Monitoring urban growth in Metro Manila using multitemporal satellite images

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Abstract: One of the most common forms of land use change is urbanization. Fortunately, the temporal revisit capacity of remote sensing satellites and their multispectral imaging capability make it possible to monitor this process. Using two Landsat images taken in 1972 and 1989, and one SPOT image taken in 2000, urban growth in Metro Manila is monitored. The extent of urbanization in Metro Manila increased from about 39 percent in 1972 to about 74 percent in 2000, although a slowing of growth was observed in the last decade due to decreasing areas for development. Most cities and municipalities in Metro Manila exhibited urban growth rates higher than the metropolitan average. The drivers and environmental consequences of urban growth were determined as well as the relationship of the extent of urbanization with some socio-economic and environmental variables.

Keywords: Urban growth, Landsat, SPOT, Metro Manila, environment

1. Introduction

Land cover refers to the composition of the features of the earth's surface while land use refers to the type of human activity taking place at or near the earth's surface [1]. Both represent key environmental information. Changes in these two parameters have been associated with negative environmental and socio-economic consequences, including flooding [2], soil degradation [3], loss of biodiversity [4], loss of arable lands and timberlands [5], and changes in surface microclimate and hydrology [6].

Urban growth, sometimes referred to as urban sprawl or simply urbanization, may be simply defined as the increase in the area of land covered by buildings and other man-made structures. It is considered as a common form of land use change in the world, often in the name of development but always at the expense of the environment.

Satellite remote sensing, with its temporal revisit and synoptic viewing capacity and multispectral imaging capability, is a powerful tool to map and monitor the emerging changes in the urban core as well as the peripheral areas of any urban entity [7]. With multitemporal analysis, satellite remote sensing can give a unique perspective of how cities or municipalities evolve.

It is in this light that this study is conducted. The general objective of the study is to understand the spatial dynamics of the urbanization process in Metro Manila using multitemporal and multi-sensor optical satellite data.

2. Materials and Methods

1) Study Area

Metro Manila, also called the National Capital Region for planning purposes, is the capital of the Philippines, an archipelagic state with more than 7,100 islands and situated in Southeast Asia. Covering an area of 636 km², it comprises 12 cities and five municipalities. With a resident population of 10.5 million, it is one of the megacities in the world. It also has one of the highest birth rates in the world, which is nominally 2.5 percent. It is bounded on the west by Manila Bay, which, with its deep waters, makes the city of Manila a very busy international seaport.

During the early 1970s, 15 out of the 17 townships in Metro Manila was under the jurisdiction of the governor of Rizal province. However, physical and socio-economic developments in the succeeding years led to the current composition of Metro Manila. For a long time, the administration of the capital was the responsibility of the governor of Metro Manila with secretariat support from the Metro Manila Commission, making it a distinct planning unit. However, the passage of the Local Government Code of 1991 by the Philippine Senate devolved a lot of powers to mayors. As a result, each city and municipality pursued planning efforts largely on their own. This led to observations that the growth of Metro Manila is largely unplanned and unsystematic.

2) Satellite Images

Three different optical satellite images acquired at different dates were processed and analyzed in order to determine the diffusion of urbanization in Metro Manila. These are a Landsat MSS image taken in December 1972, a Landsat TM image taken in January 1989, and a SPOT image taken in April 2000.

3) Methodology

Preprocessing routines were applied to the three images and included simplified radiometric calibration, geometric correction, and registration to a common vector boundary. The last two routines are critical for the creation of spatially-corrected urban cover change maps.

In the Philippines, the term "urban" denotes a large population density, vibrant economic activity and developed infrastructure. Based on this criteria, the whole of Metro Manila will already be considered urban. However, this study considers a region as urban based primarily on its existing land use as inferred from the present land cover.

The emphasis of this paper is on the spectral differentiation between urban and non-urban areas. Using an integrated digital (*i.e.* maximum likelihood classification algorithm) and visual image classification technique, various land cover categories were delineated from the three satellite images. Thereafter, different land cover classes that are considered to be urban (*e.g.* residential, commercial, industrial, transportation) and non-urban (*e.g.* agricultural, grassland, forest, water, wetlands, barren) in character were merged to form the two super-classes.

Comprehensive land use plans, topographic maps, existing land use databases, and census tables provided supplemental information to refine the results of image classification.

Change detection analysis was done by post-classification image comparison. Then based on socio-economic and environmental data at the city/municipal and metropolitan levels, the drivers of urban growth and its environmental consequences are determined.

3. Results

The high degree of heterogeneity and subpixel mixing of surficial materials, especially at the scale of a Landsat pixel, contribute to poor classification accuracy in urban areas [8]. The reason for aggregating different urban land use-related categories into a single urban category is to reduce the effects of this problem. However, several instances of misclassification of barren land and cloud pixels as urban pixels, and vice-versa, still occurred. This appears to be a common problem in digital image classification (*e.g.* [9]-[10]).

Figure 1 depicts urban growth in Metro Manila as derived from the land cover classification of the three multisensor and multitemporal satellite images. Urban and non-urban areas are shown in blue and white respectively.

By dividing the total area of pixels classified as urban with the total land area of the city or municipality, the fraction of the city or municipality (expressed in percent) that is urban, as defined, may be computed. Table 1 shows the fraction of urban cover per city and municipality.

Table 1. Urban cover in Metro Manila.

