The Study of Multi-temporal Analysis of Urban Development and Environmental Changes of the City of Abu Dhabi

H. Hussein and M. Hussein

Abstract The city of Abu Dhabi is the capital of the United Arab Emirates. It is located on the coast of the Arabian Gulf. Forty years ago the area of Abu Dhabi was composed of nothing but a desert except a small number of buildings. When the Emirates united in the year of 1971, and the late His Highness Sheikh Zayed Bin Sultan Al Nahyan, had his vision of turning the city of Abu Dhabi specifically and the UAE generally into one of the most beautiful countries in the world. Both urban expansion and vegetation bloomed in the country. Abu Dhabi now has one of the highest GDP growth rates in the world, indicating the dramatic increase of urban areas, occupying and building cities, islands, and roads. This project studies the growth of Abu Dhabi city by studying the urban expansion and the percentage of vegetation throughout the years: 1973–2010, using satellite imagery and remote sensing techniques.

Keywords Urban expansion · Gross domestic product · Vegetation · Normalized difference vegetation index

1 Introduction

The ever-increasing quantity of multi-temporal data provided by the numerous remote sensing satellites that orbit our planet has facilitated the synergistic use of multi-temporal remote sensing data and advanced analysis methodologies resulting in the possibility of solving complex problems related to the monitoring of the Earth's surface and atmosphere. The past 10 years have shown a significant increase

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in this topic, with plenty of research introducing algorithms to study this flood of data incoming onto our servers. One of the greatest challenges for natural and social scientists in the next decades is to understand how metropolitan areas evolve through the interactions between human behaviors and biophysical processes. The complexity of these interactions is extraordinary. However, our failure to understand and to account adequately for them in policy decisions has historically yielded infrastructure investment and land use decisions with unintended long-term effects (Alberti and Waddell 2000). Previous research has indicated that urban land use/land cover change can cause changes in ecosystem functions and services (Alberti 2005; Grannemann et al. 2000; Issa 2009; Lindenmayer and Fischer 2013; Dai et al. 2011). Many studies have sought to quantify the temporal distribution and arrangement of land cover changes from classified remotely sensed data and to estimate the environmental impact of these changes using landscape metrics. Some study the growth of cities and urban expansion. Others study the atmosphere and environmental changes. This paper uses several satellite photos acquired, to study the growth of vegetation, land, and urban expansion of the capital city of Abu Dhabi in the United Arab Emirates. This city has exhibited a dramatic growth in the short span of 40 years since the 1970s when the seven emirates joined together to form the UAE.

2 Study Area and Data Description

The city of Abu Dhabi is in the northeastern part of the Persian Gulf in the Arabian Peninsula. It is on an island less than 250 m (820 ft) from the mainland and is currently joined to the mainland by several bridges. The major land cover/use classes in the area being studied are high-density built-up, low-density built-up, parks/road vegetation. The imagery was acquired from Landsat 5 TM, Landsat 7 ETM, and ALOS-AVNIR depending on their availability over the years of 1973, 1984, 1989, 2001, 2006, and 2010. Two scenes of the ALOS satellite images were necessary for each year in order to obtain full coverage of the area. The following are the images used for studying and comparing.

- 08-19730913-LANDSAT1-MSS-007
- 08-19840429-LANDSAT5-TM-M-070
- 08-19890521-LANDSAT5-TM-M-034
- 08-20010911-LANDSAT7-ETM-M-128
- 08-20060923-ALOS-AVNIR1-195
- 08-20061010-ALOS-ANVIR2-205
- 08-20100704-ALOS-AVNIR-378
- 08-20100721-ALOS-AVNIR-379

3 Methodology

3.1 Geometric Correction and Mosaicking

All images used were corrected using standard atmospheric correction usually used for high-resolution satellite imagery. This helps in comparing several multi-temporal satellite images with different times of acquisition taking the atmosphere's effect out (Liu 2013; Liu and Mason 2013). The adjacent ALOS images were mosaicked together using standard stitching. The software ERDAS IMAGINE was used in the scope of this project.

3.2 Vegetation Analysis

Vegetation has a very unique spectral analysis with two major peaks (for reflection) one in the NIR band and another in the green band. On the other hand, the spectral analysis of vegetation shows high absorption in the red band. Therefore to investigate the vegetation areas in an image, an NDVI—Normalized Difference Vegetation Index, is used.

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red}} \tag{1}$$

The NDVI is a difference formula that then uses the division to normalize the outputted values giving an output histogram range from 0 to 1. Equation 1 was adjusted a bit to make the vegetation the only thing visible in the image while all other pixels were set to 'null'.

$$\mathrm{If}\left(\frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red}}\right) > 0.2\,\mathrm{then}\,255,\ \mathrm{else}\,\mathrm{Null}$$

Contrast enhancement is not required in this case since the outputted image shows the vegetation with color and anything else in the image is not shown at all (null).

3.3 Urban Expansion Analysis

In urban expansion manually selected areas were taken to identify the high and low-density built-up areas of the city. Once chosen, default software statistics were run.

3.4 Classification

The maximum likelihood algorithm was used to classify the images, training pixels were chosen for the classification of each land cover, and LANDSAT7 in 2001 was selected for land cover classification, this image represented the majority of variance in the data.

