

Monitoring the Environmental Changes on Coasts and Islands in State of Kuwait

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Abstract- The development and life style system have exploited the coast more rather than the interior offshore land of Kuwait. The objective of this study includes review of the methods used in mapping and monitoring the spatial and temporal environmental changes that took place along the coastline of the State of Kuwait by using RS (Remote Sensing) and GIS (Geographical Information System) techniques. This is in addition to providing an accurate estimation of the areas where erosion and deposition processes have taken place. For that purpose, multi-temporal Landsat data collected in 1990, 2000, 2010 and 2014 have been used. Also, two spectral indices were used in this study, which are the Normalized Difference Water Index (NDWI) and the Soil Adjusted Vegetation Index (SAVI) to study the changes along the coastal water/land interface. In addition, accuracy assessment using ground truth is performed for the selected methods to determine the quality of the information derived from image classification. The results indicated the eroded areas, the erosion and deposition rates occurred during the period 1990-2014. Accordingly, the deposition rate along the coastline was higher than the erosion rate; however, it took place at different locations. Accuracy assessment revealed that SAVI was more accurate than the NDWI in studying the changes along the coastline.

Keywords: RS, GIS, Normalized Difference Water Index (NDWI), Soil Adjusted Vegetation Index (SAVI).

1 INTRODUCTION

The total shoreline of State of Kuwait including all the nine islands is about 500 kilometers in length. But, the shoreline of Kuwait mainland coast is about 325 kilometers long and this can be divided into two main parts. The first part is along the Arabian Gulf and the second part is around the Kuwait Bay and Khor Subiya. The increased environmental changes along the coastline has greatly affected on the sustainable developments of coastal morphology of Kuwait. The main purpose of this study is to provide basic understanding and to promote confidence in the overall quality of analysis and results of the coastal environment changes of Kuwait [Baby, S., 2010].

The first part of this study is devoted to coastal zone monitoring, along the Arabian Gulf, around the Kuwait Bay and Khor Subiya as a case study to analyze detailed coastal changes and their influence on the environment. The se-

cond part is coastal zone monitoring of islands (Boubyan, Warba and Failaka) in State of Kuwait.

The integration between remote sensing satellite data and GIS are widely used to analyses the environmental changes on the coastal zones management [Murali, R]. The Landsat imagery is well suited for generating land-water boundaries because of the strong contrast between land and water in the infrared portion of the electromagnetic spectrum [Nayak, S., 2002]. The studies on the shoreline change were very limited to the northeastern parts of the studied area. Furthermore, various development projects have been recently started in this area. Therefore, this study utilized both remote sensing and GIS data techniques, which will be very useful in assessing the impact of environmental changes on the coastline zone in Kuwait.

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2 STUDY AREA CHARACTERISTICS

The State of Kuwait is an Arab country in Western Asia. Situated in the northeastern part of the Arabian Peninsula at the tip of the Arabian Gulf, it shares borders with Iraq to the north and Saudi Arabia to the south as shown in figure

(1). The country covers an area of 17,820 square kilometers and has a Kuwaiti population of 1.3 million as of 2015 [Source: The Public Authority for Civil Information – Kuwait, June 2015].

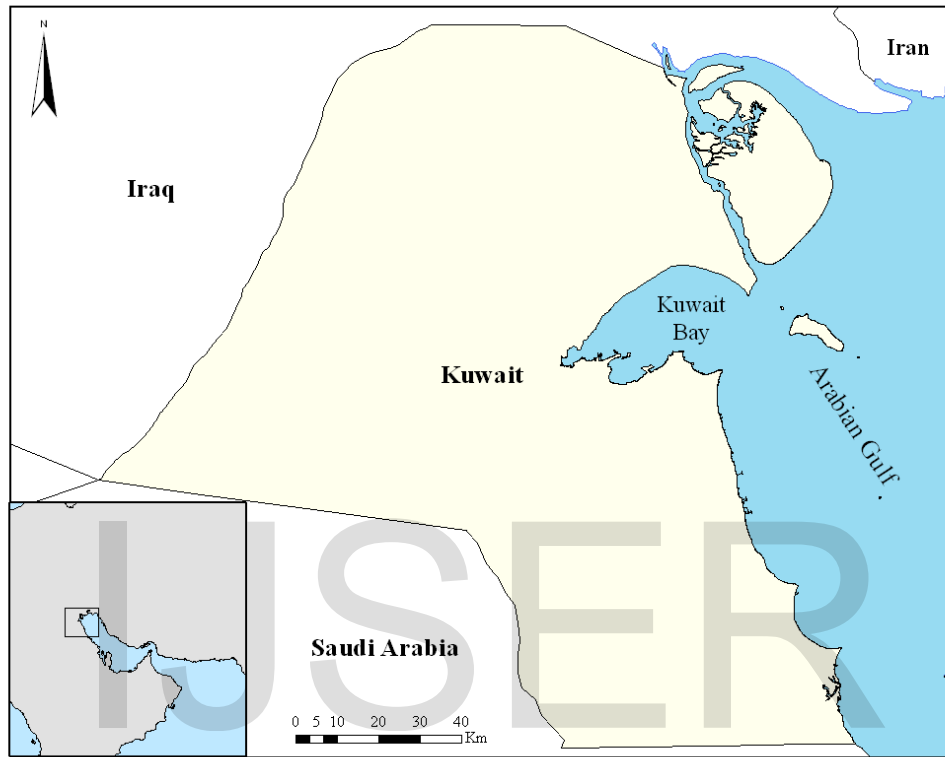


Fig. (1): Location of study area in Kuwait.

2.1 MATERIALS AND METHODS

The studied area is covered by two Landsat images (path 165, rows 39 and 40). The Landsat images are used to study the spatial and temporal changes in urban and sea water to estimate the environmental changes on coastline of mainland and islands in state of Kuwait during the period from

1990 to 2015. The acquisition dates for these images are represented in table (1), where each year was represented by two images. However, all the obtained images were cloud free.

Table (1): Acquisition dates of the study area Landsat images.

