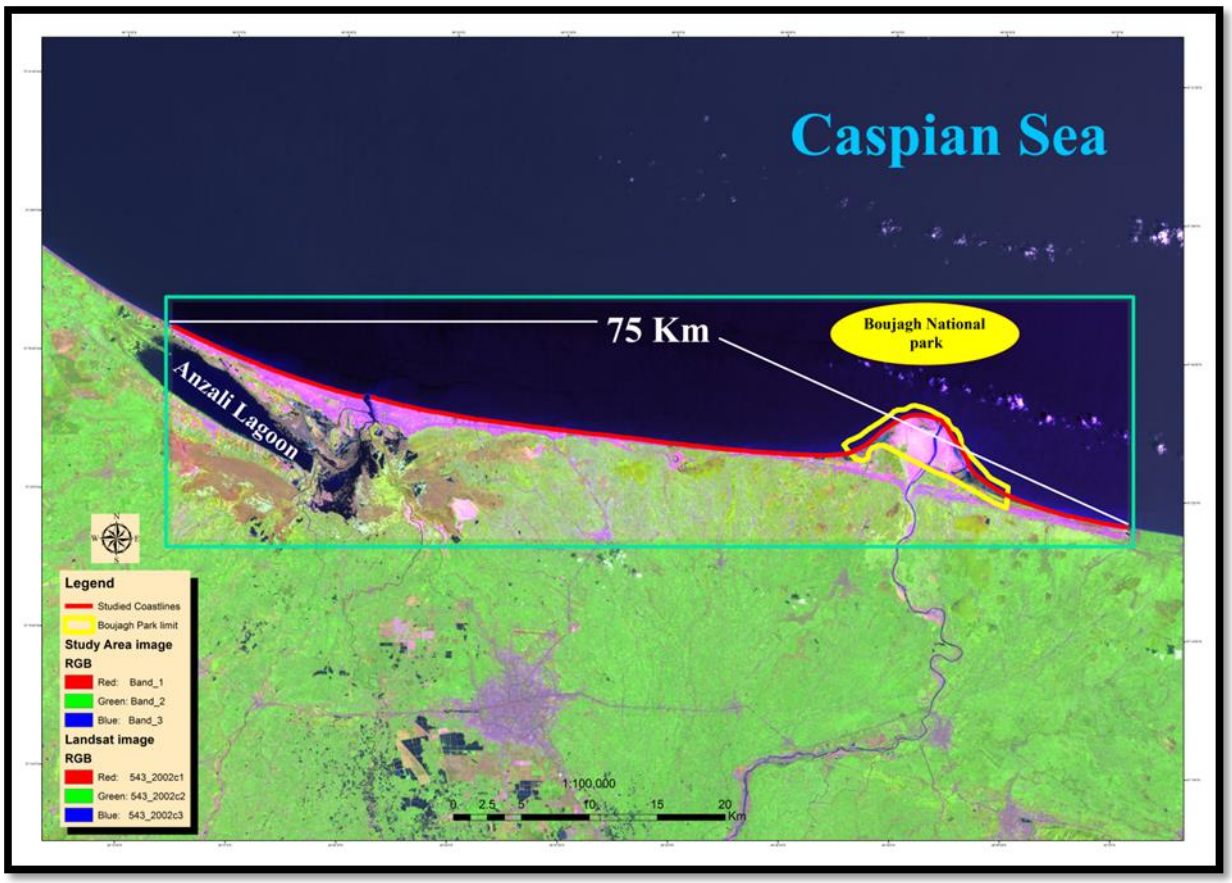


Fig. 6. Color composite of Landsat satellite images of the study region for different coastal structure locations.

Methodology

In the present study, geometric correction, radiometric and atmospheric corrections were initially performed to determine the shoreline changes using Landsat imagery. In order to achieve a better visual interpretation, colour composite of 5,4,3 bands were created and Laplacian filter was used for better resolution

of coastal strip, then coastlines were detected for 2002 and 2013. Laplacian filters are non-directional ones because they enhance linear features in any direction in an image. A gradient operator is a commonly used edge detection process.

In their simplest form, they can be seen as the result of taking the second derivative (Pak & Farajzadeh 2007). Following enhancement of images using Laplacian filter in the periods of 2002 to 2013, the shorelines were plotted and then the distance between these two lines exhibiting the morphological changes, were measured, followed by achieving the changes in shorelines (Fig. 7). Finally, using the polygon of the shorelines, the area of sedimentation was estimated during the mentioned period.

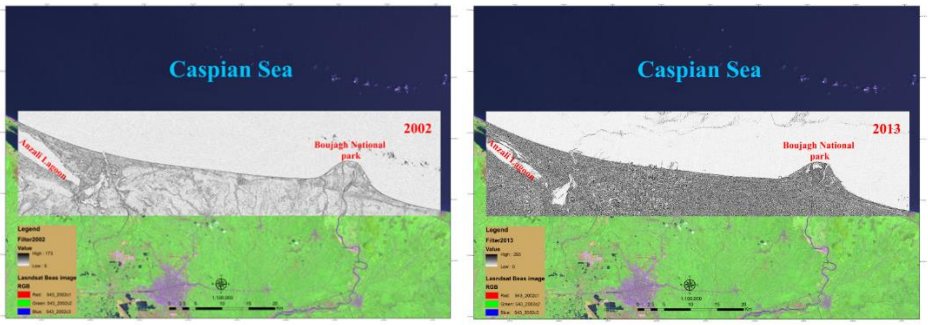


Fig. 7. Shoreline configuration using Laplacian filter from 2002 to 2013.