4 Results and Discussion

4.1 Vegetation Analysis

Inputting Eq. 1 mentioned earlier and applying this algorithm to the images provided, showed the dramatic increase of vegetation in the city of Abu Dhabi through the 30 or so years being analyzed. Figure 1 graphically shows the foliage available in the city in 1973. The scarcity of vegetation in the area can be highly noted, the merging of the vegetation highlight with the original LANDSAT image shows us where this vegetation is growing, and this can be seen in Fig. 2.

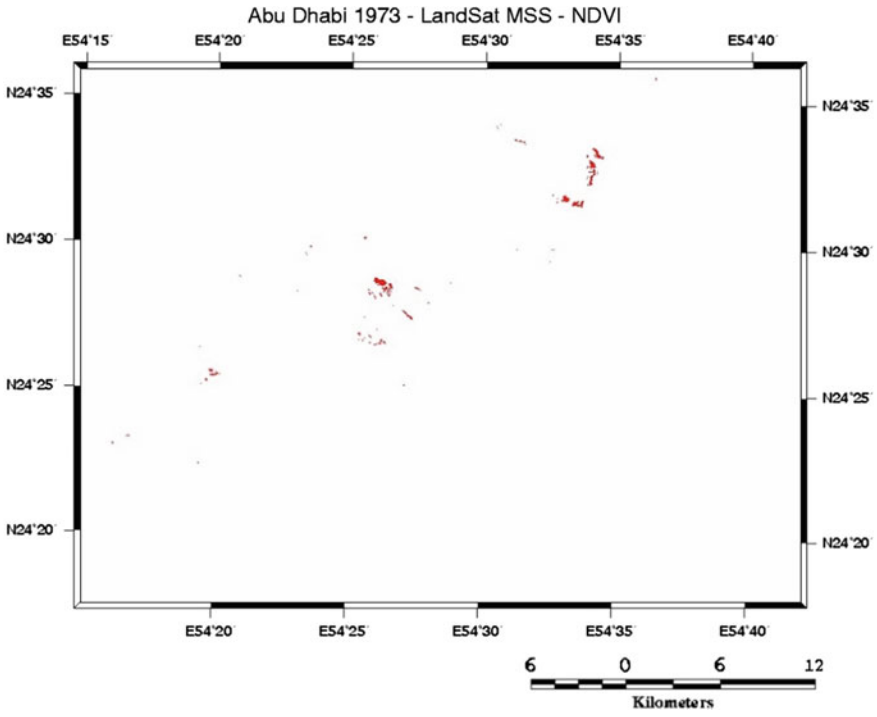

Fig. 1 Vegetation in Abu Dhabi—1973

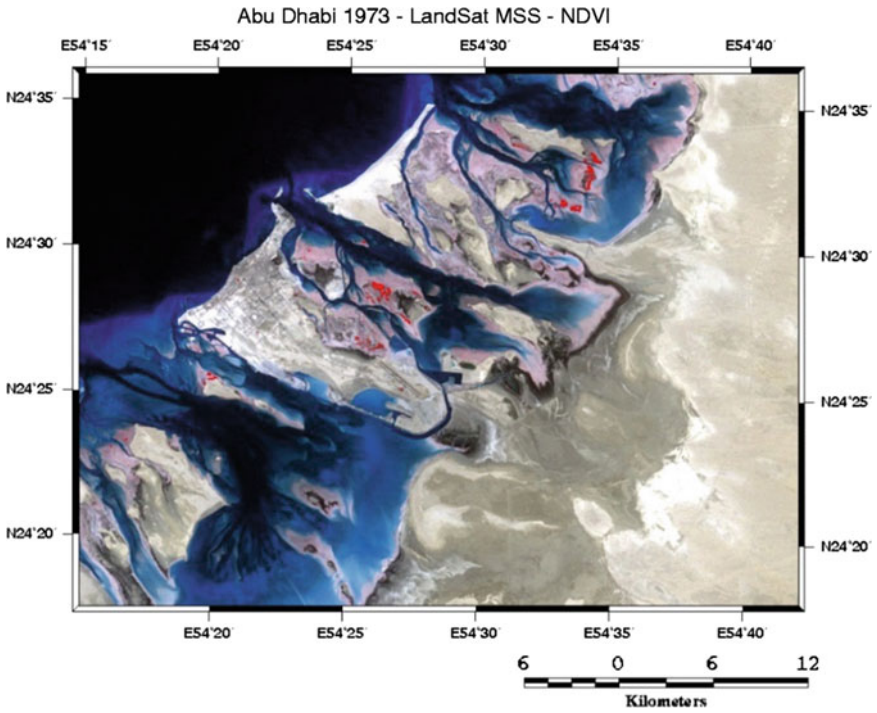

Fig. 2 Vegetation in Abu Dhabi—merged image

Looking closely it can be seen that the highlighted areas are actually in shallow water bodies, from here it can be noted that the foliage in Abu Dhabi consisted of mangroves. Mangroves are forests of salt-tolerant trees that grow in tidal waters of around the coast of Abu Dhabi. These plants are the only naturally growing vegetation in the city area.

Similar analysis was applied to all images mentioned above. For comparison, Fig. 3 shows the vegetation in 2010 of the same area.

