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Short-term analysis of coastal erosion among human intervention and sea level rise

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Abstract

This paper considers short-term coastal erosion in the Gaza Strip and its relationship to the local sea level change and human interventions on the shoreline. There is a proven relationship between increased coastal erosion and global mean sea level rise, especially in the long-term; however, the impact of human interventions on the shoreline could be more than on sea level in the short-term. Recently, cliff and coastal erosion have been widely noticed along the shoreline, mainly where human interventions occur. Therefore, remote sensing and GIS were used to derive the rate of coastal erosion in these regions while local sea level data were collected from the available Permanent Service for Mean Sea Level (PSMSL) in order to investigate sea level changes. The local sea level trends from adjacent stations to the Gaza Strip were derived. The goal is to investigate whether an upward sea level trend explains the occurring erosion of the shores. The results revealed that several regions along the Gaza Strip shoreline undergo a landward erosional process, with an average rate ranging between – 0.2 and – 0.8 m/year. Furthermore, monthly and annual mean sea level trends demonstrated a negative trend between -1.42 and –5.25 mm/year. In particular, as there is no clue of a significant upward trend in local sea level during the last eight years which is accompanied by an acceleration in the coastal erosion, informal human intervention could be considered a primary catalyst for accelerating coastal erosion in the short-term.

Keywords Coastal erosion · Sea-level rise · Gaza Strip · Human intervention · Shoreline change rates · Remote sensing · DSAS

Introduction

The urban sprawl and population growth in coastal cities raise the demand for natural resources, disturbs the natural equilibrium, and accelerates environmental deterioration. Coastal and marine environments are subject to many spatial, geomorphological, and demographic changes; some of the most common changes that occur along coastal regions are beach erosion, shoreline migration, and coastal cliffs collapsing and retreating. These changes are attributed to the natural factors of wave actions and oceanographic conditions (Łabuz 2015). Another cause of coastal deterioration is direct human activity, such as coastal urbanization and exploitation of beach resources. Human interventions and dam construction along rivers, and groins in coastal areas, cause negative impacts on the natural movement of sediments and hinder natural beach nourishments. Since the Industrial Revolution, issues of climate change, global warming, melting ice cover, and sea level rise have become some of the most important direct and indirect causes of coastal erosion. However, human factor should be considered a significant and influencing factor in coastal erosion (Carter 1991; Thanh et al. 2003; Tirkey et al. 2005; Pousa et al. 2006; El-Asmar and Hereher 2010; Trenhaile 2011; Revell et al. 2011; Appeaning Addo 2012; Devoy 2014; Tsoukala et al. 2015; Antonioli et al. 2017; Duc et al. 2017; Fatorić and Seekamp 2017; Phong et al. 2017; Fan et al. 2018).

Thanh et al. (2003) studied the impact of human activities on the on marine environment; they found that human activities have negative impacts on coastal environment through increasing floods, erosion, sedimentation, and environmental pollution. Pousa et al. (2006), in their study, confirmed that man-made interventions and actions, such as beach mining, construction of coastal structures and

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exploitation of aquifers, can cause environmental damage to the coastal zone. Phong et al. (2017) investigated the relationship between community activities and coastal erosion; their resuts demonstated that several human activities such as poor construction on coastal regions, and the interaction of anthropogenic activities and physical processes, are significant contributors to coastal erosion. Domínguez et al. (2005) assessed coastal vulnerability to erosion by combining potential coastal retreat with land-use type. The study revealed that a substantial part of the studied coastal regions is at a high to medium risk due to human structures (Domínguez et al. 2005). A study conducted on shoreline morphological changes and human factor found that human activities are moving closer to the shoreline, compared to the rate of landward shoreline movement. This result emphasizes the fact that the effects of human interventions on coastal regions could be, in some cases, greater than the natural influences (Appeaning Addo 2012). Fan et al. (2018) concluded that massive reclamation activity, expansion of the oil industry, and sea level rise, have jointly contributed to the rapid change and decrease of the intertidal zone in west of Tiao River Mouth.

Climate change is among the most important factors that contribute significantly to the deterioration of the natural resources and the environment along the coasts. Several studies have discussed the adverse effects of climate change and sea level rise on coastal regions (Orford 1987; Carter 1991; Scavia et al. 2002; Zhang et al. 2004; Torresan et al. 2008; Cooper et al. 2008; Trenhaile 2011; Ranasinghe et al. 2011; Revell et al. 2011; Ngo-Duc 2014; Łabuz 2015; Duc et al. 2017; de Winter and Ruessink 2017; Martins et al. 2018). Zhang et al. (2004) indicated in their study that there is a highly multiplicative association between long-term sandy beach erosion and sea level rise. Duc et al. (2017) confirmed that sea level rise leads to increase of coastal erosion, beach lowering, and cliff scour. Trenhaile (2011) used mathematical models to predict the effect of sea level rise on soft and hard rock coasts. Trenhaile's results suggested that rising sea level would generate faster rates of cliff recession. de Winter and Ruessink (2017) quantified the impact of sea level rise on future dune erosion at two locations along the Dutch coast; they reported a linear relationship between sea level rise and dune erosion. Martins et al. (2018) evaluated coastal erosion vulnerability under different climate change scenarios; they found that the coastal vulnerability would increase with sea level rise, and wave height change. Moreover, they reported that the high-vulnerability sections of the coast were those with high population densities and high urbanization rates.

Remote sensing techniques and Geographic Information System (GIS) have been widely used to study coastal erosion, and monitor temporal and spatial changes (Anfuso and Martínez Del Pozo 2008; Sesli et al. 2009; Ahmed et al. 2009; El-Asmar and Hereher 2010; Hereher 2011; Boateng 2011; Pereira and Coelho 2013; McCarthy et al. 2017; Al Ruheili and Boluwade 2021; Prakasam et al. 2022; El Raey 2022; Niang 2022; Susilowati et al. 2022). Moreover, satellite images provide a variety of archive data, and offer wide temporal and spatial coverage. GIS platforms are very important tools in studying spatio-temporal changes, and in monitoring dynamic phenomena such as coastal erosion and shoreline change rates, and they provide considerable accuracy (Szlafsztein and Sterr 2007; Boateng 2012; Mujabar and Chandrasekar 2013; Jana and Bhattacharya 2013; Kaliraj et al. 2013; Wu et al. 2021; Komolafe et al. 2021; Theilen-Willige and Mansouri 2022; Thinh 2022; Siyal et al. 2022). Al Ruheili and Boluwade (2021) used sentinel images and the Digital Shoreline Analysis System (DSAS) to estimate changes of the shoreline and explore the dominant coastal conditions along the Kyarr's region. Similarly, Thinh (2022) employed the same tools to monitor shoreline changes along the Ky Anh Coast. Sesli et al. (2009) utilized aerial and satellite imagery with medium and high resolution for mapping coastal land use and monitoring the changes. Their results showed the effectiveness of the remote sensing data on monitoring coastal land. Szlafsztein and Sterr (2007) identified and classified natural and socioeconomic vulnerabilities of coastal zone of the State of Pará based on GIS models. Kaliraj et al. (2013) investigated the impact of wave energy and littoral current on shorelines using multi-temporal Landsat TM, ETM + images, and the rate of shoreline change was calculated using GIS-based tool. Hereher (2011) utilized Landsat remote sensing imagery from 1973 to 2008 to estimate the quantity of land loss in terms of coastal erosion, while McCarthy et al. (2017) demonstared the capabilities and advantages of remote sensing techniques for assessments of coastal resources over larger areas that are impossible to do with traditional methods. Theilen-Willige and Mansouri (2022) were able to highlight critical areas prone to flooding hazards; they evalauted optical satellite data, and radar data for better understanding of the current development at the coasts.

Zviely and Klein (2004) used satellite imaging to assess shoreline changes; they estimated average cliff retreat rates of about 20 cm/year. Abualhin (2011) calculated the rate of shoreline change which was -14 cm/year along the Gaza Strip shoreline using remote sensing and GIS. Adler and Inbar (2007) investigated the difference in the shoreline along the North Sinai coast for over 15 years by studying TM and ETM true color Landsat photos from 1986 to 2001; the studies revealed patterns of erosion and accretion along the coastal zone of the Gaza Strip.

Locally and within the last decade, the Gaza Strip coastal zone experienced various environmental and anthropogenic issues such as sand mining from the backshore area, cliffs retreating, berms and beach levelling for recreation areas, and the establishment of coastal structures. One form of human intervention in the Gaza coastal zone is beach levelling process for creating recreation areas along shorelines; this decreases the beach berms height towards the sea, and increases coastal erosion and shoreline cliff retreat. (Peled et al. 1997; Golik and Rosen 1999; Zviely and Klein 2003; European Environmental Agency 2014; Jonah et al. 2015; Report et al. 2015; Deidda et al. 2016; Bitan and Zviely 2020).

Another form of arbitrary intervention is rubble groins and breakwaters installation by the owners of tourist sites. Although groins and breakwaters protect shorelines on the upstream side, they cause erosion on the downstream side of the beach (Badiei et al. 1995; Dabees and Kamphuis 1998; Golik and Rosen 1999; Zviely and Klein 2003; Leont'yev 2003; Abualhin 2011; Faiboona et al. 2011; Abualtayef et al. 2012; Schmitt and Albers 2014; Eriksson and Persson 2014; Zhang and Stive 2019; Leont and Akivis 2020; Lima et al. 2020). Coastal erosion has become a phenomenon often attributed to sea level rise, or climate change. While this may be true in most cases, it is not the only, or the main cause, in other regions of the world. In this study, we believe that the main factors for the acceleration of beach erosion in the short term at the Gaza Strip is the unwell human intervention on the shoreline; this has exacerbated the erosion at a much greater rate than climate change. The main question of this study is whether the unwell human intervention or the sea level rise is the main accelerator factor for the current coastal erosion in the short term.

