Studies on Hanoi Urban Transition in 20th Century Based on GIS/RS

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STUDIES ON HANOI URBAN TRANSITION IN 20th CENTURY BASED ON GIS/RS

Ho Dinh Duan[1] and Mamoru Shibayama[2]

1 Introduction

Hanoi city, the capital of Vietnam, was founded in 1010 under the name Thang Long, has been always the political and cultural center of the nation. The name Hanoi was first given to the city in 1831 by Minh Mang king. Almost thousand years has passed since its establishment, and Hanoi has changed drastically through different periods in the country's history. One aspect to study the history of Hanoi, which can significantly give insights into the political and socio-economic development of the city, is to study its spatial expansion through the urbanization process. This, in connection with other historical data, can efficiently enhance the analysis of the city's urban transition through different periods of time.

In this work we focus on the urbanization process of Hanoi during the 20th century utilizing the methods of GIS and Remote Sensing. The data sources for the study compose of various historical maps, recent maps, satellite imageries as well as other ancillary data. The period from early 1900's to 1974 is studied based on historical maps and gives a rough picture about the spatial expansion of the city. As for the period from 1975 to 2005, maps and satellite images are available and we can carry out the study to some depth.

Hanoi has a long history of development spanning almost a thousand years. Nowadays the once core city of Hanoi (Citadel) covers only about 1.2 square kilometers. In fact, from the very beginning of Thang Long, the citadel and the adjacent commercial area (the Old Quarter) were merged together to form the capital city. This conjunction justified the Eastern expression *"thành thị"* which means a combination of a citadel (administration and defense settlement) and a business place (Phan Huy Le 2005). During this time, the city is bordered to the east by the Red River and to the west by the To Lich River (Figure 1b). 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 has extended in all directions, but mainly to the South, Southwest, West, and later to the East (crossing the Red River). The city's expansion in the past has been influenced very much by the natural barriers such as rivers, lakes and swamp areas. Until recently, the total area has increased to 921 km^2, and the population was

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estimated at 3.15 millions (2005 statistics). Hanoi now comprises nine inner districts (*"Quận"*) and five peripheral districts (*"Huyện"*) located on both sides of the Red River. The most significant enlargement of the city occurred in 1961 after the nation's three-year plan to make Hanoi into an industrialized city. 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 provide foods for the city.

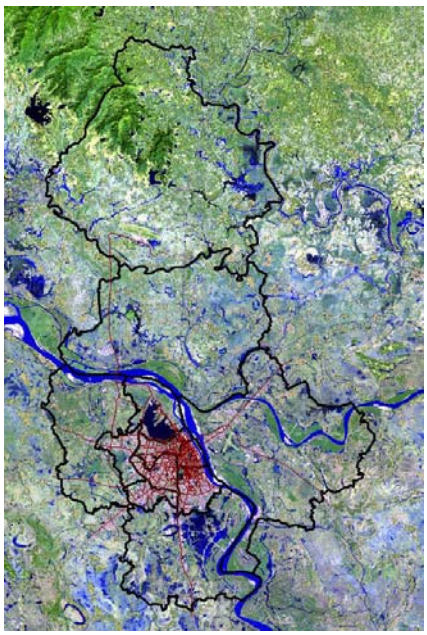


Figure 1a. Hanoi administration boundary (2002) with inner city road network overlaid on Landsat satellite image (2000).

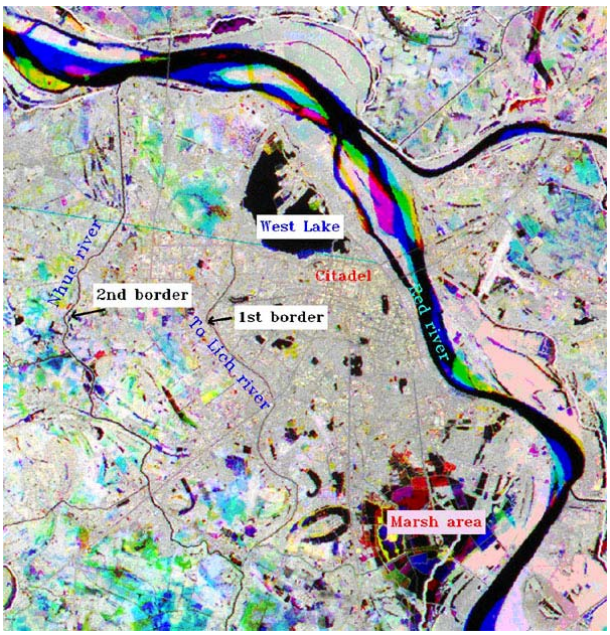


Figure 1b. Red River (east), To Lich River (west) and a marsh area (south) have been natural barrier against old Hanoi city expansion. Color composite of Water Indices in 1993 (blue), 2000 (green) and 2003 (red).

