Urban Sprawl Assessment in TAIF Area, Saudi Arabia, based on multi-temporal satellite analyses

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Abstract

Al-Taif region is inserted in Eltharwat Mountains at the southwest of the Arabian peninsula, at an altitude of 1700 m above sea level. Such location inherits valuable resorting conditions characterizing the area. Al Taif city is a good example that may show the possibility of urban sprawl on the account of green land, as previous studies pointed out its vast expansion. However, it is necessary to define the nature of urban expansion to avoid the environmental degradation. Multi-temporal satellite images proved to be an excellent tool to detect the qualitative and quantitative changes in land features. Also, multi-resolution satellite data allow insinuating on surrounding details to predict the changes nature and risk that might be induced due to continuous changes. The objective of the article is to determine the magnitude of the urban expansion and point out its nature, on the long term, at Al-Taif area, using the multi concept of remote sensing, integrated with GIS.

A number of four LANSAT thematic and enhanced thematic mapper satellite images, dated 1984, 1990, 2000 and 2011 were used. Hybrid classification concept was followed using ENVI 4.7 software depending on spectral data, ground checkpoints and the digital topographic maps. Change detection analysis is based on a pixel-by-pixel basis. The accepted mean square error (RMSE) was chosen not to exceed 0.5. Geometric correction was carried out using ground control points from digital topographic maps to geocode the image of 1984, then to register all the others. ArcGIS 4.3 was utilized in creating the needed geo-environmental database of studied area.

The results show that the study area has undergone an urban sprawl of 53.7, 75.6, 142.0 and 201.5 km² in 1984, 1990, 2000 and 2011 respectively. Moreover, the area covered by road network increased from 22.1 to 39.7 km² during the same period. The vegetated areas recorded also an increase from 60.4 to 163.8 km² from 1984 through 2011. The expansion magnitude of urban areas (3.4%) is greater than that of vegetated land (2.8%) during the 27 years period from 1984 to 2011. However, it was noticed that most of urban sprawl occurred on the account of mountainous and desert land cover classes, which decreased by 2.7 and 1.36% respectively during the study period. The wadies area also recorded a decrease of 0.49% during the study duration.

It could be concluded that urban sprawl at TAIF area does not represent a crucial problem at the current time. However attention has to be drawn to the increase rate of vegetated area, which should coincide with the higher rate of urban sprawl. It should be highlighted that conservation of wadi areas must be applied due to their great economic potentiality in agriculture, water harvesting and tourism. The study confirms the advantages of multi-temporal satellite remote sensing in detecting the environmental and land use changes. The map analyses and computational functions of GIS support the quantitative assessment and predicting the impacts of detected changes.

Keywords: Urban Sprawl, Satellite images, Remote Sensing, GIS, Al-Taif, Saudi Arabia
تتبع التغير على فحص الوحدات البدانية pixel-by-pixel المختارة من المراحل الفضائية وأكثر الخطا القبول (RMSE) مالاً يزيد عن 0.5 تم إجراء التصحيح الجيولوجي باستخدام نقاط التصحيح الأراضية من الخرائط الطبوغرافية الرقمية لتصحيح الصورة المتعلقة سنة 1984 ومنها تصحيح بباقي المراحل الفضائية. استخدم برنامج ArcGIS 10.1 لإنشاء قاعدة البيانات البيئية الأرضية لمنطقة الدراسة.

تظهر النتائج أن منطقة الدراسة تعرض لتمدد عمراني حيث بلغت مساحات العمران 94.0 %، 75.6 %، 201.5 %، 2011 على الترتيب. الأكثر من هذا قد أرتدت مساحة المنطقة المغطاة بشباكتات الطور من 60.4 % إلى 163.8 %. بالنسبة للتنوع البيئي، أوضحت النتائج النسبة المئوية لزيادة العمران (3.4 %) وهي أكبر من مثليتها للغطاء النباتي (2.8 %) خلال فترة سبعة وعشرة عاماً من 1984 إلى 2011، إلا أنه يلاحظ أن معظم الإعداد العمراني قد حدث على حساب مناطق الجبال والصحراء وتقل مساحتها بنسبة 2.7 %، 1.36 % على الترتيب، كما سجلت مساحة الأودية أيضاً نقصاً قدره 0.49% خلال نفس الفترة.

