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Hydromorphology and environmental restoration of Gorgan Bay, the Southeast Caspian Sea

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ABSTRACT

Rapid sea level changing of the Caspian Sea has affected coastal geomorphology and environmental condition of Gorgan Bay since the end of 20th century. The vast parts of the Gorgan bay and Miankaleh Wetland have been dried out. So finding efficient solutions for environmental revival of the bay, compatible with the Caspian Sea rapid fluctuation, was the main aim of the present study. The geomorphological changing of the bay was identified by comparing and interpreting satellite images and field survey. The main results show that the Caspian Sea fluctuation plays a vital role in the bay environment depletion and development during the Anthropocene time and the implementing of secure connection between the bay and the Caspian Sea is the appropriate method for ecological revival of Gorgan Bay.

Key Words: The Caspian Sea, Gorgan Bay, Fluctuation, Geomorphology, Environment.
Article type: Research Article.

INTRODUCTION

The global warming issue is an absolutely accepted concept of the first millennium. Climate change affects the human activity, agriculture and industry as well as tourism (Pezzoli *et al.* 2013). Melting polar ices and increasing the oceans water level are among the most significant mankind concerns. Moreover, it has been predicted that due to 3-degree increment of globe temperature by 2100, the vast parts of crowded coastal cities will be disappeared and inundated (Kont *et al.* 2003; Nicholls *et al*. 2008; Rosenzweig *et al.* 2011; Feng *et al.* 2014). Nevertheless, overall hydrologic response of inland seas, lakes, ponds, marginal bays in northern parts of Africa, Middle East and some other parts of the globe act differently from free ocean water bodies (Khoshravan & Vafaee 2016). Therefore, global temperature increment leads to growth of evaporation rate and precipitation reduction and finally causes drought trend development, through above mentioned regions. This consequently cause drought of vast parts of inner lakes of Iran plateau such as Urmia Lake and also Parishan, Maharloo, Hamoun, Jazmoorian and Gavkhooni wetlands. The Caspian Sea as the biggest closed inland sea in the world also has followed the similar destiny and illustrates the impacts of global warming with various ranges of fluctuations during the 20th century (Kosarev & Yablonskaya 1994; Cazanave *et al*. 1997; Panin 2007, 2014; Kroonenberg *et al.* 2013). As a matter of fact, during two time periods of 1930-1978 and 1995-2020, the Caspian Sea level has experienced severe shrinkage about 3 and 1.5 meters, respectively and as a result, the marginal bays and dependent wetlands have faced an intensive drought (Khoshravan & Vafaee 2016). The drop in the Caspian Sea water level, has reduced the inflow of water to Gorgan Bay and Miankaleh Wetland, and has led to drying up a large part of the western and northeastern extremities of Gorgan Bay overlooking connection channels. Moreover, its environment faced a serious challenge (Khoshravan *et al*. 2019). Despite the lack of proper water exchange between Gorgan Bay and the

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Caspian Sea, the high sedimentation rate of sandy materials under the influence of coastal currents has led to a great amount of sediment load inside Ashooradeh and Chopoghli channels, which cause problems in the hydraulic conditions of these channels (Gharibreza *et al*. 2018). So that about 20 cm of sediments is annually deposited in these areas of Gorgan Bay (Gharibreza *et al*. 2018). On the other hand, the growth of sandy spit in the northern part of the bay has caused the creation of Miankaleh Wetland and sand dunes, hence the bay has been transformed into a low-energy environment by the deposition of fine-grained sand and silt to clay materials (Rezaei *et al*. 2019). Based on the geomorphological evidences and geographical setting, the dunes observed in the Caspian lowland are of parabolic type, which would reflect arid to semi-arid palaeo-environmental conditions (Rahimzadeh *et al*. 2019). Uneven topography of the bay bed has caused the different environmental vulnerability in different areas. Nowadays, the drying of a large part of the western extremity area caused unfortunate conditions especially where it has been the habitat of migratory birds such as flamingos and benthic animals. The formation of large mud flats and salt marshes in these areas is a clear sign of the replacement of the aquatic ecosystem and the various aquatic biotopes by dry lands (Khoshravan *et al*. 2019). Moreover, unprincipled obstruction of surface water, used for agriculture and fish farming, has increased the drying process in these areas. The simulation model results under different water level fluctuation scenarios of the Caspian Sea have shown that due to closure of the bay inlets by 2023, it will progress the complete drought event (Sharbati & Ghanghermeh 2015). Meanwhile, it has been determined that the water level fluctuations of the Caspian Sea and its common hydrodynamic events as boundary flows, storm surges, density flows and river runoffs play a crucial role in morphological deformation of the bay (Port and Maritime Organization of Iran, 2014). The Gorgan Bay has experienced the vast dryness advancing up to complete shrinkage, for several times during geologic history of late of the Quaternary period, but upraising the Caspian Sea water level has revived the bay alternatively (Kakroodi *et al.* 2012). To save Gorgan Bay from extensive drought, it is necessary to provide sufficient information about the sedimentological properties, chemical properties of water, morphology, hydrodynamics and other physical, chemical and ecological parameters of the area. In addition, appropriate recommendations should be proposed to supply the required water through the Caspian Sea or other available water sources using comprehensive information about the hydro-morphological and morpho-dynamic characteristics of Gorgan Bay. Therefore, in this paper, we aim to study the hydro-morphological and hydrodynamic features of Gorgan Bay due to the Caspian Sea water level fluctuations and then appropriate solutions are introduced to environmental revival of the bay, based on the existing facts.

