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Full Length Research Paper

Applications of remote sensing (RS) and geographical information system (GIS) for urban land use change study in Ulaanbaatar City, Mongolia

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The aim of this study was to analyze the urban land use changes of Ulaanbaatar, the capital city of Mongolia, using very high resolution remote sensing (RS) and geographical information system (GIS) datasets. In this study, land use status in Ulaanbaatar before 1990 are compared with the land use changes that occurred after 1990 and the socio-economic reasons for the changes are described. For the basic preparation of spatial and attribute database, a large scale topographic map from 2000 and historical description of the land use elements are used. To update the land use information from 2000 to 2008, very high resolution panchromatic and multispectral Quickbird images of 2008 as well as TerraSAR image of 2008 are fused. For the fusion, some advanced data fusion techniques are compared in terms of the enhancement of spatial and spectral variations of urban features. To extract land use information from the fused RS images, a visual interpretation is applied. Overall, the study demonstrates that during the market economy Ulaanbaatar city is urbanized very rapidly and there is a need to reconsider its planning and management.

Key words: Urban land use, remote sensing (RS), geographical information system (GIS), Image fusion, change analysis.

INTRODUCTION

Because of the rapid increase in world population and the irreversible flow of people from rural to urban areas, urbanization and urban sprawl have become common problems for governments and decision-makers in both developed and developing countries (Amarsaikhan et al., 2005). For example, within the last decade, Ulaanbaatar, the capital city of Mongolia has been significantly expanded and changed due to different development activities, as well as migration of people from rural areas. Poor living conditions coupled with increasing unemployment in rural areas and an increasing interest in urban land ownership comprise major factors for urban migration of rural populations. Generally, unplanned and uncontrolled urban expansion may have different negative consequences and such kind of problem is rather new in Mongolia. In developed countries, it is common that the controlling and coordination of the land use types from a view point of urban planning are based on the research about urban internal structure and land use. However, in Mongolia, such research studies are very rare. For example, in the case of Ulaanbaatar city there is a lack of thorough studies in relation to the internal structure and land use types. Therefore, in order to investigate different problems of the capital city, it is vitally important to thoroughly investigate its fundamentals, that is the internal structure and land use types, and make a rapid decision in order to solve not only socio-economic, but the major urban environmental-ecological related problems (Amarsaikhan et al., 2005, Amarsaikhan et al., 2009b).

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Abbreviations: GCP, Ground control points; **GIS,** geographical information system; **RS,** remote sensing; **IHS,** intensity hue-saturation; **FFT,** fast Fourier transform; **LP,** low pass; **HP,** high pass; **PCA,** principal components analysis; **RMS,** root mean square.

Before 1990, Mongolia was a socialist country and it had a centrally planned economy. The centrally planned economy means an economic system where economic decisions are made by the state or government rather than by the interaction between consumers and businesses. Unlike a market economy in which the prices of goods and services are determined in a free price system (Altvater, 1993), a centrally planned economy seeks to control what is produced and how resources are distributed and used. The rapid political changes of 1990 marked the beginning of Mongolia's efforts to develop a market economy. Commencing from 1991, many of the state owned industries and properties started to be privatized. By the middle of 1990s, it was evident that Mongolia's market economy development was irreversible.

The development plan of Ulaanbaatar during the time of the centrally planned economy represented not only urban construction and physical architectural plan, but it was based on the capital city's investment planning and had a legal power to plan and control the urban internal land utilization. The reason for this was that the prevailing majority of industrial plants, economic and infrastructure sites, residential and dwelling apartments of the country were mainly concentrated in the capital city. On the other hand, everything was based on such a system, where the entire land of the country belonged to the government and was distributed under the tenure of factories and economic establishments of socialist features and the utilization rules and orders were established by the state power and the tenure had been controlled and inspected by the society via state organs. However, when the country entered the market economy, it was not possible to control all of the rapidly changing activities and many things had happened without any control (Chinbat et al., 2005).

Since the transition to a market economy in 1990, Ulaanbaatar city has experienced much more privatized development, which resulted in changes of the spatial and functional structures of the city and the most significant changes have been the increase of commercial functions in the city centre and inner city area, the expansion of the urbanized areas along with the growth of formal and informal ger-settlements, the formation of satellite nodes with clusters of commercial functions, and the residential suburbanization in the outer city by single family houses (Chinbat et al., 2005). To analyze the current changes, urban planners and decision-makers need to regularly evaluate development procedures using updated urban planning maps. How-zever, many city planners in developing countries lack access to updated maps and often rely on old data that are not relevant. One of the possible solutions could be the use of RS images with different spatial and spectral resolutions. Present remote sensing (RS) images allow extraction of different thematic information at various scales, to integrate the extracted information with other historical datasets stored in a geographical information system (GIS) and to conduct sophisticated analyses (Amarsaikhan et al., 2009b).

The aim of this study is to analyze the urban land use changes of Ulaanbaatar city using RS and historical GIS datasets. In this study, the changes that occurred in Ulaanbaatar before 1990 were compared with the changes that occurred after 1990 and the socio-economic reasons for the changes have been described. For the development of databases, a large scale topographic map of 2000 and historical description of the entities have been used. To update the database of 2000 up to the year of 2008, very high resolution Quickbird and TerraSAR images of 2008 have been fused. For the fusion, some advanced 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.

Study areas and data sources

In this study, Ulaanbaatar, the capital city of Mongolia was selected as a test site. Ulaanbaatar is extended from the west to the east about 30 km and from the north to the south about 20 km. The present study covers the whole city and also some selected land use types. The selected land use types cover 7 sites such as low density apartment area (15-microdistrict), middle density apartment area (Metromall area), high density apartment area (13-microdistrict), ger district (7 Buudal area), central business district (Baga toirog), light industrial area (Suljmel area), and mixture of light industrial and residential areas (100 ail). The locations of these sites delineated on a Quickbird image are shown in Figure 1.

A 1:5000 scale topographic map from 2000 with Quickbird images taken in March 2008 and TerraSAR-X data from March 2008 were used. The Quickbird image has four multispectral bands (B1: 0.45–0.52 μm, B2: 0.52–0.60 μm, B3: 0.63–0.69 μm and B4: 0.76–0.90μm) and one panchromatic band (Pan: 0.45-0.9 μm). The spatial resolution is 0.61 m for the panchromatic image and 2.4 m for the multispectral bands. In the current study, panchromatic red and near infrared bands were 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. It images the Earth's surface at a rate of one million square kilometres a day and provides information at various spatial resolutions. In this study, HH and VV polarization images of TerraSAR X-band (wavelength is 3.1cm) data with a spatial resolution of 1 m was used.

