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Original Paper

THE IMPACT OF GAZA FISHING HARBOUR ON THE MEDITERRANEAN COAST OF GAZA

Mazen Abualtayef[1], Said Ghabayen[1], Ahmed Abu Foul[1], Ahmed Seif[2], Masamitsu Kuroiwa[3], Yuhei Matsubara[3], Omar Matar[1]

[1]Environmental Engineering Department, Islamic University of Gaza, Gaza, Palestine
[2]Coastal Research Institute, Water Research Center, Alexandria, Egypt
[3]Civil Engineering Department, Tottori University, Tottori, Japan

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ABSTRACT

The Mediterranean coast of Gaza strip, which is covered about 40 km in length, is rich by coastal resources. The development that occurred along the coastal lines has led to the host of problems such as increased erosion, siltation, loss of coastal resources and the destruction of the fragile marine habitats. In order to conserve the depleting coastal resources, the changes due to development and associated activities must be monitored. Studying the temporal pattern of shoreline change is considered one of the most effective means of monitoring the cumulative effects of different activities. An attempt was made to study the impact of Gaza harbour on shoreline displacement along 6 km. This paper was intended to detect changes of coastal area in Gaza city to provide future database in coastal management studies. The analysis was carried out using image processing technique (ERDAS) and Geographical Information System platform. The variation during 38 years in the shoreline along the Gaza coast was determined by analyzing MSS, TM and ETM Landsat images from 1972 to 2010. The analyses identified the erosion and accretion patterns along the coast. The shoreline was advanced south of the Gaza fishing harbor, where the wave-induced littoral transport was halted by southern breakwater and the annual beach growth rate was 15,900 m^2. On the downdrift side of the harbor, the shoreline was retreating and beaches erode at an annual rate of -14,000 m^2. This study was emphasized that the coastal band is considered as a critical area, it is therefore necessary to monitor coastal zone changes because of the importance of environmental parameter and human disturbance. In particular, the projections of future shoreline erosion and accretion rates are considered important for long-term planning and environmental assessment for a variety of projects, including the construction and tourism facilities.

Keywords: Erosion, accretion; Gaza fishing harbour; GIS; ERDAS

Correspondence: Phone +970-599-857-931; mabualtayef@iugaza.edu.ps

INTRODUCTION

Most of the soft sandy coasts are subject to the dynamics of sediment transport which is supplied to the coast by valleys or rivers and then redistributed along the shore and seashore by the action of waves, tides and winds. The littoral active zone is therefore a dynamic area, where sand is stored, transported and exchanged. Sandy beaches are the central element of this sedimentary system and are considered as buffer zones, protecting the coast from sea attack and erosion. Therefore, reduction in sand supply or increase in sand loss, by natural or anthropogenic factors, can result in the long term change in beach morphology. Human activities like harbor's construction on beach can modify and upset the fluxes in the beach mechanisms. These changes cause the localized erosion or deposition of sediments or their shifts along the coastline.

The rapid increase of the population on and near the coastal areas leads to an increase of coastal resources exploitation. Thus, coastal zone areas are under great pressure from both the human activates and geomorphologic coastal processes. Coastal erosion is evidenced by collapsed trees, buildings, roads and other structures, including groins which prompting the need for immediate and local protection to prosperities, there is a need to ensure the long-term protection for the overall coast from serious problems such as erosion.

The focus of the present research was to study the impact of Gaza harbor on the shoreline changes over a long period of time from 1972 to 2010. ERDAS and GIS techniques were used because they provide the best sources to study the long term shoreline changes and are widely applied in environmental resources monitoring.

The coastline of Gaza Strip was formed over 15 thousand years ago by the deposits coming from the Nile originated in the first place from the mountains of Africa; therefore two main factors have created the beach of Gaza, the availability of sand and the motion of waves (Perlin and Kit, 1999). The available data indicates that 190,000 m^3 of alongshore sediment transport on the beaches of Gaza every year (Matar O. *et al.,* 2012).