This study aims to examine the link between the current acceleration of coastal erosion at several locations along the Gaza Strip coastal zone, and multipurpose human interventions at these sites. Additionally, an investigation of sea level rise trends in the region will be carried out.

Study area

The Gaza strip is located along the southeast coast of the Mediterranean Sea, between longitudes 34° 22″ 34° 25″ East, and latitudes 31°16″ 31°15″ North. The area of the Gaza Strip is 365 km^2, with a maximum length of 42 km and a 7 km average width (Fig. 1). Beaches are affected by unplanned development in marine areas, and coastal denudation happens as a result. The Gaza Strip coastal region is a small strip of sandy beach; the entire coast of the Gaza Strip is sandy in most places, forming dunes particularly in the south, while the Kurkar cliffs can be found from the middle to the north. Through marine currents moving from south to north, Nile River sediments have been feeding the coasts of Palestine, including the Gaza Strip coastal region, with sand sediments. The majority of the coastal zone sand is medium to coarse (78%), and fine sand (~20%) (Perlin and Kit 1999; Ali 2002; Zviely et al. 2007; Ubeid 2014). The Gaza Strip is located in an arid to semi-arid region, with an average annual precipitation of 250—450 mm per year, while most of the Gaza Strip is covered by Quaternary sediment. Geologically, the coastal plain consists of a series of formations, mainly from the Tertiary and Quaternary eras, sloping gradually from the East towards the West.

The Kurkar Group, from the Pleistocene, consists of: (1)—marine and terrestrial calcareous sandstone known as Kurkar; (2)- layer of yellowish to reddish silty sand with varying amounts of clay and iron oxides known as Hamra; (3)—layer of silty clays with unconsolidated sands and conglomerates. The Kurkar Sediments extend along the coast but are more exposed in the northern part of the Gaza Strip than in the southern part. In some part of the Gaza coast, the Kurkar sediments from high coastal cliffs range between 5–18 m. The Holocene deposits overlie the Pleistocene Kurkar ridge with a thickness of up to 25 m. The Holocene deposits are terrestrial origin deposits and can be divided into four subdivisions: (1) dunes that extend along the shoreline, and originate partly from Nile River sediments; (2) Sand, loess, and gravel whose beds are small in thickness of about 10 m; (3) Alluvial deposits spread in the area around Wadi Gaza and have a thickness of about 25 m; (4) Beach formation composed of a thin layer of unconsolidated sand with shell fragments (Hudleston 1883; Horowitz 1975).

The Gaza Strip coast is characterized by low tide, semi-diurnal tide which varies between 0.4 m during spring tides and 0.15 m during neap tides. Winds blow most frequently from west and north directions, while the high winds tend to come from the south-west. During winter, winds blow from the west and southwest with an average speed of 4.2 m/s, whereas in summer winds blow mainly from the northwest direction. In general, the wind climate is mild and wind speed hardly exceeds 13 m/s, where the direction is mainly between 240° and 0°. The dominant waves approach the Gaza Coast from West-Northwest (WNW) direction. On open sea, waves of 2.25 m and higher occur about 2.5% of the time from directions between Southwest (SW) and Northwest (NW), while at 10 m depth waves occur about 1.4% of the time from directions between West and North-Northwest. Waves of significant height larger than 2.25 m rarely occur outside November to March. The direction of extreme offshore waves ranges between 270° and 315°. Short period waves are waves generated by local wind ranges from 3-20 s. Long periods waves are waves with a period over 25–30 s with usually small amplitudes up to 0.5 m. The nearshore currents at Gaza coastal zone are weak currents of up to 0.5 m/s (Smaling 1996).

The Gaza Strip suffers from a high population density which negatively affects a variety of environmental disciplines. In recent years, the region has witnessed an elevation in the frequency of human activity and construction

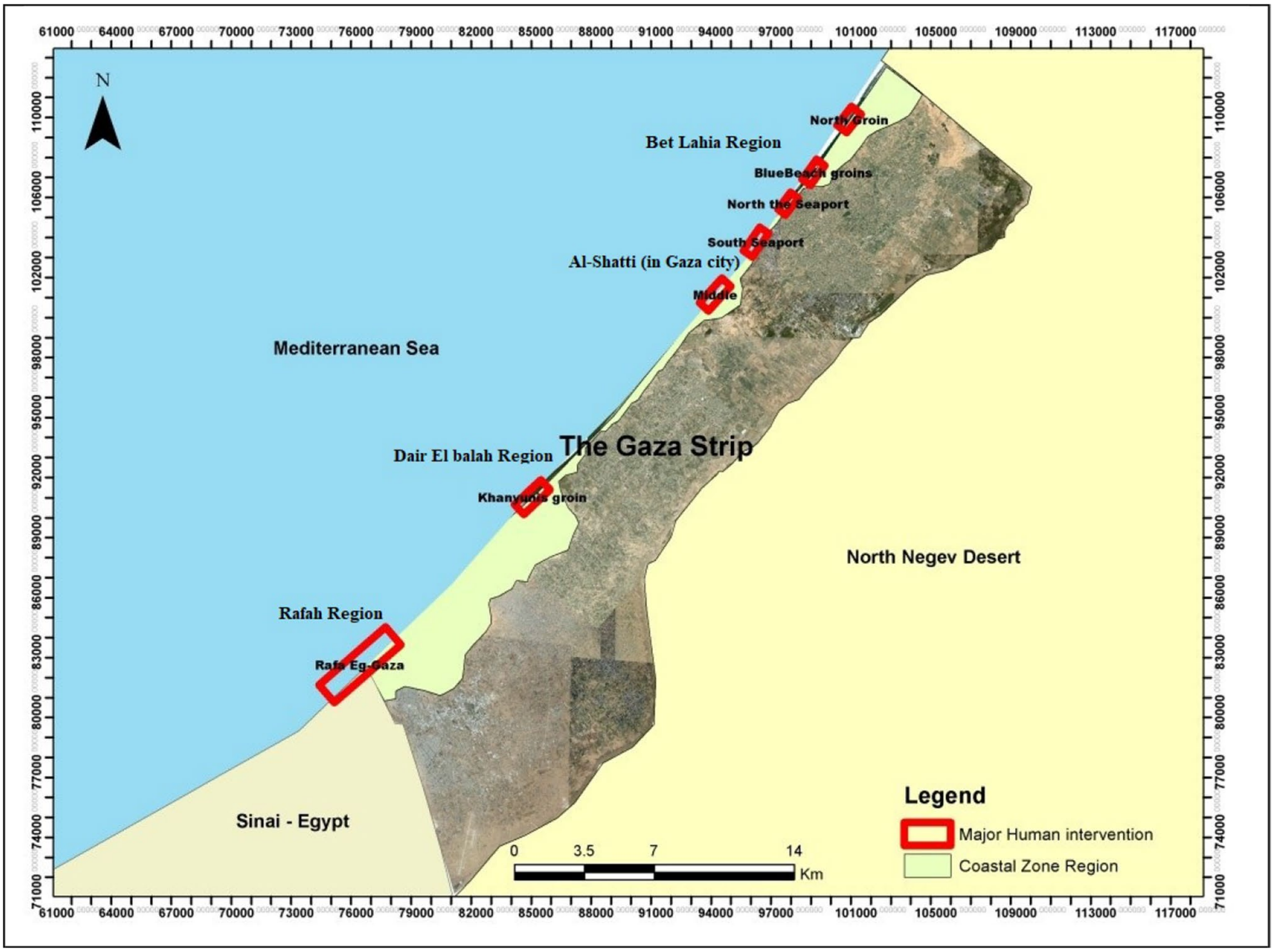


Fig. 1 Location of the study area showing the areas affected by human intervention

along the coast, including the construction of tourist resorts, groin structures, water desalination plants, fishermen facilities, and wastewater treatment outlets. The majority were built in an arbitrary manner rather than with an integrated scientific plan, thus contributing to spreading the coastal deterioration (Fig. 2).

Materials and methodology

The methodology relies on the use of remote sensing techniques and GIS to extract shorelines from multi-temporal satellite data. The change in shoreline rate was calculated using statistical models incorporated into the digital shoreline analysis system (Alhin and Niemeyer 2009; Himmelstoss 2009; Oyedotun 2014; Himmelstoss et al. 2018a; Tsokos et al. 2018).