Co-registration of panchromatic, multispectral and synthetic aperture radar (SAR) images

In general, a high geometric accuracy and good geometric correlation should be needed between the images in order to perform successful data fusion. Initially, 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, 15 regularly distributed points were selected. For the transformation, a second order transformation and nearest neighbour resampling approach

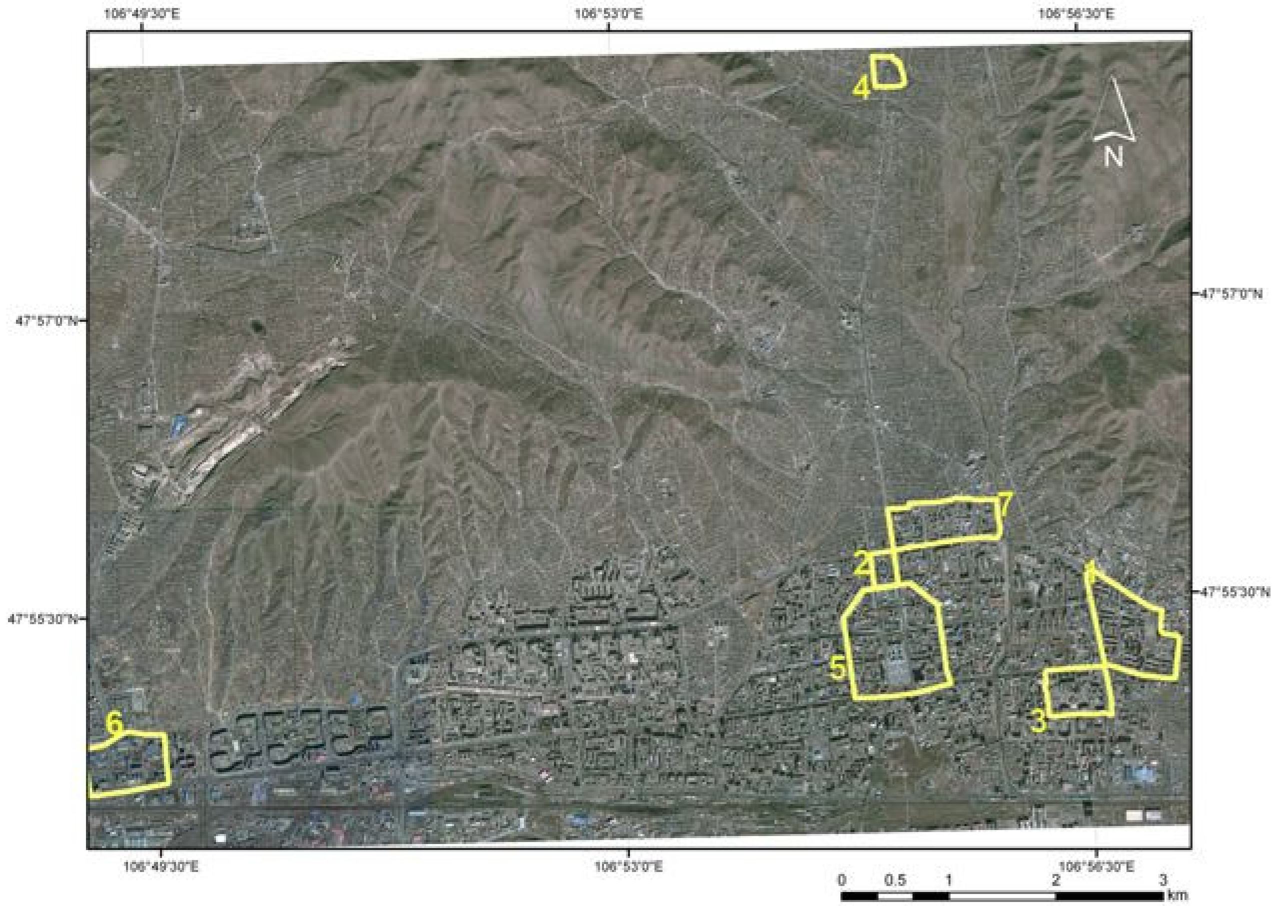

Figure 1. Quickbird image of 2008. 1, low density apartment area; 2, middle density apartment area; 3, high density apartment area; 4, ger district; 5, central business district; 6, light industrial area; 7, mixture of light industrial and residential areas.

(Richards and Jia, 1999) was applied and the related root mean square (RMS) error was 1.12 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 was used and the related RMS error was 1.05 pixel. In each case of the georeferencing, an image was resampled to a pixel resolution of 1m.

Then, the TerraSAR HH and VV polarization images were geometrically corrected and their coordinates were transformed to the coordinates of the georeferenced Quickbird images. In order to correct the SAR images, 16 more regularly distributed GCPs were selected from different parts of the images. 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 1.38 pixel. As both optical and microwave images had a very high spatial resolution, the errors of less than 1.5m were considered as acceptable for further studies.

Speckle suppression of the TerraSAR HH and VV polarization images

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 before further analysis. The analysis of the radar images must be based on the techniques that remove the speckle effects while considering the intrinsic texture of the image frame (Ulaby et al., 1986; Amarsaikhan and Douglas, 2004; Serkan et al., 2008). In this study, five different speckle suppression techniques such as local region, median, lee-sigma, 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 filtered 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.

Image fusion using different methods

The concept of image fusion refers to a process which integrates images from different sources to obtain more information from a single and more complete image, considering a minimum loss or distortion of the original data (Zhang, 2010). In other words, the image fusion is the integration of different digital images in order to create a new image and obtain more information than can be separately derived from any of them (Pohl and Van Genderen, 1998; Ricchetti, 2001; Amarsaikhan et al., 2009a). In the case of the present study, for the urban areas, the SAR image provides structural information about buildings and street alignment due to the double bounce effect (it is a corner-reflector like scattering and results in brighter appearance on a radar image), while the optical images provide the information about the spectral variations of different urban features. Moreover, the SAR images provide some additional information about soil moisture condition due to dielectric properties of the soil (Amarsaikhan et al., 2007). Over the years, different data fusion techniques have been developed and applied individually, and in combination, providing users and decision-makers with various levels of information. Generally, image fusion can be performed at pixel, feature and decision levels (Abidi and Gonzalez, 1992; Pohl and Van, Genderen, 1998). In this study, data fusion has been performed at a pixel level and the following techniques were compared.