Construction of the Low Aswan dam in 1902 and the High Aswan dam in 1964 has almost completely interrupted the Nile river sediment discharge to the sea. Fortunately for Gaza, the Bardawil Lagoon sandbar continues to act as a significant source and supplier of sand to the Gaza coast. As a consequence, any measures to prevent the current erosion at Bardawil could seriously affect the sand supply to the Gaza and Sinai coast (Perlin and Kit, 1999).

On the shore face of Gaza city, there are two low concrete groins (fishing wharves), which were built in the early of 1970's as shown in **Fig. 1a.** These structures, which are 500 m apart, have a total length of 120 m, protruded some 40 m into the sea. These coastal structures act as barriers to the alongshore sediment transport. In the early 70's it was necessary to defend the coast north of these two groins in order to control the erosion of the shoreline and to protect hotels located on the cliff. This coastal defence consisted of a linear row of rock armour present on the beach around MSL over a length of approximately 800 m as shown in **Fig. 1b** (Zviely and Klein, 2003).

At present, these armour rocks do not form a continuous defence structure anymore because they moved to Gaza fishing harbor. At irregular intervals, they contain sometimes wide gaps, with pools formed behind the smaller gaps.

Recently, beach constructions as breakwaters, roads, restaurants, hotels and other buildings have been constructed very close to and even right on the active part of the shore, thereby constraining the range of free space needed for the seawater dynamics and blocked the alongshore sand transport. They have caused an erosive effect on the coast downstream.

Gaza fishing harbor is located on the Mediterranean coast of Palestine. It was built between 1994 and 1998 (**Fig. 1c**) on a straight sandy beach backed by sand dunes. The length of the existing main breakwater is 1,000 m and that of the lee breakwater is 300 m. The head of the main breakwater is at water depth of 9 m, and the entrance of the harbor was 6 m deep when it was built. The harbor penetrates seaward from the shore to a distance of about 500 m.

The fishing harbor has locally disturbed the coastal erosion and sedimentation pattern, resulting in local coastal sand erosion problems. Buildings and roads that have been constructed close to the shoreline are already faced stability problems and other related negative impacts. It is expected to have serious erosion problems in the coming years.

Generally, deposits are in balance with erosion, however changing the shape of the present coastal line by building barriers, wave breakers and sea ports can prevent the movement of sand and therefore cause beach erosion. Recently after the construction of the fishing harbor, the need to protect the coastal zone of Gaza is increased.

The main aims of this research are: to check the shoreline changes during 38 years along the coast of Gaza and calculate the associated loss and gain of land (erosion/accretion) values by analyzing Thematic Landsat images from 1972 to 2010, to study the changes on Gaza beach morphology since the construction of the Gaza harbor using GIS and ERDAS techniques, and to provide baseline data that can facilitate the long term monitoring of the target area.