No	Monitoring Period	Satellite Sensor Type	Date	Time	Sea Level from (ACD)			
					Warba Island	Boubyan Island	Failaka Island	Kuwait shoreline
1	1990 - 2000	Landsat 5 (TM)	12/6/1990	06:45:57.93	2.2 m	2.0 m	1.8 m	1.6 m
2			7/8/1990	06:35:52.53	1.6 m	1.9 m	1.8 m	1.5 m
3			15/8/1990	06:44:56.96	4.1 m	3.0 m	2.6 m	2.1 m
4			20/12/1990	06:41:59.73	0.5 m	0.4 m	0.5 m	0.1 m
5			3/9/1994	06:32:44.14	3.2 m	2.8 m	2.4 m	1.9 m
6			10/2/1995	06:27:26.26	2.3 m	2.2 m	1.7 m	0.8 m
7			9/11/1995	06:15:21.62	0.5 m	0.5 m	0.5 m	0.4 m
8			15/10/1998	06:54:42.44	3.5 m	2.9 m	2.5 m	1.8 m
9			10/5/2000	06:54:20.61	3.1 m	2.6 m	2.1 m	1.6 m
10			15/6/2000	06:52:13.699	2.4 m	2.4 m	2.4 m	1.6 m
11			18/8/2000	06:53:33.85	1.5 m	1.4 m	1.3 m	1.2 m
12			11/9/2000	07:06:57.33	4.0 m	3.0 m	2.5 m	2.0 m
13			5/10/2000	06:54:44.46	2.8 m	2.0 m	1.6 m	1.4 m
14	2001- 2010	Landsat 7 (ETM+)	29/5/2003	07:05:02.43	2.4 m	2.4 m	2.2 m	1.5 m
15			4/5/2005	07:05:52.54	2.8 m	2.8 m	2.2 m	1.4 m
16			7/7/2005	07:06:00.00	2.3 m	2.3 m	2.2 m	1.7 m
17			4/9/2009	07:06:00.00	2.0 m	2.0 m	1.7m	1.5 m
18			15/3/2010	07:08:00.78	1.0 m	1.0 m	0.9 m	0.5 m
19	6/8/2010	07:08:29.18	4.2 m	3.3 m	2.8m	2.2 m		
20	2011-2015	Landsat 8 (OLI-TIRS)	18/5/2013	07:17:52.94	3.2 m	2.6 m	2.2 m	2.2 m
21			5/5/2014	07:15:55.37	2.7 m	2.2 m	1.8 m	1.4 m
22			9/8/2014	07:15:54.94	4.2 m	3.2 m	2.8 m	2.1 m
23			8/3/2015	07:21:37.58	0.6 m	0.8 m	0.8 m	0.4 m
24			18/7/2015	07:22:01.47	1.5 m	1.7 m	1.6 m	1.4 m
25			12/8/2015	07:15:33.68	3.4 m	3.1 m	2.6 m	1.9 m
26			28/8/2015	07:15:40.54	3.2 m	3.0m	2.5 m	1.9 m

All obtained images are referenced in the World Geodetic System (WGS84) datum, in Geo Tiff format and are projected using the Universal Transverse Mercator system (zone

UTM 39 North). A false color composite (FCC) of these images is illustrated in figure (2).

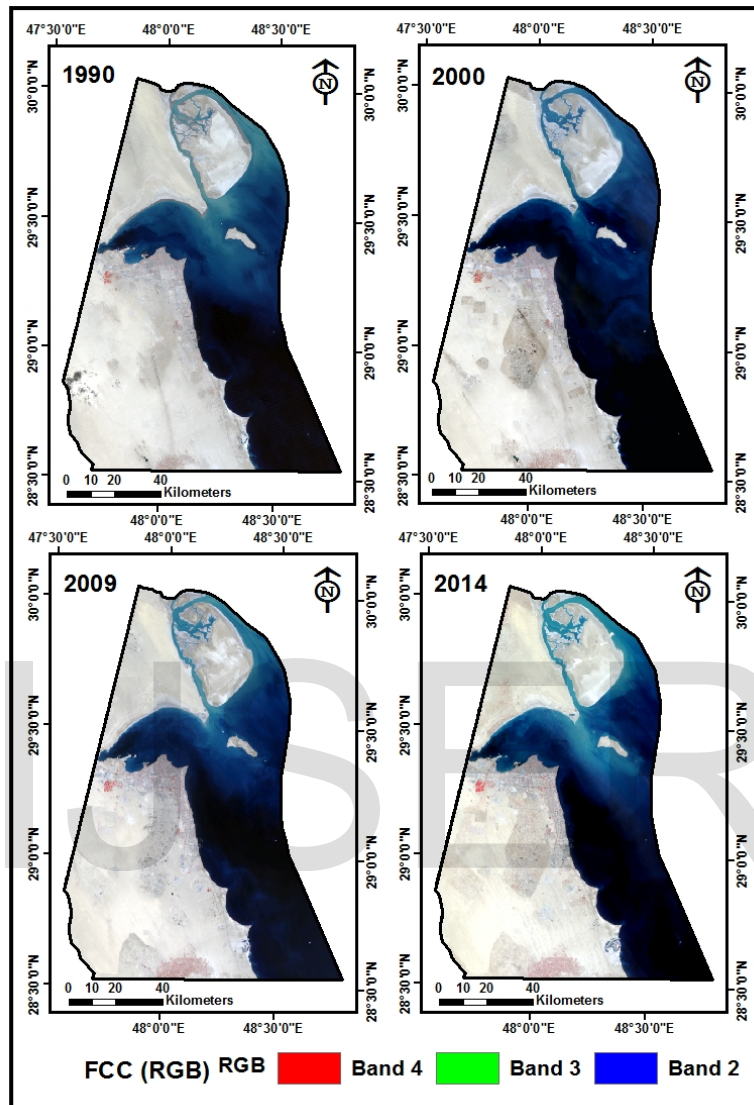


Fig. (2): False Color Composite (FCC) and shape file of the study area Landsat images acquired in 1990-2014.

3 IMAGE PROCESSING

Atmospheric and Radiometric Corrections: Landsat images were atmospherically corrected by using the dark-object subtraction method in the ENVI software package. This was to reduce the atmospheric interferences (dust, haze, smoke, etc.). Also, the images were radio-metrically corrected. In this process, the Digital Number within each pixel was converted into at sensor reflectance based on the metadata associated with that image. The two images for each year were mosaicked to form a single image using the histogram matching process and resampled to have a 30 m pixel size. Each image mosaic for each of the four monitoring period was substituted to cover coastal zone of Kuwait.

Image Geometric - Correction: Landsat images were geometrically corrected using 32 ground control points with least (0.5 of a pixel) RMS error. All images were projected to have the same projection (UTM, Zone 38N, Datum WGS (1984) and a pixel size of 30 meters.

