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An assessment of natural and human-induced changes along Hurghada and Ras Abu Soma coastal area, Red Sea, Egypt

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Abstract. The Red Sea coastal zone is characterized by its sensitive, fragile, unique natural resources and habitats. In the Hurghada coastal region, major changes in the tourism industry have taken place in the last few decades. The detection of environmental changes, in a selected site of the Red Sea coastal zone, will be helpful to protect and develop this coastal environment.

A methodology for separating natural and man-made changes in satellite images was developed. It was based on the following assumptions: (1) slow changes, which occur within the range of the class reflectance, represent a natural change rather than an anthropogenic one; (2) natural changes tend to be in the same land-use/land-cover class in each date, i.e. slow changes in the reflectance, not leading to changes in the type of land-use/land-cover class from the master image to the destination one; and (3) rapid changes in the reflectance of the Earth's objects are usually related to anthropogenic activities. This technique is used to identify and assess changes along the coast of Hurghada and Ras Abu Soma, the Red Sea.

Results indicate serious human impacts and the necessity for control measures and monitoring. Recommendations are presented.

1. Introduction

The Red Sea coastal zone is characterized by its sensitive, fragile, unique natural resources and habitats. Hurghada, as a representative part of the Red Sea coastal zone, is characterized by a wide diversity of natural resources, such as coral reefs, mangroves, sandy beaches, clear water and skies, barren terrain and many rare wildlife species. In the Hurghada coastal region, major changes in the tourism industry, with an increased rate of building hotels and tourism villages, have been experienced in the last few decades. So, the detection of environmental changes, in a selected site, and for Hurghada in particular, will be helpful to protect and develop this coastal environment.

The study area, shown in figure 1, is located in the north-western part of the Red Sea coastal zone. It lies between 33° 42′ and 34° 01′ E, and 26° 48′ and 27° 18′ N. The study area is divided into two sectors, Hurghada and Ras Abu Soma. The northern sector, Hurghada, is already developed without any sustainable planning.

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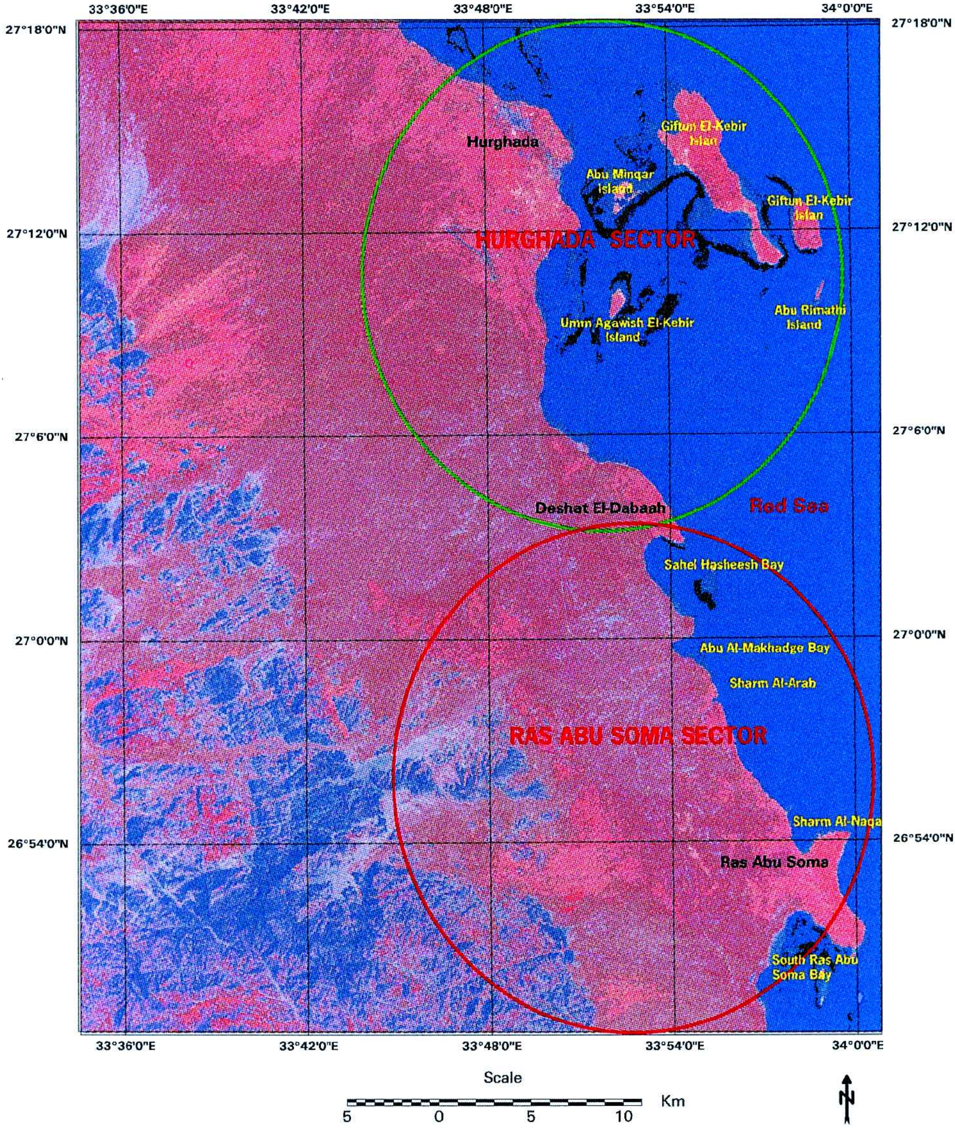

Figure 1. The study area of Hurghada and Ras Abu Soma coastal zone.

The southern sector, Ras Abu Soma, is the most promising one for tourist development.

The main aim of this study was to determine if satellite data can be used to identify natural changes and human-induced changes in the coastal zone. A change detection analysis is suggested. Change detection is the process of identifying differences in the state of an object or phenomenon by remotely observing it at different times.

