APPLICATIONS OF GIS AND VERY HIGH RESOLUTION RS DATA FOR URBAN LAND USE CHANGE STUDIES IN MONGOLIA

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ABSTRACT: The aim of this study is to analyze urban land use changes occurred in central part of Ulaanbaatar, the capital city of Mongolia before and after 1990 using geographical information system (GIS) and very high resolution remote sensing (RS) data sets. As data sources, large scale topographic map, panchromatic and multispectral Quickbird images as well as TerraSAR data are used. The primary urban land use database is developed using the topographic map and historical data about bulidings. To extract updated land use information from the RS images, Quickbird and TerraSAR images are fused. For the data fusion, different fusion techniques are used and the results are compared. For the final analysis and image processing ArcGIS and Erdas Imagine systems installed in a PC environment are used.

1. INTRODUCTION

Within the last few decades, cities all over the world have experienced rapid growth because of the rapid increase in world population and the irreversible flow of people from rural to urban areas (Amarsaikhan *et al.* 2009). Mongolia, as many countries of the world has problems with the urban expansion and the growth of population in the main cities. For example, over the last two decades Ulaanbaatar, the capital city of Mongolia has experienced different urban related problems. In the city, various problems had been previously accumulated during the centralized economy and they have been intensified by the reforms of the entire political and economic systems, unregulated market development and the rapid population growth caused mainly by migration from rural areas (Amarsaikhan *et al.* 2005, Amarsaikhan *et al.* 2009).

To prevent rapid urban expansion, urban planners and decision-makers need to regularly evaluate development procedures using updated urban planning maps. However, many city planners in developing countries lack access to updated maps and often rely on old data that are not relevant (Amarsaikhan 2005, Amarsaikhan *et al.* 2009). One possible solution is the use of RS images with different spatial and spectral resolutions. Over the past few years, RS platforms, techniques and technologies have evolved. System capabilities have greatly improved. Meanwhile, the cost of many of these data sets has drastically decreased. Now the highest spatial resolution image can be acquired with centimetres-accuracy, whereas the ordinary high-resolution images can be acquired with a few metres accuracy. It is now possible to extract different thematic information at various scales, to integrate the extracted information with other historical data sets stored in a GIS and to conduct sophisticated analyses (Amarsaikhan *et al.* 2009).

The aim of this study is to analyze urban land use changes occurred in central part of Ulaanbaatar, the capital city of Mongolia from before (when the country had a centralized economy) and after (when the country started to have a market economy) 1990 using RS and histroical GIS data sets. For the basic preparation of spatial and attribute databases, a large scale topographic map of 2000 and historical description of the buildings have been used. To update the database of 2000 up to the year of 2009, very high resolution Quickbird image of 2009 and TerraSAR image of 2008 have been fused. For the fusion, different data fusion techniques have been compared in terms of the enhancement of spatial and spectral variations of urban features. To extract land use information from the fused images, a visual interpretation has been applied. The final analysis was carried using ArcGIS 9.2 and Erdas Imagine 9.2 systems and different techniques were applied.

2. TEST SITE AND DATA SOURCES

As a test site, Ikh toiruu area of Ulaanbaatar, the capital city of Mongolia has been selected. The selected area covers the central part of the capital city covers and extends from the west to the east about 3.75km and from the north to the south about 2.65km. Figure 1 shows a Quickbird image of the test site, and some examples of its land cover.

Figure 1. 2006 Quickbird image of the selected part of Ulaanbaatar.
1- building area; 2-ger area; 3- roads; 4- bare soil; 5-vegetation; 6-central squire.
The size of the displayed area is about 3.75kmx2.65km.

In the current study, 1:5000 scale topographic map of 2000, Quickbird image of June 2009 and HH polarization of TerraSAR-X image of March 2008 have been used. The Quickbird data has four multispectral bands (B1: 0.45–0.52µm, B2: 0.52–0.60µm, B3: 0.63–0.69µm, B4: 0.76–0.90µm) and one panchromatic band (Pan: 0.45-0.9µm). The spatial resolution is 0.61 m for the panchromatic image, while it is 2.4 m for the multispectral bands. In the current study, panchromatic, red and near infrared bands have been used. TerraSAR-X is a German Earth Observation satellite carrying a cloud-piercing, night-vision radar which is designed to create the most precise maps and images ever produced by a civilian space radar system. In this study, HH polarization of TerraSAR X-band (wavelength is 3.1cm) data with a spatial resolution of 1m has been used.

