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Built-up Area Change Analysis in Hanoi Using Support Vector Machine Classification of Landsat Multi-Temporal Image Stacks

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Abstract

Vietnam is experiencing one of the greatest urban transitions over the last two decades after the embankment of "Doi Moi" policy in 1986. The urban transition is vividly manifested in social, economic and physical aspects. While the urbanization can boost the industrialization and modernization goals of the country, it can cause adverse impact on natural environment as well as society and economy. To support a sound urban development plan, it is important that data and analysis on urban built-up areas are accurate and timely available. In this study, the Support Vector Machine Classification Algorithm (SVM) was applied to the multi-temporal image stacks of Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM) from 1993 to 2010 to quantify the changes of built-up areas over three time periods, 1993-2001, 2001-2006, and 2006-2010 and across twelve buffer zones. Our SVM classification algorithm has produced a highly-accurate map of land use/ land cover change with the overall accuracy of 95%. The study showed that most of the urban expansion occurred in the periods 2001- 2006 and 2006 – 2010. The analysis was strengthened by the analysis of population census and other socio-economic figures. Through out this study, an implicit correlation between the urban growth, the trend of spatial expansion and other relevant geographic and socio-economic factors can be proposed. Result of this study would allow urban planners and decision makers to timely evaluate and adjust accordingly the urban growth and be aware of the sustainable usage of the invaluable natural lands and other environmental, social and economical problems.

Keywords: *Urbanization, built-up change, support vector machine, remote sensing, GIS, gradient approach.*

1. Introduction

In this 21st century, we have witnessed the world's fastest-growing cities in Asia, Africa and Latin America (Satterthwaite, 2007) where urbanization is faster than what governments and city planners can manage. The urbanization in the urban fringe is particularly hard to control, resulting in sprawl patterns of land use which in turn have a negative impact on infrastructure and the sustainability of the cities. In most cases, sprawling cities will result in high cost of transport, public infrastructure and residential and commercial development. Sprawling patterns also demand more energy, metal, concrete and asphalt than do compact patterns because homes, offices and utilities are set further apart (DiMuzio, 2012). Likewise, urban sprawl leads to new developments that cause significant loss of prime farmland and ecosystem complexity as well as disruption of ecosystem structure (Marshall & Shortle, 2005).

Vietnam is experiencing one of the greatest urban transitions in the world. The country has started a rapid economic liberalization with the inception of Doi Moi (Economic Renovation Policy) in 1986 which introduces liberal market mechanisms, encouraging private-sector initiatives, while retaining its role as the nation’s strategic planner and enforcer (World Bank, 2011). At the same time, its government has also implemented a variety of policies in an attempt to foster a more even distribution of economic growth and urban development. For example, Government Decision No. 10 (1998) on the Urban System and Development Strategy to 2020 called for the development of medium and small sized cities creating balanced development among different regions or the Decision 445/QD-TTG issued by the Prime Minister dated 7th April 2009 on Approval of Adjusting Orientation for General Planning to Develop Vietnam Urban System until 2025 and Vision to 2050. In the 2011-2020 Socio-Economic Development Strategy, Urbanization was considered as an integral part to promote the country’s goals of industrialization and modernization (World Bank, 2011).

These policy reforms and economic vitalities have fostered a swift transition to an urban society through combined processes of rural-urban migration, occupational shifts away from agriculture, the physical expansion of existing urban areas, and the creation of new cities and towns in densely-settled rural communes. Rural – urban migration by people seeking employment is steadily increasing. Urban population has increased from 23.7% in 1999 to 29.6% in 2009 (with 25.4 million urban residents out of the country’s 85.8 million people) (Population & Housing

Census, 2010). The urban population continues to grow at an unprecedented rate and is projected to increase by 45% by 2020, which translates to more than 30 million urban resident population (Campbell, 1999). Consequently, the development of public amenities and infrastructure will require increasing areas of land, which will in turn have the effect of increasing the pressure on land use.

Cities are often located on the most productive agricultural lands (L Imhoff, Lawrence, Stutzer, & Elvidge, 1997), so any expansion of built-up areas quickly consumes natural resources, compromising not only food production, but also the provision of ecosystem goods and services that are derived from these landscapes (e.g. climate regulation, water infiltration, etc.) (Foley et al., 2005). Ignoring topological relationships and underlying biophysical and socio-economic processes would result to a chaotic pattern and unsustainable urban land development (Carsjens & van der Knaap, 2002). Expanding urban, in the way out of control and changing land use pattern, will bring about new issues (Brook, Dávila, & Britain, 2000), including both positive and negative impacts on the natural environment as well as society and economy.

The study of urban spatial expansion always needs accurate data on urban built-up areas such as the size, shape, and spatial context. Timely availability of the data is of great importance for urban planners and decision makers. Fortunately, satellite remote sensing technology offers considerable promise to meet this requirement. With different spatial and spectral resolutions, the satellite observations can provide globally consistent and repetitive measurements of the Earth's surface conditions.

While the administrative boundary and area of Hanoi were well documented overtime as provided in the background, its spatial entities are not always updated. At certain level, data on land uses are available in census format but lack consistency, are of limited access to users and have non-spatial references. The objective of this study was to develop a comprehensive understanding of the built-up land features for Hanoi capital city using multi-temporal image stacks developed from freely-available Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM) data from 1993 to 2010. The Support Vector Machine Classification Algorithm was applied to the image stack to quantify the changes of built-up areas across temporal and spatial scales. We evaluated the impact of urban expansion on open land especially in the peri-urban environment. This study focused on understanding the urbanization and peri-urbanization of

Hanoi as a case study by looking at the extent of built-up overtime and across urban-rural gradient. The information derived in this study should allow urban planners and decision makers to timely understand and evaluate urban growth with related land-cover changes and be aware of the sustainable usage of the invaluable nature lands.

2. Historical overview of land change in the study area

Vietnam has developed two independent and dominant core-periphery urban systems: Hanoi, the capital city of Vietnam and Ho Chi Minh, the largest metropolitan in the south. Vietnam's rapid economic growth is strongly driven by these two urban systems with high growth and industrial concentration within these cities and their surrounding areas. Hanoi is a typical example of rapid urbanization in Vietnam in particular and in Asian countries in general. In this section, we describe the history of Hanoi since its initial establishment with a focus on the major turning points and current development stages.

