Integration Of Multi-Temporal Remote Sensing Imagery And Gis For Mapping And Analysis Of Land Use Change In Jeddah City, Saudi Arabia

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KEYWORDS: Land use, urban growth Jeddah City, remote sensing, GIS.

ABSTRACT

During the last three decades, Jeddah City in Saudi Arabia has witnessed rapid growth in urban population from less than 1 million to 3.4 million. The essential goal of this paper was to detect the land use land cover (LULC) change in Jeddah City. Supervised classification and post-classification comparison, was used to detect the changes between 1984, 2000 and 2013. The data were acquired by Landsat Thematic Mapper (TM) on June 22nd 1984 and May 1st 2000 and Landsat-8 Operational Land Imager (OLI) on May 21st 2013. Four classes were mapped: build-up area, barren lands, vegetation and water.

Because of the difficulty to distinguish urban area from barren desert areas using spectral information alone, texture was produced using the red band and incorporated into image classification. The spectral-textural datasets produced more accurate LULC maps for change detection. The results show significant increase in build-up areas from the middle to the east, north and south, while barren lands shrank. The vegetation increased and was found to be related to urban areas. The water class shows slight change in the coastal areas, specifically around the international port and some recreation areas in the north.

1. INTRODUCTION

Over three billion people reside in urban areas as a result of fast urbanization (Aljoufie, 2012). The major cities worldwide are growing at an unprecedented rate over the last 100 years due to population growth and migration. Land use and land cover (LULC) change were the main environmental change which is happening in all countries. The land use change transferred the elements of natural environment to urbanized area. Most cities around the world are facing LULC change, especially with urban growth by increased urban population. An approximately 15 percent of the population was living in urban areas in 100 and in 200 years later, the urban population has increased to reach 50 percent (United States Geological Survey [USGS], 1999).

This research attempted to quantify the LULC change in Jeddah, Saudi Arabia, by detecting the changes of land use in the area, using post-classification comparison change detection. Change detection is the process of determining differences in the state of the feature or phenomenon by monitoring it at different times (Singh, 2010). Particularly, it consists of the ability to quantify temporal impacts using a multi-temporal dataset. Moreover, one of the most essential applications of remotely sensed data acquired from Earth-orbiting satellites is change detection due to frequent revisit at short intervals and reliable image quality (Anderson et al., 1978; Ingram et al., 1981; Nelson 1983). Remote sensing was used first through applying supervised classification and texture analysis with multi-temporal data of Landsat Thematic Mapper (TM) of 1984 and 2000 plus Landsat-8-Operational Land Imager (OLI) of 2013. The satellite imagery was classified into four classes that were urban area, barren land, vegetation and water. The changes of the LULC were characterized through the comparison of 1984, 2000 and 2013.

Remote sensing of urban areas provides the information of the spatial and temporal pattern of growth which are important for understanding differences in socioeconomic and environmental effects (Mertes et al, 2015). Geographic Information Systems (GIS) technique was essential to map the results of remotely sensed data. In addition, integrating remote sensing technique and GIS tools with
the available data are considered significant and necessary. The goals of integrating these tools are to create database and to update the urban growth map of Jeddah City, analyze the change of LULC in the arid area, and understand the spatial and temporal urban growth and vegetation change in the study area.

The results of the change detection will help the decision makers and planners to compare and develop solutions of the urbanization encroachment and associated environmental issues. Many studies have addressed the LULC change worldwide with different approaches. Using remotely sensed data to extract the information of LULC has become the routine. In addition, information extracted must be of high accuracy because the important decisions will be made using the information (Jensen, 2005).

The main objective of this research is to identify and analyze the spatial and temporal land use change patterns in Jeddah using remote sensing and Geographic Information System (GIS) techniques.

Multi-temporal Landsat imagery was collected for 1984, 2000 and 2013. The specific aims were: (1) to determine the best effective tools to map LULC and detect the changes in the land use, (2) to explore the temporal and spatial characteristics of land-use change and urban expansion from 1984, 2000 to 2013.

2. METHODOLOGY

2.1. Study Area

The study area for this research is Jeddah City, Kingdom of Saudi Arabia. Jeddah City is located on the west coast, in the middle of the eastern shore of the Red Sea (Aljoufie, 2012; Youssef et al, 2015; Murad, 2007). Jeddah City is situated between 21°17’ - 21°47’ N and 39°05’ - 39°39 E’ (Alsaud, 2010; Hassan et al., 2013).