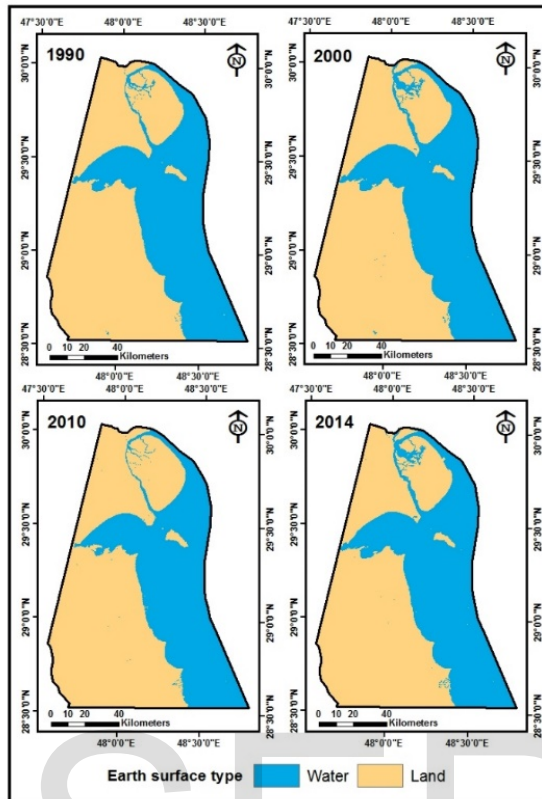


Fig. (3): The Earth surface type of Kuwait (1990-2014).

4 THE SHORELINE POSITION CHANGE IN STATE OF KUWAIT

In this study the Kuwait shoreline was defined using available Landsat satellite imagery acquired from 1990 to 2015 (Figure 3). The satellite image data was acquired during high tide in the same period of those data used to produce the maps of shoreline changes over time. The southern area of Kuwait coast, specifically Al-Khairan area, is experiencing extensive urban development that significantly altered the shoreline of this area.

4.1 ACCURACY ASSESSMENT OF THE STUDIED INDICES

Accuracy Assessment was carried out on the obtained binary images from the two studied indices named; the Normalized Difference Water Index (NDWI); the Soil Adjusted Vegetation Index (SAVI) to study the changes along the coastal water/land interface and to evaluate the efficiency

The SAVI is calculated using the following equation as described by [Huete, R. 1988]:

$$SAVI = (NIR - Red) \times (1 + L) / (NIR + Red + L) \quad (2)$$

of each index in accomplishing the water and land cover classification process. They depend on the reflectance of land surface, which is very different in the near infrared and red bands. Healthy land surface absorbs the visible spectrum and reflects most of the near infrared spectrum. On the other hand, unhealthy vegetation reflects more visible light and less near infrared spectrum. Spectral reflectance, in the visible range is associated with the chlorophyll pigments in plant leaves; however, it depends on the cell structure in the near infrared portion of spectrum.

The NDWI is calculated using the following equation [McFeeters, K. 1996]:

$$NDWI = (\rho_{Green} - \rho_{NIR}) / (\rho_{Green} + \rho_{NIR}) \quad (1)$$

Where ρ_{Green} and ρ_{NIR} are the reflectance of the green and NIR bands, respectively.

Where: L is a correction factor ranging from 0 for very high plant densities to 1 for very low plant densities (a value of 0.5 was used in this work).

The difference between SAVI and NDWI is that SAVI is more sensitive than the NDWI in detecting land surface areas such as urban and desert areas. The SAVI can work with areas that have a plant cover as low as 15%, whereas NDWI is designed to (1) maximize the reflectance of a water body by using green wave lengths, (2) minimize the low reflectance in NIR of water bodies and (3) take advantage of the high reflectance in the NIR of vegetation and soil features [Karsli, F., et al., 2011]. As a result, the water body information will be enhanced and the background (vegetation and soil features) information will be restricted in McFeeters NDWI images. This means that the water bodies can be identified by applying a threshold to McFeeters NDWI images. Image manipulation techniques were carried out using both ERDAS Imagine 2014, Envi 5.1 and ArcGIS desktop 10.3 Software packages.

Accuracy Assessment was carried out on the obtained binary images from the three studied indices in 1990, 2000, 2009, and 2014 to determine how well each index accomplish the task. The classified image was compared with a variety of data such as aerial photographs, topographic maps, high-

resolution images and ground truth data (for the 2014 images). The error matrix was developed for that purpose. It represents a table in which values that were assigned to each land use during the classification process (water = 0 and land surface = 1) were compared to the actual land cover from the mentioned sources of data. These were compared on a point-by-point basis, where a random set of about 300 points were randomly generated throughout the studied area. Then using the aerial photos and the other resources of data, the land cover for each point was identified. After that, the same random points were used to identify each point's known land cover in the classified image. The error matrix table was completed by comparing these two values. Cohen's kappa coefficient was also calculated from the error matrix. Kappa coefficient is an important component of accuracy assessment that tells us how well the classification process was performed as compared to randomly assigning values [Karsli, F., et al., 2011]. The average values of Producer's Accuracy, User's Accuracy, Overall Accuracy and Kappa Coefficient are presented as shown in figures (4a, b, c& d) for the NDWI and the SAVI respectively.

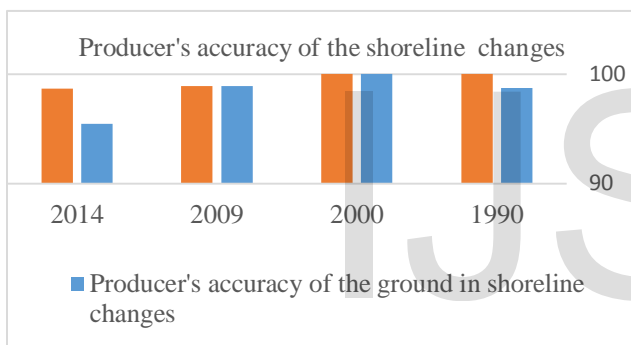


Fig. (4a): Producer's accuracy of the shoreline changes.

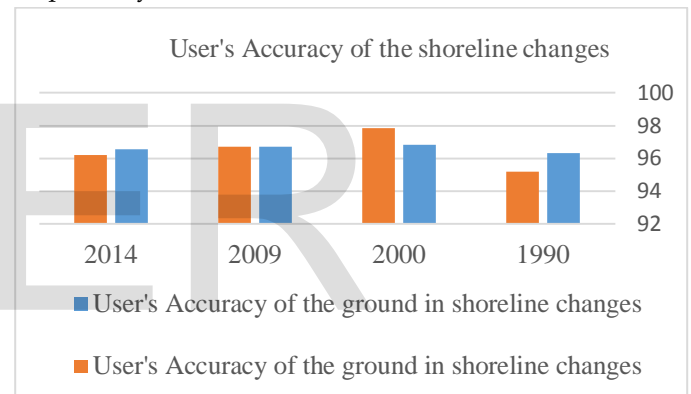


Fig. (4b): User's Accuracy of the shoreline changes.

