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Full Length Research Paper

Detection of urban irregular development and green space destruction using normalized difference vegetation index (NDVI), principal component analysis (PCA) and post classification methods: A case study of Saqqez city

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Due to inappropriate planning and management, accelerated urban growth and tremendous loss in land, especially green space, have become a great challenge for sustainable urban development. Detection of such changes may help decision makers and planners to understand the factors in land use and land cover changes in order to take effective and useful measures. Change detection is a technique used in remote sensing for detecting the changes which may have occurred in the existing over two or more periods of time in a particular area. In this paper, Saqqez, a city in Kurdistan province has witnessed a rapid growth in construction which has caused destruction of green spaces areas. It is fragmented and dispersed, causing impairment and dysfunction of these important urban elements. The objective of this study was to detect changes in extent and pattern of green areas of Saqqez city and to analyze the results in terms of landscape ecology principles and functioning of the green spaces. Three remote sensing techniques, including normalized difference vegetation index (NDVI) comparison, principal component analysis (PCA) and the post classification were employed to detect the green space changes. To carry out these techniques, Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) LANDSAT data within the year 1989 to 2009 were used to recognize land use changes, especially the physical development of the area and its devastating effects on the green space. The result showed that green space has been reduced from 530 ha in 1989 to 198.3 ha in 2009. In this research, the capabilities of LANDSAT data which is oriented towards determining land use changes, via the standard methods is examined. The result showed that NDVI and post classification analysis methods are better than principal component analysis in detecting the devastating effects of unplanned constructions and forming projects on Saqqez's green space.

Key words: Multi-temporal images, change detection, destruction of green space, urban development, Saqqez.

INTRODUCTION

Green space in urban science is referred as vegetative areas in a city (Moll, 1991). Nowadays, among the main urban problems, unplanned land cover changes are being noticed all around the world. Urban growth is occurring at an unprecedented rate worldwide with 65% of the population expected to reside in urban areas by 2025 (Schell and Ulijaszek, 1999). Most of the environ-mental impacts of urbanization are associated with green space. The loss or degradation of green space may deprive the habitats for creatures, reduce biodiversity and disrupt the structure and process of the urban ecosystem (Breuste

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et al., 1998; Kim and Pauleit, 2007; Cheng and Masser, 2003). Urban green spaces provide the opportunity for recreation and experiencing nature. These functions are essential for improving the quality of citizen life. However, allocation of urban land to green spaces as a class of land use is an important policy issue in almost all cities (Rafiee et al., 2009).

Therefore, in many parts of the world, current urban planning activities are shifting toward a focus on "green" living. Many cities around the world are now developing integrated solutions to major environmental challenges and are transforming themselves into more sustainable and self-sufficient communities (Dizdaroglu et al., 2009). Among the environmental benefits achieved by such green interventions are the following: reduced cooling and heating demand, improved air quality, reduced storm water runoff, the enrichment of urban biodiversity and urban agriculture, a reduced urban heat island effect, a contribution to carbon-neutral architecture and the economic impact of the green spaces (Roehr and Laurenz, 2008; Lwin and Murayama, 2011).

Satellite image analysis through remote sensing techniques helps us to detect and manage these changes in the right way. There are several reported studies that investigate land use changes using satellite data in which some will be referred to in this part of the work. Sunar (1998) used five techniques, including: adding, subtracting, dividing, principle component (PCI), and post classification analysis to detect land cover changes in Aykitali, Turkey. He found out that the technique of adding and subtracting images was the most simple among these techniques, while PCI and post classification analyses showed better results in change detection. Tardi and Contalgon (2001) also used three methods including: multi-temporal color composite, subtraction, and classification in order to examine physical development of Massachusett's urban area and the resulting land cover changes. Finally, they used post classification analysis in order to estimate total accuracy. Qiasvand (1997) also concluded similar study via PCI and subtraction techniques so as to present South Tehran land cover map and he reported that regression analysis in conjunction with PCI showed better results. Jahani (1997) utilized satellite images (Spot) and normalized difference vegetation index in Tehran land cover mapping project. Consequently, on the basis of the earlier studies about land cover change detection, it is obvious that most researchers used subtraction and PCI techniques to detect changes in land cover and, in further steps, by classifying multi-temporal images, they showed results in quantitative form. Due to the rapid physical extension of Saqqez city, this city plays several functional rules, and its population growth is also with a considerable fast rate. As a result, lack of sufficient green space, pollution, soil erosion, and other critical environ-mental outbreaks calls for new planning approach for this city. As the first stage of impact assessment, in this paper, we focus on green space changes within a particular period. Therefore, three change detection methods were evaluated by this study and the best method was used to detect the changes observed in the area map.

