MONITORING LANDCOVER CHANGES ON THE COASTAL ZONE OF NORTH-LEBANON USING OBJECT-BASED IMAGE ANALYSIS OF MULTI-TEMPORAL LANDSAT IMAGES

George Mitri[1], Manal Nader[1], Irna Van der Molen[2], and Jon Lovett[2]

1. Institute of the Environment, University of Balamand, Lebanon; University of Balamand - P.O.Box: 100, Tripoli - North Lebanon, Lebanon, Email: george.mitri@balamand.edu.lb
2. Technology & Sustainable Development (TSD) Group, Center for Clean Technology and Environmental Policy (CSTM), University of Twente, the Netherlands Email: p.vandermolen@utwente.nl

ABSTRACT

Monitoring landcover changes in Lebanon using multi-temporal satellite images is considered an important step towards investigating environmental change over large areas with the severe lack of environmental measurements and records. Automated change detection presents a valuable tool for monitoring large areas. Until present, Lebanon lacks an operational mechanism for monitoring changes in landcover/landuse at the National level. Simultaneously, there is continuous demand for techniques such as Object-Based Image Analysis (OBIA) that allow the integration in the analysis of more than one image (possibly of different spatial resolution) and produce GIS-ready results. This work aimed to characterize landcover changes during the last four decades on the coastal zone of North-Lebanon using an OBIA approach. This was an initial step towards conducting a more advanced investigation for assessing the effect of repetitive armed conflicts on the Northern coastal environment. A total of five Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM) images covering the same geographical area of North-Lebanon were employed. The methodology of work included 1) satellite data pre-processing, 2) image segmentation and classification, and 3) post-classification comparison of the results. Pre-processing of data included geometric calibration and masking of images. OBIA comprised segmentation of images at different levels and classification incorporating spectral and contextual information. Overall, OBIA proved to be successful in monitoring landcover change with the use of multi-temporal satellite images. Field visits combined with visual interpretation of the results derived from landcover classification of multi-temporal very high spatial resolution SPOT imagery showed that recorded changes in landcover came in the form of: deforestation, land reclamation from the sea, indiscriminate construction, new road networks, and quarrying, among others. Future work will include 1) the investigation of the possible direct and indirect effect of repetitive armed conflicts on observed landcover changes, and 2) the assessment of land degradation risk as a result of changes in the landcover.

INTRODUCTION

Landcover change is one of the most sensitive indicators for environmental change. It reveals how human activities, such as deforestation and urbanization, are having a serious effect on ecosystem characteristics. Among human activities causing severe changes to the environment, war is considered to be both intensive and far reaching (1). Repetitive armed conflicts in Lebanon have significantly changed the physical environment. Reliable monitoring and effective analysis techniques need to be implemented in order to estimate landcover change and its ecological impact (2).

Remote sensing images not only provide extensive coverage of wide areas, but also provide comprehensive information about these areas. For almost 30 years, they have been used in many different types of studies covering numerous scientific areas (3). The wide area coverage and high frequency offered by satellite sensors, as well as their ability to provide information about non-visible spectral regions, makes them a very valuable tool for the detection and mapping of landcover changes. Indeed, remotely sensed data can contribute to a better, cost effective, objective and time-saving method to quantify the location, aerial extent and frequency of changes in the landcover.

Different satellites have proved to be useful in achieving this. From 1975 to 1993, the Landsat MSS sensor has been providing periodically digital images of the Earth. Its spatial resolution (80 x 80 m) makes the MSS one of the most interesting sensors of Earth Observation satellites to be employed in monitoring and studying landscape dynamics (4). In addition, Landsat with its Thematic Mapper (TM) instrument is able to provide very impressive color images covering an area of 180x180 km with 30 m of spatial resolution. Monitoring landcover changes in coastal areas, which have been severely affected by human activities (5,6,7), is considered an important step towards investigating environmental change over large areas with the severe lack of environmental measurements and records.

