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# Erosion and Accretion Index for Kuwaiti Coast

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**ABSTRACT:** Assessment of long term erosion and accretion rate of the coastal area is essential for selection of different types of coastal structures. For example, it is not advisable to develop housing infrastructure on the coast, which is historically eroding. Similarly it is not preferable to select an accreting site for the construction of a port in order to avoid annual maintenance dredging after construction of the port. Kuwait is a coastal country and hence it is essential to understand the long term coastal morphological changes of the coast and identify the historically accreting or eroding or stable coast over a period of many years, say 10 to 15 years. The coastline evolution of Kuwait is investigated using Landsat remote sensing images (30 m resolution) from 1989 to 2003, IRS-P5 images (2.5 m resolution) obtained for the year 2006-07 and 2003 aerial photos (0.38 m resolution). A total of 130 grids, each at a spacing of 1 nautical mile is used. The extent of accretion/erosion for 17 years (from 1989 to 2006) for the mainland coastline of Kuwait is assessed. The average shoreline change/year is calculated. Erosion and accretion index for each location is assigned based on the average annual erosion and accretion. From this study, it is found that annual erosion of more than 25 m does not exist in Kuwait. 1.54% of the coast has experienced annual erosion of 10 to 25 m and 0.77% of the coast has experienced 0 to 10 m annual erosion. 3.85% of the coast is stable. 43.85% of the coast has annual accretion of 0 to 10 m, 11.54% has annual accretion of 10 to 25 m and 38.46% has annual accretion of greater than 25 m. The complete details of this study are presented in this paper. The results will be useful for integrated management of Kuwaiti coast.

**Keywords:** Erosion, Accretion, Stable coast, Kuwaiti shoreline, Coastline evolution, Remote sensing, Natural and manmade coastal changes

## INTRODUCTION

Coastal erosion or accretion is considered as hazards for infrastructure developments in the coastal area. For example, if a coastal area is eroding systematically over a period of many years, then the sea will occupy the coastal infrastructure and destroy the foundations of such structures. It is a hazard for such type of coastal structures. On the other hand, if sand/silt is accreting systematically, then it will a stroke of luck and provide a wide beach and good for recreation. In certain areas, sand/silt accumulation is not wanted. For example, if sand is accumulating around seawater intake structure sites, it is a hazard. So one cannot say that erosion is hazard and accretion is a piece of good fortune. It depends upon the type of coastal project activity. Kuwait is a coastal country (Fig.1) and has a total coastal length of 496 km. Most of the population lives closer to coast. The latitude and longitude at its southern tip is N 28° 32' 8.16'' and E 48° 26' 00''. The northern tip of the country is near N 29° 59' and E 48° 00' 48'' as shown in Fig.1.

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The government is also planning for many more infrastructures in the available coastal area. Hence a general understanding of whether a stretch of Kuwaiti coast is historically eroding or accreting will be useful for selecting a suitable site for different types of coastal project like Marina, Port and Harbors, Public Beaches, Marine outfalls from power and desalination plants, Culverts and natural drains**,** Sea Water Intakes, Piers, Moles, Beach Nourishments etc. The coastline evolution of Kuwait is studied using Landsat remote sensing images (30 m resolution) from 1989 to 2003, IRS-P5 images (2.5 m resolution) obtained for the year 2006-07 and 2003 aerial photos (0.38 m resolution). The extent of accretion/erosion during the year 1989-2006 for the whole coastline of Kuwait is brought out. Most of the man made coastal developments is focused from the Southern Kuwaiti coastal boundary to Shuwaikh Port and hence the coastal morphological changes are found to be mainly due to the responses of these developments. The developments of sand spits in many parts of southern coastal areas were

