USING SATELLITE IMAGERY TO STUDY SPATIAL URBAN EXPANSION OF HANOI CITY

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ABSTRACT

Urbanization results in the expansion of administrative boundaries, mainly at the periphery, ultimately leading to changes in landcover. Agricultural land, naturally vegetated land, and other land types are converted into residential areas with a high density of constructs, such as transportation systems and housing. These changes can be identified by comparing satellite images acquired at different time periods. We analyzed satellite images from Landsat MSS (1975), Landsat TM (1993) and Landsat ETM+ (2000) for Hanoi, Vietnam. In addition, other images, including Aster, Ikonos, and QuickBird images, and a number of historical maps were also used to help identify differences between high and low construction densities in the inner city and periphery. The results indicate that the spatial growth of Hanoi is limited by natural barriers, such as streams to the northeast and east, water bodies to the north, and wetlands to the south. Spatially, expansion of the urban center stretches in obvious directions, and urbanization has taken place along main transportation axes connecting the inner city to neighboring areas, whereas the administrative boundaries have extended into other directions.

***Keywords**: Urbanization, Spatial city expansion, Land cover change, Remote sensing*

1 INTRODUCTION

Located along the right bank of a bend in the Red River, in the center of the river delta, Hanoi represents the center of development for north Vietnam in terms of its economy, society, and urbanization. Hanoi has a long history of development spanning thousands years; the core city, called the Ha Noi Citadel, was once the capital (Thang Long) and now covers

about 120 hectares. The growth of Hanoi has occurred in stages, gradually expanding into the surrounding area to reach its current size and spatial distribution. The boundary of the city currently extends to the north side of the Red River; the total area has increased to 921 km^2, and the urban population was estimated at 3 million in 2003. Hanoi now comprises nine inner districts and five peripheral districts located on both sides of the river (Fig. 1). Three suburban districts totaling 667 km^2 span the north side, and urban areas of 257 km^2 comprise seven inner districts plus two suburb districts along the south side. Four of these districts, Ba Dinh, Dong Da, Hai Ba Trung, and Hoan Kiem, are considered the core urban area of Hanoi. Other suburbs were once agricultural areas that provided the city with food.

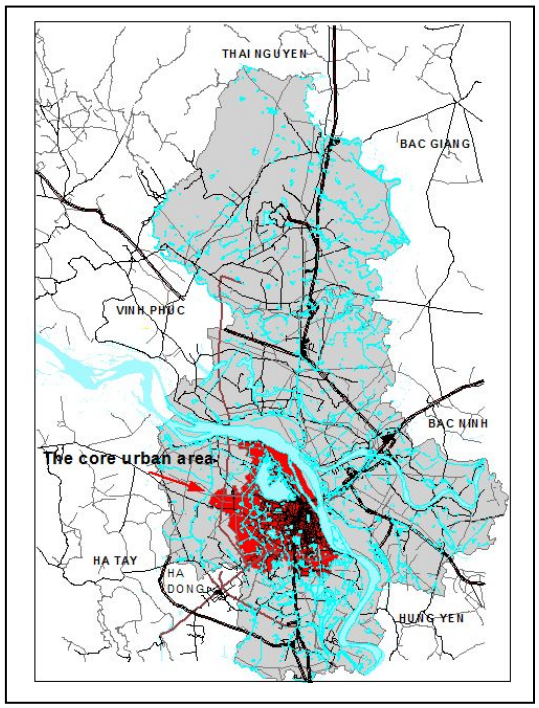


Figure 1: Hanoi and surrounding areas

Factors that are relevant to the development of a city, in terms of spatial expansion and urbanization, include physical features, vegetation coverage, water surface, infrastructure conditions (roads and streets), and housing construction. These factors change with increased urbanization, and are usually considered key parameters for studying urban development. In terms of landcover, these factors can be recognized by analyzing remotely sensed data.

Various studies have investigated urbanization in the Hanoi area. Douglas et al. (2002) considered urbanization a process of transition from an ancient city to a modern one, particularly a conversion of cultivated land into settlement sprawl. Two indicators were used in the study: population density according to levels of urbanization, and vegetation cover based on the Normalized Difference Vegetation Index (NDVI) from Landsat data. Small et al. (2004) used Landsat and nighttime data sets to identify the possible relationships between light intensity and urban areas. They found different linear relationships for periods between 1992 to 2000. Pham Van Cu (2004) used Aster data to detect urban changes based on an analysis of thermal bands. Waibel (2004: 31–45) focused on the urbanization process of Hanoi through various periods corresponding to urban management practices, from ancient quarters in previous centuries to modern planned-development periods.