In order to distinguish between beach erosion caused by climate change and sea level rise, and beach erosion driven by human intervention, the effects of both factors must be examined and compared. Consequently, fieldwork was necessary to identify the areas that witnessed a significant decline in coastal cliffs and erosion in beaches, and monitor collapses in coastal facilities. In addition, the fieldwork was essential to monitor human interventions in these regions. Figure 2 shows the regions with significant human interventions that already suffer from severe coastal erosion. The land use map was created to identify human activities, whether tourism, industrial or agricultural, in areas that suffer from coastal erosion and the decline of cliffs in general (Fig. 4). On the other hand, it is necessary to know the state of sea level in recent years and to find the general trend in sea level to determine whether there is an upward trend or whether there is stability in sea level. Therefore, sea level fluctuation records were collected, compiled and analyzed to determine the sea level rise trends. The sea level records were gathered from the Sea Level Station Monitoring programs, the Global Sea Level Observing System (GLOSS), and the Permanent Service for Mean Sea level (PSMSL) (Woodworth 1991; Tolkatchev 1996; Woodworth and Player

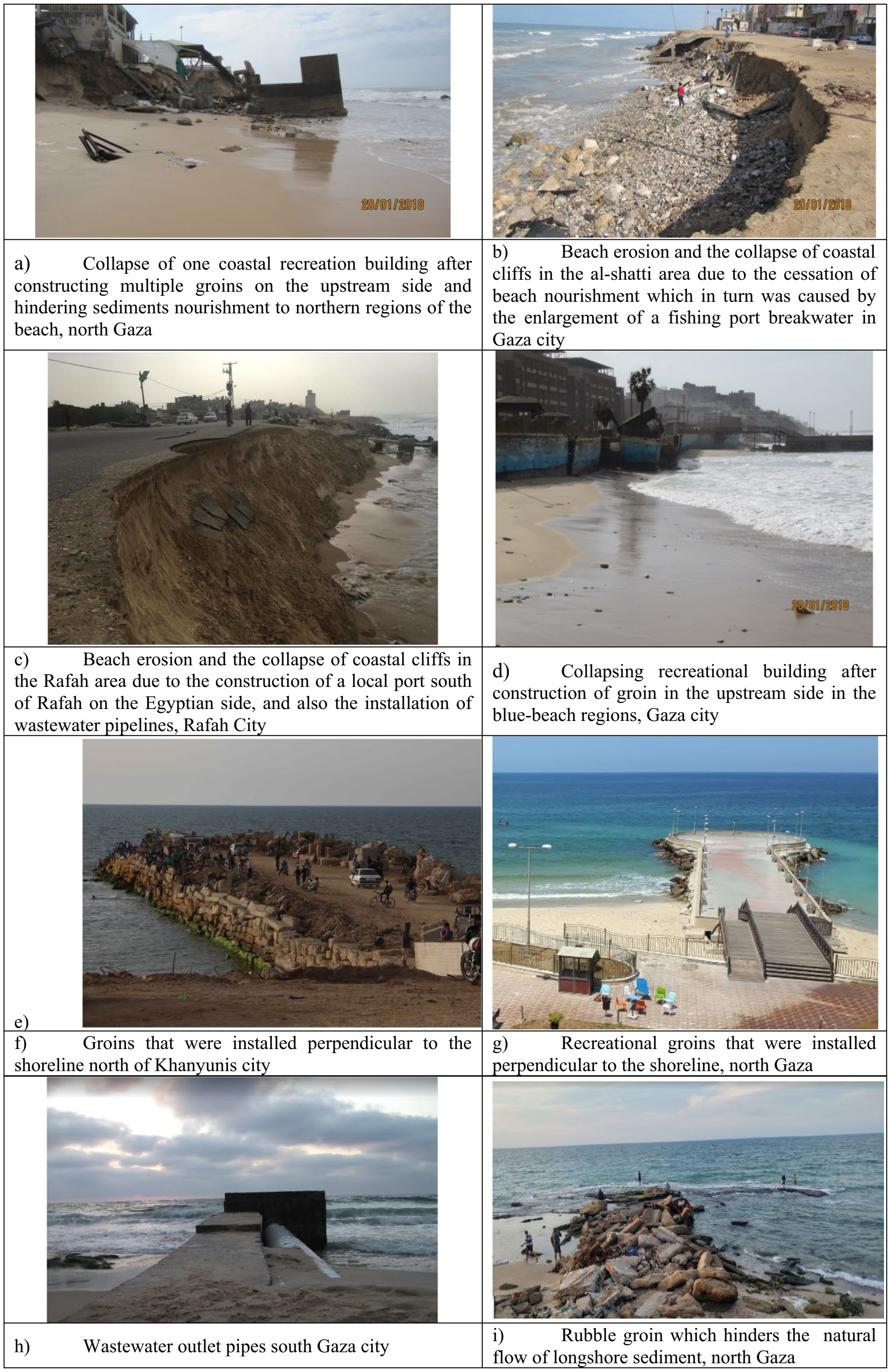


Fig. 2 Pictures of several locations affected by human interventions and showing the severe coastal erosion in these regions along the Gaza Strip shoreline

a) Collapse of one coastal recreation building after constructing multiple groins on the upstream side and hindering sediments nourishment to northern regions of the beach, north Gaza

b) Beach erosion and the collapse of coastal cliffs in the al-shatti area due to the cessation of beach nourishment which in turn was caused by the enlargement of a fishing port breakwater in Gaza city

c) Beach erosion and the collapse of coastal cliffs in the Rafah area due to the construction of a local port south of Rafah on the Egyptian side, and also the installation of wastewater pipelines, Rafah City

d) Collapsing recreational building after construction of groin in the upstream side in the blue-beach regions, Gaza city

e)

f) Groins that were installed perpendicular to the shoreline north of Khanyunis city

g) Recreational groins that were installed perpendicular to the shoreline, north Gaza

h) Wastewater outlet pipes south Gaza city

i) Rubble groin which hinders the natural flow of longshore sediment, north Gaza

2003; Aarup 2008; Holgate et al. 2013; PSMSL 2017, 2021; Toker et al. 2020). GLOSS monitors and coordinates global and regional sea level networks to support oceanographic and climate research communities(Tolkatchev 1996; IOC/UNESCO 2000; Woodworth and Player 2003; Aarup 2008; Woodworth 2016).

Satellite imagery dataset

A set of satellite imagery was gathered from 2004 to 2018, spanning 14 years. The image data were collected almost simultaneously from Google Earth aerial and satellite images with a spatial resolution of two meters (Table 1).

Table 1 Aerial imagery dataset used in the study

Shoreline region	Dates	Shoreline region	Dates
Bet Lahia (North Gaza)	24–5-2005 16–6-2007 20–6-2016 23–6-2018	Dier Albalah Groin (North Khanyunis)	26–2-2004 22–11-2005 16–6-2007 24–7-2008 28–8-2011 5–9-2014 23–3-2016 23–6-2018
Al-Shatti (Gaza City)	31–12-2004 24–5-2005 16–6-2007 28–1-2016 23–6-2018	Rafah	31–12-2004 16–6-2007 1–8-2008 15–7-2010 1–7-2012 22–12-2013 29–7-2014 23–3-2016 23–6-2018

The historical images in Google Earth were collected on a specific date. The data was pre-processed and corrected for geometrical distortion. A geo-referencing process was done to ensure all pixels in the spatial data in the imagery dataset are spatially lined up with other images. Ground control points (GCPs) were collected at different locations and set for at least 16 points per image, with an average RMS error of 0.5 pixels. Shorelines were derived from the data and integrated into GIS software to measure statistical relationships and derive an actual shoreline change rate. The study covered the following regions: The North Groin (Bet Lahia), the northern side of the fishing port (Al-Shatti), the Dier Albalah groin, and the Rafah Region.

Shoreline extraction and analysis of shoreline change rates

In coastal terminology, the term shoreline can be defined as the intercept of the mean water level along the beach (Davidson-Arnott 2010). The position of the land–water interface is generally adopted as the shoreline position in geomorphological studies, while in a geodetic survey the high-water line boundary is used (Schwartz 2006). The dynamic and spatiotemporal nature of shorelines makes the mapping process of this boundary more difficult compared to other coastal features. Extracting shorelines from satellite imagery was achieved through density slicing (DS) and Binary thresholding methods. Histogram thresholding methods are mostly based on histogram analysis, and they convert greyscale images into Binary images. Shoreline extraction using thresholding techniques was adopted in several studies (Lillesand and Kiefer 1979; Wayne Niblack 1985; Johnston and Barson 1993; Solihin and Leedham 1999; Liu and Jezek 2004; Lipakis and Chrysoulakis 2005; Abu-alhin and Niemeyer 2009; Bott 2014; Aedla et al. 2015; Kafrawy et al. 2017; Karaman 2021). Thresholding can be done interactively with a raster image display by modifying Look-Up-Table and deriving values interactively from the image histogram. Meanwhile, other studies utilized simple density slicing techniques for extracting shorelines from satellite images and aerial images (Ouma and Tateishi 2006; Marfai et al. 2008; Karsli et al. 2011; Mitra et al. 2017; Sunder et al. 2017; Sekar et al. 2022). However, sea foam, nearshore turbidity, tidal flat, and the duration of beach insolation can be serious problems for determining the waterline accurately. Depending on the shoreline extraction method, seafoam, coastal structures, tidal flats, and wetlands can be misclassified as water or as land. Accordingly, the shorelines were extracted from all image dataset, and then manual digitizing was conducted to ensure shoreline accuracy and refinement. Figure 3 shows the flowchart of the shoreline change rate calculation procedure.

The accuracy of shoreline extraction is a critical issue in ensuring the calculation credibility of the shoreline change rates analysis. Uncertainties of shorelines positions have several errors, including shorelines extraction, images registration and geo-reference, and waterline position at the time of images collection (Crowell et al. 1991; Thieler and Danforth 1994; Moore 2000; Ruggiero et al. 2003; Li et al. 2004; Ruggiero and List 2009; Nassar et al. 2019). To eliminate the ambiguity of shoreline locations, the shoreline positions were first automatically extracted from the images using the histogram threshold process. The extracted shoreline from time-series imagery (2014–2018) was utilized to calculate the change of the shoreline positions through time. The Digital Shoreline Analysis System (DSAS) software incorporated on the ArcGIS platform is used to calculate the shoreline change rates along the entire zones by calculating the rate of change statistics from multiple historic shoreline positions. The baseline generated was used as a starting point for all transects casting.