يمكن الخلاصة أن الاعتداد العمراني بمنطقة الطواف لا تمثل مشكلة حرجة في الوقت الحالي، لأنه يجب جذب الانتباه للعمل على أن تتفوق زيادة المساحة الخضراء مع معدل الزيادة البالغ مناطق الأراضي، يمكّن أيضًا القضاء الضوء على ضرورة صيانة مناطق الأورية لما لها من امكانيات اقتصادية في مجالات الزراعة والتشجير. تحتاج الدراستين على بيانات منهجية لتصنيف مفهوم الاصطناعي للاستشعار من الجيل الجديد باستخدام نظام المعلومات الجغرافي الإقليمية من نوعية LANDSAT - TM و ATM. يرجع تاريخها إلى أعوام 1984، 1990، 2000، 2011. أجري التصنيف الرقمي للصورة المستخدمة باستخدام Hybrid مفهوم التصنيف المزدوج وذلك من خلال برنامج classification ENVI المعالجة الرقمية لبيانات الفضائية 4.7 اعتماداً على البيانات الطبوغرافية والخشية الميدانية والخرائط الطبوغرافية واعتبر تحليل الخرائط والوظائف الحسابية التبت التغير المرصودة.
Introduction

Tourism has recently attracted a great interest, and resulted in developing related activities having their economic, social and cultural impacts. It pushed planning to be a specialized science dealing with the studies, analyses and development of touristic activities (Hermez 2006; Zahran, and Younes, 1990). Existences of sufficient green areas are also necessarily needed for development, ethical and social points of view (Mosallam H.A.M. 2007). Urban sprawl on the account of green lands represents a challenge for most of the world. Population pressure, as a result of birth rate increase and migration from rural to urban areas, increases construction request. Moreover, transportation means has an important influence on urban sprawl, through roads construction and establishing factories and commercial entities and activities on roads sides. TAIEF city is a good example that may show the possibility of urban sprawl on the account of green land. Previous studies referred that the urban areas in TAIEF has expanded from 10.69 km$^2$, in 1970, to 55.83 km$^2$ in 2008, while the vegetated land decreased from 8.65 to 2.38 Km2 in the same period (Brown, G.F. (1960).

The study area of TAIEF is inserted in Eltharwat Mountains at the southwest of Arabic peninsula, at an altitude of 1700 m above sea level, at a distance of 88 km from Mecca, 166 Km from Jeddah and 900km, from Riyadh (Abdel-Fatah and Akram, 2005; El Farsi, 2010). It belongs, administratively, to Mecca El Mukramah region and geographically located between latitudes 21º 03´ 18´´ to 21 º 22´ 41´´ N and longitudes 40 º 15´ 36´´ to 40 º 30´ 27´´ E (Fig.1).

Figure (1) Location map of TAIEF study area

![Figure 1: Location map of TAIEF study area](image-url)
The climatic conditions of the study area have a significant relation with the diversity of plant cover distribution and density (Mahmoud and El-Tom, 1985). They vary due to variable topography resulting in variation of plant cover type and density (Abd El-Ghani and Amer, 2003; Batanouny, K.H. 1979). TIRC (2012) classified the climate of TAIEF, according to De Marthon, as dry to semi dry.

The current study aims to analyze urban expansions (Hylgaard, and M Liddle, 1981; Tag, Bankert, and Brody 2000) in comparison with the of green surfaces area situation, using the image processing techniques of satellite images. The study is based upon the digital data descriptive and analyzing approach according to Gad et. al (2011). The data are concluded from multi-temporal satellite images, topographic maps and collected ground truth data. ENVI 4.7 and ArcGIS 10.1 were utilized to fulfill the study goals.

2. Material and methods

2.1 Study Materials

The materials used in this study include the following:

1. Landsat Thematic Mapper (TM) images (path 169 and row 045) acquired on July 1984 and July 1990.

2. Landsat Enhanced Thematic Mapper (ETM+) images - Path 169 and Raw 045 acquired on September 1990 and September 2011.


<table>
<thead>
<tr>
<th>Band</th>
<th>Landsat TM</th>
<th>Landsat ETM+</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>5</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>6</td>
<td>120</td>
<td>60</td>
</tr>
<tr>
<td>7</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>8</td>
<td>-</td>
<td>14</td>
</tr>
</tbody>
</table>

2.2 Methodologies

2.2.1 Geometric correction

Accurate per-pixel registration of multi-temporal satellite data is essential for change detection because registration errors could be inferred as land use/cover changes, leading to overestimate the actual change (Stow 1999). Change detection analysis is based on a pixel-by-pixel basis; therefore any miss-registration greater than one pixel will provide an anomalous result for that pixel. To overcome this problem, the root mean square error (RMSE) between any two dates should not exceed 0.5 pixel (Lunetta and Elvidge 1998). In this study, the projected coordinate system WGS_1984_UTM_Zone_37N. The applied projection is Transverse Mercator. Geometric correction was carried out using ground control points from digital topographic maps to geocode the image of 2011, then this image was used to register all the other images; the RMSE between different images was less that 0.4 pixel, which is acceptable.
2.2.2 Image enhancement and visual interpretation

The goal of image enhancement is to improve the visual interpretability of an image by increasing the apparent distinction between the features. The visual interpretation process of a digitally enhanced imagery is an attempt to optimize the complementary abilities of the human mind and the computer. The mind is excellent at interpreting spatial attributes on an image and is capable of identifying obscure or subtle features (Lillesand and Kiefer 1994). Contrast stretching was applied on all images and the false colour composites (FCC) were produced. These FCC's are visually interpreted using on-screen digitizing to delineate land cover classes that could be easily interpreted, such as urban, cultivation, roads, wadies, Rockland and water.