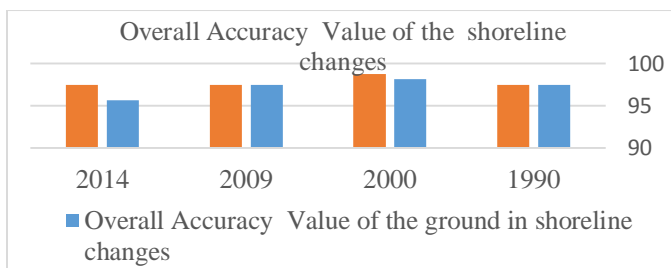


Fig. (4c): Overall Accuracy Value of the shoreline changes.

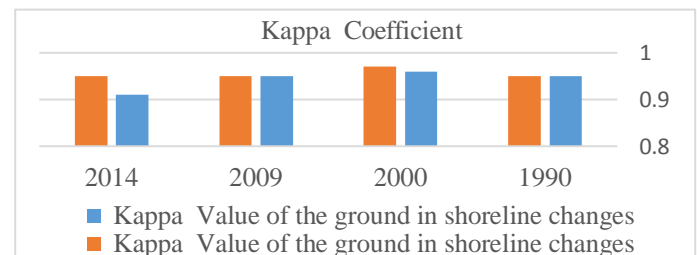


Fig. (4d): Kappa Coefficient.

5 ENVIRONMENTAL CHANGES ON COASTS AND ISLANDS IN STATE OF KUWAIT

5.1 THE KUWAIT SHORELINE CHANGES

Spatial distribution of the ground of shorelines in State of Kuwait based on the SAVI index in 1990, 2000, 2009 and

2014 is represented in figure (5a). Estimated land area were about 7001.63, 6956.72, 6955.03 and 6944 km² in 1990, 2000, 2009 and 2014, respectively. These results indicate that land areas were decreased in shorelines of Kuwait main land from 1990 to 2014 mainly due to the increase of the changes in environmental factors.

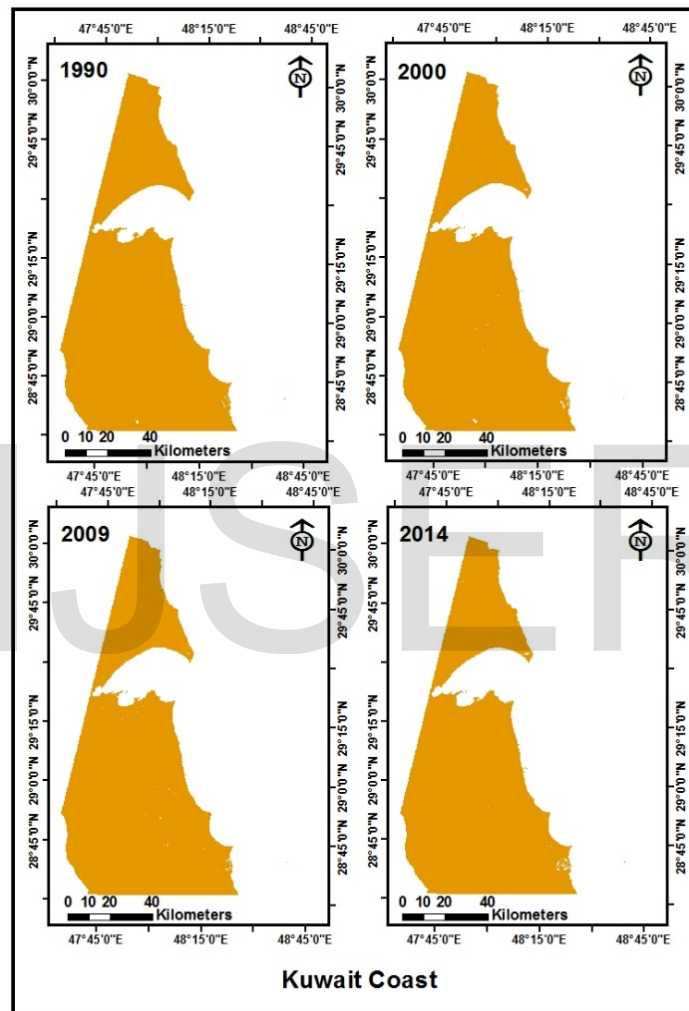


Fig. (5a): The shoreline position change of the coast in Kuwait (1990-2014).

From the shoreline position change along the coastal plain in State of Kuwait based on the SAVI index in 1990, 2000, 2009 and 2014 as represented in figure (5a). Erosion was estimated about 24.91 km² in 1990-2000 and their annual rate was about 2.491 km²/year, while the deposition was about 3.9114 km² in the same period and their annual rate was about 0.39114 km²/year. In 2000-2009, erosion was about 1.69 km² and their annual rate was about 0.1877 km²/year, while the deposition was about 3.9747 km² in

same period and their annual rate were about 0.4416 km²/year. In 2009 - 2014, erosion was about 4.150 km² and their annual rate was about 0.83 km²/year, while the deposition was about 2.5294 km² in same period and their annual rate was about 0.50588 km²/year. Figure (5b) shows the changes in shoreline of Kuwait between 1990 and 2014 based on change detection method that gave the location of changes and indicates the largest proportion of erosion and deposition in this period is especially in the northern zone.

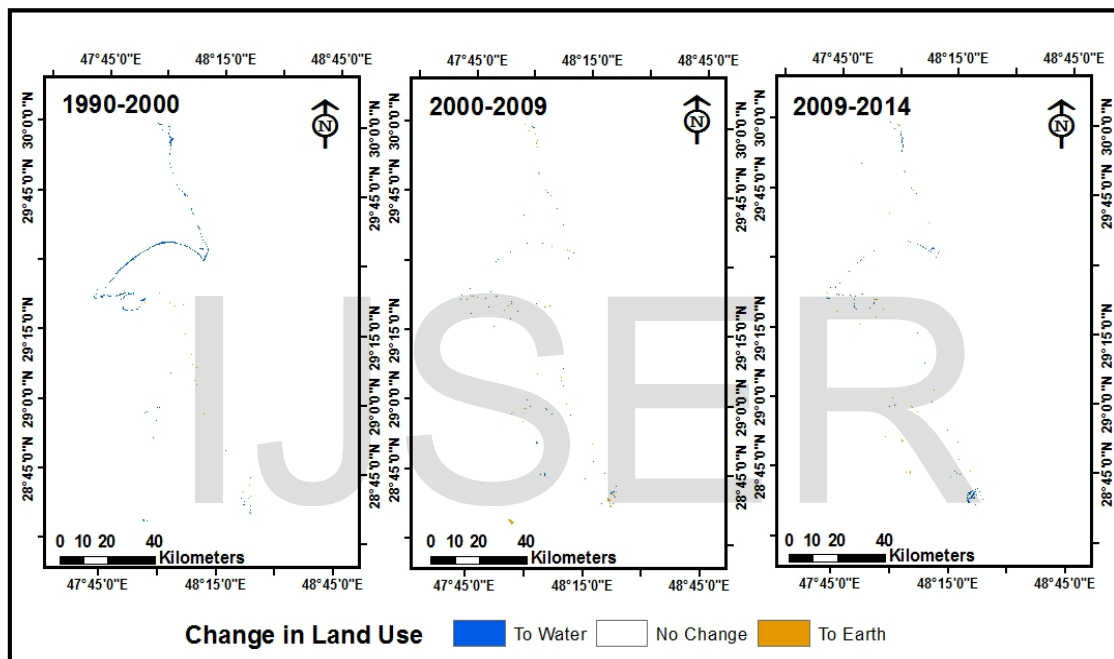


Fig. (5b):

line position change of the coast in Kuwait (1990-2014)