Jeddah is the second largest city in the Kingdom after the capital Riyadh. It is one of the rapidly growing cities that also have witnessed a great deal of land use land cover change (Aljoufie et al., 2013). It is the largest city in Makah Province, the largest port on the Red Sea (Mosli and Alahwal, 2012). Fig.1. illustrates the geographic location of the study area. Because of its geographic location by the Red Sea, Jeddah City has been the commercial city since the ancient time (Khodeir et al., 2012). The area within the boundary of Jeddah City is 1765 km$^2$ and the entire municipality accounts for a total area of 5460 km$^2$.

Jeddah City had approximately 3.4 million populations in 2009, with a 3.5% annual growth rate since 2009 (Jeddah Municipality, 2015). Due to significant increase in population, extensive transportation network has been developed to serve people inside the city and to connect it to other cities in Saudi Arabia. Urban development has extended longitudinal starting from the central city to the south and north, confined by Alsarwat Mountains to the east and the Red Sea to the west. The climate is very dry with small amount of vegetation, some of which is seasonal associated with the wetter season.

Location of Jeddah City has a direct influence on the climate of the city. The summer is hot and relatively humid with average temperature around 40° C. The winter is cooler and wetter. The prevailing winds are from the northwest. They are often light to moderate winds for most of the year. The southern winds blow during the winter. These winds are active and their speed may cause great sandstorms and it may be accompanied by heavy rain (Jeddah Municipality, 2015; Alsefry and Şen, 2006).

2.2. LULC change in the City of Jeddah

Jeddah, Saudi Arabia, is an ideal example to present the growing of urban area using remote sensing and GIS techniques. Through four decades, the urban area of Jeddah City faced several changes in land use pattern, configuration, the transportation network, and the
population growth. Specifically, as the consequence of oil wealth, the urban area was developing and extending until it reached the outside boundary of the city (Aljoufie 2012). Population growth remains the first essential factor that drives land use land cover change. Mountain areas and desert were converted to build-up area, including residential, commercial, educational, and industrial use. Change of land use has a strong impact on the transportation network and the environment.

2.3. Remote Sensing System Considerations

It is important to understand the influence of the various parameters in different remote sensing approaches such as classification and change detection for accurate information extraction (Jensen, 2005). The resolution of remotely sensed data is vital to the supervised classification and change detection in this study, including temporal, spatial, spectral and radiometric resolutions.

The Landsat images for 1984, 2000 and 2013 were obtained from different sensors: 1984 and 2000 images were collected from Landsat TM while 2013 image was acquired by Landsat 8 OLI. Both sensors have the same temporal resolution which is 16 days of revisit, more than sufficient to monitor urban expansion. The exact dates of acquisition were: June 22nd 1984, May 1st 2000 and May 21st 2013. The spatial resolution is the second important resolution which refers to the amount of spatial details in the images. The three images have the same spatial resolution which is 30 by 30 meters in multispectral bands.

This resolution was good for my research because I only distinguished broad Level I LULC based on the Anderson classification scheme (Anderson et al., 1978), but for a relativity large area. The spectral bands that the study relied on are blue, green, red, near infrared and mid infrared. The radiometric resolution is the fourth essential element in remotely sensed data. Different sensors have different radiometric resolutions which amplify the number of the bit. Landsat 4 and 5 TM acquired 8 bit data and Landsat 8 OLI provides 12 bit data, a finer radiometric resolution. Therefore, the four considerations of remotely sensed data resolution are significant for the classification and change detection approaches, to obtain accurate results and interpret the results.

2.4. Data Sources

I obtained all Landsat images from U. S Geological Survey (USGS) Earth Explorer website. The six reflective bands common to all datasets were used in the classification and analysis: bands 1-5 and 7 for the TM images and bands 2-7 for OLI. All images were rectified to UTM, zone 37 on WGS 84 datum. Ancillary GIS data was collected from various sources including respected websites, academic sources and government agencies. The variety of the data included districts boundary within Jeddah, province boundary, population, and transportation network for 2014 from Jeddah Municipality.

2.5. Geometric Correction

Geometric correction of the satellite imagery is critical prior to any further image analysis such as image classification and change detection. The goal of geometric correction (image registration and rectification) is to overlay the image dataset in proper plane metric (X, Y) location and remove geometric distortions (Baboo and Devi, 2011). It commonly relies on the ground control points (GCPs) and a mathematical coordinate transformation to correct the geometry of the dataset (Ford and Zanelli, 1985). Accurate geometric registration of time series dataset is a prerequisite for change detection (Chen et al, 2003). All Landsat images and the DEM were geo-referenced to UTM Zone 37N coordinate system on the WGS 1984 datum. Careful examination of the datasets showed no need for further geometric correction because all the three images were correctly rectified by U. S. Geological Survey (USGS).