Study area and dataset

Saqqez is located between 46°13' to 46°16' eastern longitude and 36°11' to 36°15' northern latitude within north-west of Kurdistan province in Iran and covers of approximately 1474.8 ha. At the 2006 census, the city's population was 135037, whereas its current population is about 145000. The vegetation density city was 118 ha. Building area was 618.26 ha. The average elevation of the city is about 1496 m above mean sea level. Saqqez is characterized as a mountainous area which is located within Zagros Mountains and it ranges from south-east to north-west. This area comprises about 15.5% of Kurdistan province. The difference of height between the highest elevation point (Chehel-Cheshme Mountain, 3173 m and Simineh-Rood basin, 1150 m above mean sea level) is about 2023 m. Saqqez river (Chom Saqqez) emanates from western mountains (Gardaneh Khan) and continues its path across the city toward north-east. Figure 1 shows the location of the study area in Kurdistan province, Iran. The data sets acquired for this study is as shown in Table 1.

METHODOLOGY

Images were acquired in the summer months which represent same vegetation condition of green areas in the city. The correction was conducted using the first order polynomial model and the nearest neighborhood method for re-sampling. Without radiometric calibration of multi-temporal dataset, false changes can occur in the classified maps. Therefore, for quantitative analysis based on radiometric information, such as normalized difference vegetation index (NDVI) differencing, the images should be corrected radiometrically to compensate for radiometric divergence (Mass, 1999).

Afterwards, using on-screen interpretation and digitization, a vector layer was created to extract the boundary of the study area from all images which included Saqqez city and its environs. Based on our target in this research, an aggregate level of map was deemed sufficient; hence the images were classified into four classes of green space, roads network, built up lands and sterile lands.

Purification in this context meant removal of those pixels which were a combination of different land uses and land covers mistakenly selected for different categories. Without the purification, classification accuracy is normally lower. After purification of training data, we used maximum likelihood classifier to classify the raw imagery for each date. Then, we chose another set of training samples to assess the accuracy of each classified map.

Image preprocessing

Preprocessing of satellite images prior to image classification and change detection is essential and commonly comprises a series of sequential operations, including atmospheric correction or normalization, image registration, geometric correction, and masking

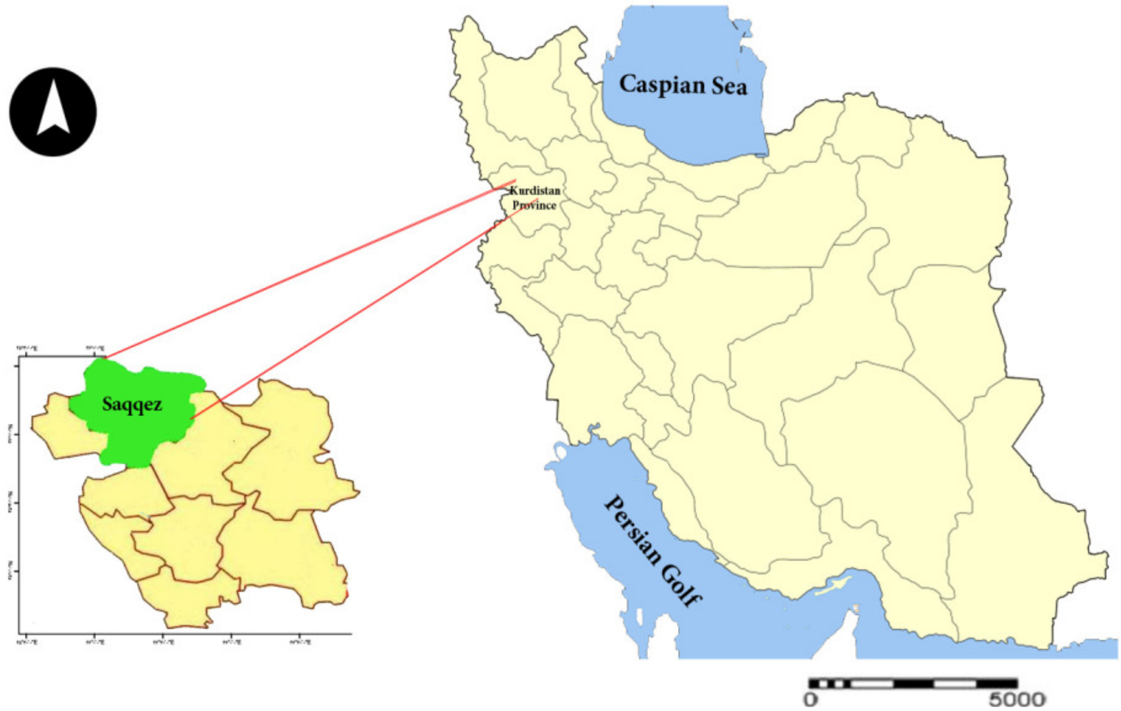

Figure 1. Location of study area.