Elhers fusion

This is a fusion technique used for the preservation of spectral characteristics of multitemporal and multi-sensor datasets. The fusion is based on an intensity hue saturation (his) transformation combined with filtering in the Fourier domain; 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, 2004; Ehlers et al., 2010).

The IHS method uses three positional parameters such as intensity (I), hue (H) and saturation (S). Intensity, is the overall brightness of the scene and devoid of any colour content; hue, is the dominant wavelength of the light contributing to any color; saturation, indicates the purity of colour. In this method, the H and S components contain the spectral information, while the I component represents the spatial information (Pohl and Van Genderen, 1998; Ricchetti, 2001). The transformation from red green blue (RGB) colour space to IHS space is a nonlinear, lossless and reversible process. It is possible to vary each of the IHS components without affecting the others. It is performed by a rotation of axis from the first orthogonal RGB system to a new orthogonal IHS system. The equations describing the transformation to the IHS (Pellemans et al., 1993) can be written as follows:

$$\begin{Bmatrix} x \\ y \\ z \end{Bmatrix} = \begin{Bmatrix} \frac{1}{\sqrt{3}} & \frac{\sqrt{2}}{\sqrt{3}} & 0 \\ -\frac{\sqrt{2}}{\sqrt{3}} & \frac{1}{\sqrt{3}} & 0 \\ 0 & 0 & 1 \end{Bmatrix} \begin{Bmatrix} \frac{1}{\sqrt{2}} & 0 & \frac{1}{\sqrt{2}} \\ 0 & 1 & 0 \\ -\frac{1}{\sqrt{2}} & 0 & \frac{1}{\sqrt{2}} \end{Bmatrix} \begin{Bmatrix} R \\ G \\ B \end{Bmatrix}$$

$$I = \frac{(x+y+z)}{I_m(H,S)}$$

$$H = \tan^{-1}\left[-\frac{\sqrt{z}}{\sqrt{x}}\right]$$

$$S = \cos^{-1}\left[\frac{\sqrt{y}}{\sqrt{x+y+z}}\right] / K_m(H)$$

Where, $I_m(H,S)$ is maximum intensity permitted at a given H and co-latitude and $K_m(H)$ is maximum co-latitude permitted at a given H.

Unlike the standard approach, the Elhers fusion is extended to include more than 3 bands using multiple IHS transforms until the number of bands is fulfilled. A subsequent Fourier transform of the intensity component and the panchromatic image allows an adaptive filter design in the frequency domain. By the use of the fast Fourier transform (FFT) techniques, the spatial components to be enhanced or suppressed can be directly accessed. The intensity spectrum is filtered with a low pass (LP) filter whereas the panchromatic spectrum is filtered with an inverse high pass (HP) filter. After filtering, the images are transformed back into the spatial domain with an inverse FFT and added together to form a fused intensity component with the low-frequency information from the low resolution multispectral image and the high-frequency information from the panchromatic image. This new intensity component and the original hue and saturation components of the multispectral image form a new IHS image. At the last step, an inverse IHS transformation produces a fused RGB image (Ehlers et al., 2008).

Principal components analysis (PCA)

The most common understanding of the principal components analysis (PCA) is that it is a data compression technique used to reduce the dimensionality of the multidimensional datasets or bands (Richards and Jia, 1999). The bands of the PCA data are noncorrelated and are often more interpretable than the source data. The process is easily explained if we consider a two dimensional histogram which forms an ellipse. When the PCA is performed, the axes of the spectral space are rotated, changing the coordinates of each pixel in spectral space. The new axes are parallel to the axes of the ellipse. The length and direction of the widest transect of the ellipse are calculated using a matrix algebra. The transect which corresponds to the major axis of the ellipse, is called the first principal component of the data. The direction of the first principal component is the first eigenvector, and its length is the first eigenvalue. A new axis of the spectral space is defined by this first principal component. The second principal component is the widest transect of the ellipse that is perpendicular to the first principal component. As such, the second PC describes the largest amount of variance in the data that is not already described by the first principal component. In a two-dimensional case, the second principal component corresponds to the minor axis of the ellipse (ERDAS, 1999).

In *n* dimensions, there are *n* principal components and each successive principal component is the widest transect of the ellipse that is orthogonal to the previous components in the *n*-dimensional space. Although there are *n* output bands in a PCA, the first few bands account for a high proportion of the variance in the data. Sometimes, useful information can be gathered from the principal component bands with the least variances and these bands can show subtle details in the image that were obscured by higher contrast in the original image (ERDAS, 1999).

To compute a principal components transformation, a linear transformation is performed on the data, meaning that the coordinates of each pixel in spectral space are recomputed using a linear equation. The result of the transformation is that the axes in *n*-dimensional spectral space are shifted and rotated to be relative to the axes of the ellipse. To perform the linear transformation, the eigenvectors and eigenvalues of the *n* principal components must be derived from the covariance matrix, as shown below:

$$D = \begin{bmatrix} D_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & D_n \end{bmatrix}$$

$$E * Cov * E^T = D$$

Where E, matrix of eigenvectors; Cov, covariance matrix; ^{T}, transposition function; D, diagonal matrix of eigenvalues in which all non-diagonal elements are zeros and D is computed so that its non-zero elements are ordered from greatest to least, so that

