Evaluating and Monitoring Changes in the coastal urban environment of Jeddah using Remote Sensing Techniques and Geographic Information Systems.

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Abstract:

Populations are highly concentrated on beaches, and increasing urbanization is putting increasing pressure on coastal ecosystems around the world. The study discussed the application of remote sensing techniques and geographic information systems to changes in the coastal urban environment of the city of Jeddah in the time period extending between the years: 1973 - 2018 AD, and through analyzing topographic maps, approved organizational charts, and Landsat 7+ ETM satellite images, and performing geometric and spectral correction. Accordingly, the coast of the study area was divided into twelve sectors. Through the study, the significant expansion of marine constructions and coastal projects in the city of Jeddah was observed, which affected the coastal urban environment. . The areas of spatial change were calculated: excavation and filling in each sector, whether resulting from human or natural action. The study also discussed identifying the spatial characteristics of the projects and other patterns of human intervention on the geomorphodynamics of the coastline of the city of Jeddah and the extent of the urban environmental balance between the human factor benefiting from the marine environment to meet pressure needs. population and achieving sustainable development goals. The study resulted in monitoring the change in the coastal urban environment, identifying current and potential problems as a result of human interventions, and contributing to developing solutions to them.

Keywords: Coastal urban environment, geomorphodynamics, coastal ecosystems, urban environmental balance, cut and fill.

تقييم ورصد التغيرات فى البيئة الحضرية الساحلية لمدينة جدة باستخدام تقنيات الاستشعار عن بعد ونظم المعلومات الجغرافية.

ملخص

تتركز التجمعات السكانية بشكل كبير على الشواطئ، كما أن التوسع الحضري المتزايد يفرض ضغوطًا متزايدة على النظم البيئية الساحلية في جميع أنحاء العالم. ناقشت الدراسة تطبيق تقنيات الاستشعار عن بعد ونظم المعلومات الجغرافية على التغيرات فى البيئة الحضرية الساحلية لمدينة جدة فى الفترة الزمنية الممتدة بين عامي: ١٩٧٣ – ٢٠١٨م، ومن خلال تحليل الخرائط الطبوغرافية والمخططات التنظيمية المعتمدة وصور الأقمار الاصطناعية من نوع Landsat 7 ETM+ وإجراء التصحيح الهندسى والطيفى عليها، تم تقسيم ساحل منطقة الدراسة إلى اثنا عشر قطاعًا، ومن خلال الدراسة لوحظ التوسع الكبير فى الإنشاءات البحرية والمشروعات الساحلية لمدينة جدة، مما أثر على البيئة الحضرية الساحلية. تم حساب مساحات التغير المكاني: الحفر والردم بكل قطاع سواء الناتجة عن الفعل البشري أو الطبيعي، كما ناقشت الدراسة التعرف على الخصائص المكانية للمشروعات وأنماط التدخل البشري الأخرى على جيومورفوديناميكية خط الساحل لمدينة جدة ومدى التوازن البيئي الحضري بين استفادة العامل البشري من البيئة البحرية لتلبية احتياجات الضغط السكاني وتحقيق أهداف التنمية المستدامة. توصلت الدراسة إلى رصد التغير فى البيئة الحضرية الساحلية وتحديد المشكلات الحالية والمحتملة نتيجة التدخلات البشرية والمساهمة فى وضع حلول لها.

الكلمات المفتاحية: البيئة الحضرية الساحلية، الجيومورفوديناميكية، النظم البيئية الساحلية، التوازن البيئي الحضرى، الحفر والردم.

Introduction:

The city of Jeddah ranks second after Riyadh in terms of population, with an estimated population of about 4 million according to the 2018 census. Economically, Jeddah has the Islamic port of Jeddah, which is Saudi Arabia's largest port.

The coastal area of Jeddah has witnessed considerable development in the social and economic fields, including tourism, industrial and commercial activities, mainly resulting in significant changes to the city's coast through many coastal engineering works and the change in the geomorphology of the coastline.

Research Problem:

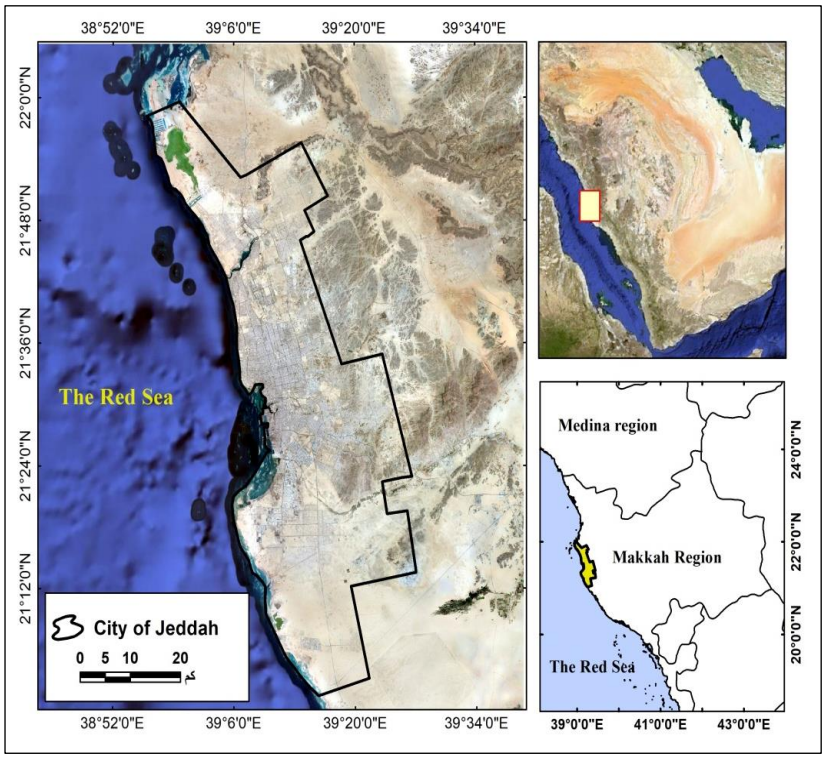
Human activities in the coastal environment cause considerable damage to coastal geomorphological forms, as a result of accelerating developments in marine and coastal construction projects (tourism, industry and service facilities) to keep pace with the process of urbanization. Tourism and industrial projects are considered the largest economic sector influencing the coastal environment of the city of Jeddah, but they are difficult to eliminate or manage easily or even reduce their potential damage, as the development of the coastline and its marine environment is subject to the interaction between the human factor and the natural environment (Nour-Eddine, 2014, p. 20). This resulted in a complete absence of coastal natural geomorphological phenomena and coral docks and the emergence of environmental degradation problems related to land-use planning and legal and administrative procedures for

tourism and economic projects, where urban growth extended at the expense of the sea and large areas were backfilled during the period of urban growth for various commercial, investment and government uses (Monnier and Guilcher, 1993).

Spatial and temporal delimitations of the study area:

Spatial Delimitations: The study area is located on the eastern coast of the Red Sea, west of Saudi Arabia, between latitudes 51.44 "59" 21O and 19.311 "1 '21^{O}" north, and between longitudes 40.16 "55" 38^{O} and 26.33 "23" 39^{O} East.

Temporal limits: The temporal delimitations of the study are the period from 1973 to 2018.



Source: From the researcher's work based on Landsat 7 ETM satellite visuals for the year 2018
Figure (1) Location of the study area

Research Objectives:

The study aims at the spatial application of GIS and remote sensing technologies in studying the impact of coastal urban development forms and associated interactions and dynamics on the coast of Jeddah and the identification of critical sites, resulting either from multiple human action interventions or marine erosion processes. The study also aims at identifying the geomorphological change of the coast within the scope of the study and contributing to the coastal management of the coast of Jeddah by applying coastal geomorphological studies.

Significance of the study:

It is hoped that this study will contribute to the planning and coastal management of the city of Jeddah and the analysis of the relationship between the significant development of tourist, commercial, industrial and social investment projects and the disruption of the coastal ecosystem, as disrupting the coastal ecosystem results in long-term problems that are difficult to solve or control. Therefore, this relationship must be based on achieving balance and giving the ecosystem an opportunity to be sustainable. The dynamic imbalance between erosion and deposition processes may result in many problems in the coastal environment. The study may also contribute to opening new horizons for future studies of other cities that are similar in their geographical conditions to the city of Jeddah.

Previous Studies:

Previous studies in the study area were numerous but were concerned with environmental aspects and not with

geomorphological and coastal urban planning and interconnection between them. Among the most important of these studies are the study of (El-Sheikh, 2004) which dealt with environmental degradation in the coast of Jeddah, and noted a negative change in the coastline; the study of (Awatif Al-Harith, 2007) that dealt with the environmental analysis of the human impact on the pollution of the marine environment of the southern coast of Jeddah, and performed a chemical survey of coastal water samples and the impact of drainage water on the coastal environment; and the study of (Al-Maliki, 2014) which revealed the environmental change of Abhor Bay in the northern city of Jeddah between 2002 and 2012 and examined the environmental impacts on the bay.

Previous studies also dealt with the study area as part of them such as the study of (Samia Abdul Ghaffar 2003) on the applied geomorphology of the East Coast of the Red Sea from Abhor Bay in the south to Ras Mastura in the north. It examined the factors and processes that formed the coastline and associated geomorphological phenomena based on cadastral maps and satellite images. There are also previous studies conducted on other regions, the most important of which are the study of Fathi Abdulaziz Abu Radi (1988) which focused on beach erosion dynamics and contemporary changes of the Nile Delta coast; the study of Hamdina Abdelkader Al-Sayed (2007) on offshore bars in the shores of the Baltim and their geomorphological effects; and the study of Mamdouh Tuhamy Akl (2009) which addressed the contemporary geomorphological changes in the Delta shores, presenting the causes and analyzing the results.

Research methodology:

Geomorphological studies require the development of a well-defined methodology, the foremost of which is to determine the scientific method on which the study is based and the approach to be followed, to analyze and discuss the results and to develop clear and expressive recommendations. The study mainly relied on the following methods:

The Descriptive Method:

This method was used to study the subject of the research and the geography of the region, discuss the scientific axes, identify the geomorphological and economic concepts, and study the human factors that contributed to the change of the coastline.

The Historical Method:

This approach was used to identify the change in the coastline over the period of time. So the study traced the change in the areas of erosion (cutting) and deposition (backfilling) in the study area so as to compare and observe the geomorphological changes and their effects.

Analytical Method:

This approach was adopted to analyze data related to the study including satellite imagery, statistical analyses and present its results in the form of maps, figures and models that help to explain the geomorphological changes of the coast of Jeddah.

