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Land Use and Land Cover Change Detection in the Saudi Arabian Desert Cities of Makkah and Al-Taif Using Satellite Data

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Abstract

Land use/land cover (LULC) changes have become a central issue in current global change and sustainability research. Saudi Arabia has undergone significant change in land use and land cover since the government embarked on a course of intense national development 30 years ago, as a result of huge national oil revenues. This study evaluates LULC change in Makkah and Al-Taif, Saudi Arabia from 1986 to 2013 using Landsat images. Maximum likelihood and object-oriented classification were used to develop LULC maps. The change detection was executed using post-classification comparison and GIS. The results indicated that urban areas have increased over the period by approximately 174% in Makkah and 113% in Al-Taif. Analysis of vegetation cover over the study area showed a variable distribution from year to year due to changing average precipitation in this environment. Object-based classification provided slightly greater accuracy than maximum likelihood classification. Information provided by satellite remote sensing can play an important role in quantifying and understanding the relationship between population growth and LULC changes, which can assist future planning and potential environmental impacts of expanding urban areas.

Keywords

Land Use/Cover Patterns, Landsat Imagery, Makkah, Al-Taif, Urban Growth, Image Classification, Change Detection

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1. Introduction

Land use/land cover (LULC) change has arisen as a fundamental component of global environmental change and sustainability research today [1]-[3]. The concept can be classified as intensely dynamic in terms of changes in both natural components and human activities that impact negatively on environmental factors such as biota, soil, topography, surface and groundwater, and human structures. Land cover changes may be classed as natural or anthropogenic [4]. However, anthropogenic LULC changes impact more rapidly than natural changes due to increases in human activities [5] [6]. As a result, the Earth's surface has been modified significantly in recent years by different kinds of land cover/use changes [4] [7]. Most ecosystems of the world have been altered or are being altered by human production of goods and services [6] [8] [9]. LULC change is widely accepted as a threat to several biomes including forests, grasslands, wetlands, tundra and deserts.

In Saudi Arabia, where the desert is dominant in more than 70% of biomes [10], land use and land cover have changed significantly during the last 30 years since the government began implementing an intense program of development, financed by huge oil revenues [11]. Saudi Arabia is recognized as a nation boasting one of the most rapid settlement expansions in the Middle East [12]. This development has resulted in changes in a number of environmental components including landscape ecology, hydrological processes, climatic system and land cover patterns. However inadequate planning structures and a lack of understanding of, and consideration for, negative consequences has brought about large excesses in development and a consequent deterioration of the desert ecosystem. A knowledge of LULC change is essential to understand and model complex environmental changes. Spatial patterns of LULC need to be accurately represented and highly detailed, in order to understand the complex changes in this particular environment.

Multi-temporal data is useful for providing a better understanding of the complex LULC change patterns [13]. The repetitive coverage of satellite images and improvement of image quality can provide valuable assistance in identification of LULC change [14]. Such information can be analyzed using remote sensing techniques which provide the ability to detect changes to the earth's surface through space-borne sensors [15]. Several techniques using satellite images to detect LULC change patterns have been developed and employed over the last three decades, the most frequently used remote sensing technique for detecting LULC change being post-classification comparison [16]-[18]. This form of comparative technique has the ability to detect the changes through map to map comparisons and facilitates the provision of greater detail in the change trajectories.

Remotely sensed imagery has been widely used for detecting LULC changes. Among others, Weng [19] and Berlanga-Robles and Ruiz-Luna [20] investigated land use change dynamics in the Zhujiang Delta south China and the Northern Coastal Region of Nayarit, Mexico respectively using satellite imagery, GIS and stochastic modelling technologies and they concluded that the integration of satellite data and GIS is an effective approach for analysing the direction, rate and spatial pattern of land use change. Chauhan and Nayak [21] adopted multi-temporal satellite data to monitor LULC changes in the Hazira Area, India and they found that remote sensing and GIS can provide a better understanding of LULC change patterns. Dewan and Yamaguchi [22] used multi-temporal satellite data and topographic maps to detect LULC changes in Dhaka Metropolitan, Bangladesh from 1960 to 2005 and they argued that multi-temporal satellite data is useful tool for sustainable land management and policy makings. Vittek, Brink [23] examined land cover changes occurring between 1975 and 1990 in West Africa using systematic sample of satellite imagery and they concluded that satellite images can provide valuable information regarding to land cover change.

This paper aims firstly to explore and analyze the characteristics of LULC changes in the desert cities of Makkah City and Al-Taif Province, Saudi Arabia, using Landsat time-series imagery from 1986 to 2013. Its second objective is to highlight the spatial and temporal patterns of change during this period and the third objective is to investigate the most accurate classification technique for deriving and mapping change detection in the study area.

2. Materials and Methods

2.1. Study Area

The study area (**Figure 1**) is located in the Makkah Region of western Saudi Arabia, on the central part of the Hejaz Mountains (a part of the Al-Sarawat Mountains) and contains two major cities (**Figure 1**). Makkah City is located in the central part of the region and has an average temperature of 40˚C in summer and 30˚C in winter. According to the 2013 Central Department of Statistics and Information (CDSI) census data, it has a population

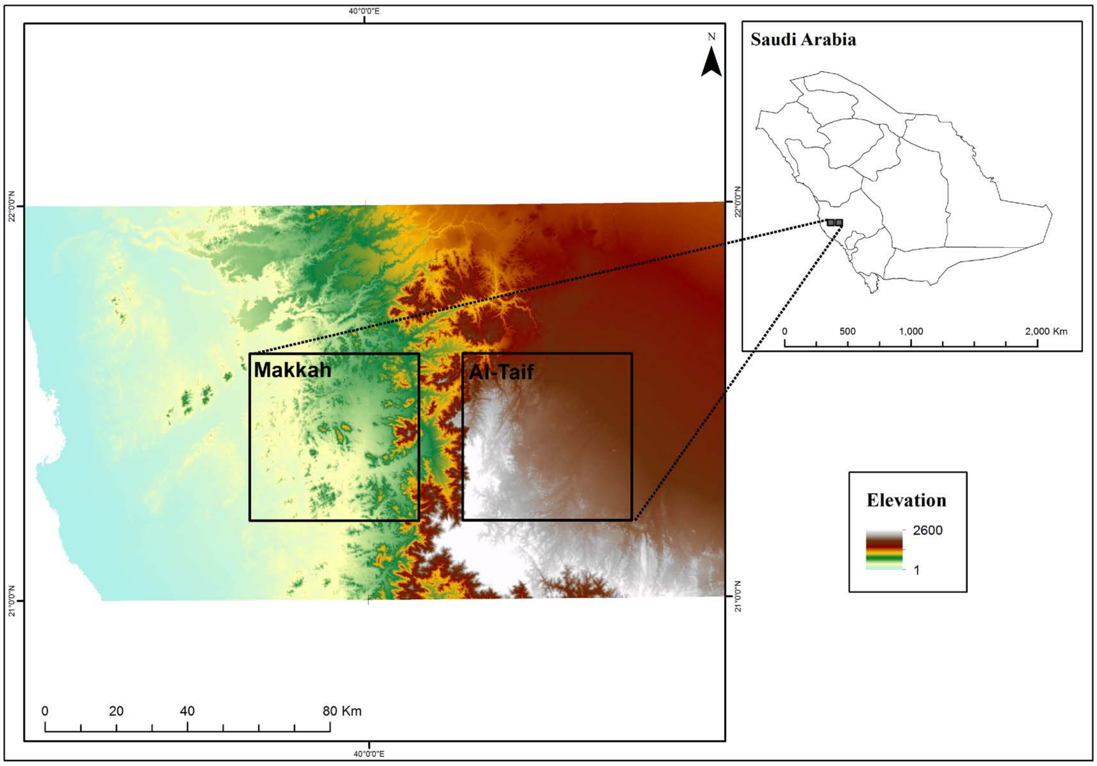

Figure 1. Study area in Saudi Arabia.

of 1,867,886. Al-Taif is located in the south-eastern part of the region and has an average temperature of 34˚C in summer and 10˚C in winter. It has a population of 1,083,693.