Throughout the history, the Vietnam's capital city has changed its name and administrative boundaries several times. Historically, Hanoi has many names such as "Thăng Long" in 1010, "Đông Đô" in 1397, "Đông Quan" in 1408, "Đông Kinh" in 1427, "Bắc Thành" in 1787. In 1805 King Gia Long renamed it again "Thăng Long". "Hà Nội" was first named in 1831 by King Minh Mang as a province which included the ancient "Thăng Long" Citadel and 4 other districts. In 1888, French colonialist established Hanoi City (Vien, Quang, & Van Dung, 2005). Hanoi became the Capital of the Democratic Republic of Vietnam in 1945 which comprised 5 wards (Lang Bac, Dong Da, Me Linh, Dai La and De Tham) and 120 suburban villages. In 1954 Hanoi was liberated from the French Colonial Regime. By then the capital city had 4 urban districts (Ba Dinh, Hoan Kiem, Dong Da, and Hai Ba Trung) and 4 peri-urban ones (Gia Lam, Dong Anh, Thanh Tri and Tu Liem) with an area of 152 km^2 (Logan, 2000). In 1960 Hanoi expanded to 586.13 km^2 but remained the same number of urban and peri-urban districts. In 1978 Hanoi's area increased to 2,123 km^2 as there were 7 districts and one more town was added to Hanoi's administration: Soc Son, Me Linh, Ba Vi, Phuc Tho (taken from Vinh Phu province) and Thach That, Dan Phuong, Hoai Duc and Son Tay town (taken from Ha Tay province) (HSO, 1990).

In 1991, the land area of Hanoi was shrunk due to the unpredictable difficulties that Vietnam was facing after the war. It was adjusted to only 913.8 km^2 (from the earlier 2,123 km^2) with same 4 urban districts (Ba Dinh, Hoan Kiem, Dong Da, and Hai Ba Trung) and only 5 peri-urban districts (Gia Lam, Dong Anh, Thanh Tri, Tu Liem, and Soc Son (HSO, 1992). From 1995 to 1997 Hanoi had expanded its urban area further to include part of Thanh Tri and Tu Liem peri-urban districts. Thereafter, two new urban districts, Tay Ho and Thanh Xuan, were established, making Hanoi's urban area 62.15 km^2. In 1998 Hanoi took more land of Tu Liem peri-urban district to make up Cau Giay urban district. It brought the urban area to 82.78 km^2. In November 2003, two new urban districts named Hoang Mai and Long Bien were established (HSO, 1998, 2003).

In sum, from 1991 to 2003 more urban districts have been established, which are Tay Ho, Thanh Xuan, Cau Giay, Hoang Mai and Long Bien. Those are mostly formed from taking land of peri-urban districts: Tu Liem, Thanh Tri and Gia Lam. In general, the number of urban districts of Hanoi has increased more than twice since 1995 with the land area increased nearly 4 times from 47.22 km^2 in 1995 to 185.72 km^2 in 2003.

In 2008, the administrative boundaries of Hanoi were again adjusted to include the neighboring province of Ha Tay as well as a number of districts and communes that formerly belonged to the provinces of Vinh Phuc and Hoa Binh. As a result, the capital reached 3,300 km^2 which is 3.6 times the size of the previous area increase (Labbé, 2010). In doing so, Hanoi absorbed wide areas of agricultural land that now constitute two-thirds of its area. This expansion also resulted in a doubling of the official population of the capital city, from 3.2 to 6.4 million inhabitants. A large part of this new population is classified as “rural” (3.7 million people, against 2.5 million classified as “urban”) (HSO, 2009). Hanoi’s population comes just after HCMC (6.8 million) but the city is now far ahead of Hai Phong (1.8 million) and Da Nang (822,000). Although encompassing less densely settled areas, Hanoi’s population density has now reached an average of 1,926 persons per km^2 (HSO, 2009). With the massive wave of immigrants from other provinces to Hanoi, mostly from other rural in the North of Vietnam and other nearby provinces, the real number of population in Hanoi is increasing at an accelerated speed and this upward trend does not seem to cease in the foreseeable future.

3. Method

3.1 Remote sensing of built-up areas

Urban areas represent the most heterogeneous landscape making it challenging for remote sensing specialists to derive mapping results with a high accuracy especially when conventional image processing algorithms and techniques are employed which largely built upon parametric statistics (Myint & Lam, 2005; Yang, 2011). In addition, urbanization in Asia often occurs onto prime agricultural land, making it a real challenge to distinguish between fallow farmland and built-up areas, since both show high reflectance in visible-infrared wavelengths. This problem is even more serious in study areas where the farmland usually supports multiple crops per year with high inter and intra-year variability (Kontgis et al., 2014), for example, the Red River Delta and the Mekong River Delta in Vietnam. Urban mapping often demands the selection of an appropriate scale of observation. There is a certain trade-off between the detail of very high resolution remote sensing imagery and the generalizing nature of moderate to high resolution sensors such as the 30 meter of Landsat data (Griffiths, Hostert, Gruebner, & der Linden, 2010) as well as the temporal and spatial coverage. The long historical archive and continuing acquisitions is an advantage of Landsat data (Wulder et al., 2008) compared to very high resolution sensors. Therefore, Landsat data was considered the most suitable in our study.

Recent studies have shown that the use of several Landsat images can provide additional information on land cover types (Hilker et al., 2009; Huang et al., 2010; Kennedy, Cohen, & Schroeder, 2007; Verbesselt, Hyndman, Newnham, & Culvenor, 2010). The high image density of the stack allows for the detection of a change through its multi-temporal signature in spectral space (Schneider, 2012). Integrating multi-temporal information helps distinguish urban from non-urban surfaces as urban spectral responses are largely persistent over time compared to non-urban surface phenology (Griffiths et al., 2010). Capitalize on this strategy; we utilized dense stacks of Landsat TM and ETM+ images from 1993 to 2010. The satellite images were acquired from the Global Land Cover Facility (GLCF) archive at the University of Maryland (GLCF-UMD) and from the United States Geological Survey (USGS)-Earth Resources Observation and Science (EROS) Center. Hanoi capital is covered by 2 Landsat tiles: p127-r045 and p127-r046. To avoid the effect of scene noise on the classification describe below, we excluded cloudy and SLC-off scenes. Landsat images and dates of acquisition are listed in Figure 1.