Research Methods:

The study relied on several phases: data collection, processing, analysis and obtaining results. The following is a brief presentation of each phase:

The data collection phase:

The first of these is satellite images of the + Landsat 7 ETM type, obtained from the site of the United States Geological Survey (USGS) to cover the study area over two time periods (1973 and 2018) followed by a 1:50000 scale topographical map, a 1: 100,000 scale geological map and a 30m resolution digital height model as well as research, studies and reports relevant to the topic of the study.

The field study phase:

It is one of the essentials of applied geomorphological research as the field study contributes to the integration of data with maps and satellite images. The researcher's stay in Mecca near the study area helped her carry out several field studies.

The data processing and analysis phase:

At this stage the geometric correction of maps and satellite images was performed based on fixed reference points, spatial analysis tools were used. The researcher also used ERDAS IMAGINE V 8.5, which is an integrated system for the analysis of land resources data, through the processing and analysis of spatial data, obtaining accurate results. Arc GIS 10.5 was also used for the processing, analysis, modeling of data and obtaining results as shown in figure (2):

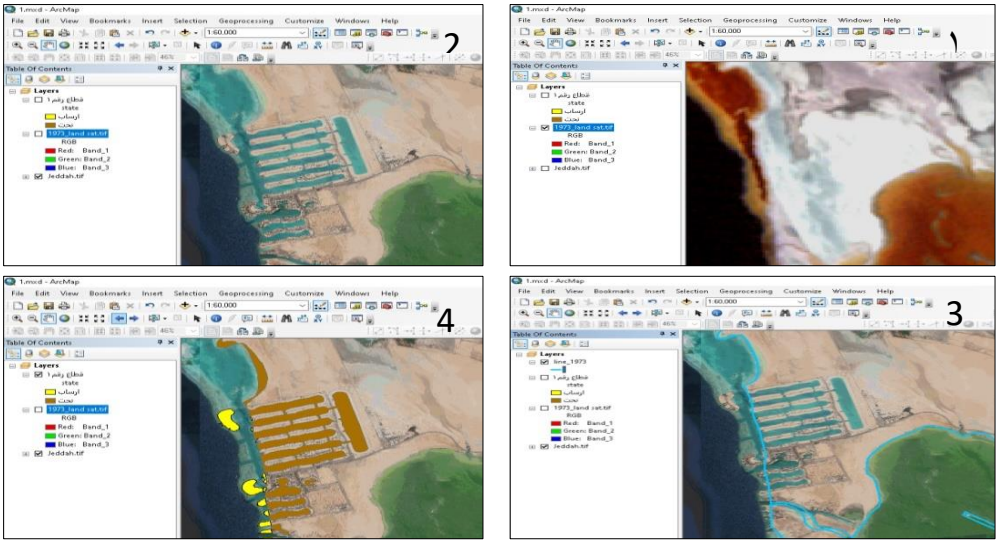


Figure (2) shows methods of analysis of geomorphological changes in Arc GIS for a model on the coast of Jeddah (Durrat Al-Arous Tourist Project). Figure (1) shows the extension of the coast in 1973; figure (2) shows the coastline and its overlap with land in 2018; figure (3) shows the numbering of the coastline in 1973 projected on a satellite image for the year 2018; and figure (4) shows the places of erosion (cutting) and deposition (backfilling) as a result of the construction work of the project.

The study was based on the following axes:

First- Spatial distribution of the sectors of the coast of the study area:

The coastline of the study area has been divided into 12 coastal sectors (as shown in figure 3) from north to south as follows:

Sector (1): It extends from the far northwest of Jeddah to the east of Dahban City and the west of Salman Bay with a length of 14.22 km.

Sector (2): It extends from the northwest of Jeddah to the southwest of Salman Bay with a length of 10.58 km long and takes a southeast northwest direction.

Sector (3): It extends from the northwest of Jeddah, encompassing the coast of Salman Bay with a length of 14.08 km, and it takes a southeast northwest direction.

Sector (4): It extends from the northwest of the city of Jeddah, specifically on the northern coast of North Abhur, with a length of 4.57 km, and takes a southeast northwest direction.

Sector (5): It extends from the northwest of Jeddah, specifically North Abhur Bay in North Abhur, with a length of 6.50 km, taking a southeast northwest direction.

Sector 6: It includes the coasts of Abhur Bay with a length of 20.71 km, and takes a southwest northeast direction.

Sector (7): It extends from the west of Jeddah with a length of 7.94 km and takes a southwest northeast direction.

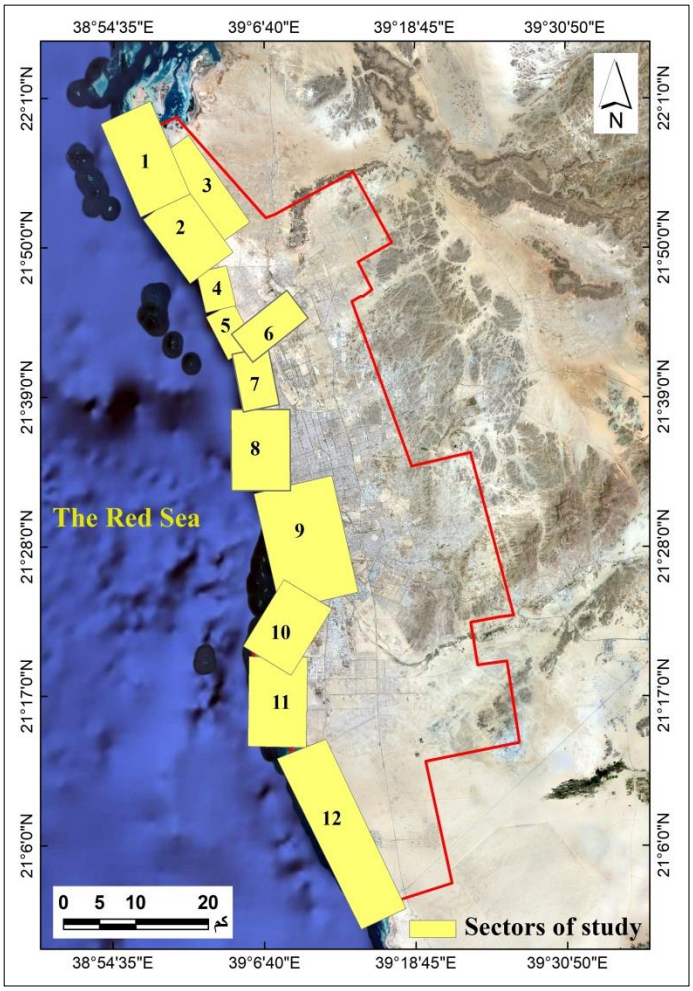
Sector (8): It extends from the west of Jeddah Downtown with a length of 11.10km and takes a south-north direction.

Sector (9): It extends from the west of the city of Jeddah in the area of Jeddah Islamic Port with a length of 17.08 km and takes a southeast northwest direction.

Sector 10: It extends west of the downtown of Jeddah to the south of the port area and is 12.10 km long and takes a southeastern, northwestern direction.

Sector (11): It extends from the southwest of Jeddah to the west of the Industrial City of in the south with a length of 15.22 km and takes a southeast northwest direction.

Sector (12): It extends from the southwest of the city of Jeddah to the southwest of the Jeddah Electric Power Plant in Ras Al-Shiddiq with a length of is 22.15 km and takes a southeast northwest direction.



Source: From the researcher's work based on Land sat satellite visuals for 2018.

Figure (3): Study Sectors of the Jeddah Coast

Second- Characteristics of the marine erosion agents affecting the geomorphodynamics of the coastline of Jeddah:

Sea waves:

There have been numerous marine studies of waves across the coasts of Jeddah, the most important of which are those of (Jin and Ji, 2001), (Al-Barakati, 2004), (Rogers et al, 2007), (Jouon et al, 2009), (Zubier et al, 2008), (Gharbi et al, 2012) and (Fery & Al-Subhi, 2015). Among the most important results of these studies was that the generation of waves in the Red Sea is limited, because it is a semi-enclosed sea (maximum width of 350 km) and its connection to the Indian Ocean is narrow, which limits the entry of large waves. Waves in the Red Sea are generated mainly by wind, and there are two dominant wind systems: the northern part of the Red Sea is dominated by the northwest winds, and the southern part is dominated by western winds in summer and spring, while the southeast winds blow in autumn and winter. The average wave height in the Red Sea off the coast of Jeddah is (0.4 - 0.6) meters with a maximum ranging between 1.2 meters and 2.2 meters, respectively. The prevailing direction of the waves is generally west/northwest. These measurements of waves and winds were observed from the deep-water buoy published by King Abdullah University of Science and Technology (KAUST), and they were verified by other altimeter measurements from Envisat and Jason-2 satellites to evaluate the wave generation environment in the coastal waters of Jeddah.

Sea currents:

The characteristics of sea currents in the Jeddah coastline region, which is part of the Red Sea coast, have been identified through the studies of (Ahmad, 1991), (Saad et al, 1999), (Ahmad and sultan, 1992), (Al-Barakati, 2004) and (Sofianos and Johns 2007). Among the most important of these characteristics was the variation in the directions of the movement of sea currents in the Red Sea, as they take the south-west direction in the northern part of the Red Sea, the north/north-east direction in the central part, and the north/north-west direction in the south, at a speed of 10 to 55 cm/seconds. This variation in flow and movement is due to varying wind directions.

Third: Marine constructions affecting the geomorphodynamics of the coastline of Jeddah:

Some factors have helped to increase the impact of the human factor on shaping the coast of Jeddah, the most important of which are the following:

- The expansion of the dock off the coast of Jeddah, which serves to weaken and break the waves.
- The large extension of the barrier reef off the coast that reduces the strength of the waves and breaks them (Public Authority for Meteorology and Environmental Protection, 2017)

Marine constructions on the coast of Jeddah are numerous, so the researcher classified them as follows:

A. Ports:

Among the most important is Jeddah Islamic Port, which is considered the gateway to the cities of Mecca and Medina. It is the main port receiving pilgrims from all over the world, and the most important port in Saudi Arabia (Ruwaithi, 1984). The development of the port resulted in a radical change in the geomorphology of the Jeddah coast.

B. Berthing Facilities

The Jeddah coast has several berthing facilities resulting in a change in the geomorphology of some locations on the coast of the study area. The berthing facilities are various and include berths for yachts, boats, picnics, and marine tourist, sports and recreational activities (Technical and Environmental Requirements for the Management and Operation of Coastal Areas, 2017). These berthing facilities consist of:

- A suitable body of water that includes a waterway to approach the open sea, a parking lot and suitable basin areas for mooring and linking marine units.

