

The Impact of Coastal Modification and Caspian Rapid Sea Level Change on the Amirabad Coastal Zone

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Abstract We measured the impacts of coastal modification on beach erosion and beach retreat conditions, selecting the Miankaleh Region as an example of a complex high-pressure free zone with high levels of engineering and tourism activity. Nine sampling transects, stretching from the shoreline to a 10 meter depth, were defined and 36 sediment samples were collected from the sea bed at depths of 1, 3, 5, and 10 m. After conducting laboratory tests, data were analyzed in terms of sediment dynamic parameters such as grain size, sediment size distribution, mean, median, skewness, kurtosis, standard deviation, and mineral composition. Beach structure and morphodynamic conditions were assessed in the Miankaleh region, by means of satellite image interpretation and field surveys. Results show that from 1978 until the present the average rate of beach retreat rapidly increased due to sea level rise and coastal constructions that have resulted in a progressive increase in sea level height in this region. Erosion vulnerability hazards have also increased in the eastern part of the study area and deposition processes have developed in the western Amirabad region.

Key words: *Caspian Sea, Coastal Erosion, Iran, Morphodynamic, Sediments*

1 INTRODUCTION

Although seasonal and natural changes in hydrodynamic energy levels can lead to changes in sediment dynamics and accumulation rates (Horikawa, 1988), human activities also have the potential to modify beach sedimentary morphodynamics and structure (Seymour and Guza, 2005). Clear links between human activities and sedimentary system responses occur in areas where coastal construction associated with ports and harbors has taken place and in restricted areas where hard coastal engineering structures have been erected (Hatfield and Cioppa, 2010). The main problems posed by human intervention arise

where construction has taken place inside the active profile of the coastal zone. For example, the replacement of fore dunes with solid infrastructure renders such infrastructure vulnerable to erosion during storm conditions (passive intervention) (Quartel and Wroon, 2008).

Human alteration of sediment movement (active intervention) occurs in association with structures (for example, groynes and jetties) that alter wave and current patterns, intercept sediment transport, and prevent sediment from being eroded (for example, seawalls) (Nordstorm, 2000). Human activities may also impede the ability of the shoreline to adjust to rising sea

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levels. Previous experience shows that there have been historical changes in human use of coastlines (Nordstorm, 2000). The first impact was probably vegetation destabilization in coastal dunes. Navigation posed the next major human threat to natural coastal morphodynamics. Increased levels of human utilization and occupation of the coast are the other human interventions that affect sediment dynamics in coastal regions. Human interventions are thus mainly associated with harbor construction, coastal land reclamation and seawall construction. At the time of writing, each one of, or combinations of, these interventions has taken place within the study area. The degrees to which beaches are modified by humans depends on the degree to which they modify primary parameters such as wave height, wave period, sediment size and current conditions. Human impacts on wave height normally relate to structures that cause additional wave breaking, shoaling and refraction. Structures designed to lower or eliminate wave height, as in harbor construction, will substantially reduce wave height at the shore and change consequent beach morphodynamics and sediment size distribution (Khoshnavan, 2007). Horikawa (1988) provides an excellent overview of morphological changes caused by the construction of structures. Such changes provide an insight into the modification of beach processes and the nature of platforms that develop following the placement of a particular structure. In this study we evaluate the response of the Amirabad coastal zone to beach modification by human activities. The monitoring of beach morphodynamic changes, sediment dynamic variation, and beach geometry have been the most vital targets in this research. Port implementation, power plants units, fishery harbor, sediment dredging and extraction, construction of oil and gas reservoir tanks and urban buildings are the most important human activities taking place within the coastal zone of the study area. The above-mentioned coastal engineering constructions, built in the study area,

have unfortunately caused some morphodynamic problems such as beach lowering, edge erosion, potential grain size changes, separation of dune and beach systems and new littoral current and sediment transport mechanisms.