Many methods for change detection using digital data have been proposed (e.g. Singh 1989). These methods include: (1) comparison of land cover classifications; (2) multi-date classifications; (3) image differencing/rationing; (4) vegetation index differencing; (5) principal components analysis, and (6) change vector analysis. An enhanced classification approach which combines image enhancement to isolate and identify change dynamics has been developed by Pilon *et al.* (1988). Before the change detection is performed, the two images must be precisely registered to a sub-pixel accuracy (Nagi *et al.* 1994). In the final stage, a separate classification is carried out for each date of images. Then, a comparison between the two classified maps is possible on a pixel-by-pixel basis (Jensen and Ramsey 1987).

The simple differencing technique of change detection can be used when images from two similar dates are available. However this requires user intervention to specify a suitable threshold to identify the environmental changes (Slogget *et al.* 1994).

The principal components analysis is one of the most popular techniques for the analysis of remotely sensed data. According to Fung and Ledrew (1987), the principal components can be standardized using the correlation matrix to minimize the differences due to atmospheric conditions or sun angles. It was noticed that land cover changes appeared clearly in minor principal components.

Singh (1989) concluded that there are two basic approaches for change detection: (1) comparative analysis of independently produced classification for different dates; and (2) simultaneous analysis of multi-temporal data. Martin (1989) found that the comparative analysis approach of separate images produced a higher level of change detection accuracy.

2. Methodology

In this study the remotely sensed data is used to detect the environmental changes, and to differentiate between natural and anthropogenic changes.

2.1. *Data description*

The following data was used.

2.1.1. *Remotely sensed data*

Two digital Landsat Thematic Mapper (TM) scenes, for near spring-time (Path = 174 and Row = 41), were used in this study to detect the overall environmental changes throughout the coastal zones of Hurghada and Ras Abu Soma sectors. The first scene is dated 9 June 1984, and the second one is dated 19 May 1991.

2.1.2. *Field data*

Extensive efforts were made to collect data about landfilling activities through field observations and interviews with local inhabitants. Both land and marine sectors from Hurghada to Ras Abu Soma coastal zone were covered with extensive field survey using GPS to verify the accuracy of classified images, as well as changed areas. According to interviews with inhabitants and field observations, major human-induced changes happened to the shoreline configuration.

2.2. *Data processing and technique*

Based on Pilon *et al.* (1988), the enhanced classification approach was applied, after modification to separate natural environmental changes from human-induced ones. Separation was based on the following assumptions: (1) slow change which occurs within the range of the class reflectance represents a natural change rather than an anthropogenic one; (2) natural change tends to occur in the same land-use/land-cover class, i.e. slow changes in the reflectance, not leading to changes in the type of land-use/land-cover class from the master image, are natural ones; and

(3) rapid changes in the reflectance of the Earth's objects are mainly related to anthropogenic activities. In this technique, the multi-date enhancement was applied to define the spectral changes. The multi-date classification is used to define the nature of changes. The combination of multi-date enhancement and multi-date classification components is used to separate areas of natural and human-induced changes. The flow chart of enhanced classification procedures appears in figure 2.

The recent date was geometrically corrected to the Universal Transverse Mercator projection, with Helmert spheroid, and 30 m grid. Ten well distributed ground control points, obtained from 1:25 000 scale topographic maps (Egyptian Military Survey 1991), were selected to calculate the geometric transform. The full TM image of the

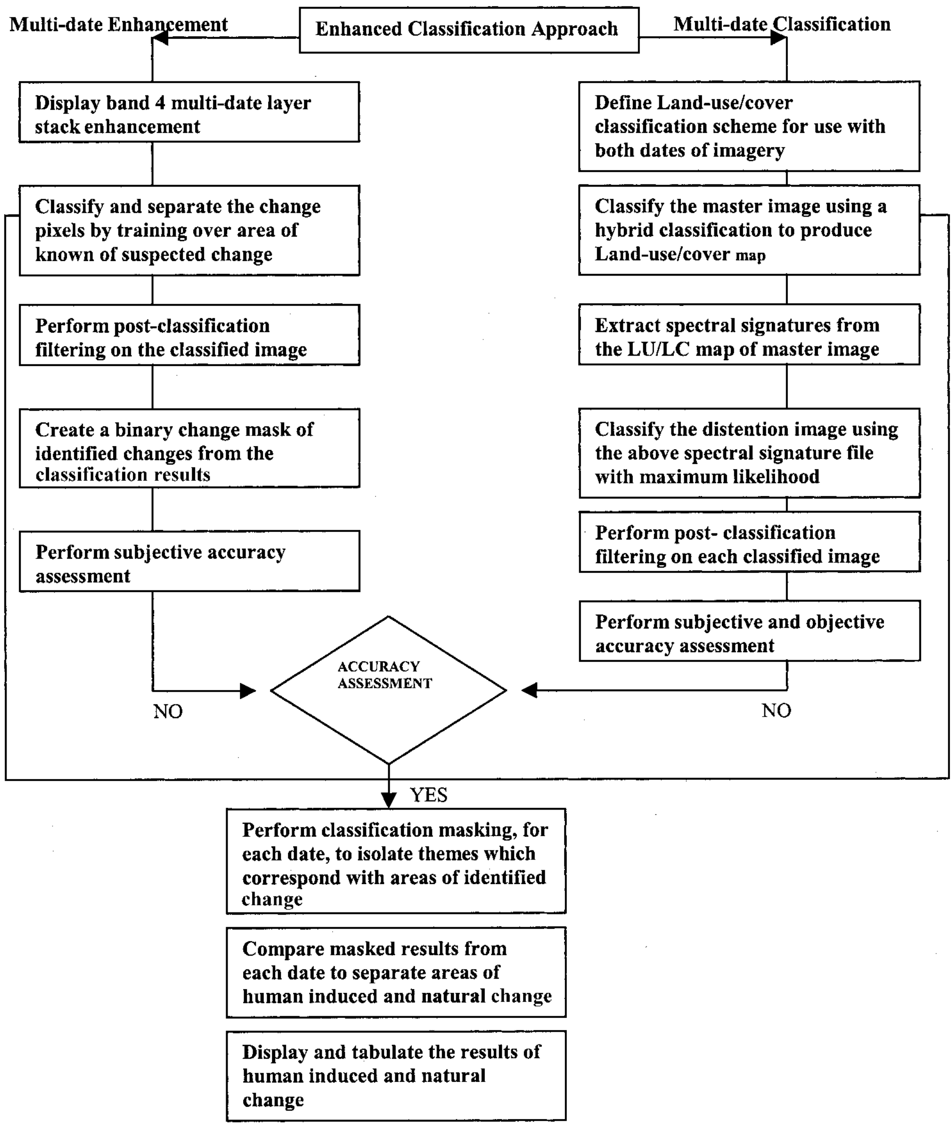

Figure 2. Flow chart of the enhanced classification procedure.

study area was resampled using the nearest neighbour method. This image was used as the master image in the process of image-to-image registration. The destination image dated 19 June 1984 was registered to the master one of 19 May 1991. Fourteen well-distributed ground control points were selected to calculate the transformation coefficients. It was registered using nearest neighbour resample method, second-order polynomial transformation. Haze reduction was applied for the two dates to minimize effects related to the differences in atmospheric conditions.