2.2.3 Image classification

Image classification is perhaps the most important part of digital image analysis. It is very nice to have a "pretty picture" or an image, showing a magnitude of colors illustrating various features of the terrain, but most important to know what the colors mean (Deng et. al. 2008). Two main classification methods, Supervised and Unsupervised are practiced based radiometric characteristic and ground truths respectively. Land cover classes are typically mapped from digital remotely sensed data through the process of a supervised or hybrid digital image classification (Campbell 1987; Thomas, Benning, and Ching 1987). The overall objective of the image classification procedure is to automatically categorize all pixels in an image into classes, in terms of a certain theme as land use/land cover (Lillesand and Kiefer 1994). The maximum likelihood classifier quantitatively evaluates both the variance and covariance of the category spectral response patterns when classifying an unknown pixel, so that it is considered to be one of the most accurate classifiers based on statistical concepts.

Hybrid classification concept was followed using ENVI 4.7 software depending on spectral data, ground checkpoints and the digital topographic maps. Then accuracy assessment was carried out by developing a confusion matrix for each classification. A number of 25 ground check points were tested, against the elaborated classification; with a total of 175 points covering the resulted classes. Table (2) shows that the overall accuracy ranged between 80 to 97.3%, giving an average accuracy of 89.5%. To increase the accuracy of different classes, ancillary data and visual interpretation analyses were integrated with the classification results using GIS. Also recently cultivated lands were on screen digitized and added to the resulted classes.

Table (2) Summary of Accuracy assessment confusion matrix

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Classified Image</th>
<th>Average Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>TM 1984</td>
<td>80</td>
<td>89.5</td>
</tr>
<tr>
<td>TM 1990</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>ET M 200</td>
<td>94.7</td>
<td></td>
</tr>
<tr>
<td>ET M 201</td>
<td>97.3</td>
<td></td>
</tr>
</tbody>
</table>

2.3.4 Urban sprawl detection

Regardless the used technique, the success of detecting the changes detection from imagery will depend on both the nature of the change involved and the success of the image
preprocessing and the classification procedures. If the nature of the change within a particular scene is either abrupt or at a scale appropriate to the imagery collected then change should be relatively easy to detect; problems occur only if spatial change is subtly distributed and hence not obvious within any image pixel (Milne 1988).

In the current study, field observation and measurements have showed that the change in land covers between the four dates was both marked and abrupt. Post-classification change detection technique was applied. It requires the comparison of independently produced classified images. Post-classification comparison proved to be the most effective technique, because data from two dates are separately classified, thereby minimizing the problem of normalizing the atmospheric and radiometric differences between different dates. Urban class was extracted from the classified images, and then cross-tabulation analysis was carried out to study the spatial distribution and areas of urban sprawl (of 1984, 1990, 2000 and 2011) on the account of other land use/land cover types. ArcGIS 10.1 software was used for this function.

4. Results and discussion

4.1 Images enhancement

The raw satellite images histograms (Fig. 2 and 3) are graphical representations of the brightness values that comprise an image. The brightness values (i.e. 0-255) are displayed along the x-axis of the graph. Application of the enhancement technique (i.e. contrast stretch) involves identification of lower and upper bounds from the histogram (usually the minimum and maximum brightness values in the image) and applying a transformation to stretch this range to fill the full range. Figures 3 and 4 demonstrate the enhanced images of 1984 and 2011. Different shades refer to variable land use/cover classes, while area differences of certain shade indicate the changes occurred during 27 years difference. The enhanced images proved to be clearer and more interpretable than the non enhanced ones.
4.2 Satellite images classification

The visual interpretation gave a general idea about the forms of land use/land cover types and changes occurred during a period of 22 years. Application of the hybrid classification scheme on the TM images of 1984, 1990 and the ETM image of 2000 and 2011 resulted in identifying a number of 6 land use/land cover classes Figures (6-9). The mapped classes include urban, vegetation cover, road network, desert, wadies and mountainous areas. The classification and table (1) show that the both road network and urban areas are continuously expanding, on the account of other classes. The most dominant class is the mountainous areas ranging between 3905.9 to 3746.3Km², representing 66.1% and 63.3% of study area in years 1984 and 2011 respectively.
The desert area is hopefully to be a target for new urban and vegetation expansion. It covers areas ranging from 1294.2 to 1213.7 km$^2$, representing 21.9 to 20.5% respectively. The Wadi exhibit areas ranging between 580.9 to 552.3 Km$^2$, representing 9.8 to 9.3% of total coverage. These areas should also be a main target for developing new green areas serving environmental protection and new food resources.