Factors that are relevant to the development of a city, in terms of spatial expansion and urbanization, include physical features such as 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 landuse/landcover change, these factors can be recognized by analyzing maps and satellite images. We have included in this study two parameters namely the road density and house density, explained in section 3.

This paper studies the spatial urban growth of Hanoi and analyzes its pattern and trends; related parameters such as road density, housing density and remote sensing derived indices namely the Normalized Difference Vegetation Index (NDVI) and Water Index have also been considered. The availability of our satellite data (Landsat, JERS, ASTER, Ikonos and Quickbird) in different dates

from 1975 to 2005 allows us to address the spatial expansion of Hanoi over this period, in an integrated approach combining remote sensing, GIS and analysis of ancillary data. In our satellite image analysis, the Landsat MSS, TM, ETM and ASTER imageries were used principally for mapping landuse/landcover changes, whereas the radar JERS and high resolution Ikonos and Quickbird images were used as supporting data. These remote sensing data and methods were applied for mapping the urban growth of Hanoi in the period 1975-2003. To study the urban transition of Hanoi in the earlier period from the 1900's to 1974, historical maps were used. The maps were scanned and carefully georeferenced based on the best ancillary data we have got, however due to its fuzziness nature, the results can only give a rough picture on the continuous expansion of the city in this earlier period. All together, the series of snapshots on Hanoi urbanization could help understanding its development throughout the 20th century.

2 Study on Hanoi urbanization and the use of remote sensing

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 2003 population was 3 million in which 1.8 million was classified as urban population. Hanoi now comprises nine inner districts and five peripheral districts located on both sides of the Red River. The five suburban districts (Soc Son, Dong Anh, Gia Lam, Thanh Tri and Tu Liem) encompass the city area of Hanoi which comprises nine districts occupying about 28% of the total Hanoi administration area. Four of these districts, Ba Dinh, Dong Da, Hai Ba Trung, and Hoan Kiem, are considered the core urban area of Hanoi. The peri-urban areas have been gradually converted and conjuncted to the city, but a large portion still remains as agricultural land and play an important role in supplying food and other agricultural products for Hanoi (Thapa et al. 2004).

The population of Hanoi is not evenly distributed between the inner city and its surrounding areas. In early 1950’s, the total population of Hanoi was about 217,000 in which 80,000 people were living in the inner city (37%), but this inner city covered only 8.5% of Hanoi area. In 1960, the urban population of Hanoi rose to a remarkable figure of 71%, which could have been a consequence of the first important urbanization of Hanoi after the Indochina war. This followed a 3-year plan 1958-60 of the D. R. Vietnam in order to boost up an industrial-based economy. The large urban population and achievements in economic growth also implied that in the next year (1961) the government has made a decision to greatly expand the administration boundary of Hanoi to a total size of 461 square kilometers (previously it was 152 square kilometers). This can be considered the first significant expansion of Hanoi in terms of administration boundary. During

this 3-year period, Hanoi has created industrial sites throughout the city (in-fill urbanization) but especially in the outskirts (expansion). Outlying quarters like Bay Mau and Van Ho were converted to urban and new residential areas sprawled along industrial sites. A great deal of water surface has been converted to built-up areas in these years.

