

# Investigation the mechanism of changes in the coastal landscapes of southeastern Iran based on geomorphological studies

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## ABSTRACT

The southeast coasts of Iran as a part of the coasts of Makran are always changing. Since the southeastern coast of Iran is one of the most important strategic regions of the country and even the Middle East, it is obvious that the information related to geomorphology and other earth sciences can be an important factor both in organizing planning plans and policies and in evaluating private demands. The most important goal of the research is to introduce the factors affecting the change of landscape and coastal geomorphology phenomena and the state of erosion and sedimentation along these coasts. Library and documentary studies, field operations, laboratory studies, combining findings and conclusions have been the main methods of conducting research. In this research, the principles of catastrophism, uniform materialism, gradualism, and Davis's theory have been used, and the method of whole-to-part study (Australian method) has been used to study and investigate the mechanism of landscapes and geological effects. Based on the geomorphology evidence of the coasts, it was determined that from west to east on the southeast coasts of Iran (from Pozm Bay to Govatr Bay), the intensity of the advance and retreat of the sea water in destroying the coasts decreases, that is, with the change of the sea tide line and the advance of the water, the coastal development of the areas It happens much less in the west than in the eastern areas such as Ramin, Lipar and Govatr. The coastal area of Makran is under the influence of three tectonic, erosion and sedimentation activities and human activities (industrial, fishing and construction) are not effective. Two general models include the dominance of erosive and tectonic processes over sedimentation processes, causing the formation of landscapes such as erosion columns, sea stacks, sea arches, sea caves, headlands, Islands and raised beaches (Cliff) are found in the coastal areas of Pasabandar, Beris, Lipar, Tis, and Konarak, and the other is the dominance of sedimentation processes over other activities, which are landscapes such as Spit, Bar, Tombolo, Lagoon, Delta, Tidal Flat, Bay Barrier, Islands and Mud Flat in the coastal areas of Ramin, Chabahar Bay and Govatr.

## 1. Introduction

Geology of coastal areas is considered as one of the basic information, the basis of some planning and implementation of coastal areas management policies. Since the southeastern coast of Iran is one of the most important strategic areas of the country and even the Middle East, it is obvious

that the information related to geology and other earth sciences can be an important factor both in the regulation of plans and planning policies and in the evaluation of private demands. The cycle of erosion of land and carrying sediments to the sea and the sedimentation process are among the important geological phenomena in sedimentary

environments that take place continuously. Weathering, erosion, deposition and finally diagenesis or hardening of sediments lead to the formation of sedimentary rocks on the coasts of seas and oceans. These rocks are again removed from the water according to the erosion cycle of William Morris Davis [1] with tectonic processes such as folding and forming new geological landscapes, and these changes always continue dynamically. This dynamic is more effective in the continental margins due to the interaction between sea water and currents.

In coastal areas, the history of sedimentation is used to document various changes [2]. When freshwater rivers enter the sea, they interact with the marine environment due to specific chemical differences such as total ion resistance, acidity, total hardness, salinity, and other characteristics, and the result of this is the occurrence of sedimentation or beach dissolution processes. Also, coastal environments are affected by interactions and human intervention [3]. Therefore, such environments are under severe tension. In coastal areas that have lower hydrodynamic energy, fine particles tend to settle and accumulate, while in areas with high hydrodynamic energy, fine particles are washed away and move away from the coast [4,5].

The structural-sedimentary zone of Makran extends from 30 degrees and 57 minutes in the southeast of Iran to 30 degrees and 66 minutes in the south of Pakistan. This zone is 1000 kilometers long and 340 kilometers wide. In other words, it extends from the Strait of Hormuz in the southeast of Iran to the Middle Gulf of Son (Deccan) in Pakistan. The difference in topographic height in Makran is from 3000 meters below the open water level and in the Oman sea bed to 1500 meters above the open water level in the heights of Makran [6]. Makran has four different sedimentary provinces, which include northern Makran, inner Makran, outer Makran and coastal Makran. Makran Sahil is located in the south of Outer Makran and represents the sedimentary basin above the accretionary wedge with a shallow sedimentary sequence from the marls of the continental slope to the bottom of the continental and coastal plateaus [7, 8].

From the point of view of geology, Makran is an ancient rift that is in the form of an accretionary

prism, from the late Cretaceous to the early Tertiary and until the Holocene, in the outer wall of a shallow and low-slope subduction zone [9]. It divides Makran into three physiographic units, including marine barracks parallel to the coast, alluvial deposits north of the barracks, and the hills and heights of Makran [10]. In the Makran area, the folding of late Oligocene-Middle Miocene rock units, which are mainly sand flysch, was formed in the Mio-Pliocene [11]. The background of geological studies corresponds to the generalities and conditions of the formation of coastal areas, among which we can refer to the basic books of land preparation [12], the basics of geology [13], the application of geology in the preparation of land and environment [14], the application of geology in planning. National-regional and economic [15], Geology of Iran [16], Geology of Iran [17], Coasts of Iran [18], Application of geology in planning [19], Coastal geology [20, 21, 22]. Several reports have been made to investigate the landforms and characteristics of the coastal regions of the country, in which either the state of the coastal regions has been discussed from a geomorphological point of view, or geomorphological conditions such as coastal landform maps have been mentioned in addition to the main topics [23, 24, 25, 26, 27, 28, 29, 30] pointed out.

Therefore, in this research, it has been tried to describe the factors affecting the shape of coastlines, especially landscapes and geological phenomena, and predict the state of formation of these beaches. Therefore, by mentioning some of the most important geological structures and stating their mechanism of occurrence, the following questions should be answered regarding the coasts under erosion, in equilibrium and during sedimentation:

- 1- What are the main factors affecting the geological changes of the southeast coasts of Iran?
- 2- Does erosion and sedimentation with tectonic processes have an effect on the deformation of the southeast coasts of Iran?

Therefore, according to the previous research and since the development of the southeast coast of Iran (Makran) is on the agenda of the Islamic Republic of Iran and the southeast coast of Iran is considered as the most strategic region of the country, the necessity of this research doubles.

### Geographical location and access roads to the area

The studied area is located between latitudes 25°14' to 25°26'N and longitudes 60°21' to 60°50'E in the north of Oman Sea and south of Sistan and Baluchistan province. From the geological point of view, this area is located in the geological zone of Makran; Makran zone is structurally divided into two outer (coastal) and inner parts [33]. The studied area is located in the outer part, although the area of Makran coastal structural land is wider than the selected area (Figures 1 and 2). One of the general features of this section is the presence of ophiolitic complexes, sedimentary deposits with felsic facies and the absence of rocks older than the Cretaceous in the region [35, 34]. The ophiolitic complexes of the region are mostly in the form of narrow and more or less continuous strips that often outcrop along the main longitudinal faults [36].