Looking at the statistics of the two images shown above we can see that the vegetation areas in the city of Abu Dhabi have increased drastically, from 438.477 acres in 1973 to 18,279.81 acres in 2010. Figure 4 shows a graph of all the statistical data of the vegetation in Abu Dhabi between the years 1973 and 2010. It has to be clearly noted here that all vegetation increase in this city is because of human planting and watering, the UAE by nature is a desert area and plants do not flourish this dramatically without help.

A slight change in the trend in the year 2001 shown in the plot in Fig. 4, in which the vegetation did not show as much increase as the previous years, noted by the change in slope in the graph. This is due to urban expansion where in some cases to expand urban areas some of the vegetation had to be removed. Once all urban areas had been planned and mapped out, vegetation was added. Looking at

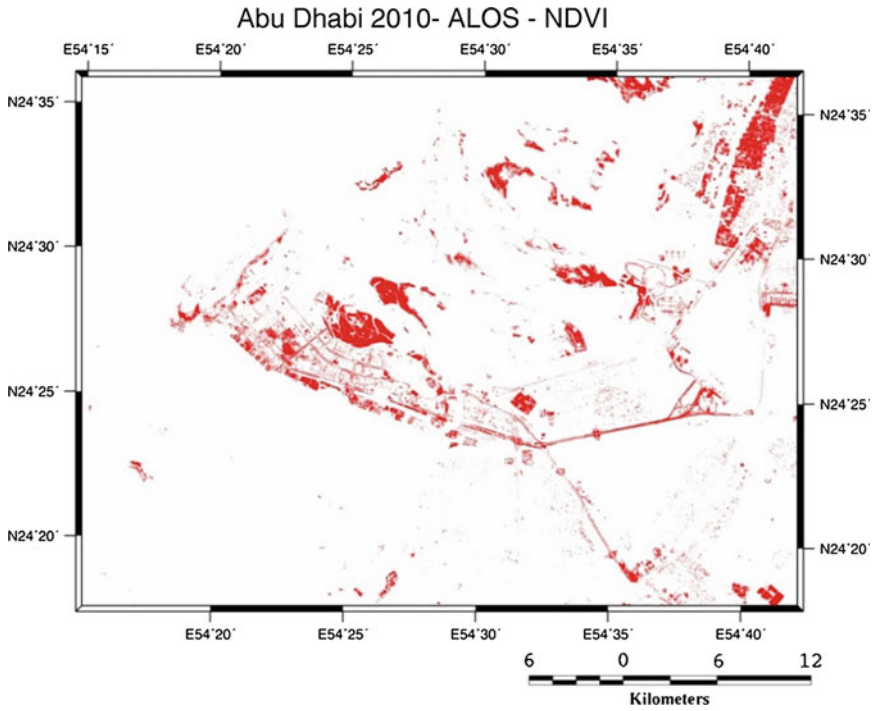

Fig. 3 Vegetation in Abu Dhabi—2010

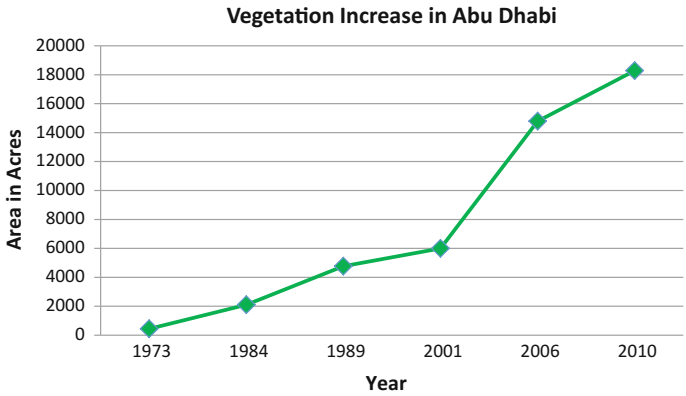

Fig. 4 Statistical data of vegetation area in Abu Dhabi

the graph further, we can see a sudden boom in the vegetation in the year 2006, increasing by almost 10,000 acres in 5 years. This then slows back down in 2010. To explain this phenomenon further, the urban areas mapping has to be done and the results compared with those of vegetation increase.

It should be noted here that almost all of the foliage seen in the city is planted and watered by man, meaning the city municipality has placed a lot of resources, manpower, money, water, and time, to better beautify the city. Usually in vegetation trends around the world, studies notice a decrease in vegetation with urban expansion. Abu Dhabi has been wise to understand the importance of planting these trees, and growing green parks for a better, healthier ergonomic city.

4.2 Urban Expansion

To investigate urban expansion in the area of Abu Dhabi city, the areas were manually chosen, labeled and the statistics for them calculated. Figure 5 shows the urban area in Abu Dhabi, in the year 1973. The selected region shows a low populated area. Looking at the image for the year 1973 there are no highly populated areas. This can be related to the statistical data of the population of Abu Dhabi shown in Table 1. In the year 1973 only 125,933 (Grannemann et al. 2000) people occupied a rough estimate of 10,025.56 acres of land, hence the low populated distribution.