Table 1. Satellite images of the study.

Sensor type	Imagery date	WRS path	WRS row	Band No.
TM	1989/6/30	34	168	1,2,3,4,5,7
ETM+	2009/7/14	34	168	1,2,3,4,5,7

(e.g. for clouds, water, irrelevant features) (Coppin and Bauer, 1996). In the preprocessing stage, it is vital to eliminate any kind of atmospheric effects before any image analysis or information extraction are carried out (Chavez, 1988). This becomes especially important when scene to scene comparisons of two or several images in applications, such as change detection, are being sought (Mather, 1997).

In this research, dark object subtraction (DOS) is used as an approach for atmospheric correction, which is perhaps the simplest, yet most widely used image-based absolute atmospheric correction approach for classification and change detection applications (Shrestha, 1994; Jakubauskas, 1996; Huguenin et al., 1997). This approach assumes the existence of dark objects (zero or small surface reflectance) throughout a LANDSAT Thematic Mapper (TM) scene and a horizontally homogeneous atmosphere. The minimum digital number (DN) value in the histogram from the entire scene is thus attributed to the effect of the atmosphere and is subtracted from all the pixels (Chavez, 1989). It is notable that DOS method is used only for TM image (Enhanced Thematic Mapper (ETM+) image was already corrected atmospherically via United States Geological Survey (USGS) center and image histogram showed no offset value within the image).

To conform the pixel grids and remove any geometric distortions, TM images of June 30, 1989, was registered to the topographic map, Universal Transverse Mercator (UTM) coordinate system zone 38 north, based on 21 ground control points collected from throughout the study and 2009 scene were registered to the June 30, 1989 image utilizing similar sets of ground control points (GCP's).

For geo-referencing GCP collection, first order transformation, and the nearest neighbor re-sampling of the uncorrected imagery were performed. It should be noted that in change detection studies, the accuracy of less than one-fifth of a pixel is required to achieve a change detection error of less than 10% (Coppin and Bauer, 1996).

Overall, root mean square (RMS) errors of less than 0.2 pixels were achieved for each transformation (3.84 m for TM, 1989 and 3.48 m for ETM+, 2009). In order to subset the study area from each of the two LANDSAT scenes, a vector file defining the city boundary having the same geo-referenced coordinates system as the LANDSAT images was utilized. Then, the scenes of city area were overlaid with the city boundary's vector file which was first converted into a binary bitmap mask and overlaid onto each of the TM scenes. The conceptual framework of the study is as shown in Figure 2.

Change detection methods

Three remote sensing techniques, namely, NDVI comparison, principal component analysis (PCA) and the post classification were applied on the data to make model of green space changes in a studied period. Healthy vegetation absorbs most of the red light, and reflects a large portion of the near-infrared spectrum of incident electromagnetic radiation. Consequently, NDVI can be used as an