2.2.1. *Multi-date enhancement and creating a binary change mask*

To apply the multi-date enhancement technique, the subsets of band 4 from each date for Hurghada and Ras Abu Soma study areas were obtained. To isolate changed pixels from unchanged ones, training areas were created over areas of highest intensity of changes (i.e. dark red and dark green). These areas were verified in the field and identified as changed areas. These training areas were used to produce a signature file, which was used to run a maximum likelihood classifier. The classification result was used to construct a binary change mask, which was used to sieve out changes from the land-use/land-cover maps of each date. A post-classification filtering using majority function, 3×3 pixel size, was performed to reduce the noise in the classified image.

A binary change mask was created by recoding the classified results of the multi-date enhancement technique. The changed areas were assigned a value of 1, while the unchanged areas were assigned a value of 0. The resultant binary change mask was subsequently used on the modification of land-use/land-cover maps for each date to produce the classification masks.

2.2.2. *Multi-date classification*

Unsupervised classification for each date is applied before the field work. The results of classification is used in conjunction with field investigations and other available data about the study areas, to identify suitable land-use/land-cover categories.

The sub-scenes of 1984 were used to produce the land-use/land-cover maps, using a hybrid classification procedure.

Band 4 was used to produce a texture theme of the study areas. Six spectral bands from the sub-scenes of study areas (1, 2, 3, 4, 5 and 7) were used to produce the first three principal components (PC1, PC2 and PC3). The six spectral bands, one texture theme, and three principal components were combined in band sequential file, using layer stack function, to produce an image file of 10 bands for each study area. The land and water sectors were separated using a binary mask.

Unsupervised classification was carried out for the water sector to produce 15 classes. The resultant signature file was modified to contain eight separable signatures only. The modified signature file was used to run a supervised maximum likelihood classifier to produce the classified image of water sector for each study area.

Supervised classification was carried out to classify land sectors for each study area. The training areas from feature space (band 3 and 5), as well as from specific objects on the image, were used to create a signature file to be used with a maximum likelihood classifier to produce land categories. This file contained three spectral signatures for urban areas, coastal sediments and basement rocks. Classified images of water and land sectors were collected using GIS analysis functions to produce the land-use/land-cover maps of the 1984 date for each study area.

The previous procedures for producing band combinations from 10 layers were applied to the sub-scenes of the 1991 date for each study area. The two signature files of land and water sectors are used to classify land and water sectors of 1991. The classified images of land and water sectors were collected, using GIS functions, to produce the land-use/land-cover maps of 1991 for each study area.

2.2.3. *Combining enhancement and classification components*

A combination of enhancement and classification results was used to produce classification masking. In figure 3, the binary change mask (image 1) was multiplied by the land-use/land-cover map for each date (image 2) to produce the masked classification of 1984 and 1991 (image 3). To produce the natural change mask (figure 4), the following procedures were applied:

(a) A constant value of 128 is added to every pixel on the masked classification image of 1991 (image 1). The masked classification image of 1984 (image 2) is then subtracted from the above modified 1991 image.
(b) All areas of natural change or no change had a value of 128 on the resultant image (image 3). It was multiplied by the binary change mask (image 4) to separate areas of natural change from those of no change (image 5). Now, all areas of natural change had a value of 128.
(c) To produce the natural change mask (image 6), all values of 128 were recoded to 1, and other values were recoded to 0.
(d) To separate the natural change from the human-induced one, the natural change mask (image 2) was subtracted from the binary change mask (image 1) to produce the human-induced change mask (image 3) (figure 5).

3. Results and interpretation

The result of the registration process shows that the root mean square error (r.m.s.) was 0.4 pixel. This error value is considered reasonable for the change detection process (Pilon *et al.* 1988).

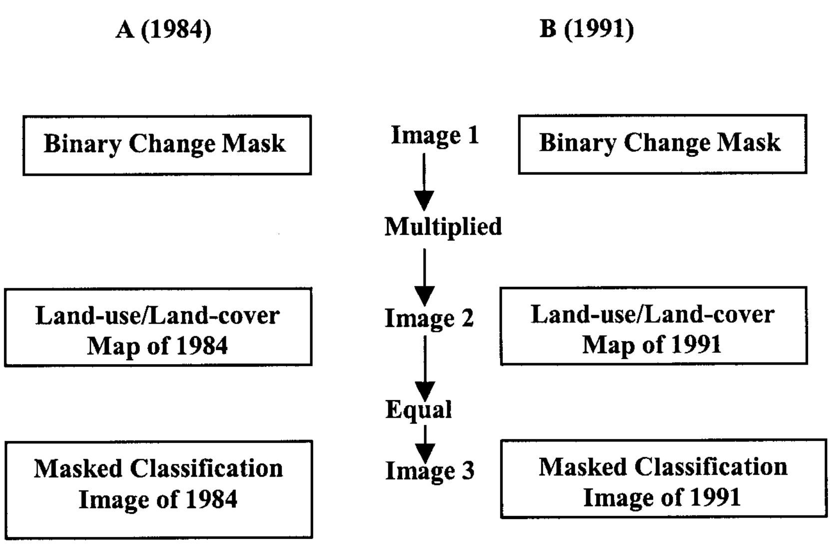

Figure 3. Procedures for producing the classification mask of each date.