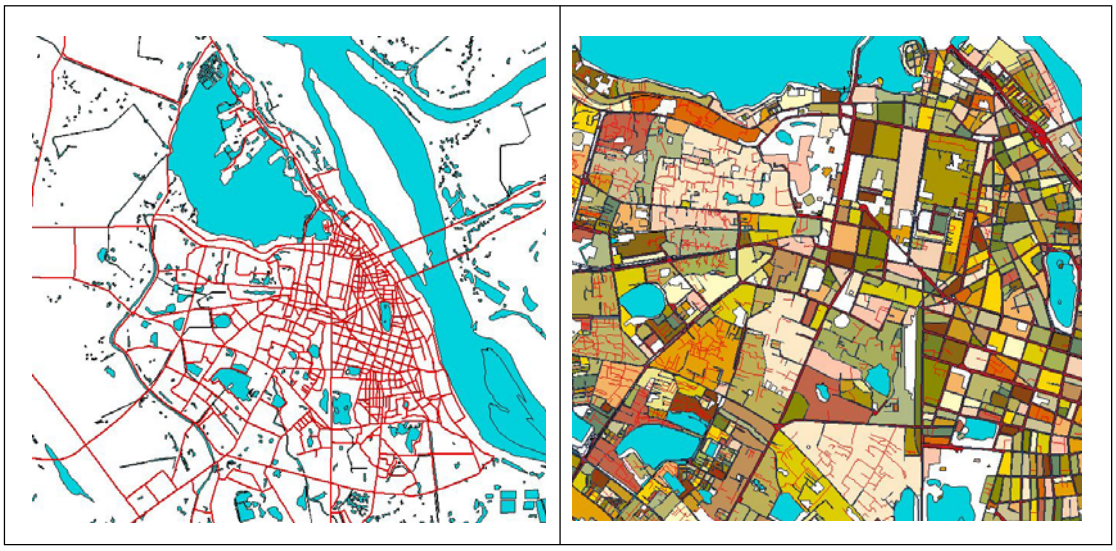


Figure 2. Road map 1:10000 of Hanoi (left) and Inner City map 1:2000

The 2003 statistics showed that up to 52.87% of Hanoi population (1.5 million) were living in the inner city, which covers only 9.15% of the total municipal area, being the most densely populated city of Vietnam with 19,163 persons per square kilometer. With wonderful economic growth, stemmed by the Doi Moi (Economic Renovation) from 1986, Hanoi has gained annual GDP increase 7.1% average in 1986-1990, exceeding 10.5% in the following years 1990-1993 and got a peak in 1994 with 13.1%. This has led to a big migration of people into the urban area of Hanoi. The rapid urbanization could be seen to take place during the period 1993-2003. Figure 6, processed from Landsat and ASTER images acquired in 1993, 2000 and 2003, gives visualization about the spatial and pattern of the city's expansion. This period also witnessed the establishment of two new urban districts - Hoang Mai and Long Bien. As a result, the total number of inner districts of Hanoi rose to 9 and area was almost doubled.

The 2006 statistics plotted a population of 3.2 million of entire Hanoi, and this is projected to be 4.5 million in the year 2020 with 2.5 million residing in the inner city (Hanoi Master Plan to the Year 2020). Other long term plan for landuse structure, functional areas, urban landscape, transport and technical infrastructure systems have also been set. All these have posed a great demand for Hanoi city in monitoring urban growth and planning for better landuse.

Urbanization can be defined as changes in the territorial and socio-economic progress of an area that includes a general transformation of landcover/use

categories (Weber et al., 2002). Apart from the socio-economic aspect, factors that are relevant to the development of a city, in terms of spatial expansion, 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 the changes from classification of multi-temporal (and usually multi-resolution) imageries. For this purpose, very high resolution satellite data (such as Ikonos and Quickbird) can be used in parallel with medium resolution data (such as Landsat, ASTER, and JERS) and they can compensate the advantages and disadvantages of each other.