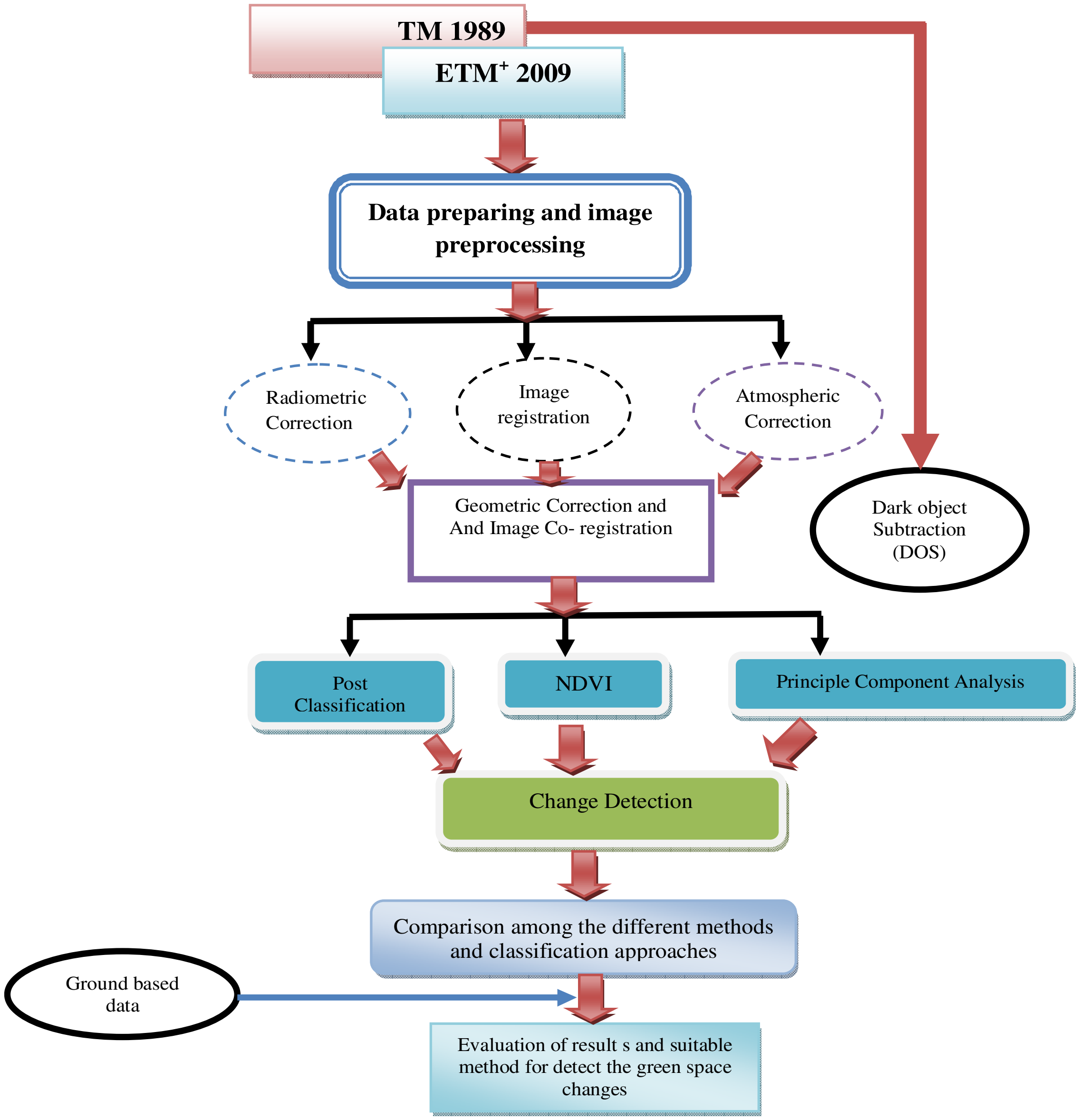

Figure 2. Framework of the methods and processes.

index for monitoring vegetative cover in a given time period (Breuste et al., 1998). NDVI is computed as the ratio of the measured intensities in the red (R) and near infrared (NIR) spectral bands. NDVI for TM and ETM+ images can be computed using the following formula:

$$NDVI = \frac{B_4 - B_3}{B_4 + B_3} \quad (1)$$

Resulting index value ranging from +1 to -1 indicates sensitivity to the presence of vegetation on the land surface of the earth which can be used to address issues of vegetation type, amount, and condition. NDVI is less affected via atmospheric condition than the other indices; therefore, it is suitable for application such as change detection (Mather, 1997). In this research, the extracted NDVI from TM (1989) and ETM+ (2009) images were used in order to compute the green space reduction of Saqqez during these 20 years. The second method of change detection performed in this study was PCA. PCA is an ordinary technique that applies a linear transformation onto the original data. It has been shown to be a notable value in the analysis of remotely sensed imagery (Jensen, 2005). Traditionally, it has been applied to image enhancement and channel reduction (Taylor, 1974; Singh and Harrison, 1985; Rundquist, 1989). However, it has also been effectively utilized in terrestrial change detection studies (Piwowar and LeDrew, 1996). In the simplest way of change detection via the PCA technique, one may use multi-temporal single spectral band (Lillesand and Kiefer, 2005; Reis et al., 2003). It is notable that there is no need to stretch data before using PCA. PCA is used normally for dimension reduction of a response matrix and to retain the dominant information in the data. PCA is closely related to singular value decomposition and proper orthogonal decomposition. Given a response matrix X containing the displacements xi (tj) obtained over n parameters on the studied structure during m time samples:

Table 2. Comparing vegetation density from 1989 to 2009 in Saqqez city, which was computed using NDVI.