2 REGIONAL SETTINGS

The Caspian Sea, the largest closed basin in the world, is adjacent to the northernmost part of Iran and surrounded by other countries, such as Azerbaijan, Russia, Ghazaghestan and Turkmenistan. From the morphological point of view the Caspian basin area is subdivided into three zones: the northern region (80,000 km) (with average depth 5–6 m, maximum depth 15–20 m); the mid-region (138,000 km) with a maximum depth of 788 m; and the southern region (168,000 km) with an average depth of 325 m (Fig. 1). The southern basin holds more than 65% of the Caspian Sea water and reaches a maximum depth of 1025 m. The southern coasts of the Caspian Sea, as a tectonical depression and sub oceanic floor, are the most vital in terms of water resources management and coastal engineering implementation. Prevailing waves — which move in a west to east, or a north western to south eastern direction — occur during an annual cycle, with maximum frequency during the cold period, have a vital effect on beach erosion and coastal vulnerability (Khoshnavan, 2007). The most important geopolitical characteristics of the southern coasts of the Caspian Sea, as a trading bridge between Asia and European countries and the Caucasus region, have attracted the attention of the Iranian government for the development of ports and harbors for shipping, fishery and energy transit. For this reason, some multi-purpose ports have been developed along the southern coasts of the Caspian Sea, such as Astara, Anzali, Noshahr, Feridounkenar, Babolsar, Amirabad and Bandar Turkmen ports. The Amirabad complex is a free zone in the most important trading and government region on the southern coast of the

Caspian Sea. Petroleum and gas reservoirs, tanks, a fishery harbor, power plants, trading, shipping, and pipelines for energy transit are the most important coastal engineering constructions that have dominated the region. This has resulted in intensive beach modification and this region has

also been affected by a rapid sea level rise in the Caspian Sea from 1978 onwards. The degree of erosion processes and beach vulnerability has also been exacerbated by coastal engineering constructions and natural events such as progression phenomena in the region.