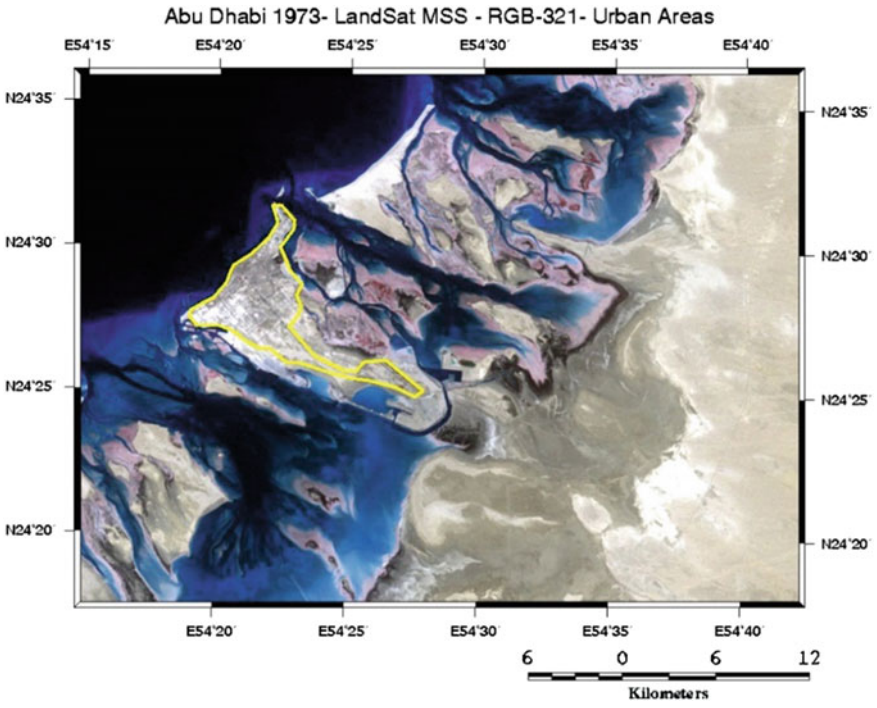

Fig. 5 Urban area in Abu Dhabi—1973

Table 1 Population of Abu Dhabi (Grannemann et al. 2000)

Year	Population
1973	125,933
1978	309,422
1980	420,455
1984	523,181
1989	678,348
1994	874,633
1999	1,071,141
2001	1,155,963
2006	1,461,479
2010	1,967,659

In comparison, the year 2010 had a total population of 1,967,659 (Grannemann et al. 2000) densely occupying 35,979 acres of land and lightly occupying 59,346 acres of land. The lightly occupied areas are mainly mapped out and being built for future expansion purposes. The urban area mapping of the city in 2010 can be seen in Fig. 6, where the yellow regions represent highly populated areas, and the green regions represent low populated areas.

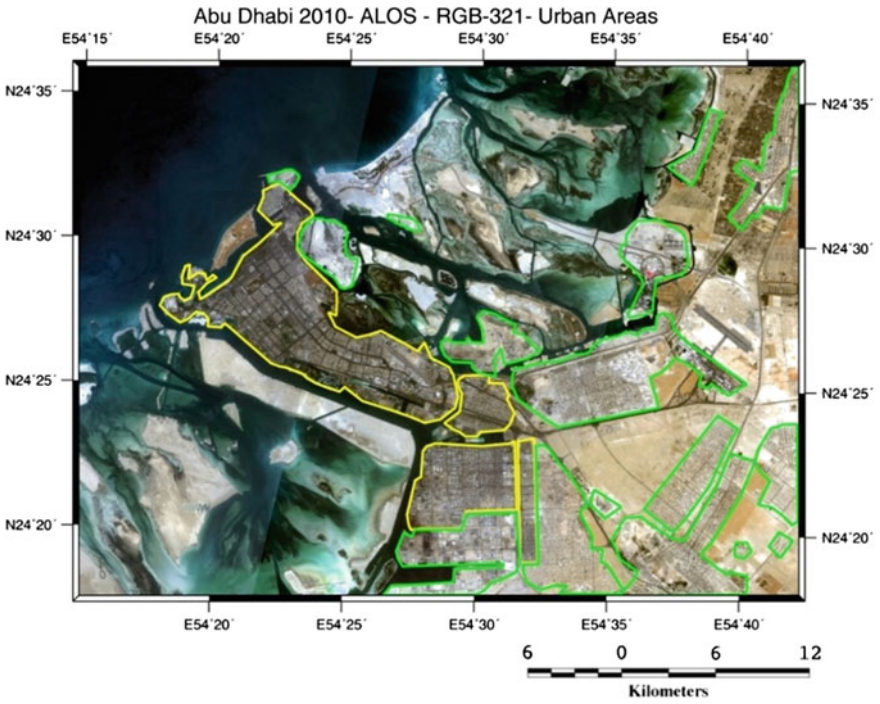

Fig. 6 Urban area in Abu Dhabi—2010

To further analyze urban expansion, a graph of the statistical data of both the highly and low populated urban areas was made shown in Fig. 7. Looking at this graph and tracking the change of low populated areas to high populated areas, the following changes have occurred between the years 1973 and 1984: the entire low populated area occupied in 1973 was expanded and built further to occupy more residents changing the label of the region to a highly populated area (all images can be found in the appendix section). A couple of other areas have been very lightly occupied on the mainland, off of the island of Abu Dhabi. The trend of highly populated areas can be seen in Fig. 7 as follows, there is a dramatic increase between the years of 1973 and 1984, and there is then a slightly less dramatic increase between the years 1984 and 2001. To relate the population increase Fig. 8 was plotted and the slopes compared. Considering that the slope of the population