2.6. Image Classification

Classification of the remotely sensed data is a common approach to extract the important information of LULC. Because popular classification methods are based on spectral similarity within class and spectral distinction between classes, it is very difficult to distinguish urban area from desert-rocky-sand area due to similar spectral response from these classes.

There is one study addressed the classification of urban area in Jeddah City by Aljoufie (2012), using unsupervised classification to quantify the urban growth. However, the study focused on finding the relationship between urban growth and length of transportation network. The study did not go through the classification in the arid environment as much as using different indices to reveal the relationship between build-up area and transportation network. In this study, I aimed to incorporate texture measures in addition to spectral bands in the classification procedure to improve the classification accuracy of urban area in Jeddah City. Texture is one of the most important characteristics that are used to identify objects in imagery (Haralick et al, 1973). Applying texture measures would help distinguish urban from the surrounding desert landscape due to roads and structures present in urban areas. The red band is...
considered the best band to distinguish man-made land cover from the natural environment, so texture was measured using the red band for each year as shown in Fig. 2 that shows an example of the texture in 1984. The texture band was stacked with spectral bands to produce a spectral-texture dataset for the supervised classification. The classification results from spectral-texture datasets were compared to that of using the spectral datasets only. Post classification, a 3×3 majority filter was applied to the classification results to see if this helped clean up the salt-and-pepper effect of per-pixel classification and improved the accuracy. In this research, supervised classification was performed using Maximum Likelihood algorithm in ERDAS IMAGINE for 1984, 2000 and 2013 imagery. Fig. 3. shows a general flow diagram of image classification and change detection employed in this study.

Training area was used to assemble a numerical interpretation key that defines the spectral characteristic of each class. The training samples were collected based on the author’s prior knowledge about the study area, ancillary GIS data, and visual interpretation of the original imagery and higher resolution imagery in GoogleEarth. Training Sites are clusters of pixels that are spectrally similar, representing LULC classes of the study area which are build-up area, barren land, vegetation and water (Table.1). Subsequently the training site signatures were evaluated for spectral separability before they were adopted.

The signatures based on training areas were used for a supervised Maximum Likelihood classifier to derive LULC classes from the three images that were acquired in 1984, 2000, and 2013. Each classification result included multiple subcategories of the four classes due to spectral diversity within each class. The Recode function was used to aggregate the classification result into the final four classes. The classification is not complete without accuracy

<table>
<thead>
<tr>
<th>LULC class</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Build-up Area</td>
<td>Build-up area includes residential, commercial, industrial, transportation network and other developed areas</td>
</tr>
<tr>
<td>Barren Land</td>
<td>Bare land, which is the land of limited capacity to support life, consists of an area of thin soil, sand or rocks.</td>
</tr>
<tr>
<td>Vegetation</td>
<td>Vegetation cover means the area that has trees or grass</td>
</tr>
<tr>
<td>Water</td>
<td>The area that is covered any source of water such as open water</td>
</tr>
</tbody>
</table>

Table.1. The definition of LULC categories that used in this study (Anderson et al, 1978)
assessments. The accuracy assessment defines quantitatively how accurate the pixels were grouped into their classes in the area of interest. Each classification entails assessment of the consistency and reliability of the results. The accuracy assessment includes three steps: independent samplings of testing areas, preparing a confusion matrix resulting from classifying randomly sampled test pixels, and calculate the accuracy measurement.

A total of 200 random points were produced using the “Equalized Random” strategy (50 points for each class in the classification result) to use as reference points. Then, the identity of all 200 reference points was determined using the original imagery, high resolution images in GoogleEarth, ancillary data and personal knowledge of the study area.

The error matrix is the most widely used tool to assess the accuracy of the classification. An error matrix has the reference data organized in columns and classified data in rows, based on the classified and reference identity of the samples. The accuracy of each class is defined along with the error in implication (commission error) and error of exclusion (omission error). The overall accuracy can be computed by dividing the total of correct pixels (the sum of the major diagonals) by the total of the pixels in the confusion matrix. Also, accuracy of individual classes can be computed in similar manner. Two classification results were generated for each year, based on spectral bands alone and the spectral-textural dataset (Fig.3).