The shore-

5.2 THE SHORELINE POSITION CHANGE IN ISLANDS OF KUWAIT

Four sets of images of the test site with different dates are compared to determine the quality of the information derived from image classification and to detect the changes in shoreline of the largest three islands of Kuwait (Boubyan, Warba and Failaka).

5.2.1 THE SHORELINE POSITION CHANGE IN BOUBYAN ISLAND

This part is devoted to study the shoreline position change in Boubyan Island, which is the largest one in Kuwait. It is

located in the north of Kuwait Bay and close to the border with Iraq and Iran. Four sets of images of the test site with different dates (1990-2014) are used as shown in figure (6a), Spatial distribution of the ground of shorelines in Boubyan Island based on the SAVI index in 1990, 2000, 2009 and 2014.

Estimated areas of the land were about 914.79 and 836.18 km². The estimated erosion was about 28.6164 km² in 1990-2000 with annual rate of about 2.86164 km²/year, while the deposition was about 0.045 km² with annual rate of 0.0045 km²/year in the same period. In 2000-2009, erosion was about 4.39 km² and their annual rate was about 0.4878 km²/year, while the deposition was about 2.8989 km² in same period and their annual rate was about 0.3221

km²/year. In 2009-2014, erosion was about 5.87 km² and their annual rate was about 1.174 km²/year, while the deposition was about 2.6528 km² in same period and their annual rate was about 0.53056 km²/year. These results indicate that the largest proportion of erosion in Boubyan Island was during the period from 1990 to 2000, while the largest deposition was during the period from 2009 to 2014.

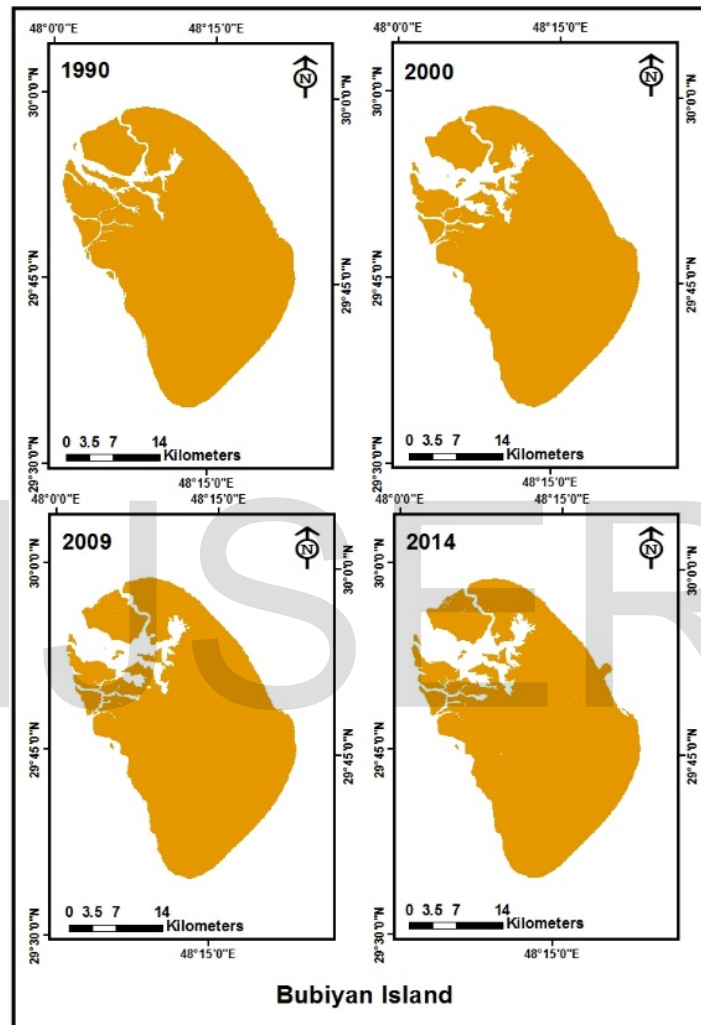


Fig. (6a): The shoreline changes of Boubyan Island (1990-2014).

Figure (6b) shows the changes in Boubyan Island between 1990 and 2014 based on change detection method that gave

the location of changes and indicated the largest proportion of erosion and deposition in this period.

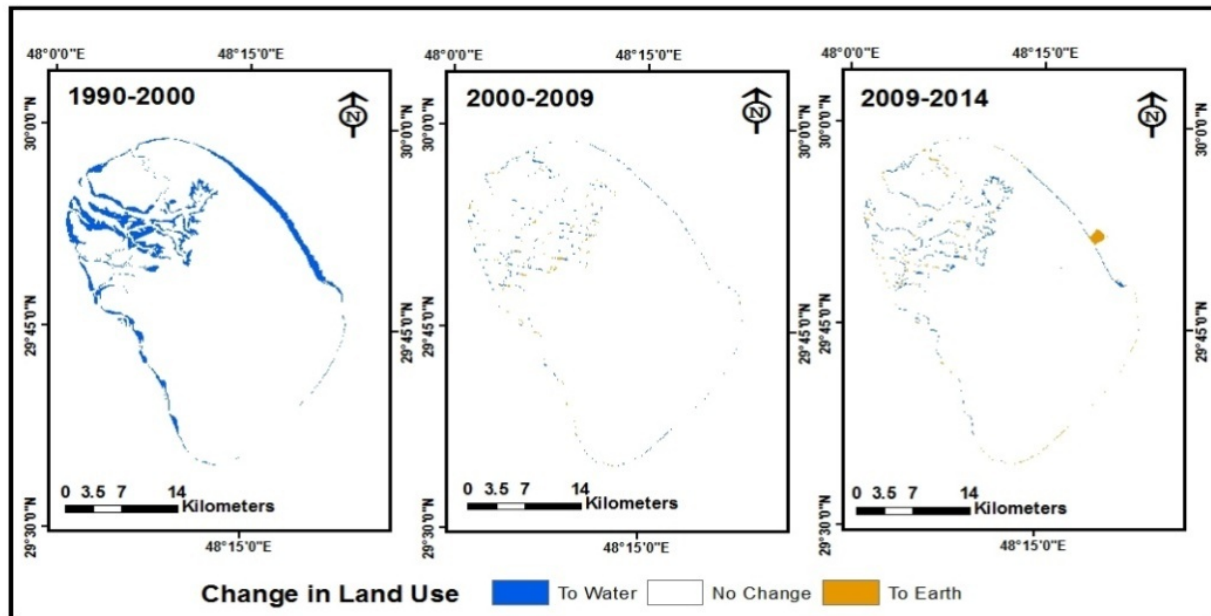


Fig. (6b): The shoreline position change along Boubyan Island (1990-2014).

