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APPLICATIONS OF MULTITEMPORAL RS IMAGES FOR THE EVALUATION OF URBANIZATION PROCESS IN MONGOLIA

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ABSTRACT: This study aims to evaluate the urbanization process of Ulaanbaatar city, Mongolia using multitemporal optical satellite remote sensing (RS) data sets. To extract reliable urban land cover information from the selected RS data sets, a refined supervised classification method based on maximum likelihood classification that uses spatial thresholds defined from the local knowledge is applied. Overall, the research indicated that in recent decades Ulaanbaatar city has been significantly expanded.

1. INTRODUCTION

In recent years, cities all over the world have experienced rapid growth because of the large increase in world population and the irreversible flow of people from rural to urban areas (Amarsaikhan *et al.* 2009). In the coming decades, the world's rapid urbanization will be one of the greatest challenges to ensure human welfare and global environment (Hamid and Bahreldin 2013). According to recent estimates, cities occupy about four percent of the world's terrestrial surface, yet they are home to almost half of the global population, consume close to three-quarters of the overall natural resources, and generate three-quarters of its pollution and wastes. The UN estimates that virtually all net global population and economic growth over the next three decades will occur in cities, leading to a doubling of current population (Redman and Jones 2004, Amarsaikhan *et al.* 2011).

Mongolia, as many other countries, has problems related with the rapid urban growth and urbanization is one of the serious concerns of the government (Janzen *et al.* 2005). For example, within the last decades, Ulaanbaatar, the capital city of Mongolia has been significantly expanded and changed. Generally, much of Mongolia's urban growth has taken place since the middle of 1970s, because, at that time, the government encouraged migration to urban areas, specifically to Ulaanbaatar in the belief that this would increase the industrialization and productivity in the country. Although, the government had encouraged the migration, it was under strict control of the state. In 1990, Mongolia entered the market economy and it totally changed the lives in the society. The government had no more strict control on the migration and many rural families officially and unofficially moved to Ulaanbaatar, approaching the central market. As a result, the population of Ulaanbaatar had been significantly increased and the city area had significantly expanded (Amarsaikhan *et al.* 2011).

In the current study, we wanted evaluate the urbanization process of Ulaanbaatar, the capital city of Mongolia using multitemporal optical RS images. As the image data sources, Landsat MSS, Landsat TM and Landsat ETM (+) data sets were used. To extract the urban land cover information from the selected optical data sets, a refined maximum likelihood classification that uses spatial thresholds defined from the local knowledge was applied.

2. TEST AREA AND DATA SOURCES

As a test site Ulaanbaatar, the capital city of Mongolia has been selected. Ulaanbaatar is situated in the central part of Mongolia, on the Tuul River, at an average height of 1350m above sea level. As of July 2015, the city has about 1.37 million inhabitants (Mongolian Statistical Year Book, 2015). The selected part of the capital city is about 24kmx18km and it covers the majority of the area belonging to the capital city, although there are some areas extending outside of the selected image frame.

As the RS data sources, Landsat MSS data of January 1974 with a spatial resolution of 79m, Landsat TM data of October 1990 with a spatial resolution of 30m, and Landsat ETM (+) data of August 2001 with a spatial resolution of 28m, and Landsat TM data of September 2011 with a spatial resolution of 30m were used. In addition, a topographic map of 1984, scale 1:50,000, and a general urban planning map were available. Figure 1 shows the test area in the selected RS images.

