Time Series Analysis of Gaza Strip Shoreline using Remote Sensing and GIS

التحليل الزمني لشاطئ قطاع غزة باستخدام الاستشعار عن بعد ونظم المعلومات الجغرافية

Mahmoud Shihda Adwan

Supervised by

Dr. Maher A. El-Hallaq
Assistant Professor of Surveying and Geomatics

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التاريخ: ٠٨/٦/٢٠١٦
نتيجة الحكم على أطروحة ماجستير

بناءً على موافقة شئون البحث العلمي والدراسات العليا بالجامعة الإسلامية بغزة على تشكيك لجنة الحكم على أطروحة الباحث/ محمود شحادة أحمد عدنان لنيل درجة الماجستير في كلية الهندسة قسم الهندسة المدنية - البنية التحتية وموضوعها:

التحليل الزمني لخط طول الشاطئ بغزة باستخدام الاستشعار عن بعد ونظم المعلومات الجغرافية

Time series analysis of Gaza Strip shoreline using remote sensing and GIS

وبعد المناقشة التي تمت اليوم الاثنين 07 جمادى الآخر 1437هـ، الموافق 16/03/2016م الساعة الثانية عشرة ظهراً، اجتمعت لجنة الحكم على الأطروحة والموافقة من:

م. ماهر عبد الفتاح الحلاق، رئيساً
د. علاء الدين داوود الحمادي، مناقشًة داخلية
د. جواد سليم الأغاث، مناقشًة خارجية

وبعد المداولة أوصت اللجنة بمنح الباحث درجة الماجستير في كلية الهندسة/ قسم الهندسة المدنية - البنية التحتية.

وأثناء إتمامه هذه الدرجة فإنها توصي به سنة الله ولزعم عزه ويستجر علما في خدمته:

وlandır والرضي،...

نائب الرئيس لشؤون البحث العلمي والدراسات العليا

أ.د. عبدالرؤوف علي المناعمة
DEDICATION

To the good soul of my resting father…

To my beloved mother who is the most helpful in this work…

To my wife, beautiful daughters and the sweet son for their unlimited support…

To my brothers Ahmed and Mohammed…

To those who provide me with their support to achieve this thesis successfully…

To my teachers who did all their best in helping me to finish this thesis…

To all martyrs of Palestine…

To all who loved Palestine as a home land and Islam as faith a way of life…

To all of them,

I dedicate this work.
ACKNOWLEDGEMENT

First of all, I would like to express the deepest appreciation to Allah for everything that has been given to me. I would also like to thank my mother for her continuous encouragement.

In addition, I would like to express my gratitude to my supervisor Dr. Maher El-Hallaq for his useful comments, remarks and engagement through the learning process of this master thesis. Furthermore, I would like to thank my committee members, Dr. Alaeddinne Ajamassi and Dr. Jawad El-Agha, who accept to examine this thesis. Special thanks to Eng. Wesam Elashqar, who helped me in GIS and kindly supported me through this thesis. Also, I wouldn’t forget Mr. Muain Abu Amsha for his help in producing this work.

Finally, I would like to give my thanks to everybody supported me during my master degree.
ABSTRACT

Understanding spatio-temporal changes is essential to many aspects of engineering, geographic and planning researches. The coastal zone is the most important and the most intensively used area compared with the other populated areas. The rapid increase of the population on Gaza coastal area leads to depletion of the coastal zone resources and change the coastal morphology.

In this research seven satellite imageries (MSS, TM and +ETM Landsat) were collected from 1972 to 2012. First all satellite images were radiometrically and atmospherically corrected using ERDAS Imagine 2014. Geographic Information System and Remote Sensing techniques were used for spatio-temporal analysis in order to detect changes in the shoreline position and the change in the coast areas.

Based on the results, Gaza Strip coastal zone could be classified into seven regions according to the rate of change and governorates; such as: A) Rafah 2.4 km B) khan Younis 10.4 km C) Southern of middle governorate 8 km D) El-Wadi region 2.4 km E) southern Sea port 6.4 km , F) northern sea port 3 km, and G) North Gaza Governorate 6.2 km.

The results indicated that the regions A, B, C were exposed to accretion in the first five periods, but the last periods the erosion is being the large, the region D is expose to erosion in the whole periods of time 1972-2012, the average annual erosion rates and rate of change from 1972 to 2012 were 2,120 m² and 1.23 m, respectively. Most substantial changes have been observed in the south side of Gaza sea port (region E) which obtained positive annual rate 14,940 m² and change rate about 2.2 m. Region F was exposed to a serious problem of erosion. The annual erosion rates is about 9,550 m² and 2.2m. The region G also expose to erosion patterns.

Finally, this study was emphasized that the coastal band is considered as a critical area, it is therefore necessary to move all stakeholders to monitor and protect Gaza Strip beach from the risk of drift that threatens vital installations and environmental parameter along the beach, such as streets, hotels, tourism facilities, mosques and houses etc.
ملخص الدراسة

إن فهم التغيرات المكانية خلال فترات الزمن المختلفة أو ما يسمى التحليل (الزمني) يعد من أهم الجوانب الهندسية والجغرافية والبحث التخطيطي. إن المنطقة الساحلية هي المنطقة الأكثر أهمية واستخداما مقارنة بالمناطق العامة الأخرى، حيث أن الزيادة السريعة في التعداد السكاني في المنطقة الساحلية لغزة يؤدي إلى استثناف المصادر الساحلية والتغير في شكل الساحل.

في هذا البحث تم جمع سعة مرباتهم للنهر الصناعي لإندسات (+) من عام 1972 إلى عام 2012. بداية كل المراتب المستخدمة تم تصحيحها إشعاعيا وجهابا باستخدام برنامج ERADAS Imagine 2014، تم استخدام نظام المعلومات الجغرافية وتقنيات الاستشعار عن بعد للتحليل الزمني وذلك لاستكشاف التغيرات في موقع الخط الساحلي، والتغير في شكل الساحل. وقذ بين التحليل أنماط التلال والازدياد على طول ساحل قطاع غزة.

بناءً على نتائج البحث تم تقسيم ساحل قطاع غزة إلى سعة مناطق حسب معدلات التغير والمحافظات إلى منطقة Rفح (A) بطول 2.4 كم، منطقة خانيونس (B) بطول 10.4 كم، منطقة جنوب المحافظة الوسطى (C) بطول 8 كم، منطقة جنوب غرب غزة (D) بطول 2.4 كم، منطقة جنوب ميناء غزة (E) بطول 6.4 كم، منطقة شمال ميناء غزة (F) بطول 3 كم، وأخيرا منطقة شمال غرب (G) بطول 6.2 كم.

وقد خلصت نتائج البحث إلى أن المناطق A, B, C تتعرض إلى تعاظم في المنطقة الساحلية وذلك في الفترة من 2008 إلى 2012 الطالق أصبح هو السائد، المنطقة D تتعرض إلى تأكل في الفترة بأكملها من 1972 إلى 2012 بمعدل تناقص سنوي على النحو التالي 1210 متر مربع و 1.23 متر. والتغير الأكثر جوهري هو في الناحية الجنوبية لمنبئ الصيادين في المنطقة (E) التي تتعرض لزيادة سنوية بمعدل 14940 متر مربع و معدل تغير حوالي 2.2 متر، وذلك المنطقة (F) تتعرض إلى نهر في الشاطئ بشكل كبير و بمعدل سنوي 9550 متر مربع و 2.21 متر. والمنطقة (G) تتعرض إلى تأكل بمعدل 4240 متر مربع و 1.49 متر في السنة.

وأخيراً فقد أكدت الدراسة بأن الشريط الساحلي يعتبر منطقة حرجة جدا لذلك من الضروري تحرك كافة الجهات المعنية لمراقبة وإصلاح شاطئ قطاع غزة من خطر الانحراف الذي يهدد المراقبة الحيوية والمعالم البيئية على طول الشاطئ مثل الشواطئ والفنادق والأماكن السياحية والمساجد والبيوت الخ.
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<tbody>
<tr>
<td>AOI</td>
<td>Areas of Interest</td>
</tr>
<tr>
<td>AVHRR</td>
<td>Advanced Very High Resolution Radiometer</td>
</tr>
<tr>
<td>CTEM</td>
<td>Coastal Terrain Models</td>
</tr>
<tr>
<td>DN</td>
<td>Digital Number</td>
</tr>
<tr>
<td>DSAS</td>
<td>Digital Shoreline Analysis System</td>
</tr>
<tr>
<td>EPR</td>
<td>End Point Rate</td>
</tr>
<tr>
<td>ERDAS</td>
<td>Earth Resources Data Analysis System</td>
</tr>
<tr>
<td>ETM+</td>
<td>Enhanced Thematic Mapper Plus</td>
</tr>
<tr>
<td>GeoTIFF</td>
<td>Geostationary Earth Orbit Tagged Image File Format</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>HWM</td>
<td>High Water Mark</td>
</tr>
<tr>
<td>IR</td>
<td>Infra Red</td>
</tr>
<tr>
<td>IRS</td>
<td>India Remote Sensing Satellite</td>
</tr>
<tr>
<td>ISODATA</td>
<td>Iterative Self-Organizing Data Analysis Technique</td>
</tr>
<tr>
<td>LISS-III</td>
<td>Linear Imaging Self-Scanning Sensor-III</td>
</tr>
<tr>
<td>LRR</td>
<td>Linear Regression Rate</td>
</tr>
<tr>
<td>MODIS</td>
<td>Moderate Resolution Imaging Spectroradiometer</td>
</tr>
<tr>
<td>MRSO</td>
<td>Malaysian Rectified Skew Orthomorphic</td>
</tr>
<tr>
<td>MSL</td>
<td>Mean Sea Level</td>
</tr>
<tr>
<td>MSS</td>
<td>Multispectral Scanner</td>
</tr>
<tr>
<td>NDVI</td>
<td>Normalized Difference Vegetation Index</td>
</tr>
<tr>
<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration</td>
</tr>
<tr>
<td>NSM</td>
<td>Net Shoreline Movement</td>
</tr>
<tr>
<td>PCA</td>
<td>Principal Components Analysis</td>
</tr>
<tr>
<td>RS</td>
<td>Remote Sensing</td>
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<tr>
<td>SLC-off</td>
<td>Scan Line Corrector Failure</td>
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<tr>
<td>TM</td>
<td>Thematic Mapper</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>TST</td>
<td>Tasseled Cap Transformation</td>
</tr>
<tr>
<td>USGS</td>
<td>U.S. Geological Survey</td>
</tr>
<tr>
<td>UTM</td>
<td>Universal Transverse Mercator</td>
</tr>
<tr>
<td>WLR</td>
<td>Weighted Linear Regression</td>
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CHAPTER 1: INTRODUCTION

1.1 Background

The coastal zone is the most important and the most intensively used area compared with the other populated areas. 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. In some parts along the coast of the Gaza Strip, coastal erosion is considered a threat to buildings, roads and other installations located directly on the coast. This is clearly seen along the coast of the city of Gaza. Erosion in the coast occurs in the form of beach erosion. Beach erosion is the consequence of sea waves breaking upon the coast, thereby flooding and scouring the area as it ebbs and removing part of the unconsolidated sands. In case of higher waves, the flooding water arrives at the Coarse sand (Kurkar) cliff removing parts of sandstone or clay beds (Abualtayef et al., 2013).

1.2 Significance of Shoreline Studies

Change information of the earth’s surface is becoming more and more important in monitoring the local, regional and global resources and environment. The large collection of past and present remote sensing imagery makes it possible to analyze spatio-temporal pattern of environmental elements and impact of human activities in past decades (Jianya et al., 2008).

Coastal behavior must be understood in order to avoid the mistakes of the past and ensure that the best uses will be selected for each place. Every step toward a better understanding of the dynamics of the Gaza Strip coastal systems and forecasting its changes with the purpose of assisting in future developments will be one more step in the right direction.

1.3 Research Problem

The main problem is there is no studies on the Gaza strip coastal zone so the result which obtain in this research can be used by the concerned authorities to protect the beach from erosion. Coastal erosion is evidenced by collapsed trees, buildings, roads and other structures, including groins which prompting the need for immediate and local
protection to prosperity, there is a need to ensure the long term protection for the overall coast from serious problems such as erosion. Furthermore, the buildings and roads that have been constructed close to the shoreline are facing a stability problem and it is expected to have a serious erosion problem in the coming few years (Matar et al., 2012).