Over the past 30 years, both Makkah city and Al-Taif have experienced rapid urbanization and exhibit a wide variety of land use and land cover types. Makkah, as the most revered holy place of the international Muslim community, receives more than 3 million visitors annually, embracing the rituals of the Hajj pilgrimage [24]. Natural growth and both internal and external migration has led to a large population increase in Makkah with many pilgrims deciding to remain in the city after their pilgrimage [25]. Additionally, the migration of the rural population towards the city due to either religious or economic factors has also contributed to the population increase. Al-Taif, the other city forming part of this study, is about 170 km from Makkah and is the most important tourist city of Saudi Arabia and the Arab States of the Gulf. Al-Taif is the summer destination of many Saudi and Arabian Gulf citizens annually. During the last 30 years, the land use and land cover over Al-Taif has seen changes to its rural surrounds due to high revenue from tourism. Many of the agricultural areas have been converted to tourist facilities and attractions. This development and its associated environmental consequences need to be assessed and addressed in order to avoid negative impacts of future developments.

2.2. Data and Analysis

Data used in this research comprised four cloud-free Landsat (TM4, 5 and OLI-TIRS) images, path 169 and row 45, which were collected on 21 June 1986, 27 August 1990, 10 May 2000 and 30 May 2013. All four images were obtained from the USGS Global Visualization (GloVis) site and geometrically corrected and rectified to UTM zone 37. An IKONOS image for Makkah City and a SPOT image for Al-Taif Province (provided by the King Abdulaziz City for Science and Technology (KACST)) were used for visual interpretation in order to assess the classification process. **Figure 2** shows the flow diagram of the research process.

2.3. Image Classification

2.3.1. Pixel-Based Classification

The most common parametric classifier, maximum likelihood classification, has been used in this study. It as-

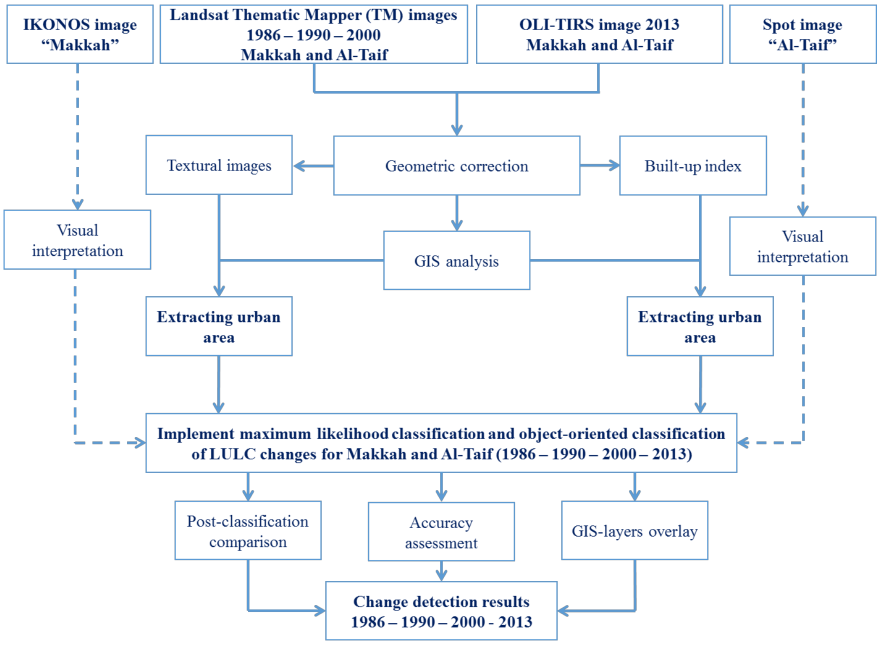

Figure 2. Flow diagram of the research process.

sumes normal or near normal spectral distribution for each feature of interest and an equal prior probability among the classes [26]. The classification scheme used was based on the land use and land cover classification system provided by Anderson, Hardy [27]. Five level 1 classes were identified: vegetation, urban, sand, barren land and rocky (**Table 1**). Prior to classification, all satellite data were interrogated using spectral and spatial profiles to ascertain the digital numbers (DNs) of different land cover categories. A combination of six Landsat TM layers (band 1 through 5 and 7) and seven Landsat 8 bands (band 1 through 7) were used to perform the maximum likelihood classification. Mixed pixels are a common problem when using medium-spatial resolution data such as Landsat [28]. In order to reduce the mixed pixels between some land cover features (e.g. urban and barren land) due to similarities in their spectral properties, the urban features were extracted using the urban built-up index provided by Xu [29]. In addition, textural image based on variance, with a window size of 3 × 3 pixels, was employed to extract the heterogeneous and complex combination of urban features. However, there were also missed pixels (urban) which were overcome using visual extracting in GIS.

2.3.2. Object-Oriented Classification

Unlike pixel-based classification, object-oriented classification uses image segments to divide the pixels into groups that represent the landscape objects [30]. Segmentation is the process of partitioning images into isolated objects so that each object shares a homogeneous spectral similarity [26]. In this research, object-oriented classification was performed using eCognition® Developer 8.9. All Landsat images were individually classified for both Makkah and Al-Taif. Each image was segmented using multi-resolution segmentation algorithm using 5 scale parameters. Five classes of land cover schemes as described above (**Table 1**) were used on an object-oriented classification platform.

2.3.3. Accuracy Assessment

In general, the accuracy assessment determines the quality level of information extracted from remotely sensed data [31]. Classification accuracy refers to the rate of correspondence between the remotely sensed data and reference information [32] [33]. A common method for accuracy assessment is through the use of an error matrix which provides detailed information of the agreement between the classification results and reference information [31]. Additionally, accuracy assessments such as overall accuracy, producer's accuracy, user's accuracy and overall kappa coefficient were carried out using the error matrices. Equation (1) was used to compute the kappa coefficient [34]:

Table 1. Land cover classification scheme.