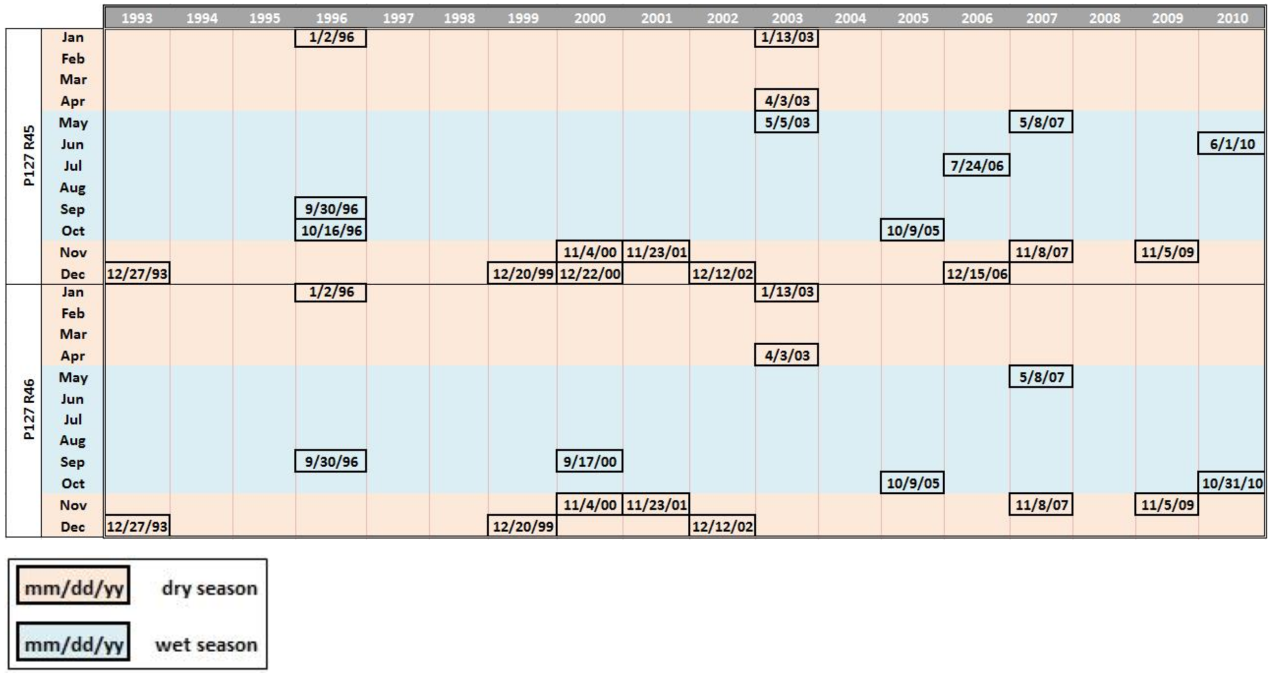


Figure 1: *Landsat scenes selected for multi-temporal image stacks*

To prepare the image stacks, we selected all visible and infrared bands (1-5, 7) of each Landsat and compiled them into a single image stack for each tile, then we subset each tile via Hanoi boundary.

The support vector machine (SVM) supervised classification was applied to the dense stacks of Landsat TM and ETM+ images for mapping the land use/cover of the study area. Note that radiometric correction was not performed since this step is only necessary when images are analyzed individually, but not simultaneously as we did here (Song, Woodcock, & Seto, 2001). The advantage of Support Vector Machine is that it can handle a large volume of data by processing a stack of multiple-year remotely sensed imagery at one time. In addition, SVM is a supervised non-parametric statistical learning technique, therefore, there is no assumption made on the underlying data distribution (Mountrakis, Im, & Ogole, 2011). Instead, they obtain their decision directly from the training data in a suitable space that is described by a kernel function. Although some studies have underlined that kernel selection can be crucial in the production of satisfactory classification accuracy by SVMs (Kavzoglu & Colkesen, 2009), very little guidance exists in the literature concerning the criteria to be used in selecting kernel-specific parameters (Carrão, Gonçalves, & Caetano, 2008; Li & Liu, 2010), that may need more expert judgment.

First, our classification scheme was formulated which includes seven classes: agriculture; built-up; forest; water; and three change classes (agriculture to built-up) between the time periods of 1993-2001, 2001-2006 and 2006-2010. We determined these three time periods in order to match them with the dates of the national census surveys for the convenience of comparison and combination of these two datasets. Our decision to use the above classification scheme was based primarily on photo interpretation of the high resolution imagery acquired from Google Earth, assisted by historical and present field photos and our familiarity with the study region from previously conducted work in the same site.

Second, ground truth points representative of each of the above classes were collected from visual interpretation of high resolution imagery from Google Earth and Bing Maps with an acquisition date close to that of our Landsat imagery following both random and strategic sampling strategies. Approximately, about 130 pixels per class (in total 927 pixels) were identified as the ground truth points representing the classes identified in our classification scheme.

Third, the SVM algorithm was implemented in ENVI 4.4 (Exelis Visual Information Solutions, Inc., Boulder, CO, U.S.A.) using the training dataset which was made by randomly-selecting a subset from the ground truth data collected during the previous steps. The SVM classifier has four kernels namely linear, polynomial, Radial Basis Function (RBF) and sigmoid. We chose the RBF kernel as it generally requires defining a small number of parameters and is also known to generally produce good results (Huang et al., 2008; Petropoulos, Kontoes, & Keramitsoglou, 2011).

After classification of each subset, we mosaicked them together and performed accuracy assessments based on the computation of the overall accuracy (OA), producer accuracy (PA), user accuracy (UA) and the kappa coefficient (Kc) statistic (Congalton & Green, 2008). Ten-fold cross validation was applied (Steele, 2005) to obtain relatively realistic accuracy estimates using limited number of reference data samples for both training and accuracy assessment. We randomly divided our groundtruthing data into training and validation samples with a proportion of 80% and 20% respectively. We repeated this process ten times to generate ten independent sets for training and validation. Then the classification and accuracy assessment were performed for each training and validation set. The average value of all validation iterations represents the estimated accuracy of the map. In reality, a ten-fold cross-validation allows the user to estimate the repeatability of the classification model. Our supervised classification was an iterative process (Figure 2) that involved evaluating the misclassified points, editing point labels and locations, and then re-running the classifier.

Once the classification was satisfied, several post classification steps were performed to produce final maps. Due to the seasonal change of the water level in the Red River, some of the alluvial plain areas were misclassified as built-up change classes. To resolve this misclassification issue, a raster layer of the Red River (Song Hong) for Hanoi was manually digitized as a mask then raster calculator was applied to merge the original land cover classification with the raster of the Red River. Many of the isolated built-up pixels falsely identified in agriculture areas were removed from the merged map, which was then smoothed with a 4 pixel-by-4 pixel majority filter. Last but not least, one of the disadvantages of SVM classifier is the "salt and pepper" effect (Fung, So, Chen, Shi, & Wang, 2008). Therefore, SVM classification is necessarily followed by post-classification methods, such as using the filter kernel, to reduce the "salt and pepper" effect on final classification result.