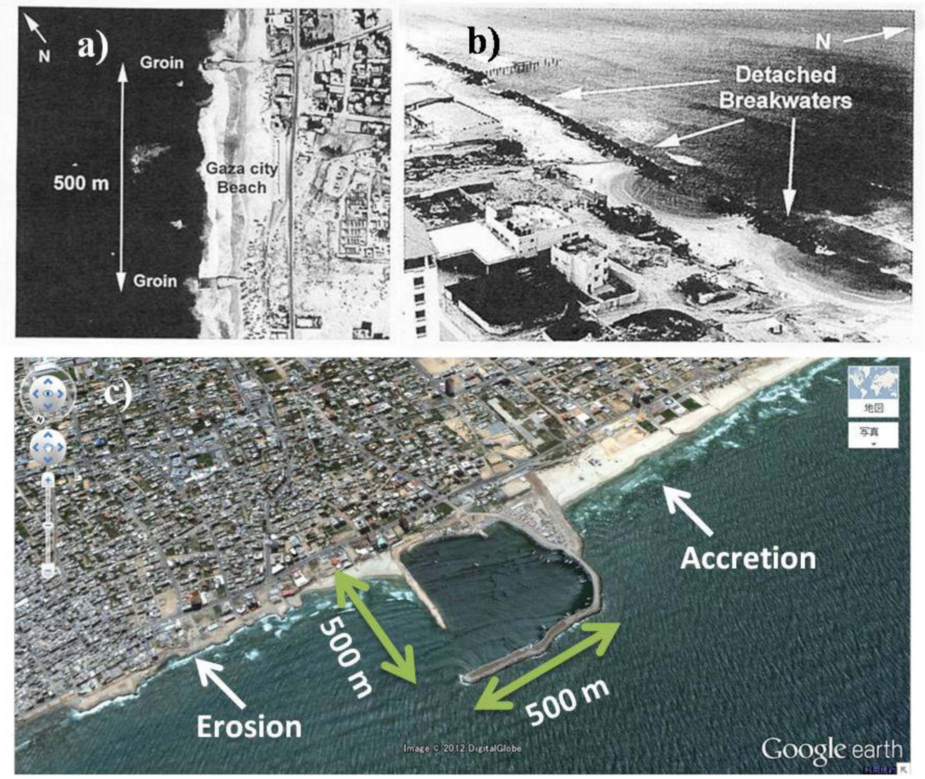

Fig. 1. Marine structures along Gaza coast: a) Two groins built in 1972, b) Nine detachedbreakwaters built in 1978 (Zviely and Klein, 2003), and c) Gaza fishing harbor built in 1994~1998

Description of the study area

Gaza coastal zone is growing fast, and the growth rate is attributed to its potential for several economic activities and the existing pressure of urban expansion. The study area covered the shoreline stretch from Assodanya at the north to Gaza valley at the south, with a stretch extent over 6 km as shown in **Fig.2.**

Wave action is seasonal in intensity and direction, and is strongly related to large-scale pressure systems over the Mediterranean sea (Hamed 1983; Nafaa *et al.,* 1991). Low (swell) waves prevail during spring and summer, when wave heights reach 1.16 m and average 0.4 m and the prevailing wave direction is NW. Winter waves can be much higher, fluctuating between storm and calm and coming from the N, NNW and NW. The overall maximum wave height is 4.25 m. Wave data previously reported by Nafaa *et al.,* (1991) and Frihy *et al.,* (2003), Abo Zed and Gewilli (2006) indicate that waves from the NW predominate (81%), with small components from the NE (14%) and the SW (5%). The prevailing wave directions generate an eastward-flowing alongshore current. Waves approaching from the N, NNE and NE generate reversed alongshore currents towards the SW. High rates of sediment transport (450,000 m^3 $year^{-1}$) were reported by Inman *et al.,* (1976) west of El Arish beach. According to Frihy *et al.,* 2002, the tide along the Mediterranean coast of Sinai is microtidal and semi-diurnal with a range of 31 cm.

