Mapping the Expansion of Urban ‘ger districts’ in Ulaanbaatar with Landsat Data

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Abstract

Urban growth is a worldwide phenomenon that is particularly visible in developing nations as part of a thrust into modernity. Mongolia’s capital Ulaanbaatar is home to many people who have recently emigrated from rural areas in a search of the security, opportunity and connectivity that cities can provide. In many cases these new arrivals live in informally established neighbourhoods on the city fringe and often endure a low standard of wellbeing in an attempt to enter the global economy. Ulaanbaatar has many such neighbourhoods, where they are known as ger districts. Their rapid growth and change makes it difficult to adequately plan for public infrastructure and services. Remotely sensed data can monitor and map geospatial changes over time and project future change at a relatively low cost. This paper uses Landsat TM satellite images from 1989 and 2011 to map ger districts as distinct low-density urban hotspots in contrast with high-density constructed urban areas in Mongolia’s capital city. This was achieved via a supervised maximum likelihood pixel classification that was validated by a confusion matrix for each image with accuracies of 94.7% and 96.9%. The ger districts were found to have increased by 154% over the time period, growing to cover an additional area of 149km². The application of this data is of critical importance to urban planning, which thus far has been relatively uncoordinated in Ulaanbaatar’s ger districts.

Key words: urbanisation, remote sensing, humanitarian aid, urban planning, mongolia.

1. Introduction

1.1 Background

All Mongolian citizens are permitted to freely claim a portion of land as their own on previously undesignated property in Ulaanbaatar (Fernandez-Gimenez & Khishigbayar, 2002). This law, among other factors such as environmental stress and agricultural downturn, has led to the rapid expansion of the capital’s ger districts and a declining rural population. A social divide has formed between the recent arrivals who live in gers and people who live in apartment blocks (Fan et al. 2016). The physical representation of this can be seen in Figure 1 where ger plots averaging 700m² fan out from the multi-storey apartments of the city centre.

Mongolia is a young nation, having declared its sovereignty in 1911. Most of Ulaanbaatar’s built environment was constructed in the 1960’s (Altai, 2013). Until recently the country was a socialist people’s republic, whose administrators from the Soviet Union designed the capital for a population capacity of 600,000 (Altai, 2013). Soviet apartments, roads and city buildings form the core of the city’s architecture, though this is steadily changing as high-rise office buildings and shopping centres begin to take precedence in the central business district (CBD). An influx of free market-inspired global culture began in 1992 when Mongolia’s first democratically elected party was elected and along with it steadily grew an urban population from intra-national migration (Pomfret, 2000). With half the nation’s registered population (1.5 million) now living in the capital, Ulaanbaatar is grossly overpopulated. The majority of new arrivals live in ger districts fringing the city, as most people migrate with little financial capital (Byambadorj et al. 2016).

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1Ger: a traditional portable shelter made of wood, felt and canvas with a combustion stove/heater
Modern land reform policy has provided opportunities for some urbanites to profit from their allotted land in a budding property market, which in turn also acts as a divider in community development. Byambadorj et. al. discusses land reform in Ulaanbaatar along with the barriers they present to centralised urban planning. There has been little integration of qualitative and quantitative research toward suggesting solutions to urban socio-spatial problems in the city. Indeed, Byambadorj et. al. suggest that it is a lack of communication between government and non-governmental organisations that has contributed to a lack of direction in Ulaanbaatar’s urban planning.

1.2 Urban Monitoring Using Remote Sensing

There are a number of ways that remotely sensed image data can be applied to complex urban areas, foremost being the ability to spatially estimate population densities. The areas of most concern in Ulaanbaatar can be classified as low-density (ger districts) that represent contemporary urban sprawl. Typically these are residential blocks from 400m²-600m². Information about the distribution of these low-density urban areas can then be used to plan projects of civil engineering and public service that are widely non-existent in ger districts (JICA and MRTCUD, 2009). Enabling the supply and distribution of fresh water, electricity and waste management should take priority. Density maps will also help in the provision of public services such as hospitals, police, public transport and road access. All of the above mentioned are essential for good health, security and mobility and are at the core of an integrated urban life (Lhamsuren et. al. 2012). However, it should be noted that remote sensing can only be used as a guide for further in-depth studies of population. Implications from geospatial data can be vague, particularly in the interpretation of social exclusion/integration (Huby et. al. 2009). Thus, it should not be inferred from remotely sensed data whether geographic attributes such as distance from the CBD are related to socioeconomic well-being.