1.4 Research Aim and Objectives

This research aims to conduct a spatio-temporal analysis of the Gaza Strip shoreline between 1972-2012 based on satellite imagery using Remote Sensing (RS) and Geographic Information System (GIS) techniques. To achieve this aim, the following objectives are to be considered:

a) Performing time series analysis of Gaza Strip shoreline using satellite images.

b) Detecting the magnitude of change occurred at Gaza Strip coast area and rate of change.

1.5 Methodology

The methodology used to achieve the study aim can be outlined through the following lines (see Figure 1.1):

- Literature review.

- Collecting data: Data is collected from U.S. Geological Survey (USGS). The study focuses on satellite images which captured by the Landsat (1,5,7) satellites.

- Using image processing environment (e.g., Earth Resources Data Analysis System software, ERDAS) in restoring, enhancing, classifying and transforming images when required.

- Using ArcGIS software and its tools to detect the change in areas and rate of change in the Gaza Strip coastal zones.

- Getting conclusion and recommendations.
1.6 Research Structure

This research is oriented into six chapters;

Chapter One is intended to give a brief overview of significance of shoreline studies, research problem, aim and objectives, general methodology as well as the structure of this thesis.

Chapter Two gives an overview about the study area location, geography, geology, topography, physical conditions of Gaza Strip beach such as geometry etc. Finally Gaza coastal erosion is discussed.

In chapter Three, sediment transport, shoreline, factor that influence shoreline, change detection and spatio-temporal analysis are defined. An overview of the change detection methods over time is discussed. Then, case studies about coastal change detection and Gaza shoreline are summarized from previous literatures.

In Chapter Four, methodology is described in details; image pre-processing, supervised classification, shoreline extraction and change detection analysis are explained.

Chapter Five lists and discusses change of the Gaza Strip shoreline shape.

At the end, Chapter Six gives a general conclusion and recommendations.
CHAPTER 2: LITERATURE REVIEW

2.1 Scope
In this chapter, sediment transport, shoreline, factors that influence shoreline position change, change detection and spatio temporal analysis (time series analysis for spatial scenes), are defined. Then, change detection development over time, remote sensing and shoreline data acquisition techniques are overviewed. After that, methods and case studies about shoreline change detection are summarized from previous literatures. Finally, previous studies about Gaza Strip shoreline are summarized from previous literatures.

2.2 Introduction
The study of historical shoreline data can be useful to identify the predominant coastal processes operating in specific coastal locations using change rates as an indicator of shoreline dynamics. The real importance of such studies is to avoid decisions based on insufficient knowledge, wrong assessments or arbitrary decisions, leading to losses in resources and infrastructure that could have been prevented.

2.3 Sediment Transport
Sediment is any particulate matter that can be transported by fluid flow and which eventually is deposited as a layer of solid particles on the bed or bottom of a body of water or other liquid. Sediment, moved by waves and wind, may be academically divided into cross-shore and alongshore sediment transport. Sediment movement can result in erosion or accretion (removal or addition of volumes of sand). Erosion normally results in shoreline recession (movement of the shoreline inland), accretion causes the shoreline to move out to sea. (Matar et al., 2012)

2.3.1 Cross-shore Transport
If wave energy is high the sediments carried offshore and stored as sandbar as shown in Figure 3-1-a. And If wave energy is low the sediments carried onshore from sandbar to buildup of sand as shown in Figure 3.1-b.
2.3.2 Alongshore Transport

Alongshore transport is the most significant process for moving sediments in the coastal zone. The alongshore sand transport rate is a measure of the rate at which littoral materials moves alongshore in the surf zone from currents produced by obliquely breaking waves as shown in Figure 3.2. Information on prevailing alongshore sand transport rates is needed for the planning and design of all beach stabilization projects.

Figure 2.1: a) High wave energy b) Low wave energy

Figure 2.2: Longshore Current Diagram
2.4 Definition of Shoreline

An idealized definition of shoreline is that it coincides with the physical interface of land and water (Dolan, et al., 1980). Despite its apparent simplicity, this definition is in practice a challenge to apply. In reality, the shoreline position changes continually through time, because of cross-shore and alongshore sediment movement in the littoral zone and especially because of the dynamic nature of water levels at the coastal boundary (e.g., waves, tides, storm surge etc.). The shoreline must therefore be considered in a temporal sense, and the time scale chosen will depend on the context of the investigation. For example, the study for the purpose of investigating long-term shoreline change, sampling every 10–20 years may be adequate. The instantaneous shoreline is the position of the land water interface at one instant in time. As has been noted by several authors (List and Farris, 1999; Morton, 1991; Smith and Zarillo, 1990). The shoreline is a time dependent phenomenon that may exhibit substantial short-term variability (Morton, 1991), and this needs to be carefully considered when determining a single shoreline position. Over a longer, engineering time scale, such as 100 years, the position of the shoreline has the potential to vary by hundreds of meters or more (Komar, 1998).

2.5 Factors that Influence Shoreline Position Change

The transport of material along the coast is linked to natural forces such as waves, tidal movements, long and cross-shore currents, and wind. (Anders and Byrnes, 1991) discuss five of the primary factors that may change shoreline position: 1) wave and current processes, 2) sea level change, 3) sediment supply, 4) coastal geology and morphology, and 5) human intervention.

2.6 Change Detection Definitions

Singh (1989) define change detection as the process of identifying differences in the state of an object or phenomenon by observing it at different time. Another definition of change detection is a technology ascertaining the changes of specific features within a certain time interval. It provides the spatial distribution of features and qualitative and quantitative information of features changes (Kandare, 2000). Simply, U.S. Department of Defense defines change detection as an image enhancement technique that compares two images of the same area from different time periods. Identical picture elements are eliminated, leaving signatures that have undergone change.
2.7 Development of Change Detection over Time

Change detection history starts with the history of Remote Sensing. Thereafter, the development of change detection is closely associated with military technology during World Wars I and II and the strategic advantage provided by temporal information acquired by Remote Sensing. The civilian applications development of digital change detection era really started with the launch of Landsat-1 in July 1972. However, the development was limited by data processing technology capacities and followed closely the development of computer technologies (Théau, 2012).

2.8 Time Series Analysis Definition

Data gathered sequentially in time are called a time series. Environmental modeling, meteorology, hydrology, the Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTGTM-DEM) graphics and engineering are some examples in which spatio-temporal (time series of spatial scenes) arise. The simplest form of data used in time series is a longish series of continuous measurements at equally spaced time points. That is, observations are made at distinct points in time, these time points being equally spaced and, the observations may take values from a continuous distribution. Assume that the series \( X_t \) runs throughout time, that is \( (X_t)_{t=0,1,2,3,\ldots} \), but is only observed at times \( t=1,\ldots,n \) (Reinert, 2010).

Time series analysis is a technology ascertaining the changes of specific features within a certain time interval. It provides the spatial distribution of features and qualitative and quantitative information of features changes (Kandare, 2000).

There are, obviously, numerous reasons to record and to analyze the data of a time series. Among these is the wish to gain a better understanding of the data generating mechanism, the prediction of future values or the optimal control of a system. The characteristic property of a time series is the fact that the data are not generated independently, their dispersion varies in time, they are often governed by a trend and they have cyclic components. Statistical procedures that suppose independent and identically distributed data are, therefore, excluded from the analysis of time series. This
requires proper methods that are summarized under time series analysis (Falk, et al., 2011).

The quantitative analysis for identifying the characteristics and processes of surface changes are carried through from the different periods of remote sensing data. It involves the type, distribution and quantity of changes, that is the ground surface types, boundary changes and trends before and after the changes (Shaoqing, 2008).

Time series analysis is mainly used for temporal trajectory analysis. In contrast to bi-temporal change detection, the temporal trajectory analysis is mostly based on low spatial resolution images such as Advanced Very High Resolution Radiometer (AVHRR) and Moderate Resolution Imaging Spectroradiometer (MODIS), which have a high temporal resolution. The trade-off of using these images, however, is the lost of spatial details that makes auto-classification very difficult, so that the temporal trajectory analysis is commonly restricted in, for example, vegetation dynamics in large areas, or change trajectories of individual land cover classes. Quantitative parameters such as Normalized Difference Vegetation Index (NDVI) or area of given land cover class are often used as the dependent variables for the establishment of change trajectories (Jianya et al., 2008).

2.9 Remote Sensing

Over the last decade, a range of airborne, satellite, and land-based remote sensing techniques have become more generally available to the coastal scientist, coastal engineer, and coastal manager. Depending on the specific platform that is used, derived shorelines may be based on the use of visually discernible coastal features, digital image processing analysis, or a specified tidal datum.

2.10 Shoreline Data Acquisition Techniques

Various data acquisition techniques have been developed to map the position and shape of shoreline over time (Thieler and Danforth, 1994). They include ground surveys, aerial photography and satellite imagery.

Ground surveys maximize the contact between the researcher and the coast. They are the most reliable technique for studying small processes in small areas. But this
technique requires long periods of time, can only collect a limited number of sampling positions, and generally they provide a coarse spatial resolution.

Remote sensing technique allows for observation and measurement of coastline without direct contact. Aerial photographs can provide two or three-dimensional measurements, and have the advantage of covering much larger areas than ground survey method. Aerial photographs should be considered as historical records, since they represent objects at a given location at a precise time. But they also have some disadvantages, since they can only be taken on daylight and through clear skies (which makes them weather dependent), cannot properly represent objects in motion, and they require rectification to compensate for image distortions (Ritchie et al., 1988).

Over the last three decades there has been an increasing use of satellite imagery. Landsat and Spot and one-meter resolution Ikonos satellite images can be used to generate relatively accurate Coastal Terrain Models (CTM) (Li, 1998). By using radar images, data can be collected from high altitude and any time of day or night, and atmospheric conditions are no longer a deterrent.

An automated method for shoreline extraction from raster images was developed by Liu and Jezek (2003), who implemented a new technique based on the Canny edge detector algorithm. This method proved to be a reliable tool to extract shoreline along extensive coasts. Currently, the high temporal resolution and increasing spatial resolution of remote sensing systems are available for detecting and monitoring shoreline movements (White and El Asmar, 1999). Although remote sensing can easily delineate the shoreline in some places, wet tidal areas still represent a problem, and conventional field-based surveying remains as the most reliable approach to determine shoreline position change over short time scales (Ryu et al. 2002).

2.11 Previous Coastal Studies

Mageswaran et al., (2015) study was carried out along the Nagapattinam district of Tamil Nadu, India using multi-temporal satellite images from 1978 to 2013. The long-term coastal erosion and accretion rates have been calculated using Digital Shoreline Analysis System (DSAS). Linear Regression Rate (LRR) statistical method is applied to estimate the shoreline change rate. The results of the analysis shows that erosion is
dominant in Sirkali, Tharangambadi, Karaikal (Puducherry State) and Nagapattinam taluks, while Thiruthuraipundi taluk is undergoing accretion. Both natural and anthropogenic processes along the coast control the erosion and accretion activities of the coastal zones. The present study demonstrates that combined use of satellite imagery and statistical methods can be a reliable method for shoreline change analysis.

Aedla et al. (2015) use an automatic shoreline detection method using histogram equalization and adaptive thresholding techniques is developed. The shoreline of Netravati-Gurpur river mouth area along Mangalore coast, West Coast of India have been extracted from Indian Remote Sensing Satellite (IRS P6) LISS-III (2005, 2007 and 2010) and IRS R2 LISS-III (2013) satellite images using developed automatic shoreline detection method. The delineated shorelines have been analyzed using Digital Shoreline Analysis System (DSAS), a GIS Software tool for estimation of shoreline change rates through two statistical techniques such as, End Point Rate (EPR) and Linear Regression Rate (LRR). The Bengre spit, Northern sector of Netravati- Gurpur river mouth is under accretion an average of 2.95 m/yr (EPR) and 3.07 m/yr (LRR) and maximum accretion obtained is 8.51 m/yr (EPR) and 8.69 m/yr (LRR). Southern sector, the Ullal spit is under erosion an average of -0.56 m/yr (EPR) and -0.59 m/yr (LRR).

