Monitoring the development of informal settlements in Ulaanbaatar, Mongolia

Gankhuyag RADNAABAZAR & Monika KUFFER & Paul HOFSTEE

International Institute for Geo-Information Science and Earth Observation, Department of Urban and Regional Planning and Geo-information Management, P.O. Box 6, 7500AA Enschede, The Netherlands

ABSTRACT

Ulaanbaatar, the capital of Mongolia, as many cities in the developing countries, encounters increasing problems with urban expansion and in particular with the growth of unplanned (informal) settlements. Planning of urban and sub-urban development requires timely and accurate information on existing land use and land cover to analyse the existing situation and support policy making. Besides, it also requires a basic understanding of trends in land use changes.

This study tries to supply information about the urban development of Ulaanbaatar with the focus on the development of the 'Ger' areas, the traditional Mongolian dwelling that has evolved with nomadic life. These areas are nowadays rapidly growing in the outskirts of Ulaanbaatar, as predominantly unplanned settlements. These relatively low-density settlements are consuming an increasing share of land and raise the question of sufficient and efficient infrastructure supply. For this purpose different remote sensing data were analysed about the potential to supply information on the development of the informal settlements from 1986 to 2000. To perform the change detection for the urban area a SPOT XS image of 1986, a SPOT Pan image of 1989, a LANDSAT image of 1990, and an ASTER image of 2000 were used. As ground truth information a topographic map scale 1:5,000 and aerial photos scale 1:10,000 were used.

Generally urban growth between 1986 and 2000 occurred north and northwest of the city centre, mainly in mountainous and consequently quite steep areas, which are frequently non-suitable locations for urban expansion. The majority of this expansion happens in the form of growth of the traditional Ger areas.

1 INTRODUCTION

Mongolia, as many other developing countries, has an increasing problem with urban expansion and the growth of informal settlements in the capital city Ulaanbaatar, located in north-central Mongolia. The highest point of Ulaanbaatar is the Tsetsegun peak, having an altitude of 2257 metres above sea level. Figure 1 shows the localisation of the whole city area, which includes 3 rural sub districts (B, C and D). A is the capital city, which is the most urbanised city of Mongolia (see figure 1).