5.2.2 THE SHORELINE POSITION CHANGE IN WARBA ISLAND

This part is devoted to study the shoreline position change in Warba Island. Warba Island constitutes the northernmost part of eastern Kuwait and has an average elevation of

11 m above sea level. Four sets of images of the test site with different dates (1990-2014) are used. Spatial distribution of the ground of shorelines in Warba Island based on the SAVI index in 1990, 2000, 2009 and 2014 is represented in figure (7a). Estimated areas of the land were about 47.04, 45.55, 45.21, and 43.65 km² in 1990, 2000, 2009 and 2014 respectively.

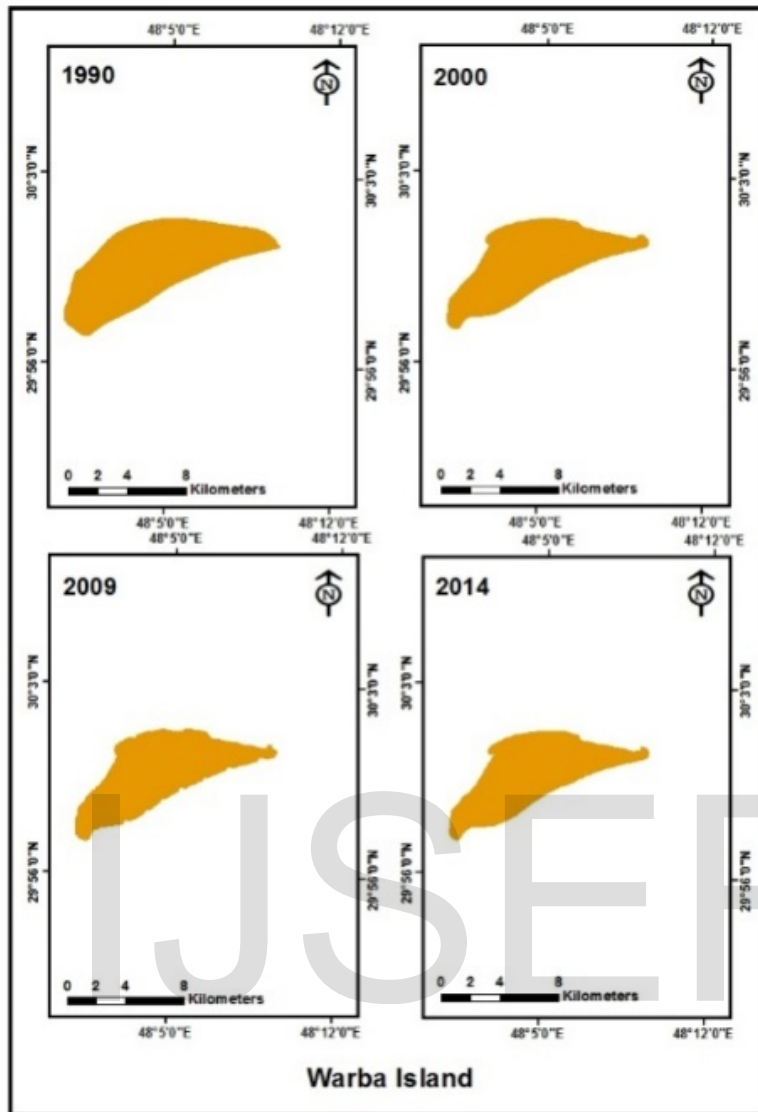


Fig. (7a): The shoreline position change along Warba Island

Estimated erosion was about 11.4867 km² in 1990-2000 and their annual rate was about 1.14867 km²/year, while the deposition was insignificant in the same period. In 2000-2009, the erosion was about 0.7632 km² with annual rate of about 0.0848 km²/year, while the deposition was about 0.4194 km² with annual rate of 0.0466 km² in same period. In 2009-2014, the erosion was about 1.9467 km² and their annual rate was about 0.38934 km²/year, while the deposition was about 0.3915 km² in same period and their annual rate was about 0.0783 km²/year. Figure (7b) shows the changes in Warba Island between 1990 and 2014 based on change detection method that gave the location of changes and indicates the largest proportion of erosion and deposition in this period. These results indicate that the largest proportion of erosion in Warba Island was during the period from 1990 to 2000, while the largest deposition was during the period from 2009 to 2014.

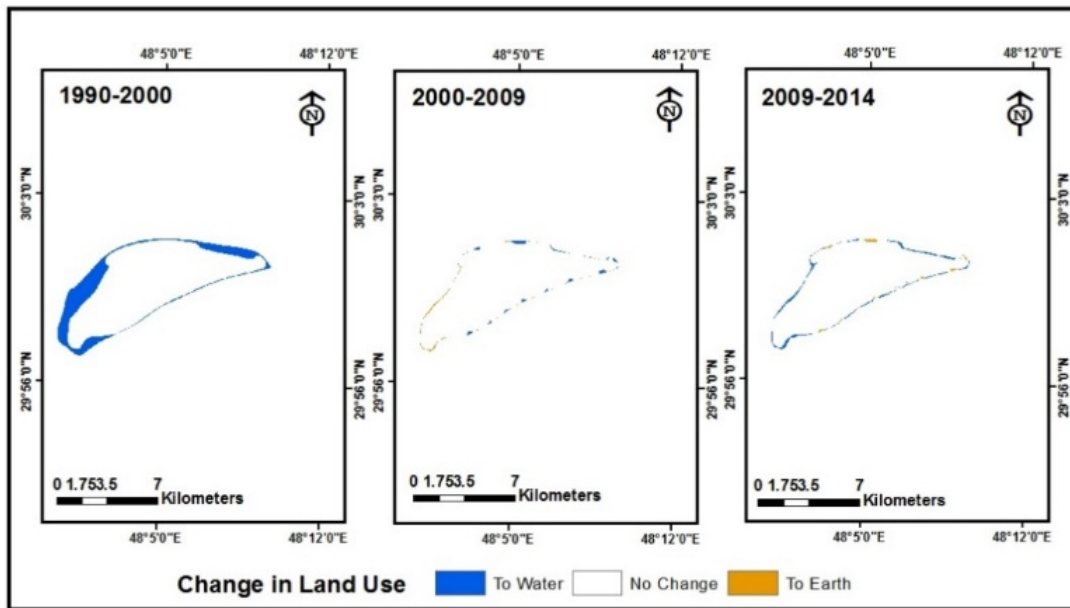


Fig. (7b): The shoreline change along Warba Island (1990-2014).

