

Urbanization analysis through remote sensing and GIS in Kuala Lumpur, Manila and Singapore cities

MUKESH SINGH BOORI^{1, 2}, MAIK NETZBAND², VÍT VOŽENÍLEK¹, KOMAL CHOUDHARY¹

¹Palacky University Olomouc, 17. listopadu 50, 771 46 Olomouc, Czech Republic

²Geographical Institute, Ruhr University Bochum, Germany

mukesh.boori@upol.cz, maik.netzband@rub.de, vit.vozenilek@upol.cz,

Abstract: - This research work intends to explore the spatial analytical methods to identify both general trends and more subtle patterns of urban growth. In Kuala Lumpur, Malian and Singapore, where urban area have experienced an unprecedented rate of growth over the last 30 year. In this uncontrolled situation, city planners lack tools to measure, monitor and understand urban sprawl processes. Multi-temporal remote sensing has become an important data-gathering tool for analyzing these changes. The objective of this study is to explore an approach for combining remote sensing and spatial metrics to monitor urbanization and investigate the relationship between urbanization and urban land use plans. The study areas, consisting of the cities of Kuala Lumpur, Manila and Singapore, were examined using Landsat data from 1989 to 2014. In this study an ArcGIS spatial metric was undertaken to produce urban growth maps and evaluation the characteristics of urban composition. Land cover change analyses at the metropolitan city levels reveal that over the past three decades the significant increase of built-up land in the study area was mainly at the expense of non-forest vegetation cover. The spatial and temporal heterogeneity of the land cover changes allowed the identification of fast and slow sprawling areas. The results of the analysis suggest that at the metropolitan level both the areas of non-forest vegetation and the forestland became more fragmented due to development. Several factors contribute to on-going challenges of spatial planning and urban policy in these megacities, including rapid population shifts, less organized urban areas and a lack of data with which to monitor urban growth and land use changes.

Key-Words: - Urbanization, Landsat data, Change detection, Remote Sensing, GIS

1 Introduction

Increasing of urban sprawl is a major issue in many metropolitan areas due to importance of socioeconomic development under certain circumstances. The world population is shifting continuously from rural to urban. In 2008 half the world population raised in urban areas and by 2030 it will 60% [1]. The definition and impact of urban sprawl is not achieved [2], but urban sprawl is often referred to as uncontrolled, scattered suburban development that increase traffic problems, depletes local resources and destroys open space [3]. Urbanization can be defined as the changes that occur in the territorial and socioeconomic progress of an area, including the general transformation of land use/cover categories from being non-developed to developed [4]. To develop a comprehensive understanding of the causes and effects of the urbanization process, it is important to properly cauterize the urban sprawl. However, due to its association with poorly planned urban land use and economic activity [5], urban sprawl is often evaluated and characterized exclusively based on major socioeconomic indicators such as population growth, commuting costs, employment shifts, city

revenue change and number of commercial establishments [6]. The main cause of urbanization is migration of people to search better jobs and improve living conditions. Historically, urban immigration has increased at rates that have exceed those of infrastructure development in the destination cities, resulting in immigrants being unable to find suitable employment opportunities and subsequently becoming part of the urban poor. This rapid increase in urbanization and the concomitant effect that it has on land use means that it is becoming increasingly for city planners to adopt appropriate sustainable land use plans [7].

The objective of this study was to validate the applicability of spatial metrics for characterizing urbanization in the Kuala Lumpur, Manila and Singapore cities. In the previous study, we detected the expansion of Kuala Lumpur by using an image classification method [8]. The results visually showed the urban change of Kuala Lumpur from 1989 to 2014. However, in order to have a better understanding about the history of Kuala Lumpur development process, the local land use planners raised the questions of quantifying where and when the urbanization occurred in the same period. We

developed the primary research to new direction, in which the result not only answered the questions of the local land use planners, but also provided various examples of urban change patterns as well as the policies to manage these changes. Manila and Singapore were chosen because of some reasons. Firstly, the study wanted to compare the urban change of Kuala Lumpur and other cities in different countries. Secondly, these urban areas developed very fast in the same period from 1989 to 2014. Moreover, the study areas have a particular relationship in terms of the topography. All are coastal cities. The successful land use planning of Kuala Lumpur, Manila and Singapore was valuable to solve the gap of the urban development process and know the effect of the cost. While the primary focus was on urban development in Kuala Lumpur, Manila and Singapore, we expected that the analysis of urbanization patterns in other cities is considered useful not only for these three cities but also for other countries policy makers and related officials to have appropriated local land use plans [9].