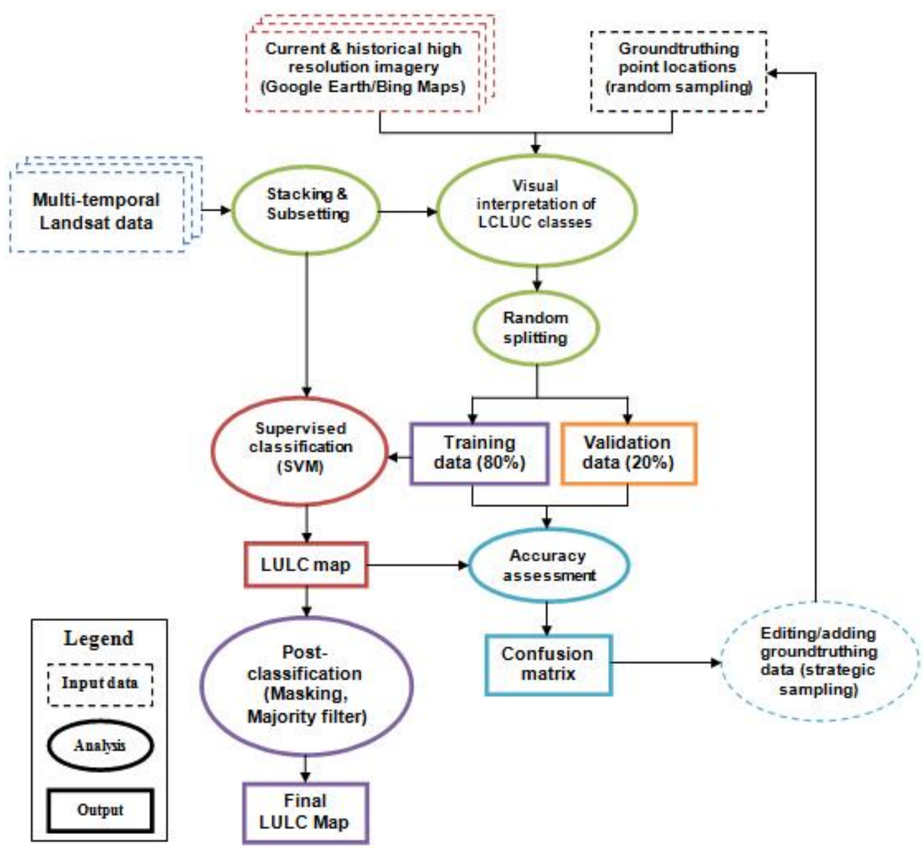


Figure 2: *Workflow for supervised classification*

3.2 Urban-rural gradient analysis

GIS-based buffer analysis was adopted in our research, which involved circular buffer zones surrounding the city center (Figure 3). Each buffer zone was employed as a basic spatial unit to characterize distance-dependent urban growth behavior. Urban-rural gradients have predominantly been quantified using concentric zones from the urban core outwards (Kroll, Müller, Haase, & Fohrer, 2012; Pillsbury & Miller, 2008; Sadler, Small, Fiszpan, Telfer, & Niemelä, 2006), and objective quantification using GIS methods (Hahs & McDonnell, 2006; Hunt et al., 2013; Lockaby, Zhang, McDaniel, Tian, & Pan, 2005; Luck & Wu, 2002; Williams, McDonnell, & Seager, 2005). In this study, we used a predefined urban core located at Hoan Kiem Lake, Hoan Kiem district as it is one among the first four urban districts of Hanoi. Then, twelve buffer zones of five-kilometer interval were created around the urban core until it completely covers the entire Hanoi boundary. We defined a five-kilometer buffer interval because the contiguous urban districts in 1993 (the beginning of study period) are encompassed within a radius of five kilometers. Within each buffer zone, we calculated the total amount of built-up area for each year, and the percentage of this total that comes from newly built-up land.

To reinforce our understanding of land use/land cover change around the concentric zone, we based classification of the communes into urban core, urban, peri-urban and rural areas on Saksena et al. (2014) (Figure 3). This classification system based on Simon Kuznets theory where the structural transition that accompanies economic development, emphasizing "the shift away from agriculture to non-agricultural pursuits and away from industry to services" (Kuznets, 1992, p. 89). Based on this theory, Saksena et al. (2014) selected a set of socio-economic indicators from the 2006 national agricultural, forestry and fishery census and vegetation density measured from MODIS Normalized Different Vegetation Index satellite data for their classification model. Post-analysis, the study characterized as rural, those communes primarily devoted to agriculture; as peri-urban, those communes with a mixture of agricultural and non-agricultural activities that often stretch along corridors between urban cores; as urban, those communes near urban cores with limited agriculture; and as urban core communes, where the 2006 agricultural census was not conducted because no households were known to practice agriculture (for a detail method, see Saksena et al. 2014). Within Hanoi, 106 administrative units were classified as urban core communes, 32 as urban communes, 230 as peri-urban communes and 206 as rural communes.

Within each categorization, we calculated the total amount of built-up area for each period, and the percentage of this total that comes from newly built-up land.

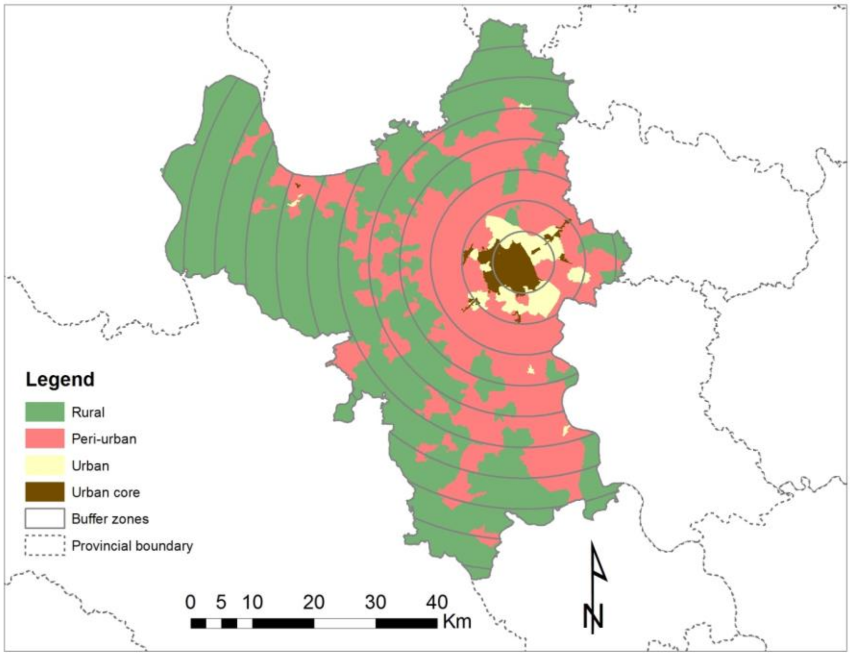


Figure 3: *Gradient analysis using 5 kilometer concentric buffer rings and commune categorization system*

4. Results and Discussion

4.1 Land use/Land cover Classification

Our resultant map of land use/land cover includes seven classes; agriculture, forest, water, built-up and three classes of change (Figure 4). The built-up land is pretty clear and well separated from other land cover classes. Many of the built-up areas appear as small "islands" surrounded by agriculture. In addition, the classification results showed numerous one-pixel outlying patches of change appearing in agricultural areas or "salt and pepper" patches that would lead to an overestimation of urban spatial patterns and configuration such as patchiness and fragmentation. This problem is quite common when using medium satellite image such as Landsat and was seen as a disadvantage of the SVM classifier (Fung et al., 2008). One solution to solve this issue is applying post-processing techniques, for example, using a sliding-window majority vote (Soergel, 2010). Here, we applied a 4x4 majority filter kernel. The land use/land cover map of Hanoi reveals that although Hanoi capital city is becoming rapidly modernized and the size of the city core is growing, the city's landscape is still largely occupied by agriculture.