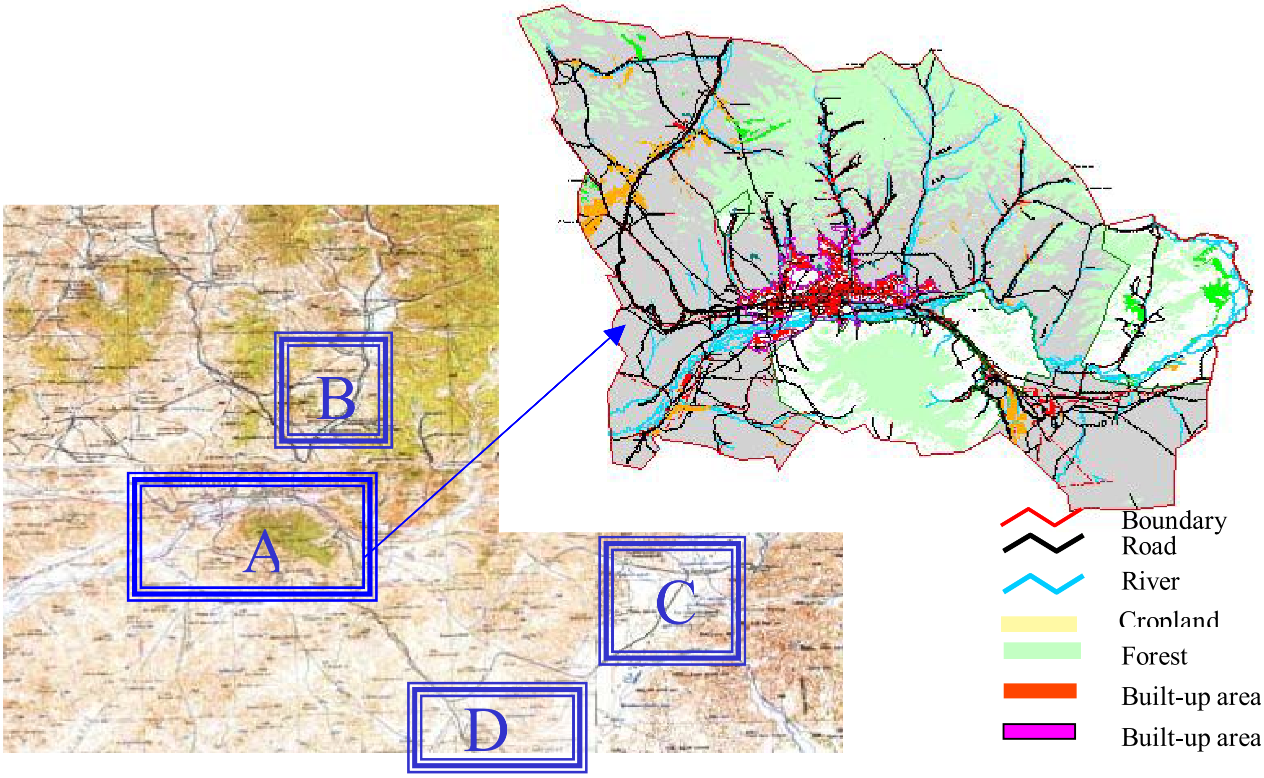

Figure 1: The land use map of Ulaanbaatar city, 1998 (scale approximately 1:300 000): city area, which includes 3 rural sub districts (B, C and D) and the capital city (A).

One reason for this rapid urbanization and growth of informal settlements is the political transformation from a centralized economy to a market oriented economy starting in 1990. Since this year the city has significantly expanded due to different development activities accompanied by the migration of people from rural areas into Ulaanbaatar. The obviously attractive city life, as opposed to the rather traditional rural life with its rigid social structure, has provoked the massive influx of people to the capital city, causing the growth of new informal residential areas in the city. These unplanned settlements are dominated by traditional Mongolian dwellings, the Gers. The Gers have evolved with the nomadic life generating the need for a portable dwelling. The history of the Mongolian Ger goes back to about 2500-3000 B.C. and still is used as a dwelling type everywhere in Mongolia. The walls of a Ger are made of narrow birch willows held together by leather strips. The entire outside surface of the Ger is covered with felt. One layer is sufficient in the summer season, two or three layers are required in winter. The assembling and taking down of any Ger is done within half an hour (Amarsaikhan, 2000). Examples of Gers are shown in figure 2.

a) Continuous Ger area | b Gers surrounded by formal residential. area | c) Ger area in an aerial photo

Figure 2: Examples of Gers

These rapid urban expansion and consolidation processes are hardly reflected by regular maps. Thus, this rapid process of urbanisation apparently would require a state-of-the-art technology that allows the city to be monitored, in order to generate reliable information in a more timely fashion. Important questions in this context are: Where are these changes taking place and which remote sensing data can assist to monitor those changes?

Ulaanbaatar's official (registered) population are in 2002 approximately 812,000. An additional 150,000 unregistered persons are estimated to live in the city. This is a 48% increase since 1989 (Bat, 2002). Based on these numbers, Ulaanbaatar had an average annual growth of slightly more than 3.6% since 1989. An estimated (and growing) 45-50% of Ulaanbaatar's inhabitants now dwell in Ger areas, which are predominantly poor. This is obviously an increasing social, economic, environmental and political concern to the government and residents alike.

2 METHODOLOGY

Forster (1985) stressed the usefulness of remote sensing approaches to urban studies because it can assist in regular and rapid updating of land use data, and is spatially more relevant for reporting urban development than census-type statistical data. In this context this study will focus on the following general tasks:

- Identification of urban objects and areas in different types of remote sensing images.
- Analysis of different images to provide up-to-date information for monitoring the urban development of Ulaanbaatar.