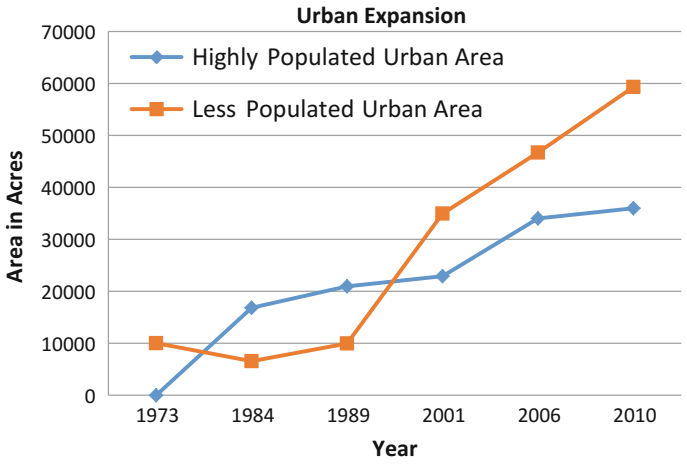

Fig. 7 Urban expansion graph

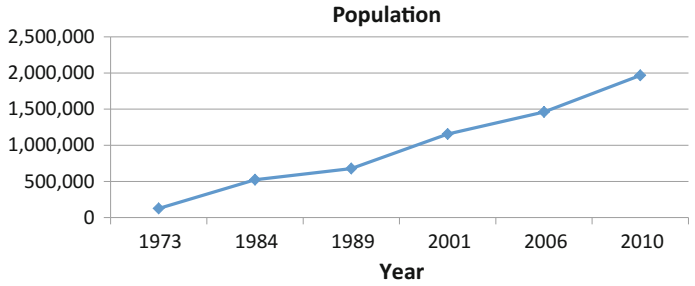

Fig. 8 Graph of the population

increase between the years 1984 and 1989 is almost the same as that between the years 1973 and 1984, the further population increase seemed to have moved into areas farther out and off the island which can be seen as the increase in the number of lowly populated areas. The trend can be followed in the same way for the rest of the graph explaining how the city of Abu Dhabi expanded over the time of 40 years.

4.3 Classification

Due to the fact that there were many different types of classes in the region, the following classes were taken when choosing training areas: highly populated urban areas, low populated urban area, vegetation, shallow water, deep sea water, and eight barren land areas highlighting the difference in texture and content of the land's sand. Figure 9 shows this classification, the legend shows the different classes chosen and identified.

It can be noted that the class that is mostly seen in the city in 2001 is the low populated area class.