- Fixed and floating facilities, depending on the location, which include wave barriers, sidewalks and scaffolds.

- An area of land for the berthing facilities, including parking lots and all kinds of services including roads, equipped buildings, fences, safety means, fresh water and electricity facilities.

The coast of Jeddah has witnessed the establishment of many berthing facilities and this has required a change in the geomorphology of the coastline until it reached its current form. This required carrying out cutting and deposition work in specific areas to be mentioned later.

Depositional Spits:

They are tongues of sediment and marine debris that stretch from the coastal area to the sea, and in parallel to it in some locations. As a result of human action, these sandspits have been transformed into concrete barriers that extend into the sea until they reach a wave-breaking range away from shallow coastal areas (Awatef, 2017). Some of them have also been transformed into roads linking the islands to the coastline.

Artificial Beaches:

They are sand waves on the front side of the wharf, and they used to take the rectangular, square or other forms. As a result of human action, these sand waves turned into artificial beaches and were greatly changed in front of the shores of the study area.

Artificial lakes:

They are bodies of water created by human action in coastal areas through cutting, backfilling and the use of installations such as retaining walls, plate curtains and other modern technologies.

The Jeddah's coastline has witnessed the creation of many artificial lakes for tourist and fishing purposes. These artificial lakes are fed with the Red Sea water to ensure water change, as the waters of the lakes are naturally changed. They were carried

out in an engineering manner commensurate with tidal movement and wind directions.

Man-made sandy beaches:

As a result of human intervention in the tidal areas of the coast of Jeddah, these areas were backfilled with beach sand and transformed into sandy beaches in some locations, as well as into hotel facilities and tourist resorts.

Concrete spits:

These spits resulted from human modification of the pointed beach teeth, and they consist of rough materials and generally head towards the deep water, and these spits have been covered with stone by human action. This geomorphological phenomenon has been exploited after being transformed by human action into concrete spits to reach deep water.

Seawater intakes:

The Jeddah coast has a number of seawater intakes and their locations have been selected in areas far from petroleum activities. These intakes have sufficient water depth to allow sea water intake openings to be higher than the deposit layer of the bottom, as in the entrance to Salman Bay and its connection to the Red Sea and the entrance to the desalination plant in the south of Jeddah.

Beach constructions in terms of protection and tourist and economic use:

They include (scaffolding, wave barriers, wharfs, artificial islands, swimming sites, parks) and have resulted in remarkable changes in the coast of Jeddah.

Fourth- Geomorphological analysis of the sectors and topological conformity with human action:

The city of Jeddah, like the world's coastal cities, has undergone geomorphological changes in the coastline since the 1970s to the present period as a result of the rapid economic progress of Saudi Arabia and taking the port of Jeddah as the Kingdom's primary port. This resulted in a change in land uses in Jeddah, and population concentration and pressure in the city. Environmental problems also arose, and as a result, the use of remote sensing has come to have a major role in geomorphological analysis by analyzing and comparing satellite images to observe changes in the coastline (Almazroui, 2017). This is done through the classification of satellite images in GIS and remote sensing software to determine the extent of coastal decline or progress (Gobert et al., 1996).

The geomorphological analysis of the coastal sectors of the study area and their correspondence with human action are as follows:

Sector 1:

This sector witnessed very clear geomorphological changes. The cutting area amounted to 4,366 km^2 with a percentage of 22,07% of the total cutting areas in the sectors of the study area, so it ranks second after sector 12 in terms of the total area of cutting. The average annual cutting was 97.022 square meters per year, figure (4) and table (1), due to the concentration of related tourist and economic projects, the most important of which are Durrat Al-Arous Project and the Tourist Lakes Project. The deposition area resulting from tourist projects was 1.81 km^2 with a percentage of 5.26% of the total cutting sectors in the study area

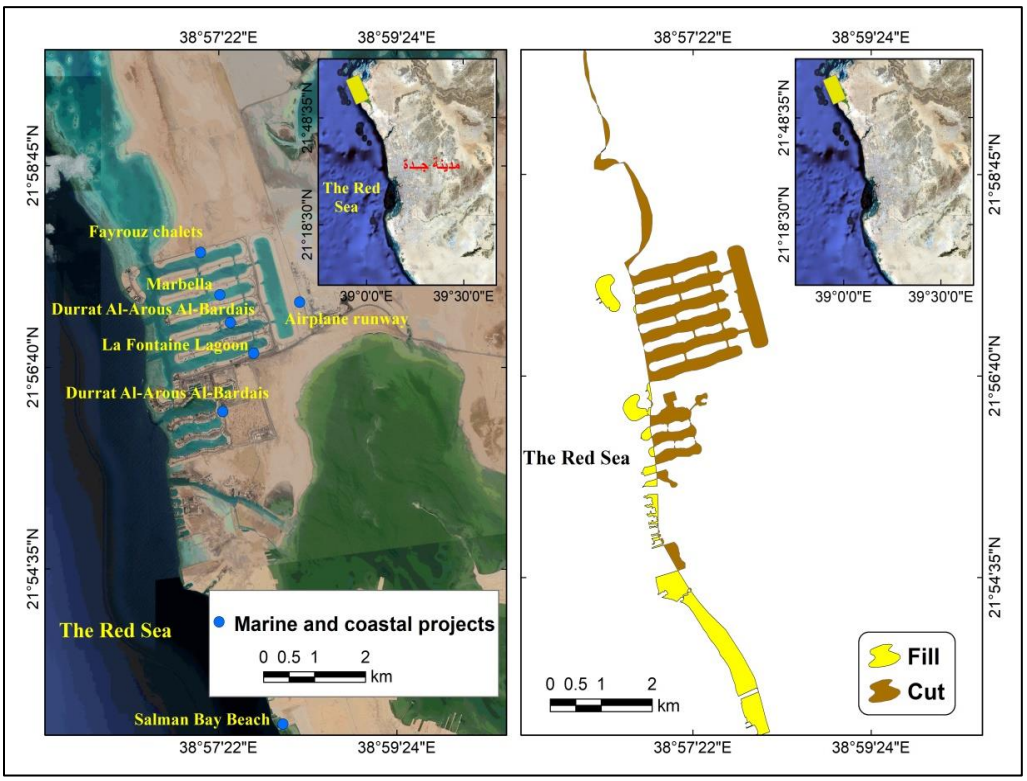
at a rate of 40,288 square meters per year. This indicates that the cutting process by human action exceeds the deposition process, figure (8).

Table (1) Quantitative characteristics of Cut, Fill in sectors of the study area

type	Cut			Fill		
Sector	Area Km^2	%	Annual Average (1,000 $m^{2)}$	Area Km^2	%	Annual Average (1,000 $m^{2)}$
1	4.366	22.07	97,022	1.81	5.26	40,288
2	1.689	8.54	37,533	1.31	3.8	29,111
3	1.472	7.44	32,711	4.309	12.5	95,755
4	0.146	0.74	3,244	0.188	0.55	4,178
5	0.0711	0.36	1,580	0.46	1.33	10,222
6	0.986	4.98	21,911	1.07	3.1	23,778
7	0.256	1.29	5,688	1.958	5.68	43,511
8	0.025	0.13	555	1.729	5.01	38,422
9	0.767	3.88	17,044	13.673	39.66	303.844
10	1.096	5.54	24,355	0.692	2.01	15,378
11	1.432	7.24	31,822	1.22	3.54	27,111
12	7.476	37.79	166,133	6.055	17.56	134.555
Total	19.78	100	439,602	34.48	100	766,155

Source: The researcher's work based on Landsat images in GIS software

This shows that the cutting rates are higher than those of deposition as a result of the engineering planning of these projects, which are as follows:



Source: The researcher's work based on Landsat images for the years 1973 and 2018.

Figure (4) Cutting and Deposition Sites in Sector (1)

Durrat Al-Arous Tourit Project:

The northern part of Durrat Al-Arous Project:

The engineering planning of this part resulted in a geomorphological change of the coastline, where six sea lanes were dug and dredged, and these sea lanes take water from the Red Sea, extend into the land and are connected to each other by narrow waterways (Figure 5). Perpendicular to them on the land side is a sea waterway. On its eastern side is located an aircraft runway, and the land confined between these sea lanes was exploited in the establishment of resorts, chalets and tourist

beaches, in which the desired tourism objectives of the project were achieved according to international standards. However, changes in the geomorphology of the coastline resulted and the existing natural phenomena were destroyed.

The northern part of the project:

It includes a number of coastal tourist facilities, including (Lafontaine Durrat Al-Arous - Durrat Al-Arous Beach - Marbella - Fayrouz Chalets), as shown in figure (5). As a result of human action and the completion of the project, an artificial island has been established adjacent to the coastline due to the backfilling process. It takes the form of an arc in the direction of land and is exploited for tourism purposes (Figure 5), which resulted in a geomorphological change in the site.