The SVM classification of the land use/land cover for Hanoi resulted in a high overall accuracy ranging from 93.85% (kappa coefficient = 0.92) to 95.37% (kappa coefficient = 0.94). Compared with our previous study using similar method ((Castrence, Nong, Tran, Young, & Fox, 2014), we obtained higher accuracy in this study. This was accounted for by the richer historical archive of Landsat images and high resolution image in Google Earth in the study area that assisted us in labeling the land cover more accurately. Accuracies of each class vary; we found that three change classes (1993-2001; 2001-2006; 2006-2010) generally have lower accuracy than other stable classes (agriculture; built-up; forest; water) (Table 1). The problem is probably due to the seasonal changes of the rice cultivation cycle and water level in the Red River that causes the confusion between fallow/alluvial plain and change areas.

Table 1: Overall accuracy, kappa coefficient, and average producer's and user's accuracy values of the ten-fold cross validation for all land cover classes

Land cover classes	Prod. Acc.	User Acc.
Agriculture	95.60%	95.11%
Built up	95.34%	95.12%
Change 1993-2001	94.10%	93.86%
Change 2001-2006	93.01%	93.15%
Change 2006-2010	92.86%	92.85%
Forest	94.61%	95.61%
Water	94.90%	95.38%
Overall Accuracy	95%	
Kappa Coefficient	0.93	

There exist a relationship between accuracy and temporal coverage of the Landsat images where we found the higher temporal coverage often results in higher accuracy of that particular period. Therefore, our most recent change class, with lower temporal coverage, often has lower accuracy. Higher accuracy would have been achieved if more images have had been included in the analysis. However, we already attempted to include all possible scenes in our analysis. We had gaps in time because we omitted several cloudy and SLC-off images. Our decision was made based on Castrence et al., (2014) that shows the SVM classifier is sensitive to noise and missing data such as cloudy and SLC-off images. Even though, recent advanced remote sensing techniques may help to fill the unscanned gaps for SLC-off images and therefore provide a better temporal coverage, this would require a considerable amount of time and effort that is beyond the scope of our study.

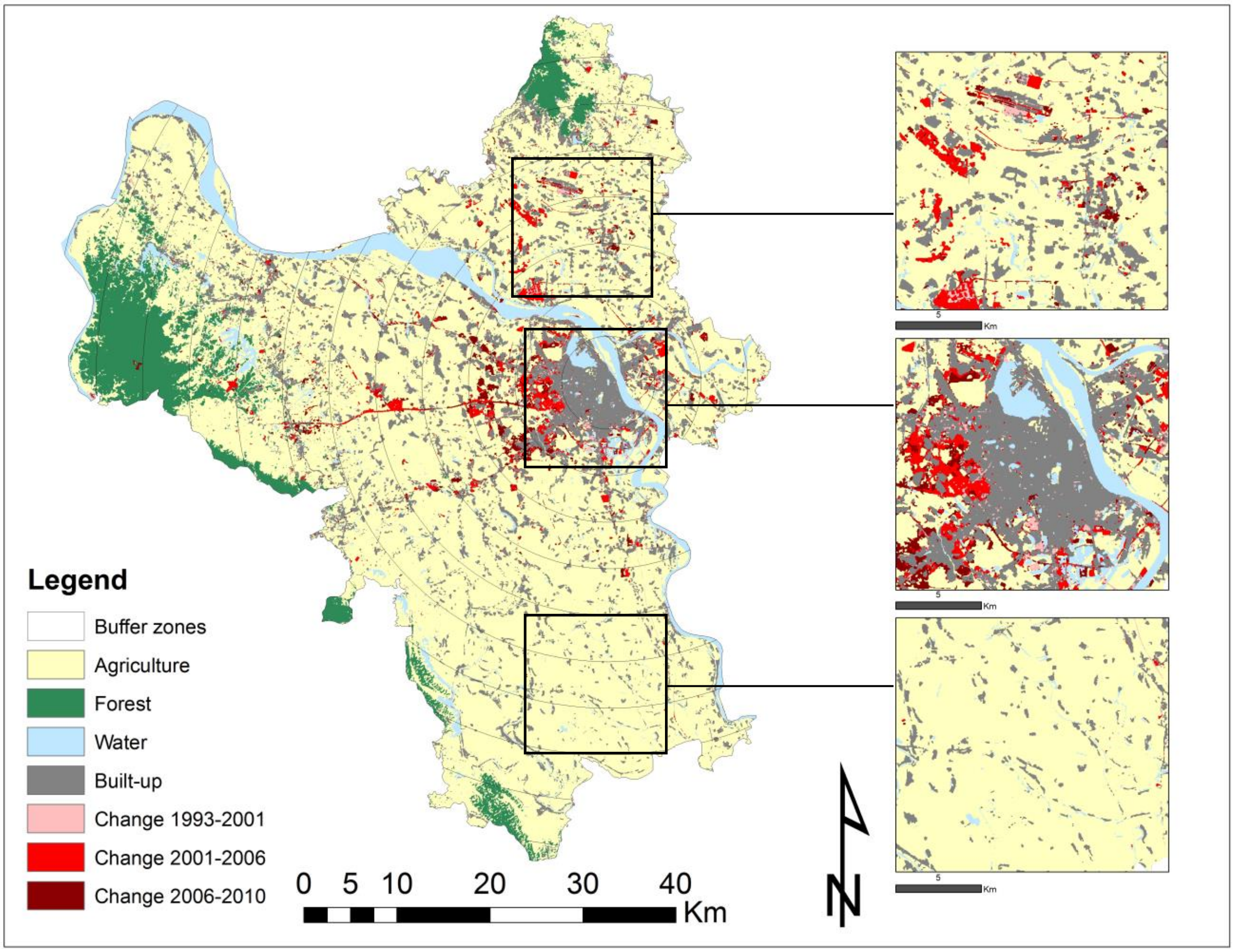


Figure 4: *Land use – land cover map of Hanoi capital city*

4.2 Urban-rural Gradient Analysis of Land use/Land cover Change in Hanoi

To summarize the number and type of communes in each buffer zone, we generated commune centroids using feature to point function in ArcGIS. We then overlaid the buffer zones on the commune centroid layer. The overlaid result of these two gradient approaches showed that within a radius of 5 kilometers, 91.1% of the communes are classified as urban core and none of them is rural. As the buffer rings move outward above 5 kilometers, we also observed that between 10 to 20 kilometers the number of communes in the urban and urban core categories became less and the number of communes in the peri-urban and rural categories grew. The number of peri-urban communes peaks between 10 to 20 kilometers. From 20 kilometers outward, the number of peri-urban communes reduces and the rural category starts rising and it peaks between 25 to 35 kilometers and remaining the majority in other buffer rings till it reaches the boundary (Figure 5).