Transects were generated automatically along the baseline at 50-m intervals. The points of shoreline intersections combine date information and positional uncertainty for each shoreline to calculate shoreline change statistics such as Linear Regression Rate (LRR), and measure elapsed distance between two dates such as Net Shoreline Movement (NSM). The Linear Regression Rate (LRR) and the Net shoreline movement (NSM) were adopted in this study as statistical bases for calculating shoreline change rates. Several studies used the DSAS model for calculating shoreline change rates via LRR and NSM (Douglas and Crowell 2000; Abualhin 2011; Ahmad and Lakhan 2012; Mahapatra et al. 2014; Natesan et al. 2015; Kermani et al. 2016; Sytnik et al. 2018; Andaryani et al. 2019; Baig et al. 2020; Muskananfola et al. 2020; Dereli and Tercan 2020; Aladwani 2022). The

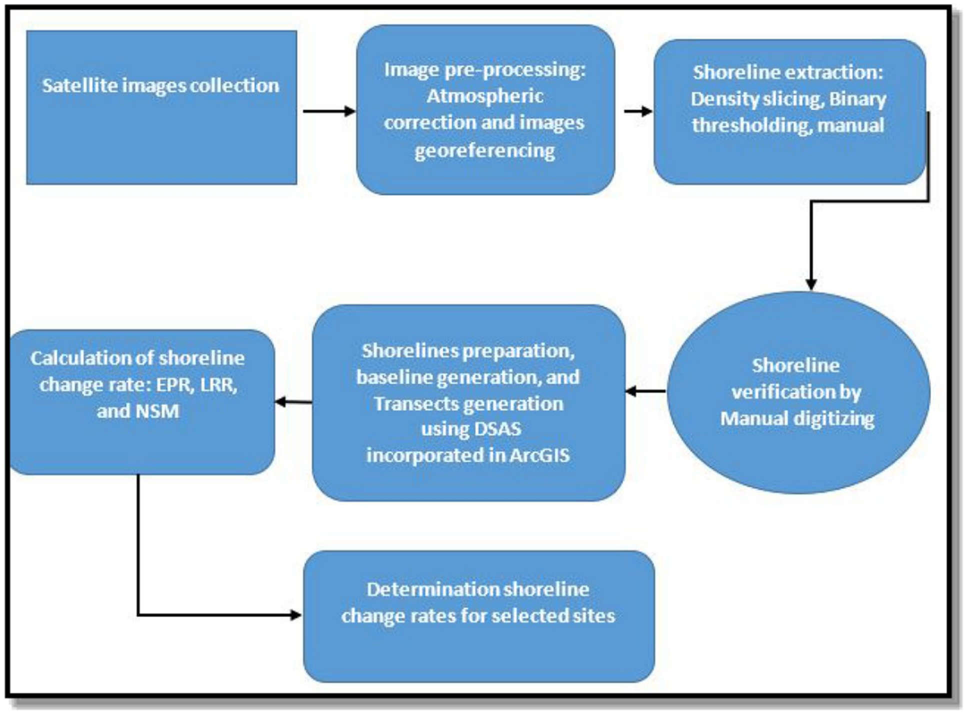


Fig. 3 Flowchart of shoreline change rate calculation

linear regression rate of change (LRR) is a reliable statistical tool for calculating the shoreline change rate by fitting a least-squares regression line to all shoreline locations along each transect. The linear regression method assumes a linear pattern of change among the shoreline dates, with the linear regression rate equal to the slope of the line. The linear regression approach is solely computational, involves all shorelines, is less prone to outliers, and it underestimates the rate of change compared to other statistical methods. A net shoreline movement calculates the total movement distance between the two shoreline positions and thus is considered an endpoint measure of change. It records the difference between the oldest and youngest shorelines for each transect in meters. On the other hand, negative rate values suggest erosion (landward displacement of the shoreline), while positive rate values indicate accretion (seaward movement of shoreline) (Fenster et al. 1993; Moore 2000; Honeycutt et al. 2001; Fletcher et al. 2003; Himmelstoss et al. 2021). The LRR measures annual shoreline change rates in meters, while the NSM estimates annual shoreline displacement in meters.

Results and discussion

The results will be divided into two main sections, the first section is related to the calculation of the rate of shoreline changes along the coastal zone of the Gaza Strip, with a focus on regions that have experienced intense human activity and interventions in the past years. The second part of the results will demonstrate the sea level rise trends along the Gaza coastal zone regions and the surrounding of southeast Mediterranean coast. We believe in this study that if there is any upward trend in sea level in the region in recent years, this increase will be the evidence and can be considered the main justification for the acceleration of beach erosion in the Gaza Strip coastal zone. However, if we cannot prove the existence of a rise in local sea level, by the principle of contravention, this confirms that human factor through intense tourist and economic activity along the shoreline is the main contributor to acceleration of coastal erosion in the short term.

Shoreline changes analysis

The rates of shoreline change were calculated for the entire shoreline of the Gaza Strip in general, focusing on the areas where there was an increase in the frequency and volume of human intervention in the past decade. The shorelines were derived from satellite imagery for the period between 2004 and 2018 for most of the regions. As mentioned above, GIS and DSAS software were used to generate shorelines matrices to calculate shoreline change statistics (Himmelstoss et al. 2018b). Two statistical parameters were used to evaluate the shoreline change patterns; the Net Shoreline Movement (NSM) and Linear Regression Rate (LRR). The land use map shows the distribution of several human activities across the coastal area and the Gaza Strip (Fig. 4). Based on the land use map, four regions can be recognized and highlighted as regions of intensive human

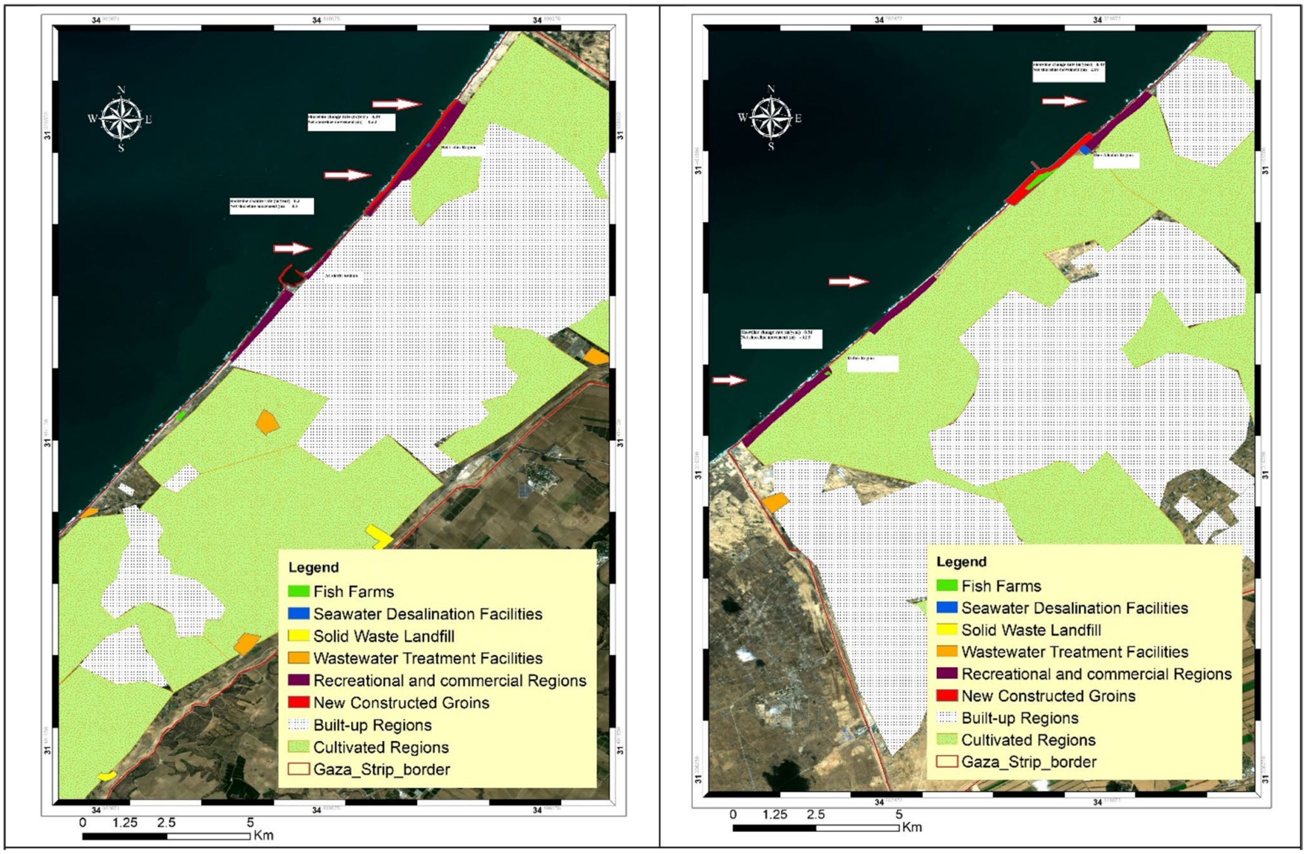


Fig. 4 Land use map of the study area. The Arrows show the regions affected by the intensive human intervention and also the rate of shoreline changes and the net shoreline movement (on the Left is the northern part and on the right is the southern part of the Gaza Strip)

intervention; two regions in the north of the Gaza Strip and two in the south. The first regions in the north are Al-Shatti region which extends from the Fishing port up to the end of Al-Shatti camp. This region is characterized by a heavy fishing industry, restaurant, and recreation facilities. The second region in the north is the Bet Lahia region which extends from Blue-beach region up to Al-Waha region and characterized by rapid construction activities for recreational regions and installation of multiple groins for tourist purposes. The second regions in the south are: Deir Albalah region which has witnessed construction of a perpendicular large groin since 2001as an infrastructure for a new fishing port in this city. The last region in the south is the Rafah region which has witnessed in recent years a booming activity in the field of tourism, commerce and construction. In addition, the construction and development of the sea port in the city of Rafah—Egypt significantly reduced the flow of sediments to the shores of Rafah- Gaza where the construction of this port began in 2010 and was completed in 2015. The next section presents the results of shoreline change rates for these four regions.