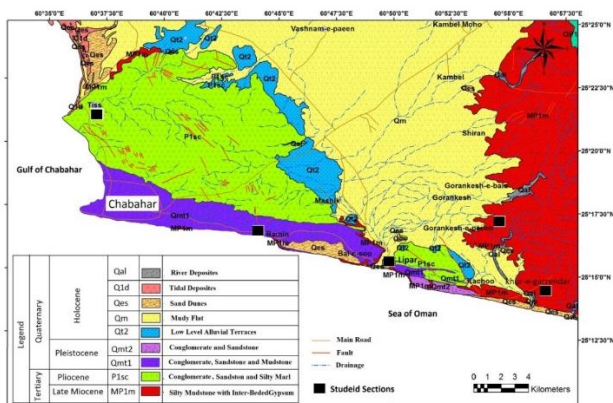


Figure 1. Geological map of Makran coasts (modified after 1:100000 geological maps of Chabahar) [31, 32]

Different rock units in the coastal area and land overlooking the sea include marl units of Miocene age, Miocene-Pliocene marl and sandstone units, Pleistocene loamshells, sandy and silty sediments of alluvial cones, and sediments of the present age contain fossil shells. In general, the stratigraphic sequence of the studied area consists of four parts: Miocene rock units, Mio-Pliocene rock units, Pliocene rock units and Quaternary rock units, which are known as Neogene and Quaternary units [36]. Quaternary deposits in coastal Makran are post-Pliocene sediments placed on Pliocene conglomerate, but in the studied area they include coastal lowlands.

Holocene alluvial sediments are spread throughout the coastal area. Another important part of the sediments of this region is the

sedimentary deposits of the estuaries in the region. The most sedimentary constructions in sedimentary deposits include gradual stratification, diagonal stratification on small and large scales, boudinage, imbrication, symmetrical and wave ripple marks, flute cast, toll mark, mud cracks, traces of biological disturbances and the activity of burrowing organisms.

### Material and Methods

In this research, library and documentary studies, field operations, laboratory, data integration and conclusion were the main methods of doing the work. In library studies, it was first tried to collect and study books, articles, research reports, maps and what was related to the research topic.

Then, in field operations and field studies, numerous geological visits, taking pictures of geological landscapes and studying them took place. In this research, different principles of geology, namely the principle of catastrophism (sudden and large processes), the principle of uniformitarianism or the principle of similarity of processes (present key to the past) and the principle of gradualism or the principle of slow and gradual land changes (sudden events on a small scale) have been used. The method of studying geological structures has been using the Australian method, that is, studying the whole structure into parts after the formation and emergence of the structure.

For this purpose, the most important geological landscapes in the study area were identified and then the way of their occurrence was identified according to the geological characteristics. Also, with their structural reconstruction, the necessary be determined modeling and then destructive and constructive areas were introduced. Therefore, the coastal areas of Govatr, Bris, Pasabandar, Lipar, Ramin, Chabahar Bay, Tees, Kanarak and Pozm along the southern coastal strip of Sistan and Baluchistan province were selected and studied. Since erosion, tectonics, and sedimentation are probably the most effective and active processes in the Makran area, these areas were chosen because many geological landscapes are being formed, changed, or developed in this area.

### Results and Discussion

The southeastern region of Iran is one of the regions in the country that has unique structures and landscapes. These natural potentials are due to special climatic and geological conditions,

including sea level fluctuations during different geological times, interactions related to external processes such as weathering and erosion conditions, as well as internal processes including tectonics caused by the subduction zone and its effects. Among these landscapes and natural structures, we can find head land, raised beaches, sea fans, barracks or coastal cliffs, Bad Land, Sea Caves, Sand Dune, Mud Volcano, Coastal Plain, Delta Plain, Estuary, Creek, Lagoon, Tidal Flat, Mud Flat, Spit, Bar, Tombolo, Bay, Cove, Erosion Column) and dozens of other examples, each of which in turn shows the geological activities of Makran over many years. Below, firstly, the introduction and mechanism of their occurrence and then their impact on Makran's coastal changes have been investigated.

### Morphological landscapes with the influence of tectonic activities

As mentioned in the introduction of the research, the Makran area in the coastal part includes the east-west elevations that continue from the northern shores of the Oman Sea (south of Sistan and Baluchistan) to the Jazmurian depression. The western border of these mountains is separated from the collision zone of Zagros by the Minab fault, and in the east, after passing through Pakistan's Baluchistan, it continues to the axis of Las Bela. It should be mentioned that out of the 160,000 square kilometers of Makran, about 70,000 square kilometers are in Iran and the rest are in Pakistan [36]. The continental crust that separates North Makran from South Makran is the southern edge of Lut Block, which was placed in the Makran flysch basin after being separated [38]. According to the increasing age of the sedimentary formations from south to north, the existing shape change and the increase in height, Makran is considered to be a type of active arc system, in its formation, the subduction of the oceanic crust of Oman under Makran played a fundamental role [39, 40].

According to the researchers, the subsidence took place at a distance of 400 kilometers from the coast, and before the subsidence, the lithosphere was bent and the melting of the oceanic crust caused the formation of the magmatic rocks of the highlands. In this theory, Makran area is divided into two geological units [36]. One is the sunken part of Jazmurian, which is a type of subsiding basin, and the other is the southern

uplifted part, which continues from the Beshagard Mountains to the depths of the Oman Sea, and is composed of two parts: the Slope Basin and the Trench Fill. is [36,40].

The Makran zone is actually an accretionary prism that is located on the outer wall of a shallow subduction zone. In this region, the subduction process has started since the Late Cretaceous and the final collision between the plates has not yet taken place, so the orogeny process in Makran is still continuing [42]. The subduction of the oceanic crust of Makran under the continental crust has led to the formation of complex structures and the Oman ophiolitic belt and accretionary prisms in Makran [43, 44]. Among the colliding plates, the subducted plate is the base of continental rocks. The magmatic arc resulting from subduction includes Mount Sultan volcanoes in Pakistan, Taftan and Bazman volcanoes in Iran [41]. It should be mentioned that the bending of the oceanic lithosphere before the subduction and especially the action of thrust faults is among the factors that make Makran rocks [36]. The oceanic lithosphere of the Arabian plate is moving towards the north and goes under the Lut plate and the Afghan-Helmand block. In geodetic measurements, the rate of movement of the two Arabian and Makran coasts between Muscat and Oman has been measured at 1.9 cm per year, while the current rate of subsidence between the Makran coast at Chabahar and Eurasia has been measured at about 8 mm per year [37, 45]. The accretionary prisms of Makran are a special example and one of the largest accretionary prisms in the world, which is a subduction of the oceanic lithosphere (Figure 2).