Land cover class	Description
Vegetation	Including crop fields, pasture, grassland
Urban	Including residential, commercial services, industrial, transportation communications, mixed urban or built-up land
Sand	Including white and yellow sand and dunes
Barren Land	Including valleys, bare rocky and clay
Rocky	Including volcanic mountains, small rocks

$$K = \frac{N\sum_{i=1}^{k} x_{ii} - \sum_{i=1}^{k}\left(x_{i+} \times x_{+i}\right)}{N^2 - \sum_{i=1}^{k}\left(x_{i+} \times x_{+i}\right)} \quad (1)$$

where k is the number of rows in the matrix; x_{ii} is the number of observations in row i and column i; x_{i+} and x_{+i} are the marginal totals of row k and column i respectively; and N is the number of observations.

2.3.4. Change Detection

Multi-date post-classification comparison change detection was used to determine the change in land use and land cover. Post-classification comparison is the most common approach and provides efficiency in the detection of changes [17] [18] [35]. In addition, an overlay procedure using GIS was used to obtain the spatial changes in land use and land cover spanning three time intervals, 1986-1990, 1990-2000, and 2000-2013.

3. Results and Discussion

3.1. Land Cover Patterns

Spatial patterns of LULC changes in Makkah and Al-Taif are shown in **Figure 3** and **Figure 4** respectively, and the individual class area and change statistics for the four years for Makkah and Al-Taif are summarized in **Table 2** and **Table 3**. The percentages of land cover change from the total land cover of 1986, 1990, 2000 and 2013 are also shown in **Table 2** and **Table 3** for Makkah and Al-Taif respectively. From these tables, it is clear that there was a considerable change in land use and land cover in Makkah and Al-Taif during the 27-year study period. Urban area increased by approximately 17574 ha (174%) in Makkah and by approximately 7391 ha (113%) in Al-Taif. The vegetation cover also increased in both Makkah and Al-Taif by approximately 3145 ha (291%) and 5017 ha (262%) respectively. Rocky is the dominant land cover class for both Makkah and Al-Taif. This is because the geographical location of both cities is on the Al-Sarawat Mountain range. Sand forms another major class of land cover for both Makkah and Al-Taif.

3.2. Urban Growth

Figure 5 and **Figure 6** show the changes in urban areas from 1986 to 2013 in Makkah and Al-Taif respectively. The most dense urban areas have spread from the center of Makkah in almost all directions. The most urbanized areas were found in the north-east and south-west regions of the city. In addition, the central region of Makkah has changed between 1986 and 2013 and the trend of built-up area has moved southwards. Additionally, the north-west region of the city has expanded between 1986 and 2013. In contrast, there was little change in central Al-Taif, with most changes occurring in the north-east and eastern regions of the city. Most of these areas have been successfully urbanized, containing a diverse mix of human activity, including industrial and residential areas.

Figure 7 demonstrates the relationship between population density and urban growth in Makkah and Al-Taif from 1986 to 2013, expressed as a percentage. An analysis of the population data indicates an overall population increase for Makkah, from 711,321 in 1986 to 1,867,886 in 2013, and from 451,321 in 1986 to 1,083,693 in 2013 for Al-Taif. The relationship between population growth and growth in urban land area as determined from Landsat data change maps shows a high correlation between population growth and urban expansion. It is clear from **Figure 7** that the greater the population increase, the greater the urban expansion, for both Makkah and

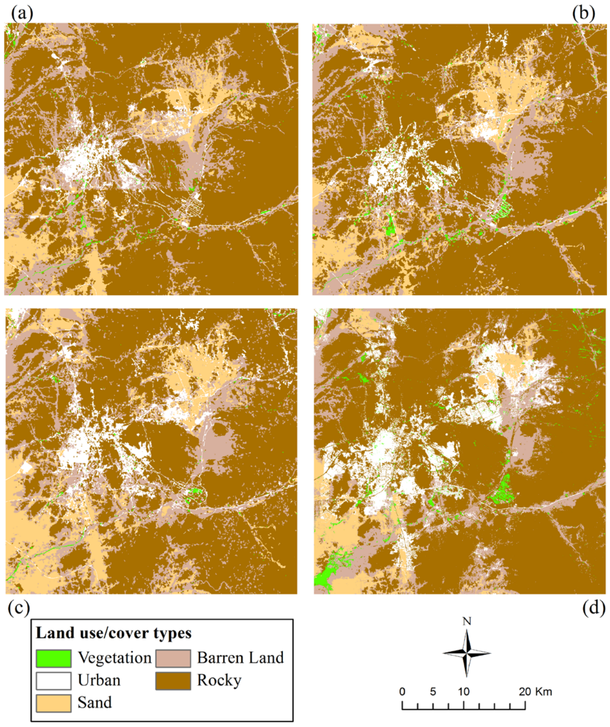

Figure 3. Land use/land cover classification of Makkah in: (a) 1986; (b) 1990; (c) 2000 and (d) 2013.

Table 2. Results of land use/land cover classification for 1986, 1990, 2000 and 2013 for Makkah showing area, area change and percentage change.

Land cover types	1986	1990	2000	2013	1986-2013		Land cover (%)			
	Area	Area	Area	Area	Area changed		1986	1990	2000	2013
	(ha)	(ha)	(ha)	(ha)	(ha)	(%)	(%)	(%)	(%)	(%)
Vegetation	1080	2102	809	4225	3145	291	0	1	0	2
Urban	10,074	11,760	17,052	27,648	17,574	174	5	5	8	12
Barren Land	44,008	43,628	47,409	34,603	−9405	−21	20	20	21	16
Sand	21,970	24,170	30,463	14,906	−7064	−32	10	11	14	7
Rocky	145,261	140,733	126,660	141,011	−4250	−3	65	63	57	63
Total	222,393	222,393	222,393	222,393			100	100	100	100

Table 3. Results of land use/land cover classification for 1986, 1990, 2000 and 2013 for Al-Taif showing area, area change and percentage change.

Land cover types	1986	1990	2000	2013	1986-2013		Land cover (%)			
	Area	Area	Area	Area	Area changed		1986	1990	2000	2013
	(ha)	(ha)	(ha)	(ha)	(ha)	(%)	(%)	(%)	(%)	(%)
Vegetation	1918	1471	4039	6935	5017	262	1	1	2	3
Urban	6517	6530	8420	13,908	7391	113	3	3	4	6
Barren Land	24,491	24,431	6383	19,343	−5148	−21	11	11	3	9
Sand	76,783	72,308	76,768	70,088	−6695	−9	35	33	35	32
Rocky	112,684	117,653	126,783	112,119	−565	−1	51	53	57	50
Total	222,393	222,393	222,393	222,393			100	100	100	100