(Alemayehu et al., 2014) find the trend of shoreline changes, and the factors attributed to the changes. Aerial photographs of 1969 and 1989 and a recent satellite image of 2010 were used to digitize the shoreline of Watamu area in Kenya. The Digital Shoreline Analysis System (DSAS) in ArcGIS environment was used to create transects and statistical analyses for the shoreline. Several Global Positioning System (GPS) points were taken in October 2013 and 2014 during ground truthing following the High Water Mark (HWM). The 9.8 km long Watamu shoreline was divided into 245 transects with 40 meter spacing in order to calculate the change rates. The rates of shoreline change were calculated using the End Point Rate (EPR), Net Shoreline Movement (NSM), and Weighted Linear Regression (WLR) statistic in DSAS.

According to Kaliraj et al (2013), the multitemporal Landsat TM and ETM+ images acquired from 1999 to 2011 are used as primary data source for shoreline extraction. The Survey of India topographical maps (1:25,000) are used for preparation of the base map. The images were geometrically corrected by applying the Universal Transverse
Mercator (UTM)-WGS 84 projection and coordinate system using the auto-sync tool in ERDAS Imagine 9.2 software. Moreover, the spectral and spatial properties of the image were enhanced to improve the coastal features using histogram equalization and convolution techniques. The long-term coastal erosion and accretion rates have been calculated for the periods between 1999 and 2011, and the subsequent short-term changes were performed during 1999-2000, 2005-2006, and 2010-2011. Thus, the long-term coastal changes indicate that the net erosion rate is higher on the coasts of Kanyakumari, Kovalam, Manavalakurichi, Mandaikadu, and Thengapattinam; the values are 0.118, 0.105, 0.127, 0.133, and 0.017 m², respectively. Meanwhile, the annual erosion rate of these areas is 10,000, 9,000, 11,000, and 1000 m²/year.

Kumaravel, et al., (2013) investigated the spatial as well as quantify the shoreline changes along the coast in the parts of Cuddalore district, east coast of Tamil Nadu by using geospatial techniques. The Survey of India topographic map, multi-temporal Indian Remote Sensing satellite data were used to extract the shorelines. The data is processed and analyzed by software like ERDAS image processing, ArcGIS respectively. The rates of shoreline changes are estimated by overlay analysis by using GIS environment. Due to length of the shoreline, the study area has divided into five segments namely A, B, C, D and E. The study reveals that most of the study area has been undergoing erosion around 3.21km² for the past four decades except Segment D. Both natural and anthropogenic processes along the coast modify the shoreline configuration and control the erosion, accretion activities of the coastal zones.

Dewidar and Frihy (2010) used Landsat images (MSS, TM and ETM+) between 1972 and 2007 along the northeastern coastline of Nile Delta in Egypt. They analyzed these images to quantify erosion and accretion patterns along the northeastern coastline of Nile Delta, from Gamasa to Port Said. Rates of shoreline changes were calculated from automated waterline positions generated at 852 locations using a Digital Shoreline Analysis System (DSAS). Results indicate that the general alongshore erosion/accretion pattern is locally disrupted by the construction of protective engineering structures. The erosion at the tip of the Damietta promontory is terminated due to the construction of the 6 km seawall built in the year 2000; erosion was originally -43 m/yr before construction of this wall. The 8 km sand spit that has been formed from the eroded
zones at the promontory tip before construction of the seawall is now under erosional processes due to deficiency of sediment supply. Further west and prior to protection of Ras El Bar resort, erosion (-10 m/yr) is spatially replaced by a formation of salient accretion (15 m/yr) following emplacement of the detached breakwaters between 1991 and 2002. However, local adverse erosion has been resulted in at the western end of the breakwater system, averaging -5 m/yr. This erosion has resulted from the interruption of the westerly longshore sediment transport by these breakwaters. The seasonal reversal of the North-NorthEast (NNE) waves is responsible for generating of this westward-flowing longshore current along Ras El Bar coastline.

Remote sensing and GIS techniques was used by Mousavi et al. (2007) to determine the morphological changes of Sefidrud delta, Iran over the last three decades (1975–2005). Landsat MSS, TM and ETM+ and IRS data for the period of 1975 to 2005 was processed. The data were georeferenced with respect to 1:25,000 topographic maps. All the required datasets were registered to the IRS-Pan image. The data were then imported into GIS environment for analyzing and possible change detection. The updated features were digitized on screen and overlaid with the previous data. The obtained results demonstrated that the land area eroded at an average rate of 215.6 m/yr. The Caspian Sea level raised 2.6 m from 1975–2005, affecting the coast of Sefidrud delta promontory. It was observed that its promontory moved to eastward about 2 km as a maximum shoreline change over the last three decades. They emphasized the use of geospatial information for coastline change detection.

Zakariya, et al., (2006) used Landsat 5 (1996) and Landsat 7 (2002) images to detect shoreline areas, and the Terengganu River mouth, Malaysia. Both images were geometrically corrected and transformed and then connected to the same spatial location and projection. The Iterative Self-Organizing Data Analysis Technique (ISODATA) was then used to delineate the inter-tidal zone and land and water areas. Unsupervised classification on hue, intensity and saturation imagery with ISODATA produced different ranges of values for the different coastal features. Spatial analysis of the changes within a GIS permitted the detection of erosion and accretion at different scales. Between 1996 and 2002 there was more accretion than erosion in the study area.
Changes along the Guamare coastline, Rio Grande do Norte State, Brazil were studied by Grigio, et al., (2005) with remote sensing and geographic information systems techniques. Images from Landsat 5 TM and Landsat 7 ETM+ were utilized, and the Normalized Difference Water Index (NDWI) was computed. The authors found that the use of the NDWI index method in Band 3 produced a large enhancement in the submerged and emerged areas, providing a better definition of water bodies and tidal channels. The resulting NDWI image compositions for the years 1989, 1998, 2000 and 2001 provided the required delimitation of the coastline. The results indicated that in the time period 1998–2001 the accretion and erosion processes of the coastline were more intense when compared with those of the earlier 1989–1998 period. In 2000–2001 erosion prevailed, contributing 78.1% of the total alteration of the coastline. GIS and remote sensing were found to be useful to evaluate evolution of the coastline.

Muslim et al. (2004) utilizes multi-temporal satellite imagery to monitor shoreline changes from 1992 to 2009 at Seberang Takir, Terengganu, Malaysia through the use of image processing algorithm and statistical analysis. All the imagery was geo-rectified to the Malaysian Rectified Skew Orthomorphic (MRSO) projection and analysis was done to detect spatially significant areas with erosion and accretion along the shoreline and detect potential sources of the changes. The shoreline was divided into 16 sites and shoreline changes at the sites were determined based on satellite sensor imagery. Preliminary result show erosion occurring near to human activities Northeast of Kuala Terengganu shoreline while southwest of Kuala Terengganu was subjected more to accretion.

A combination of field surveys, aerial photographs, and SPOT satellite images were used by Fromard et al. (2004) to study coastal changes along the coast of French Guiana for the period 1951-1999. SPOT 3 images for 1991, 1993 and 1997 and a SPOT 4 image for 1999 were geometrically corrected and exported into a geographical information systems. Synthetic digital maps were then produced by combining the data from the various sources in the GIS. Net accretion was observed for the period 1951-1966. Between 1966 and 1991 erosion occurred, and this was then followed by an accretion phase. The integrated approach followed by the authors allowed them to state that the French Guiana coastline was unstable and continuously changing.
Siddiqui and Maajid (2004) uses Principal Component Analysis (PCA) on Landsat MSS and TM data to evaluate coastal changes between 1973 and 1998 in Pakistan. The multi-temporal PCA analysis results were integrated with each other in a GIS environment. The multi-temporal Landsat data used in this study were found to be useful for monitoring and mapping the coastal land accretion and erosion processes. The study provided the most recent database of the coastal environment along the coastal belt of Karachi.

Alves et al. (2003) utilizes Landsat 5 TM imagery for monitoring and evaluating coastal morphodynamic changes along the northeast coast of Brazil. Images for 1989 and 1998 were used to identify changes in erosional and depositional states marked by changes in coastal geometry. In analyzing the images emphasis was placed on simple contrast stretched false colour composites which revealed good reflectance contrast between clear and turbid water areas. The authors were successful in evaluating different morphodynamic areas along the coast, including beaches and dune fields. Erosion was found to be predominant over the ten-year imaging period.

Noernberg and Marone (2003) extracts shoreline positions by employing the Normalized Difference Water Index (NDWI) algorithm along the Brazilian coast. The combination of Landsat imagery and the NDWI enhanced the differences in pixel resolution between land and water. Reflectance of water was maximized at the visible end of the electromagnetic spectrum, and minimized within the near-infrared spectrum. Soil and vegetation land cover generated the highest reflectance in the near-infrared portion of the spectrum.

Twelve Landsat 7 ETM+ scenes from Louisiana and Delaware were acquired by Scott et al. (2003). The scenes were then mosaicked together to form a continuous scene, and then processed with ERDAS Imagine. The Tasseled Cap Transformation (TCT) was then used to extract shorelines. The TCT was chosen over other methods because it was efficient and consistent in classifying pixels. The TCT recombined spectral information of six ETM+ bands into three principal view components. Of the three principle view components (i.e., brightness, greenness, and wetness) the wetness component was exploited to differentiate land from water. The results demonstrated that shoreline data could be defined by increasing the temporal resolution of image data sources, even if
the spatial resolution was decreased. The claim was made that it was possible to accurately relate extracted shoreline data to elevation values obtained from coastal tide observation stations.

As the spatial and temporal resolutions of satellite images have significantly improved in recent years, the applicability of the images to coastal zone monitoring has become more promising. Scott et al. (2002) demonstrated that Landsat 7 Thematic Mapper data could be used to accurately extract land-water boundaries. The southern Louisiana coastline in the winter of 2000 was classified into land and open water using the ERDAS implementation of the tasseled cap algorithm. The land-water interface was then traced. Though the 30-m spatial resolution is comparatively low given the dynamic nature of the coastal region, this drawback is compensated by high color resolution, the increased temporal resolution and decreased cost. The land-water boundary derived from this method is equivalent in accuracy of the vector shoreline published by National Oceanic and Atmospheric Administration (NOAA).

Landsat TM imagery was used by White and El Asmar (1999) to delineate shoreline positions along the Nile Delta, Egypt. A segmentation algorithm permitted the identification of known pixels of open water, referred to as “seeds” to determine a common spectral reflectance class for water. The segmentation technique merged similar neighbouring pixels into a water classification, and proceeded to expand in a homogenous grouping in all directions until dissimilar pixels were detected. Results from the segmentation approach demonstrated differences in land and water areas along the Delta. Shoreline positions were then mapped.

Li et al. (1998) used GIS application to study shoreline changes along the coast in the state of Pinnang, Malaysia. The erosion conditions were mapped and monitored by aerial mapping techniques, as well as a coastal geographic information systems was developed to support modernized shoreline monitoring and management. It consists of three components, shoreline erosion monitoring, coastal engineering management and coastal inventory. The data involved was spatial data, time series data, social and economic data and aerial photographs. The results showed that integration of spatial and time series data proved a successful technique to monitor and manage the coastline.
2.12 Previous Studies about Gaza Strip Coast

According to Abualtayef et al., (2013) change detection analysis was used to compute the spatial and temporal change of Gaza shoreline between 1972 and 2010. The study area is extended from Wadi Gaza, 4 km to the south of fishing harbor, to Alsodania area, 3 km to the north of the harbor. The study findings showed that the sediment balance of beach area tended to be negative. This observation is based on the advance of the waterline towards the sea to the south of fishing harbor by an average 0.75 m/year and based on the treat of the waterline towards the land to the north of fishing harbor by an average 1.15 m/year. Gaza fishing harbor caused a serious damage to the Beach Camp shoreline, especially after removing six detached breakwaters. The impact of harbor construction has extended to 2.6 km to the north and less than 2.4 km to the south of harbor.