Automated change detection using multi-temporal satellite images represents a valuable tool for monitoring changes over large areas (8). Until present, Lebanon lacks an operational mechanism for monitoring changes in landcover/landuse at the National level. Simultaneously, there is continuous demand for techniques such as Object-Based Image Analysis (OBIA), which allows the integration in the analysis of more than one image (with the possibility of including images of different spatial resolution), to produce GIS-ready results. The concept of OBIA is that the information necessary to interpret an image is not represented in a single pixel, but in networked image objects (9).

This work aimed to characterize landcover changes during the last four decades on the coastal zone of North-Lebanon using an OBIA approach. This was an initial step towards conducting a more advanced investigation for assessing the effect of repetitive armed conflicts on the Northern coastal environment.

STUDY AREA AND DATASET DESCRIPTION

The study area comprised all municipalities in North-Lebanon having a border with the Mediterranean Sea (Figure 1). The Northern coastline, which is 100 km in length, constitutes around 37% to 40% of the total Lebanese coast (6). Approximately 8870 hectares of the Northern coast is currently urbanized (7). The coastal zone of North-Lebanon can be grouped into 6 categories of major land use types (6): 1) agricultural lands 23838 hectares; 2) natural areas or undisturbed areas 22881 hectares; 3) urbanized area 8870 hectares; 4) rural area 1846 hectares; and 5) wetland areas amounting to 372 hectares. The Central Administration of Statistics (CAS) estimated that the population of North Lebanon comprised approximately 768,000 inhabitants (10).

A total of five Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM) images covering the same geographical area of North-Lebanon were employed. The satellite images were acquired on 9-9-1975 (MSS), 9-11-1984 (MSS), 5-10-2006 (TM), 6-9-2007 (TM), and 3-12-2010 (TM) respectively. In addition, landcover change detection maps derived from Very High Resolution Spot images (2.5 m of spatial resolution) of 2002, 2005, 2006 and 2009 were used for validation of the results. A field survey was conducted in the summer of 2011 for data collection. The survey consisted of one visit to each of the cadastral units along the coast (a total of 26 visits). Information about changes in landcover/landuse, their location, their main causes, and time of change were collected. In most of the cases, the questions were addressed to local authorities covering each the involved cadastral units.

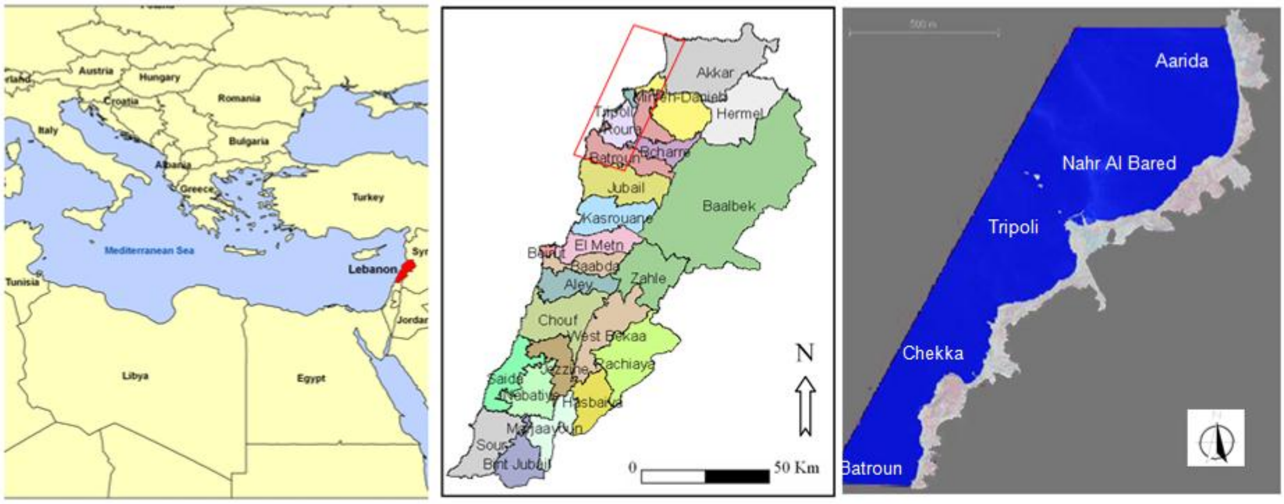

Figure 1: Location of Lebanon in red (left), the map of Lebanon (centre), and the study area of North-Lebanon (right).

