FOREST MAPPING AND CHANGE ANALYSIS, USING SATELLITE IMAGERY IN ZAGROS MOUNTAIN, IRAN

Ali Asghar Torahi
Department of Forestry, Faculty of Natural Resources, Behbahan University of Technology, P.O.Box: 6361713198, Behbahan, Iran
atorahi@khu.ac.ir

(Received 2 February 2012 - Accepted 23 March 2012)

ABSTRACT

A methodology to map and monitor land cover change using multitemporal Landsat Thematic Mapper (TM) and ASTER data in Zagros mountains of Iran for 1990, 1998, and 2006 was developed. Land-use/cover mapping is achieved through interpretation of Landsat TM satellite images of 1990, 1998 and TERRA-ASTER image of 2006 using ENVI 4.3. Based on the Anderson land-use/cover classification system, land-use and land-covers are classified as forest land, rangeland, water bodies, agricultural land and residential land. The unsupervised image classification method was carried out prior to field visit, in order to determine strata for ground truth. Fieldwork was carried out to collect data for training and validating land-use/cover interpretation from satellite image of 2006, and for qualitative description of the characteristics of each land-use/cover class. The land-use/cover maps of 1990, 1998 and 2006 were produced by using supervised image classification technique based on the Maximum Likelihood Classifier (MLC) and 132 training samples. Error matrices as cross-tabulations of the mapped class vs. the reference class were used to assess classification accuracy. Overall accuracy, user's and producer's accuracies, and the Kappa statistic were then derived from the error matrices. A multi-date post-classification comparison change detection algorithm was used to determine changes in land cover in three intervals, 1990–1998, 1998–2006 and 1990–2006. To evaluate the maps change for the 1990 to 2006 interval, areas classified as change and no-change were randomly sampled and checked whether they were correctly classified. The maps showed that between 1990 and 2006 the amount of forest land decreased from 67% to 38.5% of the total area, while rangelands, agriculture, settlement and surface water increased from 30.8% to 45%, 1.2% to 7.0%, 0.3% to 7.5% and 0.6% to 1.8%, respectively. In 1990,1998 and 2006, the area was dominated by dense forest (35.9%, 28.9%, 29.3%), open forest and degraded forest (21.9%, 24.89%, 27.5%). During a 16 year span period (1990-2006) about 10170.3 ha, 2963.4 ha, 351.7 ha and 3039.2 ha of forest lands were converted to rangeland, agriculture, water body and settlement. The overall five-class classification accuracies averaged 78.6%. Overall accuracy of land cover change maps, generated from post-classification change detection methods and evaluated using several approaches, was found to be 80.1%. Results quantify the land cover change patterns in the Zagros highlands and demonstrate the potential of multitemporal Landsat and ASTER data to provide an accurate, economical means to map and analyze changes in land cover over time that can be used as inputs to land management and policy decisions.

Keywords: land cover classification, multitemporal, change detection, Landsat, ASTER

INTRODUCTION

Forests constitute one of the world's most important valuable natural resource and play a key role in global ecological balance. Such resource has been and is being degraded and depleted worldwide. Depletion in forest area threatens the sustainability of agricultural production systems and endanger the economy of the country. Deforestation means not only loss of trees but also the loss of ecosystem and the the environmental benefits derived from it. Deforestation leads to degradation of soil, and soil erosion has impact on sedimentation in the water bodies. Every year extensive areas of forest lands are degraded and turned gradually into wastelands, due to natural causes or human interventions. There are several causes of deforestation, such as expansion of agricultural area, urban development, forest fires, commercial logging, illicit cutting, grazing, construction of dams/reservoirs and barrages, communication links, *etc*… . Depletion in forest cover, therefore, has an important impact on socio-economic development and ecological balance (Siddiqui *et al.*, 2002). Forest ecosystems have never been so affected by human pressure than currently (FAO, 2001). The rapid conversion or degradation of forest environments is thus an important international concern. Forest monitoring focuses mainly on detecting and estimating the land conversion rate and, more recently, on assessing carbon stocks in the forest ecosystem. Operational systems for monitoring and updating forest maps are thus needed for many applications such as forest management, carbon budgeting and habitat monitoring (Wasseige & Defourny, 2004; Foody, 2003; Sader *et al*., 2001). Global land cover change, particularly from forest to other land cover types due to increased human activity, is one of the most important issues in global change research. It has been especially remarkable in the last few decades, which witnessed an increasing rate of deforestation due to pressure caused by population growth. Since forest provides basic resources and external benefits for the sustenance of the ecosystem, it is becoming increasingly important to make predictions about the state of forest under different scenarios to suggest appropriate policy measures. Even though significant progress has been made in global change research in recent years, the lack of a reliable spatial dataset on deforestation continues to be a major obstacle for modelling global change (Murai, 1995). However, it is still possible to analyze the trends of global environment, including deforestation with the existing satellite data. Iran's forests are very important, not only to Iran but also to the whole region, due to its capability of supporting biodiversity. Infrastructure development, new settlement, timber extraction, fodder and grazing are the main causes for the rapid deterioration of physical environment and natural resource base in Iran. These factors have been generally cited as causes of land cover change and deforestation in Zagros mountains where most of Iranian forests are found (Fattahi, 1995). For these reasons, there is an urgent need for adequate information from which appropriate resource management strategy and interventions could be derived. The use of satellite imagery in conjunction with Geographic Information System (GIS) enables such changes to be monitored, mapped and analyzed in a timely and cost effective manner. Therefore, a study has been carried out focusing on strategies by mapping the past and present conditions and extent of Zagros highlands forests using temporal Landsat TM and ASTER data of 1990, 1998 and 2006 and GIS technology.