Abualtayef, et al., (2012) utilizes MSS, TM and ETM+ Landsat images from 1972 to 2010 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. They applied a post classification change detection matrix using ERDAS Imagine to estimate the amount of change between the several dates. Then digital shoreline analysis was used to calculate the rate of change along the Gaza coastal zone. 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. The results showed that shoreline was advanced south of the Gaza fishing harbor and the annual beach growth rate was 15,900 m². On the downdrift side of the harbor, the shoreline was retreating and beaches erode at an annual rate of -14,000 m². While the average annual accretion and erosion rates from 1972 to 2010 were 5.3 m and 4.7 m, respectively.

Abu-Alhin & Niemeyer (2009) use a series of Landsat ETM+ images (30m resolution), Landsat TM-5 imagery (30m), SPOT-5 panchromatic imagery (5m) for long-term evaluation use remote sensing and geographic information systems (GIS) to monitor and analyze the coastline dynamics during the last two decades using medium resolution satellite images. Tasselled Cap Transformation, Band Ratio and NDVI were used in order to automatically extract the coastline. Accuracy assessment was performed
between the these different methods using manually digitized coastlines. Principle Component Analysis and Band Ratio exhibit the best results compared to the other methods. The coastline were then automatically extracted from all images. Following, the DSAS was used to calculate the rate of change along Gaza coastal zone. The rate of change was computed using two methods. The first calculation technique is EPR and the second method is LRR. The results indicated a negative rate in general. Erosion has been the predominant process on Gaza Coastal zone and the increasing of sea level has surely affected Gaza coastal zone. The southern side of Gaza seaport obtains a positive rate and accretion in the beach area. This positive rate is due to Gaza seaport which interrupts the natural flow of the longshore currents and traps the sediments on the south western side. Based on this results, Gaza coastal zone could be classified into five regions according to the rate of change as shown in Table 3.1:

<table>
<thead>
<tr>
<th>Date of shorelines</th>
<th>Region</th>
<th>EPR</th>
<th>LRR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shorelines from 1986 to 2008</td>
<td>A (North Gaza)</td>
<td>-0.06</td>
<td>-0.32</td>
</tr>
<tr>
<td></td>
<td>B (northern Sea-port)</td>
<td>-0.26</td>
<td>-0.16</td>
</tr>
<tr>
<td></td>
<td>C (southern Sea-port)</td>
<td>0.98</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>D (Wadi region)</td>
<td>-0.26</td>
<td>-0.36</td>
</tr>
<tr>
<td></td>
<td>E (South Gaza)</td>
<td>0.32</td>
<td>0.30</td>
</tr>
</tbody>
</table>

2.13 Conclusion

The previous studies concentrate on the region locate to the north and the south of Gaza sea port and studied its effects on the shoreline. The studies showed that the Gaza coast especially to the north of sea port. 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. But none of these studies was concerned in details about Gaza coastal zone. Different methods were used to study the coastal zone such as aerial photograph, field surveying and remote sensing. Therefore, the aim of this study to use remote sensing and geographic information systems (GIS) to calculate the rate of coastal change along Gaza coastal zone.
CHAPTER 3: THE STUDY AREA

3.1 Scope

This chapter consists of eight sections. It involves location and geography which discusses the position of the study area according to WGS84 coordinate system. Gaza Strip climate is then reviewed temporally and quantitatively. After that, Gaza Strip geology and topography is discussed in the fifth and sixth sections. Then Gaza beach physical conditions such as geometry, water level, tide, wind, wave and geology of seabed are discussed in the seventh section. Finally Gaza coastal erosion is discussed in the eighth section.

3.2 Historical Background

The coastline of the Gaza Strip forms only a small section of a larger concave system (a “litoral cell”) that extends from Alexandria at the west side of the Nile Delta, via Port Said, Bardawil Lagoon, El Arish, Gaza, “Ashqelon”, and “Tel Aviv” to the Bay of Haifa. This litoral cell forms the South East (SE) corner of the Levantine Basin (Figure 2.1). This entire coastline, including the coastline of the Gaza Strip, has been shaped over the last 15,000 years by the Nile river and especially its sediment yield originating from Africa’s mountains. The Nile sand moves along the entire concave coastline in an anticlockwise direction, generally in a North East (NE) direction. Within this concave SE corner of the Mediterranean, the relatively short 42 km Gaza coastline is almost straight (Ali, 2002).

3.3 Location and Geography

The Gaza Strip is a coastal area along the eastern Mediterranean Sea, 42 km long and between 6-12 km wide, with total area of about 365 km². The Gaza Strip is located on 31° 25’ 0” N, 34° 20’ 0” E WGS84 coordinate system, bordering Egypt to the south, historical Palestine to the east and north and the Mediterranean Sea to the west as illustrated in Figure 2.2.
Figure 3.1: Gaza coastline in the Mediterranean Context

Figure 3.2: Gaza Strip location
3.4 Climate

3.4.1 Air Temperature

The area has a Mediterranean dry summer subtropical climate with mild winter, this is because of its locations as transitional zone between semi-humid Mediterranean climate and arid desert climate. The mean monthly lowest temperature in January is 15.10 C and the highest in August is 28.30 C, with the mean annual temperature of 21.70 C (see Figure 2.3).

The sea affects temperature nearby because of the moderating effect a large body of water has on climate. During the winter, sea temperature tend to be higher than land temperature, and vice versa during the summer months. This is the result of the water's mass and specific heat capacity.

![Figure 3.3: The average temperature of Gaza Strip between 1990-2009](image)

3.4.2 Rainfall

The rainfall occurs in the winter period, which is between Octobers to March, and the mean annual rainfall varies 350-400 mm per year (PNA-MEA, 2000).
3.4.3 Wind Speed
The wind velocity with northwest direction at 2 meter above the surface in the summer is about 1.5 m/s, which is less than that's during winter months where velocity reaches values of 2.8 m/s (PNA-MEA, 2000).

3.4.4 Air Humidity
The daily relative humidity varies between 66% in the night to 86% at the daytime in summer and between 53% to 81% respectively in winter (Matar et al., 2012).

3.4.5 Solar Radiation
The mean annual solar radiation is about 2200 J.cm\(^2\) day\(^{-1}\). The mean monthly values in winter are about one third of the mean monthly values in summer. These values are applicable for the whole area since Gaza Strip is too small to have a distinct climate (Matar et al., 2012).

3.5 Topography
Topography refers to the altitude of the land surface. Gaza Strip is a coastal foreshore plain gradually sloping westward toward the sea allowing for surface run-off to reinfiltrates the soil. A sandy beach stretches all along the coast, bound in the east by a ridge of sand dunes known as coarse sand (Kurkar) ridges. This alternating sequence of permeable and impermeable layers serves as a natural catchment area for rainfall and renders the sand favorable for growing crops. The topography in the Gaza Strip is influenced by the ancient coarse sand ridges, which run parallel to the present coastal line. The altitude of the Gaza Strip land surface ranges between zero meters at the shore line to about 90 meters above mean sea level (MSL) in some places. The height increases towards the east from 20 to 90 meters above the sea level (Matar et al., 2012).

3.6 Geology
The Gaza Strip is a shore plain gradually sloping to the west. It is underlain by a series of geological formations from the Mesozoic to the Quaternary. The main formations known were composed in the last two system periods, Tertiary formation called “Saqiya formation” of about 1200-meter thickness, and the Quaternary deposits in the Gaza Strip are of about 160 meters thickness and cover Saqiya formation (Matar et al., 2012).
3.7 Gaza Beach Physical conditions

3.7.1 Geometry of the seabed (bathymetry)

The geometry of the seabed (bathymetry) of Gaza is given in Figure 2-4. One finds the 100 m depth line off Gaza 28 km away in the south and 14 km in the north. So the average seabed slope between the coast and the 100 m depth line is about 1 in 200. Beyond the 100 m depth line, the sea bottom drops quickly to a depth of 1500 m.

Recent figures present a single near-shore coastal profile surveyed in 1986 at a location about 1 km South of the present Fishing Port, where the depth contour lines are relatively straight and parallel to the coastline (Port Consult, 1987). The 20 m depth contour is found some 1600 m seaward of the shoreline, so the average sea bed slope is 1 in 80 (Delft Hydraulics, 1994). For easy reference, Table 2.1 represents the bathymetry of the sea of Gaza Strip (various source).

Table 3.1: The bathymetry of the sea of Gaza Strip

<table>
<thead>
<tr>
<th>Depth (m) below MSL</th>
<th>Distance from shore (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>200</td>
</tr>
<tr>
<td>6</td>
<td>350</td>
</tr>
<tr>
<td>8</td>
<td>500</td>
</tr>
<tr>
<td>10</td>
<td>670</td>
</tr>
<tr>
<td>12</td>
<td>870</td>
</tr>
<tr>
<td>14</td>
<td>1070</td>
</tr>
<tr>
<td>16</td>
<td>1260</td>
</tr>
<tr>
<td>18</td>
<td>1460</td>
</tr>
<tr>
<td>20</td>
<td>1660</td>
</tr>
</tbody>
</table>

A more complicated coastal profile form, with one or two offshore submerged sand bars, has been described for an area. Such sand bar feature is also found along the coast of Gaza, at a depth of Mean Sea Level (MSL) -4 to -5 m (Haskoning and Team Palestine, 1998). These bars can also be seen on most aerial photographs. They play an important role in the sediment transport, both alongshore and cross-shore.
Figure 3.4: The bathymetric map of the sea of Gaza Strip
3.7.2 Water Level and Tides

The astronomical tidal range in the Mediterranean is small. From the Admiralty Tide Tables of 1988 the following tidal levels were found in Table 2.2 (D. Hydraulic, 1994).

Table 3.2: Tidal ranges in Gaza Strip

<table>
<thead>
<tr>
<th>Tide level</th>
<th>Value(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HAT</td>
<td>+ 0.45</td>
</tr>
<tr>
<td>MHWS</td>
<td>+ 0.35</td>
</tr>
<tr>
<td>MHWN</td>
<td>+ 0.15</td>
</tr>
<tr>
<td>MSL</td>
<td>0</td>
</tr>
<tr>
<td>MLWN</td>
<td>-0.15</td>
</tr>
<tr>
<td>MLWS</td>
<td>-0.25</td>
</tr>
<tr>
<td>LAT</td>
<td>-0.35</td>
</tr>
</tbody>
</table>

Where,

- HAT: Highest Astronomical Tide.
- MHWS: Mean High Water Springs.
- MHWN: Mean High Water Neaps.
- MLWS: Mean Low Water Springs.
- MLWN: Mean Low Water Neaps.
- LAT: Lowest Astronomical Tide.

Extreme water level variations are commonly caused by barometric pressure variations, rather than by tides. These meteorological variations may often have more effect on the sea level than tides. The design water level along the eastern Mediterranean coast is taken as MSL + 1 m, which corresponds approximately with a water level which is being exceeded once in 50 years (Matar et al, 2012).

