

Change Detection in Urban Areas using Satellite Data

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Abstract. Satellite data can be regarded as a powerful tool for providing information for urban monitoring that can be used by urban and regional planners in fraction of the cost and time compared to traditional methods (e.g. Aerial photos or field survey). However, most of the methods used in the literature to process such data will need a considerable time and experience. This has limited the application of such technology, since such experience is not always available in urban development sector of the community.

The study was conducted over the city of Riyadh, central Saudi Arabia, to test a simple Image Difference (ID) technique for urban change detection. Landsat Thematic Mapper (LTM) data on 21 July, 1987 and 15 September, 1996 and SPOT Panchromatic Linear Array (PLA) data on 2 August, 1996 were acquired over the study area. The change detection using image difference procedure involves: (i) Spatial registration of multi-temporal data sets collected by the different sensors. (ii) Image difference were then used to detect changes in urban areas which enable the detection of changes in brightness values using Pixel by Pixel subtraction of the registered data sets. Three small sub-scenes from the whole study area were generated to evaluate the method in more details. It was found that such technique emphasizes temporal changes and provides an excellent and easy to interpret first level indication of change in urban areas.

Introduction

In remote sensing change detection is referred to as the process of identifying changes for earth surface by observing differences between a number of multi-temporal images taken over the same area. Digital change analysis techniques are predicted on the assumption

that pixel brightness values are correlative with the condition of the land surface. Monitoring landscape change, particularly urban growth, with remotely-sensed data provides a means for studying national economy (oil revenues, migration rate to the city, food demand, water resources demand, etc.) and for studying ecosystem responses to natural and manmade influences at regional scale. Remotely-sensed data provide a suitable spatial and temporal context to map the extent and rate of urban development. It may help in the systematic and quantitative monitoring and in regulation in areas of intensive urbanization. Detecting temporal changes for earth surface by observation at different times is one of the most important applications of earth orbiting satellites because they can provide multi-date digital imaging with consistent image quality, at short interval, on global scale, and during complete seasonal cycle [1].

Aerial photography is known to be the traditional and frequently used method to study the growth in urban areas owing to its high spatial resolution. However, the fast urban growth of the major cities in the developing countries make it very difficult and very costly to follow up such growth using such method. The advancement in space technology and the improvement of spatial resolution in satellite imagery as well as the advancement in digital image processing (both in hardware and software) make it possible to use such technology in urban studies with very low cost and a high temporal resolution compared to aerial photos or ground survey.

This study aims to evaluate the usefulness and efficiency of satellite data to bring out the temporal changes (change detection) in a highly growing urban area, city of Riyadh, to provide the necessary information in fraction of the costs and time compared to traditional methods. This information is of considerable interest to urban and regional planners as well as resource managers. Several approaches were indicated in the literature to detect changes in urban areas using landsat and SPOT data. These approaches include, principal component analysis [2], [3], [4], and [5], multi-date composite image [6] and [3], Image difference [4], [7], and [8] (for forest defoliation), and Digital classification [9] and [10]. A useful review of different approaches of change detection are provided by [11] and [12, pp. 257-279].

Although a huge amount of remotely- sensed data are available and can easily be provided, only a small amount of this data were effectively utilized by a small number of users. This may be due to the fact that most of the methods used in the literature needs a considerable time as well as experienced operators which limits the application of remote sensing for change detection. It is the aim of this study to use a simple technique of detecting changes in urban areas that would provide a reliable first-level indication of urban change and would be possible to use by inexperienced operator, particularly for urban planners concerned with changes over large administrative areas. In developing countries and, to some respect, in developed countries an experienced operator or image analyst is not always available in the urban development section who can perform a complex image processing

or will even have that computer power needed for such processing. This study is therefore aimed to use a method that is simple to perform and does not need a high speed hardware or a complex software to execute.

Study Area

The study area selected (approximately 55 km by 60 km), comprises all of the city of Riyadh, the capital city of Saudi Arabia (figure 1), at latitude 24° 38' North and longitude 46° 43' East. The city of Riyadh, is located at the east bank of the Wadi Hanifa Valley that runs from north west and west toward the south of the city. It is one of the oldest human settlements (2,000 years) in central Saudi Arabia [13]. Except for Hanifa Valley, the city of Riyadh has the capacity for growth. This was partially overcome by bridges enabling growth to extend to the west bank. However, the large number of the valley tributaries in the west made large areas undeveloped. The climate is a typical continental climate, hot dry summer (exceeding 40°C with large fluctuations in the average maximum and minimum temperature) cold dry winter (5-8°C).