In a first stage the remote sensing data listed below were used for this study to analyse the potential of remote sensing data with different spatial resolutions to identify and extract urban objects of Ulaanbaatar city, with a focus on the identification of unplanned areas. For this purpose standard image processing methods and procedures including geo-coding and image enhancement techniques have been applied to the aerial photo, the SPOT XS, the SPOT Pan, ASTER and Landsat TM. For the visual interpretation the classic parameters of image interpretation have been used: shape, size, pattern, tone, texture, shadow, site and association (Lillesand and Kiefer, 1994).

Sensor	Resolution / Scale	Date	Remarks
Spot XS	20 m	01/05/1986	
Spot Pan	10 m	10/21/1989	
Landsat TM	30 m	09/10/1990	
Terra - ASTER	15 m	06/09/2000	
Aerial photo	1 : 10 000	26/07/1998	Covers the central part of the urban area
Topographic map	1 : 5 000	1999	

Table 1: Data Sources

Based on the high resolution aerial photos and the topographic map a set of relevant urban objects was selected and these objects have been identified in a next step in the different satellite images. The capabilities of different spatial and spectral resolution remote sensing data for detecting different classes of urban objects were then compared. This knowledge was later used for performing a change detection for urban growth patterns between 1986 and 2000 for the urbanised part of Ulaanbaatar. The method used for the change detection is a visual interpretation of the individual satellite images of the different years and finally comparing them in order to detect changes.

3 RESULT AND DISCUSSION

3.1 Identification and classification of urban objects in the study area

To evaluate the capability of the different remote sensing data to identify urban objects and types of urban structure, five classes were defined based on the topographic map scale 1:5 000 of 1999. These classes were considered as the most relevant surfaces for analysing the changes in the selected target area of Ulaanbaatar city.

Class 1 is **residential** discontinuous urban structure, where buildings have more than **5 floors**.

Class 2 is **residential** discontinuous urban structure, where buildings have **2 - 5 floors**.

Class 3 is **residential individual** urban structure composed of **1 floor** buildings.

Class 4 is residential continuous urban structure dominated by traditional residential **Gers** and some wooden buildings.

Class 5 is continuous **open sp**ace of grass fields, vegetation and bare soil.

First, for a comparison submaps for representative areas of the five classes were created from the different geo-coded remote sensing data (aerial photo, SPOT panchromatic, SPOT XS, ASTER and Landsat images) and topographic map (see figure 3).