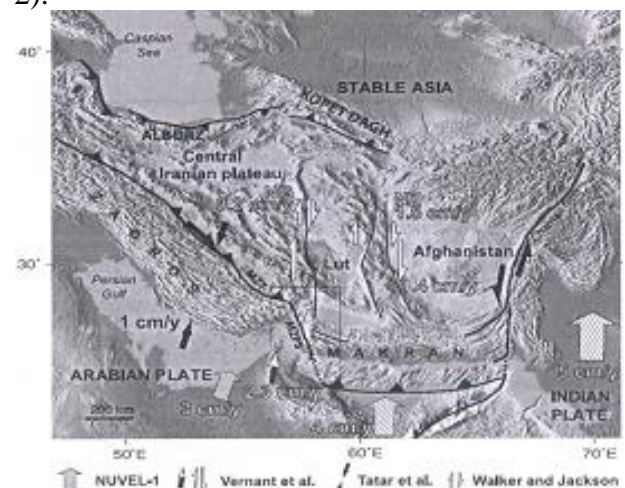


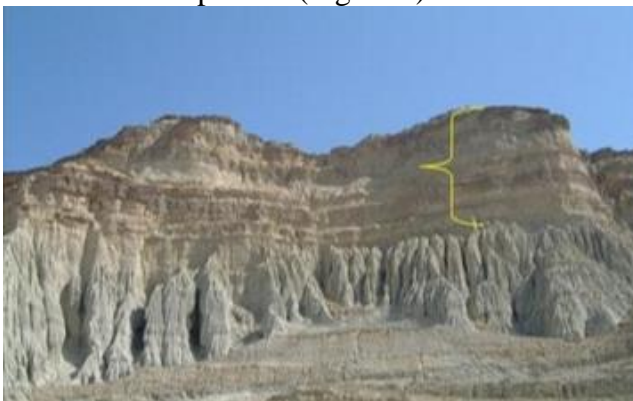
Figure 2. The subduction of the Indian Ocean crust under the Makran crust [48]

the angle of this subsidence is very low and less than 2 degrees. The width of the subduction system (deep subduction zone to the magmatic arc) is 400 kilometers on the Iranian side, which increases to 600 kilometers to the east of Pakistan [46, 47]. The rate of subsidence in the Oman Sea is estimated to be 4 cm per year [48]. The place of subsidence in the Cretaceous was at the place of the Jazmurian pit, which gradually receded towards the south and has now reached the deep area of the Oman sea bed [36].

According to the above, the tectonic face of the coasts, especially the uplift of the coasts, the existence of faults and cracks, proves that after the rock is affected by stress, it first undergoes elastic deformation and then breaks (in the state Normally, stones are brittle) but under confining pressures and high heat, many stones enter the plastic deformation stage after the elastic stage, and eventually the stones break under these conditions. This evidence is abundantly seen in the region, which is the reason for the tectonic impact.

In the following, we will describe the most important geological landscapes whose mechanism of formation is tectonic activities:

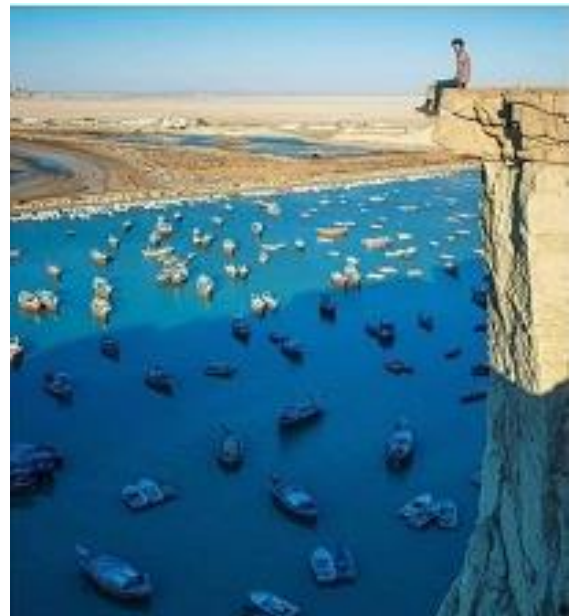
Coarsening in the sedimentary sequence upwards (Coarsening upward): The existence of a coarsening sequence on the coasts is a proof of tectonic influence in the Makran area, an example of which can be seen at the entrance of Tees village [49]. In this sequence, seven sedimentary layers can be seen, which show the coarsening of the sediments upwards (Figure 3).



**Figure 3. The Coarsening Upward of sediments in sequence at the entrance of Tis village**

High and rising costs (Cliff): The sea defenses in the east of Chabahar become older with the increase in height and record the relative change of the sea level over time. Relatively severe changes in the sea level in the mentioned

sediments are due to tectonic processes caused by the erosion rate of the subduction zone, global sea level changes and climate changes. The coastal strip area is considered one of the active areas due to its special tectonic situation. Of course, wherever the three factors of water, wind and land are in contact with each other, the process of erosion and weathering is more intense and causes the creation of special coastal forms. In the Makran area, the effect of the mentioned factors, especially the impact of the waves, has caused the destruction of the beaches, accompanied by tectonic activities, and has caused the formation of coastal heights and barracks (Cliff), which is one of the most important and spectacular geological landscapes of Makran (Figure 4). In some cases, these rocks are up to 50 meters thick, which are considered as one of the other sights of the tourist area.



**Figure 4. The Cliff in Coastal study area**

In these coasts, the existence of faults and numerous other cracks is evidence of the tectonic influence in the studied area (Figure 5).



**Figure 5. Faulted and jointed cliff coasts, Tis and Lipar coastal areas**

Mud volcano: one of the very beautiful and spectacular geological forms and processes in the study area are the Mud volcano (Figure 5). This phenomenon is actually a natural phenomenon similar to a volcano, which is in the form of a

conical hill and instead of lava, gas and mud come out of its mouth. The mechanism of the formation of these glaciers is tectonic factors, including the movements caused by the subduction of the oceanic crust of the Indian Ocean and Oman Sea under the continental crust of Makran. The gulfs of the Makran coast are relatively young and their origin dates back to 30,000 to 40,000 years ago [50]. In addition to being one of the interesting and beautiful sights of geotourism, the flowers have therapeutic properties in traditional medicine, so that their flowers are used to treat diseases such as joint and spine pain, joint stiffness, neurological diseases, the early stages of vasoconstriction and muscle spasms, diseases femininity are very beneficial [51].