The remarkable growth of the city has started in 1973. The factors influencing the growth of the city were described by Al-Gadhi [13] and can be summarized in the following :

1. The rapid growth of the national economy owing to the increase of oil prices after 1973 oil crises.
2. The high rate of migration to the city, the population of the city of Riyadh has increased from 609,000 in 1974 to 1,517,000 in 1986 and to 3.4 million in 1992 (20% of the total population of the country) in which 0.92 million is international immigrants.
3. The Real Estate Development Fund (REDF) public agency that was found in 1974 to provide interest free loans for residential units subject to an upper limit of 80,000 US\$, and commercial complexes with an upper limit of 2,700,000 US\$. These loans should be returned in annual premium during 25 years for private housing, and within 10 years for commercial complexes.

The continuous increase in population and consequently growth rate in urban areas need continuous monitoring plan to provide suitable land for development as well as utilities and services.

Data Sources

The main data source in this study were digital imagery which include:

1. A SPOT panchromatic linear array (PLA) data acquired on 2 August, 1996 (10 m spatial resolution) Path 146/ Row 301.
2. Landsat-5 TM data acquired on 21 July, 1987, and 15 September, 1996 (30 m spatial resolution) Path 165/ Row 043.

Both Landsat TM and SPOT PLA data were acquired by the satellite receiving station of the Saudi Center for Remote Sensing (SCRS), one of the King Abdulaziz City for Science and Technology divisions. All of the three data sets over the study area were free of clouds and distortion. The satellite data used were acquired at approximately the same season of the year. This step was taken to eliminate seasonal differences either in sun angle or vegetation, that can severely affect change detection [12, p. 259].

Methodology

Pre-processing

The SPOT (PLA) data of 1996 were geometrically corrected using the Meridian software available at SCRS. Approximately 25 scattered control points were selected, a cubic convolution resampling were applied with a sub-pixel error. Accurate spatial registration of data sets collected by different sensor systems (in this study, Landsat TM and SPOT PLA), with a different instantaneous field of view (IFOV) is essential for change detection. Precise image to image registration is a critical step in order to minimize miss-registration that can provide false detection of change [12, p. 259]. No correction for atmospheric effects was performed since the imprecision of scattering model might influence change detection results.

After performing the geometric correction on the SPOT (PLA) data of 1996, It was then registered on the Landsat TM data of 1996 using the warping algorithm of the Meridian Software which allow image to image registration to be performed via an interactive selection of control points in the two scenes. The same procedures used for the geometric correction of the SPOT PLA data (image to map registration) were used for the Landsat TM 1987 and Landsat TM 1996 registration (image to image registration) as well as for SPOT (PLA) 1996 and Landsat TM 1996.

In order to combine the Landsat (TM) data of 1996 and SPOT (PLA) data of 1996 in one enhanced data set, it was decided to use a different colour space transformation, Hue-Saturation-Intensity (HSI) transformation ([14] and [15, pp. 227-231]. Three Landsat (TM) bands (of 1996) were chosen, one in the visible (Band1), one in the near infrared (Band 4), and one in the mid infrared (Band 7). These three bands were transformed from blue, green, and red (BGR) colour space to (HSI) colour space. The intensity (I) were then substituted by an edge enhanced SPOT (PLA) data and were then transformed back to the BGR colour space. This step was taken to ensure that the colour balance of original data is maintained [16].

Data Processing

Image difference technique were used in this study to detect changes in urban areas. This technique enable the detection of changes in brightness values between two or more data sets using pixel by pixel subtraction of registered data sets [15, p. 182] and [8]. The

subtraction resulted in positive and negative pixel values in area of change and zero values in areas of no change. The resulted image should be rescaled to a positive value by adding the medium value of the quantization level which is 127 for 8 - bit data (256 levels) the operation is expressed mathematically as:

$$P(3)_{i,j,k} = P(2)_{i,j,k} - P(1)_{i,j,k} + C$$

where,

$P(1)$, $P(2)$ and $P(3)$ are pixel values at date 1, date 2 and difference pixel respectively.
 i,j,k are line, column and band number respectively.
 C is a constant (127 for an 8 Bit data, 256 levels).