The reports of accuracy assessment include the user’s accuracy and producer’s accuracy. The producer’s accuracy is the ratio between the total number of correct pixels in a grouping and the total number of the pixels from the reference data (the column total), a measure of omission error. On the other hand, the user’s accuracy is computed by dividing the total number of correct pixels in a category by the total number of classified pixels (the row total) for that category, a measure of commission error.

Accuracy assessment report also shows the $K_{\text{hat}}$ Coefficient of Agreement. (Equation 1) The $K_{\text{hat}}$ Coefficient of Agreement determines the performance of the classification compares to chance which is random assignment of pixels into classes. The result of $K_{\text{hat}}$ closer to 1 (one) means that the classification is considered much better than chance agreement, and closer to 0 (zero) means that the classification is no better than chance.

$$
\hat{K} = \frac{N \sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r} (X_{ii} \cdot X_{i.})}{N^{2} - \sum_{i=1}^{r} (X_{ii} \cdot X_{i.})}
$$

(Equation 1)

Where: $r$ = the number of the row in the matrix,
$X_{ii}$ = sum of diagonal,
$X_{i.} = $ the total observation in row $i$,
$X_{.i} = $ the total observations in column $i$, respectively,
$N = $ the total number of the samples (Congalton, 1991)

2.7. Change Detection and Information Extraction

Detection of LULC change provides essential information for land use planning, management and ecological studies (Serra et al., 2003). In addition, LULC changes around urban areas are results of the human activity on the environment. LULC change implication for sustainable resource use has become important in many communities (Alphan et al., 2009). Post-classification comparison method detects change by identifying where the categories of the classification are found different between two years (Liu and Zhou, 2004). Each image was processed using supervised classification approach and then compared to create change detection map (Macleod and Congalton, 1998). The results of the post-classification comparison change detection include “from” and “to” information (Macleod and Congalton, 1998).

For each year, the highest overall classification accuracy was achieved through supervised classification of the spectral-textural image for 1984, 2000, and 2013. Thus, the classification results of the highest accuracy were the input to change detection. With just four categories, the function of the post-classification comparison is (classification result of the earlier date)*10+ (classification result of the later date).

If the output is 11 for a pixel, it indicates category 1 no change; 12 would mean that this pixel has changed from category 1 to category 2, and so on. This method would result in a change detection map where the location and amount of the changes between the classes can be calculated. The post-classification comparison approach was applied for 1984 and 2000, and 2000 and 2013 to reveal the changes between different dates.

3. RESULTS AND DISCUSSION

3.1. Classification result of the 1984 image

Fig.4. and Fig.5. present the four classes which were build-up areas, barren lands, vegetation, and water. Fig.4. displays the result of spectral method and Fig.5. the spectral-textural method. The urban areas were located in the center of the study area and along The Red Sea. Most of the study area consisted of barren lands, located in the south, east, and north. The Red Sea was the only source of surface water in Jeddah City. Vegetation was closely associated with build-up area and it was a very small
Comparing the result of using spectral bands along, the inclusion of texture in classification helped distinguishing urban area better. Some pixels of barren lands were misclassified as build-up area in Fig.4; built-up areas were better defined in Fig.5.

Table 3. Accuracy reports of the classification results for 1984

Table 2 and 3. present the accuracy of the results produced by the two classification methods for 1984. The overall classification accuracy was 88% with a $K_{\text{hat}}$ statistic of 0.84 without incorporating texture in the classification. With texture, the overall accuracy increased to 97% and $K_{\text{hat}}$ improved to 0.95.

For individual classes, the spectral-textural dataset resulted in higher accuracy in both producer’s accuracy and user’s accuracy in general, all of which were above 94%. The user’s accuracy of built-up area improved from 82% to 96% with comparable producer’s accuracy. The producer’s accuracy of barren land improved from 84% to 98%, with 100% user’s accuracy. The improvement in classification accuracy demonstrated the effectiveness of incorporating textural information in classification in this arid study area.
The resolution of the 1984 image was 30 by 30 meters. As a result of the classification, the number of the pixels that covered by each class multiplied by 900 square meters gave the total area for each class in square meters. Then, the square meters were converted to hectares. The LULC results from the spectral-texture dataset are shown in Table 4. Barren land occupied the largest area on land in 1984, which was 450,275.4 ha. Urban area accounted for 12,750.21 ha, which equal to 1.23% of the study area. Because of the dry conditions, the vegetated area was the smallest, with only 1,925.19 ha. Water class had the largest areas between all classes which was 499,711.14 ha. Because of the relatively small population in 1984 which was 960,000, build-up class covered a small area where the services are located in.