3.7.3 Wind and Wave

The wave rose for year 2004-2005 at IDKU station in Egypt is illustrated in Figures 2.5 and 2.6 (Seif, 2011). Summary of wave conditions derived from IDKU station are shown in Tables 2.3. Table 2.4 shows the presented wave scenarios for Gaza data derived from Ashdod measurements (D. Hydraulic, 1994). The waves in Gaza Strip are considered swell waves, resulting from the wind, although there are some other waves resulting from other climatic conditions but in small effects. The dominated waves are from West-NorthWest (WNW) direction along year.
Figure 3.5: Significant wave height vs. direction at Idku station for year 2004-2005

Figure 3.6: Significant wave period vs. direction at Idku station for year 2004-2005
**Table 3.3:** Average yearly wave data at Idku station for year 2004-2005

<table>
<thead>
<tr>
<th>Wave scenario</th>
<th>$H_s$ [m]</th>
<th>$T_s$ [s]</th>
<th>Direction [deg.North]</th>
<th>Duration [days]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H \leq 1.0$ m</td>
<td>0.5</td>
<td>6.3</td>
<td>284</td>
<td>289.0</td>
</tr>
<tr>
<td>$1.0 &lt; H \leq 2.0$ m</td>
<td>1.3</td>
<td>7.1</td>
<td>295</td>
<td>63.0</td>
</tr>
<tr>
<td>$2.0 &lt; H \leq 3.0$ m</td>
<td>2.4</td>
<td>8.0</td>
<td>293</td>
<td>10.0</td>
</tr>
<tr>
<td>$3.0 &lt; H \leq 4.0$ m</td>
<td>3.4</td>
<td>8.8</td>
<td>292</td>
<td>2.7</td>
</tr>
<tr>
<td>$H &gt; 4.0$ m</td>
<td>4.2</td>
<td>9.4</td>
<td>305</td>
<td>0.3</td>
</tr>
</tbody>
</table>

*H*: significant wave height; *T*: significant wave period; Direction is the wave direction; *H*: wave height

**Table 3.4:** Average yearly wave condition for Gaza from Ashdod station

<table>
<thead>
<tr>
<th>Wave scenario</th>
<th>$H_s$ [m]</th>
<th>$T_s$ [s]</th>
<th>Direction [deg.North]</th>
<th>Duration [days]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H \leq 1.0$ m</td>
<td>0.67</td>
<td>5.9</td>
<td>342.0</td>
<td>197.1</td>
</tr>
<tr>
<td>$1.0 &lt; H \leq 2.0$ m</td>
<td>1.00</td>
<td>6.5</td>
<td>275.0</td>
<td>159.8</td>
</tr>
<tr>
<td>$2.0 &lt; H \leq 3.0$ m</td>
<td>2.25</td>
<td>7.9</td>
<td>323.0</td>
<td>1.80</td>
</tr>
<tr>
<td>$3.0 &lt; H \leq 4.0$ m</td>
<td>3.50</td>
<td>8.8</td>
<td>290.0</td>
<td>3.32</td>
</tr>
<tr>
<td>$3.0 &lt; H \leq 4.0$ m</td>
<td>3.55</td>
<td>8.8</td>
<td>268.8</td>
<td>2.92</td>
</tr>
</tbody>
</table>

*H*: significant wave height; *T*: significant wave period; Direction is the wave direction; *H*: wave height

3.7.4 Coastal Geology

Grabowski and Poort 1994 showed that the deposits of the Holocene and the Pleistocene in Gaza terrestrial area are approximately 160 m thick, covering the underlying Pliocene sediments. These deposits consist of marine kurkar formation, shell fragments and quartz sands cemented together. Calcareous sandstone is also found in some areas. It was found that the marine kurkar forms a good ground water aquifer where most of the groundwater of Gaza Strip is extracted from this layer. The thickness of the marine kurkar varies between 10 m and 100 m with a tendency thicker near the coast. The formation of the continental kurkar is varied from friable to very hard, depending on the degree of cementation. Alluvial and wind blown sand deposits are found on top of the (Pleistocene) kurkar formations reaching a thickness of 25 m.
According to (Grabowski and Poort, 1994) four types of alluvial deposits can be distinguished:

1. Sand dunes are oriented in the south near Rafah, mainly East-NorthEast (ENE) to West-SouthWest (WSW). The north dunes become sporadic with scattered sand in a zone of 2 to 3 km from the coast.
2. Wadi fillings consisting of sandy loess and gravel beds, which can reach a thickness of 10 to 20 m.
3. Alluvial and aeolian deposits of varying thickness. In the northern part from the Wadi Gaza alluvial deposits are widely distributed and are dominated by heavy, loamy clay.
4. Beach formation consisting of a fairly thin layer of sand and shell fragments.

3.7.5 Coast and Seabed Characteristics

Going from sea to land, the coastal profile can be divided into the seabed, the beach, the dune face or Kurkar (coarse sand) cliffs, and the adjacent body of the dune or cliff plateau. The coastal profile does not only consist of sand, but locally also erosion resistant formations of rock and Kurkar (coarse sand) protrude, on the seabed, on the beach, and in the cliffs (Sogreah, 1996).

On the beach and near the waterline of the Gaza shoreline on many places Kurkar (coarse sand) outcrops and rocky ridges can be seen. These hard ridges are important coastal features in that they form natural breakwaters which tend to mitigate an eroding trend. Where these hard layers are covered only by a relatively thin layer of sand, a retreating coastal profile will gradually consist of an increasing amount of erosion-resistant surface, as shown in Figure 2.7.

Defining the erodibility and composition of the steep Kurkar (coarse sand) cliffs along the Gaza coastline is another important challenge. These cliffs themselves are to an uncertain extent able to retard an erosion tendency. If they are attacked by waves and locally collapse, the eroded coarse sand (Kurkar) material will feed the beach with a mixture of very fine to very coarse sediment. The fines will soon be transported to deep water, whereas the coarse particles will act as an armour layer, protecting the freshly exposed coarse sand (Kurkar) cliff face during some time.
Coastal erosion is the removal of beach or dune sediments. The causes of erosion are many and varied and can be divided into natural and man-made causes as shown in Figure 2.8.

3.8.1 Natural Causes of Erosion

Changes in wave climate such as an increase in wave height, change in the angle of wave approach or increased frequency of high magnitude waves. These changes influence the amount of energy that affects the shoreline and can alter the main direction of sediment. Rising sea level may increase water levels at the coast and allow greater wave energy to erode the shore (Matar et al, 2012).
3.8.2 Man-made Causes of Erosion

A wide range of human activities can alter wave and tide processes, and the supply of sediment at the coast, thereby promoting erosion. The following summarize the human-induced causes for Gaza beach:

- The coast of Gaza was affected by manmade structures prior to the fishing port. In early 1972's two groins 120m long beach and 500m apart were built in Gaza city as shown in Figure 2.9 (Zviely and Klein, 2003). Sand accumulation occurred south of the southern groin. On the other hand, erosion took place north of the northern groin.

- The erosion was controlled by a series of nine detach breakwaters built in 1978. The detached breakwaters, 50-120m long, were built 50m from the coastline at a depth of 1m as shown in Figure 2.10 (Zviely and Klein, 2003).

- In 1994, the construction of fishery port was started by building the main breakwater of fishing port in between the two groins as shown in Figure 2.11 (Zviely and Klein, 2003).

- The detach breakwaters, were used in the construction of fishery port. The fishing port extended some 500m into the sea. The construction of the fishing port has caused an accumulation of sand at the southern fringe of the port.
Figure 3.9: The two groins built in 1972

Figure 3.10: The detacher breakwaters built in 1978

Figure 3.11: The Fishing Port built in 1994
CHAPTER 4: METHODOLOGY

4.1 Scope
In this chapter, methodology framework is described in details. Then data collection criteria is explained and justified. After that, image pre-processing of satellites imageries are illustrated. Next, supervised classification process is discussed. Finally, change detection analysis is described.

4.2 Methodology Framework
Figure 4.1 illustrates the methodology followed in this research which consists of nine major stages;

1. Problem identification and objectives.
2. Literature review.
3. Data collection and preparation: In this stage, data is collected based on criteria illustrated in data collection.
4. Pre-processing: aims to remove atmospheric effects. After that, removing black gaps if exist.
5. Supervised Classification.
7. Change detection analysis: In this stage, changes of the coast change area and rate of change, are analyzed.
8. Results and discussion.
9. Conclusion and recommendations.

In order to achieve this methodology, the following software and supporting tools are used:

- ERDAS Imagine 2014: Used for image pre-processing and supervised classification.
- ArcGIS 10.2: Used for shoreline extraction, spatio-temporal analysis, computed the enclosed areas between two shoreline and compute the rate of change using DSAS tool.
- MS Excel: Used for tables and chart representation.
Figure 4.1: The methodology followed in this research
4.3 Data Collection and Preparation

4.3.1 Data Collection

In this research, the data is mainly Landsat remotely sensed imageries downloaded from U.S. Geological Survey (USGS) website – Landsat archive from 1972 to 2012.

The first criterion in data collection is to download even-year imageries, the time between two image is not less than 4 year, including the oldest and newest Landsat archived imageries, 1972 and 2012. The second criterion is to give TM imagery a priority over ETM+ and/or MSS since TM sensor life span is longer than ETM+ (approx. 23 years) so consistent data will be collected. In contrast, Landsat ETM+ imageries have the problem of the Scan Line Corrector Failure (SLC-off) which presented in black gaps. Moreover, Landsat ETM+ has the only advantage of the panchromatic band existence. However, the resolution in the multispectral bands in ETM+ is the same of TM, 30 m.

The third criterion is reducing the pre-processing by downloading all imageries in the same date, month of September is chosen to avoid clouds in the scene. In case of September imagery does not match the listed criteria, the closest imagery to September matching the listed criteria will be downloaded. The fourth criterion is downloading a full-bands imagery in a Geostationary Earth Orbit Tagged Image File Format (GeoTIFF). In case of GeoTIFF does not available, the closest imagery to September matching the listed criteria will be downloaded. The fifth criterion is downloading free clouds scenes, at least above the study area. In case of cloud existence above the study area, the closest imagery to September matching the listed criteria will be downloaded. Based on these criteria, seven imageries are downloaded as illustrated in Table 4.1.

<table>
<thead>
<tr>
<th>Image Source</th>
<th>Date</th>
<th>Resolution (mxm)</th>
<th>Image Source</th>
<th>Date</th>
<th>Resolution (mxm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat1 MSS</td>
<td>22-10-1972</td>
<td>60 x 60</td>
<td>Landsat5 TM</td>
<td>25-05-2002</td>
<td>30 x 30</td>
</tr>
<tr>
<td>Landsat5 TM</td>
<td>24-05-1984</td>
<td>30 x 30</td>
<td>Landsat7 ETM+</td>
<td>26-09-2008</td>
<td>30 x 30</td>
</tr>
<tr>
<td>Landsat5 TM</td>
<td>14-09-1990</td>
<td>30 x 30</td>
<td>Landsat7 ETM+</td>
<td>18-09-2012</td>
<td>30 x 30</td>
</tr>
<tr>
<td>Landsat5 TM</td>
<td>22-10-1998</td>
<td>30 x 30</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.1: Satellite image source and resolution
4.3.2 Image Subset
A subset image was created from each image, which covers only the study area on each date (1972-2012) by using ERDAS Imagine 2014 as shown in Appendix A1-7.

4.3.3 Image Pre-Processing
Preprocessing of image data often will include radiometric correction, geometric correction and removing black gaps.

4.3.3.1 Geometric Correction
The images are projected to the Universal Transverse Mercator (UTM), with a spheroid and datum of WGS 84. Landsat images were geometrically certificated.

To correct the geometric distortions, one should apply two steps, geo-referencing and resampling using ArcGIS 10.2 or ERDAS 2014. After correcting the coordinate system, the spatial characteristics of pixels may be changed. So resampling should be applied to obtain a new image more pronounced in which all pixels are correctly positioned within the terrain coordinate system to more accurate feature extraction methods.

4.3.3.2 Radiometric Correction
Since digital sensors record the intensity of electromagnetic radiation from each spot viewed on the Earth’s surface as a Digital Number (DN) for each spectral band, the exact range of DN that a sensor utilizes depends on its radiometric resolution. For example, a sensor such as Landsat MSS measures radiation on a 0-63 DN scale even as Landsat TM and ETM+ measure it on a 0-255 scale (Green, et al., 2000). Radiometric correction involves the processing of digital images to improve the fidelity of the brightness value magnitudes. Any image contains radiometric errors and inconsistencies will be referred to as "noise" these errors should be corrected before the extraction and analysis of information from the image.

The sources of radiometric noise and therefore, the appropriate types of radiometric corrections, partially depend on the sensor and mode of imaging used to capture the digital image data such as satellite image, optical scanners, sensors and others.
Improvement quality of images which is used in satellite image acquired in 2002, radiometric noise reduction, is performed using ERDAS 2014 as shown in Figure 4.2.

**Figure 4.2:** Noise reduction of satellite image

### 4.3.3.3 Black Gaps Removing

Removing black gaps in ETM+ since Landsat 7 ETM+ downloaded imageries (2008 and 2012) are SLC-off data (contains black gaps, DN=0). This type of gaps has been minimized by taking two ETM+ scenes, radiometrically corrected, and then combines them for more complete coverage (USGS, 2008). Another model has been built by the researcher to do this kind of correction in order to make it easier and less time consuming sense this correction will be run for tow imageries (2008 and 2012) each consists of several bands.

Figure 4.3 represents the model which consist two inputs (a band from each year) and one output; the merged image. The process concept of this model as illustrated in (USGS, 2008) is as follows: Where band N in image 1 > 0, use band N in image 1 data,
Otherwise, use band N in image 2. In other words, Image 2 data will fill the gaps in Image 1. Black gap removing of satellite image acquired in 2008 shown in Figure 4.4.