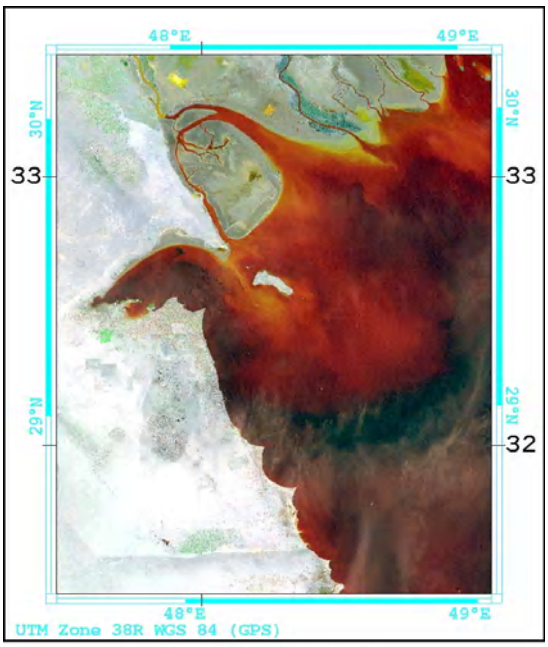


**Fig.1. Latitude and Longitude details of Kuwait**

observed. Accretions in most of the southern Kuwaiti coasts are found to be due to the influence of slipways which are acting as groin fields. A detailed comprehensive geo-environmental data base is prepared (Neelamani *et al.*, 2009). The scientific details used for the analysis of remote sensing images are also described in detail in Neelamani *et al.*, 2009.

A proper understanding of the extent of erosion and accretion and the spatial variation is essential for planning future projects. It is hence useful to create an index, which will reflect whether a coastal area is stable or has low/medium/high erosion rate or low/medium/high accretion rate, using index values for better understanding. This paper gives such information.

## MATERIALS & METHODS

The change deductions of the coastline are obtained through superposition of remote sensing images belong to 1989 and 2003 as well as 2006-07. The tidal corrections were applied for the correct change deduction of the coast. An index value of 0 is assigned for stable coastline. Low/medium/high coastal erosion is given index value of -1, -2 and -3 respectively. Index value of -1 is assigned if the annual rate of erosion is 0 to 10m, -2 for annual erosion in between 10 to 25 m and -3 for annual erosion rate of greater than 25 m. Similarly low/medium/high accretion rates are assigned with index value of 1, 2 and 3 respectively. Index value of 1 is assigned if the annual rate of accretion is 0 to 10m, 2 for annual accretion in between 10 to 25 m and 3 for annual accretion rate of greater than 25 m. The following section describes the details of the hazard assessment index purely based of the order of average rate of annual erosion and accretion for the Kuwaiti coastal area. The hazard index values are provided for a total of 130 locations along the Kuwaiti coast. This will give a firsthand impression of the order of annual erosion and accretion occurred at these sites during 1989 to 2006-07.

## RESULTS & DISCUSSION

The hazard assessment is carried out purely based of the order of average rate of annual erosion and accretion in Kuwaiti coastal area. The information is gathered from the change detection of coastline obtained by superposing the coastlines (after tide correction) of landsat image of 1989 and IRS P5 images of 2006-07. The maximum value of erosion/accretion on each grid of 1' x 1' is extracted. The average shoreline change per year is calculated. An erosion/accretion index is formed based on different ranges of annual rate of erosion or accretion as explained in Table 1.

**Table 1. Erosion and Accretion Index Based on Annual Rate of Change in Kuwaiti Shoreline**

| Annual shoreline change (m) | Meaning | Index Value |
|---|---|---|
| Accretion greater than 25 m | High accretion rate | 3 |
| Accretion in the range of 10 to 25 m | Medium accretion rate | 2 |
| Accretion in the range of 0 to 10 m | Low accretion rate | 1 |
| No change in coastline | Stable coast | 0 |
| Erosion in the range of 0 to 10 m | Low erosion rate | -1 |
| Erosion in the range of 10 to 25 m | Medium erosion rate | -2 |
| Erosion greater than 25 m | High erosion rate | -3 |

Table 2 to 7 gives the index values for each 1' x 1' grid for different coastal segments in Kuwait.

Table 2 shows the erosion and accretion index based on shoreline change in Kuwait during 1989 to 2006 from Nuwaisib to Ras Al-Julayah Covering Al-Khiran and Az-Zour. Since the southernmost Kuwaiti coast (28° 32' 8.16" N to 28° 38' N) has high accretion rate during 1989-2006, it carries index value of 3. One location has index value of -2, indicating medium erosion rate during 1989-2006. Most of the locations in this coastal stretch carry index value of 1, which indicates that this coastal stretch from 28° 42' N to 28° 51' N has dominated by low accretion rate during 1989-2006.

