STRESS OF IMPERVIOUSNESS ON URBAN ENVIRONMENT UNDER URBANIZATION PROCESS: A REMOTE SENSING APPROACH

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Abstract

Imperviousness is a key environmental indicator. It is a sign to aware the process of urbanization. Information about impervious surfaces distribution is essential for several environmental applications and the planning and management of sustainable development of urban areas. The growth and spread of impervious surfaces within urbanizing areas pose significant thread to the quality of natural and built environment. These threads includes increased stormwater runoff caused urban floods, reduced water quality, higher maximum summer temperatures, degraded and destroyed aquatic and terrestrial habitats and diminished aesthetic appeal of stream and landscapes. Satellite remote sensing based mapping of impervious surfaces has shown important potentials to acquire such information in great spatial detail. This paper introduces the using Landsat satellite images to detect the extent of urban imperviousness in Ho Chi Minh city, which is one of the biggest cities in Vietnam. Under urbanization development during the last decades, Ho Chi Minh city has exposed inadequate pictures on insufficient general and synchronous planning, caused a great impact on environment and human health.

Keywords: Endmember, Imperviousness, impervious surface, remote sensing, sub-pixel classification, urbanization

1. Introduction

Over the past several decades, a concern has arisen over the rate at which humans are altering the environment. Society's need for expansion combined with environmentally irresponsible settlement practices have been increasingly converting natural landscapes into suburban and urban environment (Arnold and Gibbons, 1996). Monitoring growth and change brought on by urbanization has been a critical concern both to those who study urban dynamics and those who must manage resources and provide services in these rapidly changing environments.

Urban areas reflect a complex mix of different land cover types and materials. These are built up areas (roads, roofs, pavements, etc.), vegetated areas, soil surfaces and water bodies. The urban land cover composite is quite different from rural and natural environments and resulting in significant differences in the physical processes, e.g. hydrologic system response (Schueler, 1994) and variations in the local urban climate (Oke, 1987). In urban environments, where vegetation is fairly sparse, build up or impervious surfaces are stronger absorbers. The absorbed radiation is gradually re-emitted as long-wave radiation that is responsible for warming up the boundary layer of the atmosphere within the urban canopy layer (Oke, 1987). The amount of impervious surfaces within urban area is considered a significant environmental indicator of watershed health, water quality, and overall ecosystem well being. Imperviousness is generally defined as a sum of impermeable landscape features that include buildings, roads, parking lots, sidewalks and other built surfaces.

In natural landscapes such as forests and meadows, spongy soil and plant roots enable water to infiltrate the soil. After water seeps into the ground, it may:

- Nourish plants, and cycle back into the air through plant processes
- Continue to flow just beneath the surface to nearby streams (as subsurface flow), or
- Continue into deeper groundwater.

Physical and chemical processes accomplished by microorganisms and plant roots help to filter and purify this water. Large volumes of water are stored in the soil and in wetlands. Therefore, sudden rainstorms in natural areas cause only a gradual change in the water level of streams. Evaporation of stored water also helps to cool the air in natural areas.

Along with urbanization, some natural land cover is removed to create a reliable hard surface and to facilitate access to and from our homes, work, schools, commercial, and recreational opportunities. It is essential that a system be developed which quickly and efficiently drains water away from these human activity areas. Impervious surfaces have replaced roots, leaf litter, and forest canopies that were once available to absorb and recycle precipitation. Where precipitation was able to percolate into the ground and infiltrate to the watertable or contribute to stream and lake base flows, now most precipitation runs off directly into our wetlands, lakes, and streams. Natural processes are no longer available to absorb and recycle rainwater. Under natural conditions, overland runoff is a relatively minor component of the water balance. Urbanization suddenly makes runoff a significant and probably the most visible component of the hydrologic cycle (Bowles, 2002). The temperature response and reflective properties of impervious surfaces are linked to the "urban heat island" effect, which makes cities often several degrees warmer than the countryside. The hot cities affect human comfort and health because of changes in sensible heat fluxes and the concentration of atmospheric pollutants (Barnes et al., 2001). The percentage of impervious surfaces also directly affects the processes of non-point source water pollution, and is strongly related to the physical and chemical properties of surface water bodies (Arnold and Gibbons, 1996).