RESULTS

The remote sensing and GIS studies on the Caspian Sea coastline provided a classic study, input, process, and output of information and maps. The aims of this study were to determine the position of erosion and sedimentation in the coastline along with the natural factors in the photography of two periods, as well as to determine the location of sedimentation and erosion. The Caspian Sea in Guilan Province and its impression on the morphological transformation of the coasts were reviewed in two periods. The water proceeding in coastal areas of Guilan Province plays a fundamental role in geomorphological transformations as well as deposition of coastal units and transformation in their position. The erosion and deposition phenomena were concentrated mainly on specific areas, across the Caspian coast and coast lands which have been transformed under the influence of these processes, the division was carried out from a geomorphic point of view and same maps were provided. Deposition of sediments in the region, due to environmental conditions, result in different geomorphic forms such as ponds and coastal swamps (Bird 2000). The summary of investigation in study area shows deposit morphology bars. Based on the field survey and the conclusions derived from it, changes occurring in the units of erosion result from various processes like coastal erosion, sedimentation, the creation of new units of erosion, and human activities in the field of building ports, roads, cities, and coming into being of small ponds behind sand dunes and changes in the coastal morphology (Neshaei *et al.* 2011). Fig. 8 shows the location of port structures inducing morphologic changes in the study area by comparing their situations before and after the construction, addressed later in the maps.

Notably, since the pattern of the currents in the Caspian Sea is from North-West to South-East (Fig. 9), expectedly, the majority of materials were deposited at the left end of the structures.

DISCUSSION

A comparison between the two resulted coastal line in the images show that in a period of eleven years, the shoreline has made a change of 60 to 500 meters with respect to beach slope. A remarkable amount of the

changes have taken place surrounding the expanded Anzali Port as well as the newly-established Caspian Trade-Industrial Free Zone and Zibakenar pier (Fig. 10).

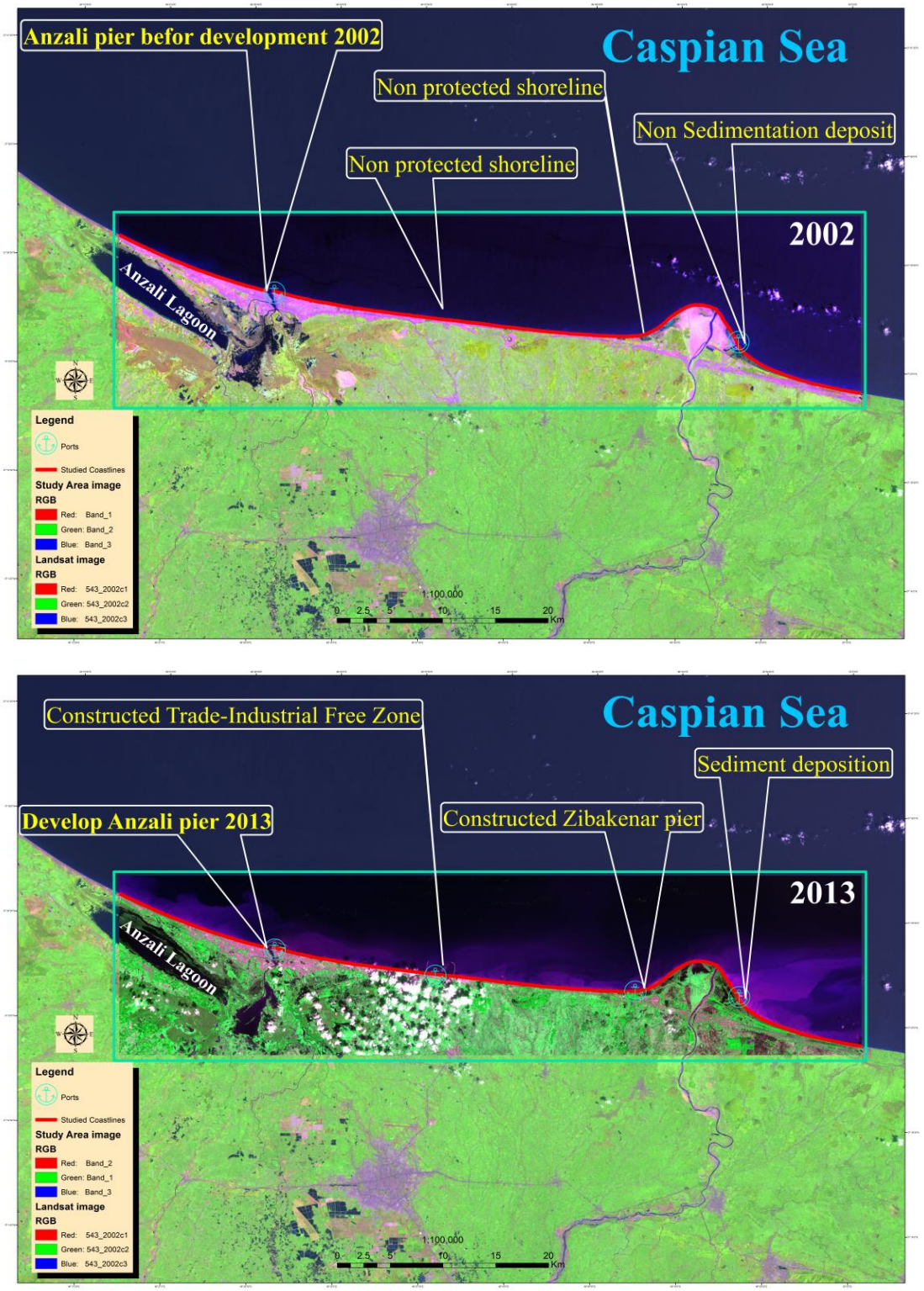
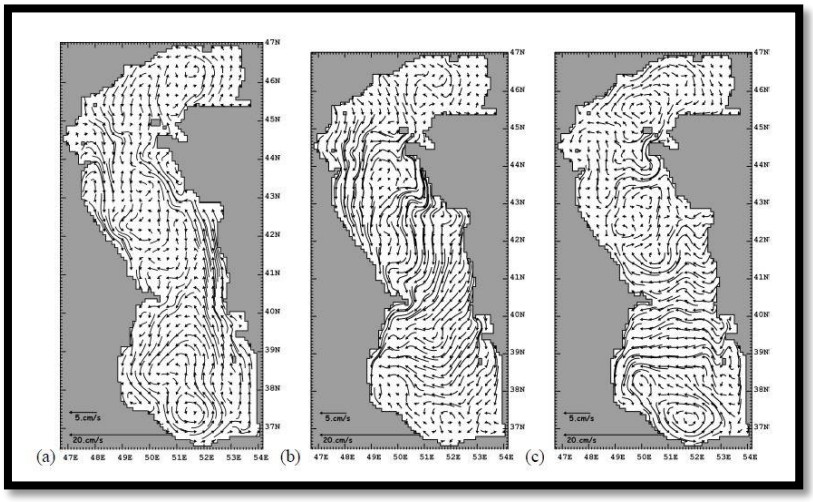