### 3.2. Classification result of the 2000 image

Fig. 6 and 7. show the classification results of 2000 produced by the two classifications using spectral and spectral-textural datasets. Urban area grew from the center of Jeddah city and along The Red Sea to the south, east and north, with some additional urban development in the far south and north. The barren land shrank compared to the 1984 maps. Vegetation areas have also increased and were located in urban area, recreation and resort areas. The water class was located in the west side where The Red Sea is. Without texture, the spectral classification result showed considerable spectral confusion including barren land inside the build-up area. In contrast, spectral-textural classification resulted in great improvement with the build-up area being much better defined.

### Accuracy of Spectral Dataset

<table>
<thead>
<tr>
<th>Class Name</th>
<th>Producer’s Accuracy</th>
<th>User’s Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Build-up area</td>
<td>91%</td>
<td>82%</td>
</tr>
<tr>
<td>Barren Land</td>
<td>92%</td>
<td>94%</td>
</tr>
<tr>
<td>Vegetation</td>
<td>87%</td>
<td>92%</td>
</tr>
<tr>
<td>Water</td>
<td>94%</td>
<td>96%</td>
</tr>
<tr>
<td>Overall classification accuracy</td>
<td>91%</td>
<td>96%</td>
</tr>
</tbody>
</table>

### Accuracy of Spectral-Textural Dataset

<table>
<thead>
<tr>
<th>Class Name</th>
<th>Producer’s Accuracy</th>
<th>User’s Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Build-up area</td>
<td>100%</td>
<td>88%</td>
</tr>
<tr>
<td>Barren Land</td>
<td>93%</td>
<td>100%</td>
</tr>
<tr>
<td>Vegetation</td>
<td>98%</td>
<td>100%</td>
</tr>
<tr>
<td>Water</td>
<td>98%</td>
<td>100%</td>
</tr>
<tr>
<td>Overall classification accuracy</td>
<td>97%</td>
<td>96%</td>
</tr>
</tbody>
</table>

Table 5 and 6. Accuracy reports of the classification results for 2000

![Fig. 6. The classification result of spectral bands, with an inset to show an example of the build-up area in Jeddah City, Saudi Arabia, 2000](image1.png)

![Fig. 7. The classification result of spectral-texture dataset, with an inset to show an example of the build-up area in Jeddah City, Saudi Arabia, 2000](image2.png)
The accuracy report of the classification results for 2000 was shown in Table 5 and 6 for the two methods. The accuracy was relatively high overall, with an overall accuracy of 91% without texture and 97% with texture. Texture helped to improve both the producer’s and the user’s accuracy for every individual class. Without texture, build-up areas had the lowest percentage of the user’s accuracy among the four classes (82%), which demonstrated the difficulty of distinguishing build-up area in the arid landscape.

Using spectral bands alone, the vegetation also had relatively lower accuracies (92% for the user’s accuracy and 87% for the producer’s accuracy) because vegetation existed between the build-up areas and in small amount, which made the classification difficult. Incorporating texture in the classification procedure resulted in much improved producer’s and user’s accuracies for the build-up area.

<table>
<thead>
<tr>
<th>LULC category</th>
<th>LULC class</th>
<th>Number of Pixels (30m by 30m)</th>
<th>Total area (hectare)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Build-up area</td>
<td>636289</td>
<td>57,266.01</td>
</tr>
<tr>
<td>2</td>
<td>Barren Land</td>
<td>4482672</td>
<td>403,440.48</td>
</tr>
<tr>
<td>3</td>
<td>Vegetation</td>
<td>99755</td>
<td>8,977.95</td>
</tr>
<tr>
<td>4</td>
<td>Water</td>
<td>5499750</td>
<td>494,977.5</td>
</tr>
</tbody>
</table>

Table 7. LULC results for 2000 spectral-texture classification

The LULC area tabulation based on the higher accuracy classifications shown in Table 7. The barren lands occupied an area of 403,440.48ha. Build-up area increased rapidly to 57,266.01 ha. Increasing build-up area accompanied the decreasing in barren land and increasing in the vegetation. The decreasing was remarkable in barren lands from 450,275.4ha in 1984 to 403,440.48 ha in 2000. Also, increasing the vegetation was obvious from 1,925.19 ha in 1984 to be 8,977.95 ha in 2000. Urban growth was expected to continue in the city of Jeddah.