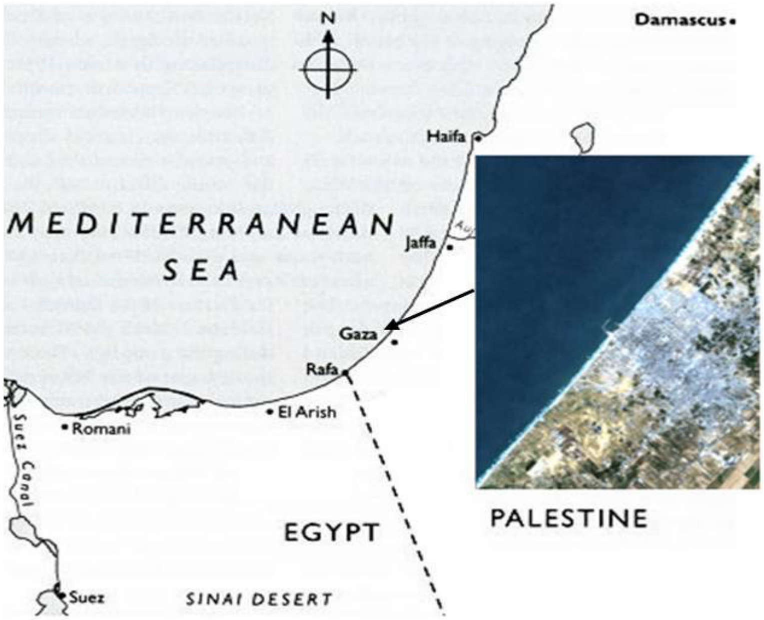

Fig. 2. The location of study area

Materials And Methods

Five satellite Landsat images were obtained for the study area covering path 175 and row 38. The Landsat multispectral scanner (MSS) sensor images are acquired on June 1972 and May 1984, Landsat thematic mapper (TM) sensor images are acquired on May 1998 and March 2003, and Landsat Enhanced Thematic Mapper Plus (ETM+) sensor image is acquired for June 2010 as shown in **Fig. 3a~e.** The Landsat image of 2010 has gaps due to the transferring of data from satellite to ground stations and an interpolation method was used for the missing parts. The images are of medium quality and free from clouds. The raw MSS images consist of four bands, TM images consist of seven bands and ETM+ images consist of nine bands. The infrared band was selected for the subsequent image processing. The pixel size in each image is shown in **Table 1.** The image processing procedures were carried out using ERDAS Imagine and ArcGIS.

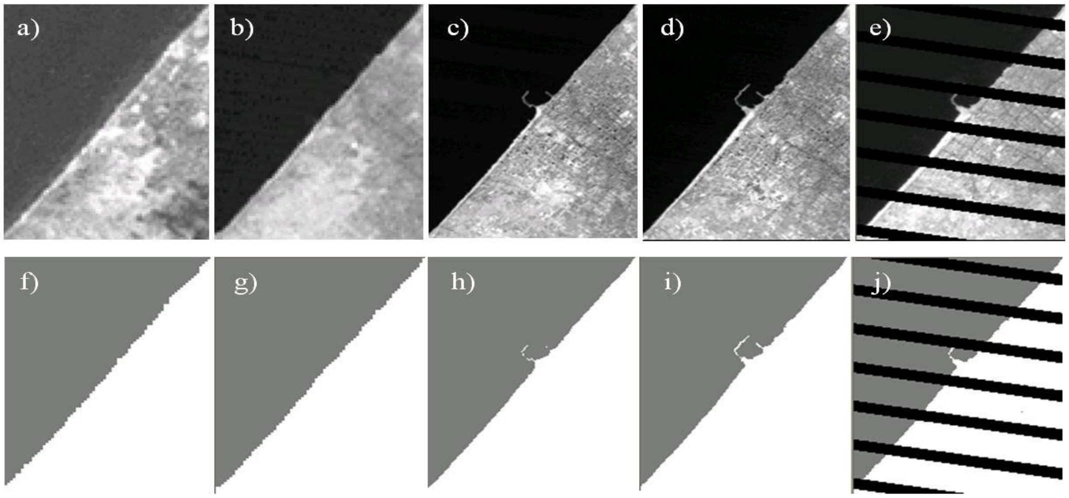

Fig. 3. Satellite Landsat images of band-4 were acquired in a) 1972, b) 1984, c) 1998 d) 2003 and e) 2010 for the study area; and f~j) the classified images for 1972~2010.

Table 1. Satellite images source and resolutions

Image source	Date	Resolution [m×m]
Landsat 1 MSS	29-06-1972	60.0×60.0
Landsat 5 MSS	14-05-1984	60.0×60.0
Landsat 5 TM	29-05-1998	30.0×30.0
Landsat 5 TM	29-03-2003	30.0×30.0
Landsat 7 ETM+	04-06-2010	30.0×30.0

The images are projected to the Universal Transverse Mercator (UTM), with a spheroid and datum of WGS 84. Landsat images were geometrically certificated. The rectified images were then used for the image classification. A subset image was created from each image, which covers only the study area on each date. An unsupervised classification algorithm was applied requesting 2 classes and applying 24 iterations, a convergence threshold of 0.95 and a standard deviation of one. The classified images produced two clusters in each image and the clusters for the terrestrial and sea parts were recorded.

To estimate the amount of change between the several dates, we applied a post-classification change detection matrix using ERDAS Imagine. This approach is very useful since the images were classified independently. Areas changed from sea to land and vice versa were recorded. The digital shoreline analysis was used to calculate the rate of change along the Gaza coastal zone. This requires at least one of them representing the baseline which is 1972. The total area and the location of change between 1972 and 2010 were measured.