Fig. 8. Location of port construction in the study area before (above map) and after (below map) the development.

A



B

Figs. 9 (A & B). Pattern of the coastal current in the Caspian Sea. A: Schematic map of the Caspian Sea currents (Lednev, 1943), B: Monthly schematic maps of mean sea surface currents (cm s^{-1}) in December **(a)**, May **(b)** and August **(c)** (Ibrayev *et al.* 2010).

Fig. 11 shows the magnitude of morphologic changes in the shorelines as a result of the satellite image data analyses based on prepared maps in the present study. The morphological changes are obviously dominant in the coasts located beside the coastal structures (Hoque *et al.* 2001).

The total area of the deposited sediments was 7.83 km^2 including 60 to 500 meter of intrusion zones (Figs. 12 - 13).

Interestingly, the retreatment of the shoreline seems to be observed in the northern west of Sefidroud delta. These observations are consistent with those reported by Afsoos Biria *et al.* (2014) who measured the amount of sediments deposited on the back face of a groin located in Sefidroud delta, then compared it with the empirical and numerical models, concluding that the construction of protective structures has a considerable effect on coastal morphology.

The reason why the majority of changes in the shorelines is of the accretion type could be associated with the resignation of the sea water level during the last decade based on Fig. 3.

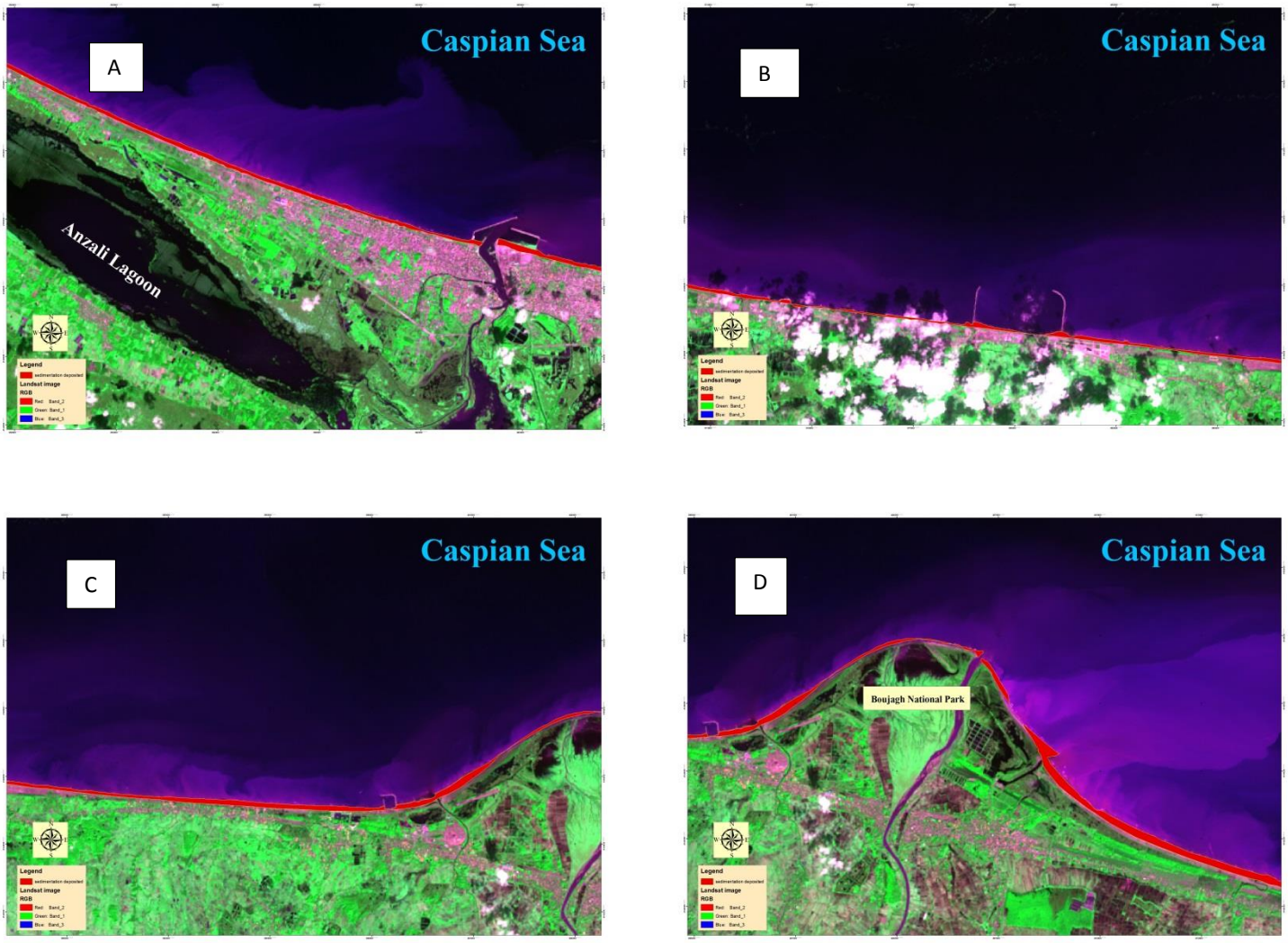


Fig. 12. The volume of sedimentation deposited in the study area. A:Anzali Port; B:Free Zone; C:Zibakenar Port; D:Sefidroud Delta

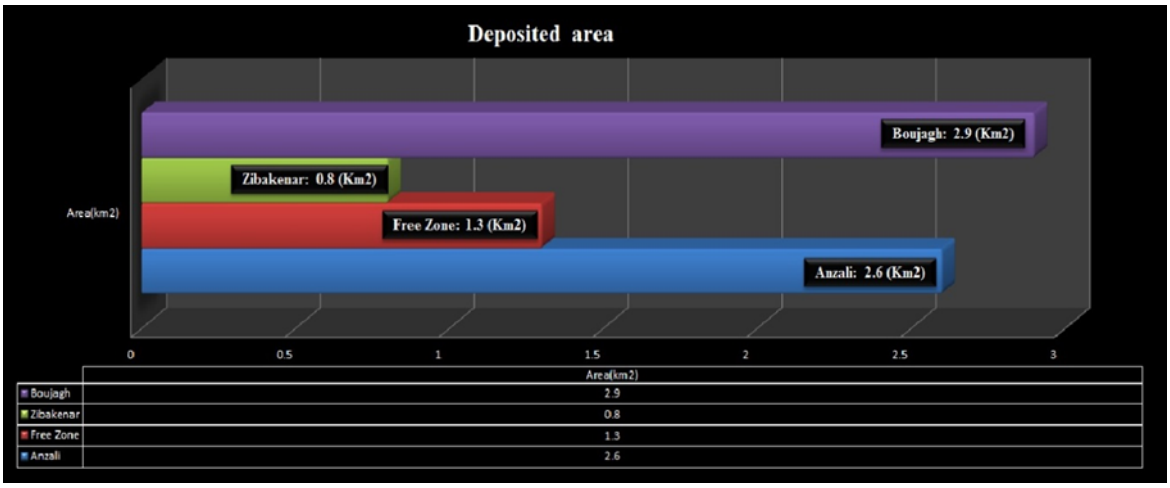


Fig. 13. Magnitude of deposition in the shorelines of the study area.

The Sefidroud delta includes the Boujagh National Park which is the largest one in the Middle East registered by the Ramsar convention (2009). It is a broad, shallow

embayment of the Caspian Sea and associated with deltaic wetlands at the mouth of the Sefidroud River. By a variety of marine, coastal and inland freshwater and brackish wetland types, the site is important as a spawning and nursery ground for fish, and as a breeding, staging and wintering area for waterfowl. The site is used for recreational and commercial fishing including aquaculture, livestock grazing, reed-cutting, hunting, rice farming and recreating tourism.

