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Analysis of impervious land-cover expansion using remote sensing and GIS: A case study of Sylhet sadar upazila

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ABSTRACT

Unplanned urbanization practice creates pressure on the natural functioning of land and resources. In this context, it is essential to monitor its expansion. This study seeks to analyze the pattern and process of urban expansion at Sylhet Sadar Upazila from 1981 to 2016 by extracting impervious land-cover from satellite images and using Shannon's entropy. To find out a comparatively accurate method of extracting impervious land-cover from satellite images, three classification methods viz., supervised maximum likelihood algorithms, index-based classification and neural classification are experimenting with a single Landsat images of 2016. A method is selected on the basis of accuracy measures. The study finds the neural classification can extract impervious land-cover accurately (about 90% accuracy) than other classification. This classification method is adopted to classify the Landsat images of 1981, 1991, 2001, 2011 and the amount of impervious land-cover is estimated in ArcGIS platform. Finally, the entropy value is calculated using the amount of impervious land-cover for each union and city corporation. Up to 2011, the city expands mainly along north-south direction and this expansion occurs at northen and eastern direction after 2011. The urban expansion in Sylhet city and its vicinity is scattered in nature but the compactness increases slightly in 2016. Number of Population and elevation acted as the driving force of urban expansion in case of Sylhet city.

1. Introduction

Rural to Urban conversion has become more rapid in recent human history because of increasing population and their movement from rural to urban. The conversion affects the natural functioning of ecosystems (Turner, 1994). Planned urbanization occurs in developed countries, but the situation is opposite in developing countries. This practice increases the concentration of households and economic activities and changes the land-use pattern of urban-rural fringe (Sudhira et al., 2004).

Urban authorities and municipal corporations need knowledge about the urban sprawl phenomena and its likely movement for effective planning. Mapping the built-up area is one of the basic activities required for this purpose. It is difficult, time-consuming, and costly to estimate the urban sprawl using conventional surveys. In addition, such information is not available for the municipal corporations, especially for developing countries. As a result, researchers have to rely on GIS and RS technology to quantify the magnitude and direction of urban expansion because of its cost-effectiveness (Yang & Liu, 2005). In RS, a land-cover whether it is pervious or impervious is determined based on image pixel and its reflectance value and visual appearance. Pervious surface means vegetation cover, soil, and sand through which water can penetrate into the ground, whereas impervious surface cannot penetrate water into the ground. Impervious surface-driveways, roads, parking lots, rooftops, and sidewalks-is considered as a parameter for quantifying urban expansion (Barnes, Morgan, Roberge, & Lowe, 2001, pp. 1–24; Epstein, Payne, & Kramer, 2002).

The most accurate, but time-consuming process of estimating the amount of impervious land-cover from the remotely sensed image is heads-up digitizing (Jat, Garg, & Khare, 2008). Hence, researchers mainly try to develop new methods for accurate estimation and modeling of urban growth. Researchers use different types of methods such as band combination, index-based classification, supervised classification, unsupervised classification, machine learning, and decision tree classifier for classifying satellite image. For example, supervised classification using a maximum likelihood algorithm was used by Morshed, Yorke, and Zhang (2017), Islam and Sarker (2016), Liu and Yang (2015), Al-sharif, Pradhan, Shafri, and Mansor (2013), Bitelli, Franci, and Mandanici (2013), Mamun, Mahmood, and Rahman (2013), Deka, Tripathi, and Khan (2011), Dewan and Yamaguchi (2009), Billah and

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Rahman (2004). Maximum likelihood algorithm depends on the estimation of the mean vector and variance-covariance matrix of each feature class (Mather & Koch, 2011) and classification accuracy depends on the size of training sample and smaller training sets produce erroneous results (Dobbertin & Biging, 1996). In addition, this algorithm often fails to classify a heterogeneous urban area accurately (Kýnová & Dobrovolný, 2015). On the contrary, Uddin, Anwar, Rahman, and Mobin (2015) used unsupervised classification in their study. However, researchers also use the machine-learning algorithms such as an Artificial Neural Network (ANN), Support Vector Machine (SVM), and Decision Tree (DT) in classifying satellite Images. For example, Ma, Zhao, and Li (2016), Griffiths, Hostert, Gruebner, and van der Linden (2010), Alkheder and Shan (2005), Li and Yeh (2002) used machine learning algorithm. According to Ma et al. (2016), ANN produces a more accurate result than SVM and DT classifier whereas Griffiths et al. (2010) applied the SVM method in their work. In each research work, the accuracy of the classification was 90% or more than 90%. Apart from these preceding methods, some researchers focus on indexes (NDBI, NDVI) for classifying satellite image such as Bhatti and Tripathi (2014), Emch and Peterson (2006).