In general, the unintended results of urban development attributed to imperviousness are:

- Removal of natural storage, retention, and recycling of precipitation
- Significant increases in overland runoff into surface waters
- Decreases in stream base flow and groundwater recharge
- Increases in floodwater velocities, the magnitude and frequency of flooding
- Increases temperature in the cities in compare with countryside, formed "urban heat island" effect
- Toxic chemicals are often present on impervious surfaces, and are carried directly into streams, harmed the water habitat.

With those significant impacts of imperviousness on urban environment, understanding and detecting impervious surfaces become essential for several environmental applications and the planning and management of sustainable development of urban areas. There are many efforts to map the impervious surfaces in urban environment, such as, field measurement, visual interpretation of aerial photography. But they cost labor intensive, time consuming and expensive task to manually survey and map them. As a more cost-effective alternative, remote sensing technology has been widely used in numerous applications to obtain much of the impervious spatial information.

Derivation of urban imperviousness using remote sensing imagery is traditionally based on the "hard" classification of spectral image pixels. Since each pixel can only be labeled with one class, urban imperviousness is recorded as either present or absent. Information on physical continuum or spatially-mixed nature of ground features in relation to sampling resolution, which is captured by "mixed" pixels (Jensen, 1996), is not retained. The hard classification of mixed pixels will lead to information loss and degradation of classification accuracy (Ji and Jensen, 1996).

New techniques in the field of digital image processing that can derive information at the subpixel level are emerging as potential solutions to this problem. One type of classification scheme that can estimate subpixel impervious surface information is spectral mixtute modeling (Ji and Jensen, 1996; Ward, et al., 2000; Yang et al., 2003a). This paper tries to use this new analysis to detect the imperviousness areas in Ho Chi Minh City as an indicator for urbanization degree and urban environmental health.

2. Methods

Natural surfaces are rarely composed of a single uniform material. Spectral mixing occurs when materials with different spectral properties are represented by a single image pixel. Mixed pixels are normally found in boundaries between two or more mapping units (materials), along gradients, etc. when the occurrence of any linear or small subpixel object takes place. To address the mixed pixel problem, there is a growing interest in the use of techniques designed to estimate class proportions for individual pixels (Ji and Jensen, 1999; Flanagan et al., 2001; Yang et al., 2003b). Such methods attempt to model the spectral response from a mixture of classes and the approach, which is generically termed as spectral mixture analysis or unmixing, can calculate the fractional presence of those predetermined materials.

The linear spectral unmixing method assumes that the spectrum measured by a sensor is a linear combination of the spectra of all components within the pixel (Adams, *et al.*, 1995; Roberts, *et al.*, 1998a). The mathematical model can be expressed as

$$R_i = \sum_{k=1}^{n} f_k R_{ik} + \varepsilon_i$$

where i is the number of spectral bands used; $k = 1, \ldots, n$ (number of endmembers); R_i is the spectral reflectance of band i of a pixel, which contains one or more endmembers; f_k is the proportion of endmember k within the pixel; R_{ik} is known as the spectral reflectance of endmember k within the pixel on band i, and ε_i is the error for band i. Two methods, i.e. constrained and unconstrained solutions are often used to unmix the linear mixture model. For a constrained unmixing solution, f_k is subject to the following restrictions:

$$\sum_{k=1}^{n} f_k = 1 \quad \text{and} \quad 0 \le f_k \le 1$$

For the unconstrained solution, the fraction f_k may assume negative values and is not constrained to sum to one. Therefore, the results from the unconstrained solution do not reflect the true abundance fractions of endmembers.