METHODS

The methodology of work included 1) satellite data pre-processing, 2) image segmentation and classification, and 3) post-classification comparison of the results. Pre-processing of data included geometric calibration and masking of images.

Multi-resolution segmentation

OBIA comprised segmentation of images at different levels. Multi-resolution segmentation was first applied to the images. The strategy behind the image segmentation was to create different levels of image objects of different scales. Thus, different object levels can be analyzed in relation to each other. As such, image objects can be classified by extracting information from classified sub-objects or super-objects. A series of segmentations was generated by adjusting the parameters of scale, band weights, color, and shape. Next, a six-level graded scale of segmentation was created. Size of image objects varied from small size objects at level 1 to large size objects at level 6. Super-objects at higher levels in the hierarchy would provide information about the classification of sub-objects at lower levels.

Classification

Classifications were carried out at five segmentation levels. Level 6 was the first to be classified, followed by levels 5, 4, 3, and 2 respectively. The lowest segmentation level with the smallest size of objects was reserved for further investigation of changes in landcover/landuse. The Normalized Differenced Vegetation Index (NDVI) was used for the classification of vegetated and non-vegetated cover. Obtained classifications from two different images in t1 and t2 were compared independently.

The following three "parent" classes were created at each level: vegetation, no vegetation, and water. Subclasses to vegetation comprised the following classes: "no change in vegetation between t1 and t2", and "positive change in vegetation between t1 and t2". Subclasses to "no vegetation" comprised: "no change in un-vegetated cover", "negative change in vegetation cover between t1 and t2", and "change of seawater surface to no vegetation" (e.g. sea filling).

RESULTS

The following thematic maps were created:

- Level 1: Reserved for further investigation of the results
- Level 2: Landcover change detection between 1975 and 2010

- Level 3: Landcover change detection between 2006 and 2007
- Level 4: Landcover change detection between 1984 and 2006
- Level 5: Landcover change detection between 1975 and 1984
- Level 6: Landcover base map of vegetation cover in 1975

The results indicated an approximate 1,020 ha of lost vegetation cover during the last four decades. Also, a total seawater area of 265 ha was converted to land (existence of new jetties, marinas, sea filling, etc.). Comparison of classifications between two consecutively dated images showed that most of changes in coastal land filling happened between 1984 and 2006. Rate of negative change in vegetation cover was highest between 2006 and 2007.

Field visits to 21 coastal villages where changes were recorded combined with visual interpretation of the results using multi-temporal very high spatial resolution SPOT imagery showed that recorded changes in landcover (Figure 2) came in the form of: deforestation, land reclamation from the sea, indiscriminate construction, new road networks, and quarrying, among others.

The destruction of vegetation resources is one of the most important physical indicators of land degradation in the Mediterranean basin. Artificialization of the coastline in Lebanon including major construction of quays, marinas and sand siphoning has resulted in reduced access to public beaches, major reduction of water circulation, an alteration of the water current patterns and stripped sea bed. The results can serve as valuable information to further investigate direct and indirect effect of repetitive armed conflicts on observed landcover changes, and to assess land degradation risk as a result of changes in the landcover.