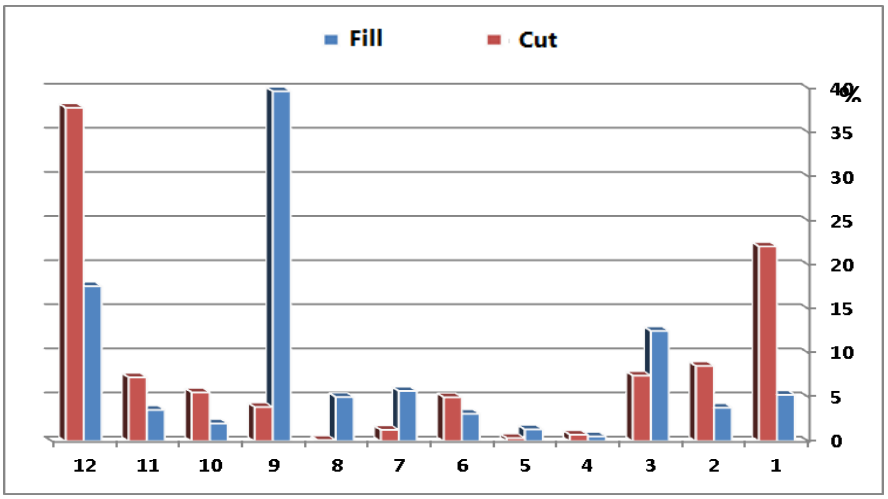
Source: The researcher's work based on satellite images
Figure (5) Engineering Planning of Durrat Al-Arous Project

The southern part of Durrat Al-Arous Tourist Project:

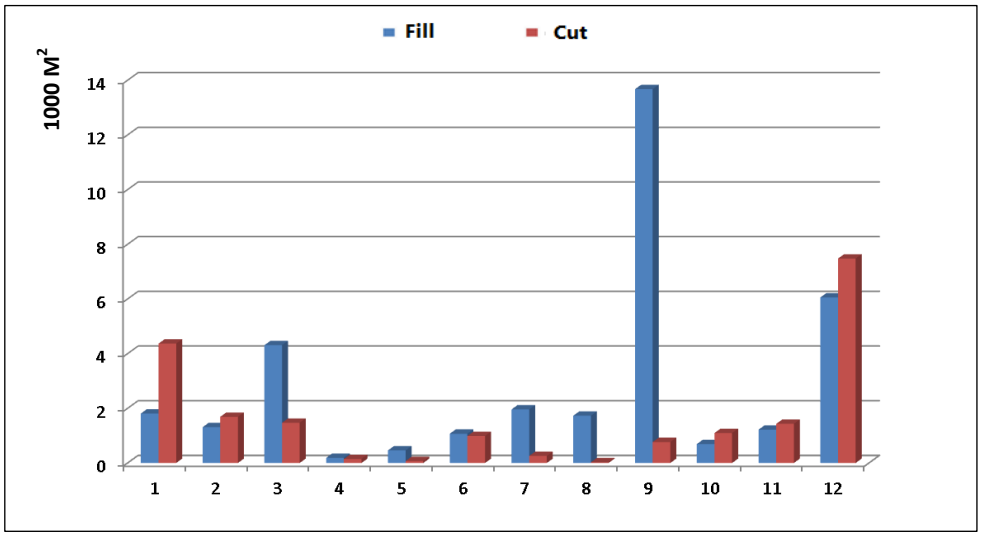
It resulted in a significant and clear change in the geomorphology of the coastline in this part, which led to the disappearance of all existing geomorphological phenomena and their replacement by forms resulting from human intervention. The structural engineering planning of this project was based on the idea of establishing a group of artificial lakes through cutting and dredging and controlling the extension of the coastline into the land. The project includes 5 artificial lakes, four of which extend in a semi-rectangular form into the land and are connected to the waters of the Red Sea through water entrances that as wide as the lakes. The fifth lake is located in the northeast of the project, isolated on land, but it is connected to a small water channel to supply it with water and change the water of the lake. This lake takes a semi-circular shape (figure 6).

Source: The researcher's work based on Landsat images for the year 2018
Figure (6): Engineering planning in the southern part of Durrat Al-Arous Project

The Lay Out of this project also contained a crescent-shaped artificial island towards the land, which achieved the engineering integration of the project containing artificial lakes, artificial sand beaches, and artificial islands, significantly altering the geomorphology of the coast.



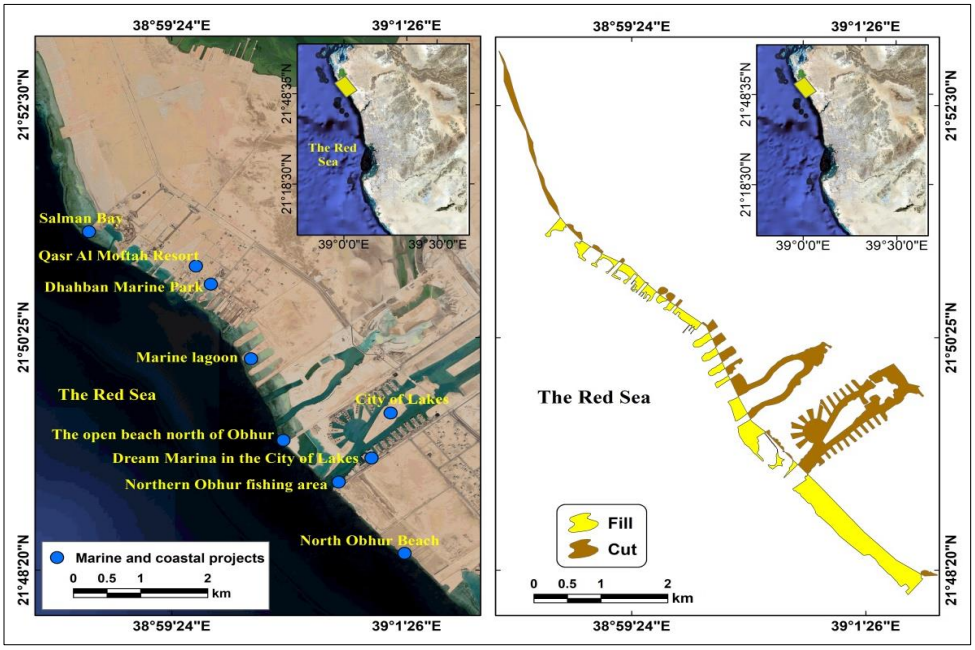
Source: The researcher's work based on Landsat images for the year 2018
Figure (7) Percentages of cutting and deposition rates in the sectors of the study area



Source: The researcher's work based on Landsat images for the year 2018
Figure (8) Areas of cutting and deposition in the sectors of the study area (1,000 m^2)

Sector (2):

This sector was characterized by the geomorphological changes resulting from human action in the planning of coastal projects. The cutting area amounted to 1,689 km^2 with a percentage of 8.54% of the total cutting areas in the sectors of the study area with an annual average of 37,533 m^2, while the deposition area resulting from tourism projects reached 1.81 km^2 with a percentage of 3.8% of the total cutting sectors in the study area at a rate of 29,111 mm^2 per year, as shown in figures (8-9).



Source: The researcher's work based on Landsat images for the years 1973 and 2018.
Figure (9): Cutting and deposition sites in Sector No. (2)

This sector is characterized by the multiplicity and diversity of human interventions in changing the geomorphology of the coastline in this part of the study, where human intervention in changing the geomorphology of the coastline resulted in the establishment of tourist resorts such as (Qasr Al-

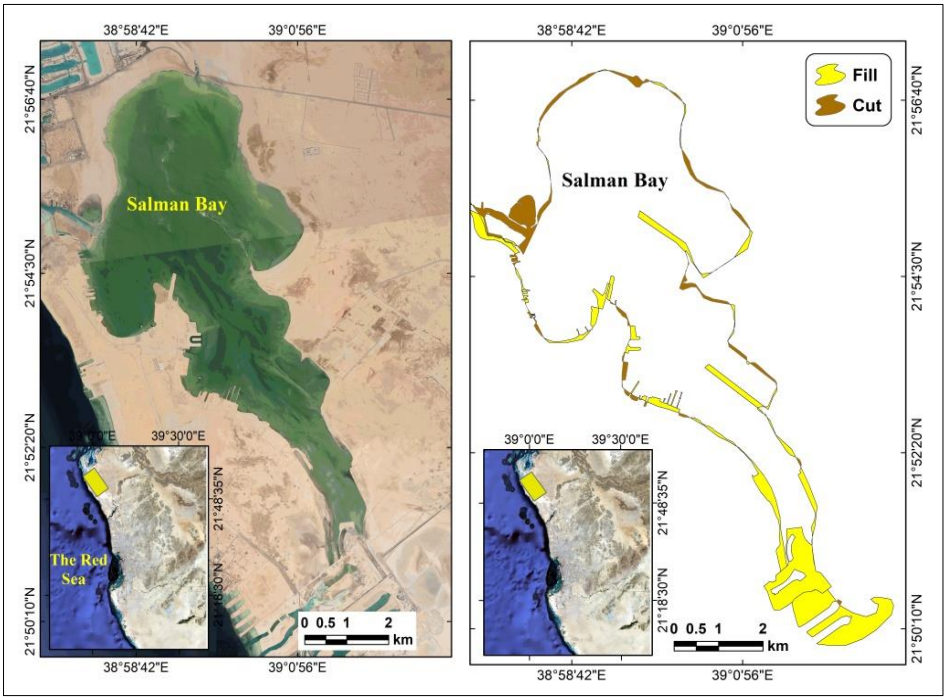
Muftah Resort - Salman Bay Resort), coastal tourist parks such as (Dahban Marine Park), berthing facilities such as (Al-Ahlam Marine Berth in the City of Lakes), sandy beaches such as (North Abhor Beach) and wave barriers.

One of the most important planning tourism projects affecting the geomorphology of this sector is the Tourist Lakes Project (Figure 10), which is an integrated tourism project in which the cutting process from the coastline towards the land was largely concentrated and lakes and sea lanes were established within the land on whose shores integrated tourist facilities were established and these include: berthing facilities for marine units such as Al-Ahlam Marine Berth in the lakes and sandy beaches. Wave barriers were also erected to reduce marine cutting operations and protect the project from sea waves. Moreover, an area was allocated in the project for marine fishing and was equipped with the latest means used for that purpose.

Figure (10) Engineering plan for the Tourist Lake City Project
Source: The researcher's work based on Landsat images for the year 2018

Sector (3):

This sector includes the coasts of Salman Bay in the northwest of Jeddah, and is considered an extension of the coast of the same city. Salman Bay is considered one of the sites of future investment urban expansions of the city of Jeddah, where the Jeddah Municipality has developed organizational plans for this bay. These plans are considered touristic in the first place, which results in a change in the geomorphology of the bay coast. This sector differs in its geomorphological changes from the first and second sectors, where geomorphodynamic changes resulted from both natural factors and human action together.



Source: The researcher's based on Land sat images for the years 1973 and 2018.
Figure (11): Cutting and deposition sites in Sector No. (3)

Through the geomorphological analysis of satellite images, the cutting area in this sector amounted to 1,472 km^2 with a percentage of 7.44% of the total cutting areas in the sectors of the study area (figure 8) with an annual average of 32,711 m^2 (table 1), while the deposition area amounted to 4,309 km^2 with a percentage of 12.5% of the total cutting sectors in the study area at a rate of 95,755 m^2 per year as a result of tourism projects (figure 11).

It was also found that deposition rates are greater than cutting rates for some reasons, the most important of which are increased evaporation processes and lack of continuous dredging of the sea entrance to the bay where it is connected to the Red Sea effectively, variation in the strength of sea currents and waves. Besides, the southern part of Salman Bay has already been backfilled by human action and made as an extension of the Tourist Lakes Project, which is located in Sector (2).