In this research work, we used Landsat data for three different dates in Kuala Lumpur, Manila and Singapore. The land cover classification was based on maximum likelihood supervised classification [10]. Landsat was medium resolution data so not cluttered with microscopic details but differentiate urbanized and non-urbanized areas with high accuracy. We quantify the spatiotemporal growth with a combination of zonal statistics, landscape metrics and gradient analysis to characterize types of urban development. Our strategy for quantitatively describing urban footprints is twofold. First, we calculate parameters of the full extent of urban areas to identify types of spatiotemporal growth in Kuala Lumpur, Manila and Singapore. Second, analyze built-up density with respect to location (city center to outwards). In particular, we use zones with increasing distance to the urban centers to map the spatial development of the parameter. The results paint a characteristic picture of spatial pattern, gradients and landscape metrics and thus support to understand spatial growth and future modelling of urban development in Kuala Lumpur, Manila and Singapore [11].

In brief, we have emphasized that a strong need exists to investigate spatiotemporal urban growth dynamics in developing countries by means of geospatial simulation models to help governments prepare for the explosion of urban living. Developing countries cannot be expected to replicate the growth trends of developed countries [12]. Consequently, empirical research dedicated to these dynamic urban landscapes is of paramount

significance to ensure sustainable development. This study merged prospective analyses of the period from 1989 to 2014. The present study was conducted to investigate the previous land use change and urban growth of Kuala Lumpur, Manila and Singapore, few of the largest and fastest-growing megacities in the world [13].

2 Materials and Methods

2.1 Study area

Manila (coordinates 14°35'N 120°58'E) is the capital region of the Philippines, located on the eastern shore of Manila Bay and is bordered by the cities of Navotas and Caloocan to the north; Quezon city and San Juan to the northeast; Mandaluyong to the east; Makati to the southeast and Pasay to the south. It has a total population of 1,652,171 according to the 2010 census http://en.wikipedia.org/wiki/Manila_-_cite_note-2010_census-5 and is the second most populous city in the Philippines, behind Quezon City. The populace inhabit an area of only 2,498 hectares (6,172.69 acres), making Manila arguably the most densely populated city in the world with an area of 38.55 square kilometers. The city is developed on both the narrow coastal plains with an elevation of 0–10m and on inner hilly areas with an elevation of 20–70m. A mountain range with altitudes around 1000 m is on the NE side of the city. The Pasig River flows as a major river through Metro Manila, crossing between Manila Bay and Laguna de Bay (Fig. 1). Exchange of sea water and lake water is commonly observed in this river. The area has a tropical monsoon climate with an average annual temperature and precipitation of 27°C and 1970mm, respectively (<http://www.weatherbase.com/>). It has a distinct dry season from November to May and a wet season from June to October. Geological units underlying the study area are mainly Tertiary basement rocks, Plio-Pleistocene sedimentary rocks of the Guadalupe Formation, which is widely exposed in the central hilly areas and overlying coastal alluvium 10–60m thick.

Singapore (1°17'N 103°50'E) consists of 63 islands, including the main island, widely known as Singapore Island or Pulau Ujong in Malay. There are two man-made connections to Johor, Malaysia: the Johor-Singapore causeway in the north and the Tuas second link in the west. Jurong Island, Pulau Tekong, Pulau Ubin and Sentosa are the largest of

Singapore's smaller islands. The highest natural point is Bukit Timah Hill at 166 m (545 ft). Ongoing land reclamation projects have increased Singapore's land area from 581.5 km² (224.5 sq mi) in the 1960s to 718.3 km² (277.3 sq mi) presently. The country is projected to grow by another 100 km² (40 sq mi) by 2030. Some projects involve merging smaller islands through land reclamation to form larger, more functional islands, as has been done with Jurong Island. Temperatures usually range from 22 to 35 °C (72 to 95 °F). Relative humidity averages around 79% in the morning and 73% in the afternoon (Fig. 1).