**Figure 4.3:** Black gaps removing model

**Figure 4.4:** Black gap removing of satellite image
4.4 Supervised Classification

In this research, supervised classification is used since the Areas of Interest (AOI) are known and clear to be distinguished (the water and land), so the spectral signatures of the sea body and the land are developed and then the software assigns each pixel in the image to the type to which its signature is most similar. Figure 4.5 summarizes the steps performed for supervised classification.

![Figure 4.5: Steps for supervised classification](image)

In order to classify the images based on these signature files. Each pixel in the study area has a value in each of the Blue, Green, Red, Near Infrared, Middle Infrared, Thermal Infrared and another Middle Infrared bands. The pixel is then assigned to the type that has the most similar signature.

In term of evaluation how similar signatures are to each other, there are several different statistical techniques that can be used; minimum distance, maximum likelihood classifier and parallelepiped classifier. In this research the Maximum Likelihood method is used since Jesús D. Chinea (2006) recommends that if your training sites are well defined as in the coast Area the Maximum Likelihood classifier should produce the best results. However, when training sites are not well defined, the Minimum Distance classifier with the standardized distances option often performs much better.

In the maximum likelihood classifier, the distribution of reflectance values in a training site is described by a probability density function, developed on the basis of Bayesian statistics. This classifier evaluates the probability that a given pixel will belong to a category and classifies the pixel to the category with the highest probability of membership (Jesús D. Chinea, 2006).
Figure 4.6 represents the image supervised classification process which begins with identifying Area of Interests (AOI) as shown in Figure 4-6-a. Figure 4-6-b illustrates the resulted supervised classification; dark blue represents the water while dark brown represents the land. Figure 4-6-c is the classified image in a vector format exported to ArcGIS software to start change analysis process.

| Area of Interest (AOI), Supervised classification results, Vectorized classified image |
|---|---|
| (a) | (b) |
| ![](image1.png) | ![](image2.png) |
| (c) |  |
| ![](image3.png) | a) Area of Interest (AOI)  
|  | b) Supervised classification results  
|  | c) Vectorized classified image |

**Figure 4.6:** Supervised classification and vectorization
4.5 Shoreline Extraction
All most ArcGis 10.2 can extract the shoreline by using Arc Toolbox to convert the polygon feature to line feature as shown in Figure 4.7, then the user should use editor toolbar to remove the edge lines as shown in Figure 4.8, the remaining line which separate two classify cluster represent shoreline. Finally user should repeat these step to extract all shoreline Figure 4.9 show Gaza Strip shorelines from 1972-2012.

Figure 4.7: Convert polygon feature to line feature

Figure 4.8: Extraction of shoreline
Figure 4.9: Gaza Strip shorelines from 1972-2012
4.6 Change Detection Analysis

In this stage, area and change rate detection analyses are done using ArcGIS tools.

4.6.1 Area Variation

In order to calculate the change in areas between different dates, the ArcGIS tools were used. First, two different shorelines (line feature) should be appended in one feature class by using Arc Toolbox as shown in Figure 4.10. Then, by using Arc Toolbox to convert feature to polygon to detect the change in areas. Figure 4.11 illustrates the change in areas between 2002-2008.

![Figure 4.10: Append two different shoreline](image)

![Figure 4.11: Change in Areas between 2002-2008](image)
4.6.2 Shoreline Change Rate Computation

In order to calculate the rate of change along Gaza coastal zone, the Digital Shoreline Analysis System (DSAS) version 4 was used. DSAS is an ESRI Arc-GIS extension that enables users to calculate shoreline rate of change statistics from a time series of Multiple shoreline positions.

DSAS works by generating orthogonal transects at a user-defined separation and then calculates rate-of-change and associated statistics that are reported in an attribute table.

The DSAS tool requires different shorelines and baseline. The baseline is created by the user and serves as the starting point for generating. The DSAS extension generates transects that are cast perpendicular to the baseline at a user-specified spacing alongshore. The transect intersections are used by the program to calculate the rate of change statistics. Figure 4.12 illustrate the steps necessary to establish transect locations and compute change-rate statistics by using the DSAS application (Himmelstoss, 2009).

So all DSAS input data must be managed within a personal geodatabase, which includes all the baseline created for study area and shorelines for 1972, 1984, 1990, 1998, 2002, 2008, and 2012. Totally 794 transects were generated with 50 m spacing and the length of transects was 300 m as shown in Figure 4.13.

The End Point Rate (EPR) is calculated by determining the distance between the oldest and most recent shoreline in the data and dividing it by the number of years between them. The main advantages of the EPR approach are the simplicity of computation and its widespread application and provides an accurate net rate of change over the long term. But the major disadvantage is the EPR is not able to manage information about shoreline behavior provided by additional shoreline in cases where more than two shorelines are available and this method does not use the intervening shorelines so it may not account for changes in accretion or erosion rates that may occur through time. All the images were taken at the same month to reduce the effect of seasonal variation, tide effects are considered to be negligible in this study.
Figure 4.12: Transect locations and change-rate using the DSAS
Figure 4.13: Transects cast by DSAS software
CHAPTER 5: RESULTS AND DISCUSSION

5.1 Scope

This chapter contains a detailed description of the steps of the methodology of the research and illustrates the results of the detected changes in areas and rate of change of the Gaza Strip coast over time.

5.2 Introduction

The shoreline in the study area has never been constant and shows a continuous changing pattern. Both the spatial and temporal variations in the deposition and accretion have been observed in the study area. The temporal intervals (being 1972 to 1984, 1984 to 1990, 1990 to 1998, 1998 to 2002, 2002 to 2008 and 2008 to 2012) used in the study for assessing the changes have not been uniform. Based on the results, Gaza Strip coastal zone could be classified into seven regions according to the rate of change and governorates; such as: A) Rafah 2.4 km B) khan Younis 10.4 km C) Southern of middle governorate 8 km D) El-Wadi region 2.4 km E) southern Sea port 6.4 km, F) northern sea port 3 km, and G) north Gaza governorate 6.2 km, as shown in Figure 5.1.

The analysis of historical shoreline displacement is the understanding of the past, in order to associate it with the present, and make forecasts about future shoreline positions.
Figure 5.1: Gaza coastal zone classification
5.3 Area Change Analysis

Using GIS tools, the area enclosed between periods intervals (six intervals) is counted. Then The calculation results are listed in Tables and are shown graphically in Figures, with negative values representing erosion (recession) and positive values indicating accretion(advanced). During relatively stable periods, the advance or retreat areas were small, and their values similar.

5.3.1 Region A (Rafah Governorate)

The coastal region analyzed extends from the borders of Egypt to the intersection between Rafah and Khan Younis Governorate. The amount of erosion and accretion rate are listed in Table 5.1 and are shown graphically in Figure 5.2.

<table>
<thead>
<tr>
<th>Image Period</th>
<th>Erosion</th>
<th>Accretion</th>
<th>Net of Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total $x 10^3$ $[m^2]$</td>
<td>Rate $x 10^3$ $[m^2/ year]$</td>
<td>Total $x 10^3$ $[m^2]$</td>
</tr>
<tr>
<td>1972-1984</td>
<td>-0.29</td>
<td>-0.02</td>
<td>48.5</td>
</tr>
<tr>
<td>1984-1990</td>
<td>-2.40</td>
<td>-0.40</td>
<td>16.30</td>
</tr>
<tr>
<td>1990-1998</td>
<td>-5.30</td>
<td>-0.66</td>
<td>14.80</td>
</tr>
<tr>
<td>1998-2002</td>
<td>-2.60</td>
<td>-0.65</td>
<td>14.20</td>
</tr>
<tr>
<td>2002-2008</td>
<td>-2.00</td>
<td>-0.33</td>
<td>25</td>
</tr>
<tr>
<td>2008-2012</td>
<td>-5.20</td>
<td>-1.30</td>
<td>0.60</td>
</tr>
<tr>
<td>Total</td>
<td>-17.79</td>
<td>-0.43</td>
<td>119</td>
</tr>
</tbody>
</table>

Note: (+) sign indicates accretion, (-) sign indicates Erosion

There is not a consistent pattern, it is evident that in this sector accretion processes are dominant during the first five periods, the total area gain to accretion is larger than the total area loss to erosion. Except in a time at 2008 to 2012 the erosion appears larger than the accretion. This could be attributed due to human intervention in the Egyptian side such as groins. A large trend in the ratio between eroded and accreted area, which is vary over the time. Erosion is growing during these periods.
In general Rafah coastal area is being exposed to increase in the coastal areas at a rate of 2,540 m$^2$/year.

![Figure 5.2: Average change rate for region A](image)

**Figure 5.2**: Average change rate for region A

### 5.3.2 Region B (Khan-Younis Governorate)

The coastal region analyzed extends from Rafah and Khan Younis Governorate. The amount of erosion and accretion rate are listed in Table 5.2 and are shown graphically in Figure 5.3.

**Table 5.2**: The amount of erosion and accretion for region (B)

<table>
<thead>
<tr>
<th>Image period</th>
<th>Erosion</th>
<th>Accretion</th>
<th>Net of Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total x 10$^3$ [m$^2$]</td>
<td>Rate x 10$^3$ [m$^2$/year]</td>
<td>Total x 10$^3$ [m$^2$]</td>
</tr>
<tr>
<td>1972-1984</td>
<td>-1.50</td>
<td>-0.13</td>
<td>178.08</td>
</tr>
<tr>
<td>1984-1990</td>
<td>-26.80</td>
<td>-4.47</td>
<td>58.00</td>
</tr>
<tr>
<td>1990-1998</td>
<td>-36.30</td>
<td>-4.54</td>
<td>51.15</td>
</tr>
<tr>
<td>1998-2002</td>
<td>-31.70</td>
<td>-7.93</td>
<td>35.30</td>
</tr>
<tr>
<td>2002-2008</td>
<td>-48.60</td>
<td>-8.10</td>
<td>82.20</td>
</tr>
<tr>
<td>2008-2012</td>
<td>-60.10</td>
<td>-15.03</td>
<td>12.70</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>-205.00</td>
<td>-5.13</td>
<td>417.43</td>
</tr>
</tbody>
</table>

*Note: (+) sign indicates accretion, (-) sign indicates Erosion*
In some interval of time there is roughly balance between erosion and accretion, also in the first five region accretion is large than erosion, Except the period between 2008 to 2012. During the whole study period, the portion of this sector that exposed to the highest amount of accretion with a rate of 5,310 m$^2$/year.

![Average Change in Area (10$^3$ m$^2$/year)](image)

**Figure 5.3:** Average change rate for region (B)

### 5.3.3 Region C (Southern of Middle Governorate)

This region is located to the north of Khan Younis and south Gaza El-wadi. The amount of erosion and accretion rate are listed in Table 5.3 and are shown graphically in Figure 5.4.

**Table 5.3:** The amount of erosion and accretion for region (C)

<table>
<thead>
<tr>
<th>Image period</th>
<th>Erosion</th>
<th>Accretion</th>
<th>Net of Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total x 10$^3$ [m$^2$]</td>
<td>Rate x 10$^3$ [m$^2$/ year]</td>
<td>Total x 10$^3$ [m$^2$]</td>
</tr>
<tr>
<td>1972-1984</td>
<td>-0.94</td>
<td>-0.08</td>
<td>175</td>
</tr>
<tr>
<td>1990-1998</td>
<td>-20.90</td>
<td>-2.61</td>
<td>62.00</td>
</tr>
<tr>
<td>1998-2002</td>
<td>-31.00</td>
<td>-7.75</td>
<td>34.00</td>
</tr>
<tr>
<td>2002-2008</td>
<td>-20.00</td>
<td>-3.33</td>
<td>105.20</td>
</tr>
<tr>
<td>2008-2012</td>
<td>-57.00</td>
<td>-14.25</td>
<td>10.56</td>
</tr>
<tr>
<td>Total</td>
<td>-143.34</td>
<td>-3.58</td>
<td>425.66</td>
</tr>
</tbody>
</table>

Note: (+) sign indicates accretion, (-) sign indicates Erosion
In the first five intervals the accretion is larger than the erosion. Except the last interval between 2008-2012 is exposed to erosion larger than accretion. During the whole study period, the portion of this sector that exposed to the highest amount of accretion with a rate of 7,000 m$^2$/year.