STUDY AREA

The study was carried out in Dehdez area that is located in the southern part of Iran and in south-eastern Khuzestan province between the 50˚ 12′ 14″ to 50˚ 33′ 25″ E and 31˚ 35′ 05″ to 31˚ 58′ 12″ N (Fig. 1). The area consists of hills and mountains and some gentle slope. The altitude ranges from 580 to 3000 m (asl) and covers an area of

512 km^2. Mainly three forest types are dominating in the area. They are *Amygdalus scoparia* forest, *Quercus persica* forest and *Pistacia atlantica* forest. *Quercus* sp (*Quercus persica*) forest is pioneer and dominant forest species of this (Fattahi, 2002). The area is covered by forest, shrub land, agriculture, settlements, villages, riverbeds and water body. According to literature, three main soil types can be seen in the study area, consisting of Mollisols, Entisols, Inseptisol and Alfisols (Etezadi, 1996). Different lithology in parent material on mountains and hills are seen that make a top sequence with different slopes. On the steep slopes, soils are shallow with high drainage and highly affected by erosion.

Figure 1. Location map of Dehdez in Khuzestan province, Iran.

MATERIAL AND METHODS

Image pre-processing

Two clear, cloud-free Landsat and one ASTER images were selected to classify the study area: June 17, 1990; May 18, 1998 and June 21, 2006. The Dehdez area is entirely contained within Landsat and ASTER path 164, row 38. All images were rectified to UTM zone 39, WGS84 using at least 25 well distributed ground control points and nearest neighbor resampling. The root mean square errors were less than 0.25 pixel (7.5 m) for each of the three images (Schroeder *et al*., 2006). Image processing was performed using ENVI 4.3. Land-use/cover mapping is achieved through interpretation of Landsat TM satellite images of 1990, 1998 and TERRA-ASTER image of 2006. Numerous researchers, including (Lillesand *et al*., 1998; Lunetta *et al*., 2006; Oettera *et al*., 2000; Wolter *et al*., 1995; Yuan *et al*., 2005) have demonstrated the value of multi-temporal imagery for classification of land cover.

Image classification

Training

Classification scheme was based on the land cover and land use classification system developed by (Anderson, 1976) for interpretation of remote sensor data at various scales and resolutions. Based on the Anderson land-use/cover classification system, the land-use and land-covers are classified as forest land, rangeland, water bodies, agricultural land and residential land. The unsupervised image classification method was carried out prior to field visit, in order to determine strata for ground truth. Fieldwork was carried out to collect data for training and validating land-use/cover interpretation from satellite image of 2006, and for qualitative description of the characteristics of each land-use/cover class. Also, it is necessary to collect other ancillary data and historical data required for classification of 1990 and 1998 images. In order to create a testing sample set, first of all a set of testing points is selected randomly. However, reaching all those random points is not feasible in practice because the study area is very complex with very a steep slope and difficult to access, especially those which are very far from the road/path. So, a modification is made in the field, whereby 95 randomly points used and all cover classes, which were mapped in the vicinity of these points were checked. For classification of images of 1990 and 1998 simple random sampling is applied (Jensen, 1996). The land-use maps of the corresponding years used as data source for ground truth, which were made based on the field surveys by technical staff of Natural Resources Research Center (NRRC) in Khuzestan province.