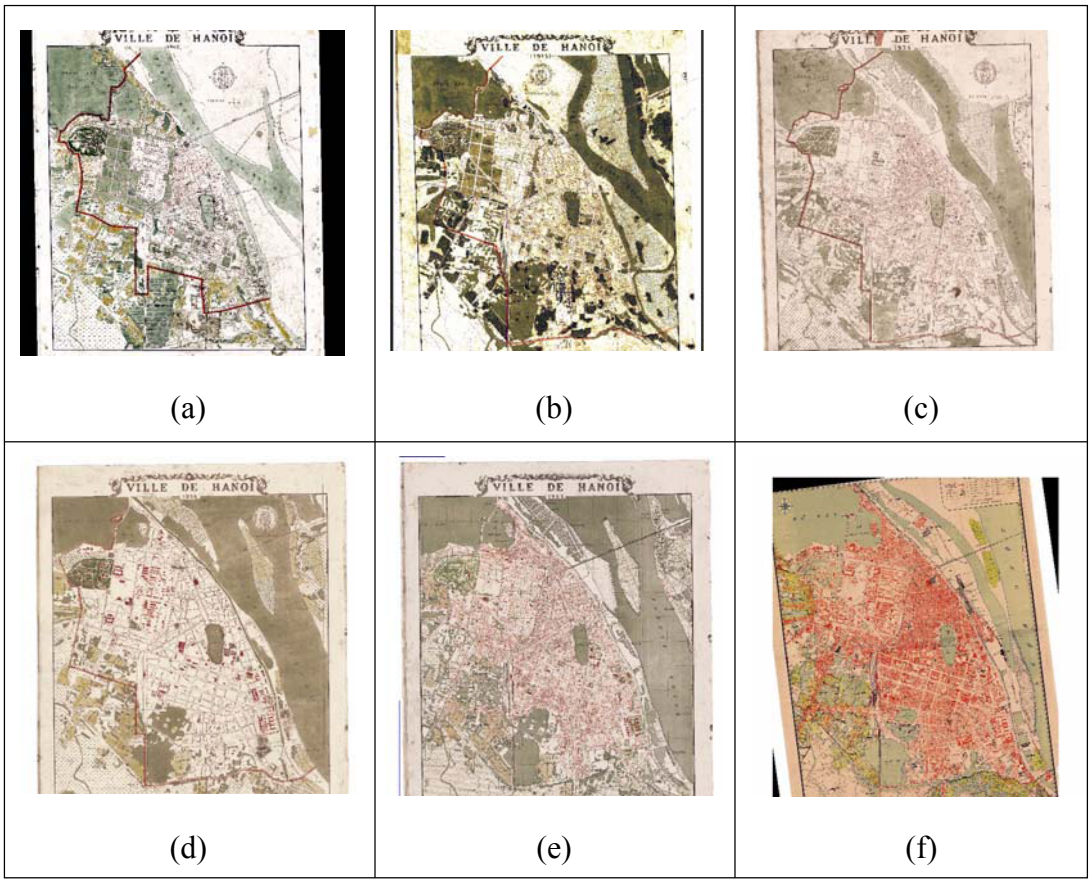


Figure 3. Rectified Hanoi historical maps of different dates: (a) 1902; (b) 1915; (c) 1925; (d) 1936; (e) 1942; (f) 1958

During the urban transition, the change of landuse leads to the increase in some spatial parameters like road density, housing density, and decrease in some other parameters like greenness and water body. Current road and street system of Hanoi, reported by Tran Tuan Hiep (2004), showed 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).

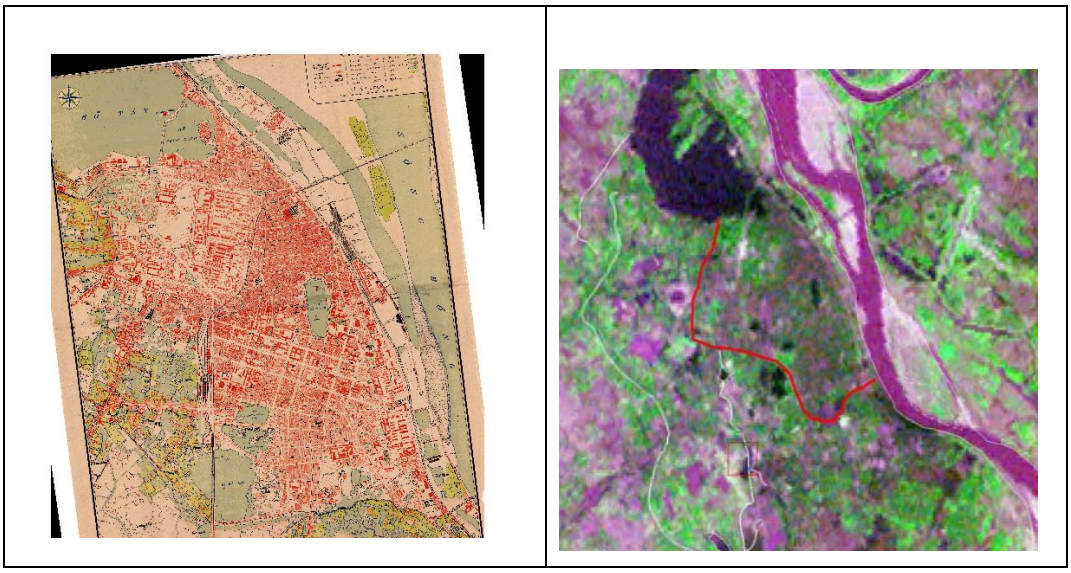


Figure 4. Hanoi map 1958 (left) and Landsat MSS image 1975 (right)