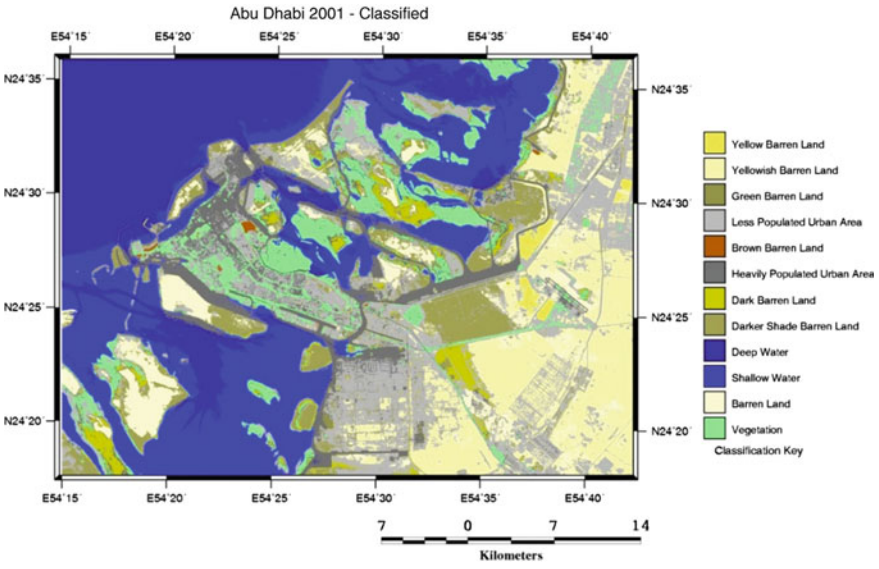

Fig. 9 Classified image of Abu Dhabi

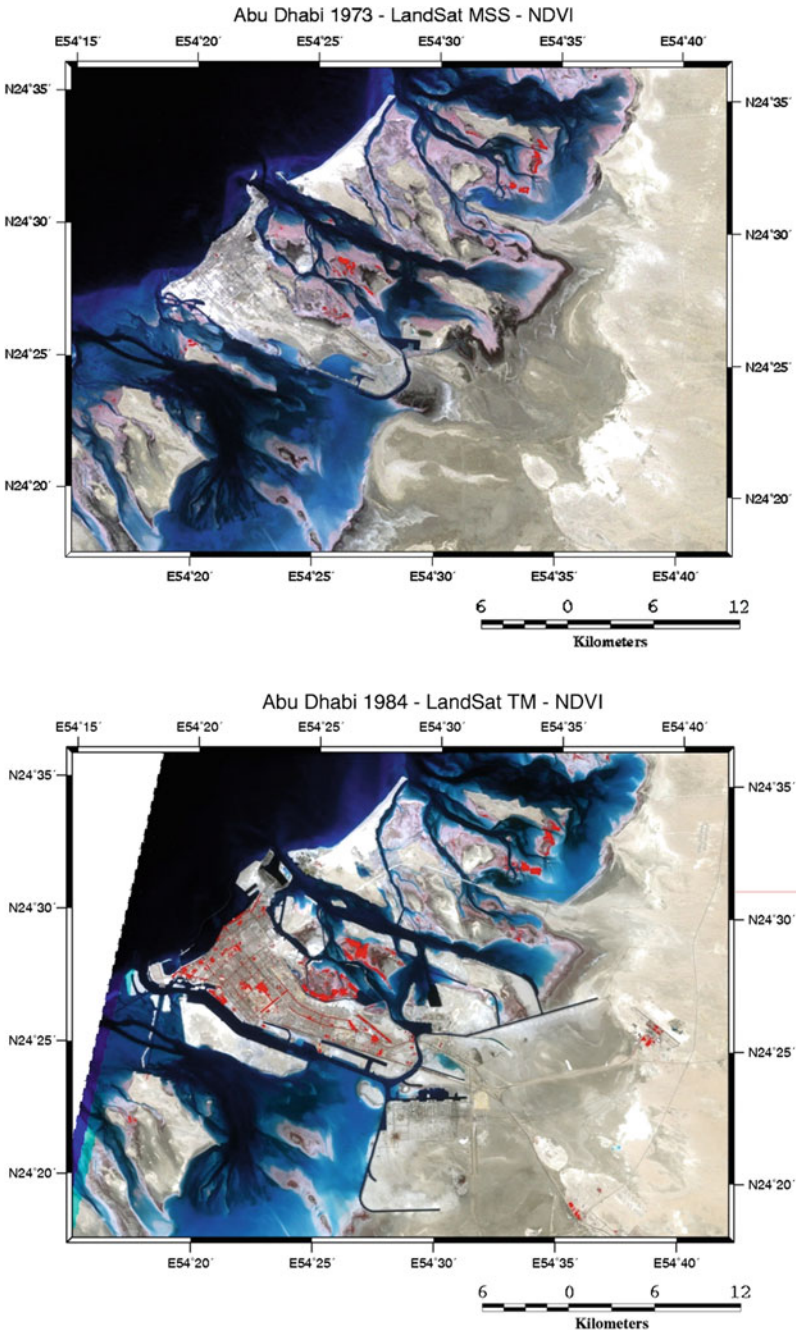

Fig. 10 NDVI and RGB-432 overlapped for vegetation

4.4 Relating the Plots

In order to further study the vegetation/urban expansion, their relative plots are to be compared in details. The comparison will be done in segments between each two corresponding years.

The year 1973–1984

The population increase was first looked at and an increase of roughly 397,000 can be estimated within this time frame. As mentioned earlier, the entire lightly populated area in 1973 became a highly populated area in 1984. While little areas of the light population were built to accommodate and future expansion. The vegetation has increased in this period, considering the UAE had become an officially united country in 1972 and started expanding and building a city. Figure 10 shows the vegetation in years 1973 and 1984 respectively. The figures are shown in an RGB-432 fake color composite to highlight vegetation in red. It was then overlapped with the NDVI red and white images mentioned earlier, to make the vegetation a solid red. It can be seen that the city put more effort into planting and making grass parks in the year 1984.