Allocation

Image classification is carried out in ENVI software. A supervised classification technique with Maximum Likelihood Algorithm was applied. The classification was based on 48 training samples for the image of 2006, and 42 samples for the images of 1990 and 1998. The land-use/cover maps of 1990, 1998 and 2006 were produced by using supervised image classification technique based on the Maximum Likelihood Classifier (MLC) and 132 training samples (Richards, 1993). Finally, a 3*3 majority filter was applied to each classification to recode isolated pixels classified differently than the majority class of the window.

Testing

An independent sample of an average of 95 polygons, with about 100 pixels for each selected polygon, was randomly selected from each classification to assess classification accuracies. Error matrices as cross-tabulations of the mapped class vs. the reference class were used to assess classification accuracy (Congalton & Green, 1999). Overall accuracy, user's and producer's accuracies, and the Kappa statistic were then derived from the error matrices. The Kappa statistic incorporates the off diagonal elements of the error matrices (*i.e*., classification errors) and represents agreement obtained after removing the proportion of agreement that could be expected to occur by chance.

Change detection

Following the classification of imagery from the individual years, a multi-date post-classification comparison change detection algorithm was used to determine changes in land cover in three intervals, 1990–1998, 1998–2006 and 1990–2006. This is perhaps the most common approach to change detection (Jensen, 2004) and has been successfully used by (Yang, 2002) to monitor land use changes in the Atlanta, Georgia area. The post-classification approach provides ‘‘from–to’’ change information and the kind of landscape transformations that have occurred can be easily calculated and mapped. A change detection map with 25 combinations of ‘‘from–to’’ change information was derived for each of the four seven-class maps.

Change detection accuracy assessment

A concern in change detection analysis is that both position and attribute errors can propagate through the multiple dates. This is especially true when more than two dates are used in the analysis. The simplest method of accuracy assessment of change maps is to multiply the individual classification map accuracies to estimate the expected accuracy of the change map (Yuan *et al*., 1998). A more rigorous approach is to randomly sample areas classified as change and no-change and determine whether they were correctly classified (Fuller *et al*., 2003). This approach was taken to evaluate the change maps for the 1990 to 2006 interval. Sample size was determined using the standard formula, $N = Z^2 * P * (1 - P) / E^2$, where Z= Z value (*e.g*., 1.96 for 95% confidence level), P= expected accuracy, and E =allowable error. For 50% accuracy, 95% confidence level, and 5% margin of error, a sample of 384 pixels was randomly selected from each class. Pixels on the boundaries of change areas (*i.e*., mixed pixels) were excluded, leaving 305 samples of change and 324 of no-change. Each sample point was compared to the reference data from Natural Resources Research Center (NRRC) of Khuzestan province land use maps to determine whether the Landsat and ASTER classified change had actually occurred. This method required intensive visual analysis because of the different formats and spatial characteristics of the several sources of reference maps. Nevertheless, it provided additional information to evaluate the accuracy of the Landsat and ASTER change detection.

RESULTS AND DISCUSSION

Classification and maps change and statistics

Classification maps were generated for the three studied years (Fig.2). The individual class area and change statistics for the three years are summarized in Table 1. About 67%, 48.8% and 38.5% of the total area was under forest cover in 1990, 1998 and 2006. Rangeland covers about 30.8%, 36.7% and 45% of the total geographical area of the Dehdez in 1990, 1998 and 2006. About 1.2%, 4.9% and 7% of the area was under agricultural practices in 1990, 1998 and 2006. The surface water body covers about 0.6%, 4% and 1.8% of the total area of the region. while about 0.3%, 5% and 7.5% of the area was under settlement in 1990, 1998 and 2006. Spatial distribution pattern reveals that the area was dominated by dense forest and rich rangeland at the ridge tops, open forest in the middle, and poor rangeland and agriculture in the valley areas. Based on the forest density, there were three types of forest viz., dense forest, open forest and degraded forest in Dehdez region (Fig.3). The percentage of the study area occupied by dense, open and degraded forest for 1990, 1998 and 2006 years are given in Table 2. The northern and eastern parts of the Dehdez region were dominated by dense forest. The Open forests were located mainly in western part and some places in southern part, and degraded forests were located in southern part and some places in western part of the Dehdez region, where the forest is more closed to the villages. From 1990 to 2006, settlement increased approximately 3710 ha (7.2%), agriculture increased 3038 ha (5.8%), water bodies increased 597 ha (1.2%) and rangeland increased 7298 ha (14.2%), while forest decreased 14643 ha (28.5%). Although the extent of water bodies and wetlands may change from year to year due to varying precipitation and temperature, the variation in wetland area is also likely due to classification errors (Table 4). However, the small fluctuations in water are believed to be related to varying lake levels given the high classification accuracy for water.