Bet Lahia Region

Recently, the northern section of the Gaza Strip has been overwhelmed with a variety of construction, including recreational sites and small groins of building rubbles along the coast. In addition, an impermeable seaward extended groin was developed for recreational compounds in 2016. This impermeable structure, perpendicular to the shoreline, impeded the regular migration of nearshore sediments to the northern side of the Groin, resulting in a sediment deficit on the downstream side of the beach region. The study revealed that this area is affected by a negative rate with an average shoreline shift change rate of -0.38 m/yr., and erosional rates were observed on 70% of all transects in this region. About 57.35% of all transects generated in this region show a negative distance or coastal regression. Table 2 shows that the total shoreline displacement MSN is about -0.62 m, and the mean distance of beach erosion is about -27 m. Figure 5-a shows a map of the North Groin and surrounding area.

Table 2 The shoreline changes rate (LRR) and the net shoreline movement (NSM) at Bet Lahia Groin

Shoreline change rate	Parameters	Bet Lahia
NSM (m)	Average distance (m)	-0.62
	Percent of all transects that have a negative distance	57.35%
	Maximum negative distance (m)	-27.32
LRR (m/yr)	Average rate (m/yr)	-0.38
	Percent of all transects that are erosional	70.59%
	The maximum value of erosion	-3.7

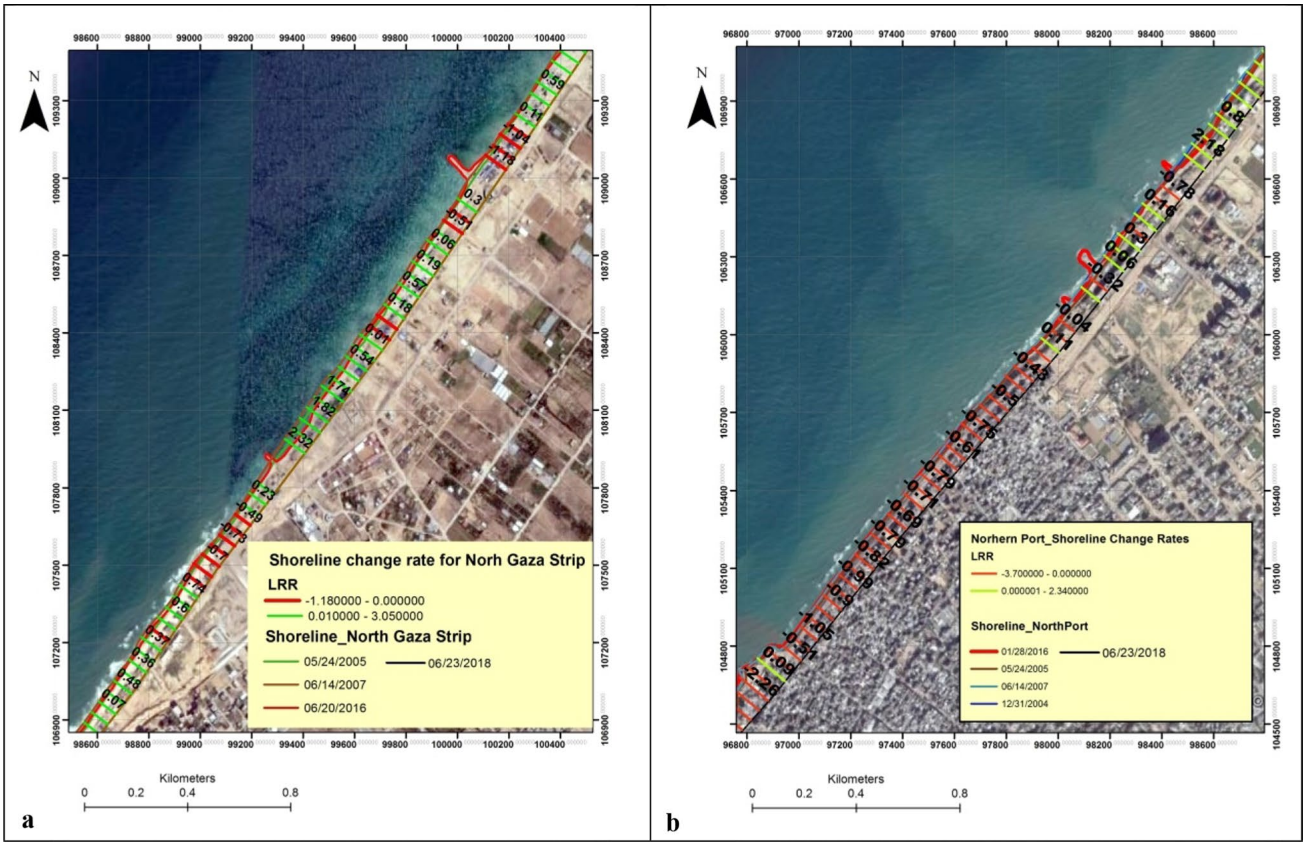


Fig. 5 **a** The shoreline change in the Bet Lahia region, **b** The shoreline change in the Al-Shatti region

Al -Shatti Region

Few studies have evaluated the impact of the Gaza fishing port breakwater on Al-Shatti shoreline. The studies demonstrated that the breakwater accelerated coastal erosion downstream (Zviely and Klein 2003; Abu-alhin and Niemeyer 2009; Abualhin and Niemeyer 2009; Abualhin 2011; Abualtayef et al. 2012). The average shoreline change rate in this region was about -0.34 m/yr. The large breakwater structure scatters nearshore sediments flux offshore and hinders sediment flow into the northern part of the Gaza city and the Al-Shatti region. Although the condition has somewhat improved in the last decade, a safety gabion was installed to mitigate beach erosion in this area. As a result, the coastal erosion rate decreased from -0.34 m/year in 2010 to -0.2 m/year in 2018 (see Table 3). Nevertheless, erosional processes are the dominant processes in this region where erosional rates were observed with 50.9% and 55.2% of the transects generated in this region showing a negative distance. Figure 5-b shows the shoreline change rate on the northern side of Gaza Fishing Port in the Al-Shatti region.

Deir Albalah Region

A long groin has been built between Deir Albalah and Khanyunis regions, running perpendicular to the shoreline, and extending 200 m seaward. The groin is characterized

Table 3 The shoreline changes rate (LRR) and the net shoreline movement (NSM) et al.-Shatti Region

Shoreline change rate	Parameters	Al-Shatti region
NSM (m)	Average distance (m)	-0.5
	Percent of all transects that have a negative distance	55.2%
	Maximum negative distance (m)	-13.32
LRR (m/yr)	Average rate (m/yr)	-0.2
	Percent of all transects that are erosional	50. 9%
	The maximum value of erosion	-1.9

by average width of about 35 m and more than 5-m height above sea level, and it is about 7 m below sea surface at the groin head. Undoubtedly, the construction of groins at this location was not according to coastal engineering investigation because the current direction and sediment circulation were not considered. In addition, the land levelling process altered the geomorphological pattern, where coastal cliffs were downgraded and collapsed during the construction stage. Negative impacts on the surrounding environment have been noted as a natural consequence of such installations that were not built to account for beach erosion. The finding shows that the rate of shoreline changes is higher in this region than in the north of the Gaza Strip (Fig. 6). About 64.56% of all transects in this region are showing a negative distance. The average shoreline rate was about -0.49 m/year, and the percentage of transects that exhibited erosional rates in this region was 78% of all transects, as seen in Table 4. The findings indicate that coastal cliff retreat accelerated after installing the groin.

Rafah Region

Rafah city is a border city with Egypt, and recently, the region has been under intensive human activity on both sides of the border. Scenes such as coastal roads falling, and cliffs demolished due to wave scour have become more common phenomenon after 2011. The newly built Port on the Egyptian side was completed in 2013, located only about 1.7 kms from the Gaza Strip border (Fig. 7-a). The port breakwater has influenced sediment flux circulation in this littoral cell. The existence of this Port on the upstream sediment flux has implications for downstream shorelines; it has stifled natural nearshore sediment movement, limited net sediment flux to the north, and accumulated significant amounts of sediment on the upstream side of the port breakwater. Due to the shortage of sediment flux reaching the Rafah city beach, coastal erosion intensified and became very noticeable. Fortunately, even a detrimental effect will not last long, as the beach will usually revert to its natural state within a few years if no more change occurs and the beach enters a state of dynamic equilibrium.

The study reveals that the shoreline change rate in this region was about -0.8 m/year, and the average shoreline movement distance was about -11.9 m (Table 5). The overall shoreline movement was about – 48.8 m during the port building stage, and much of the upstream sediments were trapped behind the port breakwater. The dominant process affecting the Rafah shoreline are erosional processes (Fig. 7-b). Several land processes in the Rafah region are also linked to anthropogenic practices, including beach levelling and beach sand quarrying for different industries. The human intervention in these cases were the reasons for the acceleration in coastal erosion in the past years.

In short, the study showed shoreline change rates at several locations along the shoreline (Table 6); the findings confirm that coastal erosion is a dominant process affecting this region in the last few years. Moreover, the study shows the close relationship between the erosion factors prevalent in the different areas of the Gaza Strip and the intense human activities that these areas witnessed.

