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Mapping recent built-up area changes in the city of Harare with high resolution satellite imagery

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A B S T R A C T

Spatial information about human settlements is key information in times of continuous urban growth and high rates of uncontrolled urbanisation in developing countries, but there is often little geographic information on where the population growth occurs. Built-up area is a good proxy for population that can be extracted from Earth observation data. At the example of the city of Harare in Zimbabwe, this research shows how remote sensing technologies can be used to obtain refined information on hot spots of built-up area change that allow a monitoring of population. This was achieved through an automated mapping of built-up area changes between 2004 and 2010 from multi-temporal high resolution satellite images. The designed workflow combines an automatic feature extraction method with an automatic, grid based change analysis. Built-up area was extracted from Spot images with accuracies between 78% and 84% and changes were computed as percentage change in a grid using an object-based hierarchical method. The derived built-up area and its changes were compared to population figures from the last two censuses at ward level. The comparison reveals a good match of the pattern of changes of both parameters; however, more detailed information was derived from the Earth observation data.

Introduction

Worldwide, more people live in cities than in rural areas. The appeal of the city remains strong in particular in Africa, where currently the highest growth rates are observed (UN-Habitat, 2012). Urban policy- and decision-making require objective, accurate and city specific information to target the right scale of intervention. However, the scarcity of data on urban areas remains a challenge to urban managers (UN-Habitat, 2010). Even though population growth of urban areas is relatively well monitored by international organizations, like the United Nations, measurable spatial information on where the urbanisation occurs on the ground is difficult to obtain. This would require at least data at sub-district level which are difficult to obtain for developing countries.

Earth observation (EO) data can help to map built-up area and to measure the growth of a city over time. This potential was demonstrated in many studies (e.g. Bhatta et al., 2010; Gamanaya et al., 2009; Li et al., 2013; Owen & Wong, 2013; Pesaresi et al., 2011a; Rahman et al., 2011; Sun et al., 2013; Taubenbröck et al., 2012; Vermeiren et al., 2012; Wu & Zhang, 2012). Some studies used the derived change information to identify driving forces and to prospect future trends (Li et al., 2013; Vermeiren et al., 2012; Wu & Zhang, 2012). Such information is useful for territorial planning, which is especially relevant for cities in developing countries, where the growth is – compared to cities in developed countries – very fast and mostly uncontrolled. Indeed, there is an increasing demand among cities in developing countries for using remote sensing and Geographic Information Systems to establish an Urban Information System (Maktav et al., 2005). In developing countries satellite image data are particularly important information sources, because they can fill information gaps, they can be obtained with relatively few efforts and short acquisition time (cost-effective), and they are an independent information source.

The study of urban areas from space-born sensors is a relatively new application in remote sensing (Maktav et al., 2005). Monitoring urban growth is an important application herein and it has become a global issue with methods being currently developed for massive processing on multiple scenes (Pesaresi et al., 2013; Taubenbröck et al., 2012). In many studies medium resolution data are used to monitor urban growth (e.g. Bagan & Yamagata, 2012; Griffiths et al., 2010; Rahman et al., 2011; Sun et al., 2013).

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In most cases these are Landsat data at 15 or 30 m resolution, which are available through a systematic collection that started in the late 1970s. Most of these studies exploit the spectral signature to distinguish between different land use types (Bagan & Yamagata, 2012; Gamanya et al., 2009). Others include object-specific characteristics like texture, shape etc. (Sun et al., 2013). A prerequisite of methods using the spectral signature of objects, like supervised classification, are training sets that are usually defined through ground measurements or by using topographic maps and higher resolution data. Similar to this, methods using other object characteristics like decision trees or object-oriented methods require setting up sets of rules, which are defined after intensively studying the objects of interest. Both methods are usually very time-consuming and challenging due to the spectral similarity of land use classes. Moreover, in most cases training or rules sets are specific for the study area it was collected for, which reduces the level of transferability to other areas.

With the continuous technical improvements, the level of detail provided by satellite images has increased. The Spot satellite constellation increased in resolution since the first platform was launched in 1986. With a current resolution of up to 1.5 m (Spot-6) it is able to capture very well local variations that are characterising urban areas. With the higher level of detail, these data offer good possibilities to distinguish built-up from not built-up areas and to analyse the internal variation of settlements. Methods that are capable of dealing with the higher level of detail are continuously developed (Pesaresi, 2000; Pesaresi et al., 2013). The developments of these information extraction methods focus not only on exploiting the level of detail but also on increasing the level of automation in order to increase transferability.