3.3. Classification result of the 2013 image

Fig. 8. shows the classification result of spectral bands for 2013. The confusion between build-up pixels to barren land is very noticeable. Fig. 9. presents a clearer land use pattern due to the effectiveness of the texture. In addition, Table 8 and 9. show the producer’s accuracy and user’s accuracy for both methods of the supervised classification. Once again, texture was effective in improving both producer’s and user’s accuracies for individual classes, along with overall accuracy and $K_{hat}$. The greatest improvement is found in build-up area and barren land. Incorporating texture, the producer’s accuracy for build-up area increased from 84% to 90%, and user’s accuracy increased from 76% to 92%. For barren land, the producer’s accuracy improved from 80% to 92% and user’s accuracy from 88% to 94%.

![Fig.8. The classification result of spectral bands, with an inset to show an example of the build-up area in Jeddah City, Saudi Arabia, 2013](image1)

![Fig.9. The classification result of spectral-texture dataset, with an inset to show an example of the build-up area in Jeddah City, Saudi Arabia, 2013](image2)
Also, it has 10 private and public universities and colleges (Jeddah Municipality, 2015); King Abdulaziz University has more than 40,000 students. Also, the length of the road increased from 101 km in 1964 to 826 km in 2007 made the access in Jeddah City easier and helped urban population growth (Aljoufie, 2012). In addition, commercial activities led to the study area to have 67 malls (Jeddah Municipality, 2015).

Meanwhile, barren lands decreased remarkably to 387,767.43 ha, comparing to 450,275.4 ha in 1984 and 407,462.31 ha in 2000. Classification results also showed that vegetation increased slightly to 9,789.39 ha, comparing to 8,977.95 ha in 2000 and 1,925.19 ha in 1984. The reason of increasing the vegetation was the increasing in build-up areas. In Jeddah, vegetation is next to built-up areas in small amount, such as parks and tree-lined streets.

### 3.4. Results of LULC change detection

The results of post-classification comparison method demonstrated the “from and to” differences in LULC from one time to another. Changes were mapped using the classification results of the higher accuracy, i.e., based on the spectral-textural datasets.

#### 3.4.1. LULC change between 1984 and 2000

Fig.10. highlights land use conversion from others categories to build-up areas. The established build-up area in 1984 was located in the middle of Jeddah City. The orange color represents the great amount of change from barren land to build up area.

It shows that urban areas extended into the desert in all directions from the established core. Moreover, some water areas were converted to build-up area along the coastline in the middle and south and most of them in the north due to land reclamation to develop recreation and resort areas.

Table.11. shows the results of the change detection between 1984 and 2000 with the number of the pixels and hectares for each category. Build-up areas were the focus of this study. Build up area that existed in 1984 was 8,048.34 ha. The conversion from barren lands to build-up areas were the largest amount of change to urban, which had 45,354.78 ha; and 2,961.45 ha of water was converted to build-up area.

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Table.8 and 9. Accuracy reports of the classification results for 2013

<table>
<thead>
<tr>
<th>Class Name</th>
<th>Producer’s Accuracy</th>
<th>User’s Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Build-up area</td>
<td>84%</td>
<td>76%</td>
</tr>
<tr>
<td>Barren Land</td>
<td>80%</td>
<td>88%</td>
</tr>
<tr>
<td>Vegetation</td>
<td>98%</td>
<td>88%</td>
</tr>
<tr>
<td>Water</td>
<td>91%</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Overall accuracy</strong></td>
<td>90%</td>
<td></td>
</tr>
<tr>
<td><strong>Overall K_statistic</strong></td>
<td>0.86</td>
<td></td>
</tr>
</tbody>
</table>

Accuracy of Spectral Textural Dataset

<table>
<thead>
<tr>
<th>Class Name</th>
<th>Producer’s Accuracy</th>
<th>User’s Accuracy</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Build-up area</td>
<td>90%</td>
<td>92%</td>
<td></td>
</tr>
<tr>
<td>Barren Land</td>
<td>92%</td>
<td>94%</td>
<td></td>
</tr>
<tr>
<td>Vegetation</td>
<td>100%</td>
<td>96%</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>100%</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td><strong>Overall accuracy</strong></td>
<td>96%</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Overall K_statistic</strong></td>
<td>0.94</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table.10. LULC results for 2013 spectral-texture classification