MATERIALS AND METHODS

The Gorgan Bay watershed is one of the most important southern catchments of the Caspian Sea basin with an area about 15000 km^2 consisting of mountainous, sub mountain regions, and coastal plains (Alizadeh 2010). According to the wetland classification conducted in Ramsar Convention (1975), Miankaleh Wetland and Gorgan Bay were classified as type A, the permanent shallow sea water bodies. Gorgan Bay is located at the southeastern part of the Caspian Sea and lies in west-east direction parallel with shoreline (Fig. 1). At the moment, the length of the bay is 44 km and its width at the widest section is about 12 km. The area of Gorgan Bay is 360 km^2 and its maximum water depth is evaluated about 4 m. This marginal depression is separated from the Caspian Sea by Miankaleh sand barrier and is related to the Caspian Sea at the most northeastern end by Chopoghli and Ashooradeh channels (Fig. 1). The morphometric studies on these channels show that the western channel, Ashooradeh, is 2000 m in length, 150 m in width and its maximum depth is about 4 m; while the eastern channel, Chopoghli, is 3 km in length, 500 m in width with a maximum depth about 2 m (Fig. 1). Currently, the vast parts of these channels have been dried out due to the Caspian Sea water level decrease and the water depth has been reached to less than 50 cm, especially in Chopoghli channel, which is a salt marshy area today, covered by halophytic vegetation and completely has lost its efficiency. Various permanent and seasonal rivers are flowing in to the bay from southern and eastern parts of Alborz Mountains, which among them, Gharesoo and Gorganrood rivers at the northeast of the bay are the most important with the average annual discharge and sediment load about 0.5 million m^3 and 3.5 million tons respectively (Afshin 2004). The hydro-geochemical studies of the Gorgan Bay have shown that the amount of water input from the Caspian Sea to the bay has a crucial impact on chemical characteristics of water and sediment deposits, and the effect of rivers is not that much significant (Bashari *et al*. 2015). Given TDS and the ratio of main anions and cations, characteristics of Gorgan Bay and the Caspian Sea water are classified as the same (Bashari *et al*. 2015). The

comparison between water chemical combination of rivers and the average situation of the bay via Piper diagram has shown that the chemical characteristics of all solutions in the bay are controlled by the Caspian Sea rather than the rivers (Bashari *et al*. 2015). The comparison between hydrograph maps of the Gorgan Bay inlet (1999-2000), has shown that the deposition rate at the inlet is so high that only during the mentioned 2 years about 861098 m^3 sediment has been deposited at the inlet of the bay (Gharibreza 2004).