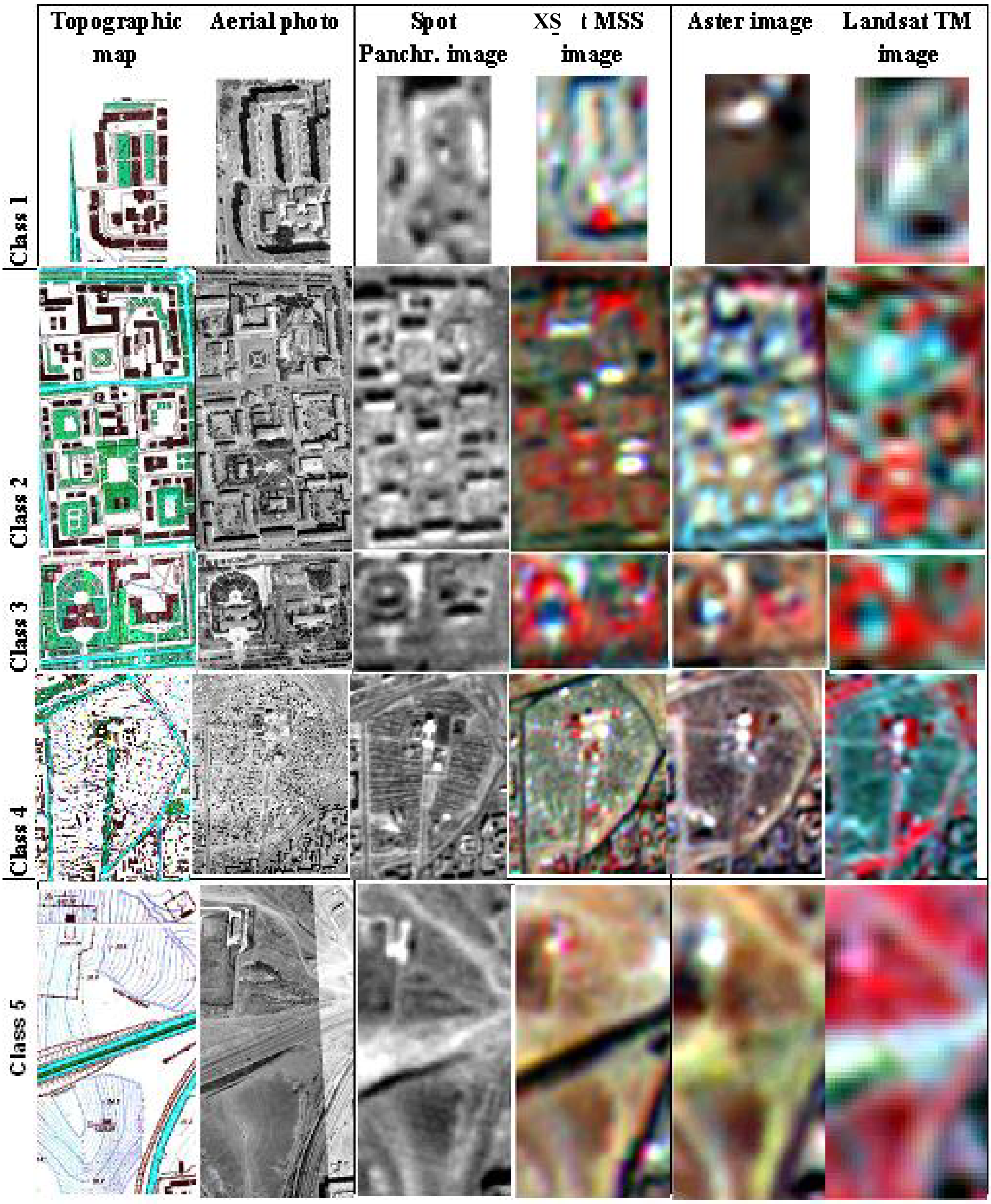

Figure 3: Comparisons of images in the different resolutions

After comparing the result of the interpretations a summary of the observations for the different image data has been made (see table 2).