It is said that bathing in the flowers of Mud volcano is very beneficial for the skin due to the presence of special chemical elements in their compositions, and it rejuvenates human skin and improves skin ailments [52]. Glaciers cause ion exchanges due to the influence of underground water or sea water penetration. Therefore, it is possible to manage mudflows by building baths next to them, so that while visiting tourists, they can use the facilities installed there due to their therapeutic properties. It should be mentioned that with the previous researches and according to the chemical composition of the mud (organic and inorganic compounds), the therapeutic properties of Mud volcano in the treatment of diseases such as joint and spine pain, joint stiffness, neurological diseases, vasoconstriction, muscle spasms and Women's diseases etc. have been proven [52]. So far, 20 gulfs have been identified on the coast of Makran, and of these, 5 are located between Jask and Minab ports, 9 between Chabahar and Jask ports, and 6 between Chabahar and the Iran-Pakistan border, especially in the north of the Gulf of Govatr.

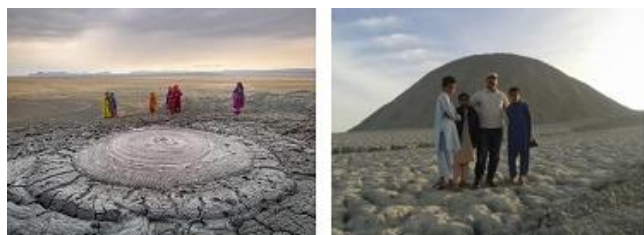


Figure 6. Mud volcano of Kahir in the northeast of Chabahar

### Morphological landscapes with the dominant effect of erosion

he main formations of Makran region are mainly destructive and include shale, marl, sandstone and conglomerate, in the meantime, shale and marl have a high spread in the whole region. Most of the existing geological landscapes are formed in the sequence of shale, marl and sandstone units (Figure 6). Most of the geological landscapes of the Marni coast are hilly slopes, which are generally weak and resistant, and have deep valleys (known as a thousand valleys) formed due to the influence of surface water flow. In a wide area of the coastal strip, many fossil traces can be seen, which indicates that the area was covered by water in the past. The existence of whale fossils inside these sediments is a proof that the sedimentary environment of these formations is marine.



Figure 7. Clastic sediments in the northeast of Chabahar

The existence of various types of surface erosions, grooves and watersheds (Figure 7) as well as nesting erosion (Figure 8) is also a proof of the impact of weathering and erosion processes as well as the blowing of two-way winds in the coastal formations of Makran.



Figure 7. Grooving, surface and hydrostatic erosions in marl sediments (Ramin)



**Figure 8. Honeycomb erosions in sandstone and marl sediments (Ramin)**

In most of the coastal areas of Makran, due to the presence of strong, weak and non-resistant rocks, the topography of the beach's changes under the influence of the weight of the rocks. This means that the loose marl sediments are weathered and eroded and fall. This factor affects the resistant sandstone and loamy rocks, and over time, they begin to break and fall as the underlying rocks become empty. This causes the formation of a talus in the lower part of the heights (Figure 9).



**Figure 9. Erosion in sandstone sequence, rock fall and talus formation, Lipar coastal area**

Bad Land: between 25 and 20 kilometers from Chabahar on the northern shores of the Oman Sea (Chabahar-Govatr road), surface water and wind erosion on the green marl-sandstone formations of the region, beautiful views from the regular and numerous highlands. which is known as bad lands or Martian mountains or miniature mountains (Figure 10). These deposits were formed under the influence of water and wind erosions, which spread parallel to the sea coast line (east-west extension) from the Quechua area to the vicinity of the Gulf of Govatr.



**Figure 11. Badlands in the southeast of Chabahar**

Erosion Columns: Wind as the main factor of erosion in the region, like running water, causes erosion and transport of low-resistant sediments, and after hitting stone obstacles, it wears their surface. This process in the coastal areas has created beautiful constructions such as the elf chimney (Figure 4) and the devil's bed (Figure 5), which will attract the attention of every viewer. The height of these erosion columns sometimes reaches 46 meters. Also, in the northern part of Makran region, due to the placement of hard sediments on the soft sediments that have been exposed to weathering and erosion, very large masses of hard parts have been separated and placed on the road, which was created by the initiative of the highwaymen due to the size of the parts and the preservation of natural resources from They have used it as a field or field, which is very spectacular (Figures 11 and 12). Debt is that wherever the three factors of water, wind and land are in contact with each other, the process of erosion and weathering is more intense and causes the creation of special coastal forms. In the studied area, the effect of the aforementioned factors combined with tectonic activities has increased the intensity of the formation of these structures.



Figure 12. Erosion columns in the northeast of Chabahar



Figure 13. Placement of a large sandstone mass on the road with the initiative of road users

Fungal-shaped erosion forms known as oysters: Wind erosion combined with the action of running water, especially rain, has created beautiful mushroom-shaped and beehive-shaped buildings, which the natives of the region call oysters (Figure 13). These beautiful forms can be seen in the sandstone and carbonate part of Beaufort.



Figure 14. Mushroom-shaped structure in the southeast of Chabahar

Sea Arch: One of the geological landscapes resulting from water erosion caused by waves hitting the shore is the creation of coastal niches (Figures 14 and 15).



Figure 15. Sea arch in the coastal area of Beris

Sea Cave: Like the sea arch, one of the other geological landscapes resulting from the erosion of waves is the creation of sea or coastal caves (Figure 16).



Figure 16. Sea Cave in the coastal area of Pasbandar

Sea Stack: Like the sea arch, one of the other geological landscapes resulting from the erosion of waves is the creation of sea stacks (Figure 17).



Figure 17. Sea Stack in the coastal area of Pasabandar

Sea Island: One of the geologic landscapes resulting from water erosion caused by waves hitting the coast and transferring sediments to the parts of the sea island is the creation of Sea Island (Figure 18).



Figure 18. Sea Island in the coastal area of Pasabandar

Hollow beaches and dissolution holes: chemical and biological erosions in Makran region have caused geological landscapes. Coastal organisms such as worms, crabs, seabirds, etc., by digging in soft sediments (Barrowing), leave biological traces on the beaches, which indicate biological activity. Also, the effects of sea water, especially the effect of acidic water combined with the drilling of organisms in hard rocks (Boring), especially the beaches of Lomashelli, cause the creation of medium and large-scale holes on the rocks, which cause geological landscapes (Landforms) (Figure 19).



Figure 19. Cavity beaches, soft (right) and hard (left) rocks

Jointed masses (Tor): The presence of three fault systems crosswise and widely and its impact on the coastal rock units form a wide network of joints and cracks and fault wedges. One of the geological landscapes resulting from the combined effect of tectonics, weathering, water erosion (caused by the hydrodynamics of waves) and wind erosion is the formation of jointed beaches or rocks full of fractures (Figure 20).