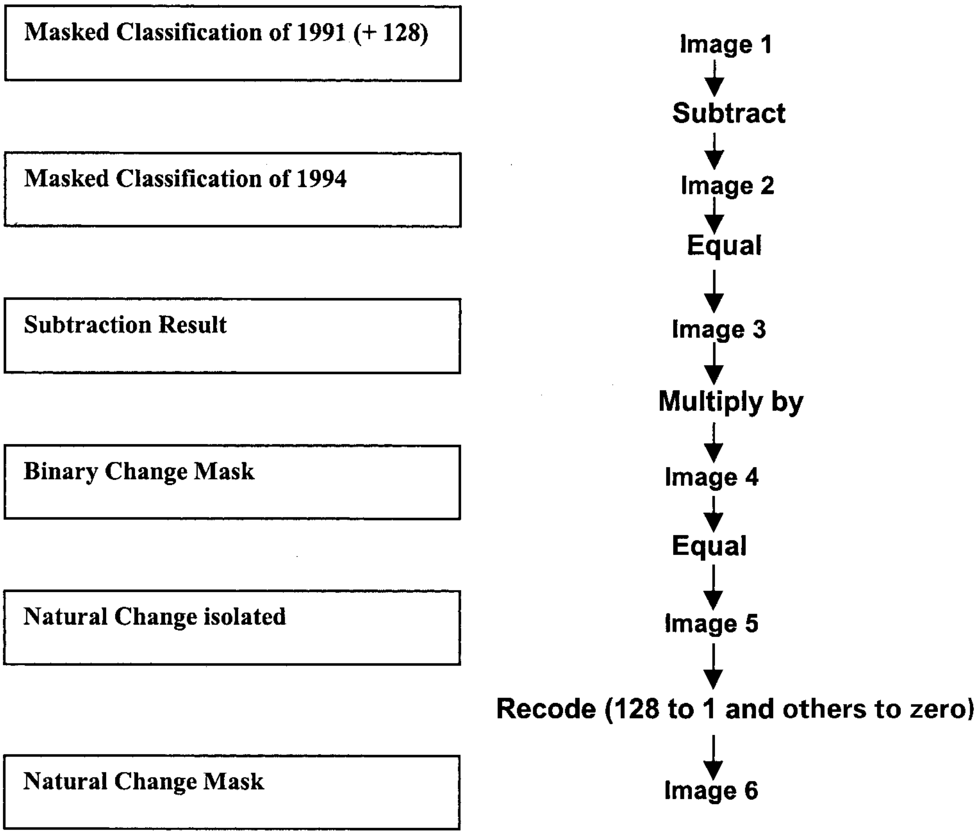

Figure 4. Procedures for identifying areas of natural changes.

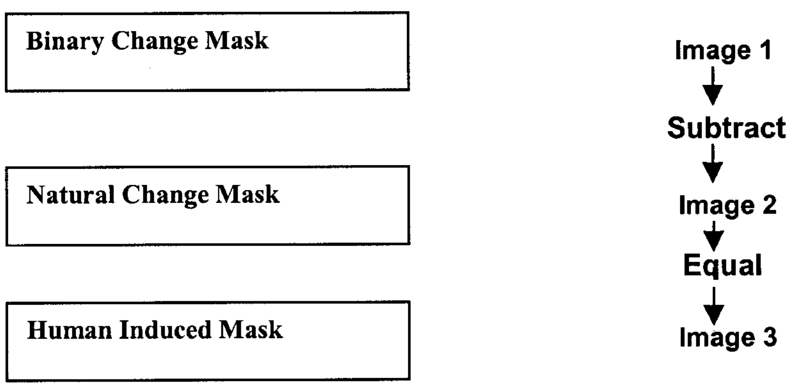

Figure 5. The process of separating human-induced change from natural ones.

3.1. *Multi-date enhancement*

Figure 6 illustrates environmental changes extracted from multi-date band combination in the coastal zone of both study area. It shows that the environmental changes have either a red or green colour. The reasons for these changes can not be obtained from the results of the enhancement process. In the Hurghada study area,