Class	Topographic map	Aerial photo	SPOT Panchromatic	SPOT XS	ASTER	Landsat TM
Class 1	All relevant objects are visible.	Compared to the topographic map detailed objects can be identified and it is easy to analyse the situation	Only location and shape of buildings can be identified, their exact boundary cannot be defined	No clear information	Only location and shape of buildings can be approximated, their exact boundary cannot be defined. Small trees are highly reflecting and can be identified.	Some parts of buildings are reflected as well as small green vegetation areas.
Class 2	All urban objects are mapped.	Compared to the topographic map detailed objects can be identified and it is easy to analyse the situation.	Only location and shape of large buildings can be identified, their exact boundary cannot be defined. The information given by the shadow improves identifying buildings.	Some green area and large buildings can be approximately identified but the exact boundary cannot defined.	Only the location of the green areas can be approximately identified and the exact boundary cannot be defined. Some buildings having a strong reflection and can be identified.	Some green areas and buildings can be approximately identified but the exact boundary cannot be defined.
Class 3	All urban objects are mapped.	Compared to the topographic map detailed objects can be identified and it is easy to understand the situation	Only location and shape of buildings can be identified, their exact boundary cannot be defined. The information given by the shadow improves identification of buildings.	Some green area and buildings can be approximately identified but the exact boundary cannot defined.	Only the location of the green areas can be approximately identified and the exact boundary cannot defined. Some buildings have a strong reflection and can be identified.	Some green areas and buildings can be approximately identified but the exact boundary cannot defined.
Class 4	Basic data for interpretation, but there are no individual Gers and houses displayed in the streets.	Very clear to identify urban objects, including individual Gers and wooden buildings. It could be used to update the topographic map scale 1:5 000, especially urban objects that are located inside fences.	Possible to identify the boundary of Ger areas and the street line between 2 Ger areas can be identified.	Less ability than the ASTER image to identify the boundary of the Ger area (boundary of the Ger area is the road network).	Boundaries of Ger areas are less identifiable than in the SPOT Pan image.	Less ability than SPOT XS and ASTER to identify the boundary of the Ger area (boundary of the Ger area is the road network).
Class 5	All urban objects are mapped.	Compared to the topographic map detailed objects can be identified and it is easy to understand the situation	Possible to identify roads and shadows of the steep hills. Possible to identify buildings, located within the area.	Less potential than the ASTER image to identify roads and the shadows of the steep hills.	Possible to identify shadows of the steep hills. Possible to identify the buildings, which is located within the area.	Less potential than the other data to identify objects.

Table 2: Detailed interpretation of images with different spatial resolutions

Following conclusions can been drawn based on figure 3 and table 2 regarding the identification of urban objects in the study area:

- The potential of the different remote sensing data identifying urban objects in the study area varies.
- Aerial photos are a very useful data source, not only for identifying urban objects, at the same time they can help to update the existing topographic maps.
- Based on the SPOT XS, SPOT Pan, ASTER and Landsat TM images it was not possible to identify exactly the shape, size and calculate the area of individual buildings or urban objects. But it was possible to identify approximately their locations in the images.
- The boundaries of areas in the city (blocks of buildings) can be identified using SPOT XS, SPOT Panchromatic, ASTER images.

Comparisons of the potential of the different remote sensing data in the case of Ulaanbaatar:

Aerial photo In the aerial photo urban objects can be clearly identified, including small parcel units (individual Gers and wooding buildings). It could be used to update the topographic map.

SPOT Pan It has a better ability to identify urban objects than the other satellite images, but not on the same level of high accuracy as the aerial photo. Further, it has a good ability to define boundaries of sections or blocks of built-up areas of different types/classes.

ASTER For this study it showed a better effectiveness than SPOT XS and Landsat TM images in identifying urban objects, but it does not offer the same capability as the SPOT Pan image to define boundaries of sections or blocks of built-up areas of different types/classes.

SPOT XS It has the capability to identify approximately urban objects and defining boundaries.

Landsat TM It has less capability for the identification of urban objects than the other satellite images. Only main landcover classes could be identified.

3.2 Change detection analysis

For the change detection of the urbanised part of Ulaanbaatar only changes in terms of sections or building blocks were analysed (not changes of individual buildings). The change detection was based on the SPOT XS image (pixel size 20 m) of 1986, the SPOT Pan image (pixel size 10 m) of 1989 and the ASTER image (pixel size 15 m) of 2000.

The Ulaanbaatar city area is 470,444 ha. The urbanised or built-up area is only 5 percent (approximately 23,700 ha) of the total city area (Land Administration Authority, 2002). First, a target area was selected containing the built-up area in the central part of Ulaanbaatar city, which covers approximately 23 km x 14 km or an area of 32,200 ha, sub maps were made for the SPOT XS image of 1986, SPOT Pan of 1989 and ASTER of 2000.

For the visual interpretation of the urban core area 7 classes of urban structures were defined, based on the results of the urban object classification. These were determined as the most important built-up surfaces in the selected target area of Ulaanbaatar city.