Figure 20. Joint stones (Tors) in the coastal area of Lipar

#### **Morphological landscapes with the influence of sedimentation processes**

According to the cycle of erosion, wherever weathering and erosion are active, there is a process of sediment transport and finally sedimentation. This issue has caused the formation of various geological landscapes in the studied area, the most important of which are mentioned below.

Sand Dunes: In the Makran area, especially in the parts where the permanent or temporary winds carry the existing debris (sand) sediments and by reducing the transport speed, the sediments settle and as a result of this process, sand dunes are formed. In the studied area, this process has caused sand dunes to expand along with wavy and symmetrical ripple marks. These effects are recorded and unrecorded on the beaches of Chabahar (Figures 21 and 22).



Figure 21. Sand dunes in the study area, Kachu Beach



Figure 22. Sand therapy in the sand dunes in the southeast of Chabahar

Tidal flat beaches: In the studied area, the increase in the erosion of the upstream beaches and the introduction of fine-grained sediments, the sedimentation process becomes more intense and causes the laying of new sediments and the expansion of sandy beaches. This process has formed coastal geological landscapes in the northwest and west of Chabahar (Figure 23).



Figure 23. Tidal beaches of the Tees coastal area

Lagoon: Many lagoons or lagoons can be seen on the coasts of the studied area, which are caused by the fluctuations of the sea level. Lipar Lagoon is located in the south of Lipar village and 15 km east of Chabahar on the Chabahar-Govatr coastal road with a wonderful view (Figure 24). The red lagoon of Lipar has a beautiful view with its red waters, some believe that its red color is due to the presence of bacteria that use the salt in the lagoon.



Figure 24. Lipar lagoon in the southeast of Chabahar

Estuary: Another geological landscape of Makran is the coastal estuaries. The mechanism of formation of estuaries is in such a way that with the advance of sea water, the upstream parts of the coast are flooded and with the deposition of sedimentary particles, its connection with the sea is cut off and they expand and cause the occupation of these sedimentary basins. Estuaries are intermediate environments between land and sea, which, due to their location, have special characteristics (high tolerance of salinity and being affected by land due to tides), which completely affect their environmental and living conditions and create a special ecosystem. provided (Figure 25).



**Figure 25.** A view of the coastal estuary of Hotan Parak

Small bays and omega-shaped bays: In the studied area, coastal sediments under the influence of sea level fluctuations, sedimentation and the combined effect of tectonics over time cause a drastic change in the coastline and the formation of a horseshoe-shaped bay. Omega) and give beauty (Figure 26). Among these sights are the bays of Chabahar, Pozm, Tis, and Govatr. On the coasts of the region, the effects of the prevailing sea currents on a large scale, along with the effects of the rivers entering the sea, have created beautiful bays in the region, which are known as omega bays due to their semicircular shape. Due to the expansion of stabilized sand dunes in the coastal strip and the effect of permanent winds, the movement of coastal sands along with degraded sand from sandstone formations on the one hand causes the expansion of plains full of quick sands and the release of fine sediment particles and remaining sediments. Coarse grain, on the other hand, has caused the formation of desert pavements in the coastal strip (Figure 27).



**Figure 26.** A view of the coastal bay in the northeast of Chabahar



**Figure 27.** Desert pavement on the coast of Makran

Mud Flat: On the coasts of Makran, due to the erosion of the upstream sediments, the thickness of the sediments is reduced and the sediments are added. These sediments are transported by surface water and finally the floodplain causes the expansion of mud flats. These sediments were formed at a distance from the coastline (Figure 28).



**Figure 2.** A mud flat on the northeast coast of Chabahar

Bar: In the studied area, coastal sediments under the influence of sea level fluctuations over time cause the sedimentation of sediments in the coastal area and the formation of Bar, in a way that in parts of Makran coasts, disconnects the sea from the land. (Figure 29).



**Figure 29.** Bar in the coastal area of Lipar

Sea spits: Coastal sediments under the influence of sea level fluctuations over time cause the sedimentation of sediments in the coastal area to form sea spits (Figure 30).



Figure 30. Sea Spit in the coastal area of Lipar

#### The general mechanism of change and development of Makran beaches

The coasts of the Oman Sea have been exposed to two groups of terrestrial and marine environmental factors due to the subduction zone. In this situation, the rock units have become increasingly porous under the influence of petrification processes such as dissolution, decomposition and alteration of the constituent components, and it makes the beaches very vulnerable to the impact of waves and local loads (Figure 31).



Figure 31. The effect of chemical and physical erosion factors in the coastal area

Geological evidence of the coasts revealed that from the west to the east of southeast Iran, the intensity of the advance and from the northern shores of the Oman Sea, from the Bay of Pozm to the Gulf of Govatr, the retreat of the sea water in the destruction of the beaches decreases, that is, with the change of the sea tide line and the

advance of the water, coastal development It is much less than the eastern regions such as Ramin, Lipar and Govatr. Another important factor in the change of coasts is the presence of permanent and seasonal rivers in the region, such as the Sarkan River in the west of Pozm region and the Lipar River in the east of the region, which affect and sometimes destroy the coasts during flooding. This factor has changed the morphology of the coasts in such a way that it sometimes creates vast plains that will be covered with water in case of rains and floods. As mentioned in the first part, according to the subduction zone and the function of faults, such as conjugate faults and strike-slip faults, and the role of neotectonics and Makran subduction zone (coastal uplift), the resulting destructive changes are also significant. In such a way that the creation of cliff defenses in the coastal strip is quite evident and they are very effective in causing sedimentation and destruction of rock formations (Figure 32).



Figure 32. Neotectonics effect resulting from the Makran subduction zone and coastal uplift

In terms of engineering geology, the coastal area of Makran consists of resistant, less resistant and non-resistant rocks. The type of old sediments is soft sediments, and hard sediments are placed on top of these old sediments, which are washed away by the waves of soft sediments and become empty under the hard sediments, causing the fall of boulders and sometimes landslides occur. Like the previous two phenomena, the coastal regions of southeastern Iran are highly tectonized due to the existence of Makran subduction zone and have various type 1 and 2 fractures as well as numerous landslides and landslides. In general, there is more instability in the eastern part of the coastal areas of the province where there is an earthquake belt. In the highlands of the region,

the probability of instability will double. Therefore, the important factors that are effective in changing coastlines are wind erosion, which over time and the influence of air and sea water on the rocks of the sea intensify the destructive changes and cause the destruction of old stones and rock formations. Sea waves and currents, both deep and surface, play an important role in changing and creating the geological landforms of the coasts, and tidal currents play an important role. This process has caused the most destruction in marine structures and coastal components in the region (Figure 33).