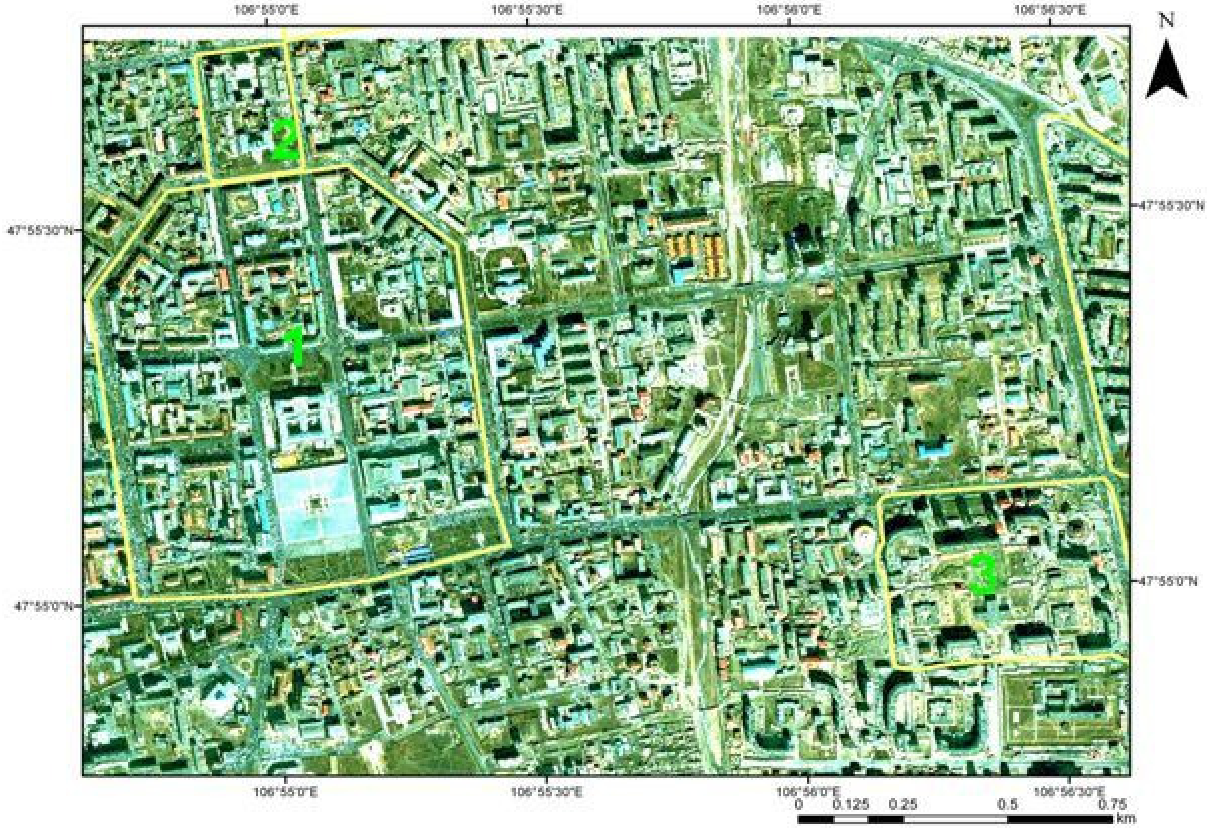

Figure 2. Fused image obtained by the wavelet-based fusion. 1, Baga toirog; 2, Metromall area; 3, microdistrict.

$D_1 > D_2 > D_3 \ldots > D_n$.

Wavelet-based fusion

The wavelet transform decomposes the signal based on elementary functions, which are 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. The wavelet transform can be expressed as follows:

$$WT(f)(a, b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} f(t)\varphi\left(\frac{t-b}{a}\right) dt$$

Where, a, scale parameter; b, translation parameter. Practical implementation of the wavelet transform requires discretisation of its translation and scale parameters. 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 the present study, 'Wavelet Resolution Merge' tool of ERDAS Imagine was used and the algorithm behind this tool uses biorthogonal transforms. Processing steps of the wavelet-based image fusion are as follows:

- Decompose a high resolution panchromatic image into a set of low resolution panchromatic images with wavelet coefficients for each level.
- Replace low resolution panchromatic images with multispectral bands at the same spatial resolution level.
- Perform a reverse wavelet transform to convert the decomposed and replaced panchromatic set back to the original panchromatic resolution level.

In order to obtain good colour images that can illustrate spectral and spatial variations of the building and other classes on the selected optical and SAR images, the results of the fused images have been visually inspected and compared. In the case of the Elhers fusion, the created image looked very similar to the original Quickbird image; 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 analysis. In the case of the PCA, the created image had too much color variation of the classes of objects and was less relevant for the analysis. In the case of the wavelet-based fusion, the fused image demonstrated a better result compared to the images obtained by both Elhers fusion and PCA. 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 an image obtained by the wavelet-based fusion and it illustrates clear views of the objects represented on 3 test areas of our study located in central part of the city. As the selected sites are distributed in different parts of Ulaanbaatar city, the whole fused image could not show clear views of individual objects.

Database development and its update

Generally, urban areas are very complex and they include a variety of different features. However, in many cases land use information can be a determining factor in urban context. As most land use information is related to land plots, use of land and its ownership, a database of this information would mainly consist of large scale maps, though some middle and small scale maps could also be expected. Before the commencement of any physical work, the real world should be modeled and the structure of a database should be defined. As the urban entities are parts of the interrelated real world objects viewed by a specific user community, their modeling within a computer environment should follow two stages, namely conceptual model and physical model (Amarsaikhan, 1997).

Conceptual model

Conceptual modelling describes the conceptual framework for the abstraction, simplification and classification of the phenomena and their relationships as viewed by the user community of the database. At this stage, a logical structure which specifies the logical data content of the database should be defined. For proper conceptual database design one should clearly define different datasets and differentiate all possible entities and their attributes. At this stage, classification and grouping of classes of objects, the reduction of redundancies or duplications have to be thoroughly investigated. The database should consist of two types of datasets, namely, spatial and attribute. For the representation of spatial datasets, a layer based approach can be used as it can easily separate different themes and store them as logically and physically independent datasets. For proper database design and implementation, different issues related to the themes (for example, how many, symbols and annotation, relationships and identifiers) and their attributes (identifiers, relationships) should be considered. For the attribute database design, data flow diagrams, flow charts and unified modelling language might be used and the physical implementation can be carried out using relational and object-oriented structures. Here, the entities must be uniquely identified by their ID numbers and different foreign keys should be defined on the basis of determining the relationships among the entities.

In the case of the present study, as the structure of the database is very simple: only polygon (for example, building and ger areas) and line (for example, roads and rivers) entities can be defined and their related attributes can be logically modeled using a relational structure. Then, all the defined themes and their attributes can be physically implemented using ArcGIS.

Physical model

The physical model transfers the specified logical data to the internal data structure. In our study, as we decided to develop a topologically structured database, for the physical implementation of the urban database, all necessary datasets had to be converted into a digital format using ArcGIS.

For this purpose, a digital topographic map of the study area at a scale of 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 pixels. In order to acquire primary digital data, the building and ger areas were digitized from the 2000 georeferenced topographic map using ArcGIS. Then, for each defined entity, the attributes such as address, year built, use, condition and number of stories were entered and the entities were uniquely identified by their registration number. Additionally, the areal footprint of every building was calculated and stored as a new attribute within the database.