Urban expansion analysis has two phases. In the first phase, researchers have to classify the image and quantify the urban area and in the second phase, they need to use statistical parameters and indices for understanding the pattern and the process of urban expansion (Bhatta, 2009). In order to analyze the pattern and process of urban expansion, researchers apply different landscape metric such as Shannon's entropy, map density, patchiness. Some researchers also apply land-use change index for determining the rate of urban expansion such as Ma et al. (2016). However, Shannon's entropy is perhaps the most widely used and reliable technique to measure the extent of urban sprawl with the integration of remote sensing and Geographic Information System (Bhatta, 2009). This entropy can be used to measure the degree of spatial concentration or dispersion of a geographical variable (such as impervious surface) among zones (Theil, 1967, p. 488; Thomas, 1981, p. 42). The large value of Shannon's entropy indicates dispersion of considered random variable (urban sprawl) which indicates the occurrence of urban sprawl.

Bangladesh is the world's seventh most populous country, furthermore one of the densest country with more than 150 million people. Expert opines that the possibility of stabilizing or declining population is less, before 2060, when it might be 230 million, with over 70 percent being urban (Islam, 2003). The urbanization process has started in Bangladesh after 1971 and this was limited only in the Dhaka city; the process accelerated since 1991 in Dhaka. Rapid urbanization has also started in Sylhet City Corporation (SCC) after 1991. The United Nations Population Fund (UNFPA) (2016) report states that urban areas have increased rapidly in Sylhet over the 20-year period since 1991 to 2011. The following Table 1 shows a clear picture of this.

Land-use and land-cover (LULC) of SCC and its vicinity have altered due to unplanned urbanization and the capturing of lowland by real estate companies (Rahman, 2011). Therefore, it is necessary to identify whether the unplanned urbanization creates urban sprawl outside the city or not.

Very few research works have been conducted on the urban expansion of Sylhet City and Sylhet district. It was reported that water bodies of Sylhet district were 81535.2 Ha, 34535.7 Ha and 28435.6 Ha in 1988, 1997 and 2006 respectively, and unplanned urbanization played the key role in the reduction in water bodies (Haque, Alam, Shaha, & Raihan, 2008). On the contrary, it was found that the settlement area of Sylhet district was 52930.1 Ha and 46,713 Ha in 1988 and 2006 respectively (Haque et al., 2008). No classification scheme was applied in the study of Haque et al., 2008. On the other hand, it was mentioned the urbanization process of Sylhet city is unplanned and it creates obstacles in all spheres of life (Rahman, 2011). These studies provide the opposite results.

Therefore, a proper study is required, including the classification scheme, appropriate classification method, and landscape metric to estimate the urban expansion of Sylhet City and its vicinity. This played the key role in conducting this research. The main objective of this research is to quantify the impervious land-cover of Sylhet Sadar Upazila by finding out a relatively accurate technique of impervious area extraction from Landsat Images and analyze the urban sprawl pattern and process.

Table 1
Population and urban area at SCC.
Source: Population census, BBS, 1981, 1991, 2001, 2011.

Respective Years	Population	Urban area
1981	100514	10.49 square km
1991	118516	10.49 square km
2001	316311	26.05 square km
2011	485138	26.50 square km

2. Description of study area

Sylhet Sadar Upazila (SSU) of Sylhet district is a rapidly developing and resourceful area located in the northeastern part of Bangladesh. It is located at 24°53′30″N91°53′00″ E to 24.8917°N91.8833°E which is bounded by Companiganj, Gowainghat and Jaintiapur Upazila on the north, Dakshin Surma Upazila on the south, Kanaighat and Golapganj Upazila on the east, Chhatak (Sunamganj district) and Bishwanath Upazila on the west (Fig. 1). Sylhet City Corporation (SCC) is located in the center of Sylhet Sadar Upazila (SSU). The existence of land base attraction such as hill and terraces, tea gardens, forests, water bodies as well as religious monuments has made it unique from any other upazila of Bangladesh. According to National Land-zoning report (2015), urban built-up area at this upazila covers an area of 2626.69 Ha. Urban land is used mainly for commercial, residential activities. Aerial view of the study area indicates that the residential buildings are buried in wood or cling to trees and so cannot be easily traced from an elevated sensor such as satellite.

3. Data used

Raster data and vector data have been collected to fulfill the research goal. Satellite data include Landsat images of various sensors and panchromatic image of WorldView-1 Satellite. Vector data includes shapefile of the boundary layer, the road layer. Landsat satellite image (1981, 1991, 2001, 2011 and 2016) has been collected from the website https://earthexplorer.usgs.gov/. Detail of the Landsat satellite images is mentioned in the following Table 2.

The path and row of the collected image are 146 and 043 respectively, and map Projection of the collected satellite images is Universal Transverse Mercator (UTM) within Zone 46 N– Datum World Geodetic System (WGS) 84. The data type of the collected image was L1T. L1T data are corrected using ground control points (GCPs) and a digital elevation model (DEM). These data are typically quite consistent, even from product to product and require little to no image registration.

Vector data, such as boundary data, road layer, is now freeware and available on the internet. Boundary data have been collected from http://geonode.wfp.org/and the road layer of Bangladesh has been downloaded from https://www.openstreetmap.org/. Besides this, vector data of the ward of SCC has been obtained from SCC office. All the collected vector data is in shapefile (.shp) format.

4. Methodology

Understanding the dynamic phenomenon, such as urban sprawl/growth, requires land-cover change analysis, urban sprawl pattern identification and computation of landscape metrics. Different Software