Data from aerial images of the Gaza shoreline was integrated into ERDAS and GIS to determine the shoreline displacement. The results of coastal changes were disseminated in digital format, which can be used for conducting further geographic analysis. The changes have been noticed from aerial images from 1972 to 2010.

RESULTS AND DISCUSSION

The shoreline is the interface between land and sea. This is not a fixed or stationary line since it is affected by various factors such as storms, tides, waves, current, sediment transport, morphology of sea bed and sea level rise, which vary in time. A natural shoreline can therefore accrete or erode depending on the prevailing forces or elements of nature in the coastal processes. A stable shoreline is one where its mean position remains unchanged over a period of time. This is also described as being in a state of dynamic equilibrium. When one or more of these natural forces or elements are disturbed or changed, it results in imbalance in sediment transport in the coastal system and the coastline will no longer be in dynamic equilibrium and a net erosion or accretion will take place.

It is important to assess the natural behavior of the undisturbed Gaza coastline, because this will give us a basis for comparison and a more clear insight into possible causes and remedies when we subsequently turn to the situation after human interventions.

Until the construction of High Aswan dam in 1964, few human interventions were imposed on the natural coastal system of Gaza; therefore it may be assumed that before that time the coast of Gaza largely behaved in an undisturbed, natural way and steady state condition. Unfortunately, regarding that period no structured information is readily available on whether the coastline of Gaza was changing, either landward or seaward.

A factor of overwhelming importance in shaping the coastline of Gaza was the semi continuous supply of Nile sediment. In addition to the fact that sand can be transported from the seabed onto the land, also a sediment transport to deep waters may take place. The impact of anthropomorphic activity on the coastal zone is a matter of serious concern. The damage is especially grave adjacent to coastal structures which have caused changes in the coastline position and accretion on one side of the structure and erosion on the other.

One can understand the proportion of beach erosion by comparing the width of the beaches south and north of the Gaza harbor. The lack of data and regular monitoring constitutes a serious obstacle in assessing the erosion rate and observe any trends in erosion and accretion. Therefore, the accuracy of the computed results is heavily leaning on the quality of the input.

The classification results of the remotely sensed images between 1972 and 2010 are shown in **Fig. 3f~j. Fig. 4** shows the shoreline change and the rate of erosion and accretion extent during the mentioned periods.

Using ERDAS and GIS tools, the area enclosed between four intervals is counted and the computation results of erosion and accretion rates along Gaza coastal zone are shown in **Table 2.** The average annual accretion and erosion rates from 1972 to 2010 were 5.3 m and 4.7 m, respectively. Detailed analysis for the four intervals of times is as follows:

Table 2. Accretion and erosion rates for the study area

Image period	Erosion			Accretion		
	total $\times 10^3$ [m^2]	rate $\times 10^3$ [m^2 $year^{-1}$]	average [m $year^{-1}$]	total $\times 10^3$ [m^2]	rate $\times 10^3$ [m^2 $year^{-1}$]	average [m $year^{-1}$]
1972-1984	180	15.0	5.0	122	10.2	3.4
1984-1998	200	14.3	4.8	224	16.0	5.3
1998-2003	8	1.6	0.5	190	38.0	12.7
2003-2010	143	20.4	6.8	70	10.0	3.3
Total	531	14.0	4.7	606	15.9	5.3

Shoreline change from 1972 to 1984 before the construction of Gaza harbour

The post-classification change detection image (**Fig. 4**) reveals a total accretion of 122×10^3 m^2 with a rate of 10.2×10^3 m^2 $year^{-1}$, and a total erosion of 180×10^3 m^2 with a rate of -15.0×10^3 m^2 $year^{-1}$ (**Table 2**). After the construction the two groins and nine detached breakwater, the advancing shoreline and accretion occurred on the updrift side of these structures that was constructed in 1972 and 1978. These structures have interrupted the prevailing northward-flowing alongshore current; consequently, its load of sediment has been deposited south of the structures. When the alongshore current reaches the downdrift side of the breakwaters, it becomes active and thus erosion and retreat of the shoreline occurs.