In order to analyse the changes that occurred between 2000 and 2008, it was necessary to update the database created from the topographic map. For this purpose, the image obtained by the wavelet-based fusion was used. For the thorough registration of the GIS and fused satellite datasets, the coordinates of the fused image were transformed to the coordinates of the digitized map using 24 ground GCPs. For the transformation, a second order transformation and nearest-neighbour resampling approach were applied and the related RMS error was 0.93 pixels. 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 and ger areas were screen digitized and updated in the previously created database. After that for all new entities, all attributes were entered according to the methods described for pre-2008 buildings. As an example of the created database, the digitized original and updated buildings and ger area are shown in Figure 3.

Urban land use change analysis

Overall changes in Ulaanbaatar city

At present in Ulaanbaatar city, agricultural land, urban district and settlement areas, roads and infrastructure, forest resource, water area and special protected areas occupy 274478, 33116, 5668.3, 76383, 4143, 76656 ha of the total land, respectively. However, until 1990, agricultural land, urban district and settlement areas, roads and network, forest resource and water area occupied 256164, 19599, 7136, 67267, 4108 ha of the total land, accordingly, and there was no land allocated for special protection. As seen during the market economy, agricultural land, urban district/settlement areas and forest resource have increased by 7.1, 68.9 and 13.6%, respectively. Meanwhile, roads and network have been decreased by 20.6% and there was a very little change in water class. Comparison of these classes before and after 1990 is shown in Figure 4. As could be seen, the most significant change had occurred in urban district and settlement areas. This has been connected with the fact that during the free market economy, many rural families moved, as people prefer to live in settlement areas having good infrastructure.

Among the available land use classes, some of them play major role. Such land use class includes urban district and settlement area. Of these major land use classes, 51% is occupied by the building areas and 22% is occupied by the ger districts. Generally, in Ulaanbaatar city, the land use class that shows the most significant change is the ger area. In the ger districts of the capital city, one could define such land use classes as the houses, ger area, commercial area, central government and public organizations, warehouse area, roads, dams, water area and free area. The total areas related to each class defined from the digitized map as well as the RS

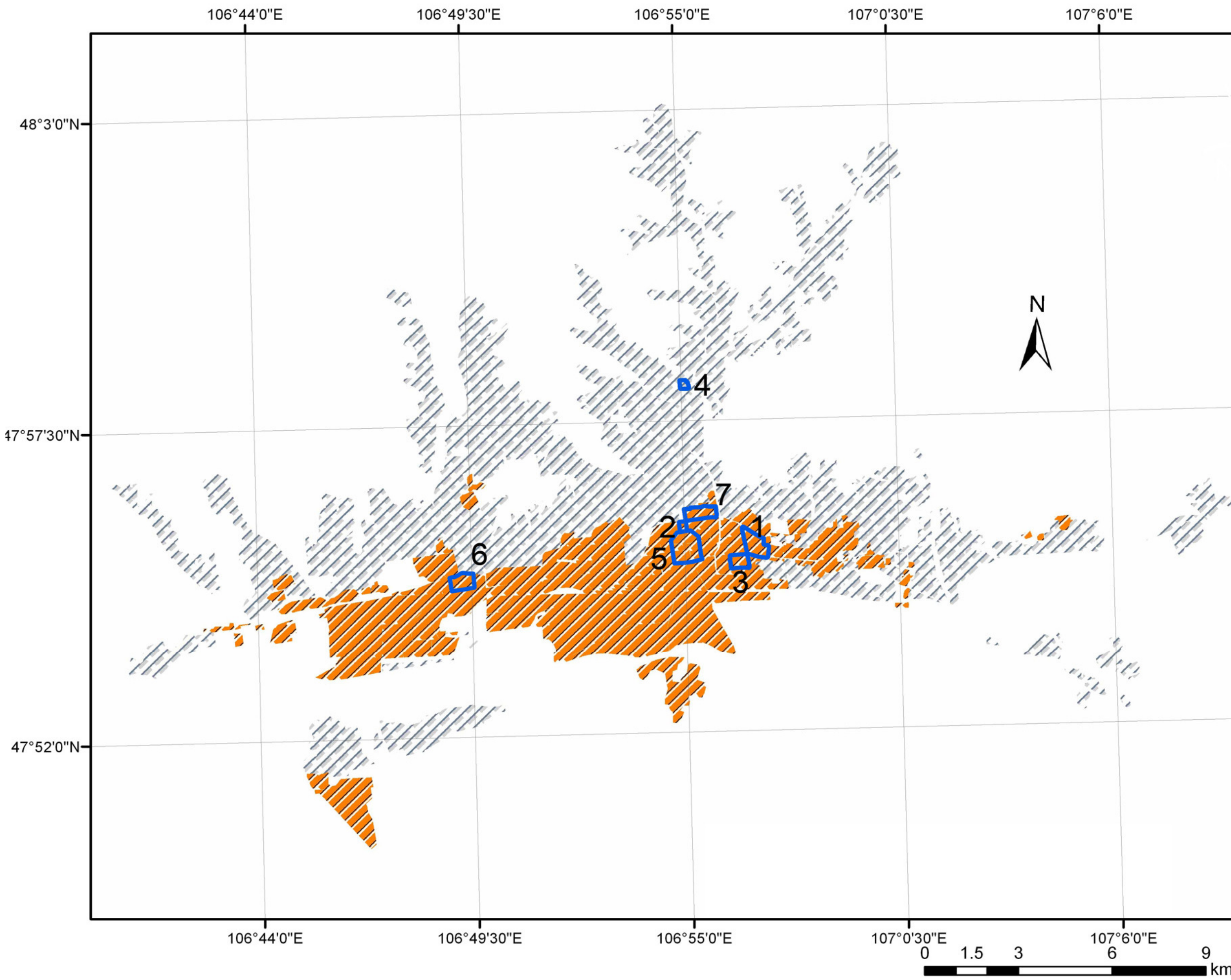

Figure 3. The digitized original and updated buildings and ger areas.

images are shown in Table 1. As seen from Table 1, before 1990 in Ulaanbaatar city, the land for houses, ger districts, commercial area, central government and public organizations, warehouse area, roads, dams, water area and free area occupied 7120, 82729.6, 1772, 3850, 1920, 9520.5, 18000, 23758, 231000.5 m^2, respectively. However, after 1990, theses land use classes have been changed to 5214 m^2, 147862, 21241, 5107, 55667.6, 19508, 16000, 20758, 54520 m^2, respectively. It is seen that the most significant increase occurred in ger districts, commercial and warehouse areas, while some decrease occurred in housing area, dams and water area.