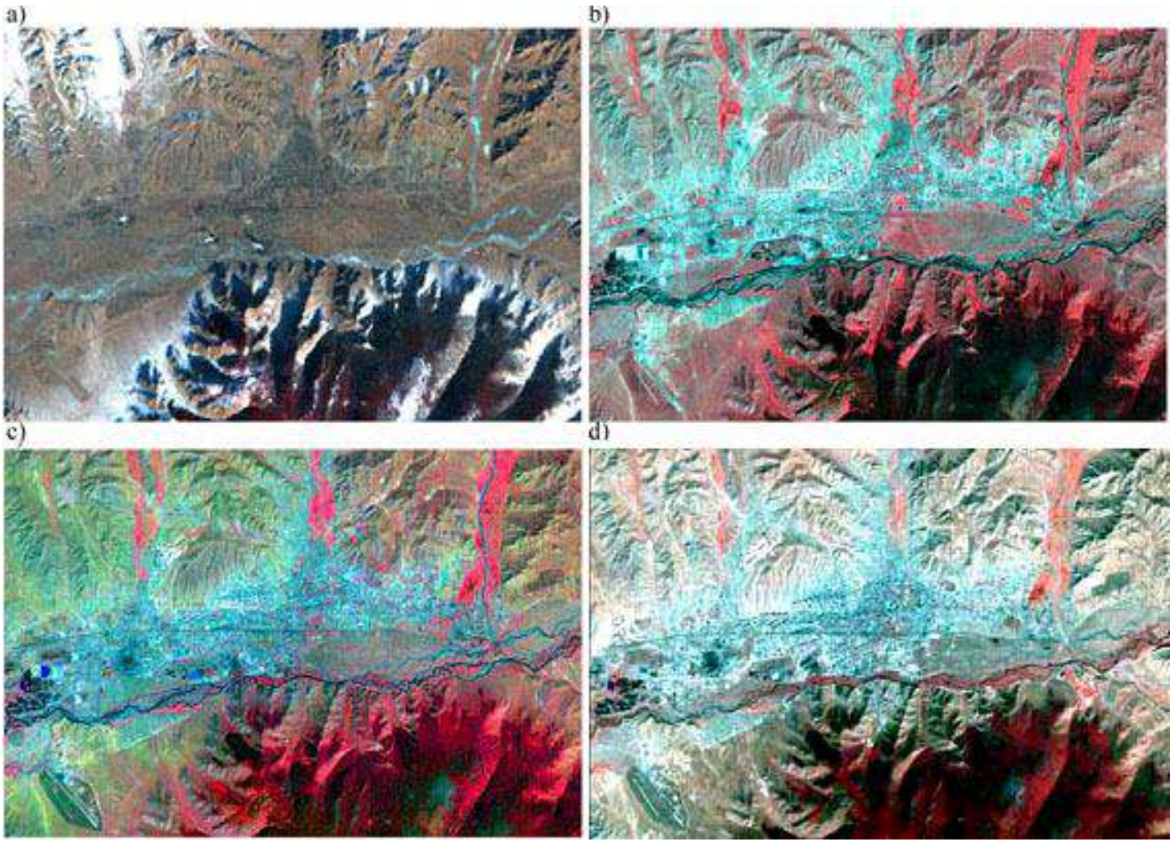

Figure 1. Landsat images of Ulaanbaatar area. a) MSS image of 1974, b) TM image of 1990, c) ETM+ image of 2001, d) TM image of 2011.

3. RADIOMETRIC CORRECTION AND GEOREFERENCING OF THE IMAGES

At the beginning, all the images were thoroughly analyzed in terms of radiometric quality and geometric distortion. The Landsat MSS data had a destriping effect and it was corrected by applying a destripe removing function followed by a 3x3 size average filtering (GONZALEZ and WOODS, 2002). Then, the TM image of 1990 was georeferenced to a UTM map projection using a topographic map of 1984, scale 1:50,000. The ground control points (GCP)s have been selected on well defined cross sections of roads, streets and other clearly delineated sites. In total, 12 regularly distributed points were selected. For the transformation, a linear transformation and nearest neighbour resampling approach (ERDAS, 1999) have been applied and the related root mean square (RMS) error was 0.67 pixel. In order to georeference other images, 12-16 more regularly distributed GCPs were selected on each image comparing the locations of the selected points with other information such as the already georeferenced Landsat TM and the selected topographic map. Then, the images were successively georeferenced to the UTM map projection using the topographic map of 1984. For the actual transformations, a second order transformation and nearest neighbour resampling approach were applied. The RMS errors of the image transformations were 1.25 pixel for the MSS, 0.91 pixel for the ETM+, and 0.93 pixel for the TM of 2011, respectively. In all cases of the georeferencing, an image was resampled to a pixel resolution of 30m.

4. CLASSIFICATION OF THE IMAGES AND EVALUATION OF THE URBANIZATION

Over the years, multispectral RS data sets have been successfully used for land cover mapping and for the generation of thematic information, diverse classification methods have been applied. In recent years, rapid and timely mapping of urban areas, specifically at regional and global scales has become an important task for many urban planners. This is associated with the rapid urbanization process, because the planners and decision-makers need to evaluate the related environmental and social problems (Amarsaikhan *et al.* 2012). However, in most cases urban areas are complex and diverse in nature and many features have similar spectral characteristics and it is not easy to separate them by the use of common feature combinations or by applying ordinary techniques (Cao *et al.* 2009). For the successful extraction of the urban land cover classes, reliable features or an efficient classification technique should be used.

In the present study, to extract the reliable urban land cover information from the selected RS data sets, a refined classification method that uses spatial thresholds defined from the local knowledge has been used. As the features for the classification, for all data sets green, red and infrared bands have been selected. To define the sites for the training signature selection, from the images, several areas of interest (AOI) have been selected for the available classes such as building area, ger (Mongolian national dwelling) area, green vegetation, soil and water using the local knowledge. Then, the separability of the selected training signatures was evaluated using TD distance (MATHER, 1999) and the samples which demonstrated the best possible separability were chosen to form the final signatures. The final signatures included about 86-512 pixels.