**Table 2. Erosion and Accretion Index Based on Shoreline Change in Kuwait During 1989 to 2006 from Nuwaisib to Ras Al-Julayah Covering Al-Khiran and Az-Zour**

| Latitude | Longitude | Total shoreline change during 1989-2006 (m) | Average shoreline change/year (m) | Erosion/ Accretion index |
|---|---|---|---|---|
| 28° 32' 8.16" | 48° 26' 00" | 2170 | 127.6 | 3 |
| 28° 33' | 48° 25' 12" | 2046 | 120.4 | 3 |
| 28° 34' | 48° 24' 24" | 1612 | 94.8 | 3 |
| 28° 35' | 48° 23' 55" | 3410 | 200.59 | 3 |
| 28° 36' | 48° 23' 36" | 496 | 29.18 | 3 |
| 28° 37' | 48° 23' 12" | 1426 | 83.88 | 3 |
| 28° 38' | 48° 23' 40" | 496 | 29.18 | 3 |
| 28° 39' | 48° 23' 33" | -310 | -18.24 | -2 |
| 28° 40' | 48° 23' 24" | 372 | 21.88 | 2 |
| 28° 41' | 48° 23'00" | 0 | 0 | 0 |
| 28° 42' | 48° 22' 48" | 124 | 7.29 | 1 |
| 28° 43' | 48° 22' 54" | 124 | 7.29 | 1 |
| 28° 44' | 48° 23' 26" | 1240 | 72.9 | 3 |
| 28° 45' | 48° 20' 10" | 124 | 7.29 | 1 |
| 28° 46' | 48° 18' 35" | 62 | 3.65 | 1 |
| 28° 48' | 48° 17'00" | 124 | 7.29 | 1 |
| 28° 49' | 48° 16' 48" | 62 | 3.65 | 1 |
| 28° 50' | 48° 16' 54" | 124 | 7.29 | 1 |
| 28° 51' | 48° 16' 48" | 124 | 7.29 | 1 |

**Table 3. Erosion and Accretion Index Based on Shoreline Change in Kuwait During 1989 to 2006 from Ras Al-Julayah to Al-Fintas Covering Shuaiba, Ahmadi, Fahaheel and Fintas**

| Latitude | Longitude | Total shoreline change during 1989-2006 (m) | Average shoreline change/year (m) | Erosion/ Accretion index |
|---|---|---|---|---|
| 28° 52' | 48° 16' 54" | 186 | 10.94 | 2 |
| 28° 53' | 48° 16' 00" | 124 | 7.29 | 1 |
| 28° 54' | 48° 14' 00" | 62 | 3.65 | 1 |
| 28° 55' | 48° 12' 36" | 62 | 3.65 | 1 |
| 28° 56' | 48° 12' 30" | 62 | 3.65 | 1 |
| 28° 57' | 48° 11' 48" | 62 | 3.65 | 1 |
| 28° 58' | 48° 10' 42" | 62 | 3.65 | 1 |
| 28° 59' | 48° 10' 18" | 62 | 3.65 | 1 |
| 29° 00' | 48° 09' 54" | 62 | 3.65 | 1 |
| 29° 01' | 48° 09' 36" | 62 | 3.65 | 1 |
| 29° 02' | 48° 09' 30" | 0 | 0 | 0 |
| 29° 03' | 48° 09' 18" | 0 | 0 | 0 |
| 29° 04' | 48° 09' 00" | 62 | 3.65 | 1 |
| 29° 05' | 48° 08' 24" | 62 | 3.65 | 1 |
| 29° 06' | 48° 08' 15" | 93 | 5.47 | 1 |
| 29° 07' | 48° 08' 09" | 62 | 3.65 | 1 |
| 29° 08' | 48° 08' 00" | 124 | 7.29 | 1 |
| 29° 09' | 48° 07' 42" | 62 | 3.65 | 1 |
| 29° 10' | 48° 07' 30" | 62 | 3.65 | 1 |
| 29° 11' | 48° 07' 12" | 124 | 7.29 | 1 |

Table 3 shows the erosion and accretion index based on shoreline change in Kuwait during 1989 to 2006 from Ras Al-Julayah to Al-Fintas covering Shuaiba, Ahmadi, Fahaheel and Fintas coastal areas. Most of the locations carry index value of 1, which indicates that this coastal stretch has dominated by low accretion rate during 1989-2006. The low accretion is due to slipways built by the population living in this

coastal area, for handling their pleasure boats. Two locations (29° 02' N to 29° 03' N) carry index value of 0 indicating stable coastline. These two locations has Shuaiba power station and Mina As-Shuaiba Port, build using concrete structures and the coastal are protected from possible erosion using ripraps.