The park is impacted by waterfowl hunting, transport pressure from commercial fisheries, recreation, uncontrolled summer grazing and illegal fishing. Decreased wintering waterfowl has been associated with fishing and hunting disturbance. A management plan for this area is under development. Boujagh National Park is an important bird area and is considered as a potential site for the reintroducing the Siberian Crane. The original Ramsar site (1975) was significantly enlarged in September 17, 2009. (Winarso & Budhiman 2001). The Sefidroud delta, is the most famous of its type in southern coast of the Caspian Sea. The eroded deposits and the shore line under the alluviation of Sefidroud delta (next to Caspian Sea) is clearly distinguishable in Kiashahr region, particularly in the location of Boujagh national park. The completion date of this delta is complicated, so that the estimated age of the new Sefidroud delta seems to be 250 to 530 years (Khoshraftar 2006). The importance of this delta is also because of its remarkable impact on the environment. Every year some immigrant winter birds from Siberia enter and reside for some times in this area which is covered by many different plant species.

The morphological changes of this delta in the shoreline during the study periods are more than other areas which seems to be associated with the construction of ports and marine structures as well as general pattern of currents in the southern parts of the Caspian Sea (Haghani *et al.* 2016).

Assessment of the morphologic changes detected during an eleven-year period using remote sensing and GIS in the study area, clearly shows that the combination of natural and human-based factors has caused remarkable changes in the shoreline and coastal patterns particularly in the vicinity of ports and man-made structures. Considering the fact that this area is one of the most important ecosystems in southern part of the Caspian Sea due to the existence of the national park, it is possible to plan the further works in such a way that the minimum environmental impacts are applied to the area.

In particular, the average distance of about 15 kilometers between the coastal structures affects the configuration of the coastlines around the structure at least about 300 meters from each side. Based on the maps produced from satellite images, it is evident that the morphology of Sefidroud Delta has been changed during an eleven-year period. So, it can be concluded that we face a residue movement from the west side of the Delta to its eastern side. One of the most important reasons for this change, is coastal currents in the Caspian Sea.

Notably, due to the pattern of the coastal current in the Caspian Sea, which is from west to east, it is expected that almost 527 meters sediments are deposited behind the Kiashahr Port (Fig. 14). Figs. 15 - 16 are the results of field observation in the study area which clearly show the erosion and variation of shoreline during different seasons.

Figs. 17 - 18 show the morphologic changes of the Sefidroud estuary during the study period indicating the accretion in the western side equal to 12104 m^2 while in the eastern side we have 8994 m^2 erosion and 41442 m^2 accretion, respectively.