The first step to improving the living conditions for the people of Ulaanbaatar is to gather the relevant information which can be used for urban planning. Communication of the process and reasons for collecting geospatial data is essential so that local and other stakeholders can understand its value and thereby become involved. Amarsaikhan et. al. outline the ability of spatial data to represent urban growth, but do not elaborate how this information could be applied for the benefit of Ulaanbaatar residents. It is this lack of holistic engagement Byambadorj et. al. outline as a major barrier to the implementation of any master plan for infrastructure such as that produced by the Asia Foundation, Australian Government and Aid programs (2014). With the appropriate planning and community engagement, human development projects are more likely to produce sustainable results (Hopper, 2012). In perspective, perhaps a compromise of Amarsaikhan et. al. technical proficiency and the community integration of Byambadorj et. al. will produce a more achievable goal for accommodating Ulaanbaatar's growth. While acknowledging the limitations of remotely sensed data for urban analysis it is concluded that remote sensing can be a valuable tool in managing the development of a fast-growing city.

2. Study Area

2.1 Geography and Climate

Mongolia is a continental, landlocked nation sharing its northern and southern borders with Russia and China respectively. It has a land area of 1,564,116km², half the size of India, almost as large as Mexico or equal to the Northern Territory in Australia. Relative to its size, Mongolia has a small population of only 3,000,000 leading to a population density of 1.76 people per square kilometre. (United Nations, 2015). Being so far from the ocean, the capital has short, hot summers between June and August, when the city becomes hot.
dry and dusty due to a lack of ground cover vegetation. Ulaanbaatar is also the coldest capital city in the world, with winter temperatures commonly reaching -40°C (Meteorologisk Institutt, 2016). Outside Ulaanbaatar, weather conditions can be even more extreme, which has caused much of the environmental forcing for a rural-urban migratory trend as seen in Figure 2 (Byambadorj et al., 2011). This is a major barrier for a developing city when considering more than half of its residents live with minimal access to designated heating, plumbing, electricity, roads and public services (Ya, 2010). Today, Ulaanbaatar’s overpopulation is literally choking the city and its inhabitants with air pollution from combustion stoves rising far outside standards recommended by the World Health Organisation (WHO, 2005). The World Bank (2015) identifies the combination of low-density expansion and lack of infrastructure as major factors in reducing residents’ quality of life and the city’s overall economic competitiveness.

3. Materials and Method

3.1 Selection of Remotely Sensed Image Data

Due to seasonal snow inundation for the majority of each year, it was important to select satellite images taken in the Northern Hemisphere’s summer, so that types of land cover could be differentiated. Hence for this study images were selected from the warmer months of August and September. Selecting images with minimal cloud cover was also a priority to minimise areas needed to be masked from further analysis due to atmospheric interference.

The study is concentrated on the historic period of over two decades from the establishment of a free-market economy and democratic government in Mongolia in 1992 until the present. It is therefore necessary to use data collected over a long time series. Landsat Thematic Mapper (TM) was chosen as the appropriate sensor to use in this case and has been accessed through the US Geological Survey online image library. For the purpose of this application, two images toward the beginning and end of the Landsat TM data set were selected, spanning 22 of the 30 years in this series, as is seen in Table 1.

The first image taken on August 30th 1989 represents Ulaanbaatar before its rapid urbanisation and was chosen for its clarity of ground and limited cloud cover. The second image chosen was taken on September 4th 2011 and is overall similar with the same solar zenith angle of approximately 54°. Being selected at the same time of the year, the natural ground cover should be the same, particularly grass covered areas, which would have developed to a similar stage after spring shooting. It was later found from observation of the near infrared response from these two images that the 1989 image had far more grass coverage than in 2011. Some differences have occurred from forest response, which may have grown or been harvested over the two decades, particularly around newly urbanised areas north of the city centre and to the South-East, between Ulaanbaatar City and the airport.

Figure 2. Change in Population of Ulaanbaatar from 1926 to 2013 (White, 2013)

Table 1. Description of Remote Sensing Source Data.