For the actual classification, a refined maximum likelihood classification has been used. The maximum likelihood classification is the most widely used supervised classification technique, because a pixel classified by this method has the maximum probability of correct assignment (Richards, 1999). Initially, in order to check the performance of the standard method, the selected bands were classified, however, on the classified images there were different mixed classes and it was not possible to correctly evaluate the urbanization process. To separate the statistically mixed classes, the class specific features as well as spatial thresholds can be applied. The class specific features can be determined through the feature extraction process, however, the application of this approach would become difficult if there is a fewer number of bands. The spatial thresholds can be defined from the knowledge about the test area or historical data sets. The idea of the spatial threshold is that it uses a polygon boundary to separate the overlapping classes and only the pixels falling within the threshold boundary are used for the classification. In that case, the likelihood of the pixels to be correctly classified will significantly increase, because the pixels belonging to the class that overlaps with the class to be classified using the threshold boundary are temporarily excluded from the decision making process. In such a way, the image can be classified several times using different threshold boundaries and the results can be merged (Amarsaikhan *et al.* 2012).

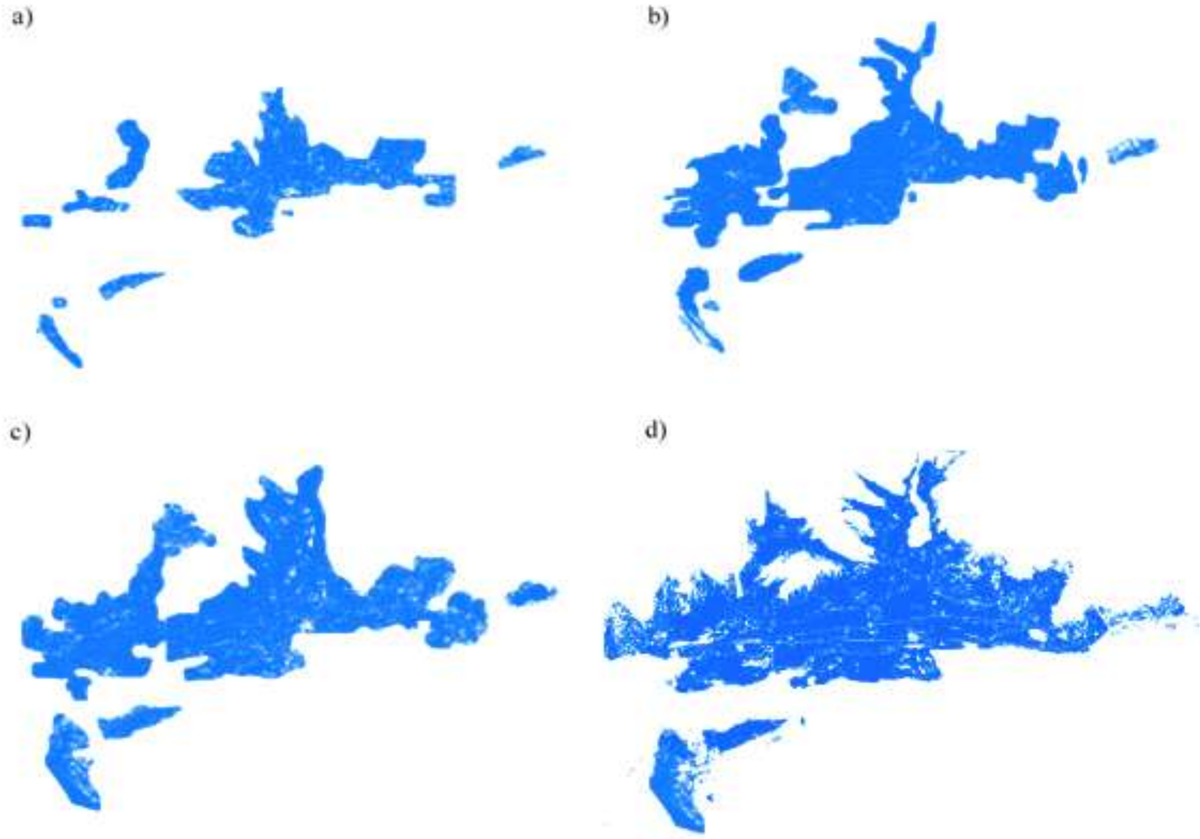

Figure 2. The results of the classifications: a) MSS image of 1974, b) TM image of 1990, c) ETM+ image of 2001, d) TM image of 2011.

Table 1. The total areas for urban class in different years, evaluated from multitemporal RS data sets.