Class 1:**Central business district** (CBD) hosting most of the governmental organisations, including the parliament and the central government and other important offices.

Class 2: **Commercial areas** (commercial buildings, which are located isolated apart from the CBD).

Class 3: **Industrial areas**.

Class 4: **Medical centre** (buildings being part of a medical complex, which could be distinguished as a separated block from other classes).

Class 5: **Military complexes**.

Class 6: **Recreational areas** (green areas, parks and a lake).

Class 7: **Formal Residential** areas.

Class 8: Residential **Ger** area.

Subsequent to the visual interpretation the summary of changes (table 3) measures the spatial variation of the classes between 1986 and 1989 and from 1989 to 2000. The table provides a class-by-class report of changes by area and percentages. Table 3 and table 4 provide details of the urban area changes during the study time (14 year) classified and digitised by the visual interpretation. For each case the change in area and change in percentages of the individual classes is presented in the tables for the respective period.

	Year / Area					
	1986		1989		2000	
	ha	%	ha	%	ha	%
Central business district	66	1.0	66	0.9	66	0.8
Commerical	195	3.1	218	3.1	218	2.7
Industrial	1785	28.0	1833	26.0	1833	22.9
Medical center	44	0.7	49	0.7	49	0.6
Miliary complec	274	4.3	278	3.9	19	0.2
Recreational	68	1.1	68	1.0	68	0.9
Formal residential	1666	26.2	1767	25.0	2077	26.0
Residential ger area	2269	35.6	2784	39.4	3668	45.9
Total	6367	100.0	7063	100.0	7998	100.0

Table 3: The urban area in 1986, 1989 and 2000 by classes in the target area

Generally urban growth occurred between 1986 and 2000 north and northwest of the city centre. The majority of the growth took place in mountainous areas with relatively steep slopes. The development of the city is restricted by the Tuul river, as well as by four highly elevated mountain valleys. The river valley, between the Tuul river and the railway line is a protected area by law and thus land use activities are not permitted. This protected area is a clean water zone, which includes a water transportation point transporting underground water to the whole city. Therefore the majority of the relatively flat land is either already developed or protected. Consequently, the urban growth has expanded in less suitable areas for urban development, even though it is more expensive to build in the mountainous areas and they are not well served by public infrastructure.

Focusing on the urban area an absolute and relative increase can be observed (see table 3). In 1986, approximately 6,372 ha of total urban area were identified in the target area by visual interpretation. From 1986 to 1989, the amount of land classified as urban area grew by 696 ha (being an increase of 11 percent) and from 1989 to 2000, the amount of land classified as urban grew by 935 ha. In total from 1986 to 2000, the amount of land classified as urban grew by 1631 ha (table 4 and figure 4).