Table 4 shows the erosion and accretion index based on shoreline change in Kuwait during 1989 to 2006 from Al-Fintas to Ras Al-Ardh. Most of the locations carry index value of 1, which indicates that this coastal stretch has dominated by low accretion rate during 1989-2006. The low accretion is due to the presence of many manmade coastal structures.

Table 5 shows the erosion and accretion index based on shoreline change in Kuwait during 1989 to 2006 in South Kuwait Bay-From Ras Al-Ardh to Jahra Beach area. Ras Al-Ardh to Shuwaikh port area shows low accretion. Most of this coastal stretch is man-made. Artificial beach formations using sand nourishments were carried out during the last few decades and has reflected in this index. The outer side of Shuwaikh port (47° 55' E) shows erosion index

**Table 4. Erosion and Accretion Index Based on Shoreline Change in Kuwait During 1989 to 2006 from Al-Fintas to Ras Al-Ardh**

| Latitude | Longitude | Total shoreline change during 1989-2006 (m) | Average shoreline change/year (m) | Erosion/ Accretion index |
|---|---|---|---|---|
| 29° 12' | 48° 06' 54" | 186 | 10.94 | 2 |
| 29° 13' | 48° 06' 15" | 62 | 3.65 | 1 |
| 29° 14' | 48° 06' 06" | 62 | 3.65 | 1 |
| 29° 15' | 48° 05' 48" | 31 | 1.82 | 1 |
| 29° 16' | 48° 05' 30" | 62 | 3.65 | 1 |
| 29° 17' | 48° 05' 24" | 62 | 3.65 | 1 |
| 29° 18' | 48° 05' 24" | 62 | 3.65 | 1 |
| 29° 19' | 48° 05' 24" | 62 | 3.65 | 1 |
| 29° 20' | 48° 05' 36" | 62 | 3.65 | 1 |
| 29° 21' | 48° 06' 12" | 62 | 3.65 | 1 |

**Table 5. Erosion and Accretion Index Based on Shoreline Change in Kuwait During 1989 to 2006 in South Kuwait Bay-From Ras Al-Ardh to Jahra Beach Area**

| Latitude | Longitude | Total shoreline change during 1989-2006 (m) | Average shoreline change/year (m) | Erosion/Accretion index |
|---|---|---|---|---|
| 29° 21' 12" | 48° 06' | 0 | 0 | 0 |
| 29° 20' 48" | 48° 05' | 62 | 3.65 | 1 |
| 29° 20' 36" | 48° 04' | 62 | 3.65 | 1 |
| 29° 20' 36" | 48° 03' | 62 | 3.65 | 1 |
| 29° 21' 00" | 48° 02' | 124 | 7.30 | 1 |
| 29° 22' 06" | 48° 01' | 62 | 3.65 | 1 |
| 29° 23' 30" | 48° 00' | 62 | 3.65 | 1 |
| 29° 23' 30" | 47° 59' | 0 | 0 | 0 |
| 29° 22' 56" | 47° 58' | 62 | 3.65 | 1 |
| 29° 21' 30" | 47° 57' | 62 | 3.65 | 1 |
| 29° 21' 10" | 47° 56' | -124 | -7.3 | -1 |
| 29° 21' 27" | 47° 55' | -496 | -29.18 | -2 |
| 29° 20' 00" | 47° 54' | 930 | 54.71 | 3 |
| 29° 19' 36" | 47° 53' | 496 | 29.18 | 3 |
| 29° 19' 12" | 47° 52' | 682 | 40.12 | 3 |
| 29° 19' 12" | 47° 51' | 930 | 54.71 | 3 |
| 29° 22' 36" | 47° 50' | 1240 | 72.94 | 3 |
| 29° 22' 30" | 47° 49' | 62 | 3.65 | 1 |
| 29° 23' 06" | 47° 48' | 62 | 3.65 | 1 |
| 29° 22' 36" | 47° 47' | 62 | 3.65 | 1 |
| 29° 22' 06" | 47° 46' | 310 | 18.24 | 2 |
| 29° 22' 06" | 47° 45' | 868 | 51.1 | 3 |
| 29° 21' 36" | 47° 44' | 930 | 54.7 | 3 |
| 29° 21' 12" | 47° 43' | 744 | 43.76 | 3 |
| 29° 21' 36" | 47° 42' | 558 | 32.82 | 3 |

of -2, which most probably due to dredging activities around this location. Most of the locations in the western part of Shuwaikh port is tidal flat and indicates high accretion with index of 3. This can be linked with long term sediment deposit as a reaction of forced deccication of Mesopotamian marshland in Iraq.