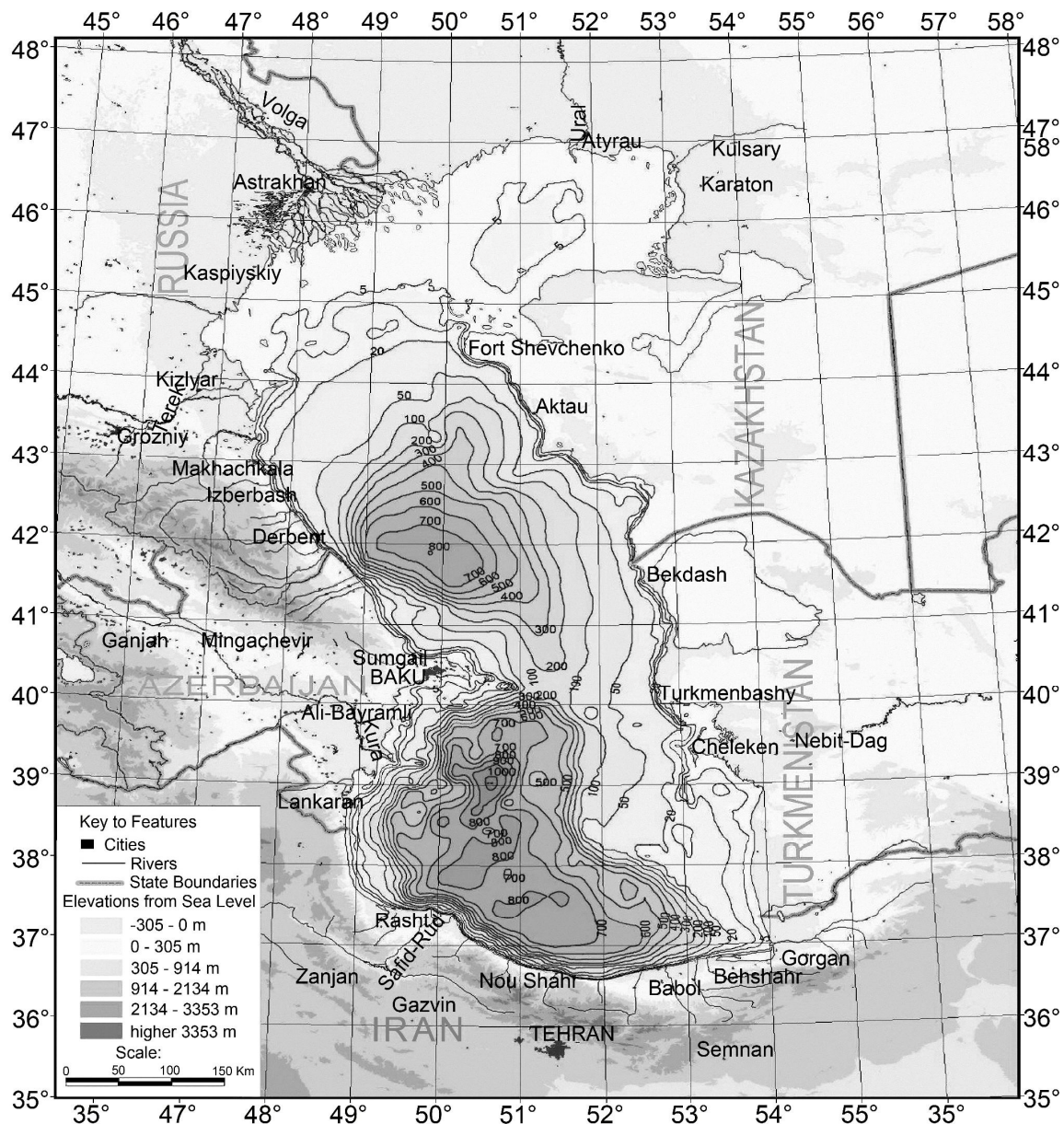


Fig. 1 Caspian Sea geographical position map (Khoshnavar, 2007).

3 STUDY AREA

The Amirabad Complex free zone is situated between 36.85393–36.89504 north latitude and 53.20494–53.46488 east longitude. An enlarged map of a 20 km stretch of coastline close (70 NE) to the Miankaleh protected lagoon area is illustrated in Fig. 2, which also shows the position of the Neka River, the Miankaleh Spit and the Zaghemarz Logoon. From the environmental and coastal management

perspective, this part of the Caspian Sea is a vital region, particularly because of its biodiversity, freshwater reservoirs and large populations of migrant birds. The study area was selected because because the region includes many important areas, described above, that can be investigated for the purpose of monitoring environmental parameters and coastal morphodynamic structures.

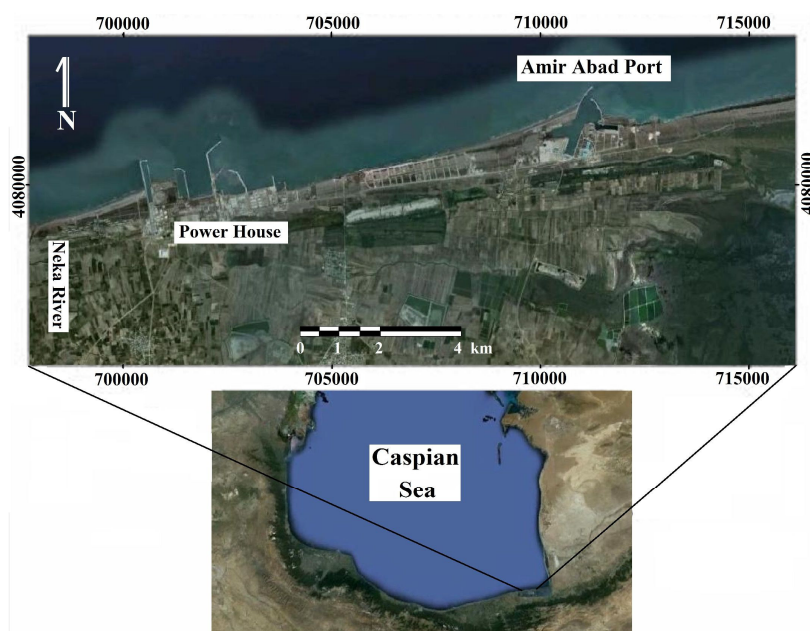


Fig. 2 Study area location map and stations position.