3. GEOREFERENCING AND SPECKLE SUPPRESSION

At the begining, the panchromatic Quickbird image has been georeferenced to a Gauss-Kruger map projection using a topographic map of 2000, scale 1:5000. The ground control points (GCP) have been selected on well defined cross sections of roads, streets and building corners and in total, 12 regularly distributed points were selected. For the transformation, a second order transformation and nearest neighbour resampling approach (Richards and Jia 1999) have been applied and the related root mean square (RMS) error was 1.08 pixel. Likewise, the multispectral Quickbird image has been georeferenced to a Gauss-Kruger map projection using the same topographic map of the test area. For the transformation the same number of GCPs has been used and the related RMS error was 0.97 pixel. In each case of the georeferencing, an image was resampled to a pixel resolution of 1m.

Then, the TerraSAR HH polarization image was geometrically corrected and its coordinates were transformed to the coordinates of the georeferenced Quickbird images. In order to correct the SAR image, 15 more regularly distributed GCPs were selected from different parts of the image. For the actual transformation, a second-order transformation was used. As a resampling technique, the nearest-neighbour resampling approach was applied and the related RMS error was 1.29 pixel.

As microwave images have a granular appearance due to the speckle formed as a result of the coherent radiation used for radar systems; the reduction of the speckle is a very important step in further analysis. In this study, three different speckle suppression techniques such as local region, frost and gammamap filters (ERDAS 1999) of 5x5 and 7x7 sizes were compared in terms of delineation of urban features and texture information. After visual inspection of each image, it was found that the 5x5 gammamap filter created the best image in terms of delineation of different features as well as preserving content of texture information. In the output image, speckle noise was reduced with very low degradation of the textural information.

4. FUSION OF OPTICAL AND SAR IMAGES

As it is known, optical data contains information on the reflective and emissive characteristics of the Earth surface features, while the SAR data contains information on the surface roughness, texture and dielectric properties of natural and man-made objects. It is evident that a combined use of the optical and SAR images will have a number of advantages because a specific feature which is not seen on the passive sensor image might be seen on the microwave image and vice versa because of the complementary information provided by the two sources (Amarsaikhan *et al.* 2007, Zhang 2010). Many authors have proposed and applied different techniques to combine optical and SAR images in order to enhance various features and they all judged that the results from the fused images were better than the results obtained from the individual images (Pohl and Van Genderen 1998, Ricchetti 2001, Amarsaikhan and Douglas 2004, Westra *et al.* 2005, Saadi and Watanabe 2009, Ehlers *et al.* 2010). In this study, for the image fusion, the following techniques were compared: (a) Brovey transform, (b) modified IHS (intensity, hue, saturation), (c) Elhers fusion, (d) wavelet-based fusion. Each of these techniques is briefly discussed below.

Brovey transform: This is a simple numerical method used to merge different digital data sets. The algorithm based on a Brovey transform uses a formula that normalises multispectral bands used for a red, green, blue colour display and multiplies the result by high resolution data to add the intensity or brightness component of the image (Vrabel 1996). For the Brovey transform, the bands of Quickbird data were considered as the multispectral bands, while the HH-polarization of TerraSAR image was considered as the multiplying panchromatic band.

The modified IHS: This method has a vast improvement over traditional IHS for fusing satellite imagery that differs noticeably in spectral response. It allows combining single band panchromatic data with multispectral data, resulting in an output with both excellent detail and a realistic representation of original multispectral scene colors. The modified IHS method is designed to produce an output that approximates the spectral characteristics of the input multispectral bands while preserving the spatial integrity of the panchromatic data. The technique works by assessing the spectral overlap between each multispectral band and the high resolution panchromatic band and weighting the merge based on these relative wavelengths (Siddiqui 2003).