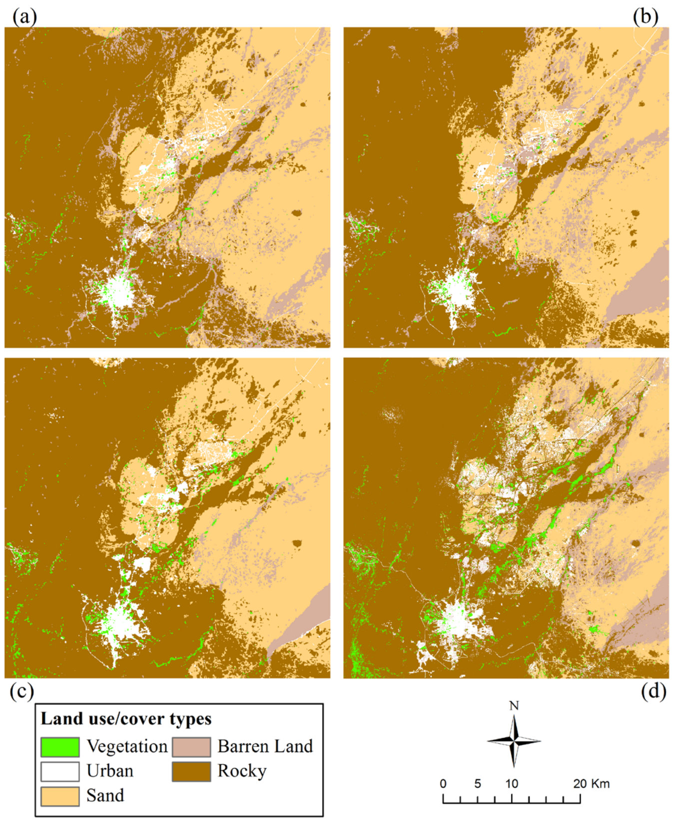

Figure 4. Land use/land cover classification of Al-Taif in: (a) 1986; (b) 1990; (c) 2000 and (d) 2013

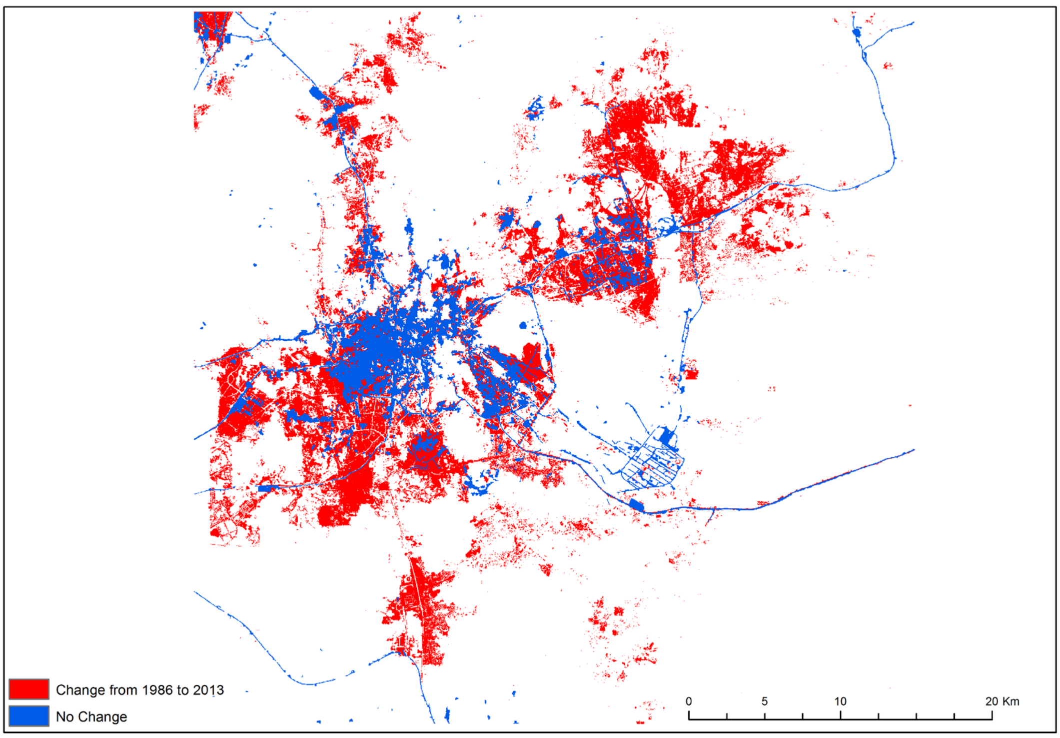

Figure 5. Urban change from 1986 to 2013 in Makkah.

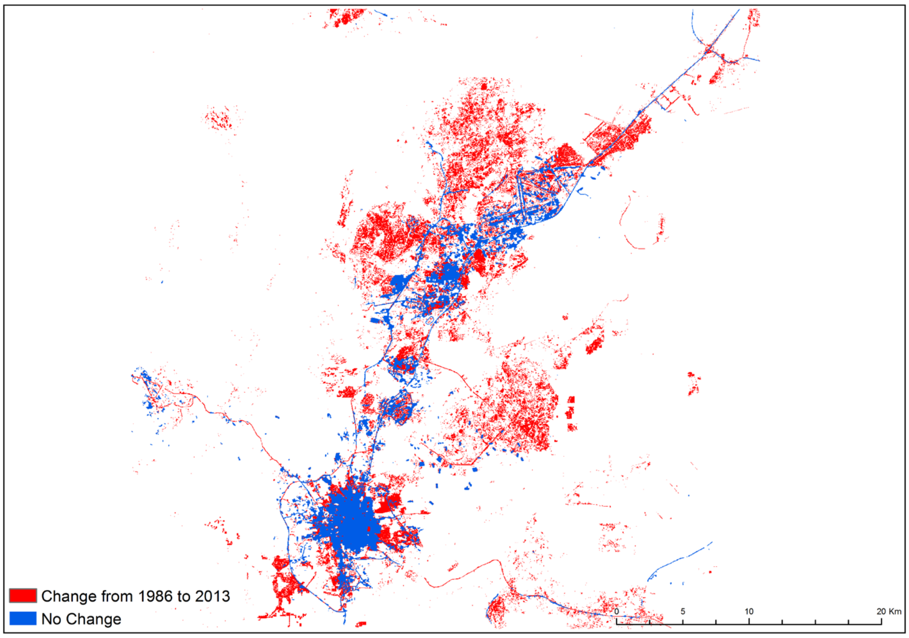

Figure 6. Urban change from 1986 to 2013 in Al-Taif.

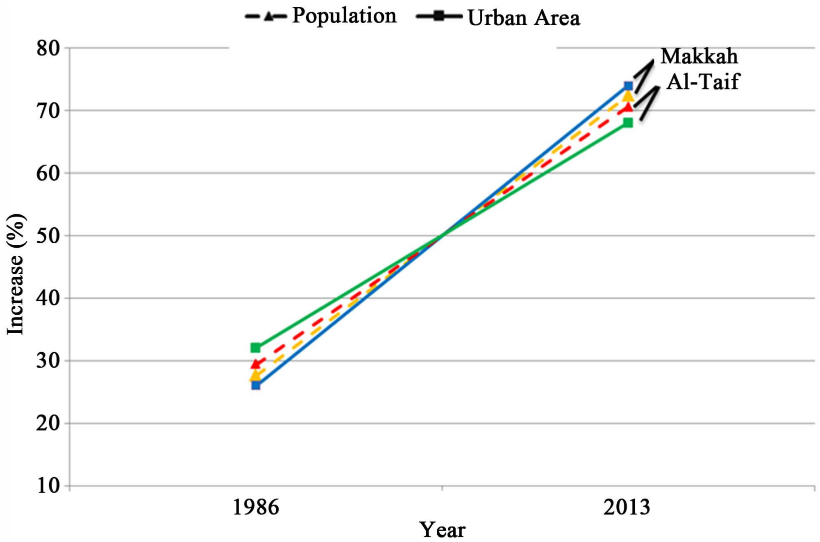

Figure 7. The relationship between population density and urban growth in Makkah and Al-Taif.