4 MATERIALS AND METHODS

Nine transects were selected for sampling (EL1, EL2, EL3, EL4, WL1, WL2, WL3, WL4 and WL5) for the purpose of surveying the Miankaleh region, a complex free zone with a high level of coastal engineering and tourism activity resorts. The characteristics of each transect, which extended from the shoreline to a 10 m depth, were defined and 36 sediment samples were taken from the sea bed (at depths of 1, 3, 5, 10 m) along each transect. Hydrographic profiles were produced for each transect. The beach structure and morphodynamic conditions in the Miankaleh

region were measured by means of satellite image interpretation and field surveys. The following procedure was adopted during surveys carried out in the Amirabad region. First, the beach zone of the study area from the backshore to the shoreline and from west to east of Amirabad harbor was evaluated by using satellite images and aerial photographs. After that the Amirabad beach area was classified into three zones (West, Central and East) (Fig. 2) and geometric measurements taken to determine the beach profile from the backshore to the shoreline at seven stations (Table 1). All beach structure parameters — such as shoreline,

beachface steepness and strike, and sand dune and berm zone geometry conditions — were measured. Sedimentary dynamic parameters — such as grain size, sediment size distribution, mean, median, skewness, kurtosis, standard deviation, and mineralogy composition — were also determined. Information was analyzed using MS Excel software.

5 BEACH STRUCTURE AND MORPHODYNAMIC IMPACT

Satellite image data interpretation shows that different areas surrounding the Amirabad port have different responses to depositional and erosion processes. The central part of the study area (Zone 1: approx. 11 km length) is the most important region in terms of beach modification, since all human activities have been concentrated in this region. Satellite images indicate that the sediment accumulation and accretion processes are dominant at the west side of study area (Zone 2). This process causes shoreline strike displacement of about 5 degrees in an anticlockwise direction, towards northeast (Table 1). The erosion rate has developed at the other side (middle and beginning of the eastern region). The maximum beach erosion and shoreline retreat occur along the Sadra ship industry to the Amirabad port (Zone 1). In this region a rapid rise in sea level, together with beach modification, has caused sand dune destruction and the beach has retreated for a distance of about 900 m. This is the most vulnerable beach zone in terms of erosion hazards. The rate of beach retreat decreases with the distance from the Amirabad port toward the eastern area. The groynes of Amirabad Port have acted as sediment traps at the west side but could develop erosion processes as the beach retreats further on the other side. The maximum beach structure change was assessed at the central area. The

retreat condition as a major impact was determined at the near east side, and the accretion processes was found to be spreading along the west side of study area. On the whole, the beach structure response to coastal modification can be summarized as follows: shoreline displacement at the west part about five degrees toward the Northeast; an increase in the steepness of shoreline and beachface at the west side between Goharbaran and the Neka River mouth in the middle region of the study area (Zone 1), and a decrease in the amount of shoreline steepness toward the eastern area (Zone 3). Beach sediment accretion at the western part of Amirabad port was developed by a longshore current along a west to east direction (Zone 2). The steepness of the sea floor along the nine transects in the study area was measured by hydrographic analysis. Data results indicate that the sea bottom steepness varied for each transect. The minimum steepness, with highest depth limitation between 2.5 and 10 m, occurred at the EL3 and EL1 transects and the maximum steepness was determined at the WL1 and WL4 transects (Table 2). The Western part of the study area is therefore steeper than the Eastern part. This however changed at depths of 2.5–5 m. The highest and lowest sloped areas were located at the EL1 the EL2 transects, respectively (Table 2). Other stations have the same situation at these depths. On the basis of these morphodynamic records, it can be concluded that the maximum stress from waves and currents are concentrated at the eastern part of the Amirabad port along the EL1 transect. Wave diffraction and refraction at the first line of the eastern transect has resulted in a much greater bed slope in at this area at the 2.5 m depth limitation than is the case in other transects.