<table>
<thead>
<tr>
<th>Date taken</th>
<th>Path / Row</th>
<th>ID</th>
<th>Notes</th>
<th>Bands</th>
</tr>
</thead>
<tbody>
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<td>Image 1</td>
<td>30/08/1989</td>
<td>131 / 27 ETP131R27_4T19890830</td>
<td>Increased cloud cover and grass shooting</td>
<td>8</td>
</tr>
<tr>
<td>Image 2</td>
<td>04/09/2011</td>
<td>131 / 27 LT513102720112478R00</td>
<td>Deforestation close to city, notable urban area increase from 1989</td>
<td>9</td>
</tr>
</tbody>
</table>

Table 1. Description of Remote Sensing Source Data.
3.2 Sub-Mapping

To minimise file size, subsets of the initial images were taken of Ulaanbaatar city and surrounds (Figure 3). The red box indicates the area of the subset taken, showing that the greater city area occupies only a small portion of the entire swath range. Using this subset also focused the statistical results on the area of interest.

3.3 Colour Composition

A false colour composite display was created for each image date with near-infrared (NIR) Band 4, middle-infrared (MIR) Band 5 and visible blue Band 1 displayed as RGB (see Figure 4). This combination was chosen primarily due to a high NIR response of vegetation and conversely a low NIR response from urban structures. Contrast between these two wavelengths clearly identifies the difference between urban and non-urban land cover, as is described by Stefanov et al. (2001) who use NIR wavelengths indicate urban expansion (Wilson et al. 2003). Band 5 showed particularly useful definition between areas of built city and the surrounding ger districts and so has been represented on the green gun to help distinguish the two. Surfaces such as shaded concrete in the CBD give a lower MIR response than that of bare soil which dominate the ger districts. Wilson et al. outline the uses of infrared response in urban zoning (Wilson et al. 2003). A higher response in the visible wavelengths from built structures and compacted soil (Wang et al. 2006) in these images was also an excellent first order measure of urban land cover, particularly using Band 1 of the Landsat TM data. This visible blue band has been represented as blue in the display to represent the high Band 1 response.

A comparison of the two dated images in Figure 4 clearly shows the extent of urban expansion in Ulaanbaatar between 1989 and 2011 and a reduction in vegetated and agricultural areas. However, for change detection to be further determined, more computational methods were used. Analysis of urban land cover change requires classification and will be elaborated on in Section 3.5 Image Classification.

3.4 Image Registration

To accurately view changes to land cover over time using images from two different dates, the images were registered to a common coordinate system. The 1989 image was used as a base and the 2011 image was transformed onto its coordinates using a first order transformation. Nine evenly spread ground control points were chosen around the image to ensure the quality of such a transformation. The root mean square error (RMS) of all chosen points was less than 0.1 of a pixel. This was a very good result, but to be expected because the two images as acquired from USGS were already georeferenced in the same coordinate system.

Once the two images were registered together, mixing spectral bands from each can be used to show changes over the time period on the one image. Figure 5 is a combined image over Ulaanbaatar where Band 3 and Band 2 of the base 1989 image represent areas that have not changed as red and green respectively. Blue in this image represents Band 1 of the 2011 image. Urban areas having a high visible blue
Figure 4. False colour images (B4,B5,B1 as RGB) of 1989 (4.1, left) and 2011 (4.2, right). Zoom for greater detail.

Figure 5. Colour Composite Image after Registration – RGB: 3, 2 (1989) & 1 (2011)

spectral response show the major incidence of urban change as blue. Areas of changed vegetation, such as forested areas that have been logged, show as dark blue, and are prevalent at the northern borders of the city.

The first interpretation of urban change followed a dendritic pattern, where ger districts have expanded along paths of low topographic relief. This clearly represents what A. Rahman describes as the “sprawling” of urbanisation, which are also characterised by “demand for essential services and infrastructure” (A. Rahman, 2007). The scale of these expansions north of the city has more than doubled the city’s total area, as is quantified in image classification following.

3.5. Image Classification

A critical part of this study is the ability to quantifiably differentiate between planned urban areas and unplanned ger districts from remotely sensed data. An overview of the main factors of these two different types of urban settlement reveal that the greatest difference between them lies in density. As outlined previously, it is the sprawl of low-density urban residential areas that has contributed to much of the city’s depleted wellbeing (The World Bank, 2015). The
classification of areas of different density is the best approach to identifying ger districts independently of the planned city.