Local sea level change trend

Climate change is one of the most important factors that reshape shorelines, influence waves and longshore currents. Globally, sea level rise has been one of the main components in increasing coastal flooding, marine erosion, and cliff retreats. One of the consequences of human activities may be an increase in carbon emissions; this contributes to global warming and an increase in global temperature, and consequently, to the melting of ice, which is one of the reasons for the rise in global sea levels, and coastal erosion (Stive 2004; Klein et al. 2004; FitzGerald et al. 2008; Nicholls and Cazenave 2010; Thiel 2012; Romine et al. 2013; Williams 2013; Church et al. 2013; Cazenave and Cozannet 2014; Zviely et al. 2015; Toimil et al. 2017; de Winter and Ruessink 2017; Abdul Maulud et al. 2018; Stronkhorst et al. 2018; Vousdoukas et al. 2018; Horton et al. 2018; IPCC 2019; Le Cozannet et al. 2019; Bramante et al. 2020). Our study did not include parts of the Gaza Strip where there are no large industrial activities because they are not considered sources of carbon emissions, and they therefore do not have any impact on changing the global or local sea level. Globally, experts believe that the rate of the global mean sea level rise during the 21st century will exceed the rate observed during 1971– to 2010, and by 2100, it will

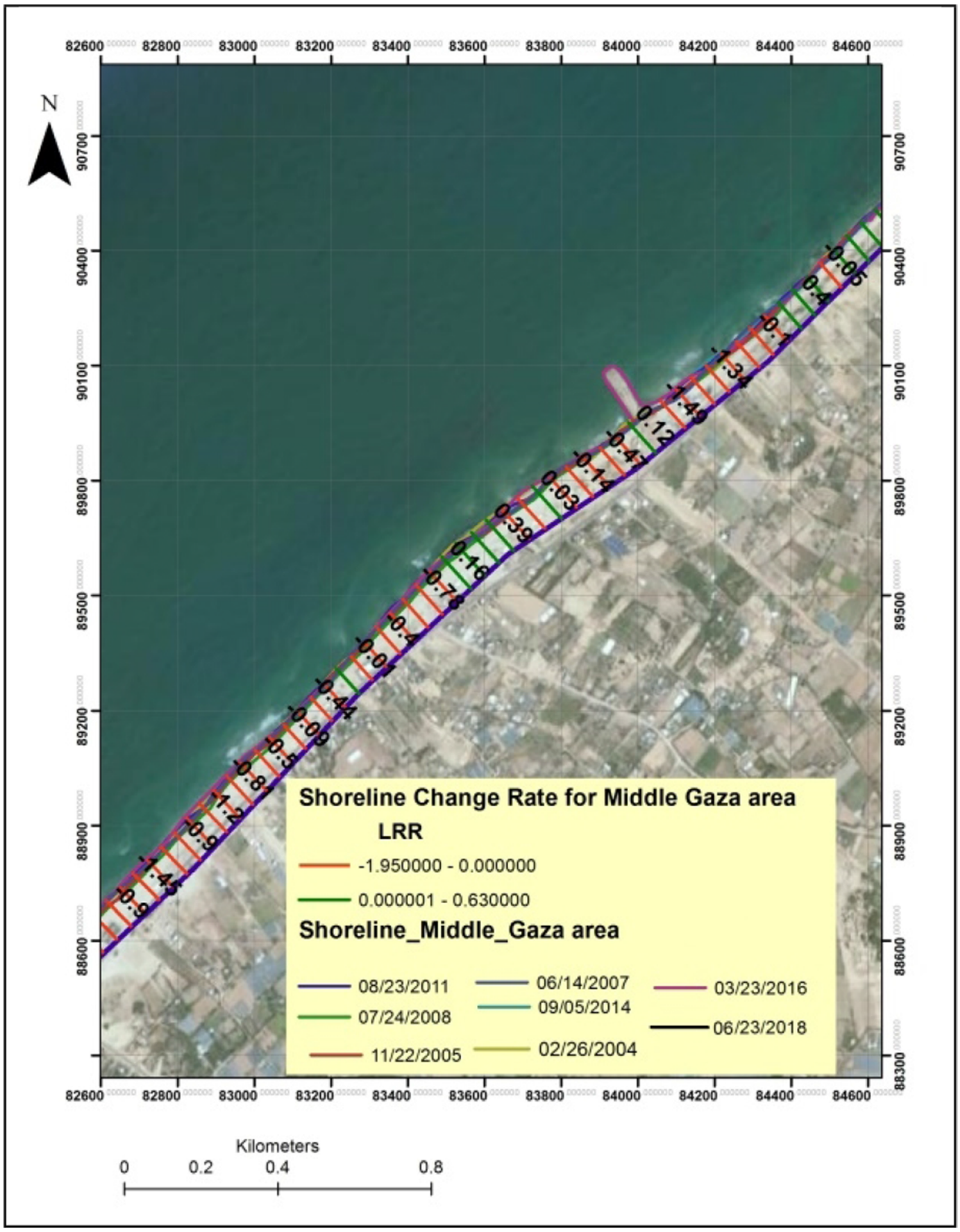


Fig. 6 The shoreline change rate at Dier Albalah

Table 4 The shoreline changes rate (LRR) and the net shoreline movement (NSM) at Dier Albalah

Shoreline change rate	Parameters	Dier Albalah
NSM (m)	Average distance (m)	-2.17
	Percent of all transects that have a negative distance	64.56%
	Maximum negative distance(m)	-20.8
LRR (m/yr)	Average rate (m/yr)	-0.49
	Percent of all transects that are erosional	78. 48%
	The maximum value of erosion	-1.95

range from as low as 0.4 m to as high as 1.5 m (Horton et al. 2020). The long-term trend estimation of the Global Mean Sea level (GMSL), based on tide gauge record, up to 2012, averaged 1.7 mm/ yr. In comparison, satellite altimeter-based measurements exhibited a GMSL rate of 3.2 mm/yr. from 1993–2012 (Church and White 2011; Ray and Douglas 2011; Williams 2013; Parker 2014; Watson et al. 2015; Yi et al. 2015; Chen et al. 2017; Dangendorf et al. 2017; Dieng

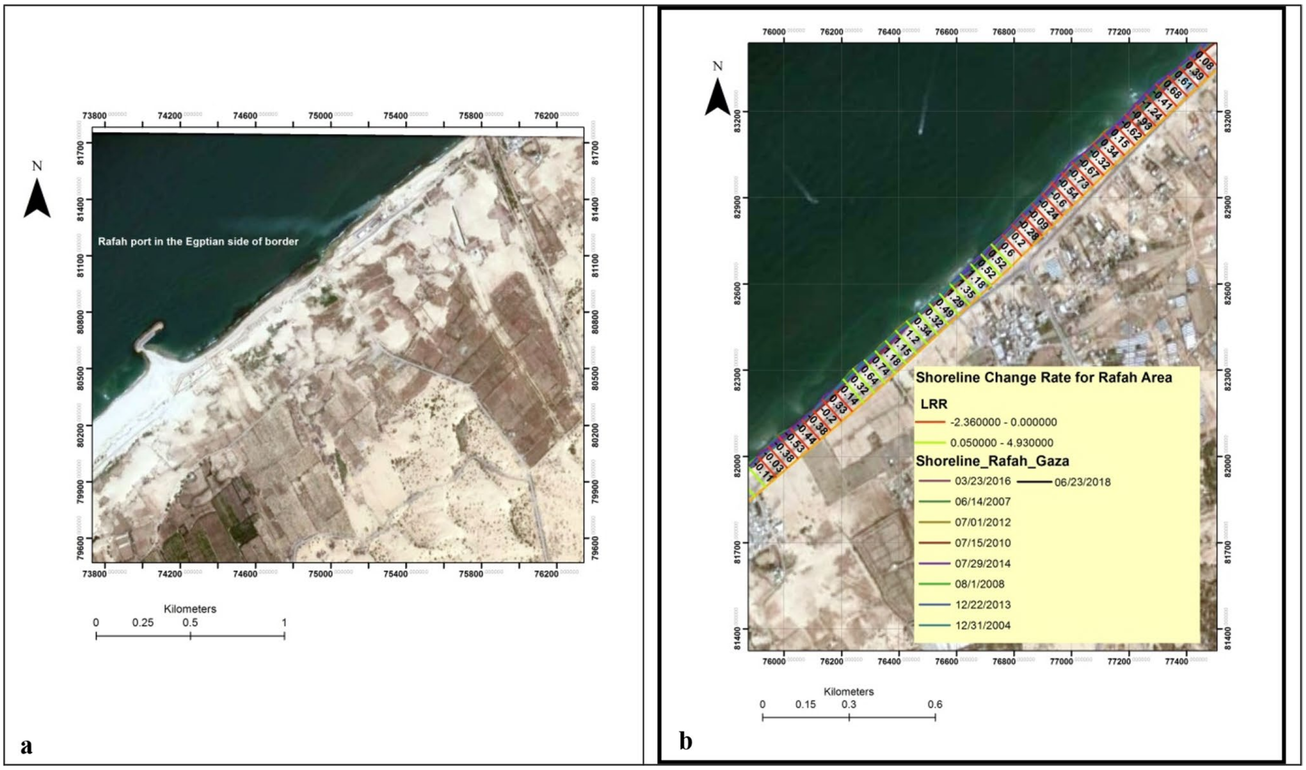


Fig. 7 **a** The Rafah Sea Port on the Egyptian side of the border, **b** The shoreline changes in Rafah Region

Table 5 The shoreline changes rate (LRR) and net shoreline movement (NSM) at Rafah region

Shoreline change rate	Parameters	Rafah
NSM (m)	Average distance (m)	-11.9
	Percent of all transects that have a negative distance	47.56%
	Maximum negative distance (m)	-48.8
LRR (m/yr)	Average rate (m/yr)	-0.81
	Percent of all transects that are erosional	66. 48%
	The maximum value of erosion	-2.36

Table 6 Summary of the Shoreline changes rate (LRR) and the net shoreline movement (NSM) for several locations along the Gaza Strip coastal zone, in particular at regions affected by substantial human intervention

Region	Shoreline change rate LRR (m/year)	Net Shoreline Movement NSM (m)
Bet Lahia	-0.38	-0.62
Al-Shatti (in Gaza city)	-0.2	-0.5
Deir Al Balah	- 0.49	-2.19
Rafah Region	- 0.81	-11.9

et al. 2017; Veng and Andersen 2020). Dangendorf et al. (2017) have reconstructed GMSL of 1.1 mm/yr before 1990 and 3.1 mm/yr. from 1993 to 2012.