Table 1 Beach structure and morphodynamic condition of study area.

Stations	Zone	Geography Location		Shoreline Strike (°)	Dip (°)	Morphodynamic Indexes	Berm Length (m)
		x	y				
1	West 2	36.83018	53.19349	62NE	14	Small beach cusp, sand trap, without erosion	94
2		36.83575	53.22120	70NE	22	River mouth and delta, beach squeeze and low erosion	85
3		36.83576	53.22121	75NE	7	River mouth, accretion	90
4	Central 1	36.85000	53.39999	65NE	22	Erosion terraces and big beach cusp, sand dune depletion, high	0
5		36.85799	53.40037	65NE	22	High erosion terraces & sand dune depletion	5
6	East 3	36.86160	53.42260	65NE	20	Big beach cusp & low erosion terraces, berm destruction	10
7		36.86837	53.47748	65 NE	12	Small sand trap, without erosion	100

Table 2 Sea floor profiling geometry in the shallow zone.

Line	Zone	Name	Geography Position		Distance 2.5–10 m	Steepness 2.5–10
			x	y		
1	West 2	W15	36.85393	53.20494	2242	0.004460303
2		W14	36.85537	53.22362	1986	0.005035247
3	Central 1	W13	36.868	53.30491	2573	0.003886514
4		W12	36.87717	53.34044	2591	0.003859514
5		W11	36.88008	53.36546	2156	0.004638219
6		E11	36.8868	53.3866	3234	0.003092146
7	East 3	E12	36.8893	53.4063	3228	0.003097893
8		E13	36.8936	53.4296	3326	0.003006615
9		E14	36.89504	53.46488	2714	0.003684598

6 MORPHODYNAMIC IMPACT

The impact of Amirabad beach modification morphodynamic structures has caused various responses within different regions of the coastal zone in the study area, resulting in the development of several morphodynamic structures such as beach cusps, erosion scars

and terraces, sand traps and rips (Fig. 3a–d). The morphology relates to the distance from the Amirabad port and other beach constructions that have been concentrated in the middle part of the study area (Zone 1). For instance, ordinary beach cusps with a moderate sinusoid shape (as an elongated ellipsoid) have developed

on the beach face of the western part of study area (Fig. 3a). There is no erosion structure in this region. The beach profile is normal without any erosion scars and it contains sand dunes, shore forest, a wide berm, and a low steepness of beachface. On the other hand, in the near to middle part of study area all morphodynamic structures were completely deformed, as explained above (Fig. 3b–d) and well-developed beach cusps, parallel sand traps and erosion terraces were observed at this location, which indicate that the beach erosion vulnerability is at its maximum degree in this

region. Erosion processes have developed towards the eastern region and morphodynamic structures gradually change to normal conditions (similar to the shapes seen in the western region) at the end of eastern part of study area (Zone 3). The increase of beach cusp radius frequency on the beach face, increase in erosion terraces elevation and shoreline steepness, shore plants destruction, and strike displacement are the most important indicators of the high degree of vulnerability in the middle part of the study area.



(a) Beach cusp condition at the West part of study area (Zone 2).



(b) Beach cusp condition at the East part of study area (Zone 3).



(c) Erosion Terraces at the middle Part (Zone 1) of the study area.



(d) Sand dune destruction at the Eastern part of the study area (Zone 3).

Fig. 3 Morphodynamic structures condition in different parts of study area.