The current road and street system of Hanoi, reported by Tran Tuan Hiep (2004), is such that the inner city has 359 streets with a total length of 254 km. The average street density is about 3.01 km/km^2. The road density is unevenly distributed, and is highest in the Hoan Kiem district (10.28 km/km^2); other districts have much lower road densities, ranging from 1.10 km/km^2 (Tay Ho) to 4.64 km/km^2 (Ba Dinh). Green spaces in Hanoi, including urban trees, parks, water bodies, and other spaces, cover approximately 20 m^2 per person, and green tree space alone does not exceed 2 m^2 per person. Large lakes cover about 550 hectares. Satellite images have revealed that the four inner urban districts of Hanoi lost 12% of treed areas and 64.5% of the water surface area of ponds and lakes but experienced a 22.4% increase in residential area in 10 years of development, from 1986 to 1996 (Vietnam Association for Conservation of Nature and Environment, VACNE 2006). Urbanization results in the expansion of administrative boundaries, stretching in various directions and

leading to changes in land use and landcover, mainly at the periphery. Agricultural lands, natural vegetation, and other sites are converted to residential areas with enhanced transportation systems, increased housing density, and lost green space (Tran Mai Anh 2005).

Most previous studies on the urbanization of Hanoi, some using satellite data, have focused only on land use/landcover changes related to economical activities, city management policies, and spatial urban planning (Douglas et al. 2002). Other aspects, such as spatial patterns of urban growth related to construction density, particularly of housing and roads, have not yet been considered. To better understand urbanization in Hanoi, we addressed the spatial expansion of Hanoi over time, considering the pattern of spatial urbanization related to physical features and construction density, by analyzing satellite images and ancillary data.

2 METHOD

2.1 Data

We used tourist street maps from 1996, digital street maps, and scanned historical maps of Hanoi from 1902, 1915, and 1942 at a scale of 1:10,000 and from 1936 at a scale of 1:20,000. These old maps were obtained from the Thang Long Project.

The satellite data used are summarized in Table 1.

Table 1: List of satellite images

No.	Satellite data	Date	Spatial resolution	Sources
1	Landsat MSS (WRS1, scene no. p136r45)	29/12/1975	57 m	Global Land Cover Facility - NASA Program
2	Landsat TM (WRS2, scene no. p127r45)	27/12/1993	30m	
3	Landsat ETM+ (WRS2, scene no. p127r45)	04/11/2000	28.5 and 14.25m	
4	Aster	13/01/2003	15 and 30m	Thang Long Project, Center for Southeast Asian Studies, Kyoto University
5	Ikonos (composed natural color)	2002	1m	
6	QuickBird (composed natural color)	2005	0.6m	

2.2 Method

All maps and satellite images were georectified in a UTM projection, datum WGS-84. To facilitate the comparison of landcover changes, the pixel sizes of the images were spatially resampled following the Landsat ETM^+ resolution of 14.25 m (panchromatic band). This spatial size was selected based on the minimum mapping unit that yields the highest

spatial resolution from a satellite data set (Jensen 1996), excluding the Ikonos and QuickBird data. Scanned maps were treated as images, and were also georectified with the UTM projection, but resampled at 1 m to maintain the map's details.

To identify patterns of urban expansion, particularly the actual boundaries of the city, we used individual indices derived from band ratio calculations, instead of focusing on the classification of land use/landcover for each date. The indices were computed as follows:

- NDVI was calculated from red and near-infrared spectral bands.

- A Water Index was used to separate land from water. The index was created by calculating a band ratio between bands with wavelengths of 1600 nm (middle infrared) and 520–600 nm (green) to identify water bodies, particularly changes in streams. We used bands 5 and 2 of Landsat TM and ETM, and bands 4 and 1 of Aster (MSS images were not used for this index). Following Remote Sensing Engineer Manual, US Army (2003), we have

Water Differrence = middle infrared band/green band

The NDVI and Water Difference images were layer-stacked to create images of NDVIs and Water from 1975 to 2003.

To determine the direction of urban expansion, street density was computed based on the digitized street map. Using a geographic information system (GIS), a street layer was spatially divided into squares of 1 km^2, and the total street length was calculated in these sections.

Street/Road Density (km/km^2) = Street/Road Length (km) / 1 Unit of Area (1 km^2).

To supplement the identification of roads and housing density, the signatures of Landsat ETM, TM, and Aster were compared to Ikonos and QuickBird. To identify the borders of the city prior to 1975, the historical maps were compared to each other and to satellite images from 1975. The boundary of the Hanoi urban area is delimited by the Red River to the east and northeast and West Lake to the north; the To Lich River to the west, an area with an observable difference between the construction-dense urban area and the surrounding agricultural lands; and wetland/swamp areas and agricultural lands to the south.