Relative	Area (ha)	Density code	Area (ha)
Density of vegetation	1989		2009
Low	298.32	0.1 - 0.2	97.3
Moderate	102.97	0.2 - 0.3	64.8
High	77.36	0.3 - 0.4	21.71
Very high	51.35	0.4 - 0.5	14.49

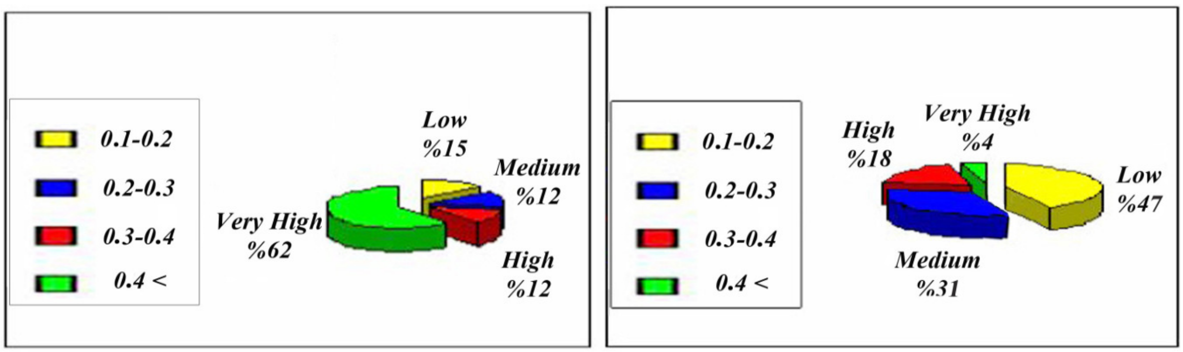

Figure 3. Comparing vegetation density from 1989 (left image) to 2009 (right image) in Saqqez city, which was computed using NDVI.

$$X = \begin{pmatrix} x_1(t_1)\cdots x_1(t_m) \\ \vdots \quad \ddots \quad \vdots \\ x_n(t_1)\cdots x_n(t_m) \end{pmatrix} \qquad (2)$$

The singular value decomposition is then calculated in order to obtain the principal directions:

$$X=U\Sigma VT \qquad (3)$$

where U is an (n×n) orthonormal matrix containing the left singular vectors of X which are the principal directions, called proper orthogonal modes (POM); Σ is an (n×m) pseudo-diagonal matrix whose main diagonal contains the singular values of X, called proper orthogonal value (POV) corresponding to the energy contained in the POM; V is an (m×m) orthonormal matrix containing the right singular vectors of X (the time modulation of the POM) (Kerschen et al., 2005).

PCA was run on NDVI images with the two dates, and a new PCA image (Figure 6) was generated with two principal components, which were later treated as separate bands for the interpretation and analysis of the changes within the green space of Saqqez. The last most straight forward method of change detection, namely, post classification method was also conducted. It involves the overlay (or “stacking”) of two or more classified images. Change areas are simply those areas which are not classified the same at different times. The post classification comparison method is one of the most widely used methods of remote sensing change detection. Some of the main advantages of this method are as follows: there is no need for radiometric co-registration of images involved in the analysis (Jensen, 2005); its sensitivity to the spectral variations due to the difference in the soil moisture, vegetation, and phenology is lower than that of the spectral change detection methods (Mas, 1999); its provision of “from-to” change information (Jensen, 2005); it has very high change detection accuracy (Mas, 1999).

The selection of the land use classification system is important because it influences the results and subsequent interpretations (Lu and Weng, 2007; Zhou and Wang, 2011). The classification scheme includes the following classes: the built up lands (low density residential, high density residential, commercial and industrial lands), green area, roads network and sterile lands. In order to develop true assumptions about the normal distribution of samples, all the training sites are evenly distributed throughout the study area. Afterwards, a supervised classification by means of the maximum likelihood approach has been performed on TM (1989) and ETM+ (2009) data and, as the next step, a majority filter with a 3 by 3 window size was utilized to suppress the isolated pixels, poor classified pixels or the pixels brought about by noise. The majority filter replaces central value pixels by a majority value.

RESULTS AND DISCUSSION

As a result of this NDVI analysis, we noticed that green space was reduced from 530 ha in 1989 to 198.3 ha in 2009 (Table 2 and Figure 3).