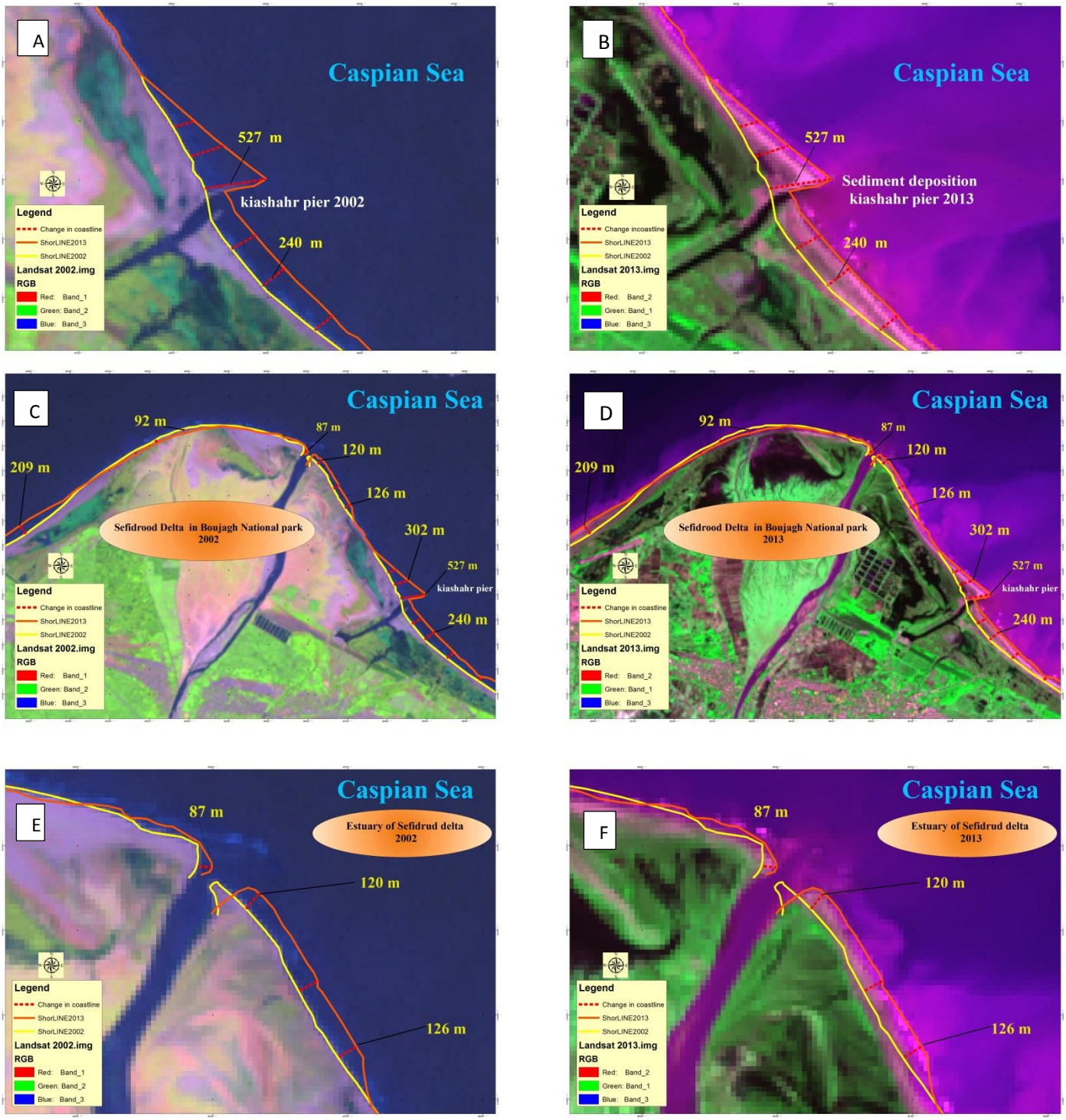


Fig. 14 (A-F). Comparison of changes in the Sefidroud Delta in the study area: A: Kiashahr Pier 2002; B: Kiashahr Pier 2013; C: Boujagh National Park 2002; D: Boujagh National Park 2013; E: Estuary of Sefidrud Delta 2002; F: Estuary of Sefidrud Delta 2013.

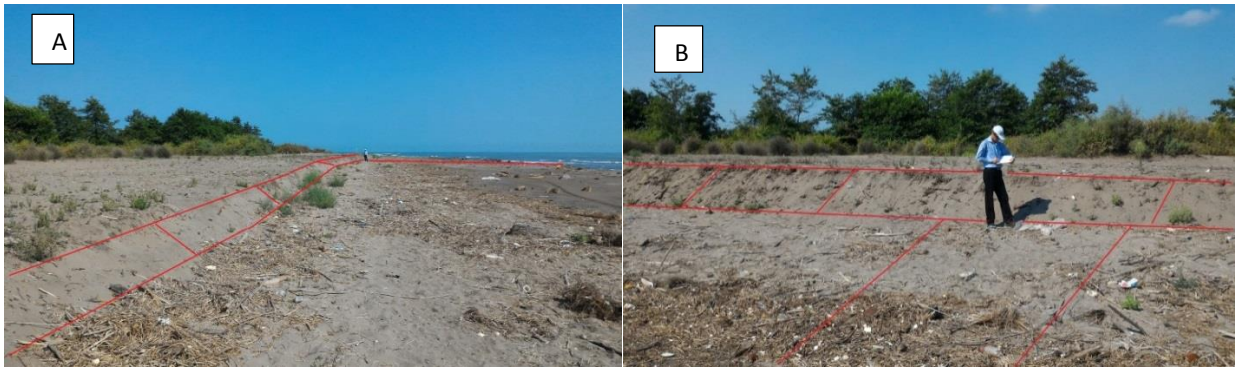