### Table: Area Changes

<table>
<thead>
<tr>
<th>Unite</th>
<th>1984</th>
<th>1990</th>
<th>2000</th>
<th>2011</th>
<th>Total changes (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Km$^2$</td>
<td>%</td>
<td>Km$^2$</td>
<td>%</td>
<td>Km$^2$</td>
</tr>
<tr>
<td>Road network</td>
<td>23.13</td>
<td>0.37</td>
<td>28.29</td>
<td>0.48</td>
<td>29.70</td>
</tr>
<tr>
<td>Vegetation Cover</td>
<td>60.41</td>
<td>1.02</td>
<td>75.29</td>
<td>1.27</td>
<td>115.80</td>
</tr>
<tr>
<td>Urban Areas</td>
<td>53.71</td>
<td>0.91</td>
<td>75.63</td>
<td>1.28</td>
<td>142.00</td>
</tr>
<tr>
<td>Wadi Areas</td>
<td>580.91</td>
<td>9.82</td>
<td>577.59</td>
<td>9.76</td>
<td>575.41</td>
</tr>
<tr>
<td>Desert Areas</td>
<td>1294.16</td>
<td>21.87</td>
<td>1273.51</td>
<td>21.52</td>
<td>1267.78</td>
</tr>
<tr>
<td>Mountainous Areas</td>
<td>3905.90</td>
<td>66.01</td>
<td>3886.89</td>
<td>65.69</td>
<td>3786.52</td>
</tr>
<tr>
<td>Total</td>
<td>5917.21</td>
<td>100</td>
<td>5917.21</td>
<td>100</td>
<td>5917.21</td>
</tr>
</tbody>
</table>

Fig. (4) Enhanced TM image of 1984, based on contrast stretch technique.

Fig. (5) Enhanced ETM image of 2011, based on contrast stretch technique.
Table (1) Areas of Land use/Land cover classes, based on Multi-Temporal Landsat images

Fig. (6) Land Use/ Land Cover map, based on the Hybrid classification of TM image, 1984.

Fig. (7) Land Use/ Land Cover map, based on the Hybrid classification of TM image, 1990.
Fig. 8) Land Use/ Land Cover map, based on the Hybrid classification of TM image, 2000.

Fig. (9) Land Use/ Land Cover map, based on the Hybrid classification of ETM image, 2011.
4.3 Urban expansion

The urban class records areas of 53.7, 75.6, 142, 201.5 km², representing 0.9, 1.3, 2.4 and 3.4% of total areas in 1984, 1990, 2000 and 2011 respectively. Fig. (10) shows the urban coverage extracted from multi-temporal Landsat images 1984 - 2011. It is clear that the initial urban areas found in 1984 are expanding around, while other new urban areas erected on other land cover classes. The total change is an expansion of 2.49 Km² referring to the maximum positive changes among all identified classes. The same trend is noticed on the expansion of road network, which areas increased from 0.37 to 0.67% of the studied region. The striking remark is noticed at the progressive expansion of vegetation cover area, almost at similar rate, compared with urban expansion (Figs. 11 and 12). It can be remarked that such expansion of settlements and Road network areas is occurring on the account of the wadi, mountainous

![Multi-Temporal change detection of urban areas from 1984 through 2011.](image)

*Fig.(10) Multi-Temporal change detection of urban areas from 1984 through 2011.*
It is also worth to point out that many urban areas were erected recently, especially along the created roads and at extension of older ones. These expansions are mostly on the expense of surrounding existing vegetated areas, which in their turn have prolonged.

5. Conclusion

The objective of this study was to investigate the urban sprawl and its impact on the surrounding environs in Taif region. It was found that integrating visual interpretation with supervised classification lead to increase in the overall accuracy by 10%. It could be concluded that urban sprawl at Taif area does not represent a crucial problem at the current time. However attention has to be drawn to the increase rate of vegetated area, which should coincide with the higher rate of urban sprawl. It should be highlighted that conservation of wadi areas must be applied due to their great economic potentiality in agriculture, water harvesting and tourism. These considerations, in addition to landscape will enhance the touristic importance. The study confirms the advantages of multi-temporal satellite remote sensing in detecting the environmental and land use changes. The map analyses and computational functions of GIS support the quantitative assessment and predicting the impacts of detected changes. It is recommended to assess the
soil quality of the study area and to point out the soil classes undergone urban sprawl.

References

10. Hermez. N. (2006). Touristic planning and development, Faculty of economy,