TABLE 1

Summary of Landsat and ASTER Classification Area Statistics for 1990, 1998 and 2006

Land cover class	1990		1998		2006	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Forest	34407.0	67.0	25072.0	48.8	19764.1	38.5
Rangeland	15814.1	30.8	18839.2	36.7	23112.2	45.0
Agriculture	580.1	1.2	2536.3	4.9	3618.1	7.0
Water	327.1	0.6	2094.1	4.0	924.0	1.8
Settlement	184.3	0.3	2771.0	5.0	3894.1	7.5

TABLE 2

Summary of Forest Classification Area Statistics for 1990, 1998 and 2006

Forest class	1990		1998		2006	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Dense forest[1]	12350	35.9	7235	28.9	5790	29.3
Open forest[2]	14526	42.2	11630	46.4	8545	43.2
Degraded forest[3]	7531	21.9	6206	24.8	5429	27.5

[1] canopy cover > 40% of land; [2] canopy cover 10-40% of land; [3] canopy cover < 10% of land

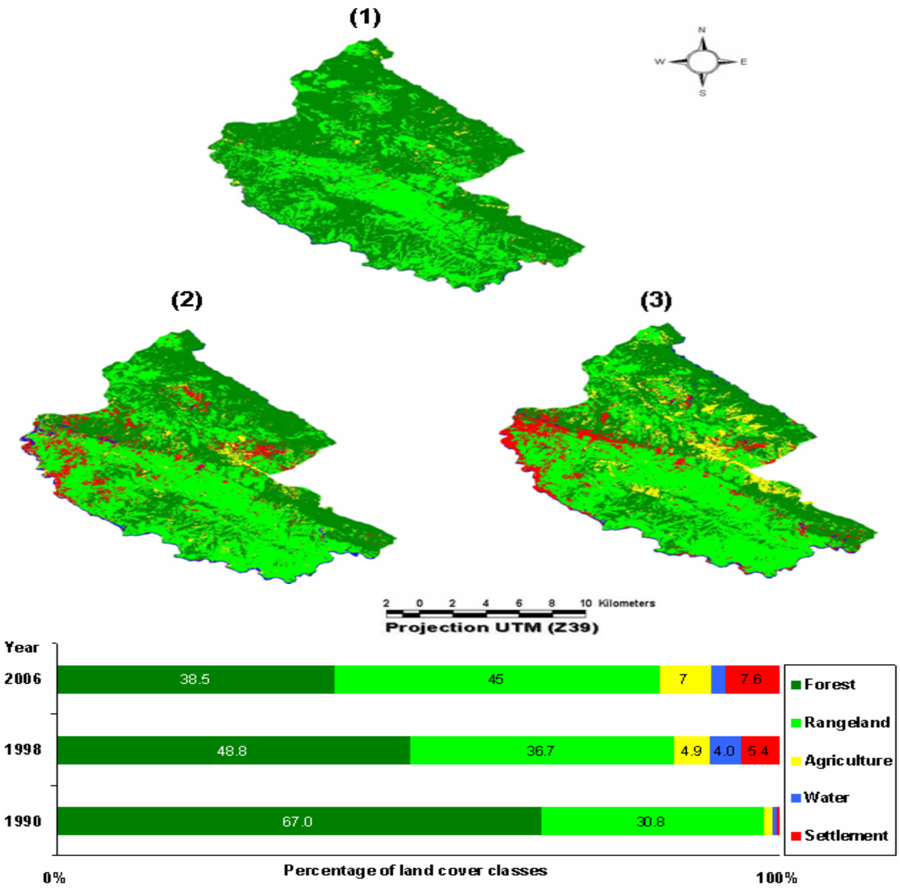

Figure 2. Land-use/cover classification maps for Dehdez area: (1) 1990, (2) 1998 and (3) 2006 and comparison of respective extents of land-use/cover classes by percentage of study area.