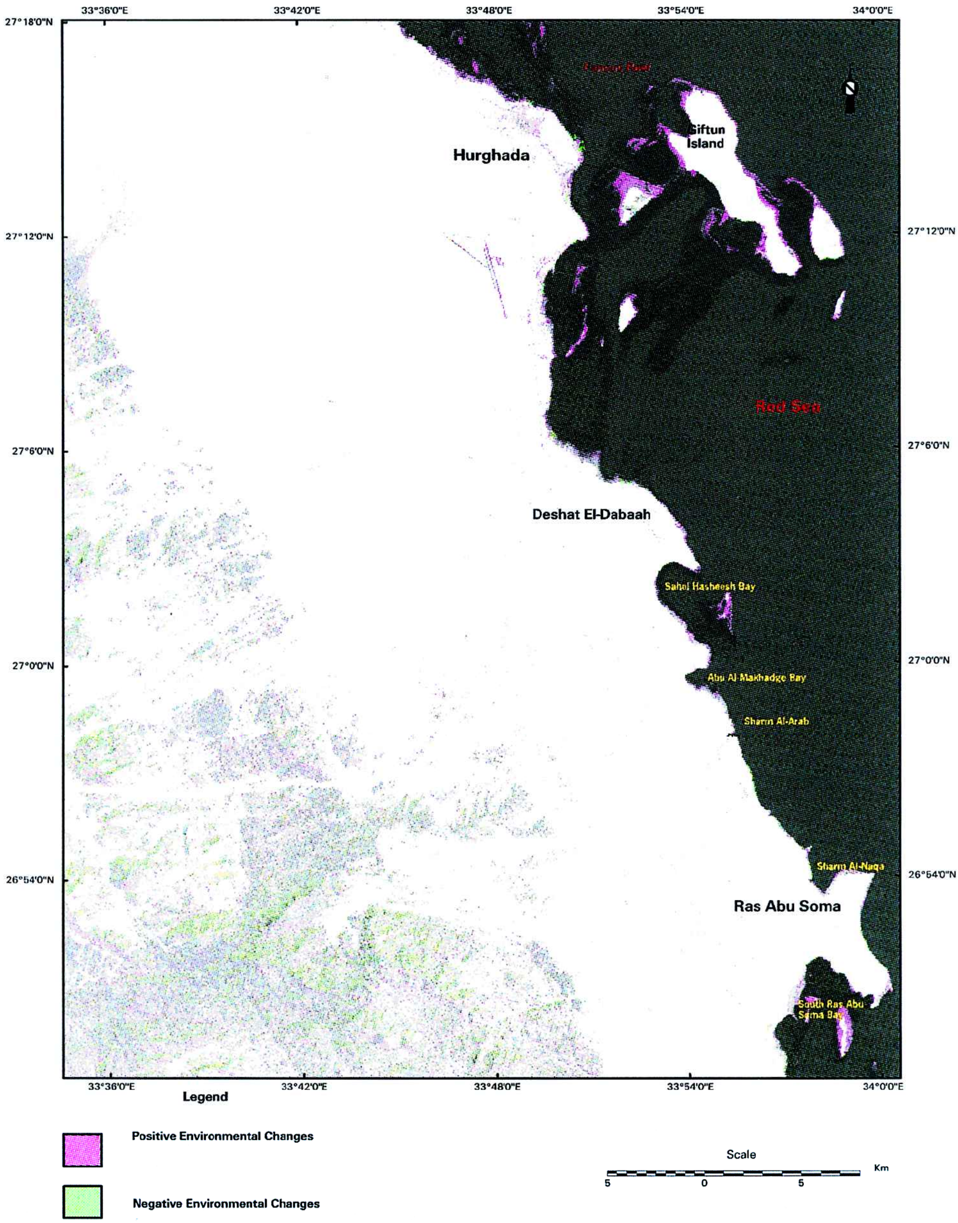

Figure 6. Environmental changes extracted from multi-dates (1984–1991) bands combination throughout the coastal zone from Hurghada to Ras Abu Soma.

the environmental changes are concentrated around: (1) coral islands; (2) main coral reefs and diving sites; (3) the shoreline; (4) old urban areas and roads network; and (5) Hurghada airport. Field investigations showed that most changes which occurred on the shoreline of the Hurghada region were related to the landfilling activities. Figure 6 shows that Ras Abu Soma region to the south is a promising site for tourism activities. It is characterized by beautiful sandy beaches, some coral islands and very healthy fringing coral reef communities. These should be carefully maintained through a sustainable development plan. The size of environmental changes in this region is very low compared with that in the Hurghada region. The main changes in the water sector are in the intertidal flats, while the main changes in the upland sector are to the west, in the basement rocks.

3.2. *Multi-date classification*

The land-use/land-cover classification scheme used with each date of imagery includes 11 classes. There are three classes in the upland sector, and eight classes in the water and intertidal sector. Figure 7 illustrates the land-use/land-cover map of Hurghada and Ras Abu Soma regions extracted from Landsat TM image dated 9 June 1984, using hybrid classification procedures. This map contains 11 classes and shows limits of urban areas (orange), in the Hurghada region. The seagrass and natural vegetation (pink–red) are predominant near the shoreline and in the intertidal zone. The intertidal flat class with patches of seagrass (pink) is predominant in contact with the shoreline of upland sector, as well as the shoreline of coral island. There are two types of patchy corals on sandy bottom. The first one (beige) lies in the inner zone and has a healthy living coral patches. The second one (dark blue) lies in the middle zone. It contains small living patches of living coral on sand bottom, in addition to fossil and dead coral patches scattered in the zone. The most popular class in the water sector is the class of patchy corals (yellowish-brown) in carpet of seagrass (inner zone). The very healthy living corals with high density appears in yellow. The most popular diving sites, in Hurghada region, are allocated in contact with this class. Figure 7 also illustrates that the intertidal flat class (pink) with patches of seagrass, and patchy corals on a carpet of seagrass class (yellowish-brown) are predominant in Ras Abu Soma region. Also, the class of living coral with high density (yellow) is predominant in the form of fringing coral reef parallel to the shoreline from north to the south.

The visual interpretation of land-use/land-cover map of Hurghada study area shows the following changes in the land-use/land-cover classes:

(1) increase of urban areas (orange), especially toward the shoreline;
(2) decrease of the living corals class (yellow) throughout the water sector;
(3) decrease of the seagrass and natural vegetation class (pink–red), especially to the west and south of shoreline reef;
(4) increase of the damaged corals because of increasing the class of small patchy corals on sand and fossil reef (dark blue); and
(5) decrease of patchy corals in carpet of seagrass class (yellowish-brown), especially to the south of Sheraton reef.

Thus, the visual analysis shows significant human-induced environmental changes in Hurghada. In Ras Abu Soma, minor changes occurred, mostly related to natural processes.

3.3. *Combining enhancement and classification components*

The above-mentioned results, of enhancement and multi-date classification procedures, gave us only an idea of the magnitude of changes, without information on the nature and type of these changes. Combining both techniques helps to separate the natural and human-induced changes.

Figure 8 illustrates environmental changes which occurred in the Hurghada coastal zone from 1984 to 1991. Visual interpretation and extensive field surveys