Changes in selected sites of Ulaanbaatar city

In the present study, for a detailed urban study, the sites representing apartment quarters (that is, low, middle and high density) ger district, central business district, light industrial area and mixture of light industrial and residential areas was selected in different parts of Ulaanbaatar city. To analyse the changes occurred before and after 1990, queries have been made using 'Select by attributes' function in ArcGIS. After selecting the entities defined for each area during the selected time interval, the related numbers of buildings, their areas were calculated (Table 2 and Figure 5).

In the low density apartment area, before the year 1990, 52 buildings (59941 m^2 total) were erected; after 1990, 70 buildings (36924 m^2 total) were erected. Although the number of buildings has increased, the total area occupied by these buildings has not increased. Likewise, in the middle density apartment area, the building area has not been drastically increased, despite the addition of 18 new buildings. The high density apartment area repeats this pattern; 16 buildings with an area of 20510 m^2 before 1990 were replaced by 46 buildings occupying only 14601 m^2 following market economy growth after 1990. The main reason for this was the fact that before 1990, the Mongolian Government built primarily large building blocks occupying large areas. However, since the country entered the market

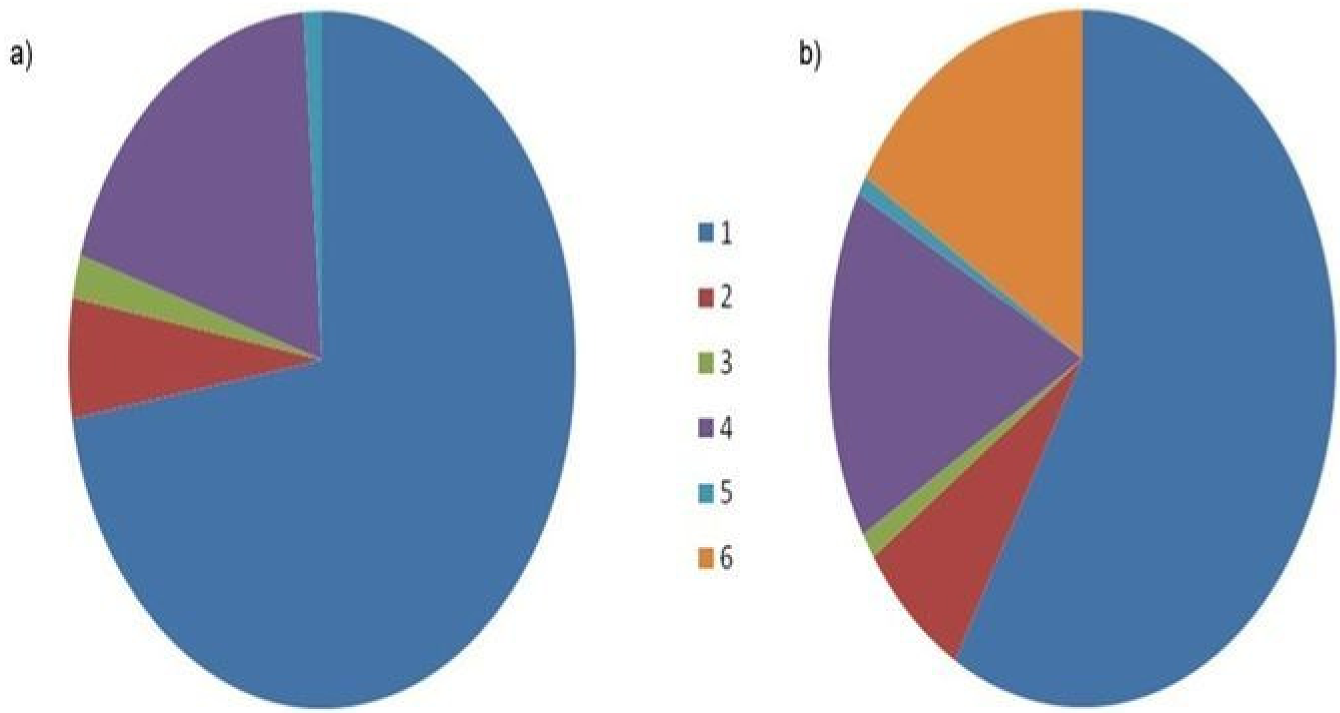

Figure 4. Comparison of land use classes of Ulaanbaatar city: a, before 1990; b, after 1990; 1, agricultural land; 2, urban district and settlement areas; 3, roads and network; 4, forest resource; 5, water area; 6, special protected area.

Table 1. Land use changes occurred in ger districts of Ulaanbaatar city before and after 1990.

S/N	Land use class	Before 1990 (m^2)	After 1990 (m^2)	Changes (m^2)
1	Houses	7120	5214	- 1906
2	Ger districts	82729.6	147862	+ 65132.4
3	Commercial areas	1772	21241	+ 19468
4	Central government and public organizations	3850	5107	+1257
5	Warehouse areas	1920	55667.6	+ 53747.6
6	Roads	9520.5	19508	- 9988.5
7	Dams	18000	16000	- 2000
8	Water	23758	20758	- 3000
9	Free area	231000.5	54520	176480.5
	Overall area	380885.6	380885.6	-

Table 2. Total number of buildings and the areas they occupy in selected areas of Ulaanbaatar city before and after 1990.

S/N	Land use class	Location	Number of buildings		Total area of buildings (m^2)	
			Before 1990	After 1990	Before 1990	After 1990
1	Low density apartment area (<5 stories)	15-microdistrict	52	70	59941	36924
2	Middle density apartment area (5-10 stories)	Metromall area	1	18	2873	14408
3	High density apartment area (>10 stories)	13-microdistrict	16	46	20510	14601
4	Ger district	7 Buudal area	-	63	-	4932
5	Central business district	Baga toirog	109	114	145523	60640
6	Light industrial area	Suljmel area	45	35	50897	15607
7	Mixture of light industrial and residential areas	100 ail	50	92	42748	35337