Sector (4):

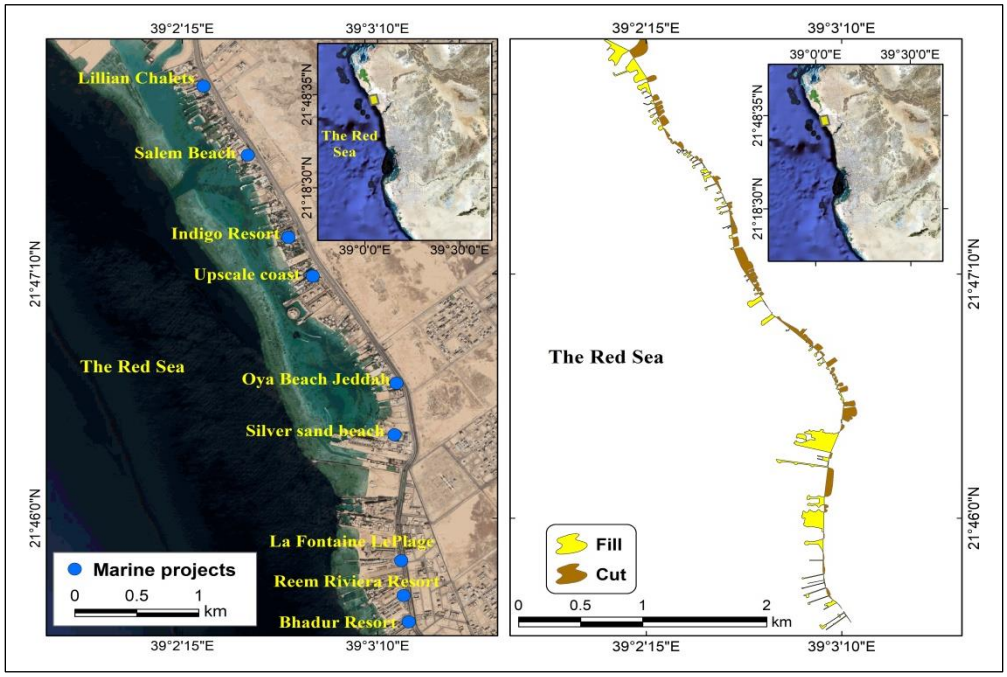
This sector includes the coastal strip of the northern Abhur in the northwest of Jeddah (figure 12). This sector differs in the rates of cutting and deposition resulting from human impact from the previous sectors, where these operations focused on the establishment of vertical wave barriers on the coastline that includes among them many tourist resorts known to the residents of Jeddah and the Kingdom of Saudi Arabia.

Through the analysis of satellite images, the cutting area was 0.146 km^2 with a percentage of 0.74% of the total cutting areas in the sectors of the study area with an annual average of 3,244 m^2, while the deposition area as a result of tourism projects was 0.188 km^2 with a percentage of 0.55% of the total cutting sectors in the study area at a rate of 4,178 m^2 per year (table 1 and figure 8).

Human interaction with the geomorphological situation of the coast resulted in the establishment of many tourist resorts such as (Lilian Chalets - Salem Beach - Indigo Resort – Al-Sahel Al-Raqi - OIA Beach - Silver Sands Beach - Lafontaine La Plage - Reem Riviera Resort and Beach - Bhadur Resort).

These resorts are at the forefront of the destination of the residents of Jeddah and the Kingdom of Saudi Arabia, where they gain a high status and popularity for the high level of services and engineering planning adopted according to the international standards recognized for tourism.

Moreover, as a result of the tourist human pressure on this sector of the coast of the city of Jeddah, geomorphological changes in the nature of the coastline occurred, which resulted in the disappearance of all coastal geomorphological phenomena.

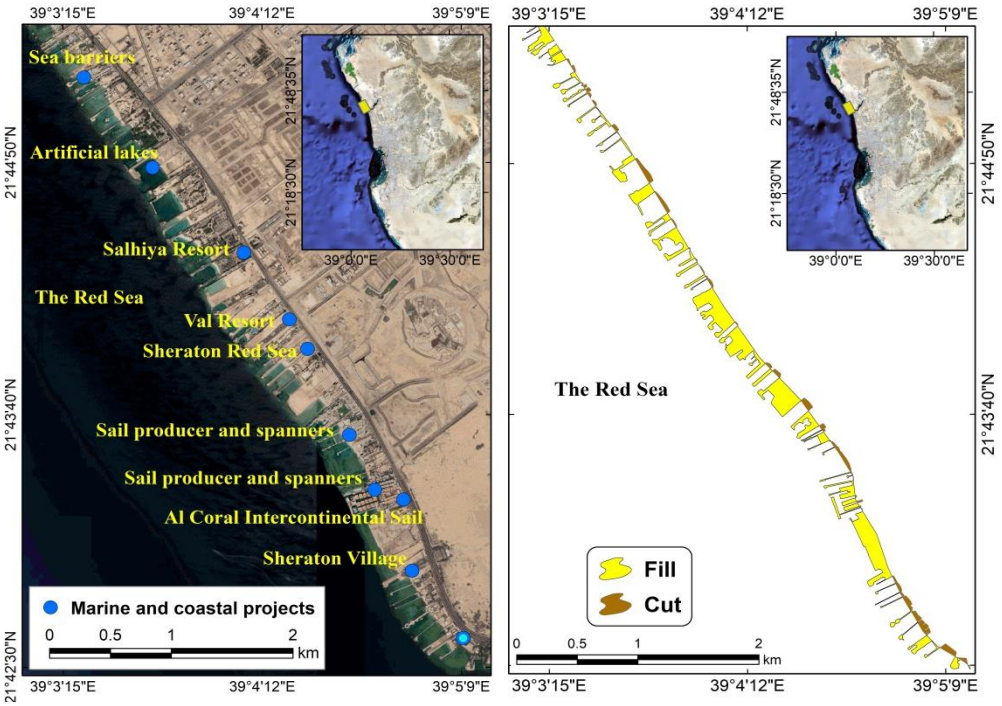


Source: The researcher's work based on Landsat images for the years 1973 and 2018.
Figure (12): Cutting and Deposition Sites in Sector No. (4)

Sector (5):

This sector includes the coastal strip of North Abhur in the northwest of Jeddah (figure 13). The human impact on modifying the geomorphology of this sector focused on the establishment of perpendicular wave barriers on the coastline containing many tourist resorts known to the residents of Jeddah.

The cutting area in this sector of the coast was about 0.0711 km^2 with a percentage of 0.36% of the total cutting areas in the sectors of the study area with an annual average of 1,580 m^2, while the deposition (backfilling) area as a result of tourism projects was 0.46 km^2 with a percentage of 1.33% of the total cutting sectors in the study area at a rate of 10.222 m^2 per year (table 1, figure 8).



Source: The researcher's based on Landsat images for the years 1973 and 2018.
Figure (13): Cutting and Deposition Sites in Sector No. (5)

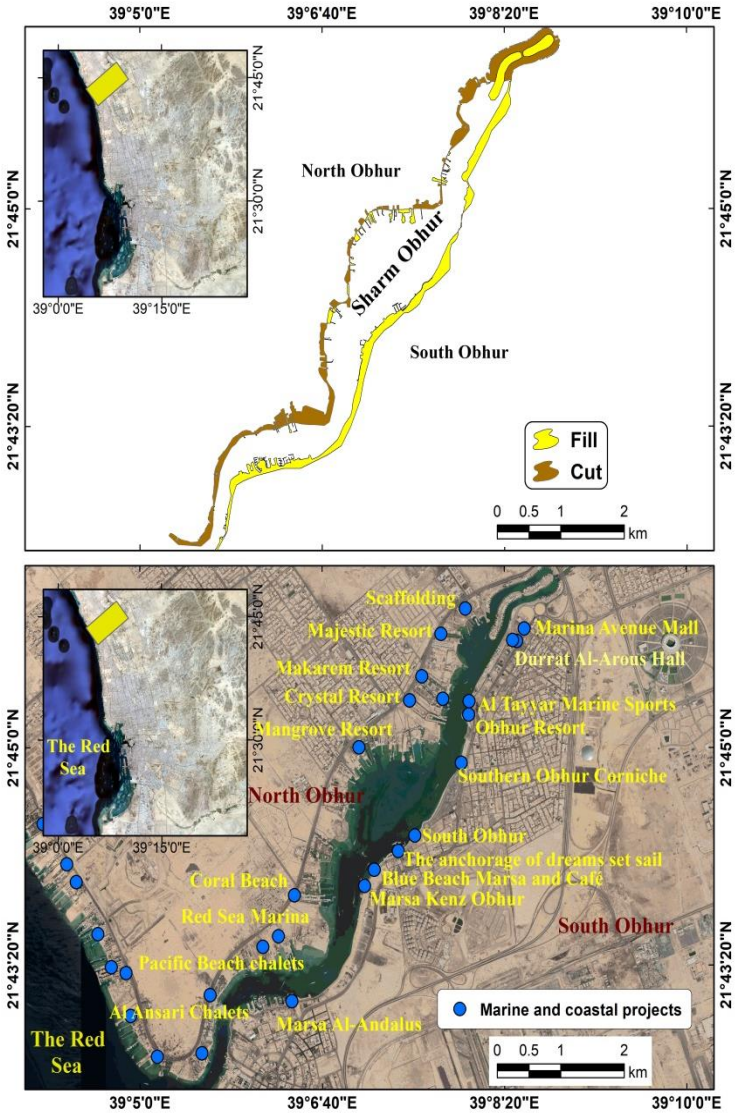
The human intervention in this sector of the coast of Jeddah resulted in many coastal tourist facilities due to the population pressure of the city of Jeddah and thus the pressure on the coast and the change of its geomorphology. At the forefront of these facilities come resorts which vary along the sector, namely (Salhia Resort - Val Resort - Sardinia Resort - Lafontaine Chalets - Narcissus Abhur Resort - Al Murjan Intercontinental Palm - Sheraton Village - Lafontaine Resorts). This sector also includes artificial lakes and multiple wave barriers.

Sector (6):

This sector includes the coastal strip of Abhur Bay, which permeates the city of Jeddah and divides it into two parts, the northern and the southern parts (figure 14). This gave the city of Jeddah an additional coast besides the Red Sea coast. The city of Jeddah was greatly luck to have this bay, as it gained a sea coastline length of 22 km that meets the population pressure of the city, which is considered the commercial gateway to the Kingdom, the gate for Hajj and Umrah and visiting the holy places.