Fig. 15 (A, B). Change of the coastline in the summer and winter (red lines show the seasonal variation of the shoreline). A: Amount of seasonal variation of change shoreline; B: Height of seasonal variation of change shoreline.

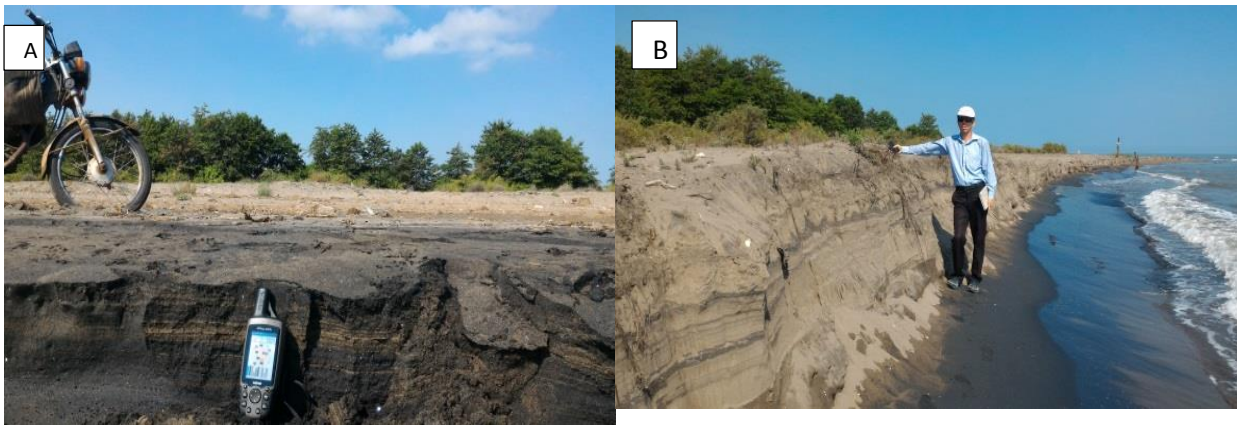


Fig. 16 (A, B). Shoreline erosion. A: Amount of erosion in the shoreline.; B: Amount of erosion near the estuary.

