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Addressing urban expansion using feature-oriented spatial data in a peripheral area of Ulaanbaatar, Mongolia

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ABSTRACT

Because of the lack of time-series spatial data on urban components, urban expansion in developing countries has usually been studied using a pixel-based approach, despite the coarse spatial resolution associated with this technique. To understand the residential-scale processes involved in urban expansion, we developed feature-oriented GIS data extracted from very high spatial resolution satellite images (IKONOS for 2000 and Quickbird for 2006 and 2008). We selected a fringe area of Ulaanbaatar, the capital municipality of Mongolia, as a case study. Residential plots in this area have developed in an unplanned manner owing to the poor execution of land reform policy. This study facilitated the residential-scale delineation of the significantly expanding area occupied by private land plots in time series. It also permitted the identification of geographical factors driving the expansion. Using a logistic regression model, we found that such expansion is related to social infrastructure rather than to natural landforms. In particular, new plots of private land tended to be built near pre-existing plots and in proximity to roads and water kiosks (which provide essential drinking water for residents). These findings and the probability map predicted by the model have implications for urban planners and decision makers.

Introduction

Cities all over the world have been expanding, driven by the concentration of the global population in urban areas (Seto, Fragkias, & Gu, 2011). More than half of the global population now lives in urban areas (United Nations, 2014) and there are currently approximately 400 cities all over the world that contain over a million residents, although only 16 cities were found at the beginning of the 20th century (Cohen, 2004). As seen that 70% of those 400 cities are located in developing countries (Agunbiade, Rajabifard, & Bennett, 2012), the urban expansion is an ongoing phenomenon there. Urban areas in developing countries in 2030 are projected to be triple as they were in 2000 and these urban agglomerations are often found in the capital cities (Agunbiade et al., 2012; Angel, Stephen, & Daniel, 2005). This spatiotemporal phenomenon occurs in an unstructured manner, with the failure of guiding development in more desirable directions (Angel, Parent, Civco, Blei, & Potere, 2011; Vaz & Nijkamp, 2015). Urban planners and policy makers struggle with this issue to achieve sustainable urban management, however, in many cases, these attempts fail and result in uncontrolled developments especially on urban fringes around developed city centers.

When such expansion occurs, the surrounding grasslands, forests, and agricultural land are transformed into residential, industrial, and commercial land (Ji, Ma, Twibell, & Underhill, 2006). Such changes can induce a range of environmental and social consequences. These include the loss of natural resources (DeFries, Rudel, Uriarte, & Hansen, 2010; Hasse & Lathrop, 2003), the threat of biodiversity loss (Mcdonald, Kareiva, & Forman, 2008; Rojas, Pino, Basnou, & Vivanco, 2013), and inequality in living standards due to the development of informal settlements (Dubovyk, Sliuzas, & Flacke, 2011; UN-Habitat, 2003). In particular, because of rapid, unplanned, and uncontrolled development in urban fringes, there is often a lack of basic infrastructure such as sewerage, electricity, garbage disposal, roads, and shops. This lack of infrastructure can inflate the costs of urban management (Frenkel & Ashkenazi, 2008;

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Hasse & Lathrop, 2003). Thus, it is essential to monitor and manage urban growth.

Urban expansion processes are not uniform in their occurrence (Catal, Saur, & Serra, 2008). Thus, in any investigation of urban expansion, the specific geographical, social, and political context must be considered. However, this phenomenon has typically been studied using spatial grids at the city or metropolitan area scale using satellite images with coarse spatial resolution, such as MODIS, Landsat, and SPOT (Cheng & Masser, 2003; Fang, Gertner, Sun, & Anderson, 2005; Gimblett, Daniel, Cherry, & Meitner, 2001; Ji et al., 2006; Martinuzzi, Gould, & Gonzalez, 2007; Sudhira, Ramachandra, & Jagadish, 2004; Tsutsumida, Saizen, Matsuoka, & Ishii, 2013; Weber, 2003). While these sensors are able to observe urban surfaces frequently, the coarse spatial resolution of these images is not sufficient to explore urban expansion because of the mixed pixel problem. Accordingly, it has proven difficult to observe changes in urban components directly and precisely, particularly because there is a lack of feature-oriented information relating to individual land use. An alternative way to capture urban expansion involves the use of very high spatial resolution (VHR) imagery such as aerial and satellite images. Although aerial images have been in use for many years, it is expensive to take photographs, and time consuming to prepare the data for GIS applications (Yuan, Wu, & Bauer, 2008). On the other hand, the decreasing costs and increasing availability of VHR satellite imagery have led to an enhanced ability to observe urban surfaces precisely (Yuan & Bauer, 2006). VHR satellite images have excellent potential. They can extend satellite remote sensing beyond what is possible with aerial photography or with satellite technologies with coarse spatial resolution. They should, therefore, be of interest to resource managers as a way to assess land resources in a timely and reliable manner (Sawaya, Olmanson, Heinert, Brezonik, & Bauer, 2003). The main advantage of the use of VHR satellite imagery is the fine-scale observation as a snapshot. Thus, the use of such data enables the depiction of land use for each urban component in a time series and can help characterize the spatio-temporal dynamics of urban expansion. When building a spatial information database, one is often hampered by the lack of temporal data, even on developed cities. This issue means that it is still difficult to follow time-series changes in land cover caused by rapid urban expansion. This has generally prevented us from analyzing urban expansion when using existing spatial data.