This sector differs from the previous sectors in the rates of cutting and deposition resulting from human impact, as these operations focused on the establishment of perpendicular wave barriers on the coastline and floating and concrete scaffolds containing many tourist resorts known to the residents of Jeddah and the Kingdom of Saudi Arabia (Daoudi Mohammed, 2015).

Through geomorphological analysis, the cutting area in this sector amounted to about 0,986 km^2 with a percentage of 4.98% of the total cutting areas in the sectors of the study area with an annual average of 21,911 m^2, while the deposition area as a result of tourism projects amounted to 1.07 km^2 with a percentage of 3.1% of the total cutting sectors in the study area at a rate of 23,778 m^2 per year (figure 8).



Source: The researcher's work based on Landsat images for the years 1973 and 2018.

Figure (14): Cutting and deposition sites in Sector No. (6)

Through geomorphological analyses, the northern coast of Abhur Bay had greater cutting rates than the southern coast of the same bay, which had greater annual deposition rates due to the increase

in the human impact, which aimed in the planning of the southern coast to increase the areas of sandy beaches at the expense of the water of the bay.

While the engineering planning for the coast of North Abhur aimed to extend wave barriers perpendicular to the waters of the bay in order to establish coastal tourist resorts, and due to the depth of the waters of the northern side of the bay, these barriers require a great economic cost. Therefore, planning efforts were directed to the deduction of parts of the coast and the establishment of resorts on them, so the result was geomorphological changes in favor of cutting rather than deposition.

As a result of the geomorphological changes resulting from human action in Abhur Bay, two islands were formed by backfilling (deposition) along the far northeast of the bay (figure 14) and converted into sandy beaches similar to the northern and southern coasts in this part of the sector. Geomorphological methods have been adopted to feed the shoreline with sand coming from the Red Sea due to sea currents in this part.

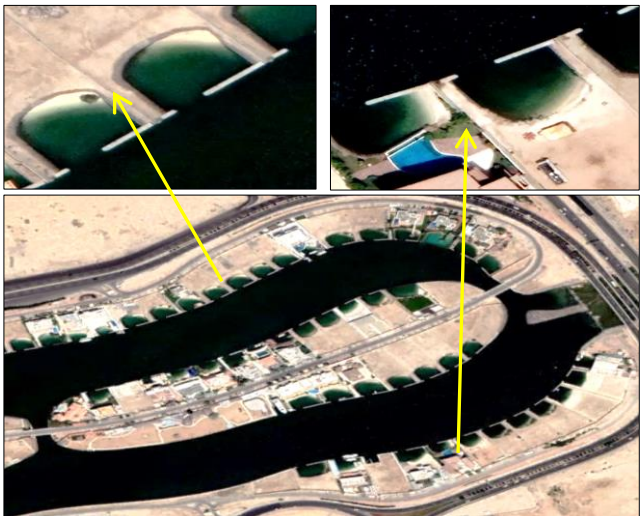
Geomorphological means applied to feed the beaches of the eastern part of Abhur Bay with beach sand:

Setting up hook-shaped sea barriers:

In this method, concrete barriers perpendicular to the beach line are formed and then twisted at their end in the sea waters to form small lagoons that take the form of open squares in part of the inner side in the sea water until the sea currents loaded with sand

enter. When they enter the lagoon, they create eddies that reduce the energy of the sea currents. Therefore, these currents leave the sand in the lagoon, and in order to prevent the sand from escaping to the deep waters of the bay, the marine barrier parallel to the beach in the sea holds this sand and the sand beaches are supplied with it (figure 15).

A type of sea currents known as slit currents helps in the process of collecting deposits, so that in some places it is sufficient to start water flows returning towards the sea in the form of returning slit currents which are recognized by the color of the deposits suspended by them (Fathy Abu Radi, 1988, p. 42). The returning slit current usually arises when the waves are perpendicular to the beaches with relatively moderate slopes, at the ramps and next to the sea spits. The Swedish scientist Hilstrom studied the impact of currents in the transport process and found that the deposits that are most transported are those which range in size between 0.25 – 0.5 mm, as they move with a current velocity of 15 cm/s, and when the size of the granules increases to 2 mm, it requires a current with a speed rate of 20 cm/s (Mohamed Mahsoob, 1991, p. 8).



Source: The researcher's work based on Landsat images for the year 2018
Figure (15): Coastal sand deposit collection sites in Abhur Bay

As a result of the modification to the geomorphology of the northern coast of Abhur Bay, many marine and coastal facilities have been established, including (Ansari Chalets – Calm Beach Chalets - Red Sea Berth - Mangrove Resort - Jeddah Yacht Berth - Crystal Resort - Makarem Al-Nakheel Resort - Majestic Resort – Al-Saqalla). The southern coast of Abhur Bay includes the following facilities (Kenz Abhur Berth - Jeddah Municipality Berth - Abhur Resort - open and private beaches - Durrat Al-Arous Hall).

Despite the human modification to the geomorphology of Abhur Bay for tourism projects, there is an environmental threat to these projects in the area of the bay and water quality, namely the mouth of the main floodwater disposal canal in Jeddah in Abhur Bay (figures 16-17). It is one of the projects that have already been established by humans and has a significant impact on the marine environment and the quality of the water of the bay,

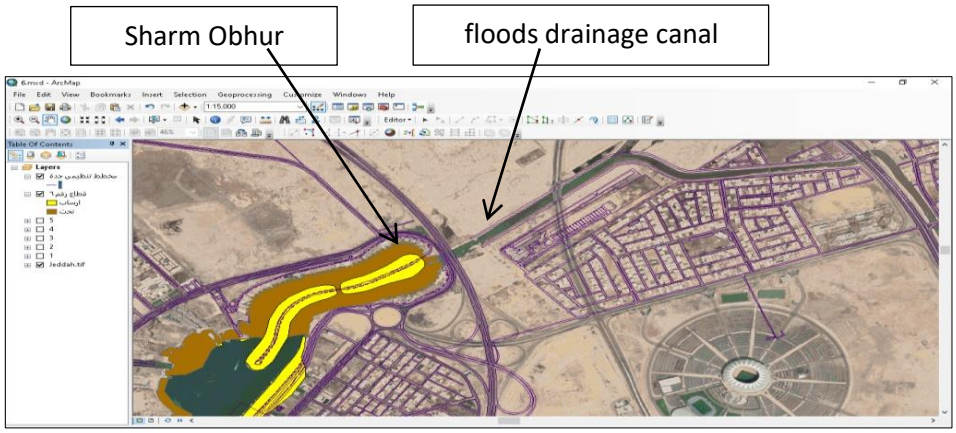
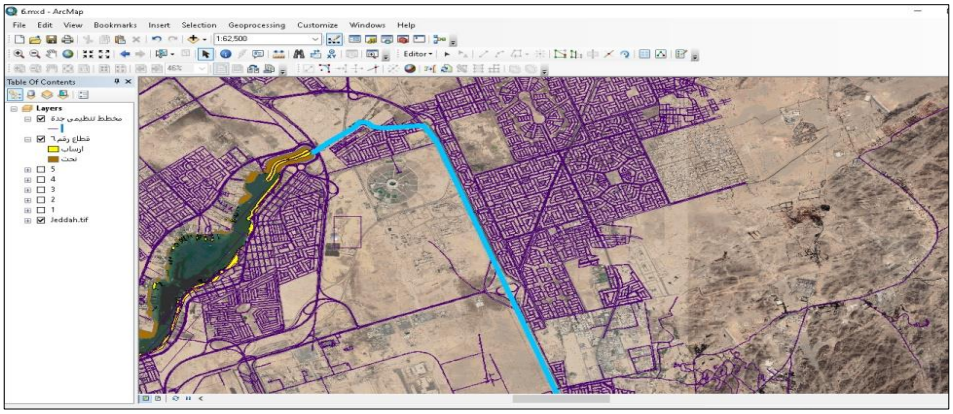


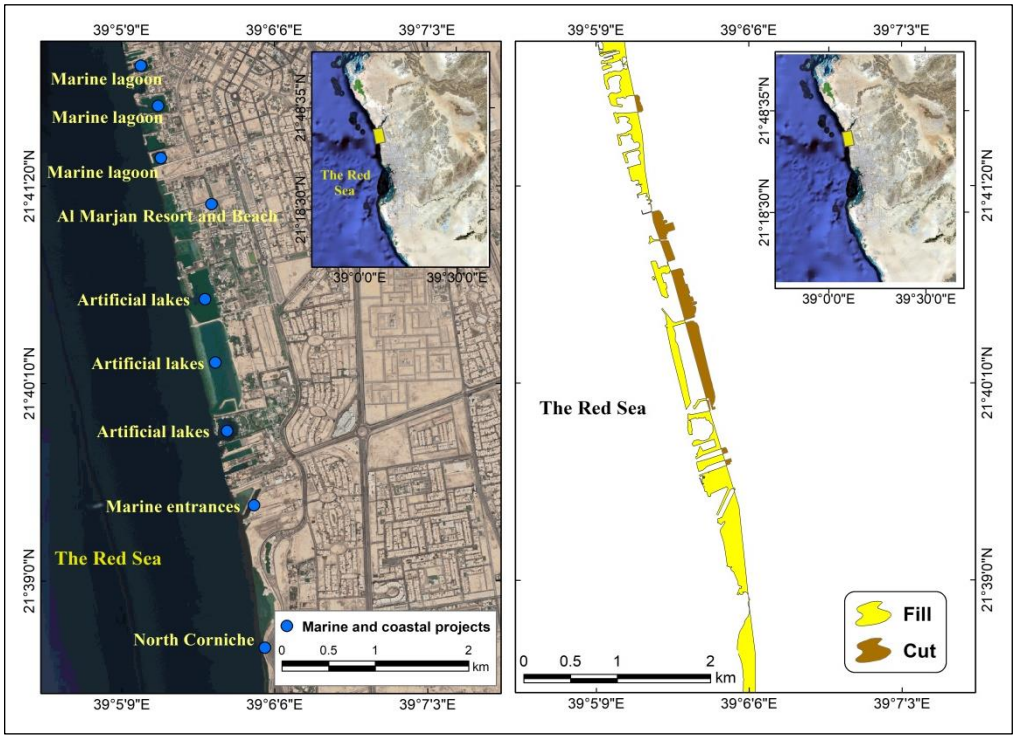
Figure (16): The mouth of one of the floodwater disposal canals in Abhur Bay

where this channel collects floodwater from the mountain back and valleys in the east and southeast of the city of Jeddah and when passing the urban block, its waters are exposed to pollution and transfer this pollution to the waters of Abhur Bay, especially in its mouth. In addition, the depth of the canal is almost equal to that of the bay, and therefore its water is stagnant most of the time of the year. To avoid these dangers, the canal must be connected to the Red Sea away from Abhur Bay.