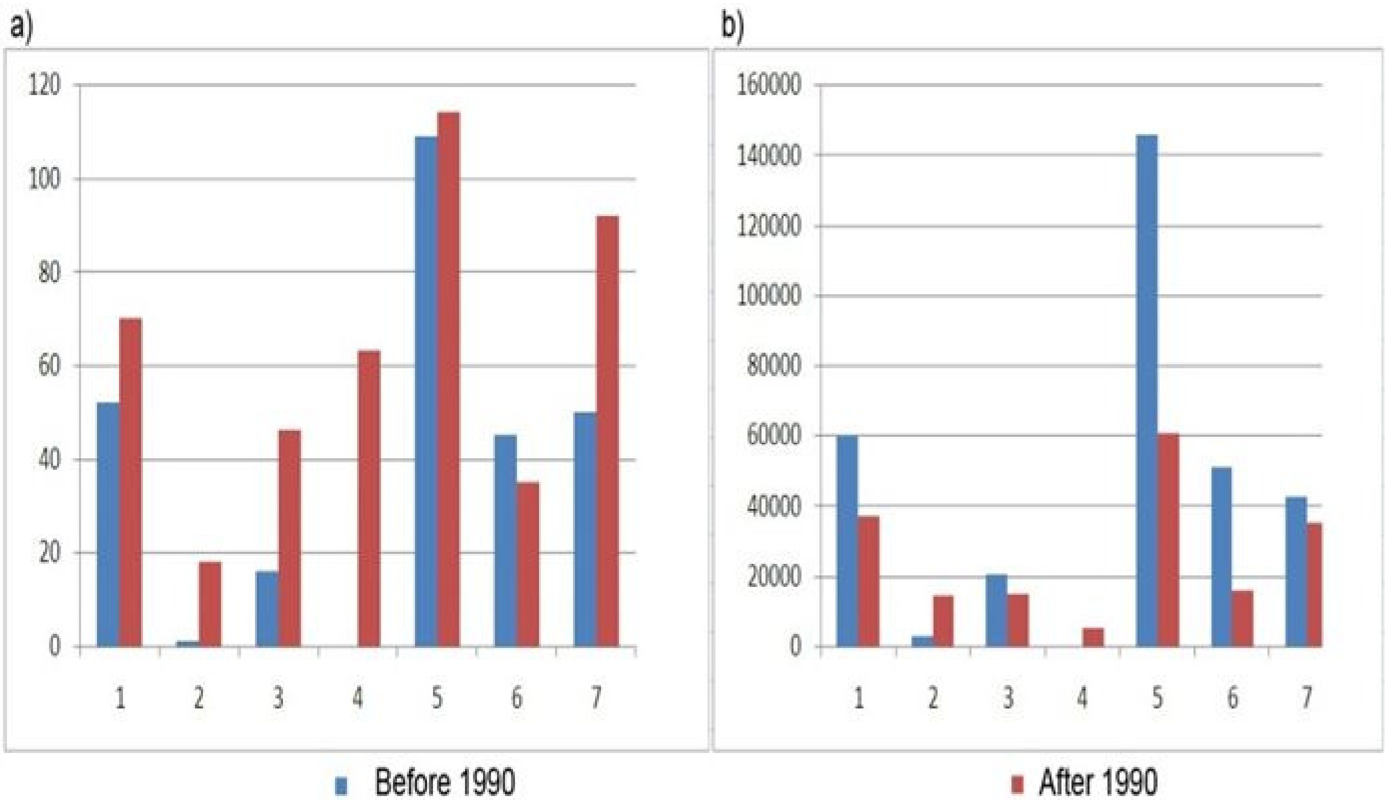

Figure 5. Comparisons of number of buildings and their occupying areas in selected areas of Ulaanbaatar city before (a) and after 1990 (b); 1, low density apartment area; 2, middle density apartment area; 3, high density apartment area; 4, ger district; 5, central business district; 6, light industrial area; 7, mixture of light industrial and residential areas.

economy in 1990, private companies and individuals began to replace these large building blocks with independent businesses and houses, typically occupying smaller areas.

Furthermore, during the market economy period in the 7 Buudal area of the capital city, 63 ger families emerged, occupying 4932 m^2. This case could be considered a typical example of urban expansion by ger districts in urban fringe areas. In the central business district of Ulaanabaatar, there existed 109 buildings occupying 145523 m^2 before 1990, while during the market economy there were 46 buildings occupying only 14601 m^2. Likewise, after 1990 in the light industrial area and mixture of light industrial and residential areas, there emerged many buildings occupying small areas. This was due to the fact that during the centralized economy, the Government owned everything and it built mainly large size buildings in order to produce something for the whole country's need. Since Mongolia entered the market economy in 1990, everything has been privatized. As a result many private entities were emerged and mainly built up middle and small size buildings and houses, occupying small areas. The increase in building density after 1990 is apparent in all of the study sites (Figure 6), which may indicate that planning and management in Ulaanbaatar city may need reconsideration.

CONCLUSIONS

The goal of this study was to analyze the urban land use changes of Ulaanbaatar city using very high resolution optical and SAR images and some GIS datasets. In the study, the changes that occurred in Ulaanbaatar before 1990 were compared with the changes that occurred after 1990 and the socio-economic reasons for the changes were described. This study shows that, during the centralized economy, the government built mainly large building blocks occupying large areas, while since the country entered the market economy, private companies and individual started to replace the existing building blocks with independent businesses and houses, occupying smaller areas. Thus, the study demonstrated that during the market economy, Ulaanbaatar city was urbanized very rapidly and finally, planning and management of Ulaanbaatar city should be reconsidered.