5.2.3 THE SHORELINE POSITION CHANGE IN FAILAKA ISLAND

This part is devoted to study the shoreline position change in Failaka Island. Four sets of images of the test site with different dates (1990-2014) are used. Spatial distribution of the ground of shorelines in Failaka Island based on the SA-VI index in 1990, 2000, 2009 and 2014 is represented in figure (8a). Estimated areas of the land were about 47.38, 46.78, 46.56 and 46.12 km² in 1990, 2000, 2009 and 2014, respectively.

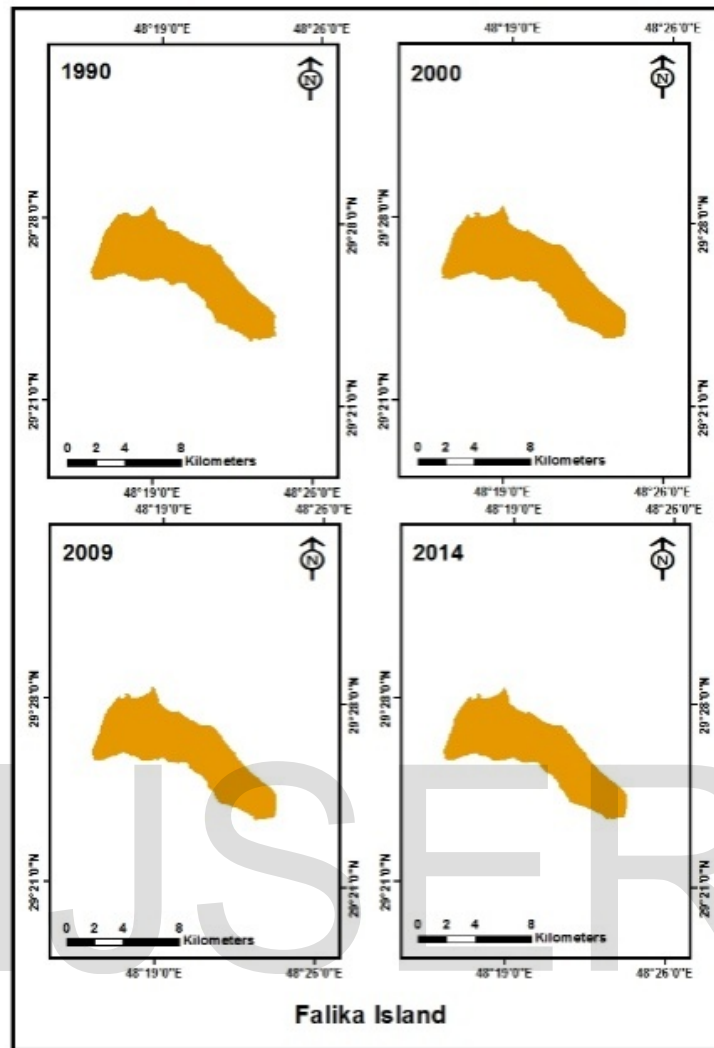


Fig. (8a): The shoreline changes for Falika Island (1990-2014).

Estimated erosion was about 1.6479 km² in 1990-2000 and their annual rate was about 0.16479 km²/year, while the deposition was about 0.0459 km² in same period and their annual rate was about 0.00459 km²/year. In 2000-2009, erosion was about 0.3483 km² and their annual rate was about 0.0387 km²/year, while the deposition was about 0.1224 km² in same period and their annual rate was about 0.0136 km²/year. In 2009-2014 erosion was about 0.5229 km² and their annual rate was about 0.10458 km²/year, while the

deposition was about 0.0864 km² in same period and their annual rate was about 0.01728 km²/year. Figure (8b) shows the changes in Warba Island between 1990 and 2014 based on the change detection method, which gave the location of changes and indicate that the largest proportion erosion and deposition in this period. These results indicate that the largest proportion of erosion in Falika Island was during the period from 1990 to 2000, while the largest deposition was during the period from 2009 to 2014.

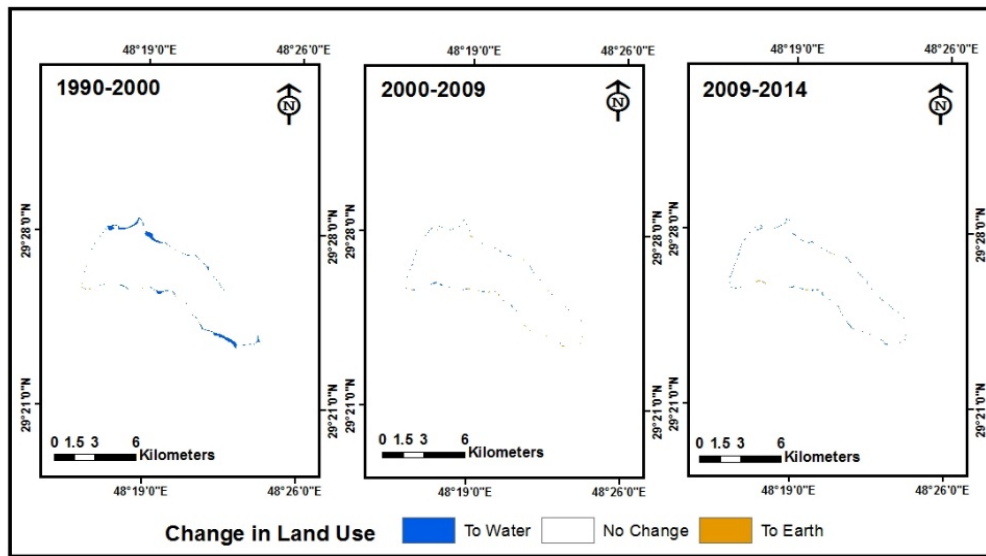


Fig. (8b): The shoreline change along the Failaka Island (1990-2014).

Finally, figure (9) shows the summary of the annual erosion in shorelines and islands of Kuwait at different monitoring periods based on the SAVI index. The results indicate that the largest proportion of annual erosion occurred in the

period (1990-2000) than the other periods. The lowest proportion of annual erosion was in the period (2000-2010) than the other periods. In addition, the significant proportion of annual erosion in period (2010-2014) was medium.