With regard to the results of NDVI analysis, it is obvious that there is a major loss of vegetative cover with "very high density" rank over a period of time (1989 to 2009). This is probably due to the physical development of the city in the north-western and eastern parts of the city (Figures 4 and 5). PCA resulted that the first component, which accounts for the maximum individual difference, with an approximate variance of 79.13, is indicated by the

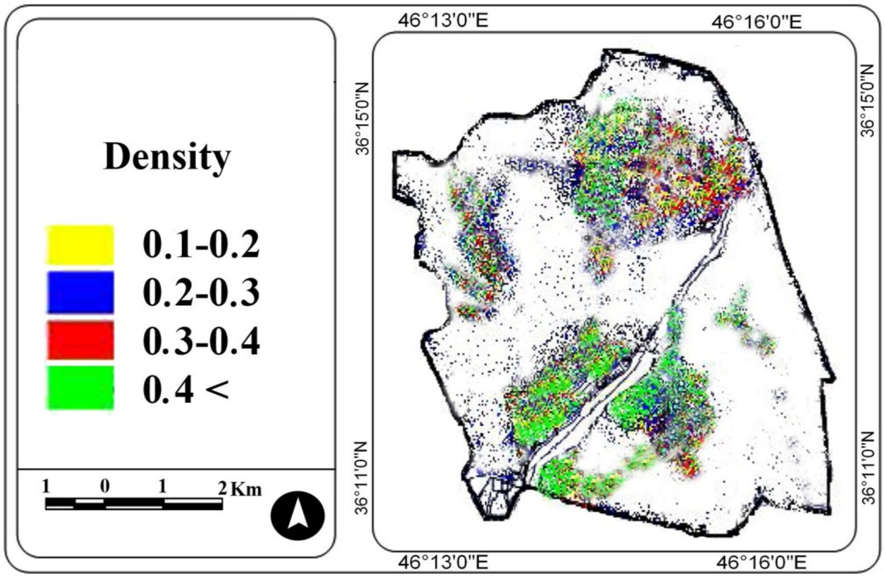

Figure 4. Green area classification of Saqqez upon NDVI value for TM image (1989).

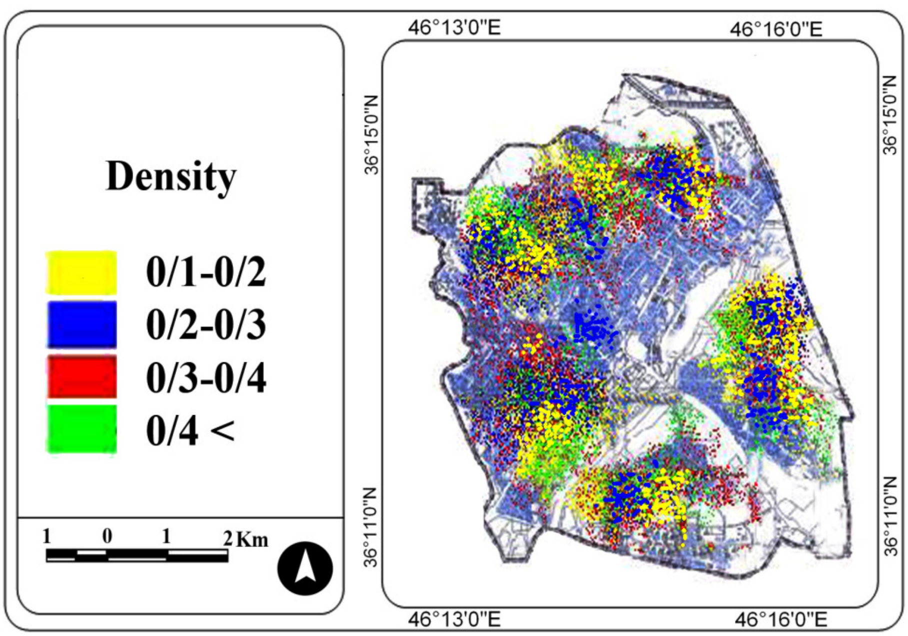

Figure 5. Green area classification of Saqqez upon NDVI value for ETM+ image (2009).

green color; the second principal component, with an approximate variance of 18.45, is a combination of variables uncorrelated with the first component and it is indicated by a red color. Figure 6 shows the change regime of the green space over the given period of time (1989 to 2009). The green color implies less disturbed vegetation cover; whereas, red shows the disturbed vegetation cover of the green space. The vegetation with no change from June 1989 to Jul 2009 is indicated by black.