Table 6 shows the erosion and accretion index based on shoreline change in Kuwait during 1989 to 2006 in the Northern Kuwait Bay stretch. Most of the locations in the this part of Kuwaiti coast is tidal flat and indicates high accretion with index of 3. Again, this can be linked only with long term sediment deposition of the sediments reached into Kuwait Bay due to forced empting of the water and sediments of 15,000 $km^2$ of the Mesopotamian marshland in Iraq during the study period. Further detailed study is required.

Table 7 shows the erosion and accretion index based on shoreline change in Kuwait during 1989 to 2006 in the mainland side of Khor As-Subiya. This channel is very dynamic and tide induced currents are significant. The accretion index value varies from 1 to 3.The accretion can be contributed to the sediment supply from the Mesopotamian marshland and supply of sediments through Shatt Al-Arab and Shatt Al-Basra. In general, the areas around river mouth is expected to grow due to the supply of sediments and the variation in the accumulation is controlled by the hydrodynamic forces due to the tidal variations.

Table 2 to 7 is useful as a general guideline to identify areas of erosion and accretion and their intensity in the Kuwaiti coastal area.

More information on Kuwaiti coastline evolution can be obtained from Neelamani et al. (2007) and Neelamani and Saif uddin (2009a, 2009b, 2010 and 2011).

**Table 6. Erosion and Accretion Index Based on Shoreline Change in Kuwait During 1989 to 2006 in Kuwait Bay- Northern Part**

| Latitude | Longitude | Total shoreline change during 1989-2006 (m) | Average shoreline change/year (m) | Erosion/ Accretion index |
|---|---|---|---|---|
| 29° 22' 48" | 47° 42' | 372 | 21.88 | 2 |
| 29° 23' 48" | 47° 43' | 124 | 7.29 | 1 |
| 29° 24' 10" | 47° 44' | 372 | 21.88 | 2 |
| 29° 24' 12" | 47° 45' | 620 | 36.47 | 3 |
| 29° 25' 24" | 47° 46' | 558 | 32.82 | 3 |
| 29° 26' 24" | 47° 47' | 558 | 32.82 | 3 |
| 29° 27' 48" | 47° 48' | 992 | 58.35 | 3 |
| 29° 28' 48" | 47° 49' | 1054 | 62.0 | 3 |
| 29° 30' 00" | 47° 50' | 1612 | 94.82 | 3 |
| 29° 30' 48" | 47° 51' | 1922 | 113.06 | 3 |
| 29° 31' 24" | 47° 52' | 1488 | 87.53 | 3 |
| 29° 31' 48" | 47° 53' | 1116 | 65.64 | 3 |
| 29° 32' 24" | 47° 54' | 1116 | 65.64 | 3 |
| 29° 32' 54" | 47° 55' | 1116 | 65.64 | 3 |
| 29° 34' 00" | 47° 56' | 1116 | 65.64 | 3 |
| 29° 36' 24" | 47° 57' | 1364 | 80.24 | 3 |
| 29° 37' 00" | 47° 58' | 1674 | 98.47 | 3 |
| 29° 37' 24" | 47° 59' | 1426 | 83.88 | 3 |
| 29° 37' 36" | 48° 00' | 930 | 54.71 | 3 |
| 29° 37' 24" | 48° 01' | 868 | 51.06 | 3 |
| 29° 37' 00" | 48° 02' | 744 | 43.76 | 3 |
| 29° 35' 48" | 48° 03' | 868 | 51.06 | 3 |
| 29° 35' 36" | 48° 04' | 682 | 40.12 | 3 |
| 29° 35' 24" | 48° 05' | 930 | 54.71 | 3 |
| 29° 33' 12" | 48° 07' | 806 | 47.41 | 3 |
| 29° 32' 30" | 48° 08' | 682 | 40.11 | 3 |
| 29° 32' 00" | 48° 09' | 1426 | 83.88 | 3 |
| 29° 31' 40" | 48° 10' | 1054 | 62.0 | 3 |
| 29° 32' 36" | 48° 11' | 434 | 25.53 | 3 |