3 RESULTS

3.1 Hanoi city development in different periods

Before 1936 and 1936–1942

The growth rate of Hanoi during this period was slow, as indicated by its size. The western border was less than 3 km from the Red River, delimited by a train station, and the southern limit was about 4 km from West Lake (Van Ho area).

1942–1975

In the 1975 image, the boundary of Hanoi is not obvious, because there is little difference between the urban core and the surrounding areas. In this period, Hanoi had a high rate of vegetation cover, represented in the MSS image by a greenbelt and large green

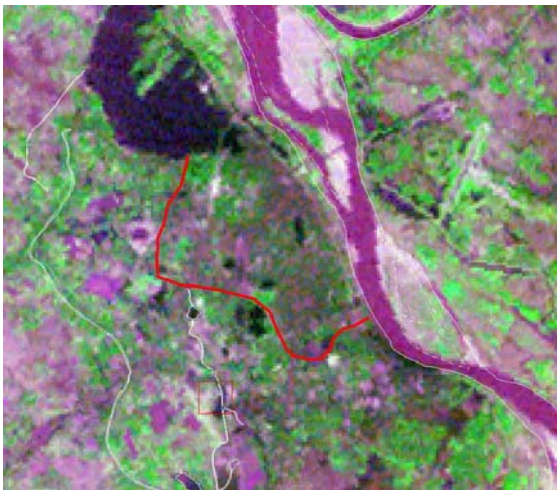
clusters within the city (Fig. 2a). Compared to the map of 1942, the urban size did not increase much.

1975–1993

A significant expansion of the urban area occurred during this period, extending far to the To Lich River in the west and the swamp area in the south. To the north, the urban area reached West Lake, and growth occurred along main transportation axes. The urban area expanded about 6 km from the Red River to the west and 8 km from West Lake to the south (Fig. 2b).

1993–2000 and 2002–2005

The urban space and direction of expansion are obvious in a composite image of NDVIs from three dates (Fig. 3a). A gradual transition from suburban to urban occurred at the periphery. From 2000 to 2003, the western border crossed over the To Lich River. Urbanization occurred around West Lake and along the north side of the Red River in the Gia Lam area. Analysis of Ikonos (2002) and QuickBird (2005) images also indicated that new buildings were constructed in areas that were formerly agricultural land or lakes. In particular, parts of West Lake to the north were filled in.



a. Hanoi in 1975

b. Hanoi in 1993

Figure 2. Hanoi satellite images in 1975 and 1993

3.2 Spatial features of Hanoi urban

Geographically, Hanoi area is situated at the right side of the Red river and it is subjected to flow regime and landform made by this stream. The Red river is characterized with many bends, low levees, shallow channel, irregular flow and stream channel has changed many times. Flooding often happens in rainy season at high water period from June to October. Within the floodplain of the river there are many oxbow lakes, marshes located at different river sections. Topographically, average elevation of Hanoi area is about 0 to 2m (asl.), which in dry seasons equals to water level of the river that raises many times higher in rainy seasons. Under this situation, Hanoi is almost lower than the river and would suffer floods without means of prevention. In order to protect Hanoi from flooding, a system of

dikes was constructed along the two river banks and these almost become new shorelines, from which the distance to river bank can reach 1-2km depending on local topography of river segments.

Preliminary located in the river floodplain, by the West lake - the largest natural lake in the area - and the Red river, Hanoi has extended toward opposite directions. These two water bodies become a natural border at the north and east parts of Hanoi. A large marsh, swamp area at Van Dien-Thanh Tri district is the farthest part southward of Hanoi. To Lich river, running from the lake to south is considered as the first border for the Hanoi urban and Nhue river as the farther second one for the city westward. These are illustrated in Figure 4, which is a color composite for Water Differences of 1993 in blue, 2000 in green and 2003 in red. In general, space of Hanoi at the west and southwest is more open to expand than at the north, south and east direction, which are restricted by large water bodies and marsh area. This is observable as analyzing old maps and satellite imageries, which indicated that border of Hanoi urban has been gradually stretched over west and southwest.

3.3 Construction features of Hanoi

Road and house density were considered as construction features of Hanoi urban and these were combined with house size and green space regarding to land cover. Integration of these makes observable signatures on satellite imageries of medium spatial resolution such as Landsat and Aster. Particularly, when QuickBird and Ikonos images were used, these features were evidently differentiated. Based on analyzed results of satellite images, these features can be basically classified as the following types, reviewed in Table 2.