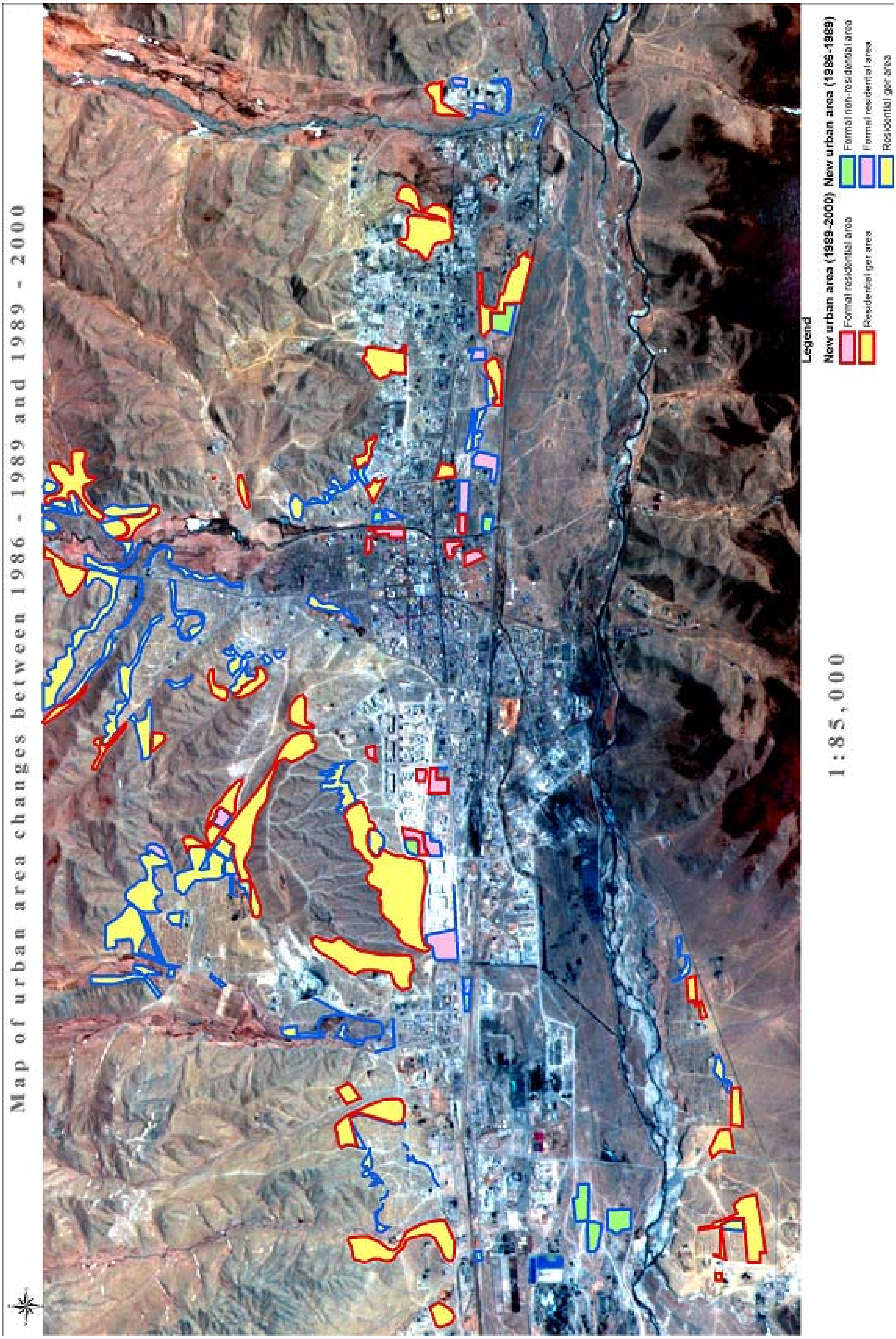

Figure 4: Urban area changes between 1986-1989 and1989- 2000 in the target area

	Differences		
	From 1986 to 1989	from 1989 to 2000	from 1986 to 2000
	ha	ha	ha
Central business district	0	0	0
Commerical	23	0	23
Industrial	48	0	48
Medical center	5	0	5
Miliary complec	4	-259	-255
Recreational	0	0	0
Formal residential	101	310	411
Residential ger area	515	884	1399
Total	696	935	1631

Table 4 Urban area changes from 1986 to 2000 in the target area, Ulaanbaatar city

When analysing the rate of urban area growth and changes in the target area by classes the following conclusions can be drawn:

- All urban areas classified in table 4 have increased or have remained constant (with the only exception of the military complex).
- During the study period, most classes had an increase in area, but the informal residential Ger area had the most significant increase of 1399 ha since 1986 compared to other classes.
- For the classes CBD, commercial centre and recreational area no recognisable spatial change has could be observed during the study period.
- The military complex decreased from 1986 to 2000, by an area of 255 ha. This area was converted into a residential district.
- The relative change in urban land indicates that substantial urban growth is occurring in the rural areas.