Al-Taif. The increase in population of Makkah and Al-Taif may be attributed to an increased life expectancy, in effect an increase in the birth rate and concurrent decrease in the death rates, and increasing internal migration to both cities due to economic opportunities over the last 27 years.

Overall, the process of urbanization in both Makkah and Al-Taif demonstrates a combination of driving forces, which include geographical location, population growth, accessibility of public services, economic opportunity, globalization, tourism and annual pilgrimage, and associated activities and industry. Landsat images reveal that the direction of urban growth in Al-Taif from 1986 to 2013 was distributed over rural areas. In Makkah, the government has started a massive expansion project in the central part (the holy place) of the city to increase its capacity to deal with the Hajj pilgrimage. Urban residential areas have been cleared and decentralized to the rural outskirts of the city in the application of this project. In general, the distribution of urban areas in Makkah and Al-Taif has been influenced by the topography which controls the trend of urbanization.

3.3. Vegetation Variation

Figure 8 shows the percentage of vegetation cover in Makkah and Al-Taif for 1986, 1990, 2000 and 2013. The distributions of vegetation cover were very similar in both cities, only exhibiting slight differences in the actual time periods and points of time of changes. Normally, increasing urban areas results in decreasing the vegetation cover, but both Makkah and Al-Taif have seen remarkable increase in vegetation cover from 1986 to 2013. For example, in Makkah the vegetation cover increased by approximately 1022 ha from 1986 to 1990 because of an increase in agricultural lands in 1990 (**Figure 9(A)**), whereas in Al-Taif, agricultural areas increased in 2000

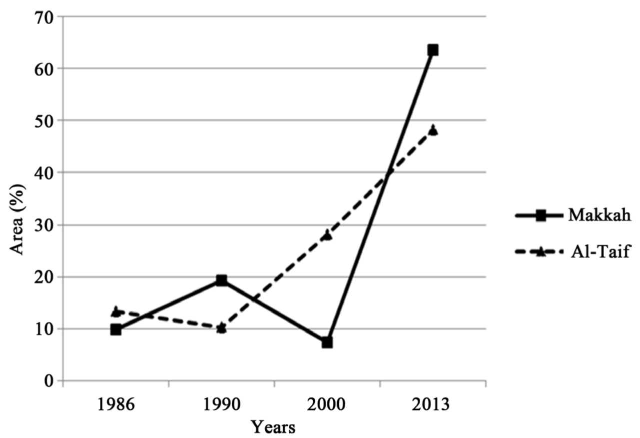

Figure 8. The area of vegetation cover variation in both Makkah and Al-Taif expressed as a percentage.

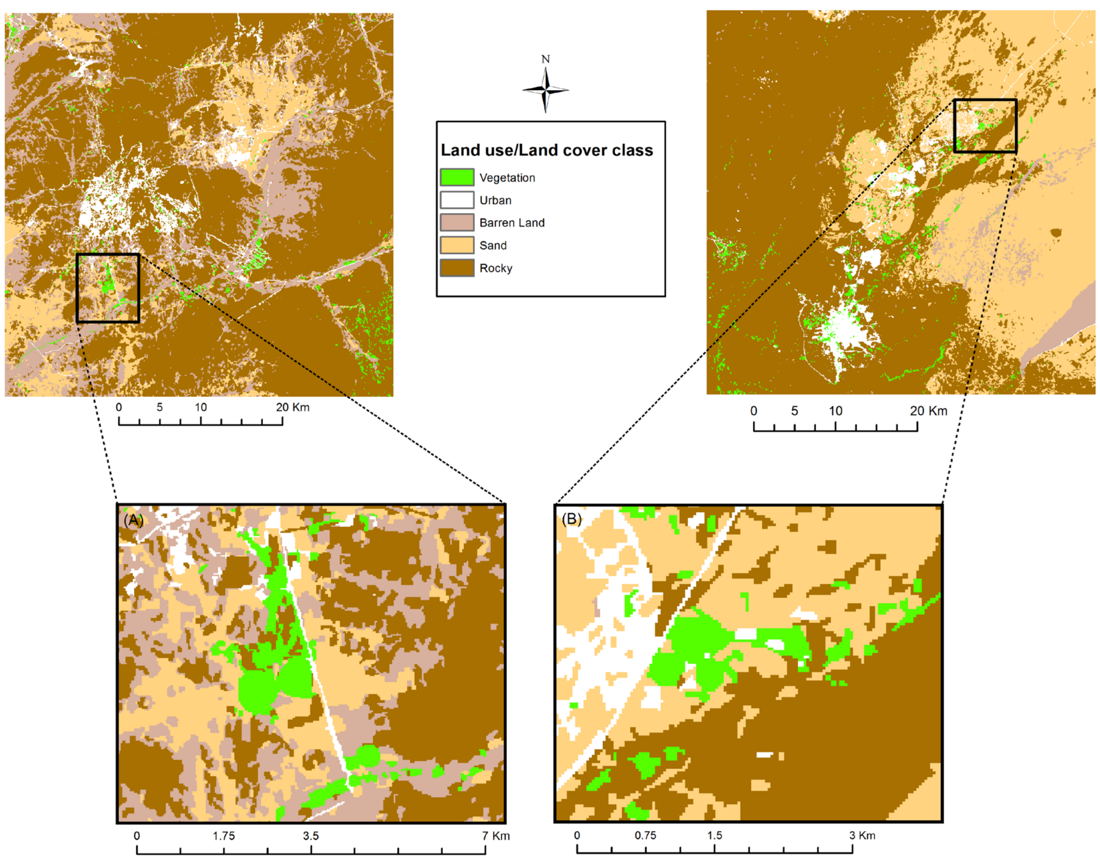

Figure 9. Agricultural lands in (A) Makkah 1990 and (B) Al-Taif 2000.

(**Figure 9(B)**). As shown in **Figure 9(A)** and **Figure 9(B)** few agricultural areas existed in Makkah 1990 and Al-Taif in 2000. The land was reclaimed for cultivation in both cities during this period using the center pivot irrigation system. In addition, in 2013 there was also an increase in the vegetation cover of both cities. For Makkah the sewage lake (**Figure 10(A)**) and afforestation in Arafat (**Figure 10(B)**) increased the total area of vegetation cover. In Al-Taif, the total area of vegetation cover increased by approximately 6935 ha in 2013, due to increasing agricultural areas in the west and south-west regions of the city.

Another aspect is the annual variations of scatterings of plants in the desert environment according to variations in average rainfall. Both Makkah and Al-Taif are arid with low precipitation levels (**Table 4**). However, Al-Taif receives slightly higher rainfall than Makkah. The level of precipitation was intermittent for both Makkah and Al-Taif and its consequent influence on the distribution of vegetation cover. For example, the vegetation cover in Makkah was low in 2000 in accordance with a low rainfall that year (**Table 4**) preceding the date of the image acquisition, while Al-Taif had reasonable rainfall preceding this date. Vegetation cover shows an association with valleys (wadis) because of higher soil moisture levels. Most plant species in this environment adapt to the dry, hot extremes through physical and behavioral mechanisms. Such species germinate after heavy rain and then quickly complete their reproductive cycle. In **Table 4** the total amount of rainfall of Al-Taif in April and May 2013 was 79.2 mm which should be viewed in conjunction with **Figure 4(d)** and **Table 3** showing that the vegetation cover was distributed through the valleys in the east and north-east regions of the city.