**Table 7. Erosion and Accretion Index Based on Shoreline Change in Kuwait During 1989 to 2006 in Khor As-Subiya-Mainland Side**

| Latitude | Longitude | Total shoreline change during 1989-2006 (m) | Average shoreline change/year (m) | Erosion/Accretion index |
|---|---|---|---|---|
| 29° 33' | 48° 11' 12'' | 124 | 7.29 | 1 |
| 29° 34' | 48° 10' 42'' | 744 | 43.76 | 3 |
| 29° 35' | 48° 09' 54'' | 186 | 10.94 | 2 |
| 29° 36' | 48° 09' 24'' | 124 | 7.29 | 1 |
| 29° 37' | 48° 09' 00'' | 186 | 10.94 | 2 |
| 29° 38' | 48° 08' 24'' | 62 | 3.65 | 1 |
| 29° 39' | 48° 08' 00'' | 62 | 3.65 | 1 |
| 29° 40' | 48° 07' 24'' | 62 | 3.65 | 1 |
| 29° 41' | 48° 07' 00'' | 62 | 3.65 | 1 |
| 29° 42' | 48° 06' 24'' | 62 | 3.65 | 1 |
| 29° 43' | 48° 06' 12'' | 310 | 18.24 | 2 |
| 29° 44' | 48° 04' 48'' | 372 | 21.88 | 2 |
| 29° 45' | 48° 03' 00'' | 434 | 25.53 | 3 |
| 29° 46' | 48° 02' 30'' | 372 | 21.88 | 2 |
| 29° 47' | 48° 02' 12'' | 186 | 10.94 | 2 |
| 29° 48' | 48° 01' 48'' | 124 | 7.29 | 1 |
| 29° 49' | 48° 01' 12'' | 124 | 7.29 | 1 |
| 29° 50' | 48° 01' 00'' | 124 | 7.29 | 1 |
| 29° 51' | 48° 00' 48'' | 124 | 7.29 | 1 |
| 29° 52' | 48° 00' 48'' | 248 | 14.59 | 2 |
| 29° 53' | 48° 01' 00'' | 310 | 18.24 | 2 |
| 29° 54' | 48° 01' 12'' | 496 | 29.18 | 3 |
| 29° 55' | 48° 00' 36'' | 1240 | 72.94 | 3 |
| 29° 56' | 48° 00' 24'' | 1984 | 116.70 | 3 |
| 29° 57' | 48° 00' 24'' | 620 | 36.47 | 3 |
| 29° 58' | 48° 00' 24'' | 620 | 36.47 | 3 |
| 29° 59' | 48° 00' 48'' | 310 | 18.24 | 2 |

## CONCLUSION

Any country with coastline/shoreline should know the general trend of shoreline changes for a long period of time. Erosion and accretion are common coastal phenomena. Both nature induced force and man-made effect contribute for the shoreline changes. The shoreline change for Kuwaiti coastal area is studied using remote sensing images from 1989 to 2006-07. Most of the Kuwaiti coastal stretches show trend of sediment accretion. Only few locations show erosions during 1989-2006. The value of the erosion and accretion index given in this paper may be of use for identifying suitable coastal sites for different types of future coastal projects. Further study is needed for fine tuning of the present results.

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## REFERENCES

Neelamani, S., Saif ud din, Rakha, K., Zhao, Y., Al-Nassar, W., Al-Banaa, K., Al-Salem, K., Al-Othman, A. and Alragum, A. (2007). "Coastline Evolution of Kuwait Using Remote Sensing Techniques, EC022C. Final Report, KISR 9051.

Neelamani, S. and Saif ud din. (2009a). Investigation on Coastline Evolution – A case study for Kuwaiti Coast. International Conference in Ocean Engineering, Feb. 1-5, IIT Madras, India, pp.721-734.

Neelamani, S. and Saif ud din. (2009b). Kuwaiti coastline evolution during 1989 to 2003. Second Conference & Exhibition on Environment & Sustainability, 16-19, Kuwait, pp.787-803.

Neelamani, S. and Saif ud din. (2010). Evolution of Coast in the Vicinity of a Seawater Intake Structure in Kuwait. International Journal of Imaging, **3**, 3-22.

Neelamani, S., Saif uddin and Anbazagan, S. (2011). Kuwait coastline Evolution during 1989-2007. Book chapter in Geoinformatics in Applied Geomorphology, Chapter 5, CRC Press, Taylor & Francis, USA, pp. 87-104.