City or Municipality	% urban (1972)	% urban (1989)	% urban (2000)
Kalookan	18	38	57
Las Piñas	22	79	85
Makati	52	80	86
Malabon	45	61	78
Mandaluyong	62	87	86
Manila	81	92	94
Marikina	22	63	81
Muntinlupa	29	62	69
Navotas	21	39	59
Parañaque	28	74	89
Pasay	52	76	88
Pasig	29	76	87
Pateros	54	83	86
Quezon City	25	52	63
San Juan	74	97	97
Taguig	23	54	67
Valenzuela	16	44	65
Metro Manila	**32**	**62**	**74**

4. Discussion of Results

In 1972, urban cover in Metro Manila was estimated to be 32 percent. With a large area of land still available for development, rapid urban growth was inevitable. Thus by 1989, the total urban cover had reached about 62 percent of the metropolis.

However, between 1989 and 2000, a decrease in the average annual rate of urban growth was observed (by 0.67 percent). This could be because the available space had already become a limiting factor for urban growth.

The general direction of urban growth may also be deduced from figure 1. The diffusion of urbanization in Metro Manila is towards the north, east and south from the central core (Manila, which was the former financial and commercial district of the metropolis). While this appears to follow the single-concentric zone and sector urban growth models developed by Ernest Burgess and Homer Hoyt, a closer look reveals that the growth actually revolves around multiple nuclei (*i.e.* Central Business Districts across the metropolis) [11].

The direction of the sprawl is headed towards the three provinces that are adjacent to Metro Manila, namely Bulacan, Rizal and Cavite respectively. This gives rise to the observation that areal reclassification is still occurring. It should also be noted that this rise of suburbia is an occurrence that is common to many countries, both developed and developing.

One of the primary drivers of rapid urban growth in Metro Manila is rapid population growth. Population increased at a rate that is three times larger than the urbanization rate, greatly aided by rural-urban migration, thus doubling the population density. The number of dwellings required to house the growing population increased from 618,134 in 1970 to an estimated 2 million in 2000. Another driver is the potential for increased income. Commercial and industrial land uses are favored by city and municipal officials because of the higher revenues per unit area generated from such land uses, compared to, say, agricultural land use. For Metro Manila, income increased from about US$ 77 million in 1972 to about US$ 517 million in 2000, while the number of manufacturing establishments grew from 2,444 in 1972 to 18,738 in 1995.

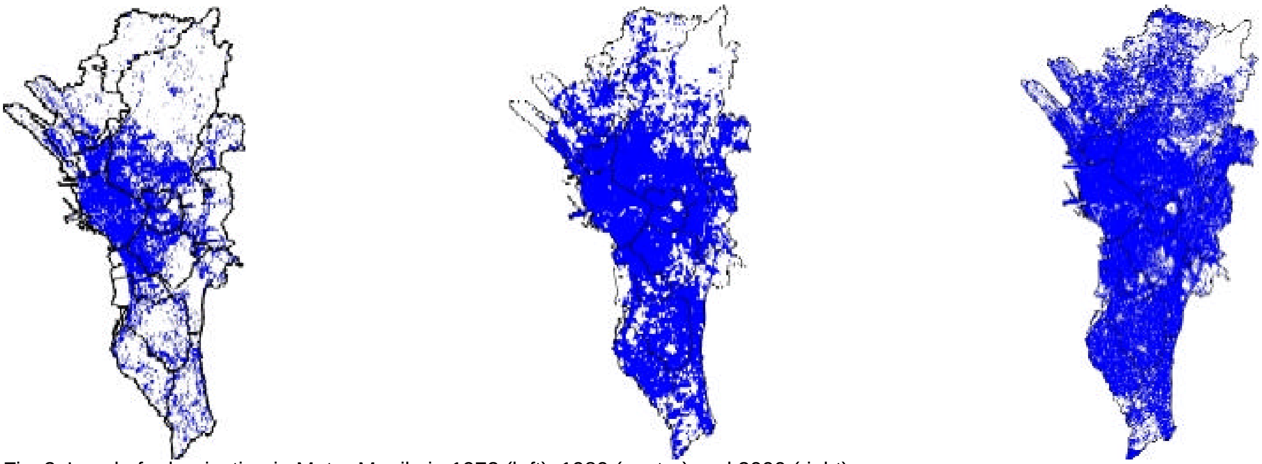

Fig. 2. Level of urbanization in Metro Manila in 1972 (left), 1989 (center) and 2000 (right).

Rapid and unplanned urban growth has disastrous social and environmental consequences. For example, the volume of solid wastes generated by a resident increased from 0.08 m³ in 1972 to 0.13 m³ in 2000. Garbage disposal is now considered as one of the major problems of Metro Manila. In 1971, Metro Manila has over 6,300 ha of farm lands. Now, its contribution to agricultural production is considered nil and Metro Manila is completely dependent on agricultural products from other parts of the country, making food prices volatile. Other urbanization-related issues such as poverty, informal settlers, access to basic services, pollution, and flooding are being faced by the region.

The use of satellite remote sensing can greatly aid land use planning practice in the country. Remote sensing can provide the spatial and physical perspectives to planning, which can then be linked to the social, economic, and environmental dimensions of planning. It can also provide a means of monitoring compliance with (or violations of) approved general land use plans. The multitemporal analysis of satellite images provides insights on the spatial limits to the growth of a city and on what possible space-constrained solutions can be formulated to alleviate urbanization-related problems.

5. Conclusions and Recommendations

This study aimed at monitoring urban growth in Metro Manila through a multitemporal analysis of satellite images. Results showed that remote sensing was useful in providing insights on the spatial dynamics of this process. Information from remotely sensed data can be linked with socio-economic and environmental data in order to determine the drivers and consequences of land use conversions. This has implications on how urban land use planning is practiced in the country.

The results reported in this paper represent a component of a larger study that is concerned with the evaluation of several urban cover classification and change detection algorithms and the development of a spatio-temporal model to characterize urban growth patterns at different spatial scales.

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