7 SEDIMENTARY IMPACT

Sedimentary analysis was conducted on all previously collected samples along the nine transects (EL1, EL2, EL3, EL4, WL1, WL2, WL3, WL4, and WL5) of the study area. Firstly, all sediment samples from each depth in transects (2.5, 5 and 10 m depths) were compared to each other. Then sediments taken from the same depths were compared to each other. We then determined that three zones in the study area (Zones 1, 2 and 3) behave differently in terms of sedimentary dynamic responses and to beach modification impacts. In the middle region (Zone 1, with high beach squeeze: EL1, WL1) sediment samples from the shoreline to a 5 m depth showed textural irregularities and disturbances (Fig. 4). The lower level of sorting and the high percent of fine particles, especially at the 2.5–5 m depth, is very obvious and a morphoscopy study confirmed erosion scars on the sand grains. As a result, it was found that all points at a 2.5 m depth near to the central part of the study area (WL1, WL2, EL1, EL2) and those collected at the western and eastern parts have different sediment texture ratios to those of other transects (Fig. 4). With depth increasing to 5–10 m, the rate of sediment dynamic variation levels decreased considerably. All points at these depths had the same structure and similar shapes except for EL1 (Fig. 5). The maximum depth limit of beach modification, that impact on sedimentary dynamics, is therefore among shoreline samples up to 2.5 m depth near the Amirabad port, with 4 km length (WL1 and EL1). It can also be observed that the sediments of the western part (WL1 and WL5) are better sorted, with lower finer particles than those from the eastern part. This means that the

velocity of nearshore current in the western region is more developed than that in the eastern region. The sediments of first line at the eastern part of study area (EL1) have certain depositional irregularities and textural disturbances ratios that are different to those measured in other areas (Fig. 4). The high percentage of very fine particles with very low sorting represents an important sedimentary index at this line that has not been previously observed at other points. As a result, the hydrodynamic impact on sedimentary deposition varies from west to east in the study area. The presence of very well sorted sand at the west suggests that this area has a better dynamic current on the sea floor than that measured in the eastern part. At the central part, beach construction impacts cause hydrodynamic condition changes and erosion processes dominated in this area. At further distances east of the central part, the tendency changed from erosion to sedimentary deposition, similar to that observed in the west part (WL3, WL4, WL5, EL3, and EL4). It is therefore clear that sea current velocities decrease from west to east and develop much more in the central part (WL1, WL2, and EL1). The impact of construction at Amirabad on sediment size distribution indicates that the central part has the most irregularities and disturbances. This effect decreased with distance toward east and west (WL3, WL4, WL5, EL3, and EL4). Sediments at all points at depths of 5–10 m were in the same condition and were not affected by beach modification impacts. The high-risk vulnerable areas in terms of erosion hazards were those areas between WL2 and EL2 with a depth of 2.5 m, and the rate of erosion vulnerability increased aggressively toward the east (EL1).