Various works have been carried out concerning the urbanization of Hanoi from different approaches. 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 from 1992 to 2000. Pham Van Cu (2004) used ASTER data to detect urban changes based on an analysis of thermal bands. Waibel (2004) 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. Yamagata et al. (1997) introduced the vegetation-soil-water (VSW) index to better analyze the category-

mixing ratio for three elements vegetation, soil and water in one pixel ("mixel") and this method was used by Pham Minh Hai et al. (2006) for investigating the urban expansion of Hanoi over time based on multi-temporal Landsat and ASTER data.

Other researches that employed more advanced and sophisticated tools on multisensor remote sensing data have been made. Tomowski et al. (2006) presented a decision based data fusion technique for detecting settlement areas using a texture-oriented hierarchical segmentation procedure on high resolution images combined with medium ones. Sheeren et al. (2006) proposed an object-oriented knowledge-based approach to create a decision tree classification that produced higher classification accuracy for urban mapping. This method was used with a machine learning algorithm on multispectral Quickbird and Landsat images to obtain not only classes such as vegetation, water bodies, soil and built-up, but also further details of classified sub-categories like low density or high density built-up areas.

An important aspect in studying urban growth is to combine multi-temporal remote sensing data and socio-economic data. From a statistical analysis of the detected changes including socio-economic information, a better understanding of the urbanization process as well as its driving forces, which can provide a good calibration for landuse change models (Goetzke et al. 2006). A purely socio-economic review of Hanoi urbanization during the period 1946-1973 can be found in Turley (1974) where a brief history of the city's urbanization in this period were presented together with important demographic and other statistical data.

Previous studies on the urbanization of Hanoi often focused only 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 the city's urban transition through a century, 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 including historical maps, landuse maps and statistical data.

The objectives of this study is to employ an integrated method of GIS and Remote Sensing to understand the urban transition of Hanoi in terms of the spatial expansion and the pattern of urbanization in the period from early 1900's to recent years[3]. 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. Although a landuse change model derived from the study is beyond the scope of this paper, we believe that a better understanding of the urbanization process over time would give a more reasonable and optimal landuse planning for the city.

[3] It should be emphasized that the different periods considered in this study of Hanoi urbanization were due to the availability of our data (satellite images and maps)

As for most part of the world, available satellite data are usually dated from the 1970's back to now. We used Landsat MSS (1975), Landsat TM (1993), JERS (1995), Landsat ETM (2000), Ikonos (2002), ASTER (2003) and Quickbird (2005) in the present study (Table 1), so remote sensing data scattered only from 1975 to 2005. The lack of data for the previous period is compensated with the use of collected historical maps that scattered from 1902 to 1958 together with recent city maps of 1996 and 2000 (Table 2). All maps were scanned, resampled to same resolution and georeferenced carefully based on the high resolution Ikonos image and digitized map 1:10000 of Hanoi. The series of rectified maps were then used to produce a time-series of vector boundary of Hanoi and two urban-sensitive index maps - road density and housing density. Obviously the accuracy of these derived maps depends on that of the historical maps collected, so comparison and validation with other sources must be made.