Image difference is computationally very simple and easy to interpret. This method was used previously for change detection in forest areas (e. g. [4] and [8]). Two images (6007 pixels X 5503 lines) of Landsat TM band-7 of 1987 and TM band 7 of 1996, after it was combined with SPOT PLA data as described previously, were selected to perform image difference. It was decided to select band-7 of Landsat TM data (mid-infrared) to be used as a



Fig. 1. The study area centered on the city of Riyadh, Saudi Arabia. The area is approximately 55 km by 60 km.

single band because when compared to other TM bands it provides the best spectral information for visual discrimination of land cover changes in this area and looks more sharp compared to other bands. This band is also the least affected by atmospheric scattering.

Results and Discussion

Figure 2 was produced from subtraction of TM band-7, 1996 from TM band-7, 1987 data, after performing the methodology indicated previously. In this figure, areas that stayed the same in the two dates are shown as medium gray tones, the light and dark tone areas are an indication of changes (new residential construction, roads, vegetation etc.). The areas that have high digital number (DN) values in 1996 and low DN values in 1987 appear in this image as dark areas. Areas that have low DN values in 1996 data and high values in 1987 data appear as bright tone, whereas areas with similar tone in both images (areas of no change) have a medium tone.

To evaluate the method in more details, three small sub-scenes of 1024 pixel x 1024 lines were selected and were shown in Figs. 3, 4 and 5. Figure 3 (i), (ii) and (iii), is a portion of the city in 1987, 1996 and difference image respectively. Four locations are of particular



Fig. 2. Difference image produced from subtraction of landsat TM band-7, 1987 data from the combined landsat TM band-7, 1996 and SPOT PLA, 1996. In this figure, areas that stayed the same in the two dates are shown as medium tone, the light and dark tone areas are an indication of changes.

interest, housing areas A1 and A2 were open field in 1987 TM image, by 1996 the areas are full of new houses which appears as bright tone in the differenced image. In area B, KACST housing area was partially constructed in 1987 but was completed in 1996, the area of change is shown as bright tone in the difference image. KACST offices area at C were an open field in 1987 but were completely constructed in 1996, the area of change is shown as bright tone in the difference image. Area D is King Saud University in which part of it was under construction (mainly the eastern part of the ring road), when the 1987 Landsat image was recorded, by 1996