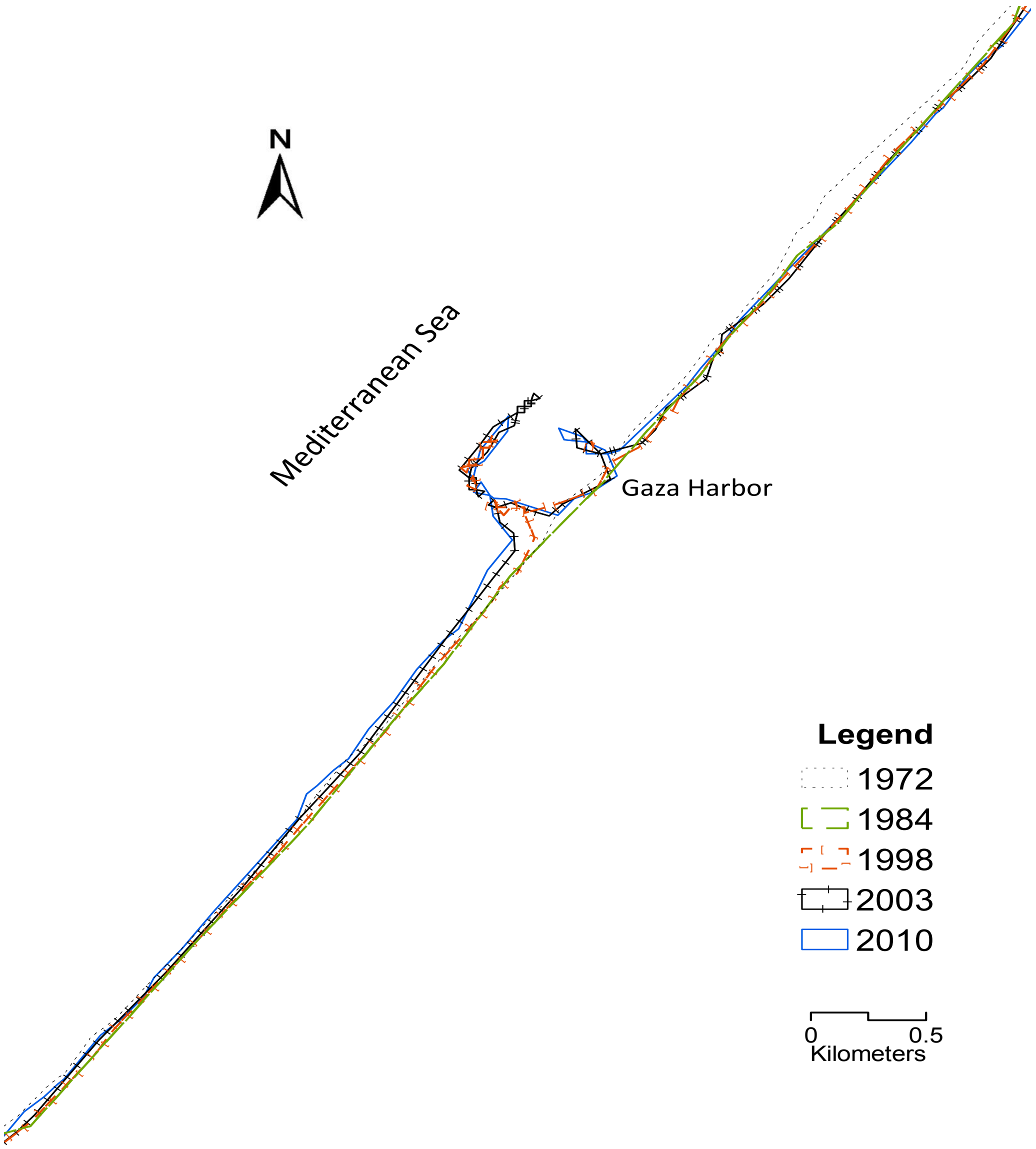

Fig. 4. Gaza shoreline change from 1972 to 2010

Shoreline change from 1984 to 1998 during the construction of the fishing harbor

Gaza fishing harbor was completely constructed in 1998, and its effect on the shoreline was examined during this interval of period. The analysis of Landsat images indicated that a total of 224×10^3 m^2 of land (accretion) has been added to this site. The post-classification change detection image (**Fig. 4**) indicates the location and magnitude of coastal change. The shoreline south of Gaza harbor has advanced as a result of the interruption of the dominant northward-flowing alongshore current by the harbor breakwater. Consequently, its sediment load was deposited and the shoreline has advanced. The new land has been added on the updrift side of the breakwater south of Gaza harbor, at a rate of 16.0×10^3 m^2 $year^{-1}$ (**Table 2**). On the other hand, severe erosion has occurred on the downdrift side of the breakwater south of the harbor, where wave-induced alongshore currents become active leading to greater erosion. The result has been shoreline retreat with a total loss of land approaching 200×10^3 m^2 with a rate of 14.3×10^3 m^2 $year^{-1}$.

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Moreover, foreshore dunes have been removed and many roads and building close to the shore have been faced instability problems (**Fig. 5a**). To mitigate this erosion, beach revetment from construction waste, gabions and series of short groins were constructed (**Fig. 5**); however, these measures failed to diminish erosion and the beach erosion is still continuing.

Fig. 5. Downdrift a) dunes and mitigation measures such as b) revetments, c) gabions and d) groins

Shoreline change from 1998 to 2003 immediately after the construction of harbor

The Landsat image analyses (**Fig. 4**) estimated a 190×10^3 m^2 have been added to the beach area in 5 years (**Table 2**) with a rate of 38.0×10^3 m^2 $year^{-1}$, which represents the highest rate of accretion. However, the erosion is the minimum rate in 38 years. This is due to the dumping of construction waste as a revetment. The revetment protection was active for a short period and the erosion rate was increased after 2003.

Shoreline change from 2003 to 2010 during the operation of fishing harbor