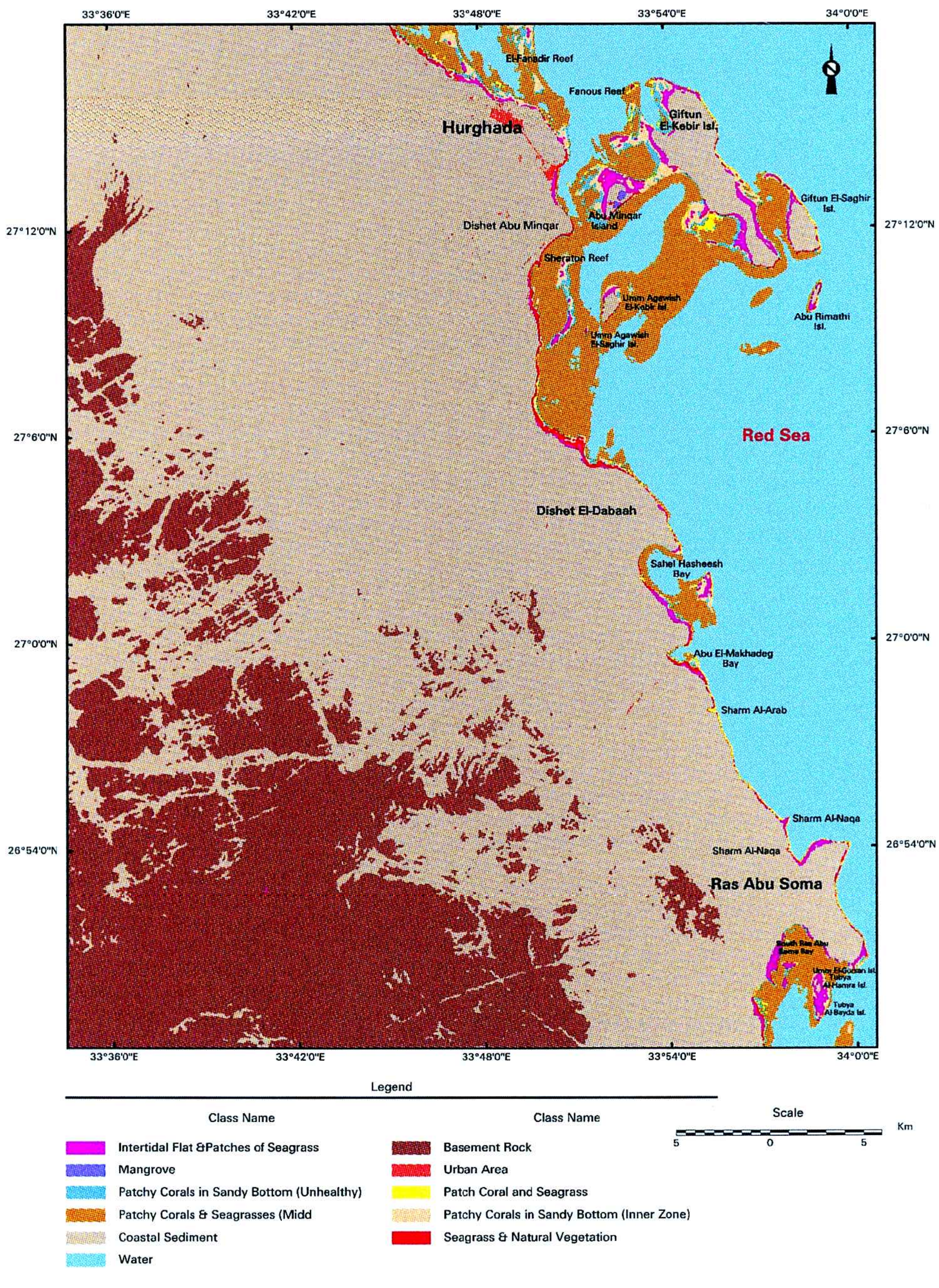

Figure 7. Land-use/land-cover map (1984) of Hurghada and Ras Abu Soma coastal zone.

were carried out to verify the results of environmental changes, both on upland and on water sector. Figure 8 shows that significant environmental changes occurred in the Hurghada region from 1984 to 1991. Environmental changes, related to the natural processes (yellow), were concentrated in the intertidal flats, as well as around the urban areas on the upland sector. The upland natural changes may be related

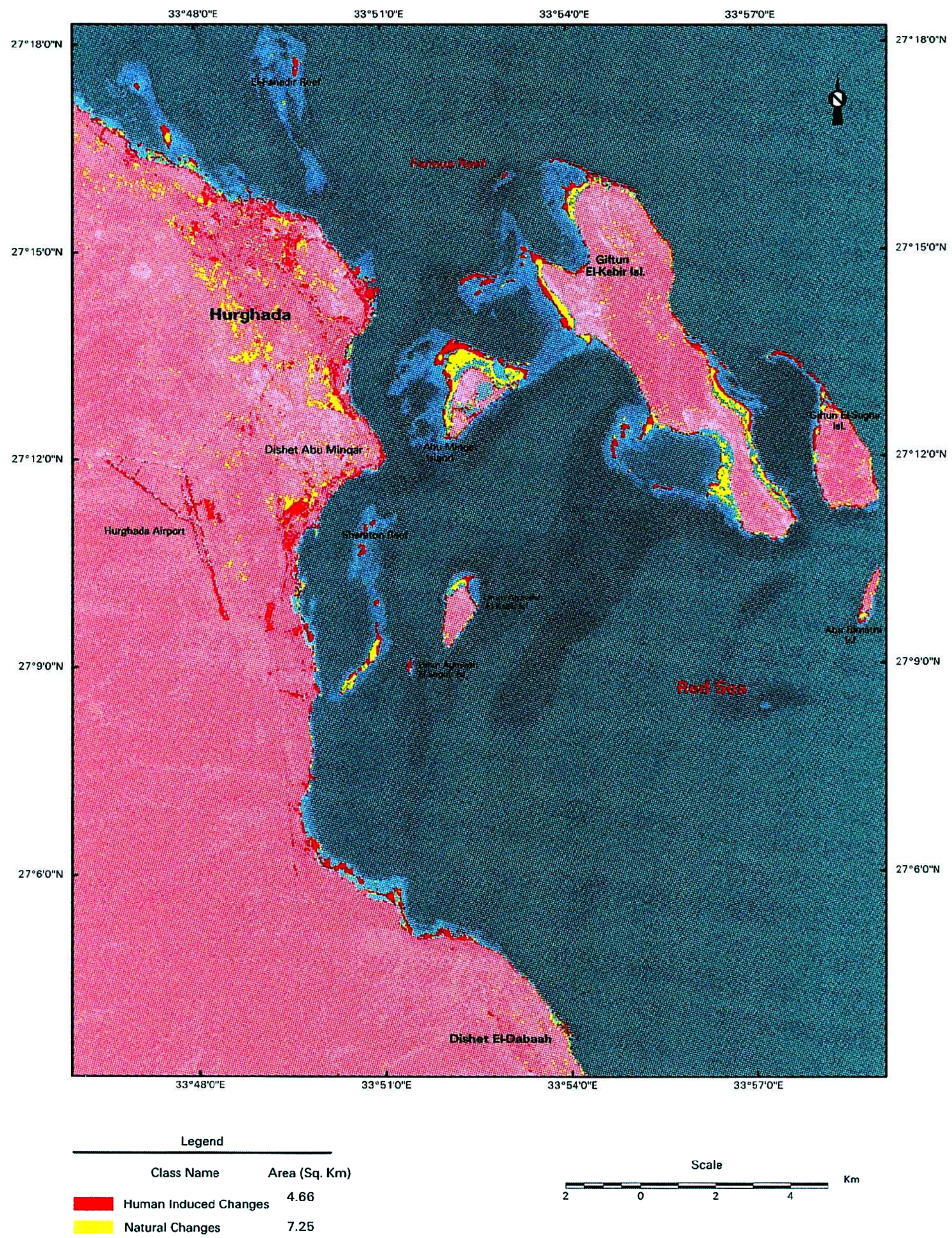

Figure 8. The natural and human-induced environment changes from 1984 to 1991 for the Hurghada coastal zone using the enhanced classification approach.