To further evaluate the results of land cover conversions, matrices of land cover changes from 1990 to 1998, 1998 to 2006, and 1990 to 2006 were created (Table 3). In the table, unchanged pixels are located along the major diagonal of the matrix. Conversion values were sorted by area and listed in descending order. Changes were greater in extent over the span of 16 years in the land under different categories. During 1990-1998, about 8097.9 ha, 1672.8 ha, 1275.2 ha and 1638.8 ha of forest lands were converted to rangeland, agriculture, surface water body and settlement, respectively. In the period 1998-2006, about 6390.6 ha, 3134.6 ha, 330.4 ha and 2979.5 ha of forest areas were converted to rangeland, agriculture, water body and settlement, respectively. During 16 years span period (1990-2006) about 10170.3 ha, 2963.4 ha, 351.7 ha and 3039.2 ha of forest lands were converted to rangeland, agriculture, water body and settlement. These results indicated that decrease in forest areas came mainly from conversion of forest land to agriculture, rangeland and settlement uses during the sixteen-year period, 1990–2006 (Table 3c). Table 3c shows that 351.7 ha of forests were converted to water between 1990 and

2006. These changes may seem to be classification errors, but conversion of forest to surface water bodies and wetlands is probably due to overflow of the rivers and flood happening in some places of this area. Roads were generally classified as settlement, but when tree canopies along the roads grow and expand, the associated pixels may be classified as forest. One notes that the changes from settlement to forest occurred almost entirely near roads. Classification errors may also cause other unusual changes. For example, between 1998 and 2006, 927.4 ha, 1301.3 ha, 139.9 ha and 89.9 ha of settlement changed to forest, rangeland, agriculture and water respectively. These changes are most likely associated with omission and commission errors in the Landsat classifications change map. Registration errors and edge effects can also cause apparent errors in the determination of change *vs.* no-change.

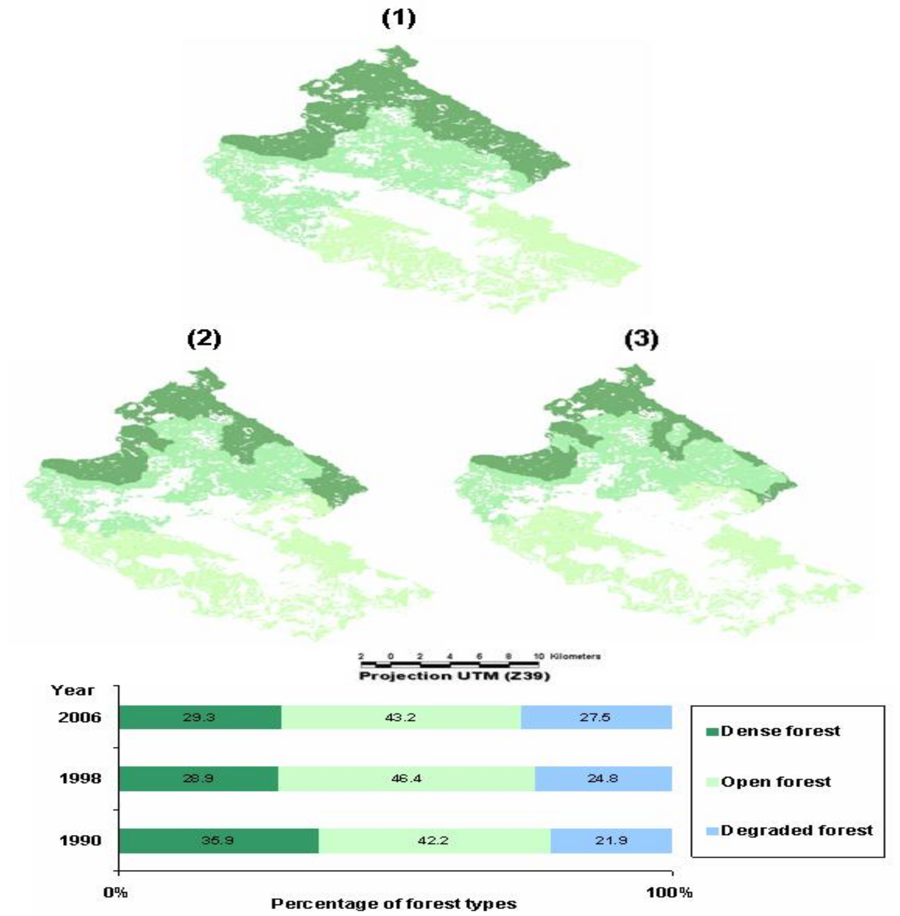

Figure 3. Forest cover classification maps in Dehdez area: (1) 1990, (2) 1998 and (3) 2006 and comparison of respective extents of forest types by percentage in the area.