3.4. Accuracy Assessment

Error matrices of maximum likelihood classification and object-oriented classification were used to assess classification accuracy and are summarized for all years in **Table 5** and **Table 6** respectively. 183 samples were selected randomly in order to examine the image classification accuracies. The producer's and user's accuracies of

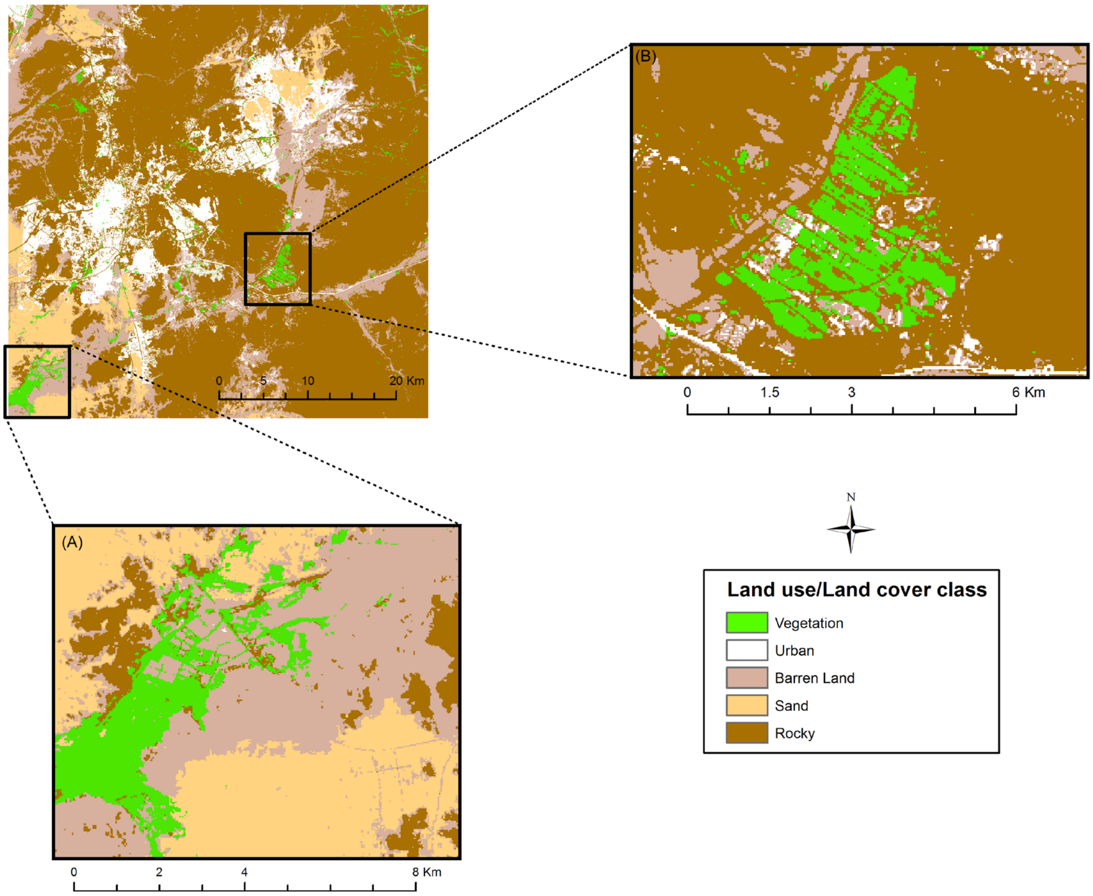

Figure 10. Vegetation cover distribution in Makkah 2013 (A) sewage lake and (B) afforestation in Arafat.

Table 4. The total precipitation of Makkah and Al-Taif in1986, 1990, 2000 and 2013.

Month	Amount of rainfall in Makkah (mm)				Amount of rainfall in Al-Taif (mm)			
	1986	1990	2000	2013	1986	1990	2000	2013
Jan	0	10	3	6.5	0	0	0	0
Feb	2.9	0	0	0	13.4	0	0	0
Mar	**24**	0	0	0	14.5	8.7	13.7	5.3
Apr	2.2	8.9	0.2	8.6	28	**46.6**	11.7	**58.6**
May	0	0	0	0.7	7	6.3	**54.8**	20.6
Jun	0	0	0	0	22	0	0	0
Jul	0	0	9.2	0	4.1	0	12.5	0
Aug	3	0	0	16.7	15.9	9.2	1.3	22.9
Sep	2	0	0	9.2	**55.1**	7.9	0.9	0
Oct	0	0	12.4	0	13.4	0	3.4	2.6
Nov	6	0	**112.5**	1.2	1	0	37.7	0
Dec	0	0	2.2	5.2	0	0	2.1	1
Total	40.1	18.9	139.5	48.1	174.4	78.7	138.1	111

Table 5. Summary of classification accuracies of maximum likelihood classification.

Land cover class	1986		1990		2000		2013	
	Producer's	User's	Producer's	User's	Producer's	User's	Producer's	User's
Vegetation	99	94	99	96	99	95	100	98
Urban	92	75	94	79	94	79	98	85
Barren Land	59	77	68	81	65	82	64	80
Sand	88	97	92	98	92	98	89	97
Rocky	92	95	89	93	87	90	92	97
Overall accuracy	88.9		90.0		88.8		92.4	
Kappa coefficient	85.2		87.1		85.5		90.1	

Table 6. Summary of classification accuracies of object-oriented classification.

Land cover class	1986		1990		2000		2013	
	Producer's	User's	Producer's	User's	Producer's	User's	Producer's	User's
Vegetation	97	80	98	80	98	91	98	89
Urban	97	84	97	83	97	84	97	82
Barren Land	70	75	82	85	65	91	90	92
Sand	96	98	86	99	98	94	87	99
Rocky	83	91	96	99	71	91	85	95
Overall accuracy	92.5		93.5		91.5		90.7	
Kappa coefficient	87.8		89.9		85.9		88.3	

both pixel-based classification and object-oriented classification showed a high percentage in the vegetation class. This is because the vegetation is scattered and easily distinguished from satellite images. Additionally, vegetation gives a unique spectral reflectance in the near-infrared bands. The producer's accuracies of urban class also showed a high percentage in both pixel-based classification and object-oriented classification, while the user's accuracies showed a medium percentage in the pixel-based classification. In contrast, object-oriented classification improved the user's accuracies of urban class. The low percentage of producer's accuracies was found in barren land because of the mixed pixels with other classes. Both producer's and user's accuracies of sand and rocky showed a high percentage using maximum likelihood classification and object-oriented classification. The overall accuracies of maximum likelihood classification for 1986, 1990, 2000 and 2013 were 88.9, 90.0, 88.8 and 92.4 percent while the overall accuracies of object-oriented classification were 92.5, 93.5, 91.5 and 90.7 percent respectively. Thus, object-oriented classification provided slightly improved overall accuracies in comparison with maximum likelihood classification.