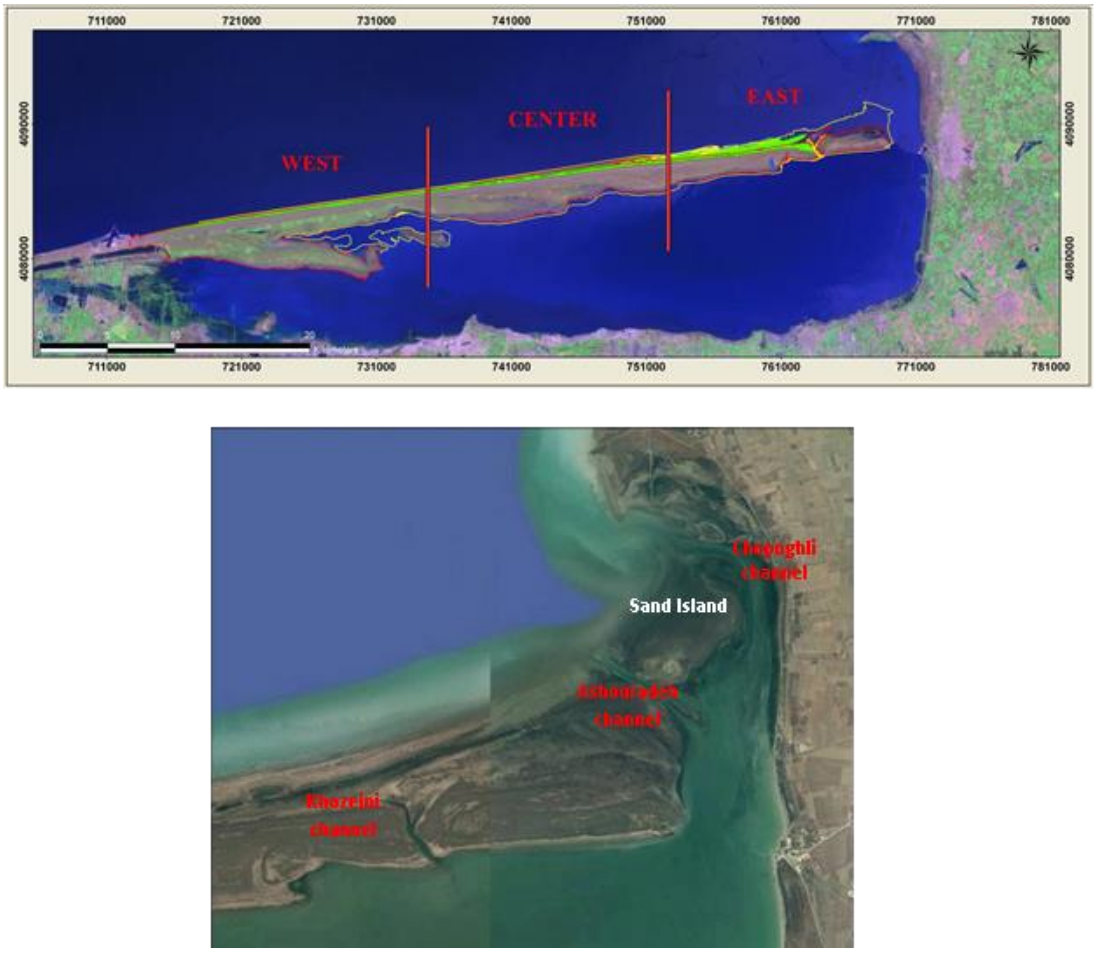

Fig. 1. The Gorgan Bay and Miankaleh Lagoon geographic location maps and three important channels connected to the Caspian Sea.

The current study has been conducted on the base of scientific documentations reviewing, field survey, and satellite images interpretation. At the first step, the special manner of creation of Gorgan Bay has been examined and the most important factors of its geomorphological development have been rebuilt due to geological evidences. The deformation rate of the bay shoreline during various fluctuations of the Caspian Sea has been evaluated by comparing the satellite images of the years 1966, 2004, and 2016. The energy level and important flows in sedimentation process in main inlets of bay, as important factors of depository environment evaluation, have been evaluated through sedimentological studies. The adaption ways with natural circumstances and global warming phenomenon have been finally presented by determining the characteristics of hydro-morphology.

RESULTS

The Gorgan Bay origin reconstructing

Morpho-sedimentological condition of Gorgan Bay shows that this longitudinal depression which is elongated in west-east direction has been separated from the Caspian Sea by Miankaleh island barrier (Fig. 1). As a result, the geomorphological development of the bay is due to the changes which have led to form the Miankaleh spit. The evaluation of geomorphological structure of Miankaleh spit shows that there are geomorphological zones located in north-south direction, such as shore line of the Caspian Sea, sandy beach, active sand dunes, the semi stable and stable sand dunes, late Holocene sandy beaches, brackish marshes, salt marshes, mudflats and coastal

line of Gorgan Bay. Moreover, the morpho-dynamical behaviors of each of these landforms vary in geometric structures, sediments covering and deposition environment from west to east, so this region may be divided into western, central and eastern parts (Fig. 1). Complete profile of the Caspian Sea shoreline can be seen in the western part, just as other coastal regions of central Mazandaran Province. Therefore, the western part is continuation of Caspian Sea coasts in southern parts. Regarding Miankaleh Wetland presence in central part, the geomorphological structures change and the sand dunes are disturbed and outspread in longitudinal direction. The eastern part of Miankaleh island barrier, overlooking the coastal line of the Caspian Sea, is actually a wetland environment, and the sand dunes and old sandy coasts have been structured behind the wetland. Through the west-east direction in Miankaleh area, three active sedimentation environments are definable: marine; marine-wetland and wetland. To date, the geo-morphological evidences are evaluated in order to find a response to this question: When was Miankaleh island barrier formed?