To solve f_k, the following conditions must be satisfied: (1) selected endmembers should be independent of each other, (2) the number of endmembers should be less than or equal to the spectral bands used, and (3) selected spectral bands should not be highly correlated.

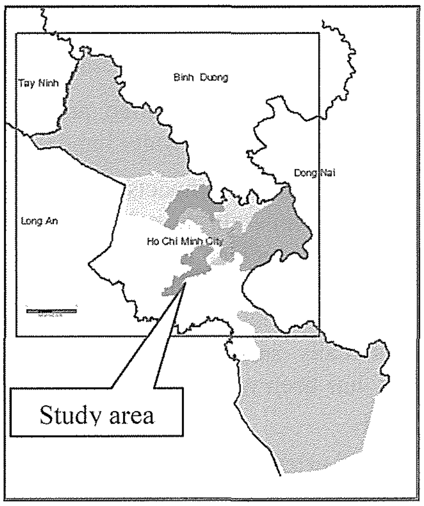


Figure 1. Map of the study area

In the linear spectral unmixing method, endmember selection is a key step and many approaches have been developed (Lu et al., 2003). In practice, image-based endmember selection methods are frequently used, because image endmember can be easily obtained and they represent the spectra measured at the same scale as the image data. Image endmember can be derived from the extremes in the triangles of an image scattergram, assuming that they represent the purest pixels in the images. In order to effectively identify image endmembers and to achieve high-quality endmembers, different image transform approaches, such as principal component analysis and minimum noise fraction, may be used to transform the multispectral images into a new dataset. Endmembers are then selected from the feature spaces of the transformed images. In this research, image endmembers were selected from the feature spaces formed by the minimum noise fraction components. The end product of this method is a set of fraction images, where the value of a pixel indicates the relative abundance of an endmember.

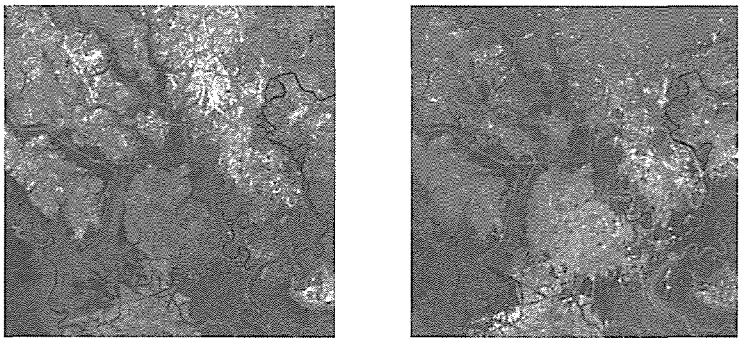
3. Study area and data

3.1. Study area

During the last decades, urbanization and urban sprawling have developed and spreaded through Vietnam, especially in Ho Chi Minh City, one of the biggest cities, with more than 6 millions population, not include nearly 2 millions immigrants according to Census Data in 2005 (Statistical Office in Ho Chi Minh City, 2005). Heavy population density is concentrated in the centre of city caused the stress on housing space and service facilities. More people more demand for houses, more land cover changes in impervious surfaces such as building, road, sidewalk, industrial zone. The study area is located at the North of Ho Chi Minh City, which is reported to have rapid built-up expansion since the last decade (Fig. 1). The areal expansion is through encroachment into the adjacent agricultural and non-urban land.

3.2. Data sets

A Landsat images with pixel size 30m x 30m, which were acquired on Jan 16, 1989 (TM) and Jan 05, 2002 (ETM$^+$), were used in this research (Fig. 2). We used just six reflective bands (bands from 1 to 5 and band 7). They were radiometrically converted to at-sensor reflectance. For change detection two dates were georectified and reprojected to the WGS-84 projection. Following georectification, the MNF was applied to transform the at-sensor reflectance data into a new coordinate set. The first four MNF component were used for spectral mixture analysis, and the last two were discarded due to their high propotion of noise contents.