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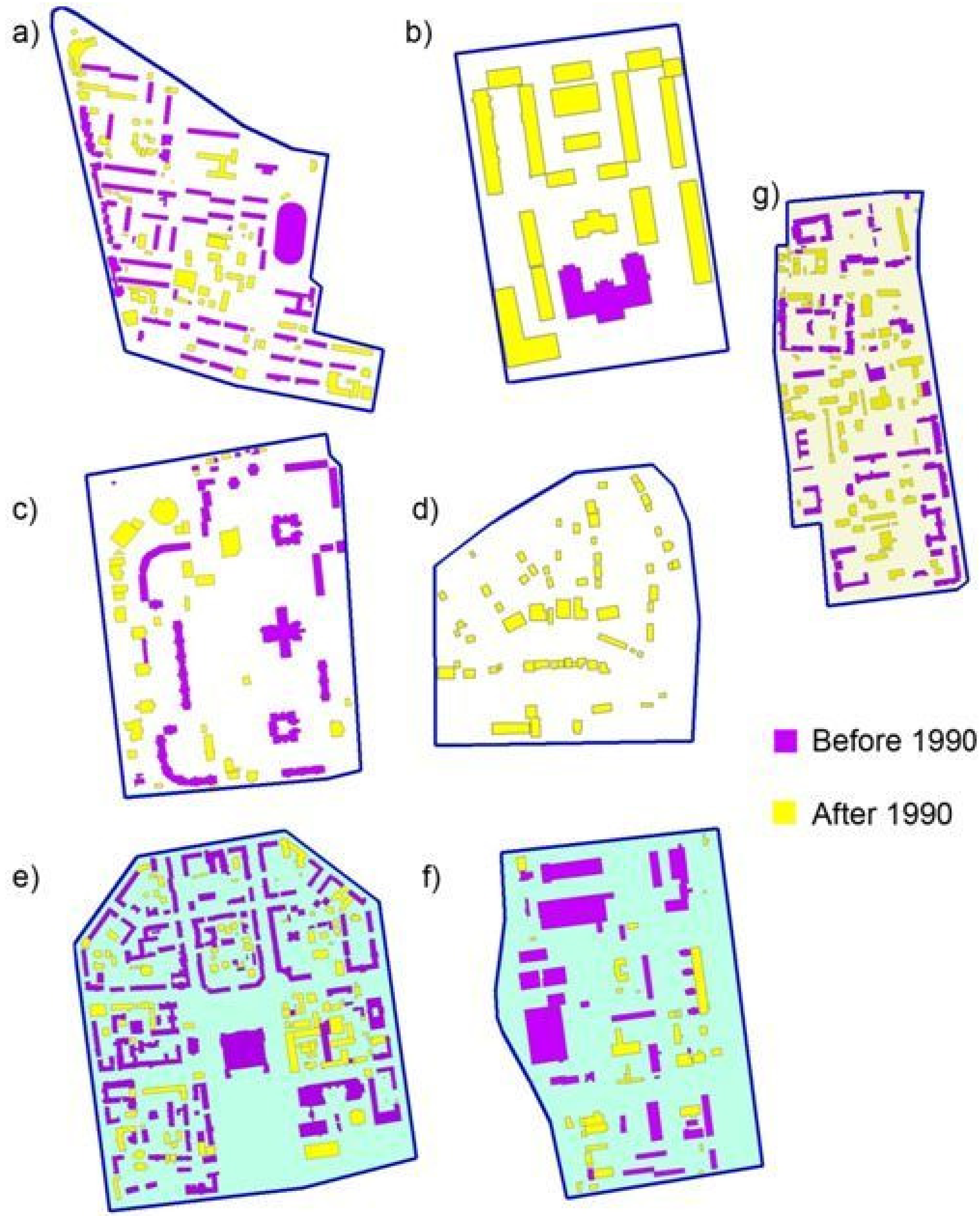

Figure 6. The sites selected for a detailed urban study: a, low density apartment area; b, middle density apartment area; c, high density apartment area; d, ger district; e, central business district; f, light industrial area; g, mixture of light industrial and residential areas.

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REFERENCES

Abidi MA, Gonzalez RC (1992). Data Fusion in Robotics and Machine Intelligence (New York: Academic Press).

Altvater E (1993). The future of the market: An essay on the regulation of money and nature after the collapse of actually existing socialism, Verso, pp. 57.

Amarsaikhan D (1997). Update of a GIS by RS data using a knowledge-based approach. PhD Thesis, Mongolian Academy of Sciences, Ulaanbaatar, Mongolia, pp.150.

Amarsaikhan D, Ganzorig M, Moon TH (2005). Application of multitemporal RS and GIS data for urban change studies. Proceedings of the Korean GIS Conference, Busan, Korea, 190-215 (in English).

Amarsaikhan D, Douglas T (2004). Data fusion and multisource data classification. Int. J. Remote Sens., 17(25): 3529-3539.

Amarsaikhan D, Ganzorig M, Ache P, Blotevogel H (2007). The Integrated Use of Optical and InSAR Data for Urban Land Cover Mapping. Int. J. Remote Sens., 28: 1161-1171.

Amarsaikhan D, Blotevogel H, Ganzorig M, Moon TH (2009a). Applications of remote sensing and geographic information systems for urban land-cover changes studies, Geocarto Int. 24(4): 257–271.

Amarsaikhan D, Ganzorig M, Blotevogel H, Nergui B, Gantuya R (2009b). Integrated method to extract information from high and very high resolution RS images for urban planning, J. Geogr. Reg. Plann., 2(10): 258-267.

Chinbat B, Bayantur M, Amarsaikhan D (2005). Investigation of the internal structure changes of Ulaanbaatar city using RS and GIS, CD-ROM Proceedings of the ISPRS Mid-term Symposium 2006, ITC, The Netherlnads, 4: 1-6.

Ehlers M (2004). Spectral characteristics preserving image fusion based on Fourier domain filtering. In: Remote Sensing for Environmental Monitoring, GIS Applications, and Geology IV, Proceedings of SPIE, pp. 93–116.

Ehlers M, Klonus S, Åstrand PJ (2008). Quality Assessment for Multi-sensor Multi-date Image Fusion, CD-ROM Proceedings of ISPRS Congresses, 3- 11 July 2008, Beijing, China.

Ehlers M, Klonus K, Rosso P (2010). Multi-sensor image fusion for pan sharpening in remote sensing, Int. J. Image and Data Fusion, 1(1): 25-45.

ERDAS (1999). Field Guide, 5th edn (Atlanta, Georgia: ERDAS, Inc.).

Pajares G, Cruz JM (2004). A wavelet-based image fusion, Pattern Recognition, Volume 37, Issue 9, September 2004, pp. 1855-1872.

Pellemans AH, Jordans RW, Allewijn R (1993). Merging Multispectral and Panchromatic Spot Images with Respect to the Radiometric Properties of the Sensor. Photogrammet. Eng. Remote Sens., 59: 81-87.

Ricchetti E (2001). Visible-infrared and radar imagery fusion for geological application: a new approach using DEM and sun-illumination model. Int. J. Remote Sens., 22: 2219–2230.

Richards JA, Xia S (1999). Remote Sensing Digital Image Analysis—An Introduction, 3rd edn (Berlin: Springer-Verlag).

Pohl C, Van Genderen JL (1998). Multisensor image fusion in remote sensing: concepts, methods and applications. Int. J. Remote Sens., 19: 823-854.

Serkan M, Musaoglu N, Kirkici H, Ormeci C (2008). Edge and fine detail preservation in SAR images through speckle reduction with an adaptive mean filter, Int. J. Remote Sens., 29(23): 6727-6738, First published 2008.

Ulaby FT, Kouyate F, Brisco B, Williams THL (1986). Textural information in SAR images. IEEE Transactions on Geoscience and Remote Sensing, 24: 235–245.

Zhang J (2010). Multi-source remote sensing data fusion: status and trends. Int. J. Image Data Fusion, 1(1): 5 – 24, March 2010.