The drowned ship of Afsharieh Era

Considering the Caspian Sea penetration and the erosion of sand dunes, exposure of old ship from the sedimentary depositions of active sand dunes in the coastal parts of Amir-Abad port in year 2002, is a prominent evidence to determine the age of aforementioned sand dunes which are distributed up to terminal eastern parts of Miankaleh region (Fig. 2). The approximate age of the ship is about 250 years contemporaneous with Afsharieh Era (Sortiji 2005). So it can be said that the ship has been drowned when the Caspian Sea water level was high and jointed to the coast as drought increased, and also the sand dunes have been structured on it related to wind procedures. As a result, it is obvious that the Miankaleh sandy active dunes are younger than 250 years and were formed due to water level shrinkage at that era. Notably, the aforementioned ship was exposed from the sand dunes at the level of -26.5 meters from the Caspian Sea (Fig. 2).

Fig. 2. The drowned ship of Afsharieh Era in Western part of the Gorgan Bay-Amirabad Port.

The Holocene marine terraces

Existence of thin layer of soil on stable sand dunes shows their older age in comparison with active sand dunes (Fig. 3). The oldest sedimentary terraces of Miankaleh coast is located near the Gorgan Bay shoreline at the -24 m level which is younger than the -22 m level located in these terraces which were identified before in the southern coasts of Gorgan Bay. Meanwhile, existence of grassland vegetation covering, illustrates the formation of thin layer of soil and stabilization of coastal region after the Caspian Sea retrogression (Fig. 3). As a result, it can be said that the formation of old sedimentary terrace in the southern Caspian Sea coasts, about 2300-2600 years ago during upper Holocene was associated with the last phase of Caspian Sea transgression, which the related evidences may be seen at the central Mazandaran coasts between Larim coastal region and the south eastern parts of the bay in Baghoo-Kenareh area (Kakroodi *et al.* 2012). Nowadays, Miankaleh Peninsula has not been structured the same as that exists at that time and the latest progress of the Caspian Sea up to -24 m level resulted to sandy materials deposition which is the bed formation of the today's Miankaleh peninsula

(Khoshravan 2011). As the last advancing phase of the Caspian Sea was experienced about 500 years ago simultaneously with little ice age (Kakroodi *et al.* 2012), so the formation of Miankaleh spit was a permanent procedure from that time to date, and filling the Gorgan Bay fovea with water due to advancing and retrogressing of the Caspian Sea is related to the fluctuation periods along with water level reduction. The geological evidences have shown that fluctuations range of the Caspian Sea was about 25 m during the Holocene (Kakroodi *et al*. 2012). The results of examined sedimentary terraces of the Caspian Sea, overlooking the Gorgan Bay and Miankaleh spit, shows the water level increment of the sea about 2300-2600 and 500 years ago, and the sandy brown reddish deposits containing weathered materials, plant pieces, plaster and salt in subsurface layers of the bay region belong to 1500 years ago, have proved the vast shrinkage of the Caspian Sea (Kakroodi *et al*. 2012). As a result, during the lower Holocene, in two periods about 500 and 2600 years ago, Gorgan bay has reached to its maximum volume due to the sea water level increment, and was completely dried out 1500 years ago while the sea was reached to -40 m (Kakroodi *et al*. 2012).

Fig. 3. Thin layer soil on the old terrace stabilize the study area.

Temporal and spatial variations of the Gorgan Bay shoreline

The comparison between 1:20000 aerial images of 1966 and satellite images of 2004 showed that the reaction of Miankaleh peninsula and the Gorgan Bay shoreline are so different towards the Caspian Sea water level variations. The maximum shoreline displacement due to 1-meter Caspian Sea water level increment has been appeared in western and the most end of north eastern of the bay overlooking to the north of Ashooradeh Island and the communication channels of Chopoghli and Ashooradeh (Fig. 4). The shoreline deformation rate has been decreased to the west side of Miankaleh Wetland overlooking to the sea coast. The reaction of Khoozini channel toward the Caspian Sea water level variations was so intensive, as it was completely coming out from water in 1966 and has been related to the bay and the sea at 2005 due to the sea water increment (Fig. 4). The comparison of gained results of satellite images interpretation for the years of 1976 through 2014 has shown that the connection channels of the bay (Khoozini, Ashooradeh and Chopoghli) have completely dried out and lost their functionality. Meanwhile the bay has reached its minimum water level, and the current condition was experienced as in the past (Fig. 4). Hydrological condition of the bay has been reversed during 1978-1995 due to the sea water level rise and the Chopoghli and Ashooradeh channels were connected to the sea again at 1986 and the other channel, Khoozini has joined to the sea another time in 1998 (Fig. 4). The aforementioned condition has been continued up to 2011, and from 2012 to date, the rapid shrinkage of the sea water level has caused the severe drought of the bay and again the communicative functionality of all three channels have been lost and caused the emergence of sandy islands at the interface between the connection channels, i.e., Chopoghli and Ashooradeh. The evaluation of satellite images in 2016 has illustrated that the vast parts of western area of the bay has been completely dried out and the Ashooradeh and Chopoghli channels are going to be fully closed. The bay area is now reduced up to 360 Km^2, while before drought, it was about 450 Km^2. Moreover, reduction of water depth at connection inlets of the bay (Chopoghli and Ashooradeh) causes the hydraulic efficiency

reduction due to deposition of sedimentary materials. Nowadays, the area of connection channels has been reduced from 15.4 km^2 at 2004 to 9.3 km^2, and the island with an area about 6.1 km^2 has been exposed from water between the Ashooradeh and Chopoghli channels (Fig. 5). The Khoozini channel at the north-eastern part of the bay has lost its capability of transferring water from the sea to the bay from 2005.