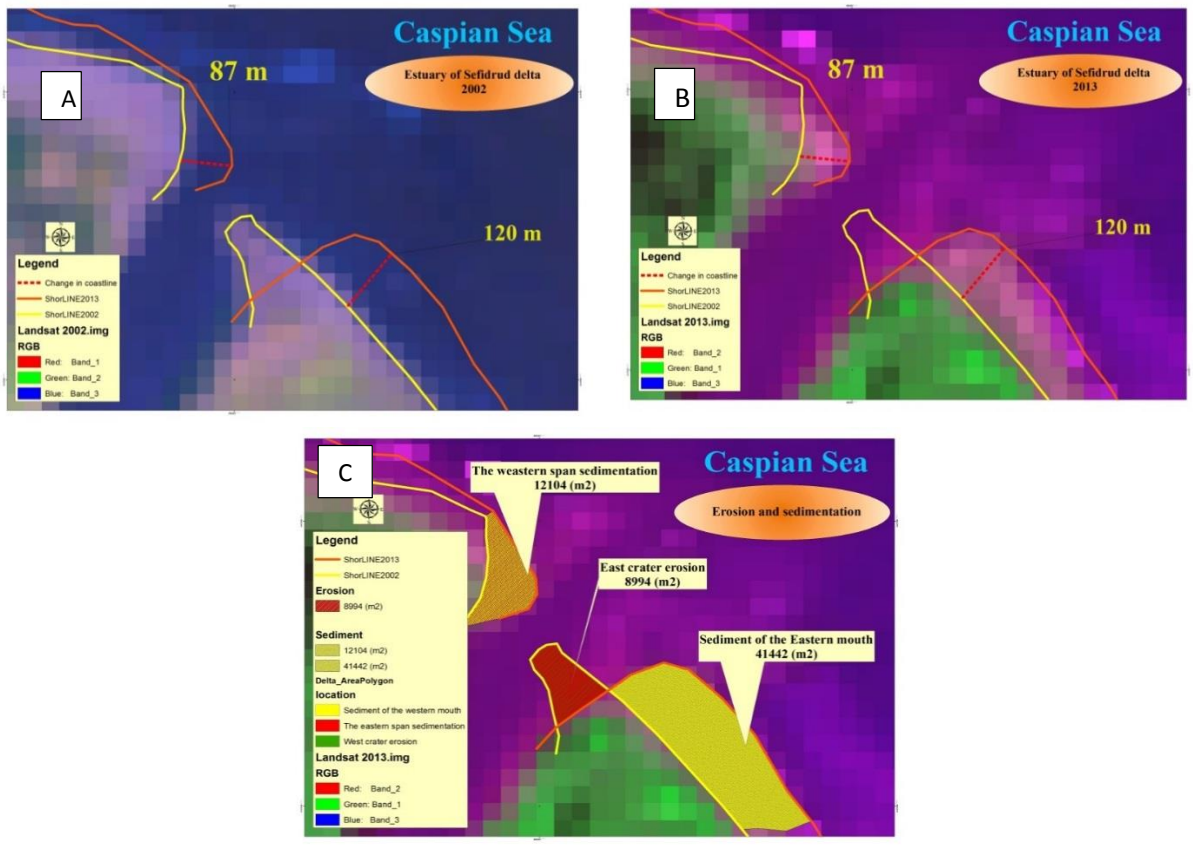


Fig. 17 (A-C). Morphological changes of the Sefidroud estuary. A: Estuary of Sefidrud delta 2002; B: Estuary of Sefidrud delta 2013; C: Erosion and sedimentation in the estuary.