The overall accuracy of classification scheme for each of the two images was estimated by means of the standard accuracy assessment procedure (error matrix). The image classification for TM, 1989 has been done with approximate overall accuracy of 96.97%, while the overall accuracy of 98.13% was obtained for ETM+, 2009.

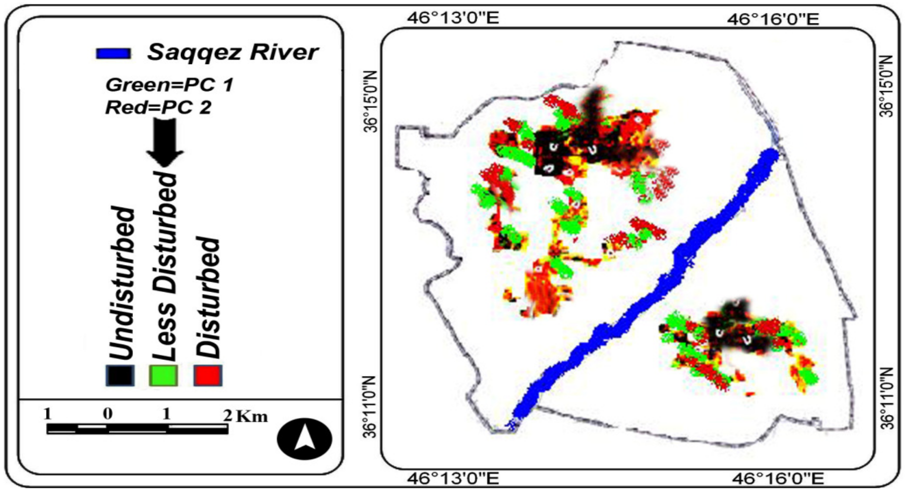

Figure 6. The classified map, derived from the PCA, that shows the disturbance regime of the green area in Saqqez.

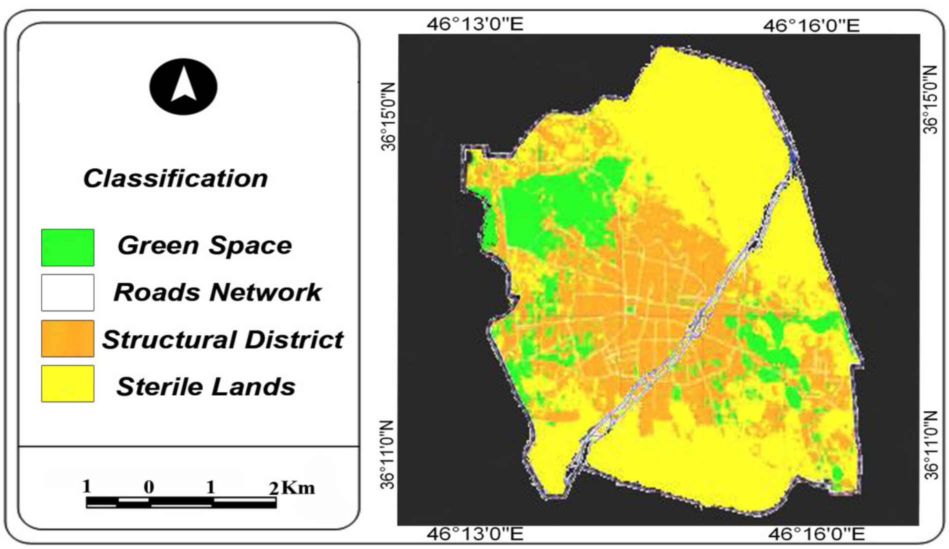

Figure 7. The classified map of TM image (June 30, 1989).

Finally, the classified images were overlaid by means of the same coordination and projection systems and the accurate percent of the change over this period of time (1989 to 2009) was calculated for each class by subtraction technique. However, the accuracy of the post-classification comparison is totally dependent on the accuracy of the initial classifications. The final accuracy is almost similar to the result obtained from the multiplication of the accuracies of each individual classification (Petit and Lambin, 2001). The result of the data processing sequence for classification and change detection using remotely sensed data is illustrated in Figures 7 and 8 and Tables 3 and 4.

The result of the post classification analysis showed that the green space has been reduced from 530 ha in 1989 to 198.3 ha in 2009. It is notable that 62.30% of this negative change in the green space was due to the devastating role of unplanned constructions and housing projects (Built up lands) of Saqqez city, Kurdistan, Iran.