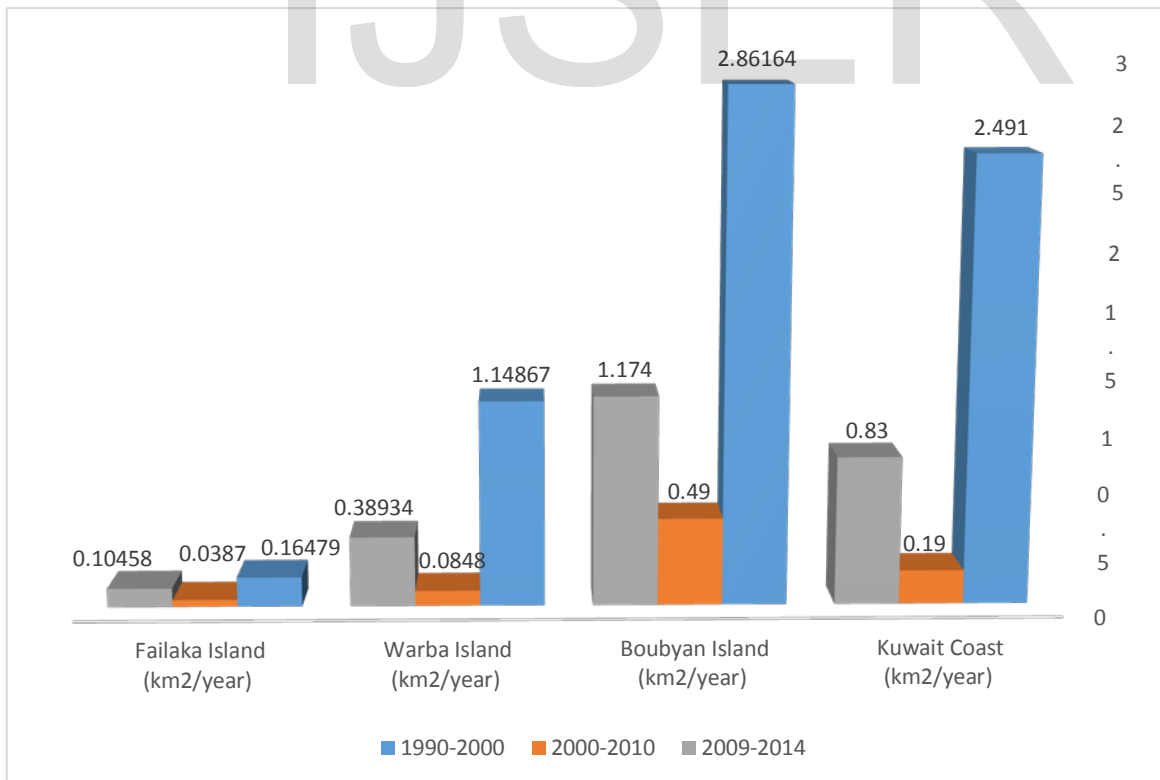


Fig. (9): Annual erosion changes in shorelines of the coast and islands of State of Kuwait.

Figure (10) shows that final summary of the annual sediment -settling (deposition) in coastline of mainland and islands of Kuwait at different monitoring periods based on the SAVI index. The results indicate that the largest proportion of annual settling was in the period (2009-2014) than

the other periods. The lowest proportion of annual settling was in the period (1990-2000) than the other periods. In addition, the significant proportion of annual settling was medium in the period (2000-2010).

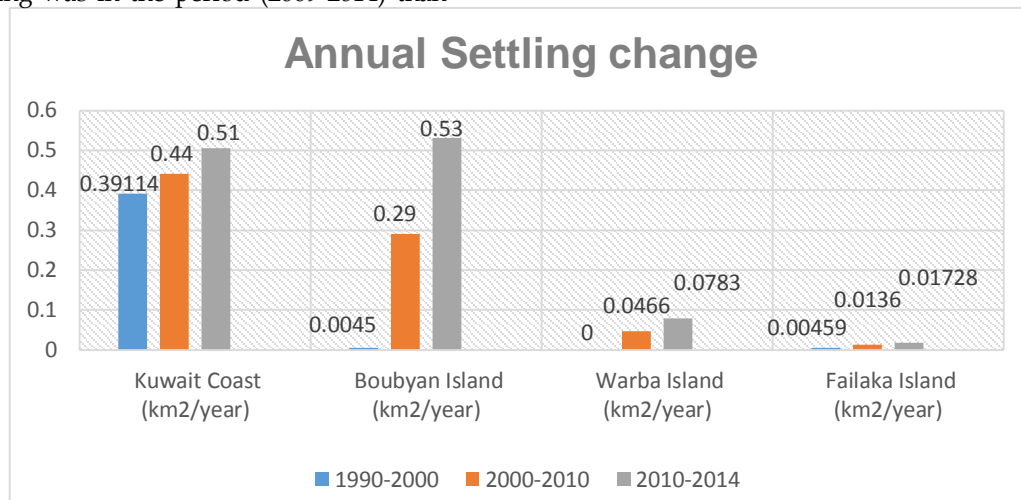


Fig. (10): Annual settling changes in shorelines of the coast and islands of State of Kuwait.

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Finally, the northern islands of Kuwait, especially Warba and Boubyan, would be highly impacted, with about 24% of the island under water at 4m height of sea level. The central zone comprises the entire area around Kuwait Bay region where much of the country's population and infrastructure

6 CONCLUSIONS

According to the data and data analysis results obtained from previous monitoring, assessment methods and techniques used for studying the environmental changes on coasts and islands in State of Kuwait, it can be concluded that:

Both remote sensing data and geographical information system could play an important role in studying and monitoring environmental changes in land cover and water bodies in coastal zones. They could provide more accurate, less expensive and timewise information. Environmental changes assessment and change detection of the coastal zones impact along the coastal zone and islands in State of Kuwait reveal detection of 6 units representing land use/cover including the wetlands, coastal plain, the coastal

exist. Extensive areas in the southern coast of Kuwait Bay would be under water at 4m height of sea level, particularly the Doha and Shuwaikh Ports. Also, significant areas on the northern coast would also be inundated, as well as almost all of Failaka Island.

sand dunes, the urban, the fish farm and the coastal tourist services. Change detections of these units using multi-temporal and multi sensor remote sensing Landsat satellite data acquired from years 1990, 2000, 2010 and 2014 show considerable changes in land surface area at coastal zone and islands in State of Kuwait especially during the period 1990-2000. Most encountered environmental hazards are attributed to erosion caused by higher sea level results; waves and currents, as well as to changes in storm characteristics and driven by climate change. Most of these areas are below the present sea level and will be the most vulnerable to the risk of sinking in case of sea level rising.

Removal of coastal sand dunes may trigger another hazard. These dunes represent the first natural defense line against coastal erosion.

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