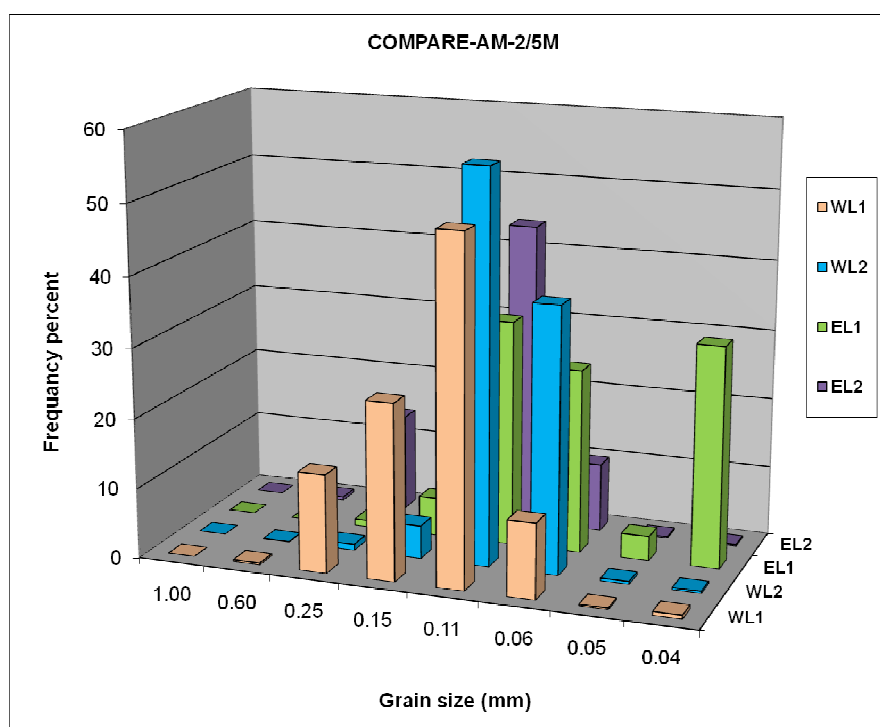


Fig. 4 Sediment size distribution changing along the middle part of study area (Zone 1) at the depth 2.5 m.

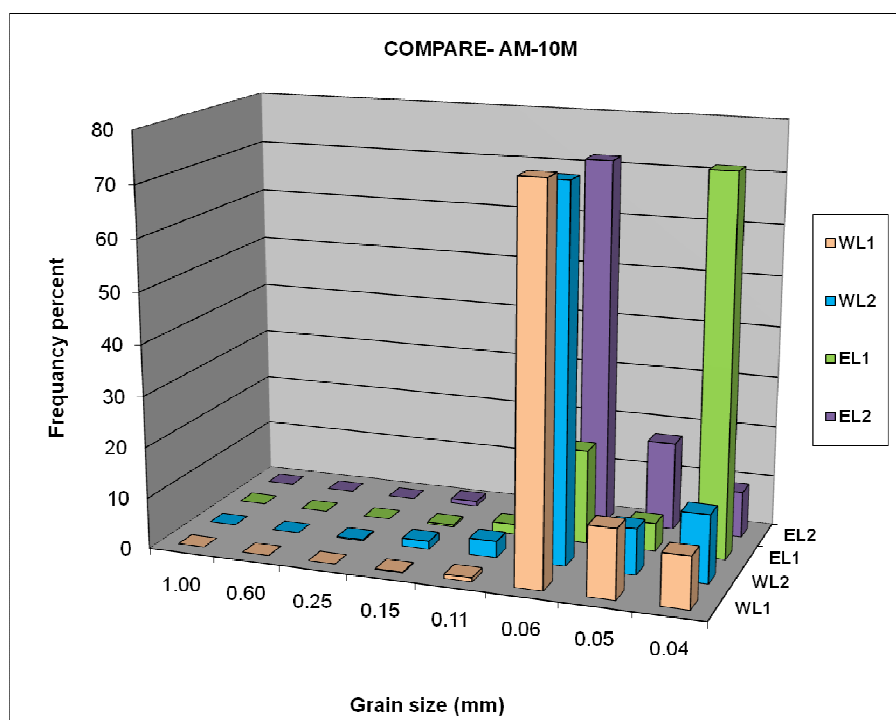


Fig. 5 Sediment size distribution changing along the middle part of study area (Zone 1) at the depth 10 m.

8 CONCLUSIONS

The interpretation of satellite image data indicates that areas at opposite sides of the Amirabad port had different responses to depositional and erosion processes. Beach modification impacts have aggressively developed at the central part of study area (Zone 1): groynes at the Amirabad port have caused sediment accretion at the west side (Zone 2) but erosion processes could develop as the beach retreats on the east side. The rate of beach retreat decreases farther away from the Amirabad port towards the eastern area. Sediment characteristics and beach steepness records indicate that wave and current conditions have changed, due to the presence of harbor groynes at depths of 2.5 m (EL1). A high degree of erosion vulnerability was therefore observed by noting changes in the morphodynamic structure in the middle part (Zone 1). The variability in the rate of sediment dynamic levels decreased considerably with increasing depth, from 5 to 10 m at all stations. The maximum depth limit of beach modification impacts on sedimentary dynamics is along the shoreline to depths of 2.5 m near the Amirabad port, along a 4 km stretch (WL1 and EL1). The degree of erosion vulnerability and erosion hazards increases aggressively from the middle part towards the east (EL1) and the high-risk vulnerable area lies between WL2 to EL2 at a 2.5 m depth