1989 2002

Fig.2. Band combination of channels 4,3,2 of two Landsat images in 1989 and 2002

4. Results and discussion

4.1. Characteristics of endmember fractions

Four types of endmembers were selected: vegetation, high-albedo, low-albedo and soil. A constrained least squares solution was then applied to unmix the six reflective bands into four fraction images. The high-albedo fraction image mainly related to impervious surface information in the urban area and some dry soils in agricultural areas. The commercial, industrial, transportation areas exhibited the highest values in the high-albedo fraction image. The value was gradually decreased from high-intensity residential to low-intensity residential areas. The low-albedo fraction image was more complex than other fraction images, because it contained different features, such as water, building shadows in the central business district, vegetation canopy shadows in forested areas. For rejecting water feature, we made the mask from the initial unsupervised classification results. The soil fraction image highlighted the soil information located in the agricultural areas, and the vegetation fraction image detected high values in forest, grass, and crop lands. The high- and low-albedo fraction images obviously shown that the urban impervious surfaces predominated in the central areas of the city and gradually decreased towards rural regions

4.2. Evaluation of Urbanization and the Consequence of Imperviousness

The results from impervious surfaces images presented by the whole city, built-up land increased and agricultural land decreased mainly in the Northern part of the city. As shown in Figure 3 the settlement in this area presented a rapid expansion and concentrated in urban districts and along the main roads in the suburban areas, where the agricultural land yielded to property development. Most evidently built-up area appeared in the districts: Go Vap, 12, 2, Thu Duc and Binh Chanh. As results, in 13 years from 1989 to 2002 the disappearance of agricultural land was shown by 14,697 ha, otherwise the land for built-up areas increased to 15,345 ha (Fig. 3). This implied that the development of imperviousness in urbanized regions rapidly reduced the vegetation cover, the open pervious surfaces, where allow the rainwater to infiltrate into the deep groundwater.

Figure 3. Results of urban expansion in the Northern part of Ho Chi Minh City in 1989 and 2002 from remotely sensed data

Due to uncontrolled rapid urban expansion, the transformation from bare soil and agricultural land into residential impervious areas has changed the aspect of Ho Chi Minh city. This causes the city to face with problem of ecological unbalance and traditional agricultural trade villages disappearance. Such as floricultural village Go Vap was disappeared, now a few points of decorative plant trade exist as the reminder of this tradition. Low-lying land areas cultivating wet rice (District 2) were place for balancing the drainage, but construction and concretezation process made flow looking to narrow sewerages, or the altitude raise of new urban areas caused overland runoff and flow into lower old urban areas and instant inundation in the city centre. As the summary report of the Seminar on Flooding Situation in Ho Chi Minh City in September 2006, there are 75% flooded points in the city with the altitude over 2.5m, influencing the living around 27.7% inhabitants. As the meteorological data, within 50 years lately, precipitation in Ho Chi Minh has the increased trend. Rainy annual intensity has generally trend due to impact of the urban temperature growth (Institute of Economic Research, 2006).

5. Conclusions

The purpose of the study was to explore remote sensing data and new techniques of linear spectral unmixing to map and visualize the degree of imperviousness in the urban areas of Ho Chi Minh City. The Landsat data have proven to be a valuable source of data for urban perviousness change monitoring. The uncontrolled conversion of land covers from permeable to impervious is a serious threat to the integrity of both natural and built environments within Ho chi Minh City and to the comfort and overall quality of life for its residents. The increase imperviousness and the outward diffusion of impervious surfaces from established urban and suburban core areas into rural lands are dramatically increasing the volumes of stormwater with which communities must contend. Due to the contributions of impervious surfaces to the urban heat island effect, human comfort is reduced during the summer.

Although urban and suburban growth within Ho Chi Minh City is inevitable, many of the environmental impacts of impervious surfaces are avoidable or controllable. Working together, local governments and citizens can reduce the amount of land changed in imperviousness, and can reduce its adverse impacts, promoting a healthier environment through sound land use planning and improved land management.

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