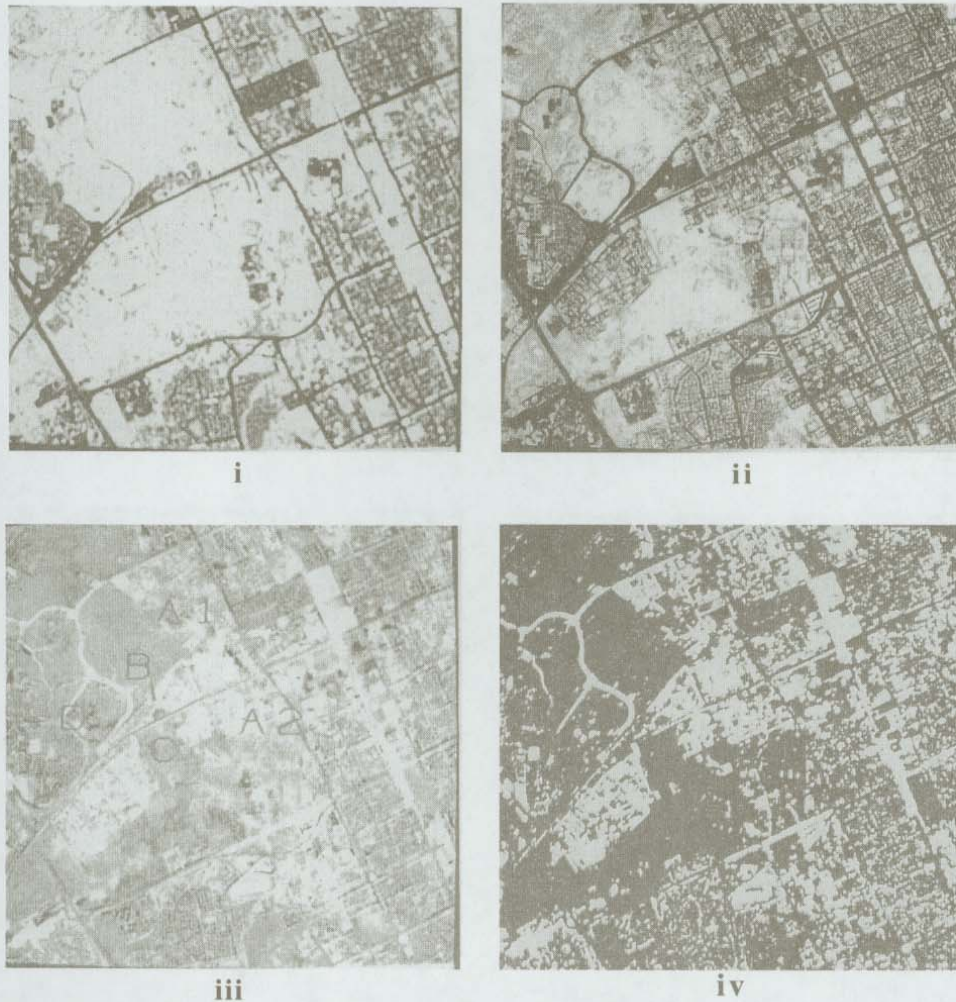


Fig. 3. Sub-scene of the study area: (i) Landsat TM band-7, 1987; (ii) combined landsat TM band-7, 1996 and SPOT PLA, 1996; (iii) difference image indicating areas of change as bright and dark tones areas of no change as medium tones; (iv) density slice image of Fig. 3 (iii), showing the distribution of change .

it was well established; In the difference image the area of change is shown as bright tones. Figure 3 (v), is a density slice image of figure 3 (iii), showing the distribution of change in yellow color, areas of no change are shown as black.

Figure 4 (i), (ii) and (iii), is a portion of the city in 1987, 1996 and the differenced image respectively. Three locations are of particular interest. Areas that had bright tone in 1987 but were dark in 1996 appear as bright on the differenced image. This was particularly