5.3.4 Region D (El-Wadi)

This region is located in the north of the Middle and Gaza governorates. The amount of erosion and accretion rate are listed in Table 5.4 and are shown graphically in Figure 5.5.

**Table 5.4:** The amount of erosion and accretion for region (D)

<table>
<thead>
<tr>
<th>Image period</th>
<th>Erosion</th>
<th>Accretion</th>
<th>Net of Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total x $10^3$ [m$^2$]</td>
<td>Rate x $10^3$ [m$^2$/year]</td>
<td>Total x $10^3$ [m$^2$]</td>
</tr>
<tr>
<td>1972-1984</td>
<td>-21.00</td>
<td>-1.75</td>
<td>5.6</td>
</tr>
<tr>
<td>1984-1990</td>
<td>-35.00</td>
<td>-5.83</td>
<td>1.00</td>
</tr>
<tr>
<td>1990-1998</td>
<td>-23.44</td>
<td>-2.93</td>
<td>2.00</td>
</tr>
<tr>
<td>1998-2002</td>
<td>-21.90</td>
<td>-5.48</td>
<td>0.64</td>
</tr>
<tr>
<td>2002-2008</td>
<td>-0.45</td>
<td>-0.08</td>
<td>26.40</td>
</tr>
<tr>
<td>2008-2012</td>
<td>-19.80</td>
<td>-4.95</td>
<td>1.20</td>
</tr>
<tr>
<td>Total</td>
<td>-121.59</td>
<td>-3.04</td>
<td>36.84</td>
</tr>
</tbody>
</table>

Note: (+) sign indicates accretion, (-) sign indicates Erosion
The results show negative rates in general, which means that erosion was the predominant process. Except the intervals 2002 to 2008 which show positive rates. The main causes of erosion in this region due to Gaza valley (Gaza-Wadi). In general El-Wadi region is being exposed to decrease in the coastal areas at a rate of 2,120 m$^2$/year.

### 5.3.5 Region E (Southern Sea Port)

This region is located to the north of El-Wadi region to the south side of Gaza sea port. The amount of erosion and accretion rate are listed in Table 5.5 and are shown graphically in Figure 5.6.

**Table 5.5: The amount of erosion and accretion for region (E)**

<table>
<thead>
<tr>
<th>Image Period</th>
<th>Erosion</th>
<th>Accretion</th>
<th>Net of Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total x 10$^3$ [m$^2$]</td>
<td>Rate x 10$^3$ [m$^2$/year]</td>
<td>Total x 10$^3$ [m$^2$]</td>
</tr>
<tr>
<td>1972-1984</td>
<td>-0.10</td>
<td>-0.01</td>
<td>220</td>
</tr>
<tr>
<td>1984-1990</td>
<td>-12.50</td>
<td>-2.08</td>
<td>36.12</td>
</tr>
<tr>
<td>1990-1998</td>
<td>-16.00</td>
<td>-2.00</td>
<td>77.00</td>
</tr>
<tr>
<td>1998-2002</td>
<td>-2.20</td>
<td>-0.55</td>
<td>81.50</td>
</tr>
<tr>
<td>2002-2008</td>
<td>-5.30</td>
<td>-0.88</td>
<td>158.70</td>
</tr>
<tr>
<td>2008-2012</td>
<td>-5.70</td>
<td>-1.43</td>
<td>66.00</td>
</tr>
<tr>
<td>Total</td>
<td>-41.80</td>
<td>-1.04</td>
<td>639.32</td>
</tr>
</tbody>
</table>

Note: (+) sign indicates accretion, (-) sign indicates Erosion
It is evident that in this region accretion processes are dominant during the whole periods, the total area gain to accretion is the largest where the erosion process is very small. This could be attributed due to human activities such as: groins which built at the early of seventy and Gaza sea port which completely constructed in 1998. These structures have interrupted the prevailing north-ward flowing alongshore current; consequently, its load of sediment has been deposited south of the structures. In general this region is being exposed to increase in the coastal areas at a rate of 14,940 m²/year.

The results have proved again the expectation of previous studies, where the positive rate have appeared in the southern side of the Gaza sea port.

5.3.6 Region F (Northern Sea Port)

This region extends from the north side of Gaza sea port to the North Governorate. The amount of erosion and accretion rate are listed in Table 5.6 and are shown graphically in Figure 5.7.
Table 5.6: The amount of erosion and accretion for region (F)

<table>
<thead>
<tr>
<th>Image Period</th>
<th>Erosion</th>
<th>Accretion</th>
<th>Net of Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total x 10³ [m²]</td>
<td>Rate x 10³ [m² / year]</td>
<td>Total x 10³ [m²]</td>
</tr>
<tr>
<td>1972-1984</td>
<td>-196.00</td>
<td>-16.33</td>
<td>----</td>
</tr>
<tr>
<td>1984-1990</td>
<td>-18.00</td>
<td>-3.00</td>
<td>4.50</td>
</tr>
<tr>
<td>1990-1998</td>
<td>-35.60</td>
<td>-4.45</td>
<td>2.00</td>
</tr>
<tr>
<td>1998-2002</td>
<td>-38.00</td>
<td>-9.50</td>
<td>10.00</td>
</tr>
<tr>
<td>2002-2008</td>
<td>-71.60</td>
<td>-11.93</td>
<td>0.50</td>
</tr>
<tr>
<td>2008-2012</td>
<td>-57.98</td>
<td>-14.50</td>
<td>18.00</td>
</tr>
<tr>
<td>Total</td>
<td>-417.18</td>
<td>-10.43</td>
<td>35.00</td>
</tr>
</tbody>
</table>

Note: (+) sign indicates accretion, (-) sign indicates Erosion

Figure 5.7: Average change rate for region (F)

The results show negative rates in general, which means that erosion was the predominant process this region. Gaza Sea port caused a serious damage to the northern beach especially after removing the nine detached breakwaters. The study show that the erosion is growing during this periods, and these pattern of change will treat the public and private property. This study show the average rate of erosion about 9,550 m²/y.
The results have proved again the expectation of previous studies, where the negative rate have appeared in the northern side of the coastal zone

### 5.3.7 Region G (North Governorate)

This region is located from the north side of Gaza governorate to the northern border of Gaza strip. The amount of erosion and accretion rate are listed in Table 5.7 and are shown graphically in Figure 5.8.

**Table 5.7:** The amount of erosion and accretion for region (G)

<table>
<thead>
<tr>
<th>Image Period</th>
<th>Erosion</th>
<th>Accretion</th>
<th>Net of Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total x 10³ [m²]</td>
<td>Rate x 10³ [m² / year]</td>
<td>Total x 10³ [m²]</td>
</tr>
<tr>
<td>1972-1984</td>
<td>-75.50</td>
<td>-6.29</td>
<td>3.6</td>
</tr>
<tr>
<td>1984-1990</td>
<td>-28.00</td>
<td>-4.67</td>
<td>5.10</td>
</tr>
<tr>
<td>1990-1998</td>
<td>-40.00</td>
<td>-5.00</td>
<td>8.00</td>
</tr>
<tr>
<td>1998-2002</td>
<td>-35.00</td>
<td>-8.75</td>
<td>16.00</td>
</tr>
<tr>
<td>2002-2008</td>
<td>-31.20</td>
<td>-5.20</td>
<td>10.23</td>
</tr>
<tr>
<td>2008-2012</td>
<td>-34.23</td>
<td>-8.56</td>
<td>24.32</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>-243.93</td>
<td>-6.10</td>
<td>67.25</td>
</tr>
</tbody>
</table>

Note: (+) sign indicates accretion, (-) sign indicates Erosion

![Figure 5.8: Average change rate for region (G)](image-url)
The results show negative rates in general, where total accretion is considerably less with respect to erosion. This pattern of erosion and accretion indicates that the equilibrium between erosional and accretional processes in this spatial unit is towards negative. This study shows the average rate of erosion that is about 4,420 m$^2$/y.

5.4 Shoreline Change Rate Analysis

Shoreline change rates have been calculated using DSAS software with statistical EPR technique.

The rate calculation results are listed according to study area as follow:

5.4.1 Region A (Rafah Governorate)

DSAS generates 47 transect from 1-47 that are oriented perpendiculars to the baseline at 50 m spacing along the distance of 2.4 km length, from the conjunction of the borders of Egypt and Rafah governorate: along the coastal line of Rafah Governorate.

The result obtained is shown in Table 5.8.

<table>
<thead>
<tr>
<th>Image period</th>
<th>Transect</th>
<th>Erosion</th>
<th>Accretion</th>
<th>Net Average (m/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Avg (m/y)</td>
<td>Max (m/y)</td>
<td>Avg (m/y)</td>
</tr>
<tr>
<td>1972-1984</td>
<td>1 - 47</td>
<td>-0.08</td>
<td>-0.12</td>
<td>2.35</td>
</tr>
<tr>
<td>1984-1990</td>
<td>1 - 47</td>
<td>-0.542</td>
<td>-3.19</td>
<td>1.61</td>
</tr>
<tr>
<td>1990-1998</td>
<td>1 - 47</td>
<td>-0.60</td>
<td>-2.90</td>
<td>1.57</td>
</tr>
<tr>
<td>1998-2002</td>
<td>1 - 47</td>
<td>-2.90</td>
<td>-4.75</td>
<td>1.92</td>
</tr>
<tr>
<td>2002-2008</td>
<td>1 - 47</td>
<td>-2.18</td>
<td>-3.73</td>
<td>2.35</td>
</tr>
<tr>
<td>2008-2012</td>
<td>1 - 47</td>
<td>-2.25</td>
<td>-10.00</td>
<td>0.24</td>
</tr>
</tbody>
</table>

Average change from 1972-2012 0.91

Note: (+) sign indicates accretion, (-) sign indicates erosion
Figure 5.9: Shoreline Change between 1972-2012 in region (A)

5.4.2 Region B (Khan-Younis Governorate)

DSAS generates 209 transect from 48-256 that are oriented perpendicularly to the baseline at 50 m spacing along 10.4 km length of Khan Younis governorate. This is the coastal line of Khan Younis Governorate.
The result obtained is shown in Table 5.9.

Table 5.9: Shoreline change rate for Region (B)

<table>
<thead>
<tr>
<th>Image period</th>
<th>Transect</th>
<th>Erosion</th>
<th>Accretion</th>
<th>Net Average (m/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Avg (m/y)</td>
<td>Max(m/y)</td>
<td>Avg (m/y)</td>
</tr>
<tr>
<td>1972-1984</td>
<td>48 - 256</td>
<td>-0.17</td>
<td>-0.85</td>
<td>2.30</td>
</tr>
<tr>
<td>1984-1990</td>
<td>48 - 256</td>
<td>-1.14</td>
<td>-3.56</td>
<td>1.30</td>
</tr>
<tr>
<td>1990-1998</td>
<td>48 - 256</td>
<td>-0.71</td>
<td>-3.90</td>
<td>1.50</td>
</tr>
<tr>
<td>1998-2002</td>
<td>48 - 256</td>
<td>-3.00</td>
<td>-6.90</td>
<td>1.32</td>
</tr>
<tr>
<td>2002-2008</td>
<td>48 - 256</td>
<td>-0.40</td>
<td>-1.23</td>
<td>2.67</td>
</tr>
<tr>
<td>2008-2012</td>
<td>48 - 256</td>
<td>-2.15</td>
<td>-6.40</td>
<td>0.63</td>
</tr>
</tbody>
</table>

Average Change from 1972-2012: 0.69

Note: (+) sign indicates accretion, (-) sign indicates Erosion

5.4.3 Region C (Southern of Middle Governorate)

DSAS generates 159 transect from 257-415 that are oriented perpendicularly to the baseline at 50 m spacing along 8 km length of South of the Middle Governorate. The result obtained is shown in table 5.10.