Table 2: Construction features of Hanoi urban

No	Type	Features				Distribution
		Houses	*Roads*	*Green space*	*Pattern*	(typical)
1	High Density	Small, dense	narrow, short	Low	unique, compact	Ancient quarter (excluded the Citadel), north Hoan Kiem lake, west Hang Co train station, Van Chuong lake area
2	Medium Density	Large, tall buildings	Larger than "1"	High, tall trees	regular, square	south Hoan Kiem lake,
3	Mixed Density (low and high)	Small and large. large block	small, main road, long	Medium	Irregular pattern, mosaic type	urban fringe, cultivated areas at suburban, zones constructed before 1995

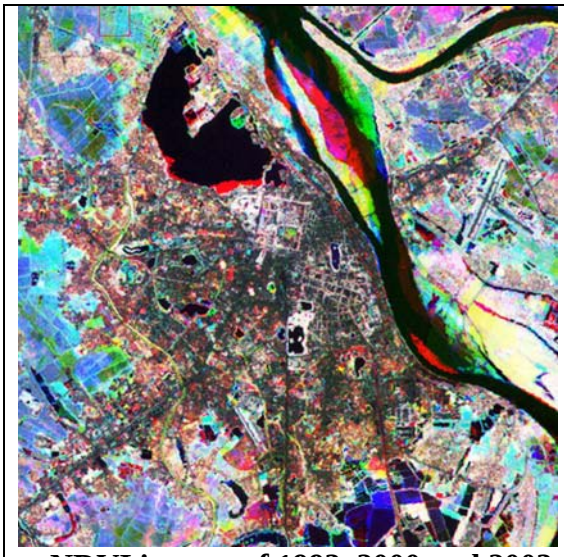
- High density: coverage of green space and urban trees (along street) are very low. Small houses, very short narrow streets, distance between two intersections less than 200m

are the features. Spatial structure is stable and compact. All these make a relatively unique spectral reflection on satellite imageries.

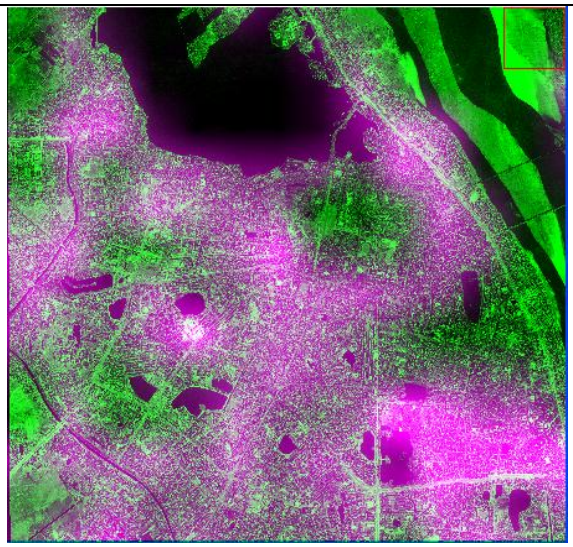
- Medium: All features of the above type is similar but spatial patterns is more regular with square quarter, larger size houses, higher density of urban trees. At some places, small houses are replaced by tall buildings.

- Mixed: small houses and tall, large buildings are mixed together at the urban fringe. Green space remained from cultivated land. Large new blocks of buildings and small houses distribute alternatively creating mosaicked, irregular patterns between high and low density.

It is noted that the space from the main dike toward river bank can be considered as an improper corridor for urban development, but housing density is still very high similar as type 1. The Citadel area is not classified in any category as it retains most urban trees including parks. Two areas of type 1 are connected together via the train station and they form one of the main axes of urban growth to the environs. At the north of the West lake, a new direction of growth has been emerged and it surpassed the administrative border of the urban core.



a. NDVI images of 1993, 2000 and 2003



b. Road density of Hanoi overlaid on Ikonos image.

Figure 3. Shape of Hanoi urban and main road axes.

4 CONCLUSIONS AND RECOMMENDATIONS

Over periods, Hanoi urban has greatly expanded to the west and southwest. Although Hanoi urban initially located by the West lake, its space has passed over the north side of the lake in recent years. Until 1993, landcover types around the lake mainly were cultivated land. Until 2000 and then 2003, 2005 at this fringe area agricultural land type has still remained and simultaneously newly constructed large and tall buildings have encroached, indicating that urbanization is in progress.

Urbanization of Hanoi largely occurred in 1993–2000, and continues today at a low rate and primarily on the south side of the Red River. To the north, growth is limited by West

Lake. Two main growth axes run in the northeast–southwest and northeast directions. The current development of the city does not match the city master plan.