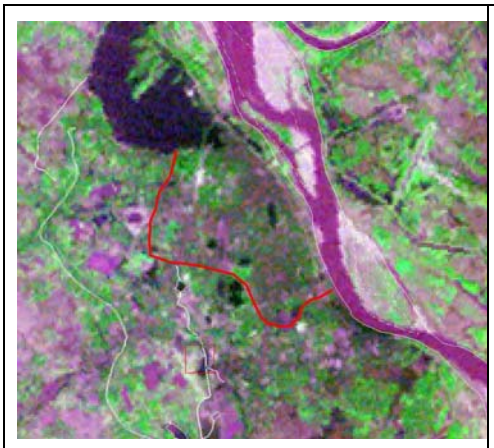


Figure 5a. Landsat image of Hanoi in 1975

Figure 5b. Landsat image of Hanoi in 1993

Satellite images were the main source for our study of Hanoi urbanization in the period 1975 to 2005. As urban growth ultimately lead to landuse changes, image classification is the essential techniques to be used. Three Landsat scenes of 1975, 1993 and 2000 and one ASTER scene of 2003 were rectified to same spatial resolution of 14.25 meters (panchromatic band of the ETM) for best use. Supplementary information were obtained from the radar JERS (1995) and the high resolution Ikonos and Quickbird images, for example to validate the signature for image classification and to verify the derived density maps. In addition, the NDVI and water indices were calculated and used in our decision-tree classification. Integration of these index maps with classification provides an effective way for detecting urban growth of the city in this period. Water masks can also be used to mark the reduction in numbers and size of water bodies (ponds, lakes, and rivers), a common phenomenon of urbanization process. Urbanized areas and the directions in which they are expanding as well as the narrowing or disappearance of greenness and water body can be visualized and depicted.

Significant landuse changes occurred during the periods 1975-1993 and 1993-2003 can be revealed and quantified.

Our results showed that Hanoi urban has expanded to the South, West, Southwest, and East as linear branch patterns, and in-fill expansion took place from time to time (Figure 6). The growth rate was not evenly distributed both in time dimension and space dimension, and more or less linked with socio-economic events happened to the city for example the fast economic growth in the 1990's. The growth is in general limited by natural barriers in certain periods of history, such as the Red River to the east, the West Lake and To Lich River to the north and west, and a swamp area to the south (Figure 1.b). It is worth to notice that the only bridge crossing the Red River in Hanoi area (Long Bien bridge) was completed in 1902 and it is the unique way to span eastward from the inner city until the 1980's where the other two Chuong Duong and Thang Long were built. This somehow explained why the city's expansion across the Red River in the east occurred rather late. Spatially, the urbanization of Hanoi stretches in obvious directions – west, southwest, south and east – with both expansion patterns and in-fill patterns, and the process follows main transportation axes connecting the inner city to neighbouring areas (linear branch pattern). A careful observation of the urban growth rate with regard to its patterns and distribution in space and time dimension could reveal as a fact that the urbanization process has been sometimes planned and sometimes not at all. The depicted trends of growth may give some insight for the planning of Hanoi city. It is expected that this study can help decision makers to better analyze the urban transition of Hanoi over time, from the viewpoint of geoinformatics, and so can contribute to a sustainable landuse plan for Hanoi city.

3 Data used and processing method

Data used

Satellite images used in this study consist of Landsat (MSS, TM, and ETM), JERS, ASTER, Ikonos and Quickbird. Except for the Landsat imagery which is a courtesy of Global Land Cover Facility (NASA), all are provided by Project GASR(S), Center for Southeast Asian Studies, Kyoto University. They are summarized in Table 1.

Historical maps of Hanoi 1902, 1915, and 1942 at scale of 1:10,000, map 1936 at scale of 1:20,000 and map 1958 at scale 1:5000 were scanned, resampled to resolution 1 meter, rectified based on vector map 1:10000 mentioned above. These old maps were also obtained from Project GASR(S), Center for Southeast Asian Studies, Kyoto University. They are summarized in Table 2.

Digitized maps 1:10000 of Hanoi and 1:2000 of inner city were used as base maps for all georeferencing (Figure 2). The 1:10000 map was updated based on the Quickbird image 2005 (0.6 meter resolution). They have been projected into WGS-84 datum, UTM zone 48 North projection, as are all satellite images.

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
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	JERS (SLC)	1995	17.6 x 27.1 m	Project GASR(S), Center for Southeast Asian Studies, Kyoto University
5	ASTER	13/01/2003	15 and 30m	
6	Ikonos	2002	1m	
7	Quickbird	2005	0.6m	

Table 2. List of historical maps used

No.	Map	Year	Scale	Sources
1	1902 VILLE DE HANOI	1902	1:10000	Project GASR(S), Center for Southeast Asian Studies, Kyoto University
2	1915 VILLE DE HANOI	1915	1:10000	
3	1925 VILLE DE HANOI	1925	1:10000	
4	1936 VILLE DE HANOI	1936	1:10000	
5	1942 VILLE DE HANOI	1942	1:50000	
6	1942-1 VILLE DE HANOI	1942	1:50000	
7	1958 BAN DO HA NOI	1958	1:5000	

Method

All maps and satellite images were georectified in UTM projection (zone 48N), 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.