To do this using remotely sensed data, a classification model was created. Classification entails the grouping of land cover types with a similar spectral signature into land cover classes. For example, areas with a low visible red and high near infrared response (Landsat TM bands 3 and 4 respectively) are likely to be covered by vegetation. Areas with this spectral signature can then be classified as vegetation. The classification method used to determine cover classes at each of the two dates was a supervised maximum likelihood method, which showed the greatest results in class homogeneity and band correlation (Stefanov et. al. 2001). Here samples of the spectral response of different ground cover classes were provided to the computer, which then calculated their statistical profile. Assuming each class is normally distributed the computer assigns pixels to a particular class depending on the probability that it belongs to that class. Unless a probability threshold is selected, all pixels are classified. In this case, pixels with an ultimate value of 0 or 1 were left unclassified and contain those pixels masked out for reasons of atmospheric interference (cloud and shadow) or glare from the sun. Each pixel between the values of 0 and 1 is then assigned to the class that has the highest probability that is: the maximum likelihood. Confusion matrices were calculated rating the accuracy of the 1989 and 2011 classifications at 94.7% and 96.9% respectively (see Tables 2(a) and 2(b)).

From image inspection six classes were found to accurately represent the land cover in each scene. A statistically valid number of samples were acquired for each cover class (minimum 100 pixels per class) and a maximum likelihood classification was undertaken for each date. A visual result of the results are represented in Figure 6 and Figure 7. A 3x3 pixel median filter was applied to both the 1989 and 2011 classifications to reduce noise.

4. Discussion of Results

4.1 Urban Change

The area of urban cover is shown to have grown significantly over the 23-year time period that the study spans. The total number of pixels classified as ‘low-density urban’ has risen from 119,735 pixels in the 1989 image to 303,314 pixels in the 2011 image. This translates to a 153% increase over an area of 149km². Low-density expansion has followed a dendritic morphology of least resistance along watercourses and areas of lower elevation, typical of ad-hoc settlement (Netzband & Rahman, 2009). However areas of high elevation, such as immediately north west of the city centre, have not remained uncovered. It is likely here that a steeper daily commute has been compromised by residents for closer proximity to the city centre. Particularly evident is the low-density expansion to the north west of the city as shown in the 2011 image, which barely existed in 1989. High-density urban areas now cover the majority of the central city area, whereas previously this class was concentrated in three smaller areas within the CBD. Variation in grass cover varies dramatically between the two dates, where it is likely that spring shooting occurred earlier in the season in 1989 than in 2011. It is also clear that forest vegetation has significantly
Table 2 (a). Confusion Matrices for 1989 Classifications (Ground Truth %)

<table>
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<tr>
<th>Class</th>
<th>Soil</th>
<th>Water</th>
<th>Agriculture1</th>
<th>Agriculture2</th>
<th>Trees</th>
<th>Grass</th>
<th>HighDensity Urban</th>
<th>LowDensity Urban</th>
<th>Total</th>
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Table 2 (b). Confusion Matrices for 2011 Classifications (Ground Truth %)

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<th>Class</th>
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<th>Agriculture2</th>
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decreased in areas close to the city, most likely due to logging for residential use as fuel in winter (Meissner et al. 2006).

5. Conclusions

Satellite remote sensing image data has shown itself to be a valuable tool in the summation of Ulaanbaatar’s urban growth. Low-density urban areas, typically associated with low standards of living have been shown to have grown substantially over the past two decades since Mongolia’s democratic political transition in 1992. The application of this geographic information includes projects of civil engineering, public service provision and population studies.
It is important to recognise that the application of remote sensing is context specific in that should this same analysis be applied to another city, the results and their application will differ. It should also be mentioned that as a body of work by authors entirely removed the context and reality of Ulaanbaatar’s poverty, the opinions expressed in this paper offer perspective rather than poignant understanding of lived experience in Ulaanbaatar’s ger districts. For further study of urban change it would prove useful to study higher-resolution areal data, hyperspectral data and further in depth time-series analysis to ascertain deeper information. This in turn could lead to the sub-classification of low-density urban areas to identify areas at greatest risk of problems associated with overcrowding. By effectively monitoring population growth in Mongolia’s capital city, it is hoped that active planning to cater for its expansion can be informed for the benefit of Ulaanbaatar’s people.

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