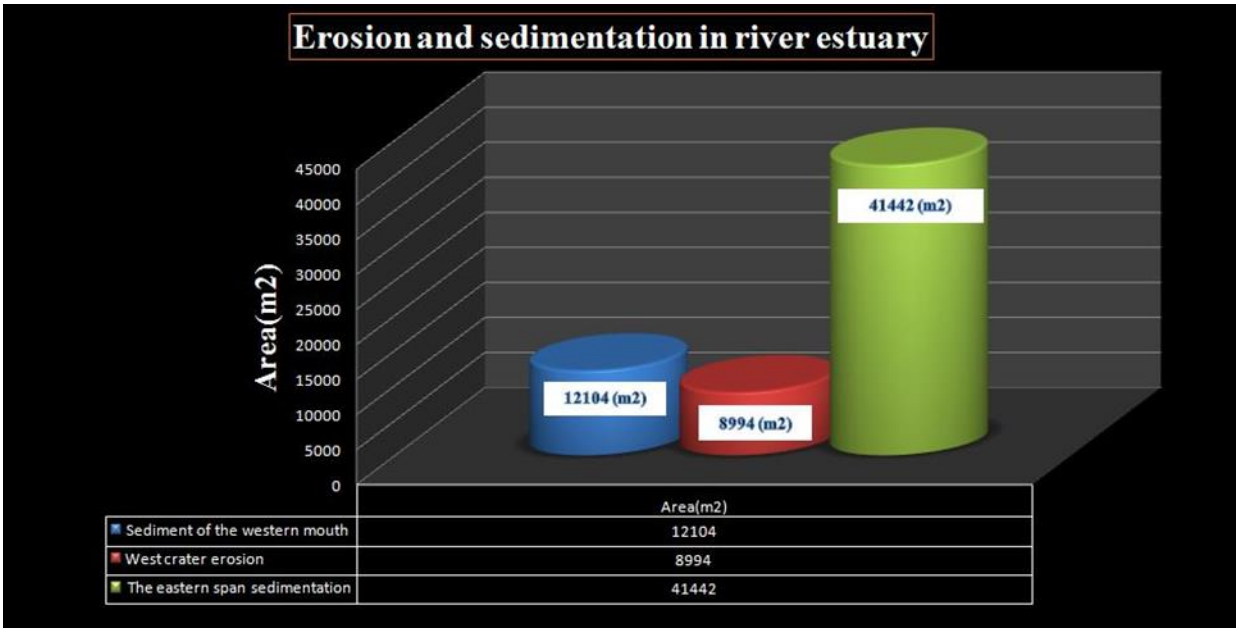


Fig. 18. Magnitude of changes in the shorelines of the estuary (m^2).

This study is a combination of remote sensing and GIS methods with field observations on the ground. The innovation of this work is application of Laplacian filter for shoreline detection and estimation of the sediment deposition area by calculating the distance between the observed shorelines.

Summary and conclusions

We can conclude that construction of any port or marine structure in the studied region can have a remarkable effect on coast morphology by means of changing the sediment transportation pattern. This will in turn, change the morphology of coasts by alternate erosion and accretion processes in combination with the periodical water level fluctuations which is in agreement with the results reported by Khoshravan & Mammadov (2017). Finally, the outputs of images processing using remote sensing and GIS in the study region clearly verify the results of reported documents indicating the effect of water level fluctuation on coastal morphology.

In summary, the following facts can be emerged from the results of the present work:

It is evident that the coastal area in the southern part of the Caspian Sea, particularly in the study region, has faced a remarkable change during the period of measurements and the results of remote sensing and GIS monitoring clearly verify and detect this observation.

The results obtained from the survey are consistent with the predictive models of shoreline morphology changes due to both natural and human-based factors applying to the coasts, particularly in the vicinity of pier in Boujagh National Park which contains the majority of sediment deposition.

To construct any port or marine structures along the coastal area in the study region, it is important to tack the environmental impact of such man-made structure and its interaction with the sea-level fluctuations into account. Results of this work can be of great help to optimize the location of the coastal structures using remote sensing and GIS for site selection in such a way that the minimum destructive impacts occur in the nature. This will lead us to the better understanding of the effect of coastal structures on the beach morphology using satellite images.

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تغییرات مورفولوژی سواحل جنوبی دریای کاسپین با استفاده از سنجش از دور و سیستم اطلاعات جغرافیایی

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چکیده

مناطق ساحلی به طور پیوسته در معرض تغییرات ناشی از روابط متقابل خشکی و دریا در کوتاه مدت و بلند مدت‌اند. مطالعه تغییرات مورفولوژی سواحل از مهمترین موارد مورد تحقیق در پروژه‌های مهندسی سواحل در سال‌های اخیر بوده است و پایش این تغییرات برای انجام پروژه‌های دریایی الزامی است. در مطالعه حاضر با انتخاب بخشی از سواحل استان گیلان، رفتار ساحل در این منطقه با استفاده از داده‌های ماهواره‌ای مورد بررسی قرار گرفت. بر اساس نتایج به دست آمده تغییرات خط ساحلی و مناطق غرقاب شده ناشی از افزایش سطح تراز آب دریا در مناطق مختلف بود (از بندر انزلی تا پارک ملی بوجاق) که با نتایج حاصل از تصاویر ماهواره‌ای مقایسه شد. نقشه‌های تولید شده از تصاویر ماهواره‌ای ETM+ و OLI در سالهای ۲۰۰۲ و ۲۰۱۳ تغییرات مورفولوژی خط ساحلی و مقدار آن را مشخص کرد. برای افزایش دقت استخراج خط ساحلی از تصاویر ماهواره‌ای، فیلتر لاپلاسین بر تصاویر اعمال شد. این مطالعه ترکیبی از سنجش از دور و سیستم اطلاعات جغرافیایی همراه با اندازه گیری‌های زمینی است. از نکات قابل توجه در این مطالعه کاربرد فیلتر لاپلاسین در استخراج خط ساحل و تخمین مساحت رسوبات انباشته شده در این ناحیه است. استفاده از تصاویر ماهواره‌ای ما را در درک بهتر تاثیر سازه‌های دریایی بر تغییر شکل ساحل یاری می‌کند. نتایج نشان می‌دهند که تغییرات رخ داده در سواحل مورد مطالعه در اثر عوامل محیطی و انسان-ساخت در طول بازه زمانی یازده ساله قابل توجه بوده است. مطالعه حاضر می‌تواند گامی موثر در جهت افزایش اطلاعات در زمینه مهندسی سواحل در منطقه مورد مطالعه استفاده شود و پایه‌ای برای تحقیقات آتی به حساب آید.

*مؤلف مسئول