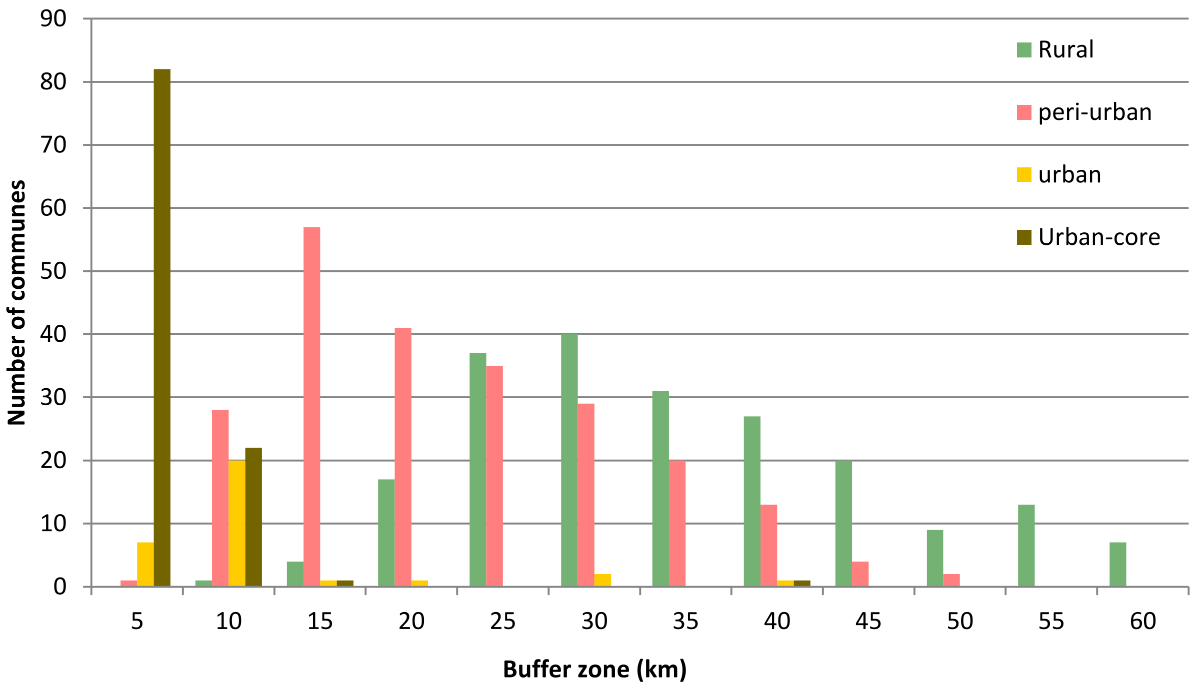


Figure 5: *Urbanicity along buffer gradients of Hanoi capital city*

(Include a table of the above graph)

It is clear that the urbanicity of Hanoi has an inverse relationship with distance from urban center. In 1993, the concentric zone of Hanoi was covered by 4 districts with an area of 47.27 km^2 (Vien et al., 2005). Overtime the urban core has been expanded to meet its growing demand as the cultural, social and economic center of Vietnam. In 2006, the urban core districts increased to 10 and covered an area of 228.55 km^2. Just in 2013, two new urban districts (Bac Tu Liem and Nam Tu Liem) were added to the core increasing the number of urban districts to 12 and covering 304.17 km^2. Along with the expansion of the urban core, the conversion of natural land to urban built up is rapidly occurring along the rural-urban gradient. To quantify the location and change of built up land overtime and along the rural-urban gradient, we used pre-defined buffer zones for the assessment. The result showed that the growth of built up area is occurring fastest between10 to 25 km radial zones (Figure 6).

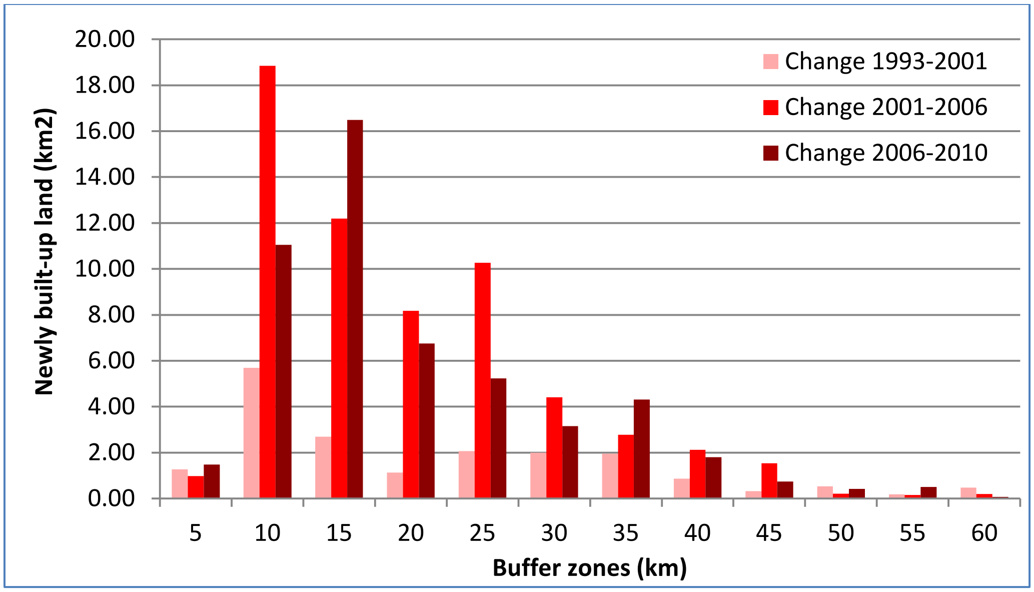


Figure 6: *Newly built-up land (converted from agriculture) along the radial zones for three distinctive periods*

Within 10 to 25km radial zones, the changes between periods are also distinctive difference; the largest growth has generally taken place between 2001 and 2006. The core zone (within 5 km) and over 35km radial zone have lower amount of change over the three periods and differences between periods are negligible. However, the question of whether the built up change in the radial zones conform to the change in different commune categories is worth to explore. We quantify the newly built-up land using the commune categorization by (Saksena et al., 2014).