to the accumulation and changes in the magnitude of coastal dunes. Meetings with fishermen and divers in Hurghada also helped to verify results of multi-date classification, as well as results of environmental changes.

The human-induced changes (red), on the upland sector were due to the expansion of the urban areas. The changes in the urban area can be divided into two categories. The first is the natural expansion of the existing urban area. The second, and important one, is the unplanned landfilling throughout the shoreline of Hurghada. The construction of the airport runway, as well as the re-paving of the old runway and the new building of Hurghada airport, are separated as human-induced changes.

The human-induced changes were predominant in both sectors in the Hurghada region. All the land-use/land-cover classes in the water sector were affected by human-induced changes. All types of living coral reefs were affected seriously. Field investigation and meetings with the local inhabitants indicated that human-induced changes, which were detected on Fanous reef, were mainly related to extensive use of dynamite on fishing processes. Human-induced changes to the south of Abu Rimathi island were related to extensive anchoring of diving boats in the living coral reef. Serious damage occurred to the healthy living corals at the north barrier reef of Giftun El-Saghir island, as well as to the north-east of Giftun El-Kebir island, due to physical damage from extensive diving, in addition to anchoring of diving boats on the living coral reefs.

There are two common factors for human-induced changes in the water sector of the Hurghada region:

(1) The presence of fine sediments layer which was recorded during field investigations throughout most changed areas. This may be due to the indirect effect of landfilling. The NE–SW prevailing waves, as well as longshore current, may have transported and precipitated the fine sediments from landfilling processes over the changed areas.
(2) The long-term effect from the recorded oil pollution throughout the coastal zone of Hurghada and its coral islands (Barratt 1982, Heathcote *et al.* 1984).

Figure 9 illustrates the two types of environmental changes in Ras Abu Soma area. The natural changes (yellow) were predominant in the upland sector as well as in the water sector. In the upland sector, the natural changes were concentrated in the mountainous basement land to the west. Some natural changes can be seen in the Ras Abu Soma peninsula, in the form of coastal dunes. In the water sector, the size of natural changes was larger than that of human-induced ones. Some human-induced changes to the south of Ras Abu Soma peninsula were due to the anchoring of diving boats in the living coral reefs (Mohamed and Abul-Azm 1992). Other human-induced changes throughout the coastal zone of Ras Abu Soma study area may be related to the long-term effects of the documented oil pollution throughout the shoreline (Barratt 1982, Heathcote *et al.* 1984). A very serious human-induced change, especially in the water sector of Hurghada study area, is the significant decrease of coral fish related to overfishing activities.

Table 1 represents the human-induced changes in Hurghada area. It shows that the major human-induced changes occurred in two classes: the urban area and the patchy corals on sandy bottom. Minor changes occurred in the basement rock. Table 2 illustrates that major human-induced changes occurred in three classes: patchy corals on sandy bottom, seagrass and natural vegetation, and intertidal flat with patches of seagrass. Other classes were almost unaffected. Tables 3 and 4 represent statistical summaries of the natural changes. Table 5 illustrates increased human activities in Hurghada as compared to Ras Abu Soma region.

4. Conclusion and recommendations

It is concluded that remote sensing and ground-based surveys offer a very valuable tool for monitoring and assessment of the changes over the coastal area of the