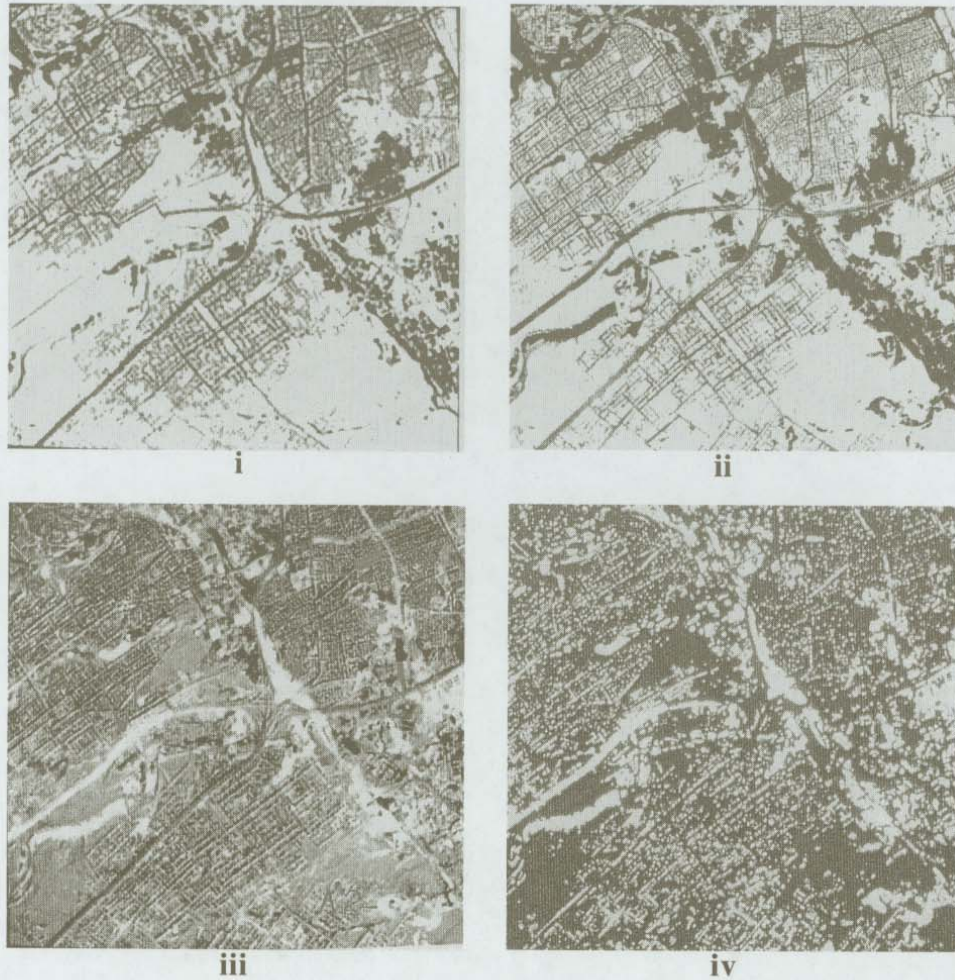


Fig. 4. Sub-scene of the study area: (i) Landsat TM band-7, 1987; (ii) combined landsat TM band-7, 1996 and SPOT PLA, 1996; (iii) difference image indicating areas of change as bright and dark tones areas of no change as medium tones; (iv) density slice image of Fig. 4 (iii), showing the distribution of change.

noticeable, for example, in vegetation areas at A1 and A2 that were bare soil in 1987 and became vegetated in 1996, as well as roads that were paved in 1996 at B1 and B2 but were not in 1987. Areas that were dark in tone in 1987 but were bright in 1996 appear as dark in tone in the differenced image. It is mostly noticeable in areas C that had vegetation in 1987 but became bare soil in 1996. Figure 4 (iv), is a density slice image of Fig. 4 (iii), showing the distribution of change in yellow color, areas of no change are shown as black.

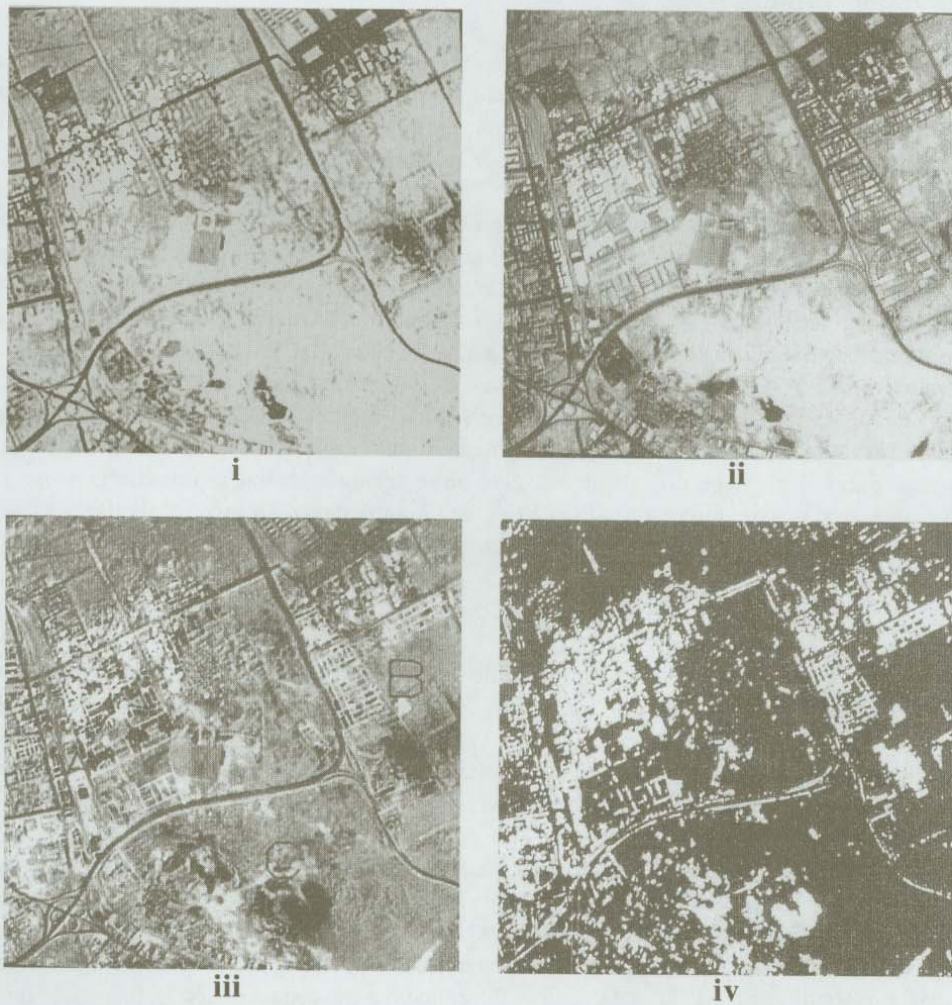


Fig. 5. Sub-scene of the study area: (i) Landsat TM band-7, 1987; (ii) combined landsat TM band-7, 1996 and SPOT PLA, 1996; (iii) difference image indicating areas of change as bright and dark tones areas of no change as medium tones; (iv) density slice image of Fig. 5 (iii), showing the distribution of change.