Elhers fusion: This is a fusion technique used for the spectral characteristics preservation of multitemporal and multi-sensor data sets. The fusion is based on an IHS transformation combined with filtering in the Fourier domain and the IHS transform is used for optimal colour separation. As the spectral characteristics of the multispectral bands are preserved during the fusion process, there is no dependency on the selection or order of bands for the IHS transform (Ehlers *et al.* 2008).

Wavelet-based fusion: The wavelet transform decomposes the signal based on elementary functions, that is the wavelets. By using this, an image is decomposed into a set of multi-resolution images with wavelet coefficients. For each level, the coefficients contain spatial differences between two successive resolution levels. In general, a wavelet-based image fusion can be performed by either replacing some wavelet coefficients of the low-resolution image by the corresponding coefficients of the high-resolution image or by adding high resolution coefficients to the low-resolution data (Pajares and Cruz, 2004). In this study, the first approach which is based on bi-orthogonal transforms has been applied.

To obtain good colour images, all the fused images have been visually inspected and compared. In the case of the Brovey transform the combination of the Quickbird and TerraSAR created an image with some noise. The spectral appearance of the Brovey transformed image was a bit similar to the original Quickbird image, but on this image the edges of the buildings were too much influenced by the speckle of the SAR image. In the case of the modified IHS method, the fused image demonstrated a better result compared to the combinations obtained by the Brovey transform. However, a thorough inspection of the image had revealed that it still contained some noise of the radar image. In the case of the Elhers fusion, the integrated image looked very similar to the original Quickbird image and demonstrated a better result compared to most other combinations. However, this image had a bit blurred appearance due to speckle noise of the SAR image which makes the image less relevant for the final interpretation. In the case of the wavelet-based fusion, the fused image demonstrated the best result compared to all other combinations. Although, the image had a bit similar spectral appearance as the image obtained by the Elhers fusion, it did not contain speckle. On this image, the buildings were very well separated from other classes both spatially and spectrally. Moreover, it could be seen that some textural information has been added for differentiation between the building and other classes. Therefore, the image obtained by the wavelet-based fusion has been used for the final analysis. Figure 2 shows the comparison of the images obtained by different fusion methods.