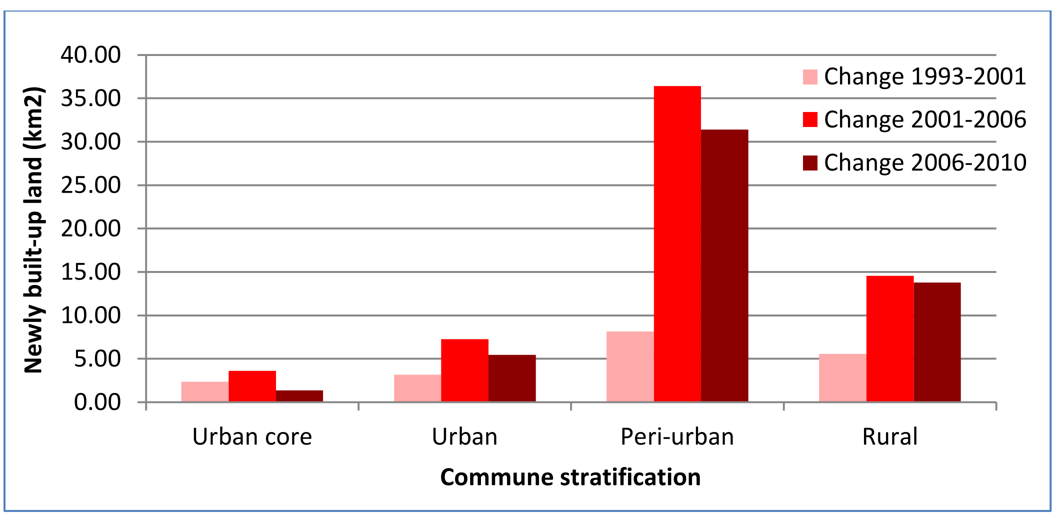
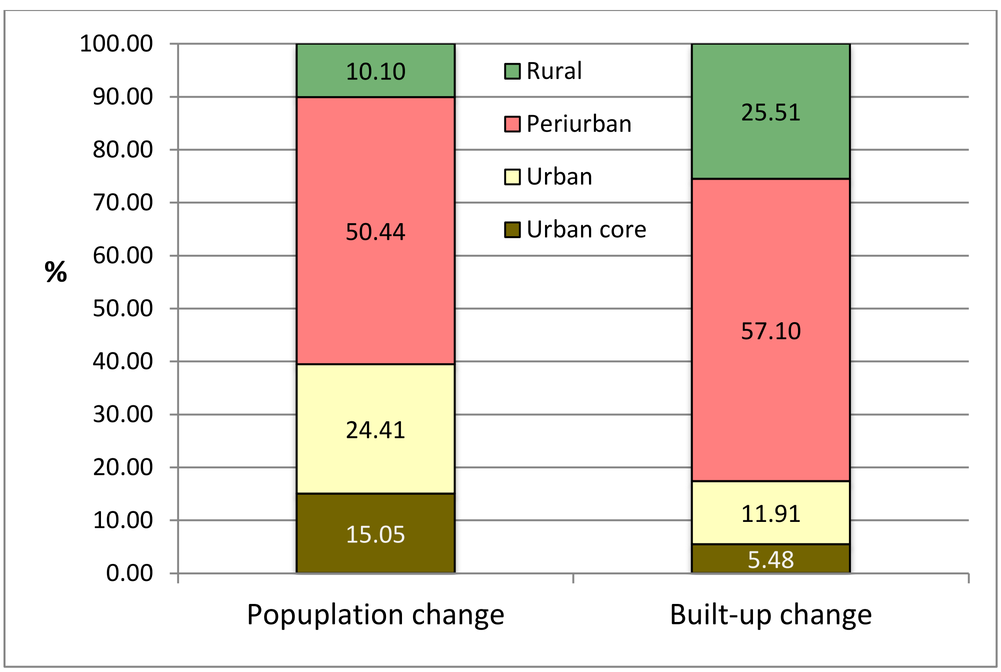


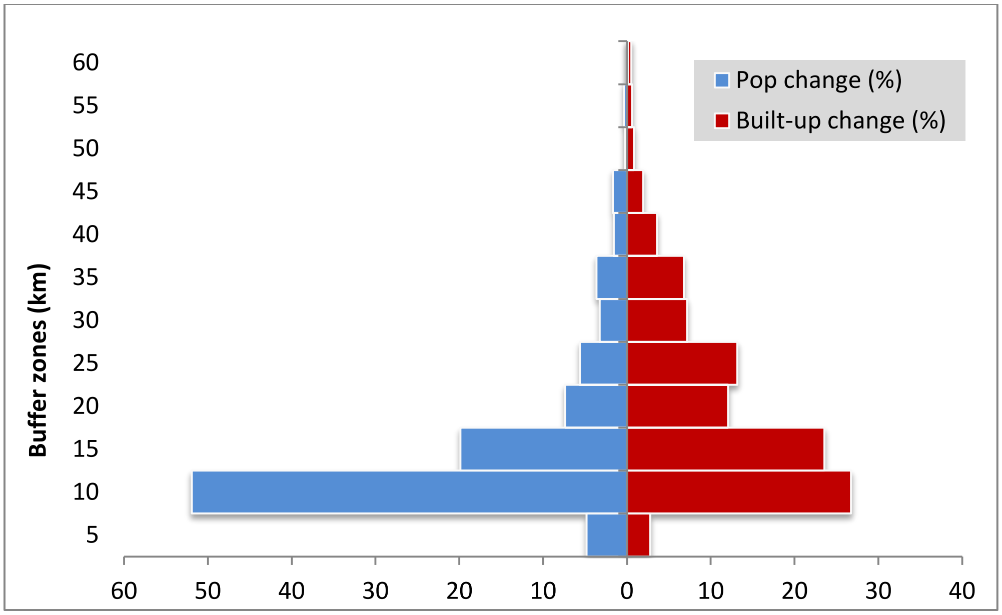
Figure 7: *Newly built-up land in different commune categories*

The result in Figure 7 shows that the urban core and urban communes experienced a very modest change over the three time periods and the growth in the peri-urban communes is standing out. Most of the changes occurred in between 2001 and 2006 in all commune types. The largest growth in the peri-urban communes is 30 times higher than that in urban core communes in the same period (2001 to 2006). Both our approaches of built-up change assessment reveal a distinction of urban growth in different commune categorizations and along the rural-urban gradient. This comparison proved that the urbanization in Hanoi is driven by both distance to the urban center and the socio-economic and natural characteristics of each every communes.