Table 5.10: Shoreline change rate for Region (C)

<table>
<thead>
<tr>
<th>Image period</th>
<th>Transect</th>
<th>Erosion</th>
<th>Accretion</th>
<th>Net Average (m/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Avg (m/y)</td>
<td>Max(m/y)</td>
<td>Avg (m/y)</td>
</tr>
<tr>
<td>1972-1984</td>
<td>257-415</td>
<td>-0.12</td>
<td>-0.73</td>
<td>2.73</td>
</tr>
<tr>
<td>1984-1990</td>
<td>257-415</td>
<td>-0.83</td>
<td>-3.5</td>
<td>1.16</td>
</tr>
<tr>
<td>1990-1998</td>
<td>257-415</td>
<td>-0.56</td>
<td>-2.70</td>
<td>1.78</td>
</tr>
<tr>
<td>1998-2002</td>
<td>257-415</td>
<td>-2.50</td>
<td>-7.00</td>
<td>2.00</td>
</tr>
<tr>
<td>2002-2008</td>
<td>257-415</td>
<td>-0.90</td>
<td>-3.45</td>
<td>2.80</td>
</tr>
<tr>
<td>2008-2012</td>
<td>257-415</td>
<td>-3.30</td>
<td>9.80</td>
<td>0.98</td>
</tr>
</tbody>
</table>

Average Change from 1972-2012: 0.71

Note: (+) sign indicates accretion, (-) sign indicates Erosion
5.4.4 Region D (El-Wadi)

DSAS generates 48 transect from 416-463 that are oriented perpendicularly to the baseline at 50 m spacing along 2.4 km. This study area is divided between the Middle and Gaza Governorates. The result obtained is shown in Table 5.11.

**Table 5.11:** Shoreline change rate for Region (D)

<table>
<thead>
<tr>
<th>Image period</th>
<th>Transect</th>
<th>Erosion</th>
<th>Accretion</th>
<th>Net Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Avg (m/y)</td>
<td>Max (m/y)</td>
<td>Avg (m/y)</td>
</tr>
<tr>
<td>1972-1984</td>
<td>416-463</td>
<td>-1.30</td>
<td>-3.50</td>
<td>1.00</td>
</tr>
<tr>
<td>1984-1990</td>
<td>416-463</td>
<td>-3</td>
<td>-4.5</td>
<td>0.30</td>
</tr>
<tr>
<td>1990-1998</td>
<td>416-463</td>
<td>-1.75</td>
<td>-5.20</td>
<td>0.50</td>
</tr>
<tr>
<td>1998-2002</td>
<td>416-463</td>
<td>-3.60</td>
<td>-8.36</td>
<td>0.50</td>
</tr>
<tr>
<td>2002-2008</td>
<td>416-463</td>
<td>-0.45</td>
<td>-7.00</td>
<td>2.20</td>
</tr>
<tr>
<td>2008-2012</td>
<td>416-463</td>
<td>-2.40</td>
<td>-6.18</td>
<td>1.00</td>
</tr>
</tbody>
</table>

**Average Change from 1972-2012**

-1.23

Note: (+) sign indicates accretion, (-) sign indicates Erosion

5.4.5 Region E (Southern Sea Port)

DSAS generates 133 transect from 464-596 that are oriented perpendicularly to the baseline at 50 m spacing along 6.4 km. This study area is located at the south of the Gaza sea port. The result obtained is shown in Table 5.12.

**Table 5.12:** Shoreline change rate for Region (E)

<table>
<thead>
<tr>
<th>Image period</th>
<th>Transect</th>
<th>Erosion</th>
<th>Accretion</th>
<th>Net Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Avg (m/y)</td>
<td>Max (m/y)</td>
<td>Avg (m/y)</td>
</tr>
<tr>
<td>1972-1984</td>
<td>464-596</td>
<td>----</td>
<td>----</td>
<td>3.70</td>
</tr>
<tr>
<td>1984-1990</td>
<td>464-596</td>
<td>-0.9</td>
<td>-2.1</td>
<td>1.20</td>
</tr>
<tr>
<td>1990-1998</td>
<td>464-596</td>
<td>-0.30</td>
<td>-2.30</td>
<td>2.10</td>
</tr>
<tr>
<td>1998-2002</td>
<td>464-596</td>
<td>-1.14</td>
<td>-2.30</td>
<td>3.00</td>
</tr>
<tr>
<td>2002-2008</td>
<td>464-596</td>
<td>-0.97</td>
<td>-2.88</td>
<td>4.16</td>
</tr>
</tbody>
</table>

**Average Change from 1972-2012**

2.20

Note: (+) sign indicates accretion, (-) sign indicates Erosion
5.4.6 Region F (Northern Sea Port)

DSAS generates 61 transect from 610-670 that are oriented perpendicularly to the baseline at 50 m spacing along 3 km. This study area is located at the north of the Gaza sea port. The result obtained is shown in Table 5.13.

Table 5.13: Shoreline change rate for Region (F)

<table>
<thead>
<tr>
<th>Image period</th>
<th>Transect</th>
<th>Erosion Avg (m/y)</th>
<th>Erosion Max (m/y)</th>
<th>Accretion Avg (m/y)</th>
<th>Accretion Max (m/y)</th>
<th>Net Average (m/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972-1984</td>
<td>610-670</td>
<td>-2.80</td>
<td>-5.60</td>
<td>----</td>
<td>----</td>
<td>-2.80</td>
</tr>
<tr>
<td>1984-1990</td>
<td>610-670</td>
<td>-0.65</td>
<td>-3.5</td>
<td>0.55</td>
<td>2.50</td>
<td>-1.20</td>
</tr>
<tr>
<td>1990-1998</td>
<td>610-670</td>
<td>-1.80</td>
<td>-4.30</td>
<td>----</td>
<td>----</td>
<td>-1.80</td>
</tr>
<tr>
<td>1998-2002</td>
<td>610-670</td>
<td>-2.80</td>
<td>-7.30</td>
<td>0.73</td>
<td>2.30</td>
<td>-1.87</td>
</tr>
<tr>
<td>2002-2008</td>
<td>610-670</td>
<td>-3.80</td>
<td>-7.80</td>
<td>0.50</td>
<td>2.02</td>
<td>-3.20</td>
</tr>
<tr>
<td>2008-2012</td>
<td>610-670</td>
<td>-3.20</td>
<td>-5.70</td>
<td>1.90</td>
<td>4.70</td>
<td>-2.40</td>
</tr>
<tr>
<td>Average Change from 1972-2012</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-2.21</td>
</tr>
</tbody>
</table>

Note: (+) sign indicates accretion, (-) sign indicates erosion.

5.4.7 Region G (North of Gaza)

DSAS generates 124 transect from 671-794 that are oriented perpendicularly to the baseline at 50 m spacing along 6.2 km: along the coastal line of North Governorate. The result obtained is shown in Table 5.14.

Table 5.14: Shoreline change rate for Region (G)

<table>
<thead>
<tr>
<th>Image period</th>
<th>Transect</th>
<th>Erosion Avg (m/y)</th>
<th>Erosion Max (m/y)</th>
<th>Accretion Avg (m/y)</th>
<th>Accretion Max (m/y)</th>
<th>Net Average (m/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1972-1984</td>
<td>671-794</td>
<td>-2.30</td>
<td>-4.70</td>
<td>0.63</td>
<td>1.87</td>
<td>-1.80</td>
</tr>
<tr>
<td>1984-1990</td>
<td>671-794</td>
<td>-1.4</td>
<td>-4.3</td>
<td>0.45</td>
<td>2.20</td>
<td>-0.62</td>
</tr>
<tr>
<td>1990-1998</td>
<td>671-794</td>
<td>-1.64</td>
<td>-3.25</td>
<td>0.40</td>
<td>1.86</td>
<td>-0.86</td>
</tr>
<tr>
<td>1998-2002</td>
<td>671-794</td>
<td>-2.20</td>
<td>-6.60</td>
<td>1.85</td>
<td>4.70</td>
<td>-1.30</td>
</tr>
<tr>
<td>2002-2008</td>
<td>671-794</td>
<td>-2.80</td>
<td>-6.70</td>
<td>0.30</td>
<td>0.80</td>
<td>-2.60</td>
</tr>
<tr>
<td>2008-2012</td>
<td>671-794</td>
<td>-2.90</td>
<td>-8.80</td>
<td>0.98</td>
<td>3.50</td>
<td>-1.76</td>
</tr>
<tr>
<td>Average Change from 1972-2012</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-1.49</td>
</tr>
</tbody>
</table>

Note: (+) sign indicates accretion, (-) sign indicates erosion.
The results which obtained above presented graphically in the following Figures from 5.10 to 5.15:

**Figure 5.10:** Annual shoreline change rate 1972-1984

**Figure 5.11:** Annual shoreline change rate 1984-1990

**Figure 5.12:** Annual shoreline change rate 1990-1998
From the Figures 5.10 to 5.15 the results are explained as follows:
For regions A, B, C they exposed to accretion in the first five periods, but the last periods the erosion is being large this is attributed to human activities especially the groins which the Egyptian governorate build near to the Rafah borders.

Region D is expose to erosion in a whole periods of time, this unbalance due to the influence of Gaza Valley.

Most substantial changes have been observed in the south side of Gaza sea port which obtained positive rate, where Gaza seaport interrupts the natural movement of the sediments along the coast.

Finally the region F,G , are expose to a serious problem of erosion especially the beach camp.
CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Analysis of satellite Landsat images for the Mediterranean coast of Gaza strip for the years from 1972 to 2012 have indicated shoreline changes in response to erosion and accretion patterns. Based on the results, Gaza coastal zone could be classified into seven regions according to the rate of change and governorates.

In this research seven satellite imageries (MSS, TM and +ETM Landsat) are collected from 1972 to 2012. First all satellite images are radiometrically and atmospherically Corrected using ERDAS Imagine 2014. Geographic Information system and Remote Sensing techniques are used for spatio-temporal analysis in order to detect changes in the shoreline position and the change in the coast areas. The analyses identified the erosion and accretion patterns along the Gaza strip coast.

The results indicate that the regions A, B, C they expose to accretion in the first five periods, but the last periods the erosion is being large, the region D is expose to erosion in a whole periods of time 1972-2012, the average annual erosion rates and rate of change from 1972 to 2012 were 2,120 m² and 1.23 m, respectively. Most substantial changes have been observed in the south side of Gaza sea port (region E) which obtained positive annual rate 14,940 m² and change rate about 2.2 m. Region F expose to a serious problem of erosion. The annual erosion rates is about 9,550 m² and 2.2m. Finally region G also expose to erosion patterns.

6.2 Recommendations

The study is greatly depends on the accuracy of environmental data and this leads to uncertainty of the results from quantitative point of view. Therefore the following recommendations should be taken into consideration for future study to enhance the results:

- Supporting researches and projects in this field from Palestinian universities.
- Utilization of the result of this research in order to find strategies and solutions to keep Gaza shoreline “alive”.

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The stockholders should make periodic check on the critical region such as the north of Gaza sea port and the south governorate of Gaza Strip which face a serious problem.

Protect northern beach of Gaza city and Rafah which expose to a real threat and could form a serious problem to structures which are near the beach such as: Roads, restaurants, mosque and hotels.

Field measurements of wave characteristics should be carried out, which is greatly affect the morphodynamic for Gaza coastal waters.

Bathometric survey should be carried out in regular basis to quantify morphologic changes.

Recent satellite images are required to monitor the temporal shoreline changes.

To make the analysis more accurate, future studies should also consider tide data, and data should be collected more frequently so that the change in the shoreline can be observed more clearly.

Further studies will be carried out in order to calculate the volumetric change in the southern side of Gaza sea port.

Using overlay analysis by using GIS environment to estimate the rate of shoreline changes.

The study on the impact of marine tongue on the Egyptian border to the Gaza Strip at the Rafah beach.
REFERENCES

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Kumaravel, S. Ramkumar, T. Gurunamam, B. Suresh, M. and Dharanirajanm, K., 2013 An application of remote sensing and GIS based shoreline change studies – A case study in the cuddalore district, east coast of Tamilnadu, South India. International journal of innovative technology and exploring Engineering (IJITEE) ISSN: 2278-3075, Volume-2, Issue-4


https://en.wikipedia.org/wiki/Longshore_drift
Figure A1: Subset for 1972
Figure A2: Subset for 1984
Figure A3: Subset for 1990
Figure A4: Subset for 1998
Figure A5: Subset for 2002
Figure A6: Subset for 2008
Figure A7: Subset for 2012

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