Source: Jeddah Municipality (2017)
Figure (17): Organizational chart showing the mouth of one of the floodwater disposal canals in Abhur Bay

This sector extends south of Abhur Bay (figure 18), and is characterized by human intervention by making many geomorphological changes to the coastline, where the deposition operations outweighed the cutting (digging) operations. By interpreting the cartographic consistency, the cutting area was 0,256 km^2 with a percentage of 1.29% of the total cutting areas in the sectors of the study area with an annual average of 5,688 m^2, while the deposition area was 1,958 km^2 with a percentage of 5.68% of the total deposition sectors in the study area at a rate of 43,511 m^2 per year (figure 8).

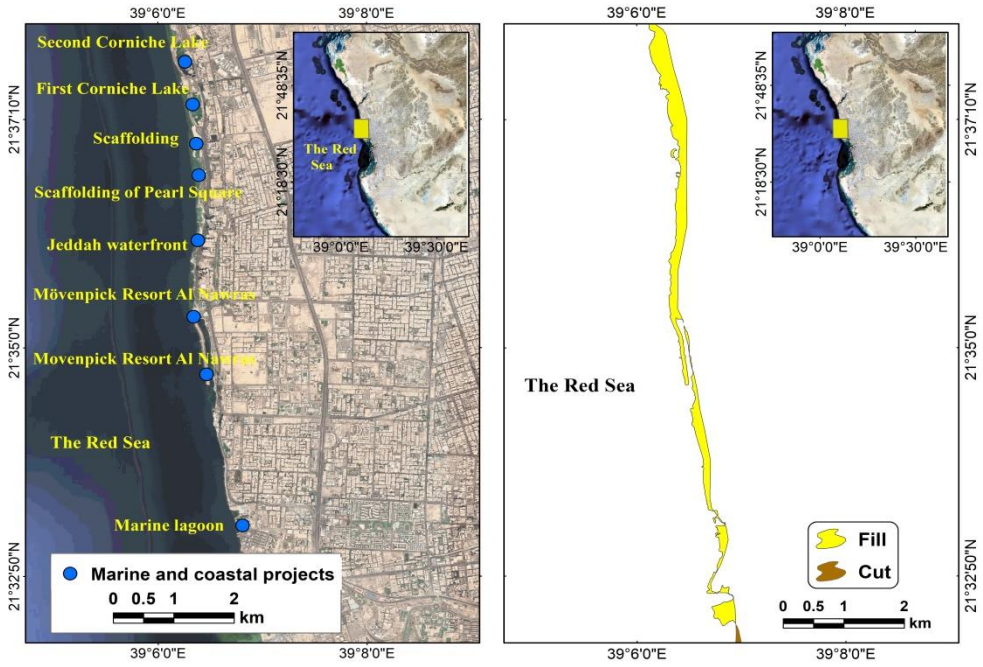


Source: The researcher's work based on Landsat images for the years 1973 and 2018
Figure (18): Cutting and deposition sites in Sector No. (7)

This sector was characterized by the establishment of many wave barriers and means of catching beach sand, the deduction and backfilling of areas from the sea off the coast of Jeddah in this part of the sector, the formation of sandy beaches and small coastal lakes that are small lagoons connected to the sea, which changed the geomorphology of the coastline. This sector includes Al Murjan Resort and Beach and the Northern Corniche in Jeddah, which is subject to continuous development by the competent authorities.

Sector (8):

This sector includes the waterfront of the city of Jeddah (figure 19) and is characterized by human intervention by making many geomorphological changes to the coastline, where the backfilling operations outweighed the depositional operations (backfilling). The cutting area was 0.025 km^2 with a percentage of 0.13% of the total cutting areas in the sectors of the study area with an annual average of 555 m^2, while the deposition area amounted to 1,729 km^2 with a percentage of 5.01% of the total deposition sectors in the study area at a rate of 38,422 m^2 per year (figure 8). However, this sector needs more means of protection from waves, and this was shown through the field study conducted on it.



Source: The researcher's work based on Landsat images for the years 1973 and 2018
Figure (19): Cutting and deposition sites in Sector No. (8)

As a result of human interventions, this sector contains the following coastal and marine facilities (Movenpick Resort Al-Nawras - Jeddah Waterfront - Pearl Square Scaffold - Floating and Diving Areas - First Corniche Lake - Second Corniche Lake).

The waterfront witnessed a comprehensive development project that qualified it to receive visitors, (pictures 1-2), where the sea walkway, services, facilities and stone cladding works were developed.

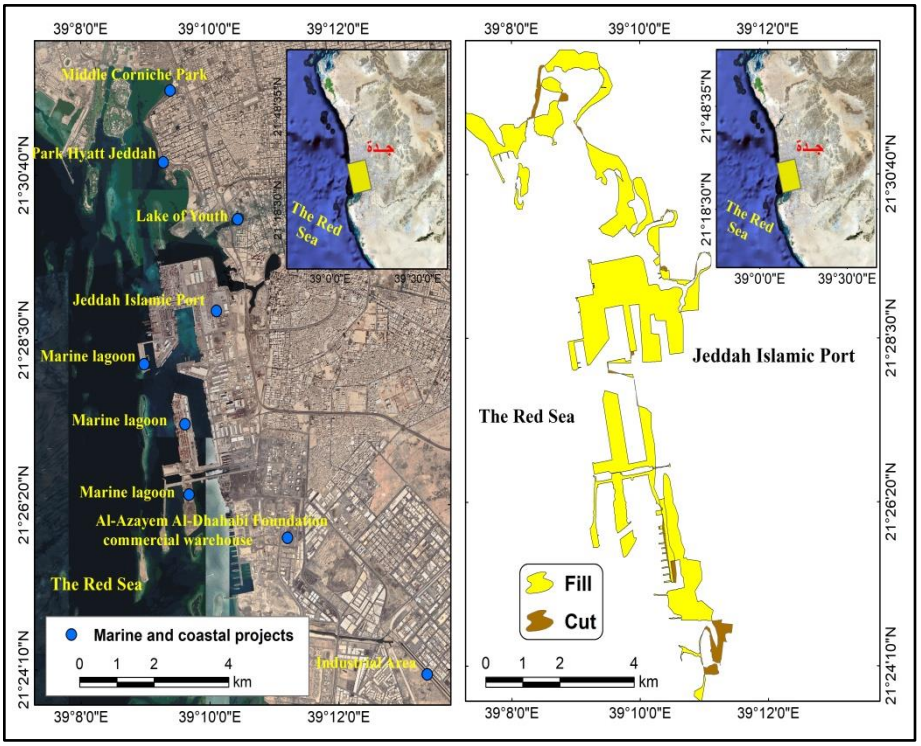
Pictures (1-2): The backfilling and development of the waterfront in the Hamra area on the coast of Jeddah

Sector (9):

This coastal sector extends in the area of Jeddah Islamic Port (figure 20). It is characterized by significant human intervention through making many geomorphological changes to the coastline, where the backfilling operations outweighed the cutting (backfilling) operations. This sector is of great importance as it includes Jeddah Islamic Port, the economic front of the city of Jeddah and the Kingdom of Saudi Arabia.

As a result of the continuous backfilling operations in Jeddah Islamic Port, its area increased to 12.5 km^2 at the expense of sea water, and after the establishment of the General Authority for Ports in the Kingdom of Saudi Arabia, that authority began to develop the port and the logistic area, where the number of piers was increased from 10 wharfs to 62 wharfs inside the sea water, and these were equipped with the latest equipment in accordance with the highest international standards.

The port is equipped with two navigational canals, one with a length of 2.2 nautical miles and a width of 300 meters, and the second with a length of 1.8 nautical miles and a width of 300 meters, in addition to four basins.



Source: From the work of the researcher based on the satellite visuals Land sat for the years 1973 and 2018
Figure (20): Cutting and deposition sites in Sector No. (9)

Through geomorphological analysis, the cutting area in this sector amounted to about 0,767 km^2 with a percentage of 3.88% of the total cutting areas in the sectors of the study area with an annual average of 17,044 square meters, while the deposition (backfilling) area amounted to 13,673 km^2 with a percentage of 39.66% of the total deposition sectors in the study area at a rate of 303,844 m^2 per year (figure 8).

It is clear that the deposition area increased in this sector, as it ranked first among the sectors of the study area, and this is due to the marine and coastal construction works in Jeddah Islamic Port and the increase in backfilling works at the expense of the sea, which resulted in a great change in the geomorphology of the coast in that sector.

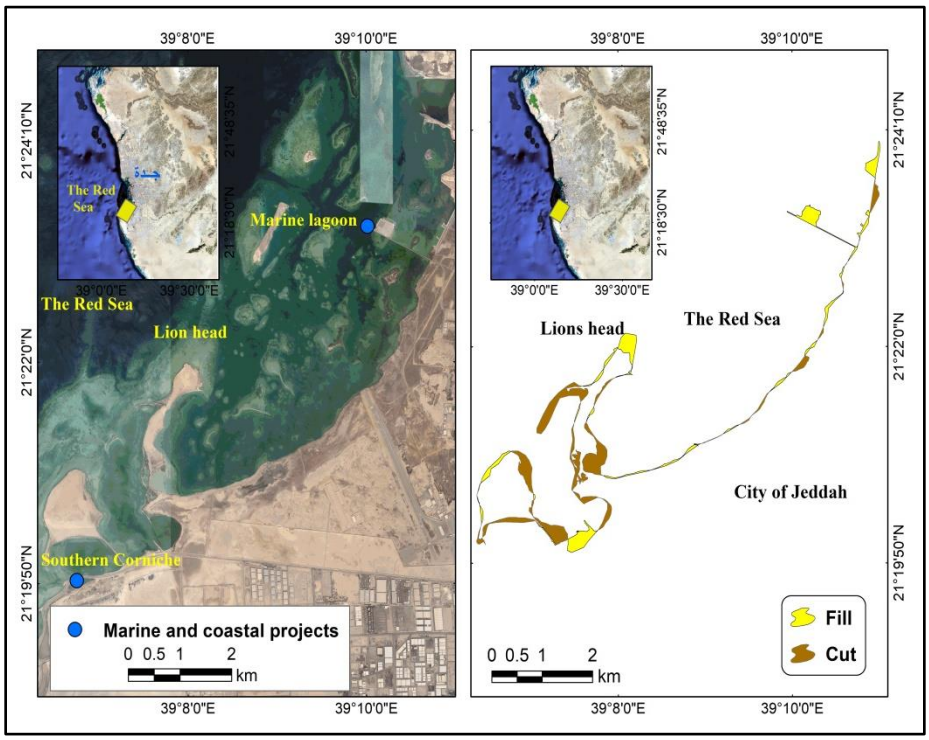
In addition to Jeddah Islamic Port, this sector includes parks such as (Middle Corniche Park - Jeddah Hyatt Park), lakes within the land connected to sea water such as (Youth Lake) and Fountain Island, which is considered one of the tourist attractions in Jeddah.