<table>
<thead>
<tr>
<th>LULC category</th>
<th>LULC class</th>
<th>Number of Pixels (30m by 30m)</th>
<th>Total area (hectare)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Build-up area</td>
<td>773302</td>
<td>69,597.18</td>
</tr>
<tr>
<td>2</td>
<td>Barren Land</td>
<td>4308527</td>
<td>387,767.43</td>
</tr>
<tr>
<td>3</td>
<td>Vegetation</td>
<td>108771</td>
<td>9,789.39</td>
</tr>
<tr>
<td>4</td>
<td>Water</td>
<td>5527866</td>
<td>497,507.94</td>
</tr>
</tbody>
</table>

Table.10. displays areas of LULC categories for 2013 based on the spectral-textural classification. Build-up areas accounted for 69,597.18 ha and equaled to 7.21% of the study area, compared to 1984 which was 1.32%. The results indicated that there was a significant urban area growth between 1984 and 2013.

This growth of urban areas was a result of the availability of services in Jeddah City, especially since it has been the second major city in Saudi Arabia after the capital Riyadh. It has the international port and airport to attract migrants from other countries and from rural areas in the country to the live in Jeddah City.
This research revealed the significant changes among the four classes between 1984 and 2000 and also between 2000 and 2013. The last time period of the change detection of 2000 and 2013 shows a remarkable increase compared to 1984 and 2000. Fig.11 shows the existing build-up area and other classes that converted to urban. The map illustrated the trend of increasing urban area to the northeast more than the north and south. The reason of that was the location of King Abdul-Aziz International Airport and availability of other services in that area. Also, build-up area to the north and the most northern area grew more than the south. This northward trend was due to the creating of King Abdullah University of Science and Technology (KAUST). That led the area to develop fast in the north.

3.4.2. LULC change between 2000 and 2013

The rapid growth of Jeddah City was again observed between 2000 and 2013. Table.12 presents the changes between LULC classes during this period. Build-up area continued growing in size through land conversion from other classes. Barren land converted to build-up area by 33,346.53 ha, the vegetated area and water class converted to urban area by 768.06 and 1,030.23 ha. The vegetated area has less amount of change from other LULC classes. Build-up, barren and water class was converted to vegetated area by 2,864.52 ha, 1,068.57 ha and 45.09 ha respectively. In addition, converting some LULC classes to be barren land such as the vegetation was very regrettable and it reached 1,668.15 ha. The condition of the weather and lack of rainfall were the main reasons behind that.
The change detection results have shown urban growth clearly. The pattern of the changing in Jeddah city has been longitudinal and it started from the middle and close to the Red Sea. When the urban area expanded, the direction of the growth increased from the north to the south. The change between 1984 and 2000 was smaller compared to 2000 and 2013. For instance, the existing build-up area in 1984 was 8,048.34 ha, which increased to 32,058.54 ha in 2000, and increased in total to be 67,203.36 ha in 2013. Vegetated area was dispersed surrounding the build-up area. Also, it increased significantly from 541.71 ha in 1,984 to be 2,859.3 ha in 2000. The total change for the vegetation between 1984 and 2000 was 8,977.95 ha and between 2000 and 2013 was 9,789.39 ha; it increased slightly in the later period.

3.5. Population of Jeddah City

Jeddah City, Saudi Arabia has witnessed a large increase in population due to migration. Table.13 represents the rapid growth of the build-up area and the population. In 1984, the build-up area was concentrated in the middle of Jeddah City with a much smaller population. The built-up area quadrupled by 2000 which the population more than doubled compared to 1984. By 2013, population had grown to 3.4 million and with an additional built-up area of close to 20,000 ha.

<table>
<thead>
<tr>
<th>Year</th>
<th>Urban area (hectares)</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>1984</td>
<td>12,750.21</td>
<td>960,000</td>
</tr>
<tr>
<td>2000</td>
<td>50,522.94</td>
<td>2,560,000</td>
</tr>
<tr>
<td>2013</td>
<td>69,597.18</td>
<td>3,400,000</td>
</tr>
</tbody>
</table>

Table.13.Population and urban area in Jeddah City (The author, 2015; Aljoufie, 2012)

4. CONCLUSION AND RECOMMENDATIONS

4.1. Conclusion

This study demonstrated the procedures and potential of integrating remote sensing and GIS to measure and assess LULC change in Jeddah City, Saudi Arabia. This research presented significant results of image classification using different methods, post-classification comparison. This research has followed several major steps to serve the objectives of the study, which include: (1) acquiring remotely sensed data, (2) preprocessing imagery, such as stack layers and apply texture on the red band, (3) supervised classification using Maximum Likelihood classifier for two different datasets: spectral and spectral-textural and (4) post-classification comparison change detection using the higher accuracy classification results.