**Figure 33.** The effect of erosion by waves on weak points and fractures and changing the coastal

Civil and human activities such as the development of coastal roads, the construction of fishing or commercial ports, urban development of both residential and commercial areas, and the construction of water catchment dams also cause major changes, especially in the location of the docks, and are affected by the creation of more sediments, which sometimes It is combined with the activities caused by the retreat of the sea water and causes the destruction or retreat of the sea and ultimately the destruction of these types of structures. These changes can be seen both in the west and in the east of the coasts. The fishing ports of Pasbandar, Breis, Ramin, Pozm and the commercial and military ports that were built especially in Chabahar Bay to Konarak have played a significant role in the changes of the coastlines (Figure 34).



**Figure 34.** The significant role of construction activities in the drastic changes of Pozm and Konarak coastal areas

**Table 1. Geomorphological and spatial characteristics of coastal study areas**

Coasts	Description of geomorphology
Govatr	In this region, sedimentation processes prevail over erosive and tectonic processes. Major geological landscapes include Omega and small bays, raised beaches (Cliff), coastal tongue (Head Land), Sea Arch, Bar, Tidal Flat, coastal estuaries. Creek & Estuary).
Pasbandar	In this region, erosion and tectonic processes prevail over sedimentation processes. The main geological landscapes include the raised coast (Cliff), coastal tongue (Head Land), sea arch (Sea Arch), islands (Island), joints and faults (Joint & Fault), sea cave (Sea Cave), mountains of a thousand valleys (Bad. Land) and mushroom-shaped forms.
Beris	In this region, erosion and tectonic processes prevail over sedimentation processes. The main geological landscapes include the raised coast (Cliff), coastal tongue (Head Land), sea arch (Sea Arch), islands (Island), joints and faults (Joint & Fault), sea cave (Sea Cave), mountains of a thousand valleys (Bad. Land) and mushroom-shaped forms.
Lipr	In this region, erosion and tectonic processes prevail over sedimentation processes. The main geological landscapes include the raised coast (Cliff), coastal tongue (Head Land), sea arch (Sea Arch), islands (Island), joints and faults (Joint & Fault), sea cave (Sea Cave), mountains of a thousand valleys (Bad. Land), Lagoon, Bar, Creek & Estuary, Boring and mushroom-shaped forms.
Ramin	In this region, sedimentation processes prevail over erosive and tectonic processes. The main geological landscapes include cliffs, barrowing beaches, honeycomb erosion, mud flats, tidal flats, and sand dunes.
Chabahar	In this region, sedimentation processes prevail over erosive and tectonic processes. The main geological landscapes include cliffs, barrowing beaches, honeycomb erosion, mud flats, bar, tidal flats, and sand dunes
Tees	In this region, erosion and tectonic processes prevail over sedimentation processes. The main geological landscapes include cliff, coarsening up ward, head land, sea arch, islands, joints and faults, erosion columns. (Erosion Column), sea cave (Creek & Estuary), dissolution holes (Boring) and mushroom shapes.

Konarak	In this region, erosion and tectonic processes prevail over sedimentation processes. Major geological landscapes include cliff, head land, sea arch, island, joint & fault, sea cave, and mushroom-shaped formations.
Pozm	In this region, erosion and tectonic processes prevail over sedimentation processes. Of course, human activities such as fishing and shipbuilding industries also affect the region. The main geological landscapes include cliffs, coastal tongues, sea arches, joints and faults, erosion columns, sea caves, mudflats. Mud Flat, Tidal Flat, Creek & Estuary, Barrowing and Bay.

**Reconstruction of geological models of the studied area**

According to the previously mentioned materials, the southeastern coasts of Iran are affected by the subduction of the Indian Ocean plate under the Iranian plate. Therefore, all coastal processes including erosion, sedimentation and human activities are affected by tectonic activities. On the other hand, from the point of view of sedimentology, it seems that a dual regime of sedimentation has prevailed in the studied coastal area, meaning that when the sea level rises, carbonates are deposited and destructive sedimentation stops, and when the sea level drops, sea water level and debris particles entering the sedimentary basin, carbonate sedimentation is stopped and destructive sedimentation takes place. In the northern regions, permanent and seasonal rivers such as Sarkan (Shor), Lipar rivers, as well as estuaries and estuaries such as Khor Shor and Park (due to the closure of the mouth of these estuaries by sediments that are associated with the limitation of the invasion area of tidal currents), The facies of the area above intertidal has grown and by leaving sediments, coastal expansion occurs. On the other hand, there are coastal currents, longshore currents, and rip currents in Makran region. In the meantime, the water that came to the coast returns to the sea due to the difference in height on the slope of the coast, but the return of water to the sea is not uniform and it may intensify from the paths that are more similar to the river channel and cause the rip currents to break the coast. and these currents occur frequently (Figure 35).



Figure 35. Splitting currents in the southern region of Chabahar

Therefore, it can be said that the coastal area of Makran is under the influence of three tectonic, erosion, and sedimentation activities, and human activities (industrial, fishing, and construction) are not effective. Therefore, two general models for the formation of landscapes and geologic features of the southeastern coast of Iran are reconstructed and proposed:

The first model: the predominance of erosion and tectonic processes over sedimentation processes causes the formation of landscapes such as erosion columns, sea stacks, sea arches, sea caves, headlands, and islands. (Island) and raised beaches (Cliff) in the coastal areas of Pasbandar, Breis, Lipar, Tis, Konarak and Pozm (Figure 36). The second model: the predominance of sedimentation processes over other activities, which are landscapes such as Spit, Bar, Tombolo, Lagoon, Delta, Tidal Flat, Barrier Islands. Bay Barrier) and mud flats in the coastal areas of Chabahar Bay cause rheumatism and goiter (Figure 37). Of course, it should be mentioned that tectonic and human activities are also effective on the processes of both models.