Here, we describe an investigation into the detailed residential-scale processes of urban expansion in a fringe area of Ulaanbaatar, the capital municipality of Mongolia. We chose this area because of the unplanned proliferation of residential plots that has dominated development here; in parallel with an increase in population, this has caused critical development issues over the past several decades. If the government is to address developmental problems, it will be essential to understand when, where, and how urban expansion happens and to clarify the real factors causing the expansion. Such knowledge would also be beneficial for urban planners and policy makers, allowing them to manage urban expansion in future. Therefore, the present study aims primarily to portray residential-scale urban expansion processes by delineating time-series changes in urban components and to identify the geographical factors contributing to urban expansion.

Study area

In the present study, we focused on a fringe of Ulaanbaatar in which residential areas have expanded throughout the last decade (Fig. 1). This study area is located in the western part of Ulaanbaatar, in an area spanning 106°43′–106°52′E and 47°54′–47°56′N and covering approximately 33 km^2. One of the main roads, Enkhtaivan Avenue, is oriented east–west along the southern edge of the study area. Residential plots in this area is primarily on the flat land and hillsides located on the north side of Enkhtaivan Avenue. The area on the south side of the road is part of the city center and includes some apartments and commercial facilities. The study area also includes other land use types—factories, schools, and governmental facilities. The open land consists of grasslands and bare ground. However, these natural land cover types have been affected extensively (i.e., degraded) by anthropogenic activity.

Overview of Ulaanbaatar

Urban expansion in Ulaanbaatar

Ulaanbaatar is the cultural, economic, political, and religious center of Mongolia (Byambadorj, Amati, & Ruming, 2011). Its population grew from 0.77 million in 2000 to 1 million in 2008 (Fig. 2). This population increase was due in part to the dramatic transition of Mongolia from a planned economy within the former Soviet-backed regime to an independent state with a free market economy (Sneath, 2003). Mongolians were freed from restrictions on internal migration and job selection; consequently, many rural Mongolians migrated into urban areas to seek jobs and education (Algaa, 2007; Byambadorj et al., 2011). Rural Mongolian, especially nomadic people, typically lives in a *ger*, which is a traditional Mongolian dwelling designed for a nomadic lifestyle in grassland (Dore & Nagpal, 2006). The *ger* is a circular tent-like structure consisting of a wooden framework and is covered with a felt made from wool of sheep, goats, or yaks, having sufficient living space for a Mongolian household. As it is mobile, lightweight, and portable, making it well suited for easy movement, the *ger* is an ideal living solution for nomadic people and well adapted to the nomadic life in a sustainable way (Dore & Nagpal, 2006; Kamata, Reichert, Tsevegmid, Kim, & Sedgewick, 2010). Considering the advantage of such portability, migrants relocate to the city often by disassembling their *ger*, loading it and its contents onto a truck, and reassembling it in peripheral areas (Badarch, Batsukh, & Batmunkh, 2003). In this manner, migrants claim open land, build *khashaas* (wooden fences) marking property boundaries, and build a *ger* or a detached house on the enclosed land (Kamata et al., 2010). Such structures are typically seen in urban fringes known as *ger* areas (Fig. 3), which are typically composed of both formal and informal residential plots. Currently, about 60% of the population of Ulaanbaatar lives in *ger* areas (Byambadorj et al., 2011; Kamata et al., 2010; UN-Habitat, 2010a).

The expansion of *ger* areas within the fringes of Ulaanbaatar may have negative impacts on the natural environment and on living conditions (UN-Habitat, 2010b). For example, in winter, air pollution caused by the emissions from household stoves used for heating is one of the critical environmental problems facing Ulaanbaatar. Residents in *ger* areas usually use raw coal and wood as fuels, whereas residents living in apartments typically use central heating. *Ger* areas lack basic infrastructure, including piped water systems, sanitation facilities, paved roads, public transportation, and heating systems (Kamata et al., 2010). Accordingly, issues such as social and spatial inequality, water supply and sanitation, waste management, and air pollution have become urgent. International donor-funded projects are helping address such issues by assisting with the development of much-needed infrastructure (Kamata et al., 2010; UN-Habitat, 2010a). In particular, because the residential plots in *ger* areas are not connected to the public water supply system, water kiosks are being constructed using funding from international donors to meet the basic human need for water (Sigel, Altantuul, & Basandorj, 2011). Most of these