3.5. Image Classification

The classification techniques used to derive the LULC maps for 1986, 1990, 2000 and 2013 were the traditional maximum likelihood classification and object-based classification. The maximum likelihood classification is based on the probability that a pixel belongs to a particular class. The advantage of maximum likelihood classification is that it is less time consuming, but the disadvantage is that it increases the salt-and-pepper effect. Although the object based classification provided a better result in comparison with per-pixel classification in the study area, identifying a suitable segmentation image is extremely time consuming [26]. In this study, both per-pixel classification and object-based classification provided good LULC maps for Al-Taif and Makkah.

Analysis of Landsat images indicated that the most observed land cover changes in our study area are vegetation cover and urban growth. The increase in urbanization was clearly shown in Makkah and Al-Taif from 1986 to 2013. Increased urbanization is a major concern in developing countries. It is expected that 60% of the world's population will live in urban areas by 2030, and most of the urban growth will occur in less developed countries [36]-[38]. Our results show that the expansion of urbanization has increased extensively in the rural areas surrounding Makkah and Al-Taif. These lands have become part of the cities due to population growth and the related increase in industry and associated activities.

The rapid population growth has resulted in uncontrolled sporadic growth on the fringe of urban areas, generally termed "urban sprawl" [38]. In 2013, the Municipality of Makkah confirmed that slums cover a quarter of the city's urban surrounds. The Landsat images examined in this study show a new slum area that has arisen in the developed area in the eastern sector of the city which leads to an increase in the degradation threats on this environment. The rapid growth of urban areas and the lack of planning frameworks have increased the impact on the ecosystem, particularly in the desert environment.

Increasing of urbanization and population at higher rates than the national government's ability to provide services for sustainable healthy living environments can be a serious threat in the urban environment [39] [40]. The results of this research indicate that the rate of urbanization was very fast and uncontrolled in both Makkah and Al-Taif from 1986 to 2013. This is known as an attributive phenomenon in developing countries, especially in Asia [41]. The major development comes from both natural growth and the migration of people who search for better employment opportunities in Makkah and Al-Taif. Thus, the major concern in these cities is the uncontrolled urban growth which leads to environmental abuses and health risks.

4. Conclusions

This study assessed LULC changes and the dynamics of urban expansion in Makkah city and Al-Taif province using Landsat images. The results can be summarized as follows: (1) Makkah and Al-Taif were found to have experienced rapid changes in LULC from 1986 to 2013. (2) The urban areas increased by approximately 17574 ha (174%) in Makkah and 7391 ha (113%) in Al-Taif. (3) The expansion of the urban areas in Makkah and Al-Taif exhibited clear spatiotemporal differences. (4) Increasing urbanization is accompanied with increasing vegetation cover over the study area due to increasing afforestation in the urban areas.

In summary, information provided by satellite remote sensing, along with ancillary data such as population data, can play a significant role in quantifying and understanding the relationship between population density and LULC changes. Furthermore, researching the nature of land cover changes can be aided and developed by analyzing the satellite data, e.g., Landsat images can provide the rate, patterns and trend of changes using the benefit of repetitive satellite coverage on a particular locality. Such information is essential for further planning and development of urban growth in the future.

References

[1] Friedl, M.A. and Brodley, C.E. (1997) Decision Tree Classification of Land Cover from Remotely Sensed Data. *Remote Sensing of Environment*, **61**, 399-409. http://dx.doi.org/10.1016/S0034-4257(97)00049-7

[2] Lambin, E.F., Baulies, X., Bockstael, N., Fischer, G., Krug, T., Leemans, R., Moran, E.F., Rindfuss, R.R., Sato, Y., Skole, D., Turner II, B.L. and Vogel, C. (1999) Land-Use and Land-Cover Change (LUCC) Implementation Strategy, USA.

[3] Zhang, Z., Wang, X., Zhao, X., Liu, B., Yi, L., Zuo, L., Wen, Q., Liu, F., Xu, J. and Hu, S. (2014) A 2010 Update of National Land Use/Cover Database of China at 1:100000 Scale Using Medium Spatial Resolution Satellite Images. *Remote Sensing of Environment*, **149**, 142-154. http://dx.doi.org/10.1016/j.rse.2014.04.004

[4] Zhu, Z. and Woodcock, C.E. (2014) Continuous Change Detection and Classification of Land Cover Using All Available Landsat Data. *Remote Sensing of Environment*, **144**, 152-171. http://dx.doi.org/10.1016/j.rse.2014.01.011

[5] Walker, R. (2001) Urban Sprawl and Natural Areas Encroachment: Linking Land Cover Change and Economic Development in the Florida Everglades. *Ecological Economics*, **37**, 357-369. http://dx.doi.org/10.1016/S0921-8009(01)00178-1

[6] Giri, C.P. (2012) Remote Sensing of Land Use and Land Cover: Principles and Applications. CRC Press, Boca Raton.

[7] Lambin, E.F. and Meyfroidt, P. (2011) Global Land Use Change, Economic Globalization, and the Looming Land Scarcity. *Proceedings of the National Academy of Sciences*, **108**, 3465-3472. http://dx.doi.org/10.1073/pnas.1100480108

[8] Vitousek, P.M., Mooney, H.A., Lubchenco, J. and Melillo, J.M. (1997) Human Domination of Earth's Ecosystems. *Science*, **277**, 494-499. http://dx.doi.org/10.1126/science.277.5325.494

[9] Ramankutty, N. and Foley, J.A. (1998) Characterizing Patterns of Global Land Use: An Analysis of Global Croplands Data. *Global Biogeochemical Cycles*, **12**, 667-685. http://dx.doi.org/10.1029/98GB02512

[10] Powers, R., Ramirez, L., Redmond, C. and Elberg, E. (1966) Geology of the Arabian Peninsula. *Geological Survey Professional Paper*, **560**, 1-147.

[11] Mubarak, F.A. (2004) Urban Growth Boundary Policy and Residential Suburbanization: Riyadh, Saudi Arabia. *Habitat International*, **28**, 567-591. http://dx.doi.org/10.1016/j.habitatint.2003.10.010

[12] Meyer, W.B. and Turner, B.L. (Eds.) (1994) Changes in Land Use and Land Cover: A Global Perspective. Cambridge University Press, New York, 537 p.

[13] Sinha, P. and Kumar, L. (2013) Binary Images in Seasonal Land-Cover Change Identification: A Comparative Study in Parts of New South Wales, Australia. *International Journal of Remote Sensing*, **34**, 2162-2186. http://dx.doi.org/10.1080/01431161.2012.742214

[14] Ramachandra, T. and Kumar, U. (2004) In Geographic Resources Decision Support System for Land Use, Land Cover Dynamics Analysis. *Proceedings of the FOSS/GRASS Users Conference*, Bangkok, 12-14 September 2004, 12-14.

[15] Jensen, J.R. (1983) Urban/Suburban Land Use Analysis. *American Society of Photogrammetry*, **2**, 1571-1666.