The analyses result showed that the total erosion between 2033 and 2010 was 143×10^3 m^2 with a rate of 20.4×10^3 m^2 $year^{-1}$. The erosion rate during this period was the highest and this was due to the continuous wave actions and the mitigation of revetment and groins were no longer being active. Furthermore, because of large quantities that trapped behind the harbor (at the updrift side) may redirect the alongshore currents to deep water and consequently large amount of sediments were redirected into deep sea. The total accretion area was 70×10^3 m^2 with a rate of 10.0×10^3 m^2 year^{-1}.

During 38 years, a total added land at the updrift side of Gaza harbor was 606×10^3 m^2 with an average rate of 15.9×10^3 m^2 year^{-1} and the total erosion at the downdrift side was 531×10^3 m^2 with an average rate of 14.0×10^3 m^2 year^{-1}. From these figures, it was found that negative rates are taken place and the erosion was the predominant process. Gaza harbor caused a serious damage to the northern beaches and it prevents the free movement of sediments that lead to sedimentation in the south and erosion in the north. Comparing aerial images from 1972 and 2010 show that the southern side of the beach was enlarged by 0.75 m per year and the northern side of the beach was eroded by 1.15 m per year over a beach length of 6 km.

The present study used GIS and ERDAS to quantify shoreline changes in Gaza coastal area. It was observed that the changes were due to both erosion and accretion processes. The study was revealed that during 1972~2010, more accretion took place in the southern part of Gaza harbor while erosion took place in the northern part.

CONCLUSIONS

Analysis of satellite Landsat images for the Mediterranean coast of Gaza for the years from 1972 to 2010 have indicated shoreline changes in response to erosion and accretion patterns. An advancing shoreline and growing beach occur south of Gaza harbor, where the littoral transport has been interrupted by engineering structures. The rate of accretion at this site during the last 12 years was 21,670 m^2 year^{-1}, after the construction completion of the harbor. A retreating shoreline and eroded beach are present north of Gaza harbor and the rate of erosion is increased up to -204,000 m^2 year^{-1}. These erosion/accretion patterns reveal the natural processes of wave-induced alongshore currents and sediment transport, in addition to the impact of human intervention by coastal engineering structures. The relationship between the incident wave angles and the average shoreline orientation suggests that the N, NNW, NW, WNW waves generate northward alongshore currents that act to move sediment towards the north and away from the south.

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