Sector (10):

This sector extends from the south of Jeddah Islamic Port to Ras Al-Aswad in the south (figure 21), and it includes clusters of coral reefs extending parallel to the coastline, but as a result of human interventions and environmental pollution from Jeddah Port, these coral reefs were exposed to cracking and degradation.

Through geomorphological analyses, the cutting and deposition rates were calculated. The cutting area in this sector was about 1,096 km^2 with a percentage of 5.54% of the total cutting areas in the sectors of the study area with an annual average of 24,355 m^2, while the deposition (backfilling) area was 0.692 km^2 with a percentage of 2.01% of the total deposition sectors in the study area at a rate of 15,378 m^2 per year (figure 8).

The marine construction work in this sector of the coast of Jeddah city included stone cladding and wave barriers, especially that this sector takes the form of an arch and is exposed to marine erosion.



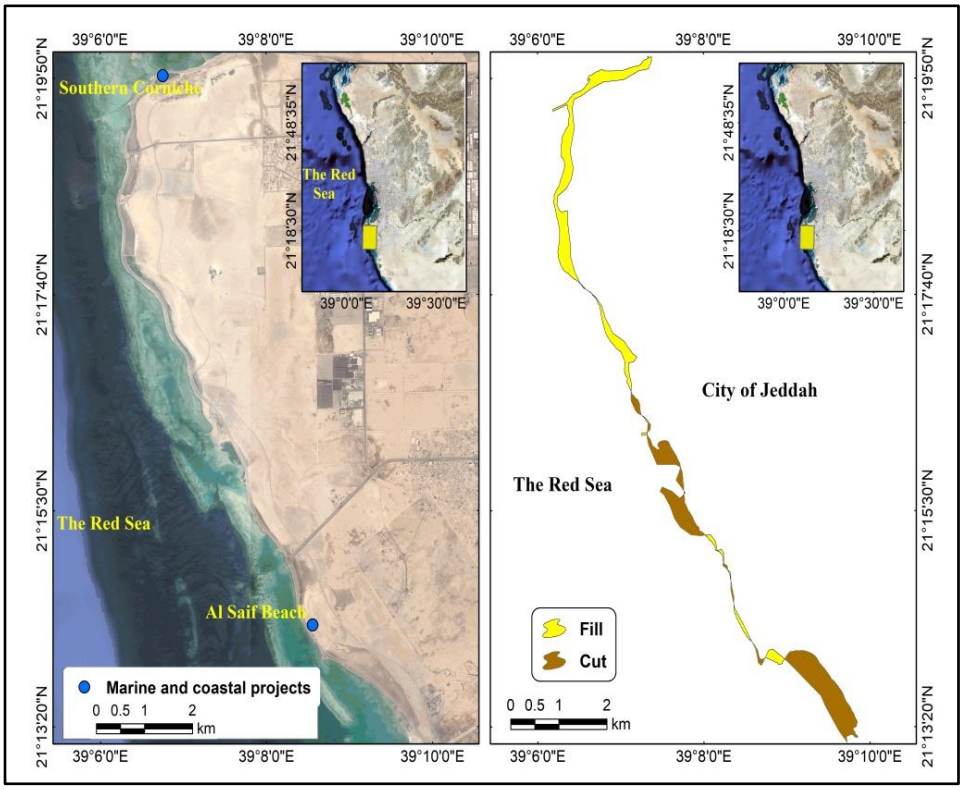
Source: From the work of the researcher based on the satellite visuals Land sat for the years 1973 and 2018.
Figure (21): Cutting and deposition sites in Sector No. (10)

Sector (11):

This sector extends along the south coast of Jeddah in front of the industrial zone (figure 22).The cutting area in this sector amounted to 1,432 km^2, which accounts for 7.24% of the total cutting areas in the sectors of the study area, with an annual average of 31,822 m^2, while the deposition (backfilling) area

amounted to 1.22 km^2, which accounts for 3.54% of the total deposition sectors in the study area at a rate of 27,111 m^2 per year (figure 8).

It is clear from this that the cutting areas are close to those of deposition. This is due to the primary goal of human interventions in this sector which is to reduce and stop marine erosion and not to set up large tourism projects as is the case in North Jeddah coast.



Source: The researcher's work based on Landsat images for the years 1973 and 2018.

Figure (22): Cutting and Deposition Sites in Sector No. (11)

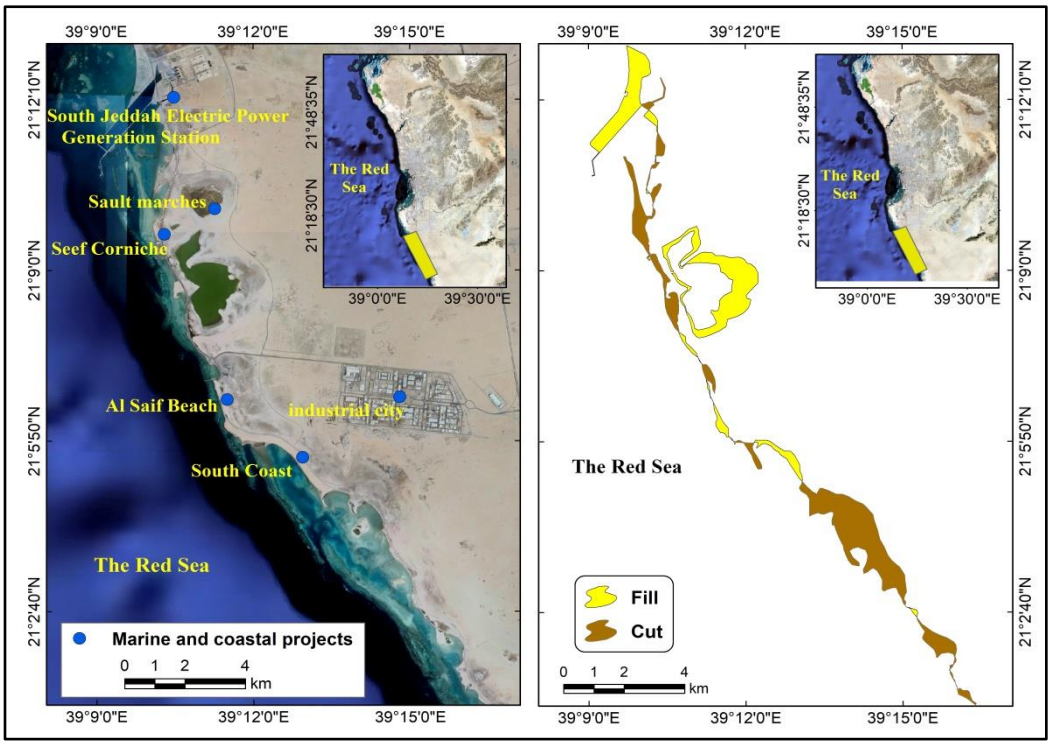
some wave barriers and stone cladding work. Lack of planning for large tourism projects in this sector has led to the concentration of the industrial zone of the city of Jeddah in the south, parallel to this sector and its southern part. Mangrove plants that grow in such coastal environments grow in this sector (Al-Awdat et al., 1997), but they are exposed to problems of pollution and cutting by human action.

Sector (12):

This sector extends in the far southwest of the study area (Figure 23), where clusters of mangrove plants grow, but they are threatened by human interventions as a result of the extension of sewage and industrial drainage canals in the industrial area (Al-Sheikh, 2004; Al-Maliki, 2014). This sector also includes Clusters of coral reefs that have been damaged by human interventions.

As a result of human and natural factors in shaping the coastline, the cutting area in this sector reached about 7,476 km^2, which accounts for 37.79% of the total cutting areas in the sectors of the study area. This sector ranks first among the sectors of the region in terms of marine erosion areas, and the annual average rates of cutting amounted to 166,133 m^2, while the deposition (backfilling) area amounted to 6,055 km^2, which accounts for 17.56% of the total deposition sectors in the study area. This sector ranks second after sector No. (9), at a rate of 134,555 m^2 per year (figure 8).The increase in cutting and deposition rates in

this sector is due to its direct exposure to marine erosion and lack of means of protection as a result of the low population density in the south of Jeddah and the confinement of the southern part to industrial planning. However, this part has high rates of pollution as a result of the increase in industrial activity in this sector, and this has had a negative impact on the marine environment and coral reef clusters which are considered one of the tourist attractions and a means of protecting the coast against marine erosion (Gobert, et al., 1996).



Source: The researcher's work based on Landsat images for the years 1973 and 2018.

Figure (23): Cutting and Deposition Sites in Sector No. (12)

Conclusion

The study came up with the following results:

- The human factor outweighed the natural factor in shaping the geomorphology of the coast of the city of Jeddah in some sectors, and this was evident in sector (1), an area of large tourist projects that includes the two projects: Durrat Al-Arous and the Lakes Tourist Village, where the backfilling and cutting amounts reached large rates and the coastline was changed very significantly, and sector (9), which includes the Jeddah Islamic Port area, which was expanded at the expense of the sea, and the geomorphology of the coastline was completely changed.

- The natural factor outweighed the human factor in shaping the geomorphology of the coast of Jeddah in some sectors, namely sector (11) and sector (12).

- Sector (10) needs more means of protection against waves.

- The geomorphodynamics of Jeddah's coasts are subject to continuous change due to the human factor, which has resulted in the disappearance and deterioration of geomorphological phenomena and the emergence of spatial problems associated with the imbalance between the cutting and deposition processes.

- Abhur Bay is exposed to environmental problems resulting from tourism projects.

Therefore, the study recommends enhancing the role of integrated coastal management of the city and the geomorphological balance between the human and natural factors and their impact on the natural resources of the coast of Jeddah, and developing an integrated plan that brings together various disciplines: geomorphologists, architects, urban planners, and specialists in sociology. The study also recommends applying engineering and environmental conditions for future tourism projects on the coast of Jeddah, and diverting the path of the floodwater disposal canal in Abhur Bay to another path to preserve the natural system of the bay.

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