The rectified historical maps were visually interpreted to depict the city boundary over time. As transportation and settlement areas are closely connected to urbanization, we suggested a semi-automatic vectorization tools to segment the road centerlines and house blocks from these maps. The resulted vector layers will be used to calculate the road density maps and house density maps. Road density is defined as the total length of roads found in a square unit, say 1 km^2. To create a fine road density map, we overlay the map by a regular grid with reasonably small cell size (for example, 100 meters) and calculate the total road length in each cell. The same procedure can be applied to compute house density (total number of house blocks in one cell). These two maps were then used to enhance the analysis of the city's spatial expansion.

To identify patterns of urban expansion, particularly the actual boundaries of the city, we used the Normalized Difference Vegetation Index (NDVI) and a Water Index (WI) derived from band ratio calculations.

- NDVI was calculated from red and near infrared bands

NDVI = (near infrared - red) / (near infrared + red)

- WI was used to separate land from water. This index was calculated by a band ratio between wavelengths of 1600 nm (middle infrared) and 520–600 nm (green) to identify water bodies. Bands 5 and 2 of Landsat TM and ETM, and bands 4 and 1 of ASTER were used.

WI = middle infrared band / green band

The NDVI and Water Index images were layer-stacked to create images of vegetated and water bodies from 1975 to 2003.

Landsat images in 1975, 1993, 2000 and ASTER image 2003 were classified using the supervised Maximum Likelihood method. Selection of training samples was guided by ancillary GIS data and the high resolution imageries Ikonos and Quickbird. Five landcover classes were considered - water, vegetation, built-up, fallow and sand. (The water in the Red River and water in Hanoi Lakes and ponds have different signatures). The sandy areas in and along the Red River and the wetland areas in the south happened to be of seasonal change and can easily be mixed with other classes, so we created masks for these areas prior to image classification. Also, urban spatial signatures of Hanoi landcover is difficult to

differentiate, even different classes mixed in one pixel ("mixel" problem), therefore we employed a decision-tree algorithm using the above NDVI and WI to support the classification. First the Landsat and ASTER images were classified using the Maximum Likelihood method and rule images were created. The decision-tree method then based on these rule images and the NDVI or WI. The final built-up mask images are shown in Figure 6. The JERS image 1995 was fused with the TM image 1993 to give a better visualization of water body for this image date (Figure 8a and 8b).

Several methods can be used to depict the landuse/landcover changes (hence the spatial urban growth can be visualized). One method is the presentation of a time-series classified images. The changes can be quantified by associated change matrices which tell how much (or percentage) of a class has been converted into others.

To compute the road density and house density using GIS tools, the base map was spatially divided into cells of size 100m x 100m. For each cell

Road Density cell value = 100 * Total road length in that cell (Km/Km2)

Housing Density cell value = 100 * Total house block area in that cell

To create a finer density map we can use smaller cell size in stead of 100 meters.

These two raster maps can be overlaid with the satellite images or the classification maps to enhance the analysis.

4 Results and discussion

The period from 1902 to 1958

City expansion seemed to have occurred in the period from 1902 to 1942, whereas little change can be observed in the period 1942-1958. 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, and the southern limit was about 4 km from West Lake (Van Ho area). A big deal of lakes and ponds can be seen, which do not appear in present imageries. Urbanization analysis should be combined with other socio-economic facts.

The table below gives some figures about the population and population structure of Hanoi during this period (numbers were rounded to thousands). This suggests another further study using statistical analysis relating to parameters that could be approximately derived from the series of rectified maps.

Table 3. Hanoi population during the period 1943 - 1954

Year	1943	1947	1951	1952	1953	1954
Total population	120,000	10,000 (*)	212,000	274,000	293,000	400,000
Inner city			81,000	127,000	130,000	

Source: Turley W. S. (1974), Urbanization in war: Hanoi, 1946 - 1973

(*) In this year of the Indochina war (1946-1954) Hanoi was drastically evacuated

The period from 1958 to 1975

In the 1975 image, the inner city of Hanoi is still not much different from its 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. 4). A great deal of water surface has been filled and converted to other landuse types.