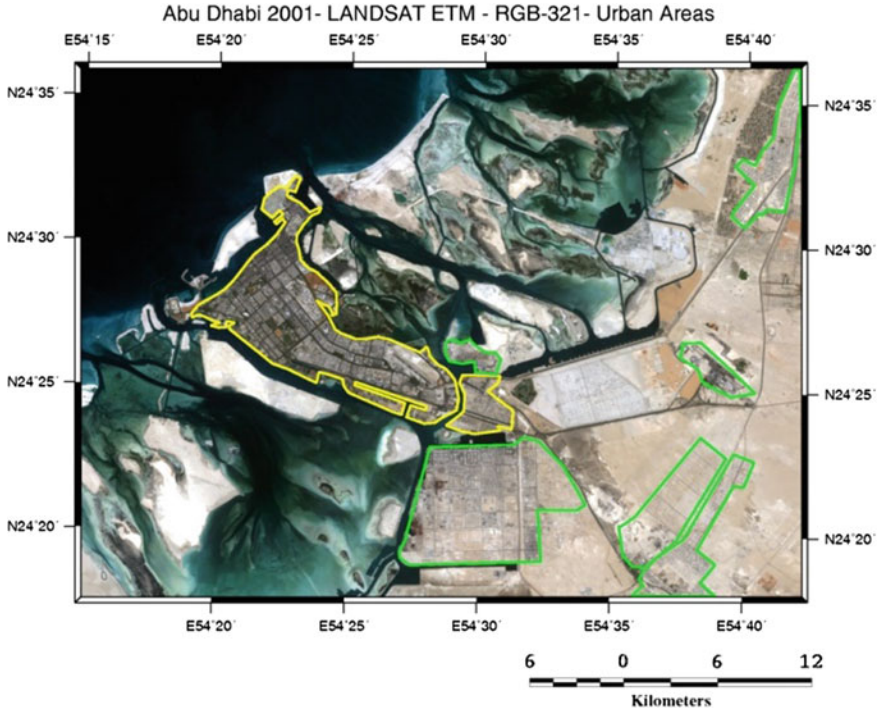

Fig. 11 Urban areas in Abu Dhabi 2001

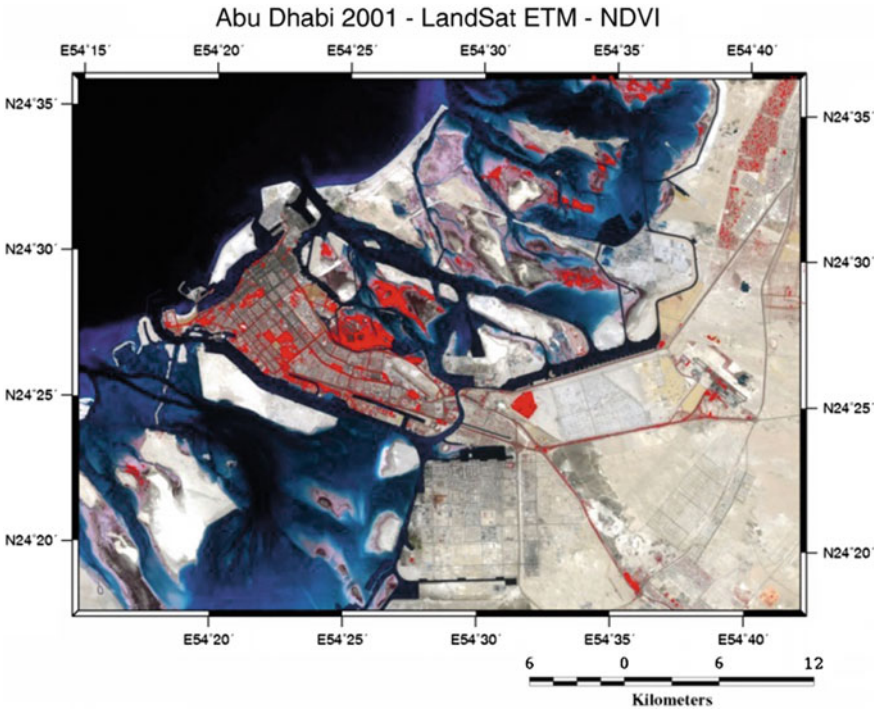

Fig. 12 NDVI and RGB-432 overlapped for vegetation

The year 1989–2001

The population increase in this time frame can be roughly estimated to 477 thousand. This is a very high increase when compared to the previous year, and would demand a huge expand in the urban area. However, looking at the area of the highly populated region there is not much of an increase—except for a small piece of land on the mainland into the connected islands (North-West)—but on the other hand, the low populated area shows a drastic increase. Looking at the relevant Figs. 11 and 12, we can see in details how each region has expanded. Statistically, the vegetation has increased with a meager 1000 acres, that can be seen in some farmland areas in the northeast, the mangroves shown with a very dense concentration in the center, and the Abu Dhabi golf club is shown as a patch of heavy vegetation on the mainland. However if we look more closely, we can see that some of the vegetation on the main roads of the city has been removed. This can explain the very small change in the overall area of the vegetation, where it increased on one side but decreased in the other.

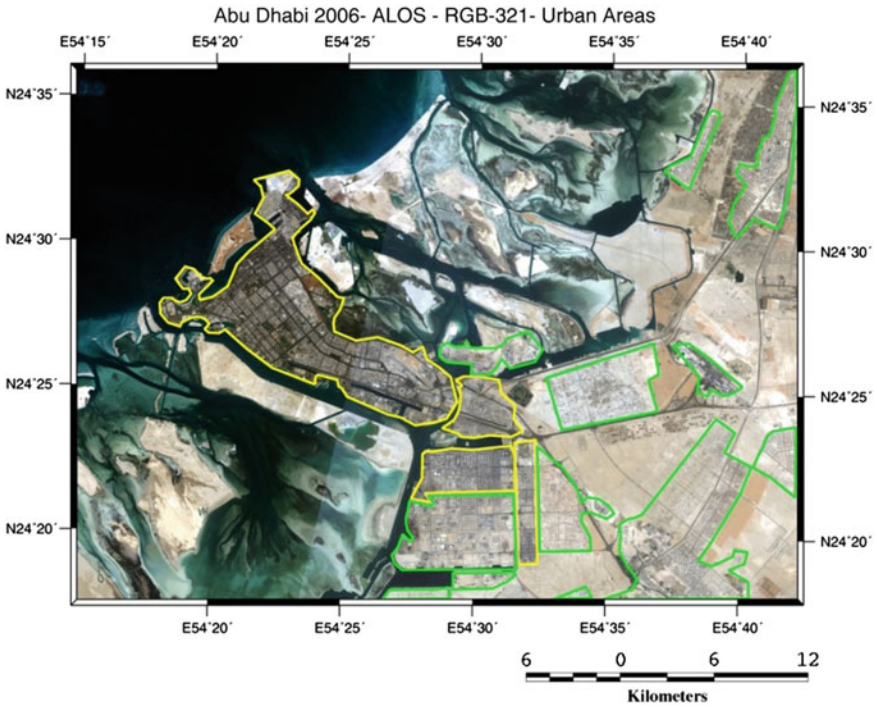

Fig. 13 Urban areas in Abu Dhabi 2006

The year 2001–2006

The population remains at a steady increase of 305 thousand, which is close to the amount of increase in the previous time frame, 1989–2001 when the urban area expansion is rather large, and we can see the regions selected in Fig. 13 are covering almost all the land in 2006. Vegetation has increased at about 8000 acres in this time frame. Looking at Fig. 14 that shows the vegetation in 2006 we can see the huge increase between this year and 2001 in Fig. 12 both in the main city and the farmlands to the northeast. A few of the lightly populated regions show beginning signs of vegetation as can be seen in Fig. 14.