No.	RS images	Total areas in hectares (ha)
1.	Landsat MSS (1974)	5217.1
2.	Landsat TM (1990)	9033.1
3.	Landsat ETM+ (2001)	9687.8
4.	Landsat TM (2011)	13206.8
Overall changes since 1974		7989.7 (253.1%)

In the present study, to separate the statistically overlapping classes, different spatial thresholds determined on the basis of the local knowledge have been used. The local knowledge was based on the knowledge about the site as well as the historical GIS data sets. The results of the classifications using the defined spatial thresholds are shown in figure 2. For the accuracy assessment of the classification results, the overall performance has been used and as ground truth information, different AOIs containing the purest pixels have been selected. The confusion matrices produced for the refined classification method indicated overall accuracies of 87.2% for the 1974 data, 90.9% for 1990 data, 93.2% for the 2001 data and 91.5% for 2011 data, respectively.

In order to define the areas related to urban expansion, initially, the total areas related to each class was defined by calculating statistical parameters of the classified multitemporal RS images. Then, the classes were merged into two classes: urban and non-urban. The urban class included building area and ger area, whereas non-urban class included all other classes. The areas related to urban class evaluated from RS images obtained at different years are shown in table 1 and their graphical representation is shown in Figure 3. As seen, in recent decades Ulaanbaatar city has faced very rapid urbanization process and its size has been significantly increased since 1974.

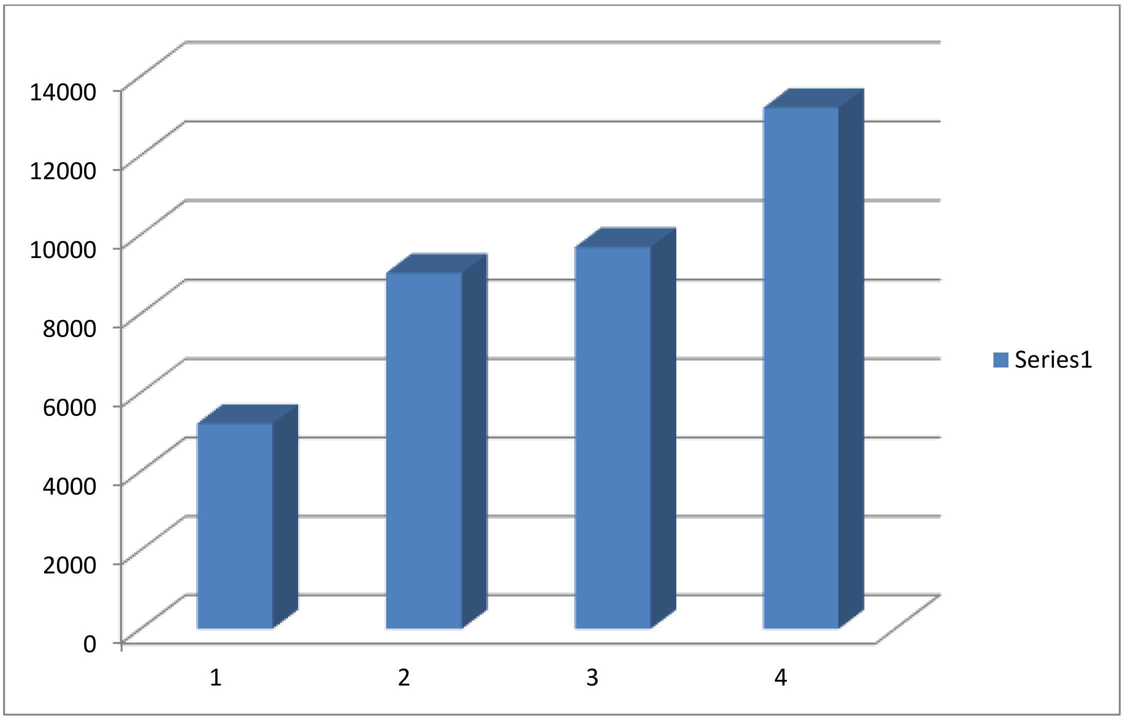

Figure 3. Comparison of the urban areas for different years (1-1974, 2-1990, 3-2001, 4-2011).

5. CONCLUSION

The overall aim of the study was to evaluate the urbanization process of the capital city of Mongolia using multitemporal optical RS images. To extract urban land cover information from the selected Landsat data sets, a refined classification algorithm based on the maximum likelihood classifier that uses spatial thresholds defined from the local knowledge was applied. After the classification, the defined classes were merged into either urban or non-urban class. As seen from the result of the evaluation process, in recent decades Ulaanbaatar city faced very rapid urbanization process and its planning and management might need to be reconsidered.

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