It is important to remark that in 1961, the administration boundary of Hanoi has been increased to 461 square kilometers (compared to 152 square kilometers in 1960) and total population increased to 900,247. A lot of industrial sites have been built during the period 1958 - 1961, as a result of the economic growth after the first 3-year plan of the D. R. Vietnam.

The period from 1975–1993

A remarkable 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. (The river can be seen in Figure 5b, west of the red curve). 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. 5b). The year 1986 witnessed the launch of new economic policy as a consequence of Doi Moi, and economy began to grow gradually. The spatial urban growth could be seen to be of strongly linear branch pattern.

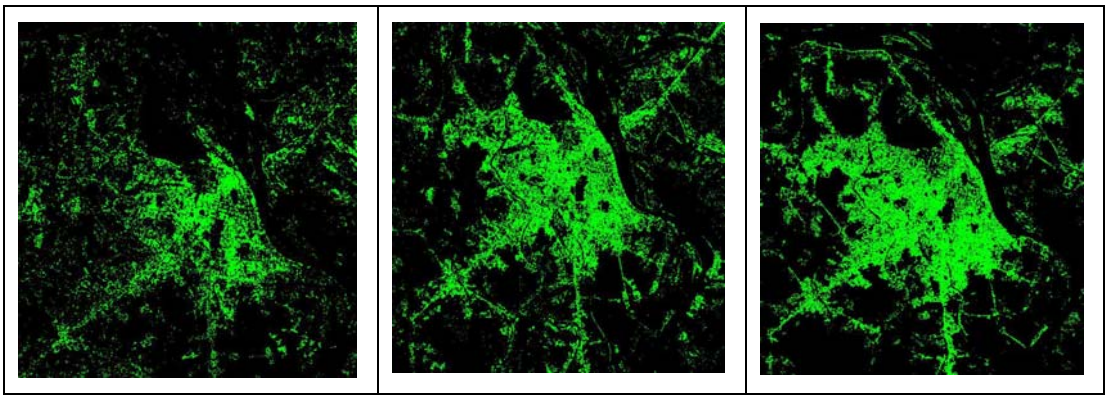
The period from 1993 to 2003

The urban space and direction of expansion are obvious in Fig. 6 and a composite image of NDVIs from three dates (Fig. 8). 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.

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 landforms 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 rises 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.



1993 2000 2003

Figure 6. Urban expansion of Hanoi during 1993, 2000, and 2003. In-fill and expansion patterns can be seen.

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 1b, which is a color composite for Water Indices 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.

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 3.

Figure 7. High house density (left) and medium density (right).

Table 3: Construction features of Hanoi urban

No	Type	Features				Distribution (typical)
		Houses	*Roads*	*Green space*	*Pattern*	
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 are similar but spatial patterns are more regular with square quarter, larger size houses, and 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.

Figure 8a. Fusion image from Landsat TM 1993 and JERS 1995: water bodies were enhanced

Figure 8b. Water mask image created from fusion image on the left.

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.

Figure 9a. Color composite of NDVIs of 1993 (blue), 2000 (green) and 2003 (red)

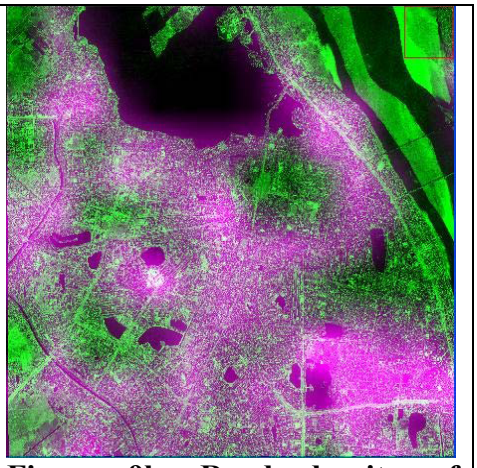


Figure 9b. Road density of Hanoi overlaid on Ikonos image.

5 Conclusions

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. The urban growth are realized in expansion, in-fill and linear branch patterns. To the north, growth is limited by West Lake. Two main growth axes run in the northeast–southwest and north - east directions (Figure 6 and 10). The west axe appeared lately, perhaps since 2003 following the construction of the national stadium My Dinh. The current development of the city does not seem to 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.

Figure 10. Color composite image 2003 with enhanced urban area of Hanoi.

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