TABLE 3

Matrices of Land Cover and Changes (Ha) from 1990 to 2006

a.	1990 - 1998					
	Forest	Rangeland	Agriculture	Water	Settlement	Total
Forest	23837	3111.6	224.2	2.5	37.8	27213.1
Rangeland	8097.9	11622	48.02	29.1	9.6	19806.62
Agriculture	1672.8	636.8	142.4	9.1	37	2498.1
Water	1275.2	481.5	31.2	185.9	21.09	1994.89
Settlement	1638.8	983.1	19.3	2.8	51.4	2695.4
1990 Total	36521.7	16835	465.12	229.4	156.89	35838.7

b.	1998 - 2006					
	Forest	Rangeland	Agriculture	Water	Settlement	Total
Forest	18001	4390.8	837.7	73.58	927.36	24230.44
Rangeland	6390.6	15632.5	918.4	423.76	1301.3	24666.56
Agriculture	3134.6	435.7	488.7	958.26	139.9	5157.16
Water	330.4	42.6	24.2	463.9	89.9	951
Settlement	2979.5	1512.0	281.4	147.3	315.6	5235.8
1998 Total	30836.1	22013.6	2550.4	2066.8	2774.06	34901.7

c.	1990 - 2006					
	Forest	Rangeland	Agriculture	Water	Settlement	2006 Total
Forest	19708.7	1738.4	122.6	1.0	10.01	24421.51
Rangeland	10170.3	14049	27.7	4.4	35.11	24642.51
Agriculture	2963.4	383.7	228.9	11.1	1.7	3588.8
Water	351.7	32.9	11.1	183.5	4.1	231.6
Settlement	3039.2	890.1	106.02	27.6	90.5	4153.42
1990 Total	36233.3	17094.1	3693.12	227.6	141.42	34260.6

Classification and change detection accuracies

Error matrices were used to assess classification accuracy and are summarized for all three years in Table 4. The overall accuracies for 1990, 1998, and 2006 were, respectively, 89.37%, 75.24%, and 71.14%, with Kappa statistics of 78.71%, 55.61%, and 51.41%. User's and producer's accuracies of individual classes were consistently high. Multiplying the individual classification accuracies from Table 4 gives expected overall change detection accuracies of 67.3% for 1990–1998, 53.5% for 1998–2006, and 63.6% for 1990–2006. The change detection accuracy was also evaluated by the method described in Section 3.4 in which 629 random samples classified as no-change or changed between 1990 and 2006 were evaluated and a change detection error matrix was derived (Table 5). The overall accuracy of change detection was 80.1%, with Kappa of 60%.

TABLE 4

Summary of Landsat and ASTER Classification Accuracies (%) for 1990, 1998 and 2006

Land cover class	1990		1998		2006	
	Producer's	User's	Producer's	User's	Producer's	User's
Forest	88.10	96.80	71.17	94.68	65.18	94.37
Rangeland	92.41	82.06	86.35	65.32	86.79	75.28
Agriculture	86.30	66.19	67.78	41.40	66.67	15.89
Water	100.00	100.0	78.00	45.61	77.00	54.23
Settlement	100.00	86.96	100.00	65.11	70.00	55.22
Overall accuracy	89.37		75.24		71.14	
Kappa statistics	78.71		55.61		51.41	

TABLE 5

Change Detection Error Matrix for 1990- 2006

Reference class	Classification		Producer's accuracy (%)
	Change	No-change	
Change	199	19	91.3
No-change	106	305	74.2
User's accuracy (%)	65.2	94.1	
Overall accuracy: 80.1 %	Kappa statistics: 60 %		

Analysis of change patterns

The above change statistics shed little light on the question of where land use changes are occurring. However, by constructing a change detection map (Fig. 4), the advantages of satellite remote sensing in spatially disaggregating the change statistics can be more fully appreciated. Fig. 4 shows a map of the major land cover types and the conversion from forest to another uses. Forest and rangelands representing 82.5% of the total area, are the two major land cover types in Dehdez. Conversions involving these two classes also represent the most significant changes. Forest conversion to rangeland and agriculture and the loss of forest resources are the most important conversions in this area. Forest cover has been shrinking rapidly, especially in lower parts. About 16524.6 ha of forests are actively affected by humans during 16 years period (1990-2006). In other words, almost 1032.78 ha forests lost each year. However, much more than this area is subject of human onslaughts that includes collection of fodder, firewood, non-timber material, burning, grazing and hunting. The main causes of deforestation are expansion of rangeland, agriculture and settlement, excessive commercial use of timber, fuelwood and cattle grazing. The conversion of forest to rangeland, agriculture and settlement is due to cutting of the trees up to steep slopes and river valleys by the local people and they use to graze their livestock, farm and settle in those areas, especially nearby the villages. Nomadic herding is a common practice in this area. Usually many herds of sheep and goats used to keep at the high altitude during the summer and bring down in the winter. This migration comes to be important problem in the region due to increasing the demolition of the forest. Firewood is the common and mostly used source of household energy. The demand for firewood is increasing with the rapid inflow of tourists in the region Forest is the source of different purposes including timber, fodder, fuel-wood, saplings, medicinal herbs, wild fruits, wild vegetables, leaf/litter and thatch in the area. Among them collection of timber, fodder and fuel wood are very common. Basically, the use depends on the species types and distance from the settlement. In the lower elevation, *Amygdalus scoparia* is the dominant species. This species is confined in the lower part of the Dehdez region. The local people accept *Amygdalus* as one of the best species for the firewood and charcoal production. *Quercus persica* and *Pistacia mutica* are the common species up to 1500m asl. These species highly used as timber for the house construction, firewood and other household purposes. In summary, information from satellite remote sensing can play a significant role in quantifying and understanding the nature of changes in land cover and where they are occurring. Such information is essential for natural resources managers to managing the area and policy makers in the formulation of forest resources management strategies.