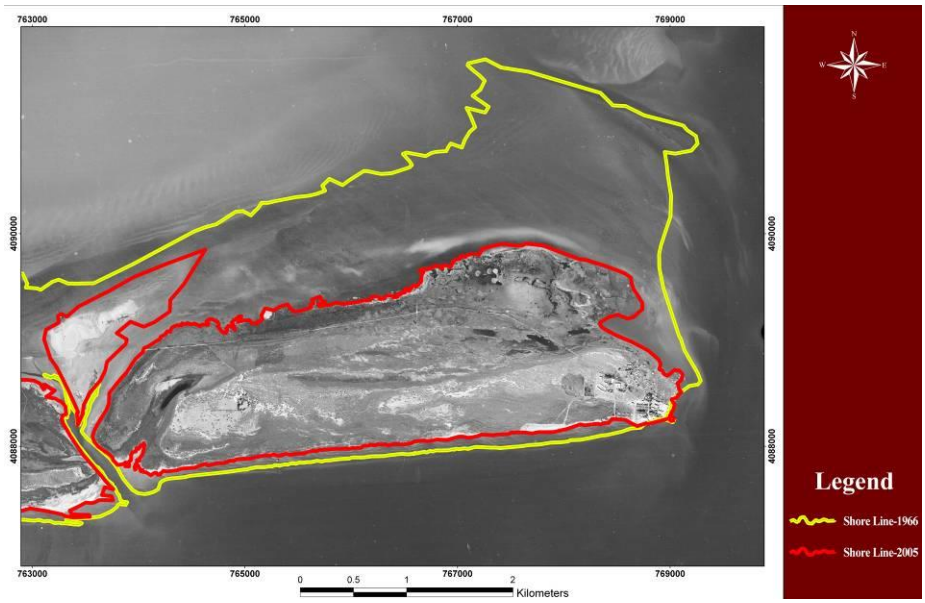

Fig. 4. The shoreline displacement of the northeastern part of Gorgan Bay between 1966 and 2005.

Fig. 5. Lagoon sedimentary environment with silty sand sediments containing organic matter in the Gorgan Bay channel.

The classification of sedimentary environments of Gorgan Bay

The field studies have shown various sedimentary environments in Gorgan Bay and Miankaleh Peninsula. The most important regions are as follows: wetlands, mudflats, salty marshes, deltas, inlet channels, sandy beaches of sea, the intermediate zones between sea and wetlands as well as sand dunes. The wetlands, mud flats and salty marshes are mostly centralized at eastern parts of the bay and are composed of fine salty sand deposits soaked in mud due to low energy depository environment and smooth bed slope. The very gentle sloped coastal regions overlooking Torkaman port are covered with fine sandy silts to clay silts sediments. However, the sedimentary materials combinations at the side of Ashooradeh Island are mostly sandy compared to fine salty sands. The Ashooradeh channel bed materials are mostly fine sandy materials and also fine sandy silt with high amounts of organic material in west marginal areas. However, at the eastern side of the aforementioned channel beside the islands newly exposed from water, originated deposits of the sea are covered with wetland sediments. Chopoghli channel is deposited with fine sandy silts along with clay and sludge materials, as it is affected strongly by the Gorganrood River depository load. In addition, the sedimentary materials of eroded Torkman port shoreline, as well as the very low water depth and existent nutrient materials causes the development of