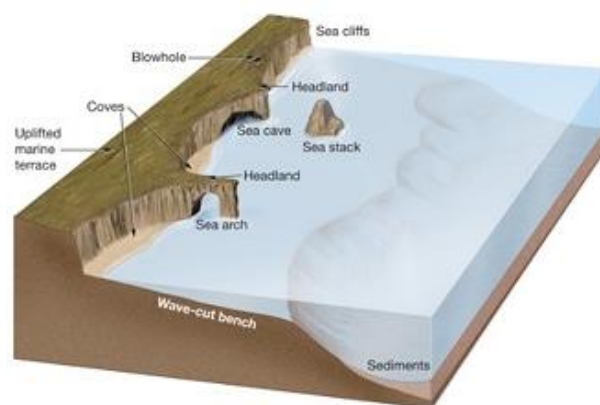


Figure 36. Erosion-tectonic model and formation of geological landscapes



Figure 37. Sedimentation-tectonic model and formation of geological landscapes

## Conclusions

The southeast coasts of Iran are affected by the subduction of the Indian Ocean plate under the Iranian plate. Therefore, all coastal processes including erosion, sedimentation and human activities are affected by tectonic activities. On the other hand, from the point of view of sedimentology, it seems that a dual regime of sedimentation prevailed in the studied coastal area, meaning that when the sea level rises, carbonates are deposited and the destructive sedimentation stops, and when the sea level drops, sea water level and debris particles entering the sedimentary basin, carbonate sedimentation is stopped and destructive sedimentation takes place. In the northern regions, permanent and seasonal rivers such as Sarkan (Shoor), Lipar rivers, as well as estuaries and estuaries such as Khor Shor and Park (due to the closure of the mouth of these estuaries by sediments that are associated with the limitation of the invasion area of tidal currents), The facies of the area above intertidal has grown and by leaving sediments, coastal expansion occurs. On the other hand, in the Makran region, there are coastal currents, longshore currents, and rip currents that come to the coast and affect them.

Therefore, it can be said that the coastal area of Makran is under the influence of three tectonic, erosion, and sedimentation activities, and human activities (industrial, fishing, and construction) are not effective.

In terms of engineering geology, the southeastern coastal region of Iran in the south of Sistan and Baluchistan province is composed of resistant, less resistant and non-resistant rocks, which causes geological changes. Also, the high sediment carrying capacity of the coastal currents in the region compared to the import of sediment from the land on rocky shores causes the sediments accumulated in the rocky slopes to be washed away and ultimately the process of coastal erosion and retreat continues.

Two general models include the dominance of erosive and tectonic processes over sedimentation processes, resulting in the formation of landscapes such as erosion columns, sea stacks, sea arches, sea caves, headlands, Islands and raised beaches (Cliff) are found in the coastal areas of Pasbandar, Bris, Lipar, Tis and Konarak, and the other is the dominance of sedimentation processes over other activities, which are landscapes such as Spit, Bar, Tombolo, Wetland. (Lagoon), Delta, Tidal Flat, Bay Barrier Islands and Mud Flat in the coastal areas of Ramin, Chabahar Bay and Govatr.

## References

- [1] Salari, H. (Translator), (2014). *William Morris Davis*, Daneshvaran Publications (Earth Science Pioneers). Author Lynn Van Gorp (2007), (32 pages).
- [2] Benmoussa, T., Amrouni, O., Dezileau, L., Mahé, G., Chiarella, D., Abdeljaouad, S., (2019). *Recent geochemical and grain size distribution of terrestrial sediment in coastal area from the watershed of Medjerda River, Gulf of Tunis. In Paleobiodiversity and Tectono-Sedimentary Records in the Mediterranean Tethys and Related Eastern Areas*, Springer, Cham, pp. 347- 351 (5 pages).
- [3] Rao, P. G., Reddy, K.S.N., Sekhar, C.R., Naidu, K.B., Krishna, K.M., Reddy, G.V.R., (2019). *Provenance studies of ilmenite from Red Sediments, Bhimunipatnam Coast, East Coast of India*. Journal of the Geological Society of India. 93(1), pp.101-108 (7 pages).
- [4] Omrani, H., Moazzen, M., Oberhänsli, R. (2018). *Geodynamic evolution of the Sabzevar zone, northern central Iranian micro-continent*. Mineralogy and Petrology, 112: 65-83 (18 pages).
- [5] Ansarian, F., (2015). *Measurement of heavy metal surface sediments in mighan wetland to investigate the effects of arak wastewater treatment plant*, Second Conference on New Findings in the Environment and Agricultural Ecosystems, Tehran University (in Persian).
- [6] Grando, G. and McClay, K. (2007). *Morphotectonics domains and structural styles in the Makran accretionary prism, offshore Iran*, Sedimentary Geology, V.198, P. 157-179 (22 pages).
- [7] Burg, G.P.; Haghypour, N., Burg, J.P., Kober, F., Zeilinger, G., Ivy-Ochs, S., Kubik, P.W., et al., (2013). *Rate of crustal shortening and non-Coulomb behavior of an active accretionary wedge: The folded fluvial terraces in Makran*