Nevertheless, the increase in coastal erosion as a result of sea level rise is indisputable, but the question is whether there is a real rise in the local sea level that is causing accelerated erosion in some areas of the Gaza Strip. To answer this question, sea level data have been collected during the past decade at several tide gauge stations in areas adjacent to the coast of the Gaza Strip. Since the Gaza Strip does not have any tide-gauging station, the data were collected from 4 stations: Ashkelon, Ashdod, Tel Aviv, and Akko, which are coastal cities along the south-eastern coastline of the Mediterranean Sea, 11 km to 160 km from the Gaza Strip. The sea level change values from the Permanent Service for Mean Sea Level (PSMSL) dataset were used to investigate the sea level change trend in short-term assessment. The mean sea level data for seasonal cycles of the four tide stations were transformed into a common datum to construct a time-series analysis of sea level rise trends. This conversion was performed by PSMSL, making use of the tide gauge datum history. Next, the PSMSL data were converted to the Revised Local Reference (RLR) data. The RLR datum at each station is set to around 7000 mm below mean sea level, an arbitrary choice made many years ago to avoid negative numbers in the resulting RLR monthly and annual mean values. Thus, the RLR data can be used for time-series sea level change studies (Holgate et al. 2013; PSMSL 2021). Accordingly, monthly and annual sea level change trends were derived, and the trendline coefficients were utilized to estimate the sea level change rates during this period.

By reviewing the results of sea level projections at the four tidal stations adjacent to the Gaza strip, we found the following:

- Comparison of the trendlines of the investigated 4 stations showed no upward sea level trends in most of the stations in the covered period. Thus, attributing the current acceleration in coastal erosion and cliff collapse to the sea level rise is not supported by data. Figure 8 shows the monthly sea level change trends over 7 to 8 years. The slopes of the trendlines range from—0.0072 mm in Tel Aviv to 0.0019 mm in Ashkelon, which means that there is hardly any upward or downward trend during this period, but the sea level has remained almost the same.
- The monthly sea level change trend at Ashkelon tide station, 11 km from the Gaza Strip, exhibited a trend slope of 0.0005 mm for the period from 2012 up to 2019 (Fig. 9). These results confirm that there is no rise in sea level in this period, and therefore, the role of climate change and sea level rise in the acceleration of coastal erosion in the Gaza Strip are negligible in the short term.

- As for the annual mean of sea level trends: the annual mean of sea level trends at Ashkelon, Ashdod, and Akko demonstrated downward trend slopes of about – 1.95, – 5.25, – 1.42 mm/yr, respectively for period between 2012 and 2019, Fig. 10. While, the annual mean sea level trend at Tel Aviv showed positive slope of about 3.44 mm/yr.
- The annual mean sea level trend at Ashkelon shows a downward trend slope of -1.95 mm/year (Fig. 11). Accordingly, three of four stations demonstrated a downward sea level trends.

By comparing the trends of sea levels in the four tide stations adjacent to the Gaza Strip (Fig. 11), and reviewing the summary of the shoreline change rates for the several regions that witnessed significant human intervention along the Gaza Strip (Fig. 12), important findings can be derived. There is no evidence of an increase in the sea level in the past decade, while a significant erosion and negative shoreline changes were found in several regions along the shoreline of the Gaza Strip.

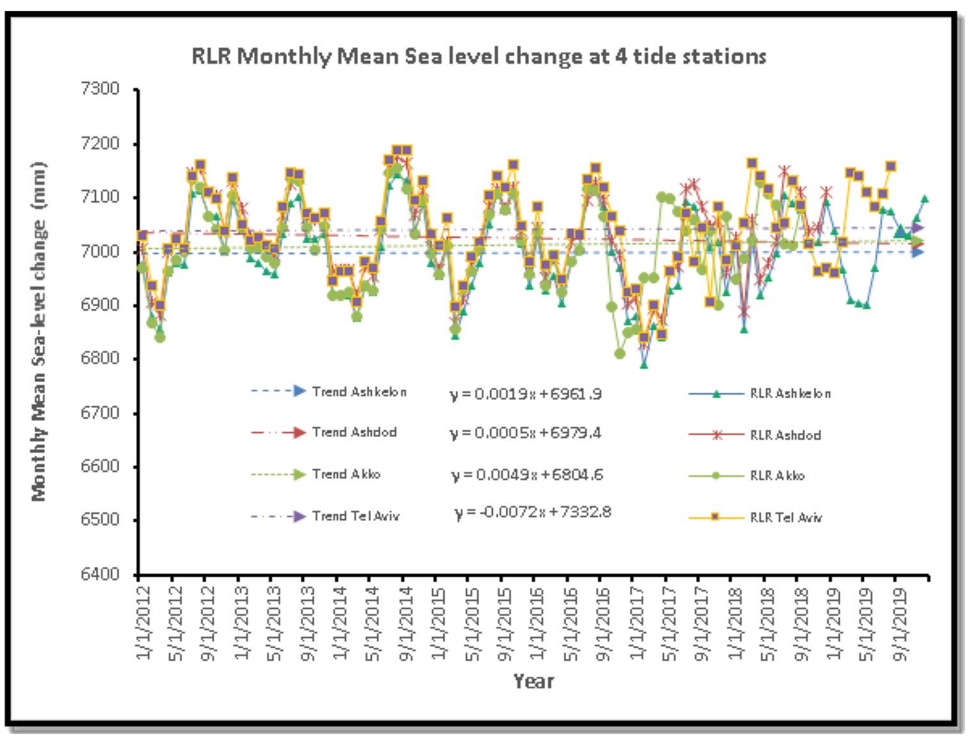


Fig. 8 The RLR monthly sea level change trends for tide stations at Ashkelon, Ashdod, Tel Aviv, and Akko. The Tide Gauge data were obtained from PSMSL (Holgate et al. 2013; PSMSL 2021)

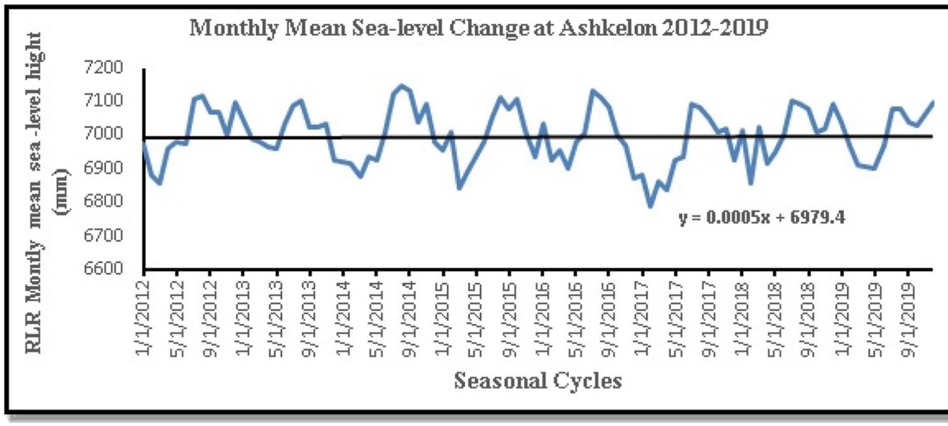


Fig. 9 The RLR monthly sea level change trend at Ashkelon, which is 11 km off the Gaza Strip. The Tide Gauge data were obtained from PSMSL (Holgate et al. 2013; PSMSL 2021)

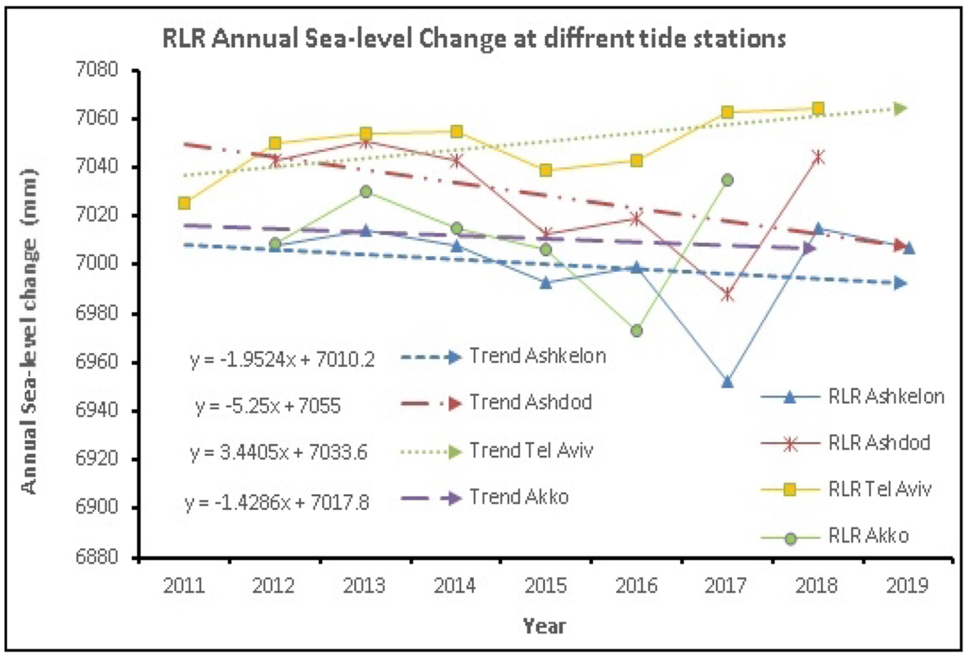


Fig. 10 The RLR annual mean of sea level change trends at Ashkelon, Ashdod, Tel Aviv, and Akko. The Tide Gauge data were obtained from PSMSL (Holgate et al. 2013; PSMSL 2021)