aquatic vegetation (Algae). The northern part of the bay at the southern margin of Miankaleh coast are mostly covered with fine sandy materials containing bivalve shells, changing to muddy organic materials at the most end of western parts. The southwestern coasts of the bay at the north of Behshahr town, Mazandaran Province are mostly included muddy zones and old sandy deposits of the sea. The gained results of analyzing the deposited sediments at the Ashooradeh channel inlet have shown that the sediment types are mostly fine well sorted sandy materials, hence, the coefficient of skewness and the sharpness of normal curve are obvious events of active hydraulic flows in aforementioned channels. However, the sediment sizes of Chopoghli channel are mostly fine sandy silt materials and fine sands, which the multi-originated sediments exhibit the low energy flows in the channel. The studies on geochemical and sedimentology of the bay have demonstrated that the frequency of sandy materials at Ashooradeh inlet are much higher than the other areas in the bay and the amounts of organic material and calcium carbonate are much higher in the bay deposits than the sea sediments. The chloride and Muscovite minerals in the bay deposits are apparently evidences of the origin of its sedimentary materials which are the weathered and eroded materials of northern Alborz Mountains, since they are not found in the sea deposits (Alizadeh 2010). The comparison between chemical combination of surface deposits and older sediments in the bay has shown that the its sediments are mostly originated from the river watersheds erosion discharging to the bay (Alizadeh 2010). As a result, the bay sediments are considered as the intermediate carbonated and calcite environments and the rivers discharging to the bay, and the sea play an important role in providing the sediment loads of the bay (Alizadeh 2010). The previous studies on the Gorgan Bay sediments age assessments have reported that the deposition rate in the bay during late Holocene was about 2.5 mm per year, elevating from east to west of the bay (Amini 2012). Therefore, as a general point of view, the Gorgan Bay sedimentary environments are classified as follows (Fig. 6):

- Paludal sediments, including dark clays with high organic materials, full of mollusks lime shells (gastropods and bivalves; Fig. 5).
- Sandy spit sediments, including well sorted brown reddish sands, with bivalve shells (Fig. 6).
- Marine sediments, fine well sorted sandy materials along with microorganisms and marine mollusks lime crusts (Fig. 7).
- Sand dunes and Aeolians, including fine light brown well-sorted sands and iron oxide without marine shells (Fig. 8).
- Alluvial-river sediments containing a large percentage of mineral micas, with brown Aeolians and deposits including sand, silt and clay with plant and root components, and gastropods, weathered elements and pitches.

Fig. 6. The sand spit growth in the east of Miankaleh.

Fig. 7. The Caspian Sea shoreline and berm condition in the west of Miankaleh Island barrier.

Fig. 8. The active sand dune in the north of Miankaleh, on the margin of the Caspian Sea

The effect of rapid fluctuations of the Caspian Sea on Gorgan Bay

The studies on fluctuations rate of the Caspian Sea have shown that during Holocene era (from 10000 years ago to date), the Caspian Sea with a pendulous range of 25 m, has experienced vast alternative advancing and regressing periods (Kakroodi *et al.* 2012), and as a result Gorgan Bay has been dried and filled of water sequentially (Fig. 9).

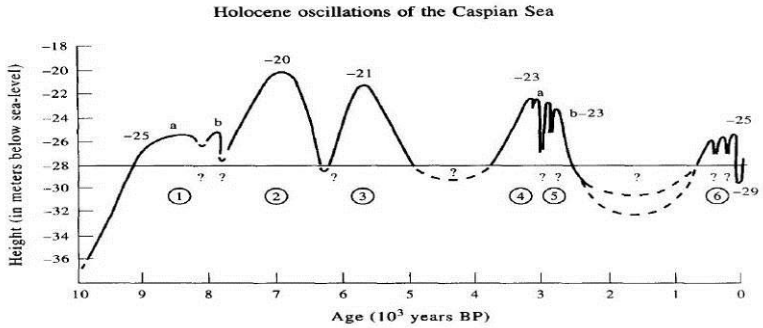

Fig. 9. The Holocene fluctuation curve of the Caspian Sea after Rychagov 1997.

The Caspian Sea water level rise up to -22 m, about 2600 years ago has caused deposition of marine sediments at the southeast of Gorgan Bay, Baghoo Kenareh region, and it was the most penetration rate of the sea to the coastal line of the bay during late Holocene (Kakroodi *et al*. 2012). Moreover, the reduction of water level during Derbant Era up to -34 m has caused bay to be complete drought, followed by deposition of Aeolians in the area (Kakroodi *et al*. 2012). It was about 500 years ago during the Little Ice Age that the Caspian Sea has elevated again up to -24 m, so that the reclamation condition of the bay has been provided again and the last sedimentary terrace of the sea has been formed at the southern coastal area (Kakroodi *et al.* 2012). Therefore, the geologic historic evidences of the case study area are the proofs of huge alterations in the Caspian Sea water level pendulous behavior which its effects are obviously visible in deformation of the bay water body. The Caspian Sea has experienced very rapid changes from 1930, so that, the alterations domain has been reached even up to 3 m (Fig. 10). The Caspian Sea water level has experienced about 3 m shrinkage during 1930-1978 and has reached to -28 m, so, as a result a huge part of the bay has been dried out. The maximum drought vulnerability has been observed in western areas of the bay and the complete obstruction of Ashooradeh, Chopoghli and Khoozini channels inlets have caused the blockage of water to the bay. Given the sequential Caspian Sea water level increment during 1978-1995, about 2.5 m, up to -25.5 m, the bay has again become completely full of water during a 22-year period. However, the abovementioned condition has not lasted so much. Hence, once the Caspian Sea second shrinkage was happened since 1995, exhibiting a reduction from 1.5 m to -27 m, the bay was dried out and the capacity of communicative channel inlets was seriously diminished. Such that, Khoozini channel in the section overlooking the sea, was completely out of water. The all abovementioned issues are apparent evidences for the claim that the hydrologic response of the bay were sensitive to rapid fluctuations of the sea water level in -27 m, hence, the maximum bay recharge was happened at -25 m sea water level. Moreover, the alteration rates of the sea water level at different times were different and follows no certain order (Table 1). Then, the pendulous acceleration of water level alterations during

downfall and development periods may cause serious challenges for related water bodies, just as the current events in Gorgan Bay and Miankaleh Wetland.