- (SE, Iran). *Earth Planet. Sci. Lett.*, 355: pp.187-198 (11 pages).
- [8] Burg, J. P. (2018). *Geology of the onshore Makran accretionary wedge: Synthesis and tectonic interpretation*. *Earth-Science Reviews*, 185: pp.1210-1231 (10 pages).
- [9] Stoklin, J. (1974). In possible ancient continental margin in Iran, Burk, G.D. and Darke, C.I. (Eds.), *Geology of continental margins*, Springer Verlag, New York, Pp. 873-887 (14 pages).
- [10] Snead, R.E. (1970). *Physical geography of the Makran coastal plain of Iran: Final Report, Reconnaissance Phase, US Office of Naval Research*, Geography Programs, Washington, 715 P.
- [11] Delaunay, S.; Smith, B. and Aubourg, C. (2002). *Asymmetrical fold test in the case of overfolding, two examples from the Makran accretionary prism (Southern Iran)*, *Physics and Chemistry of the Earth*, (J.H. Gottsmann, H.-P. Plag and H.H.G. Savenije Eds.), Elsevier, V. 27, Pp. 1195-1203 (8 pages).
- [12] Makhdoom, M., (2002). *The foundation of land development*, Tehran University Press, 211 p.
- [13] Drew, M. (1980) *Basics of geomorphology*. Translated by Maqsood Khayyam. Nima Publications, Tabriz.
- [14] Rajaei, A. (2004), *The application of geomorphology in the study of land and environment*. Nash Qomes, 344 p.
- [15] Ramesht, M. H. (1997), *Application of geomorphology in national-regional and economic planning*. Publisher of Isfahan University. 261 p.
- [16] Zamorrodian, M., J. (2003). *Geomorphology of Iran Volume 1 and 2*, Ferdowsi University of Mashhad, Volume 1, 256, Volume 2, 231 p.
- [17] Alai Taleghani, M. (2003). *Geomorphology of Iran*. Qoms publication. 414 p.
- [18] Moussavi Harami, R., (2014). *Sedimentology*, Behnashr Publications, 476 p. (in Persian).
- [19] Motamed, A., Moghimi, A. (2000). *The application of geomorphology in planning*, Samt Publications. 143 p.
- [20] Bird, E. (2000). *Coastal Geomorphology*. London. John Wiley & Sons. p322.
- [21] Leopold, L.B. and Wolman, M.G. (1975). *River meanders*, *Geol. Soc America Bull.* V71.
- [22] Reading, H.G. 1996. *Sedimentary environments: Processes, Facies and Stratigraphy*. London. Blackwell Science. p688.
- [23] Gharib Reza and colleagues, (2002). *Investigating the changes in the coastal lines of Sistan and Baluchistan provinces*. National Soil Conservation and Watershed Research Institute. Report No. 407/82
- [24] Suzengar, S., Karmi Khaniki, A. (2005). *Investigating the characteristics of the coasts of Khuzestan province*. Agricultural and Natural Resources Research Center of Khuzestan Province.
- [25] Suzangar, S., Gharibreza, M. (2006). *Examining the changes of the coastal lines of Khuzestan province*. Agricultural and Natural Resources Research Center of Khuzestan Province.
- [26] Gharib Reza and colleagues, (2005). *Investigating changes in the coastlines of Sistan and Balochistan*. National Soil Conservation and Watershed Research Institute. Report No.
- [27] Ports and Maritime Organization, (2005). *Coastal landform maps of the country*.
- [28] Ghodrati, A., Gharibreza, M., (2000). *Investigating the changes in the coastlines of Gilan province*. Agricultural and Natural Resources Research Center of Gilan Province.
- [29] Choupani, S., Gharibreza, M., (2003). *Investigating changes in the coastlines of Hormozgan province*. Agricultural and natural resources research center of Hormozgan province.
- [30] Mofidi, A, M., Karmikhaniki, A., (2003). *Investigating the characteristics of the coastal areas of Golestan province*. Agricultural and Natural Resources Research Center of Golestan Province.
- [31] Samadian, M. R., Jafarian, M. B., (1996). *Geological map of Chabahar*, scale 1:100000. Geological Survey of Iran, (In Persian).
- [32] Tajvar, A., Ahrari-Roudi, m., Elyaspour, N., (2023). *Introducing the Lomashell of Makran coast and their use for supplementing aquatic teed*. *J. Oceanography (JOC)*. Volume14 (55): 94-104.
- [33] Roddy, B. P., (2010). *The use of the sediment fingerprinting technique to quantify the different sediment sources entering the Whangapoua Estuary, North Island, in New Zealand*. Thesis, University of Waikato. New Zealand.
- [34] McCall, G. J., (2002). *A summary of the geology of the Iranian Makran*. Geological Society, London, Special Publications., 195(1): 147-204 (57 pages).
- [35] Condie, K. C., Stern, R. J., (2023). *Ophiolites: Identification and tectonic significance in space and time*. *Geoscience Frontiers*, 14(6): 101680. (32 pages).
- [36] Aghanbati, A., (2010). *Geology of Iran, Publications of the Geological Survey of Iran*, third edition, 586 p.
- [37] Dolati, A., (2010). *Stratigraphy, structural geology and low-temperature thermochronolgy across the Makran accretionary wedge in Iran*.

- [Ph.D. thesis]. Swiss Institute of Technology (ETH)(370 pages).
- [38] Arshadi, S., (1982). *The Geological and petrographical Investigations of the Fanuj Area*, Geological Survey of Iran, Internal Report, No. 35, 98 P.
- [39] Farhoudi, G. and Karig, D.E., (1977). *Makran of Iran and Pakistan as an active are system*, Geology, Pp. 664-668.
- [40] Bröcker, M., Hövelkröger, Y., Rad, G. F., Berndt, J., Scherer, E. E., Kurzawa, T., et al., (2023). *The magmatic and tectono-metamorphic history of the Sistan suture zone, Iran: New insights into a key region for the convergence between the Lut and Afghan blocks*. Journal of Asian Earth Sciences, 236: 105313 (18 pages).
- [41] Darvishzadeh, A., (2003), *Geology of Iran*, Amir Kabir Publishing House, 421 pages
- [42] Lepichon, X., (1968). *Sea-floor spreading and continental drift*, Journal of Geology Research, V. 73 (12), Pp. 3661-3697.
- [43] Jentzer, M., Agard, P., Bonnet, G., Monié, P., Fournier, M., Whitechurch, H., et al., (2022). *The North Sistan orogen (Eastern Iran): Tectono-metamorphic evolution and significance within the Tethyan realm*. Gondwana Research, 109, 460-492 (33 pages).
- [44] Ravaut, P.; Bayer, R.; Hassani, R.; Rousset, D. and Al Yaha ey, A., (1997). *Structure and evolution of the northern Oman margin: gravity and seismic constrains over the Zangros-Makran-Oman collision zone*, Tectonophysics V. 279, P. 253-280.
- [45] Vernant, P.H.; Nilforoushan, F.; Hatzfeld, D.; Abbasi, M.R. Vigny, C.; Masson, F.; Nankali, H.; Matinod, J.; Ashtian, A. and Chery, J., (2004). *Present day crustal deformation and plate kinematics in the Middle East constrained by GPS mesurments in Iran and Northern Oman*, Geophysical Journal International, V. 157 (1), Pp. 381-398.
- [46] Aiman, U., Mahmood, A., Waheed, S., Malik, RN., (2016). *Enrichment, geo-accumulation and risk surveillance of toxic metals for different environmental compartments from Mehmood Booti dumping site, Lahore city, Pakistan*, Chemosphere, 144, pp. 2229-2239.
- [47] Jacob, K.H. and Quittmeyer, R.C., (1979). *The Makran region of Pakistan and Iran trench-arc system with active plate subduction*. Geodynamics of Pakistan, V.26, Pp. 305-318.
- [48] Regard, V.; Bellier, O.; Thomas, J.C.; Abassi, M.R.; Mercier, J.; Shabanian, E.; Fefhhi, K. and Soleymani, S., (2004). *Accommodation of Arabia-Eurasia convergence in the Zagros-Makran transfer zone, SE Iran: A transition between collision and subduction through a young deforming system*, Tectonics, V. 23, TC4007.
- [49] Ahrari-Roudi, M., (2017). *A Study on Tectonic and Sedimentology in Order to Fault Rupture Potential in Coasts the Makran Sea*, Open Journal of Geology, 7, pp. 1269-1286.
- [50] Negaresh, H., (2002), *Golfans and their geographical extent in Iran*, Sistan and Baluchistan University, Journal of Humanities, No. 13.
- [51] Guliyev, I.S.A. Feizullayev, N., (2001). *All about Mud Volcanoes*, Geology Institute of Azerbaijan National Academy of Sciences.
- [52] Negaresh, H., (2005). *Investigation of some scientific and practical aspects of Golfashan*, Journal of Applied Geology, Islamic Azad University, Zahedan branch, number three.
- [53] Morovati, H., (2005). *Fundamentals of Coastal Hydraulics*, Daryasar Publications, 270 p. (in Persian).