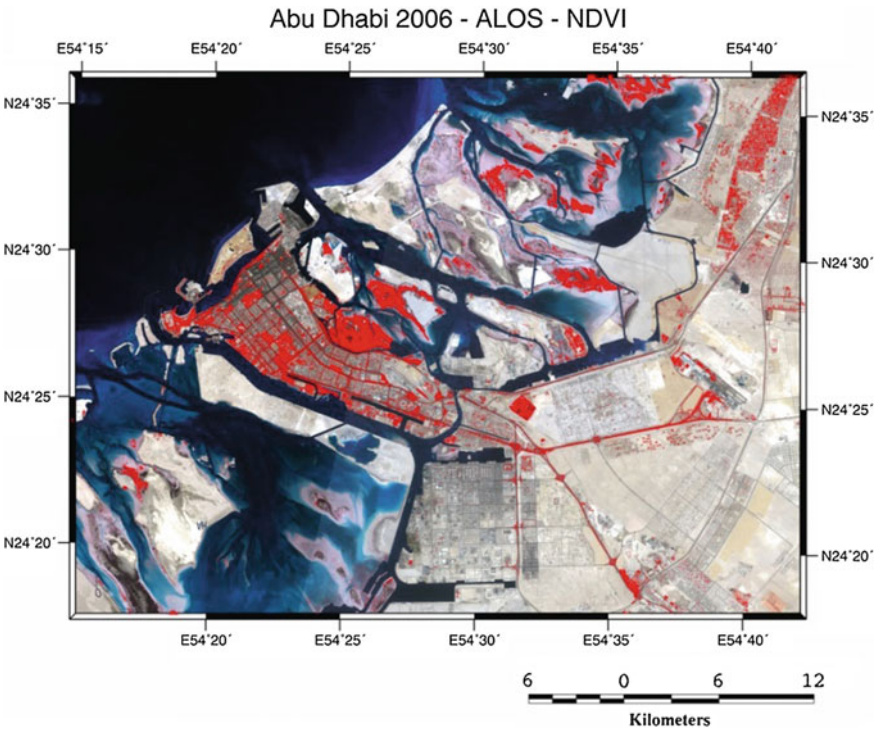

Fig. 14 NDVI and RGB-432 overlapped for vegetation

5 Conclusion

This research demonstrates the use of multi-temporal satellite images to map spatial and temporal patterns of urban and vegetation expansion.

Vegetation changes were observed and the huge difference in green areas between the year 1984 and 2001 was noted. Also, the trend of the vegetation was to increase the vegetation areas inside the Abu Dhabi Island and on the highway streets which leads to Dubai city.

In 2001, Abu Dhabi built partially new islands such as Lulu, Sadiat, Yas, and Al Reem Islands, due to this urban expansion was observed and the huge difference in the infrastructure between the year 1984 and 2001 was also commented on. Also, Abu Dhabi has shifted the concentration of the buildings to new cities like Madinat Sheikh Khalifa A and B on the Dubai road and Madinat Sheikh Mohammad Bin Zayed on the Al Ain road. Finally, this project successfully investigated the main changes in the urban areas of Abu Dhabi and the consequential environmental changes.

References

Alberti M (2005) The effects of urban patterns on ecosystem function. Int Reg Sci Rev 28(2):168–192

Alberti M, Waddell P (2000) An integrated urban development and ecological simulation model. Integr Assess 1(3):215–227

Dai Y, Zhang X, Yan C, Huijuan A, Zhu C (2011) Monitoring coastal zones land use and land cover changes using remote sensing: a case study of Jiangsu, China. In: 2011 19th international conference on geoinformatics, IEEE, pp 1–4

Grannemann NG, Hunt RJ, Nicholas JR, Reilly TE, Winter TC (2000) The importance of ground water in the great lakes. USGS Water Resour Invest. http://water.usgs.gov/ogw/pubs/WRI004008/WRIR_00-4008.pdf. Accessed 20 Mar 2012

Issa SM (2009) Land development assessment on the preserved Al Sammalyah island/UAE using multi-temporal aerial photographs and GIS. Sensors 5:8–13

Lindenmayer DB, Fischer J (2013) Habitat fragmentation and landscape change: an ecological and conservation synthesis. Island Press

Liu JG (2013) Remote sensing for earth and science applications and GIS, course portfolio

Liu JG, Mason PJ (2013) Essential image processing and GIS for remote sensing. Wiley, Hoboken

N.p. (2016) Web. 28 May 2016. http://www.geoinformatic.org/projects/remote-sensing-30-years-of-development-and-vegetation-change-in-abu-dhabi/

SCAD – Home. Scad.ae. http://www.scad.ae/en/Pages/default.aspx

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