In this study we used Spot-2 and Spot-5 multi-temporal imagery to analyse recent built-up area changes in Harare, the capital city of Zimbabwe. For achieving this, a largely automated workflow was designed that combines an automatic feature extraction algorithm with grid based automatic change detection. For the feature extraction we used the built-up presence index “PANTEX” (Pesaresi et al., 2008) that was combined with an object-oriented method (Tiede et al., 2012) to detect change hot spots in urban areas. The observed built-up area density and changes were interpreted and compared with population densities from the last two censuses.

Until now, few studies were conducted on the urban area of Harare and its evolution. The first author to describe the spatial structure and to examine factors influencing its evolution between 1890 and 1990 was Zinyama (1993). His work has become a reference for other studies as he was the first to provide maps and sketches on the city area. Tongayi (2008) modelled the past evolution of the city using qualitative data based on historical facts. Gamanya et al. (2009) used Landsat images from 1989 to 2001 to test an object-based method they had developed for analysing land use changes in Harare. Because the focus of their study was on the methodology, the observed changes were not further interpreted. Schöpfer et al. (2007) were mapping changes in the urban tissue related to a government action in specific locations between 2004 and 2005 using very high resolution satellite images.

Other studies on the city are focussing on societal and political aspects as Harare is continuously in the focus due to continuing crisis, political tensions, controversial government actions and humanitarian issues. None of those uses or provides geographic information like maps. To mention some examples, Potts (2011) discussed the history of Zimbabwean urbanisation and related these to recent issues in the housing sector. Musemwa (2012) looked into the various dimensions of the on-going crisis and the effects on Harare at the example of the water crisis and recent outbreaks of diseases. Tibaijuka (2005) analysed the objectives and effects of the 2005 government action to clear all informal settlements and squalors.

However, geographic information on the city is scarce. The national statistical office provides access to a number of socio-economic indicators on their webpage (ZIMSTAT, 2010). Most of the indicators are provided at district level which is too coarse for studying intra-urban processes. Population data though is available at higher resolution (municipal wards) through the publicly available preliminary census reports (CSO, 2002; ZIMSTAT, 2012). It is the only quantitative information which provides insights in the spatial structure of Harare. The present study aims at increasing knowledge about Harare's structure by providing geographic information about built-up area and by analysing recent changes.

Study area and data

Study area

The study was conducted on the province of Harare situated in the north-eastern part of Zimbabwe at an altitude of approximately 1500 m (Fig. 1). Harare is the largest city and capital of Zimbabwe and the centre of industrial production and commerce in the country. The province extends over 940 km^2 and is hilly in rocky areas, flatter in the south and undulating in the north. The city goes back to the British settlement of Fort Salisbury founded in 1890 close to the banks of the Mukuvisi River, where todays city centre is located (Zinyama, 1993). The population of the province of Harare currently amounts to 2.1 million inhabitants and is growing slowly with an annual change rate of approximately 1% (CSO, 2002; ZIMSTAT, 2012; Sub-Saharan average is 3.7% according to UN Population Division, 2011). Recent development of Harare's population and spatial pattern was influenced by the political change in the country with independence war in the 1970s followed by independence in 1980 that marks a major event in the development of the city.

Harare is a sprawling city, whose spatial structure is characterised by its radial road network, converging in the centre of the city (Fig. 1). The province is divided in four districts: Harare Urban, the largest district with the city centre, the second largest Harare Rural extending south of the Urban district, and the two smaller districts of Chitungwiza 25 km south and Epworth 12 km east of the centre.

There are wide disparities in the location and quality of residential areas throughout the province which are a consequence of the colonial past and control over urbanisation (Potts, 2011; Zinyama, 1993). The hilly areas in the north and north—east are characterised by spacious living conditions. In the south, west and east of the province the small plots and housing units of the African townships are the dominating housing structure. As in many other African cities these were specifically built to host the influx of people, which were moving to the city as labour force for the growing economy during the colonial period (Mlambo, 2008). Industrial areas extend south and south-west from the centre. Smaller ones are situated in the south-west of Chitungwiza district.

Harare Urban district hosts the city centre or central business district with high-rise buildings. It is surrounded in the south by mixed density suburbs and in the north and north-east by high-income and low-density residential areas (e.g. Borrowdale, Malborough; Zinyama, 1993). Most of the high-density townships are located south-west of the centre with Highfield and Mbare being the oldest black residential areas. About in the same area are also the biggest industrial areas of Harare.

South of the urban district extends Harare Rural, which is dominated by agricultural areas with some isolated low-density areas and some high-density areas in the north-west. The dominant feature of this district is the international airport in the