CONCLUSION

Results demonstrate that Landsat and ASTER classifications can be used to produce accurate landscape change maps and statistics. General patterns and trends of land-use/cover change in the Zagros highlands were evaluated by classifying the amount of land in Dehdez area that was converted from forest to rangeland, agriculture, waterbody and settlement use during three periods from 1990 to 2006. In addition to the generation of information tied to geographic coordinates *(i.e*., maps), statistics quantifying the magnitude of change, and ‘‘from–to’’ information can be readily derived from the classifications. The results quantify the land cover change patterns in Dehdez area and demonstrate the potential of multitemporal Landsat and ASTER data to provide an accurate, economical means to map and analyze changes in land cover over time that can be used as inputs to land management and policy decisions. The use of multi-temporal Landsat TM and ASTER data in conjunction with GIS provides an opportunity for environmental monitoring, surveying and change detection, which can help in monitoring deforestation and save considerable efforts, time and cost compared with traditional surveying and mapping methods. The integrated land-use/cover maps have shown not only the temporal changes that occur in the forest cover but also in the other land covers during a 16 year period. The forest cover digital maps based on satellite remote sensing data and GIS techniques can supplement existing conventional ground based sources of information for monitoring changes in the forests cover on a regular basis, which can be helpful for forest resource management and future planning for the development of the areas.

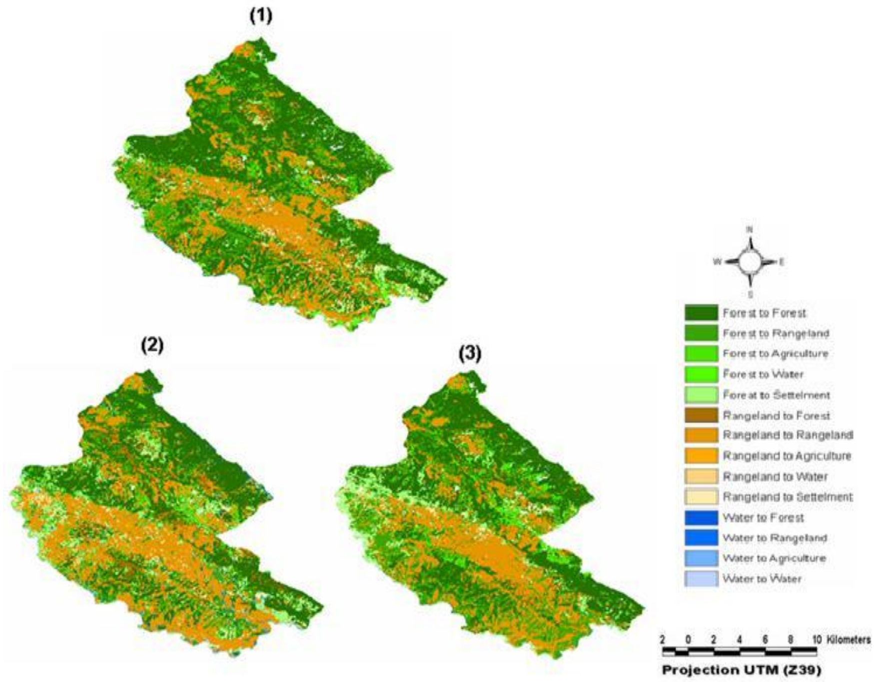

Figure 4. Land-use/cover change in Dehdez from: (1) 1990-1998, (2) 1998-2006 and (3) 1990-2006.

ACKNOWLEDGEMENTS

Satellite data have been made available by the Iran Space Agency. The authors wish to thank the “Division of Natural Resource Management” (DNRM) for providing them with the forest inventory GIS data and the “National Geographic Institute” (NGI) for the Topography data used for the field survey. The authors thank also the reviewers for their constructive comments and remarks.