Conclusion

This study presents the results of the three methods for detecting urban green space changes and destruction. The results of this analysis reveal the devastating effects

Table 3. The classification error matrix of TM image.

Class name	Green space	Roads network	Built up lands	Sterile lands	Sum	User account	Commission (0/0)
Green space	244	0	0	0	244	1	0
Roads network	0	2	8	0	10	0.2	4
Built up lands	1	0	24	1	26	0.923	0.055
Sterile lands	0	0	4	179	183	0.978	0.022
Sum	245	2	36	180	463	-	-
Product account	0.995	1	0.666	0.994	-	-	-
Omission (0/0)	0.004	0	0.333	0.005	-	-	-

Table 4. The classification error matrix of ETM+ image.

Class name	Green space	Roads network	Built up lands	Sterile lands	Sum	User. Acc.	Commission (0/0)
Green space	123	0	1	0	124	1	0
Roads network	0	4	0	0	4	1	0
Built up lands	0	5	35	0	40	0.798	0.197
Sterile lands	0	0	3	78	81	0.846	0.075
Sum	123	9	38	78	170	-	-
Prod. Acc.	1	0.381	0.846	1	-	-	-
Omission (0/0)	0	476	0.037	0	-	-	-

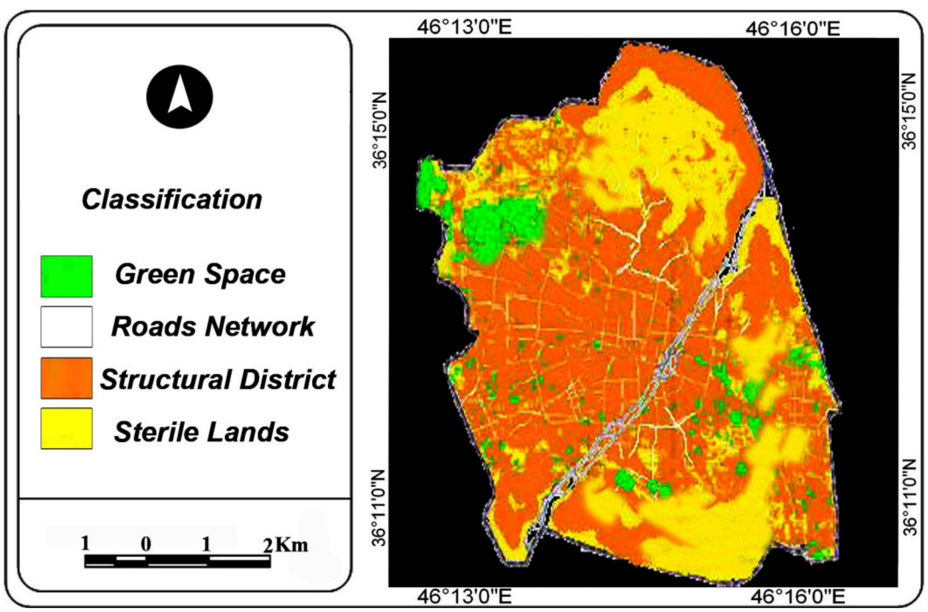

Figure 8. The classified map of ETM+ image (July 14, 2009).

of the physical development (unplanned constructions and housing projects) of Saqqez city on the green space by its 61.60% area reduction over a period of 20 years (1989 to 2009). Although, the investigation of green space changes using NDVI and image subtraction is the best, we also used PCA and post classification techniques as complementary methods to show change variation and change elements, respectively. The results of NDVI comparison shows that the green space has been reduced from 530 ha in 1989 to 198.3 ha in 2009. Afterwards, PCA scheme was run successfully with two components to show the degree of variation in the green space of Saqqez, which was explored by NDVI comparison. Finally, the post classification comparison shows the devastating role of unplanned constructions and housing projects (built up lands; low density residential, high density residential, commercial and industrial lands) on Saqqez green space. Here, the difficulty lies in identifying land classes; some land cover types have very similar spectral characteristics; some classes have a constant low reflectance over the whole spectral range with no or only trivial distinct absorption features. For example, one of the main problems of misclassification, which is caused by spectral similarities between materials covering these surfaces and the influence of shadow, occurs between the built up lands and the roads. The classification legend and parameters must be improved and some solution must be found to overcome the class confusion problem. Even though some solutions based on shadow interpretation were investigated, the shadow can still be a major problem in the interpretation of TM satellite data (Carleer and Wolff, 2006; Dare, 2005).

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