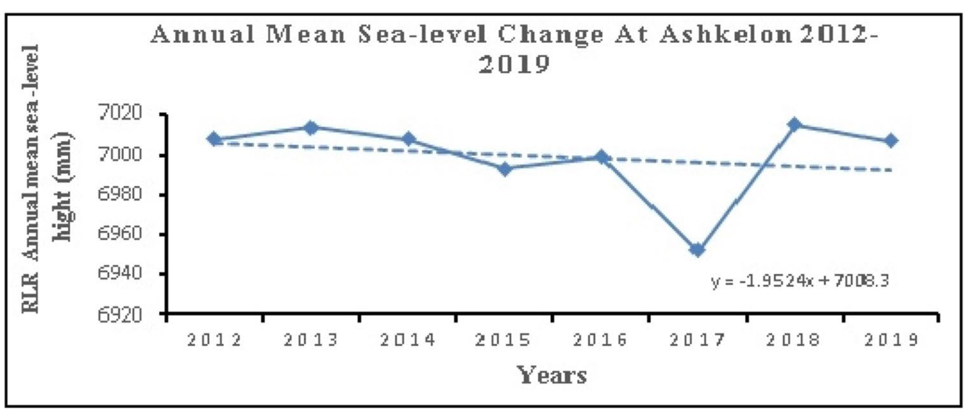
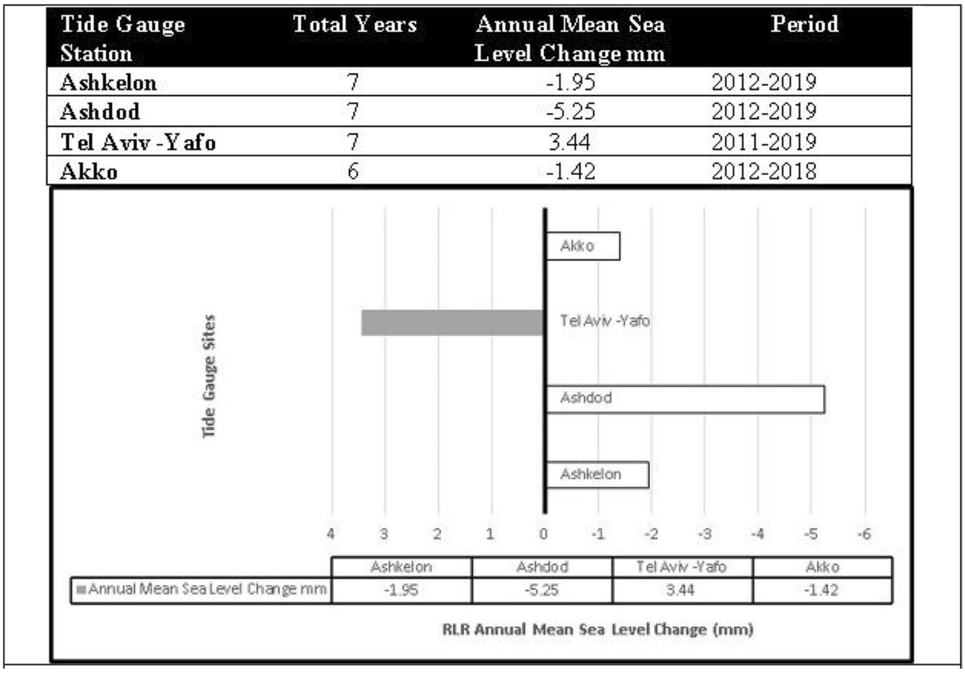


Fig. 11 The RLR Annual mean of sea level change trend at Ashkelon, which is 11 km from the Gaza Strip. The Tide Gauge data were obtained from PSMSL (Holgate et al. 2013; PSMSL 2021)



Tide Gauge Station	Total Years	Annual Mean Sea Level Change mm	Period
Ashkelon	7	-1.95	2012-2019
Ashdod	7	-5.25	2012-2019
Tel Aviv -Yafo	7	3.44	2011-2019
Akko	6	-1.42	2012-2018

Fig. 12 a Summary of the Annual sea level change trends at tide stations: Ashkelon, Ashdod, Tel Aviv, and Akko

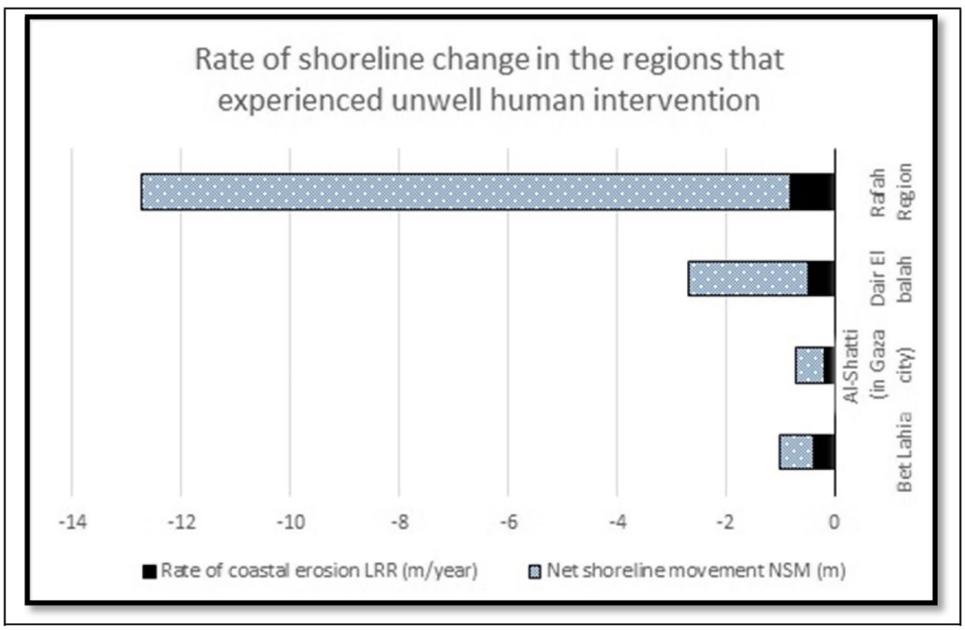


Fig. 13 The average shoreline change rates and the net shoreline movement at several locations where unwell human intervention took place at the shoreline of the Gaza Strip

For instance, Fig. 13 showed that Rafah region experienced the largest shoreline changes and also the maximum movement of shoreline position. The significant erosion and negative changes in this region can be clearly attributed to the establishment of the fishing port in Rafah-Egypt, which acts as a barrier to the natural northward sediment flow to the Gaza Strip. This is a clear example of the influence of human intervention in acceleration of coastal erosion.

In summary, in this study, the rates of shoreline change in the beaches were calculated by using remote sensing and GIS technologies, with emphasis on areas that have experienced intense human activity in recent years. The rates of shoreline change ranged from -0.2 to -0.8 m/year and the net movement of the shoreline ranged from 0.5 to 11 m over the past decade alone. At the same time, the change in local sea level was studied by comparing sea level at 4 tide gauge stations adjacent to the coastal zone of the Gaza Strip. Through the tidal values, local sea level trends were analysed; in most of them, there is no real rise in local sea level during recent years that can be attributed to any beach erosion phenomenon. On the contrary, the tide gauge stations showed a decreasing trend of the average annual sea level in three out of the four stations, which clearly indicates a small decrease in sea level during the period covered by the study.

However, there is an obvious association between the erosion locations along the shoreline and the regions affected by substantial human interventions such as port building, groins construction, establishment of recreational area, and tourist facilities. The high vulnerability areas of the shoreline were those areas affected by high population densities and hard coastal structures. Within this context, human interventions are potentially one of the major and rapid sources of coastal erosion in the short term, compared with climate change which is often more apparent in the long term. Nevertheless, the current prevalence of coastal erosion on the Gaza Strip shoreline is not, therefore, an indication of global sea level rise, but if such a sea level rise develops, there will be an acceleration of existing beach erosion. This result is consistent with some studies that have reported similar conclusions (Bird 1996; FitzGerald et al. 2008; Appeaning Addo 2012; Martins et al. 2018; IPCC 2021; Niang 2022). Technically, the techniques of using remote sensing and GIS have proven again their high capacity, efficiency and accuracy in studying and analysing changes in phenomena of a chronological dynamic nature.

Accordingly, this study does not diminish the impact of climate change and sea level rise on global coastal erosion, but the study distinguishes between factors with short-term impact such as human interventions, in this case, and changes that require decades to show their impact on the local environment, especially in a closed sea area such as the Mediterranean Sea. The finding demonstrates that demographic pressure and human intervention appear to have a substantial negative impact on coastal erosion, where unregulated interventions form a catalyst that accelerates coastal erosion.

Finally, we recommend that decision makers and government agencies responsible for beach management take the necessary scientific and technical measures to prevent encroachments on the coast. This is in addition to studying the creation of any hard structures or construction on the beach from an environmental and engineering perspective, and adopting permeable designs that allow the natural movement of the nearshore sediments and ensure beaches' nourishment.

Data Availability The data that support the findings of this study are openly available in the Permanent Service for Mean Sea Level (PSMSL) dataset at https://psmsl.org/.

Declarations

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the publication of this manuscript.

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