Together with the expansion of built up in peri-urban areas; a similar pattern of population growth is also seen in here. Data showed a relatively same pace of built-up and population change in peri-urban areas but a gap/disproportion in urban, urban core and rural communes (Figure 8A). According to the population and housing census, in ten years period, 1999 to 2009, population of Hanoi has increased more than a million people, of which over 50% was added to peri-urban communes (Figure 8A). Even though the population data was captured in a shorter time period, 1999-2009, within 0 to 10 km radial zones, the population growth exceeds the growth of built-up land which indicates an increase of population density in these intrinsically high density areas. Of the total amount of population and built-up change, the largest amount was added to the 10 km radial zone (Figure 8[B]).



[A]



[B]

Figure 8: *[A] Percentage of population change and built-up change in each commune categorization. Percentage was computed based on the total amount of built-up growth during the study period and total population increase between two census data. [B] Percentage of population change and built-up change in each radial zone. Percentage was computed based on the total amount of built-up growth during the study period and total population increase between two census data.*

This study showed that the development of Hanoi is closely linked with the growth of economy and population. The introduction of the *Doi Moi* policy in 1986 was a significant turning point into considerable transformation of Hanoi. The GDP of Hanoi increased 11.2 times in the period of 1985-2000 and 3 times between 2000 and 2008 (Labbé, 2010). The current target for GDP in 2014 is US $2,726. The city's poverty rate sharply decreased from 62.7% in 1993 to 3.4% in 2010 and the target of 2% poverty rate has been set for the year 2015 (Biau, D., 2010). The change of built-up land detected by remote sensing data is reflected in some economic values. For instance, increase in built up area is influenced by housing development on one hand and also industrial infrastructure development. The GDP growth for industry sector of Hanoi is estimated for 15% per year between 1996 and 2000 while agriculture GDP has gone down from 5.13% in 1996 to 3.8% in 2000 (Duong et al., 2003).

The expansion of Hanoi in both administrative area and the built up land over the last two decades was manifold. The urban growth of Hanoi is important to consolidate the city's position as the center of politics, culture, education, science, economics, and international exchanges of the country. In addition, the extended capital city is expected to contribute to the economic and functional development of the city by encouraging investment, including official development aid (ODA) and foreign direct investment (FDI), and by supporting the expansion and modernization of the surrounding infrastructure system. It is also expected to help accommodate the city's demographic growth and distribute the population outside of the overcrowded urban core (VET 2008). While the former expectation might be right, the later might not readily be an effect. The result in this study shows an increase of population density in the urban core area. Most of the new population in the city are rural migrants from neighboring provinces, with a minor share of natural growth (Labbé, 2010). The increase was spontaneous due to the migration to the cities by farmers who have lost their land and employment (Quertamp & de Miras, 2012).

During the 1990s, large scale conversion of agricultural land to urban land was tightly restricted and controlled by the state; requiring approval from the Ministry of Natural Resources and Environment. At the beginning of the 2000s, the state relaxed its power on the management of these lands and, in 2006, decentralized to provincial and municipal governments (Labbé, 2010). This stimulated a real estate market boom all over Hanoi's peri-urban areas. In the same vein, by the late 1990s, the central government has ratified an orientation for general planning of urban development in Vietnam up to 2020 with the goal of fostering economic development (Decision 10/1998/QD-TTg). This decision has promoted urban expansion on rural hinterland through the conversion of agricultural land to urban land (industrial development, new housing for migrant workers) and revitalization in slum areas (displacing slum dwellers into public housing complex). Whether urbanization was planned or not, these state policies have immense consequences for local communities (formerly farmers, or formerly slum dwellers, or new migrant workers arriving from other areas of Vietnam). By the late 1990s, central and municipal authorities developed an urban development model referred to as "new urban areas" (khu đô thị mới, hereafter NUAs) (Waibel, 2004). Some of the prominent ones are the new urban area Trung Hoa – Nhan Chinh, My Dinh II, Nam Trung Yen or Dinh Cong Living Quarters which were built within 10km of the historic center (Labbé & Boudreau, 2011; Waibel, 2004). These NUAs were mainly built between 2000 and 2005 and some of which are still under construction. To ensure accessibility, public policies required that 30 to 50 percent of new housing units built in NUAs be accessible to a low-income population. However, price of low income apartments is still too far to reach by majority people those are considered as low income. In addition, criteria and procedures to buy "low-income apartments" (Nhà thu nhập thấp) were too intricate and restricted to only those who are permanent residents of Hanoi, ironically, in order to register as a permanent resident of Hanoi, one have to have a house. Recently, Hanoi's People Committee has loosened the criteria by including those who have registered as temporary residents for more than 12 months with a labor contract of more than12 months. This is to say rural migrants/land lost farmers from neighboring areas or other provinces that are in the informal or private sectors and illegal migrants are likely to be disqualified. This makes the urban and urban core of Hanoi to turn into a marginal settlement zone with slum-like buildings and become the destination of impoverished city residents as well as rural migrants (Boothroyd & Phạm, 2000). Consequently, the flood of population to the urban and urban core for the convenient of work and service makes this area particularly high density.

5. Conclusion

The goal of this study was to characterize the built-up change for Hanoi capital city between 1990s and 2010s using SVM classification of multi-temporal Landsat image stacks. Our supervised non-parametric statistical learning techniques of SVM produced an highly-accurate map of land use/land cover change with the overall accuracy of 95%. We found that built-up areas in Hanoi have expanded rapidly over the last two decades. Especially, most of the change occurred between 2001 and 2006 and between 2006 and 2010 which correspond to major policy changes in the beginning of 2000 when the state relaxed its grasp on the management of the land and, in 2006, decentralized the power to approve and convert land uses down to provincial and municipal governments stimulating a real estate market boom all over Hanoi's peri-urban areas. A growing part of Hanoi's economic growth also comes from FDI which consequently goes to industrial and infrastructural development projects in the peri-urban areas. In 2008, Hanoi received close to US$18.8 billion in FDI, accounting for 7% of the total investment in Vietnam (HSO 2009: 222). Several housing development projects between 2000 and 2005 also contributed to the expansion of the city between 10 to 15km to the West and Southwest portions. Since major source of urban expansion in Hanoi came from cropland, large rural population has been squeezed out of the agricultural sectors and became unemployed. Therefore, massive migration to city in searching for alternative incomes is indispensable if social welfares and post-urbanization plan for these people are not taken into consideration and if the urbanization is haphazardly taken place. The analysis is supported by other statistical data such as the population structure of Hanoi over the years. Through this study, an implicit correlation between the urban growth, the trend of spatial expansion of the city and other relevant geographic and socio-economic features can be proposed. Knowing how, where and when the urbanization occurred would allow urban planners and decision makers to timely evaluate and adjust accordingly the urban growth and be aware of the sustainable usage of the invaluable nature lands and other environmental, social and economical problems.

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