Fig. 10. The Caspian Sea level alterations according to the data of Baku Gauge, Azerbaijan (1835- 2014).

Table1. Alteration rates of the Caspian Sea water level during the registration period

Year	Mean sea level	Period (year)	Time speed (cm y^{-1})
1837-1929	-25.07	92	1.9
1930-1941	-25.95	11	14.7
1942-1977	-27.41	36	3.8
1978-1995	-26.88	17	14.7
1996-2006	-26.13	11	6.5
2007-2014	-26.41	8	7.5

The hydrodynamic characteristics of Gorgan Bay

The erosion vulnerability of Gorgan Bay toward the Caspian Sea hydrodynamic is ignorable because of a very gentle slope of the sea bed at the channels inlets. The stormy waves lose their energy in long distances and may not be entered to the communicative channels. Moreover, the Miankaleh sandy spit prevents the erosion effect of the Caspian Sea waves, due to its role as island barrier. The abovementioned procedure provides a low energy depository environment in the bay which is favorable for aquatic animals. However, the following important hydrodynamic events may cause various morpho-dynamic procedures: storm surge, the difference of water densities between the sea and the bay, the penetration of river runoffs, and daily rise and falls of the sea water level due to limited tides. Hence, finally the hydrologic stability of the bay is dependent to these procedures. The results of previous studies by Iranian Ports and Maritime Organization (2014) have shown that during storm events, the storm surges lead to the increment of velocity of the sea water flow to the bay at the Ashooradeh and Chopoghli channel inlets. At aforementioned circumstances the salinity and water column temperature through channels are uniform. However, at the calm sea condition the saline water mass at channels and depth close to the bed is formed to the sea. The salinity alteration through Chopoghli channel is much less than Ashooradeh, due to the balancing effect of the Gorganrood River fresh water on the Chopoghli saline water. The measurements show that the bay salinity is higher than the sea, which is determined about 14 g L^{-1} close to the main inlets and alterations up to 22 g L^{-1} in some areas close to the natural saline water pond at the west of Khoozini channel. The simultaneous benchmarking results in the Caspian Sea and Gorgan Bay have shown that during storms, the water flows from the sea to the bay and in a short period of time, great volume of water influxes to the bay. Right after the storm and under the effect of more saline water of the bay, the slower water flow is formed through sub-surface layers. As a result, there is a sequential interaction between coastal flows, wind surge flows and water density. The surge flows parallel with shoreline lead to deposition of sandy sediments at inlets. However, the flows due to the wind surges and density differences, lead to open the inlets.

The flow velocity measurement at bay inlet shows that the maximum velocity is about 60 cm s^{-1} and the inflow velocity to the bay is always higher than outflow from the bay to the sea. The results of numerical modeling show that Gorgan Bay is affected by two major factors. The short term water level alterations of the sea lead to the water fluctuations less than 10 cm and the sea wind leads to the surges up to 40 cm in height in the bay. In general, the deterrent driving forces of bay inlets blocking included: the tidal fluctuations of the sea, the density variations between the sea and the bay, as well as the wind waves of the sea. The important blocking reasons of the bay inlets include the sea water level shrinkage and the deposition of sediments at inlets affecting by coastal flows and resulting from breaking waves. The results of drought development modeling studies of the bay under pendulous scenarios of 5cm shrinkage per year, have shown that the main bay inlets will be completely closed by 2023, hence, the Chopoghli and Ashooradeh channels will no longer be able to transfer water to the bay (Sharbati & Ghanghermeh 2015). Therefore, the bay will lose its life due to evaporation phenomenon from the aforementioned time.