noticeable, for example, in vegetation areas at A1 and A2 that were bare soil in 1987 and became vegetated in 1996, as well as roads that were paved in 1996 at B1 and B2 but were not in 1987. Areas that were dark in tone in 1987 but were bright in 1996 appear as dark in tone in the differenced image. It is mostly noticeable in areas C that had vegetation in 1987 but became bare soil in 1996. Figure 4 (iv), is a density slice image of Fig. 4 (iii), showing the distribution of change in yellow color, areas of no change are shown as black.

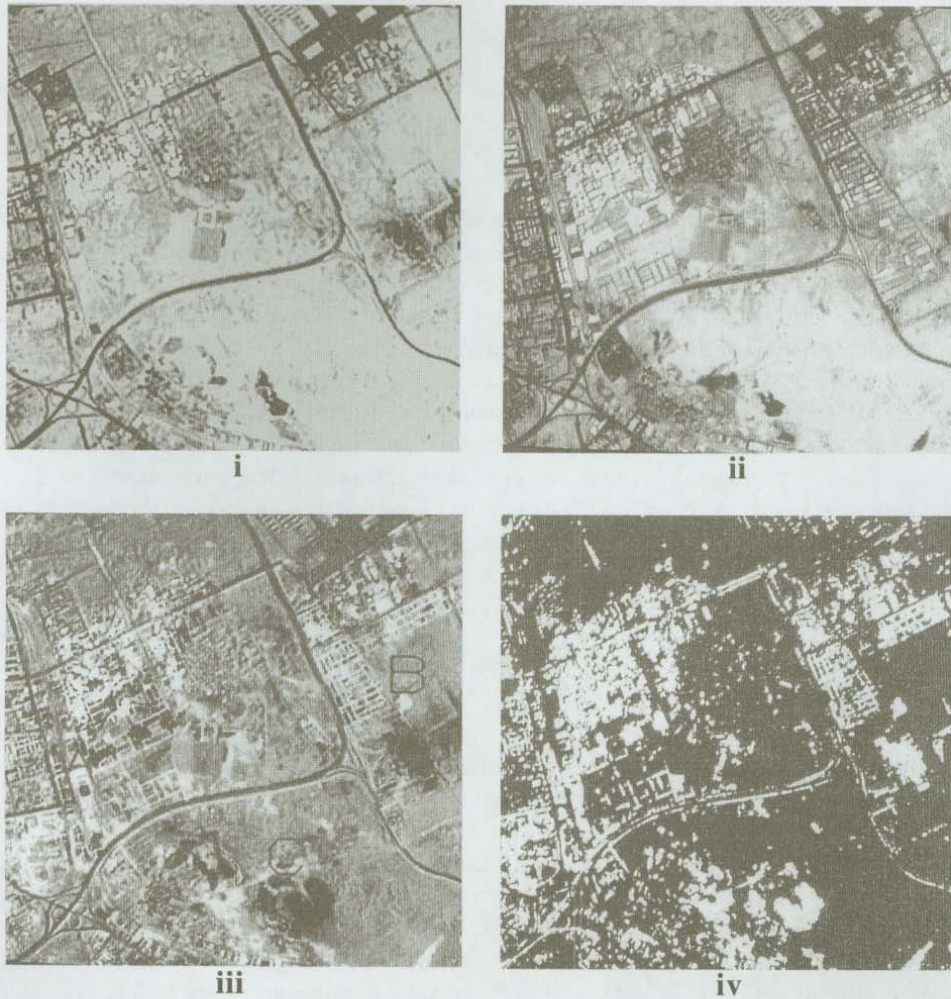


Fig. 5. Sub-scene of the study area: (i) Landsat TM band-7, 1987; (ii) combined landsat TM band-7, 1996 and SPOT PLA, 1996; (iii) difference image indicating areas of change as bright and dark tones areas of no change as medium tones; (iv) density slice image of Fig. 5 (iii), showing the distribution of change.