Our results indicate that the spatial growth of Hanoi is limited by natural barriers, such as streams to the northeast and east, water bodies to the north, and a wetland to the south. Spatially, the expansion of Hanoi stretches in obvious directions, and the urbanization process follows main transportation axes connecting the inner city to neighboring areas, while the administrative boundaries have expanded in other directions.

A combination of index images is very useful for detecting changes, urban margins, and physical limits, particularly to identify urban borders. The combination of indices used in this study illustrated a large difference between the urban center and the surrounding areas. The water index combination can help detect changes in streams, such as the Red River, which represents a significant northern limit to urbanization. However, this index was unable to identify small water bodies within the urban area, due to shadows cast by tall buildings, which were confirmed by a comparison to QuickBird and Ikonos images.

To validate and confirm these results, it is necessary to analyze more high-resolution satellite images, such as Ikonos and QuickBird, from which information on housing density can be extracted. Such an analysis would support the identification of growth patterns of Hanoi over time.

5 ACKNOWLEDGMENT

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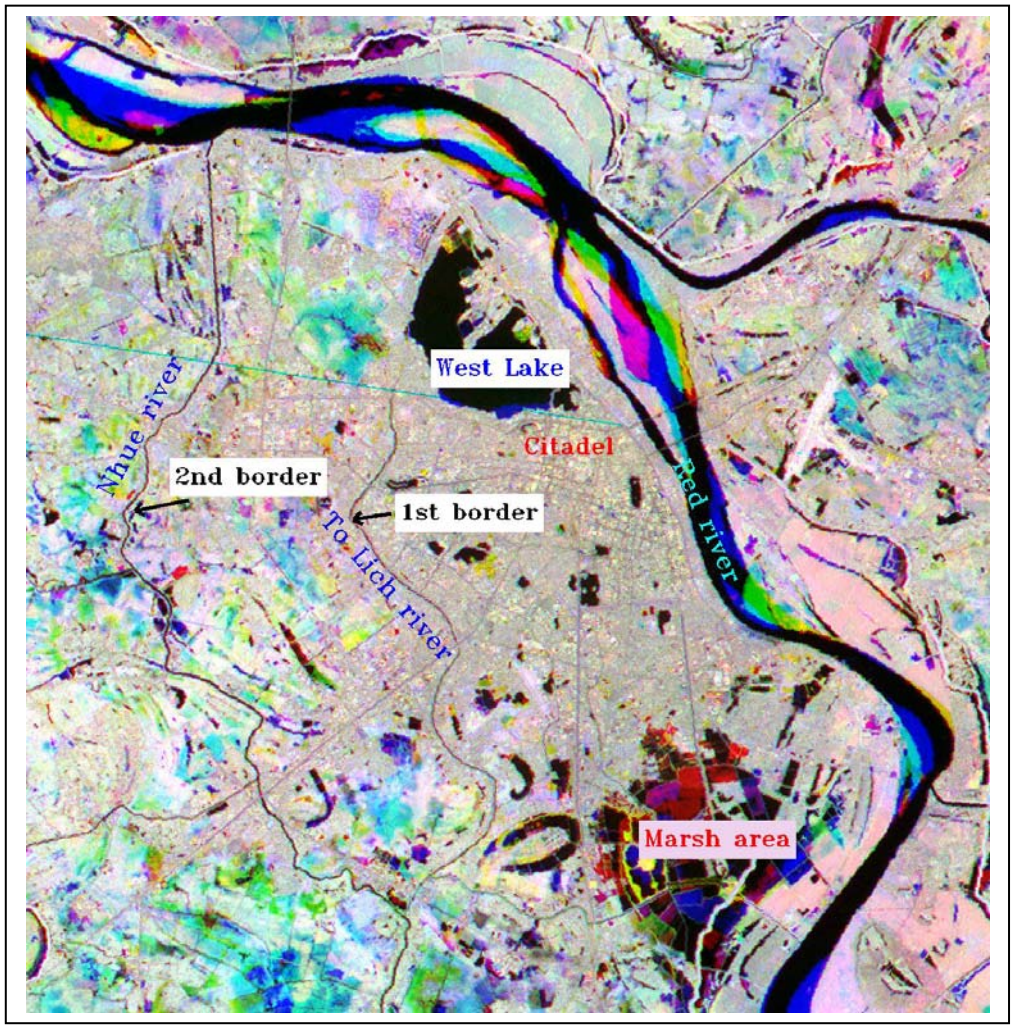

Figure 4. Color composite of Water Differrences in 1993 (blue), 2000 (green) and 2003 (red).