9 RECOMMENDATIONS

It is vital plan to concentrate our attention on conservative methods explanation in the harbors of the southern coasts of the Caspian Sea, particularly the Amirabad port that is situated near the most susceptible lagoon (Miankaleh Lagoon). The use of 'soft' engineering methods, such as beach nourishment and sand dune stabilization, are very important for preventing further sediment

disturbances and for remediation of the eastern part of the study area.

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11 REFERENCES

- Hatfield, R.G. and Cioppa, M.T.. Sediment sorting and beach erosion along a coastal foreland. *Sediment. Geol.* 2010; 31(3/4): 63–73.
- Horikawa, K. Nearshore dynamics and coastal processes. University of Tokyo press, Tokyo, 1988: 522 pp.
- Khoshnavan, H. Beach sediments, morphodynamic, and risk assessment Caspian Sea coast, Iran, *Quaternary Int.*, 2007; 167/168: 35–39.
- Nordstorm, K. F. Beaches and dunes of developed coasts. Cambridge university press, Cambridge, 2000: 383 pp.
- Seymour, R. and Guza, R. T. Rapid erosion of a small southern California beach. *Coastal Eng.* 2005; 52(2): 151–158.
- Quartel, S. and Xroon, A. seasonal accretion and erosion patterns of microtidal sandy beach, *Marine Geology*, 2008; Volume 250(1/2): 19–93.

تأثیر تغییرات ساحلی و نوسانات سریع بر خواص مورفودینامیک رسوبی امیرآباد

همایون خوشروان و سمیه روحانی‌زده

مرکز ملی مطالعات و تحقیقات دریای خزر، مؤسسه تحقیقات آب، وزارت نیرو، ساری، ایران

چکیده در این تحقیق، اثر تغییرات ساحلی روی صفات مورفودینامیک رسوبی در منطقه چندمنظوره امیرآباد به عنوان ناحیه‌ای شاخص برای توسعه ساخت و سازهای ساحلی اندازه‌گیری می‌شود. با تعیین ۹ محور اندازه‌گیری از بخش شرقی دهانه رودخانه نکارود تا بخش غربی ساحل میانکاله، ۳۶ نمونه رسوبی از رسوبات ناحیه خط ساحل تا ژرفای ۱۰ متر نمونه‌برداری گردید. سپس با انجام آزمایش‌های لازم و بهره‌مندی از نرم افزارهای تحلیل‌گر، وضعیت توزیع دانه‌بندی رسوبات و پارامترهای دینامیکی آنها (میانگین، میانه، انحراف معیار، چولگی، کشیدگی و جورشدگی) محاسبه گردید. با استفاده از تصاویر ماهواره‌ای ساختار ساحل و حالات مورفودینامیکی آن ارزیابی شد. نتایج نشان می‌دهد که از سال ۱۹۷۸ تا حال حاضر میزان میانگین عقب‌نشینی ساحل در اثر افزایش سریع سطح تراز آب دریا و ساخت و سازهای ساحلی به سرعت در این منطقه افزایش یافته است. مخاطرات آسیب‌پذیری فرسایشی در بخش شرقی منطقه مورد مطالعه شدت یافته و فرآیندهای رسوبی در ناحیه غربی امیرآباد توسعه داشته است.

کلمات کلیدی: ایران، دریای خزر، رسوبات، فرسایش ساحل، مورفودینامیک