DISCUSSION

For the reconstruction and rehabilitation of coastal wetlands, the following detailed questions should be answered appropriately. What are the most important factors in the environmental degradation of coastal wetlands? Which part of the natural structure and components of the wetland ecosystem has been damaged and what effect does it have on the performance and environmental services of the wetland? What special ecological conditions should be provided for the reconstruction of coastal wetland ecosystems? How can we reduce and manage the factors affecting the deformation and degradation of coastal wetlands (Harrison 2006). It has been determined that the distribution of sediments in different areas of Gorgan Bay follow different sedimentary regimes and textures, according to the results obtained from morphology and sedimentology studies of the bay, as well as the various habitats formed in the bay and its surrounding shores depending on the structure and texture of sediments. In addition, the morphological structure of the bay shores has been shaped in such a way that the beaches with different slopes have formed in different parts of the bay. Therefore, the Caspian Sea water level fluctuations affected the coastal sediment morphology of the bay and led to significant alterations, the most important of which are the replacement of aquatic ecosystems by land and also the development of different marshes with saline and freshwater chemical compositions along with mud flats since 1995, during the period of declining water level of the sea. It was also found that the sea level rise due to the storm, rivers and precipitation are the most important water resources in the bay. Unfortunately, adequate water does not run to the bay due to the global warming and subsequently reduction in precipitation and elevation in the evaporation rate. Moreover, reduction in the water outflow of Gorganrood, Gharesoo and other rivers as well as drains leading to the southern part of the bay, due to construction of dams and utilization of fresh water resources in agriculture, make the situation in the bay worse. In addition, enhancing the rapid drop of the sea water level during the Gorgan and Qarasu rivers and other streams and drains leading to the southern part of the bay. In the last two decades, the rapid drop in the water level of the sea by 150 cm has led to unexpected conditions in the water exchange between the sea and the bay by the existing waterways. Therefore, the revitalization of Gorgan Bay requires solutions that are consistent with the existing ecological and hydro-morphological conditions and include the scenario of long-term decline in the water level of the sea by the end of the 21st century. In this regard, the following recommendations are presented as follows:

Construction of artificial channel for water exchange with the Caspian Sea

Given the high sensitivity of the Ashooradeh and Chopoghli channels to the water level reduction of the Caspian Sea and rapid sedimentation rate, the cost of dredging in order to recover them is reported to be as high according to the maritime and ports organization. Moreover, the reducing trend of the sea water level has no guaranty to provide the required water of the channel after the dredging procedure. As a result, in order to connect the sea and bay water, it is needed to find a new location with better situation in this respects: the less distance between the sea and the bay, the sea bed slope at low depth areas. So, the distance to the Amir Abad port should be taken into consideration. On the basis of the aforementioned criteria, the best location is in about 20 km distance from the east of Amir Abad port, at northern part of Miankaleh sandy spit. At the appropriate region the distance between the sea and the bay is about 1.5 km and the narrowest width of Miankaleh spit is as the same region. The channel drilling or water transportation by pipe line through abovementioned region cost

much lower than dredging the old channels. Moreover, the drought vulnerable regions which are mostly located at the west side of the bay will be saved quite effectively, and the steeper slope of the coast in the abovementioned area leads to the lower drought vulnerability of the channel during rapid fluctuations of the sea.

Diversion of Gorganrood River to Gorgan Bay

The average annual discharge of GorganRood River is about 0.3 billion m^3. The river estuary has been repeatedly deformed during Holocene due to the Caspian Sea water fluctuations, and finally at late Holocene the river inlet which was previously connected to the bay, was shifted to the northern part (Kakroodi *et al*. 2012). Therefore, it is possible to drill a channel parallel with the most end limit of agricultural lands, and convey the river water to the bay. The massive fraction of the river sediment load is cumulated at the upper parts by the constructed rubber dam. Therefore, the bay bed will not be significantly affected by the sediment loads.

Dredging old channels

Dredging old channels is the last, costly and more economically risky way to save Gorgan Bay. The Khoozini, Ashooradeh and Chopoghli channels which are located at the north east of the bay have a connection duty with the sea through past years, which unfortunately the sequential reductions of the sea water level and the active sedimentation procedures during last four decades lead to their hydraulic efficiency shrinkage. Therefore, if the reduction rate of the sea is considered to be stopped, dredging channels in future will not be an unexpected task, just as the project at 1976. However, the main question to find a response for it is that: Will the Caspian Sea reducing trend be paused? If the answer is yes, we should expect the new development phase and then take decisions on dredging the channels on the base of macro-economic politics.

CONCLUSION

Creating a safe channel for transformation of the Caspian Sea water, with the assumption of active and stable flow, is very important among the proposed solutions. In addition, the most suitable place is where the distance between the Caspian Sea and Gorgan Bay is minimum and the suitable topographic slope of the sea bed has the capacity of water transferring to the bay. The most suitable place is located 20 km east of Amirabad port in the northern part of Ismail-Sai Island, according to the results of studies on topographic and hydrographic maps of the sea shore. Therefore, the required water of the bay can be provided by building a suitable channel in this place. The most environmentally vulnerable areas of the western region of the bay, which is the habitat of waterfowls will be rehabilitated under this condition, and the spread of mud flats and marshes will be prevented. Moreover, a suitable opportunity will be provided for the development of aquatic life.

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