REFERENCES

Anderson, A. 1976. Land use and land cover classification system, geological survey professional paper 964, Wash., D.C.

Congalton, R.G. & Green, K. 1999. *Assessing the accuracy of remotely sensed data: principles and practices* (pp. 43–64). Boca Rotan, Florida’ Lewis Publishers.

Etezadi, E. 1996. *The complete studies of Khuzestan province, section of geological study*. Planning and Management Organzation of Khuzestn province press.

FAO 2001. Global forest resources assessment 2000. *FAO Forestry Paper 140*, Food and Agriculture Organization of the United Nations, Rome.

Fattahi, M. 1995. *Investigation of Zagros natural resources and the important factors of* *demolition*. Institute of forests and range lands researches press.

Fattahi, M. 2002. *Management of Zagros forests*. Institute of forests and range lands researches press.

Foody. G.M. 2003. Remote sensing of tropical forest environments: towards the monitoring of environmental resources for sustainable development. *International Journal of Remote Sensing*, 24: 4035−4046.

Fuller, R.M., Smith, G.M. and Devereux, B.J. 2003. The characterization and measurement of land cover change through remote sensing: problems in operational applications. *International Journal of Applied Earth Observation and Geoinformation*, 4: 243–253.

Jensen, J.R. 1996. *Introductory digital image processing*. New Jersay, Prentice Hall.

Jensen, J.R. 2004. *Digital change detection. Introductory digital image processing: a remote sensing perspective* (pp. 467– 494). New Jersey, Prentice-Hall.

Lillesand. T.M., Chipman, J.W., Nagel, D.E., Reese, H.M., Bobo, M.R. and Goldmann, R.A. 1998. *Upper midwest gap analysis program image processing protocol*. U.S. Geological Survey, Environmental Management Technical Center, Onalaska,Wisconsin, pp. 25.

Lunetta, M.S., Balogh, M. 1999. Application of multi-temporal Landsat 5 TM imagery for wetland identification. *Photogrammetric Engineering and Remote Sensing*, 65: 1303– 1310.

Murai, S. 1995. Development of global eco-engineering using remote sensing and geographic information systems. *Proceeding of 8th Toyota Conference*.

Oettera, D.R., Cohenb, W.B., Berterretchea, M., Maierspergera, T.K. and Kennedy, R.E. 2000. Land cover mapping in an agricultural setting using multiseasonal Thematic Mapper data. *Remote Sensing of Environment*, 76: 139– 155.

Richards, J.A. 1993. *Remote sensing digital image analysis, an introduction*. Second edition, Springer-Velarg.

Sader, S.A., Hayes, D.J., Hepinstall, J.A., Coan, M. and Soza, C. 2001. Forest change monitoring of a remote biosphere reserve. *International Journal of Remote Sensing*, 22(10): 1937−1950.

Siddiqui, M.N., Maajid, S., Jamil, Z. and Afser, J. 2002. Integrated applications of remote sensing and GIS for mapping and monitoring changes in forest cover. *Proceedings of the International Seminar on Natural Hazard Monitoring*, Karachi, Pakistan, pp. 429–435.

Schroeder, T.A., Cohen, W.B., Song, C., Canty, M.J., Yang, Z. 2006. Radiometric correction of multi-temporal Landsat data for characterization of early successional forest patterns in western Oregon. *Remote Sensing of Environment*, 103: 16-26.

Wolter, P.T., Mladenoff, D.J., Host, G.E., G. E. and T.R. 1995. Improved forest classification in the Northern Lake States using multi-temporal Landsat imagery. *Photogrammetric Engineering and Remote Sensing*, 61: 1129– 1143.

Wasseige, C. de and Defourny, P. 2004. Remote sensing of selective logging impact for tropical forest management. *Forest Ecology and Management*, 188: 161−173.

Yang, X. 2002. Satellite monitoring of urban spatial growth in the Atlanta metropolitan area. *Photogrammetric Engineering and Remote Sensing*, 68(7): 725–734.

Yuan, D., Elvidge,, C.D. & Lunetta, R.S. 1998. *Survey of multispectral methods for land cover change analysis.* Remote sensing change detection: environmental monitoring methods and applications (pp. 21–39). Michigan, Ann Arbor Press.

Yuan, F., Bauer, M.E., Heinert, N.J. and Holden, G. 2005. Multi-level land cover mapping of the Twin Cities (Minnesota) metropolitan area with multi-seasonal Landsat TM/ETM+data. *Geocarto International*, 20(2): 5 –14.