However, this study did face some restrictions. First, the spectral resolutions of bands were not good enough to obtain some specific details of the study area, for example, the color of the rocks appear to be the same as the build-up area. Secondly, lack of existing LULC maps for reference. Despite the limitations, the research utilizes different methods and tools to achieve supervised classification and post-classification comparisons change detection to assess the changes of LULC.

Urban growth was quantified through three decades, using supervised classification and post-classification comparisons change detection processes. The pixels between build-up areas and barren lands are spectrally similar when applying supervised classification. The inclusion of texture in classification greatly improved the accuracy of LULC mapping. The red band was selected to produce the texture measurement because it is the best band to distinguish man-made structures from other land cover types. Texture was useful not only to separate urban areas from barren lands, but also to locate the roads and define shape of the build-up area. The spectral-texture method greatly improved the results. The spectral-texture classification results show higher mapping accuracy for each LULC classes, which were used in post-classification comparison to detect LULC change. The overall accuracy assessment of the spectral-texture methods shows a higher accuracy. The overall classification accuracy involving texture was 97%, 97% and 96% for 1984, 2000 and 2013 respectively, compared to 88%, 91%, and 90% without texture.

Significant urban expansion since 1984 was apparent during the years. Total build-up area was 12750.21 ha in 1984, which increased to 57266.01 ha in 2000 and 69597.18 ha in 2013. Increasing build-up area shrunk the barren lands. Urban areas have expanded from the middle to the north, the east and the south, with limitations on the east by Alsarwat Mountains. It extends along the coastal plain of the Red Sea due to accessibility.

The vegetation was another story. In 1984 the amount was 1925.19 ha and it drastically increased to 8977.95 ha in 2000, then it increased slightly to be 9789.39 ha in 2013. The vegetated areas are next to where the build-up areas are, such as resort and recreation areas, and where the streamflow is. This has caused a fluctuation in the size of the vegetation, because of the small amount of the rainfall and lack of freshwater sources in the arid area. The results show increasing in amounts of the vegetation around the built-up area and there are new batches found in various locations in Jeddah City.
Several research objectives were addressed in this study. Finding the best way to map LULC change in the arid environment and analyze the change were the main goals of this research. We can draw the following conclusions based on this study.

1) Incorporating texture significantly improved the image classification results in the arid environment;
2) Large amount of barren land around Jeddah has been converted into urban; urban growth extended into the east, north and south from the established core of the city.
3) There has been an increase in vegetation, based on both the post classification comparison of LULC between the years. This is likely due to the creation of more recreational areas and resorts, and planting of vegetation next to new development.
4) Post classification comparison provided valuable information on the LULC change. Post classification comparison gave specific nature of change.

The main reason behind the urban growth is the increasing urban population and the booming oil industry and international trade. Other reasons include the availability of services in Jeddah City, especially since it is the second main city in Saudi Arabia. It has the international port and airport to attract migrants from other countries and from the rural areas to the live in Jeddah City. Also, it has 10 private and public universities and colleges (Jeddah Municipality, 2015). Also, the length of the road increased from 101 km in 1964 to 826 km in 2007 made the access to Jeddah City easier and helped urban population growth (Aljoufie, 2012). Jeddah City is expecting to continue to growing the coming years.

4.2. Recommendations

Based on the results of this study concerning LULC change, the subsequent recommendations are made:

1. The government of Jeddah City, Saudi Arabia should make a comprehensive plan to guide future development after a survey and analysis of current population distribution, land use, transportation, economy and the environment.
2. The planner and decisions maker should take into account the natural streamflow and restore the areas that are located on or close to the streams. Also, make a detailed map that shows each stream in Jeddah City to avoid disasters in the future.
3. Because of the scarcity of vegetation and increasing population which could further impact the water, air and soil quality, the government of Jeddah City should maintain the health of vegetation and to introduce more vegetation.
4. The government of Jeddah City and researchers should continue to use remotely sensed data and effective tools in GIS to monitor urban growth and the environment. In conclusion, it is imperative to study and monitor the changes of the LULC pattern for sustainable development of Jeddah City.

12. REFERENCES