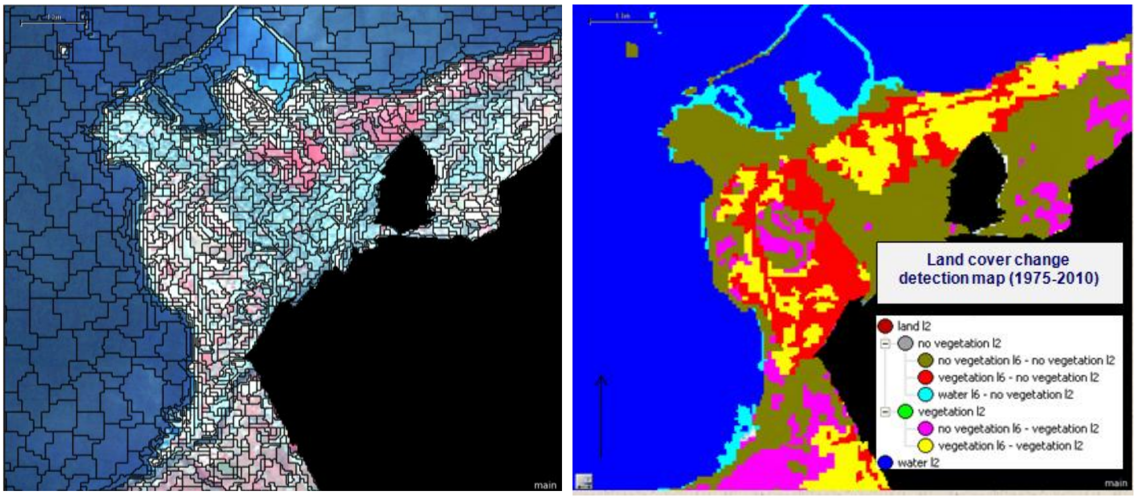

Figure 2: Example of segmented image subset of 2010 (left) and corresponding classified image subset showing landcover change detection between 1975 and 2010 (right)

CONCLUSIONS

Overall, OBIA with the use of multi-temporal satellite images proved to be successful in giving systematic monitoring results in relation to landcover change. Post-classification comparisons of the results allowed the successful identification of 1) changes in vegetation cover, 2) areas of coastal land filling, and 3) the extent and timeframe of change. Future work will include 1) the investigation of the possible direct and indirect effect of human activities, including repetitive armed conflicts, on observed landcover changes, and 2) the assessment of land degradation risk as a result of changes in the landcover.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to the Netherlands Organization for Scientific Research and the WOTRO Science for Global Development for providing financial assistance to pursue the current work. Also, the authors are thankful to the Planet Action (SPOT initiative) for providing support to pursue certain tasks of the current work.

REFERENCES

1 Machlis, G., & Hanson, T. 2008. Warfare ecology. BioScience, pp. 729-736.

2 Gitas, I., Mitri, G., Barbosa, P., Assad, N., Jomaa, I., Papageorgiou, C. and Turk, T. 2003. Land Cover Change Detection Using NOAA-AVHRR Images taken from 1989 to 2002 for the Eastern Part of the Mediterranean Region as a Tool to Support Decision-Making. Options Méditerranéennes (CIHEAM), Série B – n° 46.

3 Chuvieco, E. (Editor), 2009. Earth Observation of Wildland Fires in Mediterranean Ecosystems, Springer, Dordrecth, 2009, ISBN: 978-3-642-01753-7.

4 Hall, F. G., Botkin, D. B., Strebel, D. E., Woods K. D. and Goetz, S. J. 1991. Large-scale patterns of forest succession as determined by remote sensing. Ecology, 72: 628-640.

5 MOE/UNDP/ECODIT, 2011. State and Trends of the Lebanese Environment, Lebanon.

6 IMAC, 2009. Status Assessment Report. Integrated Management of East Mediterranean Coastlines. Institute of the Environment, University of Balamand.

7 UNEP-MAP/ECODIT, 2005. National Action Plan for the Reduction of Pollution into the Mediterranean Sea from Land based Sources, 63 pp.

8 Mouflis G., Gitas, I., Iliadou, S., Mitri, G.. 2008. Assessment of the visual impact of marble quarry expansion (1984-2000) on the landscape of Thasos island, NE Greece. International Journal of Landscape and Urban Planning, 86: 92-102.

9 Mitri, G. and Gitas, I. 2010. Mapping post-fire vegetation regeneration using EO-1 Hyperion. IEEE Transactions on Geoscience and Remote Sensing. 48: 1613-1618.

10 CAS, 2004. Living conditions nation survey. Central Administration for Statistics Lebanon, 59p.