[16] Singh, A. (1989) Review Article Digital Change Detection Techniques Using Remotely-Sensed Data. *International Journal of Remote Sensing*, **10**, 989-1003. http://dx.doi.org/10.1080/01431168908903939

[17] Lu, D., Mausel, P., Brondízio, E. and Moran, E. (2004) Change Detection Techniques. *International Journal of Remote Sensing*, **25**, 2365-2401. http://dx.doi.org/10.1080/0143116031000139863

[18] Alqurashi, A.F. and Kumar, L. (2013) Investigating the Use of Remote Sensing and GIS Techniques to Detect Land Use and Land Cover Change: A Review. *Advances in Remote Sensing*, **2**, 193-204. http://dx.doi.org/10.4236/ars.2013.22022

[19] Weng, Q. (2002) Land Use Change Analysis in the Zhujiang Delta of China Using Satellite Remote Sensing, GIS and Stochastic Modelling. *Journal of Environmental Management*, **64**, 273-284. http://dx.doi.org/10.1006/jema.2001.0509

[20] Berlanga-Robles, C.A. and Ruiz-Luna, A. (2011) Integrating Remote Sensing Techniques, Geographical Information Systems (GIS), and Stochastic Models for Monitoring Land Use and Land Cover (LULC) Changes in the Northern Coastal Region of Nayarit, Mexico. *GIScience & Remote Sensing*, **48**, 245-263.

[21] Chauhan, H. and Nayak, S. (2005) Land Use/land Cover Changes near Hazira Region, Gujarat Using Remote Sensing Satellite Data. *Journal of the Indian Society of Remote Sensing*, **33**, 413-420.

[22] Dewan, A.M. and Yamaguchi, Y. (2009) Using Remote Sensing and GIS to Detect and Monitor Land Use and Land

Cover Change in Dhaka Metropolitan of Bangladesh during 1960-2005. *Environmental Monitoring and Assessment*, **150**, 237-249. http://dx.doi.org/10.1007/s10661-008-0226-5

[23] Vittek, M., Brink, A., Donnay, F., Simonetti, D. and Desclée, B. (2014) Land Cover Change Monitoring Using Landsat MSS/TM Satellite Image Data over West Africa between 1975 and 1990. *Remote Sensing*, **6**, 658-676. http://dx.doi.org/10.3390/rs6010658

[24] Dawod, G.M., Mirza, M.N., Al-Ghamdi, K.A. and Elzahrany, R.A. (2013) Projected Impacts of Land Use and Road Network Changes on Increasing Flood Hazards Using a 4D GIS: A Case Study in Makkah Metropolitan Area, Saudi Arabia. *Arabian Journal of Geosciences*, 1-18.

[25] Wardak, A. (2005) Crime and Social Control in Saudi Arabia. In: *Transnational and Comparative Criminology*, 91-116.

[26] Li, G., Lu, D., Moran, E. and Hetrick, S. (2011) Land-Cover Classification in a Moist Tropical Region of Brazil with Landsat Thematic Mapper Imagery. *International Journal of Remote Sensing*, **32**, 8207-8230. http://dx.doi.org/10.1080/01431161.2010.532831

[27] Anderson, J.F., Hardy, E.E., Roach, J.T. and Witmer, R.E. (1976) A Land Use and Land Cover Classification System for Use with Remote Sensor Data. US Geological Survey Professional Paper 964, 28.

[28] Lu, D. and Weng, Q. (2005) Urban Classification Using Full Spectral Information of Landsat ETM+ Imagery in Marion County, Indiana. *Photogrammetric Engineering and Remote Sensing*, **71**, 1275-1284. http://dx.doi.org/10.14358/PERS.71.11.1275

[29] Xu, H. (2007) Extraction of Urban Built-Up Land Features from Landsat Imagery Using a Thematic-Oriented Index Combination Technique. *Photogrammetric Engineering and Remote Sensing*, **73**, 1381. http://dx.doi.org/10.14358/PERS.73.12.1381

[30] Walter, V. (2004) Object-Based Classification of Remote Sensing Data for Change Detection. *ISPRS Journal of Photogrammetry and Remote Sensing*, **58**, 225-238. http://dx.doi.org/10.1016/j.isprsjprs.2003.09.007

[31] Congalton, R.G. and Green, K. (2008) Assessing the Accuracy of Remotely Sensed Data: Principles and Practices. 2nd Edition, CRC Press, Boca Raton.

[32] Congalton, R.G. (1991) A Review of Assessing the Accuracy of Classifications of Remotely Sensed Data. *Remote Sensing of Environment*, **37**, 35-46. http://dx.doi.org/10.1016/0034-4257(91)90048-B

[33] Dewan, A.M. and Yamaguchi, Y. (2009) Land Use and Land Cover Change in Greater Dhaka, Bangladesh: Using Remote Sensing to Promote Sustainable Urbanization. *Applied Geography*, **29**, 390-401. http://dx.doi.org/10.1016/j.apgeog.2008.12.005

[34] Jensen, J.R. (2005) Introductory Digital Image Processing: A Remote Sensing Perspective. 3rd Edition, Clarke, K.C., Ed., Prentice Hall, Upper Saddle River.

[35] Yuan, F., Sawaya, K.E., Loeffelholz, B.C. and Bauer, M.E. (2005) Land Cover Classification and Change Analysis of the Twin Cities (Minnesota) Metropolitan Area by Multitemporal Landsat Remote Sensing. *Remote Sensing of Environment*, **98**, 317-328. http://dx.doi.org/10.1016/j.rse.2005.08.006

[36] Girard, L.F., Forte, B., Cerreta, M., de Toro, P. and Forte, F. (Eds.) (2005) The Human Sustainable City: Challenges and Perspectives from the Habitat Agenda. Ashgate, Aldershot.

[37] Curwell, S.R. (2007) Sustainable Urban Development: The Environmental Assessment Methods. Taylor & Francis, UK.

[38] Rahman, A., Aggarwal, S.P., Netzband, M. and Fazal, S. (2011) Monitoring Urban Sprawl Using Remote Sensing and GIS Techniques of a Fast Growing Urban Center, India. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, **4**, 56-64.

[39] Pauchard, A., Aguayo, M., Peña, E. and Urrutia, R. (2006) Multiple Effects of Urbanization on the Biodiversity of Developing Countries: The Case of a Fast-Growing Metropolitan Area (Concepción, Chile). *Biological Conservation*, **127**, 272-281. http://dx.doi.org/10.1016/j.biocon.2005.05.015

[40] Grimmond, S. (2007) Urbanization and Global Environmental Change: Local Effects of Urban Warming. *The Geographical Journal*, **173**, 83-88. http://dx.doi.org/10.1111/j.1475-4959.2007.232_3.x

[41] Rahman, A., Netzband, M., Alka, S. and Javed, M. (2009) An Assessment of Urban Environmental Issues Using Remote Sensing and GIS Techniques an Integrated Approach: A Case Study: Delhi, India. Urban Population-Environment Dynamics in the Developing World: Case Studies and Lessons Learned. International Cooperation in National Research in Demography (CICRED), Paris, 181-211.