4 CONCLUSIONS

This study indicates that remote sensing techniques have a potential to analyse urban expansion for the case of Ulaanbaatar. However, urban objects of more complex patterns are not easily identified by the satellite images used in this study. This would require higher spatial resolution remote sensing data, such as Ikonos or QuickBird. The following conclusions can be drawn:

- It was not possible to identify exactly shape, size and calculate the area of individual buildings or urban objects from the SPOT XS, SPOT Panchromatic, ASTER and Landsat TM images. But it was possible to identify approximately their locations in the images.
- The boundaries of areas of the city (building blocks) can be identified using SPOT XS, SPOT Pan and ASTER.
- Urban land in the study area increased continuously from 1986 to 1989 and from 1989 to 2000. The growth rate during the study period (14 years) was 26 percent (about 1631 ha).
- The majority of the growth has happened in the residential Ger area, which increased by 1399 ha since 1986. Today the residential Ger areas occupy about half of the built-up area in the city.
- No notable change occurred in the CBD, the commercial centre and recreational areas during the study time.
- Other residential buildings, including high-rise buildings are slowly increasing.
- Generally urban growth occurred between 1986 and 2000 north and northwest of the city centre,which are predominantly mountainous areas of relatively steep slopes, being less suitable for urban development, even though it is more expensive to build in this mountainous areas. As most of the relatively flat land is already built-up or developed, the expansion of the city there is very limited.

5 REFERENCES

Amarsaikhan, D., Ganzorig, M. & M. Saandar: Urban Change Study Using Remote Sensing and GIS, ACRS , 2000.
Bat, C.: Urban Poverty Profile in Ulaanbaatar, Economy and Strategy policy Department, Office of the Mayor, 2002 http://infocity.org/F2F/poverty/papers2/UB(Mongolia) Poverty.pdf. (accessed 24/11/2003).
Beek, K.J. & Juppenlatz, M: ITC and UN Habitat objectives. ITC Journal 1987-3, pp 197-201.
Davis, E.W et al: Environmental Analysis Using Integrated GIS and Remotely Sensed Data: Some Research Needs and Priorities, Photogrammetric and Remote Sensing, Vol. 63, No. 10, pp. 1211-1217, 1991.
Forster, B.C.: An Examination of Some Problems and Solutions in Monitoring Urban Areas from Satellite Platforms, International Journal of Remote Sensing, Vol. 6, No. 1, pp. 139-151, 1985.
Green, K., Kempka, D. & L. Lackey: Using Remote Sensing to Detect and Monitor Land-Cover and Land-Use Change, Photogrammetric Engineering and Remote Sensing, Vol. 60, No. 3, pp. 331-337, 1994.
Jensen, J.R.: Introductory Image Processing: A Remote Sensing Perspective, Second Edition, Prentice-Hall, Upper Saddle River, NJ, 1990.
Jensen, J.R., Cowen, D., Narumanali, S. & J. Halls: Principles of Change Detection Using Remote Sensor Data, In Integration of Geographic Information Systems and Remote sensing, Star, J.L., Estes, J.E. and McGwire, K.C. (eds), Ch. 3, Cambridge University Press, Cambridge, UK, pp. 37-54, 1997.
Land Administration Authority: Unified Land Report. Ulaanbaatar, 2002.
Lillesand, T.M. and Kiefer, R.W.: Remote Sensing and Image Interpretation, Wiley and Sons, New York, NY, 1994.
Radnaabazar, G.: Urban Objects and Change with Remote Sensing in Ulaanbaatar, Mongolia. Unpublished IFA, ITC. Enschede, 2003.
Ridd, M.K. & Liu, J.: A Comparison of Four Algorithms for Change Detection in an Urban Environment, Remote Sensing of Environment, Vol. 63, pp. 95-100., 1998.
Singh, A.: Digital Change detection Techniques Using Remotely Sensed Data, International Journal of Remote Sensing, Vol. 10, No. 6, pp. 989-1003, 1989.