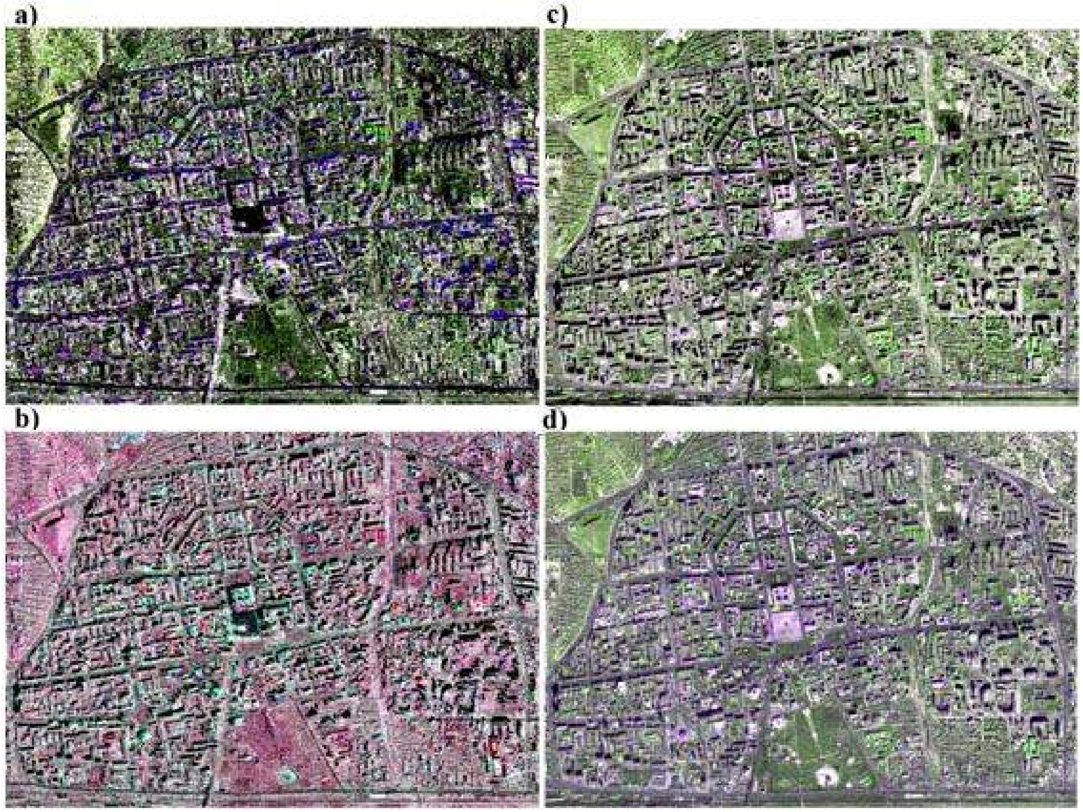

Figure 2. Comparison of the fused images: (a) Brovey transform, (b) modified IHS, (c) Elhers fusion, (d) wavelet-based fusion.

5. UPDATED DATABASE AND LAND USE CHANGE ANALYSIS

Initially, a digital topographic map of the study area of scale 1:5000 represented in a raster format, has been georeferenced to a Gauss-Kruger map projection using 12 GCPs. For the transformation, a linear transformation and nearest-neighbour resampling approach were applied and the related RMS error was 0.28 pixel. In order to acquire primary digital data, the buildings were digitized from the georeferenced topographic map of 2000 using ArcGIS system. The digitized buildings illustrated on top of the topographic map is shown in Figure 3. Then, for each building entity, the attributes such as address, built_year, use, condition and storey_number were entered. Moreover, the area of every building was calculated and stored as a new attribute within the database.

In order to analyse the changes occurred in between 2000 and 2009, it was necessary to update the created from the topographic map, database. For this purpose, the image obtained by the wavelet-based fusion has been used. For the thorough registration of the GIS and RS data sets, the coordinates of the fused image were transformed to the coordinates of the digitized map using 12 ground GCPs. For the transformation, a second order transformation and nearest-neighbour resampling approach were applied and the related RMS error was 0.86 pixel. Then, the digitized map was overlain on top of the georeferenced fused image thus highlighting the buildings appeared after 2000. After this, on the georeferenced image, the buildings were screen digitized and updated the previously created database. After that for all new building entities, the attributes such as address, built_year, use, condition and storey_number were entered. Like before, the area of each new building entity was calculated and updated the database. The updated map is shown in Figure 4. To analyse the changes occurred before and after 1990, queries have been made using ‘Select by attributes‘ function of ArcGIS.

As could be seen from the analysis, in the study area, there were built 571 buildings having 689952.6 sq.m until 1990. However, after 1990, since Mongolia entered the market economy, the interests of people to own land parcels and build houses, have greatly increased. Specifically, from the new century, Mongolian economy started to improve and people wanted to have a piece of land in areas having good infrastructure and build constructions on it and that is the main reason for a rapid increase of the buildings in the city’s central area. As seen from the analysis, there were built 792 buildings having 645892.9 sq.m after 1990.

Figure 3. A digitized map of Ikh toiruu, 2000.

Figure 4. The updated map of Ikh toiruu, 2009
(light brown represents the buildings built after 2000).

6. CONCLUSIONS

The main purpose of the study was to analyze urban land use changes occurred in central part of Ulaanbaatar city before and after 1990 using GIS and very high resolution optical and SAR data sets. As data sources, 1:5000 scale topographic map, as well as Quickbird and TerraSAR images were used. The primary urban land use database was developed using the topographic map of the study area and the related attributes. To extract updated land use information from the mulitsource images, the data fusion, where Brovey transform, modified IHS, Elhers fusion and wavelet-based fusion were compared. Of these methods, the image obtained by the wavelet-based fusion gave the best result in terms of the differentiation between the buildings and other land use types. To extract relaible land use information from the fused image, a visual interpretation was applied. Overall, the study demonstrated that the central part of Ulaanbaatar was urbanized very rapidly since the country entered the market economy.

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