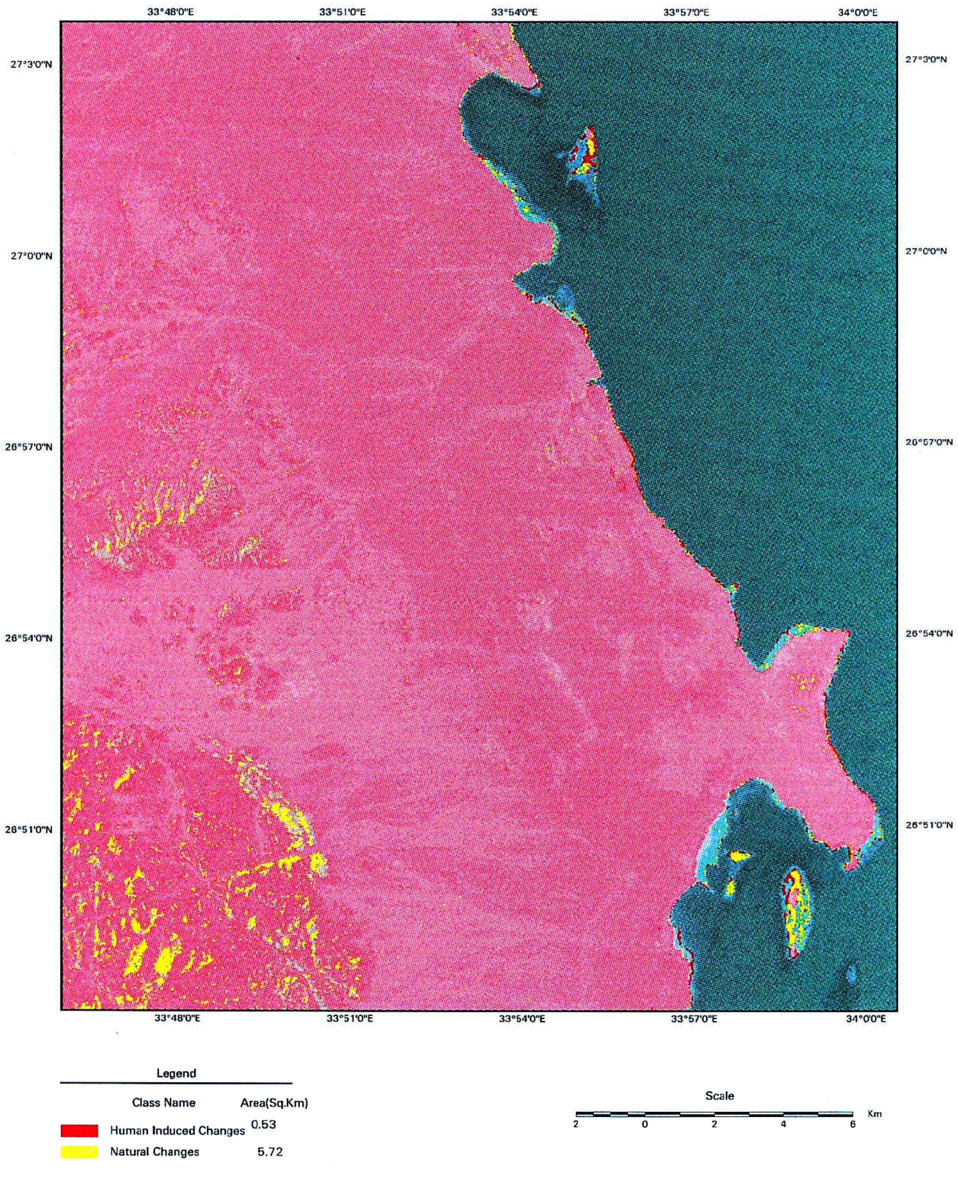

Figure 9. The natural and human-induced environment changes from 1984 to 1991 for the Ras Abu Soma coastal zone using the enhanced classification approach.

Red Sea. The same technique could be used for monitoring, law enforcement and integrated management of the area. The following recommendations are given to support the decision makers and planners to protect the sensitive environment throughout the Red Sea coastal zone.

(1) Landfilling processes should be prohibited throughout the shoreline of Red Sea.
(2) An extensive monitoring program using the remotely sensed data should be carried out to monitor changes due to landfilling, if they occur.

Table 1. Summary of the human-induced changes (1984–1991) for the Hurghada area.

	Class	Count (pixel)	%	Area (km^2)
1	Intertidal flat with patches of seagrass	499	9.64	0.4491
2	Mangrove	39	0.75	0.0351
3	Patchy corals on sand and fossil reef (middle zone)	272	5.25	0.2448
4	Patchy corals in carpet of seagrass (outer zone)	87	1.68	0.0783
5	Coastal sediment	168	3.25	0.1512
6	Water	11	0.21	0.0099
7	Basement rock	9	0.17	0.0081
8	Urban area	1874	36.20	1.6866
9	Living corals (high density)	172	3.32	0.1548
10	Patchy corals on sandy bottom (inner zone)	1528	29.52	1.3752
11	Seagrass and natural vegetation	518	10.01	0.4662
	Total	5177	100.00	4.6593

Table 2. Summary of the human-induced changes (1984–1991) for the Ras Abu Soma area.

	Class	Count (pixel)	%	Area (km^2)
1	Intertidal flat with patches of seagrass	145	24.45	0.1305
2	Mangrove	0	0.00	0.0000
3	Patchy corals on sand and fossil reef (middle zone)	3	0.51	0.0027
4	Patchy corals in carpet of seagrass (outer zone)	5	0.84	0.0045
5	Coastal sediment	84	14.17	0.0756
6	Water	0	0.00	0.0000
7	Basement rock	2	0.34	0.0018
8	Urban area	0	0.00	0.0000
9	Living corals (high density)	45	7.59	0.0405
10	Patchy corals on sandy bottom (inner zone)	159	26.80	0.1431
11	Seagrass and natural vegetation	150	25.30	0.1350
	Total	593	100.00	0.5337

Table 3. Summary of the natural changes (1984–1991) for the Hurghada area.

	Class	Count (pixel)	%	Area (km^2)
1	Intertidal flat with patches of seagrass	2722	33.80	2.4498
2	Mangrove	12	0.15	0.0108
3	Patchy corals on sand and fossil reef (middle zone)	93	1.15	0.0837
4	Patchy corals in carpet of seagrass (outer zone)	5	0.06	0.0045
5	Coastal sediment	4218	52.37	3.7962
6	Water	4	0.05	0.0036
7	Basement rock	4	0.05	0.0036
8	Urban area	359	4.46	0.3231
9	Living corals (high density)	42	0.52	0.0378
10	Patchy corals on sandy bottom (inner zone)	301	3.74	0.2709
11	Seagrass and natural vegetation	294	3.65	0.2646
	Total	8054	100.00	7.2486

Table 4. Summary of the natural changes (1984–1991) for the Ras Abu Soma area.

	Class	Count (pixel)	%	Area (km^2)
1	Intertidal flat with patches of seagrass	1228	19.31	1.1052
2	Mangrove	0	0.00	0.0000
3	Patchy corals on sand and fossil reef (middle zone)	32	0.50	0.0288
4	Patchy corals in carpet of seagrass (outer zone)	0	0.00	0.0000
5	Coastal sediment	794	12.48	0.7146
6	Water	0	0.00	0.0000
7	Basement rock	3958	62.24	3.3622
8	Urban area	0	0.00	0.0000
9	Living corals (high density)	108	1.70	0.0972
10	Patchy corals on sandy bottom (inner zone)	86	1.35	0.0774
11	Seagrass and natural vegetation	154	2.42	0.1386
	Total	6360	100.00	5.7240

Table 5. Comparison between human-induced and natural changes in the Hurghada and Ras Abu Soma regions.

	Type of change	Site	Area (km^2)
1	Human-induced change	Hurghada region	4.66
		Ras Abu Soma region	0.53
2	Natural change	Hurghada region	7.25
		Ras Abu Soma region	5.72

(3) The coral islands distributed in the Red Sea, such as Giftun, Abu Minquar and Umm Agawish islands, should be designated protected areas.
(4) Enforcement of the law (4/94) should be carried out to the investigated region.
(5) Periodic closure for some sensitive areas is very important to breeding of certain species, especially after human or severe natural impact.

Acknowledgments

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