Figure 5 (i), (ii) and (iii) is a portion of the city in 1987, 1996 and the difference image respectively. Three locations are of particular interest, the arrangement and extension of the construction to the south in area A. Area B was an open field in 1987 but in 1996 was partially filled with rectangular blocks and new constructions. Area C shows that change in soil can be detected, that may be due to land excavation. Figure 5 (iv), is a density slice image of Fig. 5 (iii), showing the distribution of change in yellow color, areas of no change are shown as black.

The percentage of change can also be estimated. For example, in Fig. 3 the percentage of change can be calculated by comparing the number of changed to the unchanged pixels in Fig. 3 (iv). The result was 17.49%. Information content of the resampled data can never be greater than the IFOV of the original sensor system [12, p. 259]. This means that although the landsat TM data (30X30m pixel) of 1987 was resampled to SPOT PLA data (10X10m pixel), the information was still acquired at 30X30m resolution, and we should not expect to be able to extract additional spatial detail in the data set. However, this is not applicable to the landsat TM data of 1996, in which the SPOT PLA data were combined (using HSI transform) with landsat TM data, this image has the spatial detail of the SPOT PLA data and not the spatial information of the original sensor (landsat TM). This can be seen, for example, in Fig. 5, where the 1987 TM data, Fig. 5 (i), show less detail than the combined SPOT PLA and landsat TM data (Fig. 5 (ii)). Most noticeable was area D in which the increased spatial resolution of Fig. 5 (ii), made it possible to identify individual highway lanes. Therefore, image difference can give more accurate spatial information change if the data used in this study were SPOT PLA data in both dates. Unfortunately this was not possible due to unavailability of SPOT data.

Conclusion

Satellite data is an efficient tool to provide information for urban monitoring. Most of the methods used in the literature needs a considerable time and experience which limits the application of such tool in change detection. In this study the capability of a simple technique (image difference) to display change were tested using Landsat TM, and SPOT PLA data for the city of Riyadh, Saudi Arabia to monitor urban change in two dates 1987 and 1996.

The results from three sub-scenes showed that image difference technique effectively emphasizes temporal changes in the study area and provides an excellent and easy to interpret first level indication of change in urban areas. If the multi-temporal data, used in this study, were SPOT PLA data, more accurate information can be extracted. This is due to the high spatial resolution of SPOT data. This will reduce the procedures used in this study and simplify the processing. Further more, there will be no need to use HSI transformation .

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كشف التغير في المناطق الحضرية باستخدام معلومات الأقمار الصناعية

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(أستلم في ١٩٩٧/٤/٩؛ وقبل للنشر في ١٩٩٧/٧/٢ م)

ملخص البحث. يمكن اعتبار معلومات الأقمار الصناعية من الوسائل الفعالة لمتابعة النمو الحضري، حيث يمكن استخدامها بواسطة مخططي المدن في فترة زمنية قياسية وبتكاليف محدودة مقارنة بالطرق التقليدية (الصور الجوية والمسح الميداني). إن أغلب الطرق المستخدمة لتحليل هذه المعلومات تحتاج إلى كثير من الوقت والخبرة لإجرائها، وقد قلل هذا من تطبيق هذه التقنية، وذلك لكون عنصر الخبرة في تحليل هذه المعلومات نادراً ما يتوافر في الجهات المسئولة عن النمو الحضري.

تم في هذه الدراسة استخدام صور القمر الصناعي (لاندسات) الملتقطة في ١٩٩٧/٧/٢١ م وكذلك في ١٩٩٦/٩/١٥ م إضافة إلى صور القمر الصناعي (سبوت) الملتقطة في ١٩٩٦/٨/٢ م لمدينة الرياض - عاصمة المملكة العربية السعودية - واستخدمت هذه الصور في اختبار تقنية بسيطة لكشف التغير (image difference)، وقد تم ذلك على النحو التالي: (١) دمج الصور (image registration) الملتقطة في فترات زمنية مختلفة وراصدات مختلفة. (٢) استخدام تقنية الفرق بين الصور (image difference) لتحديد مقدار التغير في النطاق العمراني. لاختبار هذه الطريقة بتفصيل أكثر تم اختيار ثلاث مناطق صغيرة من الصورة، وأوضحت الدراسة أن تلك التقنية أعطت نتائج دقيقة لتحديد التغير في النمو العمراني.