Kuala Lumpur was chosen as the study area because urban dwellers perceptions on issues pertaining vegetation retention and urban development have not studied before and the values affected their daily lives. Kuala Lumpur (Latitude 3°8'N; Longitude 101°44'E) is situated in the Federal Territory of Kuala Lumpur in the west Peninsular Malaysia (Fig. 1). The total population of Kuala Lumpur in 2014 is 1.67 million people in an area of 94 square kilometers. This gives the city proper a very high population density of 17,310 people per square mile or 6,890 per square kilometer. Greater Kuala Lumpur or the Klang Valley is a large urban agglomeration with an estimated population of 7 million in 2014 with a population density that is nearly equal to that of the city proper (City Hall of Kuala Lumpur 2008). According to the 2010 census major ethnic groups in Kuala Lumpur are: Malays: 44.2%, Chinese: 43.2%, Indians: 10.3% and others: 1.8%. Kuala Lumpur is an aging city as birth rates have fallen in the last decade or two. This has led to a lower percentage of young people under 15 a group that has fallen from 33% in 1980 to under 27% in 2000. The working age group between 15 and 59 has increased from 63% in 1980 to 67% in 2000 as more people move to the city for opportunities. By 2020 Kuala Lumpur is projected to have a population of 2.2 million.



Manila, Philippines (Population: 11.85 million; 2010).



Singapore (Population: 5.39 million; 2013).



Kuala Lumpur (Population: 1.72 million; 2013).

Fig. 1. Study area and multi-buffer ring zones around city center of Kuala Lumpur.

2.2 Data

A selection of multi-sensor, multi-resolution and multi-temporal images was used for this study [14]. The specific satellite images used were Landsat TM for 1989, Landsat ETM+ for 2001 and finally Landsat 8 for 2014 an image captured by different types of sensor. According to [15] the time interval between images for the investigation of land use/cover changes levels I and II [16] Should be between 5 and 10 years and the spatial resolution should be 10m or larger so that the selected images and sensors comply with these criteria. Another reason for selecting these images was their availability. Cloud cover was less than 20% in all images and the visible and near infrared (NIR) bands used for data processing. All data was rectified geometrically to a common Universal Transverse Mercator coordinate system. In addition, Landsat images are frequently updated and are available free of charge through the Global Land Cover Facility repository.

2.3 Maps Processing

The images were rectified and georeferenced to the UTM projection (WGS 84 datum) by USGS prior to their distribution. We conducted an image to image registration of all images to the master scene, the 1989 image. We conducted the land cover classification at the metropolitan level. The nine Landsat images were classified based on the maximum likelihood algorithm [17]. The prime importance in this study was the footprints of built-up areas, subsuming residential, commercial and industrial buildings and transportation, among other factors. All image pre-processing, classification and classification accuracy assessment were performed using ArcGIS (ESRI Inc.) and ER Mapper software's. During the supervised classification a spectral signature file was generated and used for each of the nine images. In this process, with information from city maps and online high-resolution images, the areas with known land cover types were identified on the images as class signature training sample sites. For different land cover types, the number of the training samples varied from approximately 10–25. For example, approximately 10 training samples were selected for water, which can be easily identified, while over 25 training samples were used for the non-forest vegetation that could be mistakenly classified into residential/commercial types. In the signature evaluation, individually selected training samples in each signature file were manipulated (deletion or merging with other samples) until the most

satisfactory classification was achieved. For the purpose of characterizing urban sprawl, we identified four major types of land cover: built-up area, forestland, Agriculture, and water body (Fig. 2). The “built-up” class depicts residential areas of single houses and apartment buildings, shopping centers, industrial and commercial facilities, highways and major streets and associated properties and parking lots. The “agriculture” class includes grasslands, brush land and cropland. The omission of this small portion of the metropolitan area applied to all the analyzed images, thus did not affect the understanding of general trends of urban land cover changes through comparing these images. Spatiotemporal mapping includes quantitative time series analysis and transformation of land cover classes. Because land use maps are a fundamental prerequisite for modeling future growth, individual land use classes were extracted from the remotely sensed images for each timestamp [18].

As all nine images was geometrically corrected up to orthorectified level. Images from different sensors have different spatial resolutions. In this study we preferred to retain the spatial detail, original pixel size and value of each image. Therefore the images were kept without changing their pixel sizes despite the possible varying accuracy level of classification with the different spatial, spectral and radiometric resolutions. Next at the classification stage all of the images were classified by creating accurate polygons as training areas for introducing ideal classes for each image separately and by using the maximum likelihood classification method. To create a closer correspondence between the maps produced the classification was done by only considering four main classes: urban/built-up area, agriculture land, forest land (tree/park) and water [16, 19]. The selected main classes and their descriptions are presented in table 1.

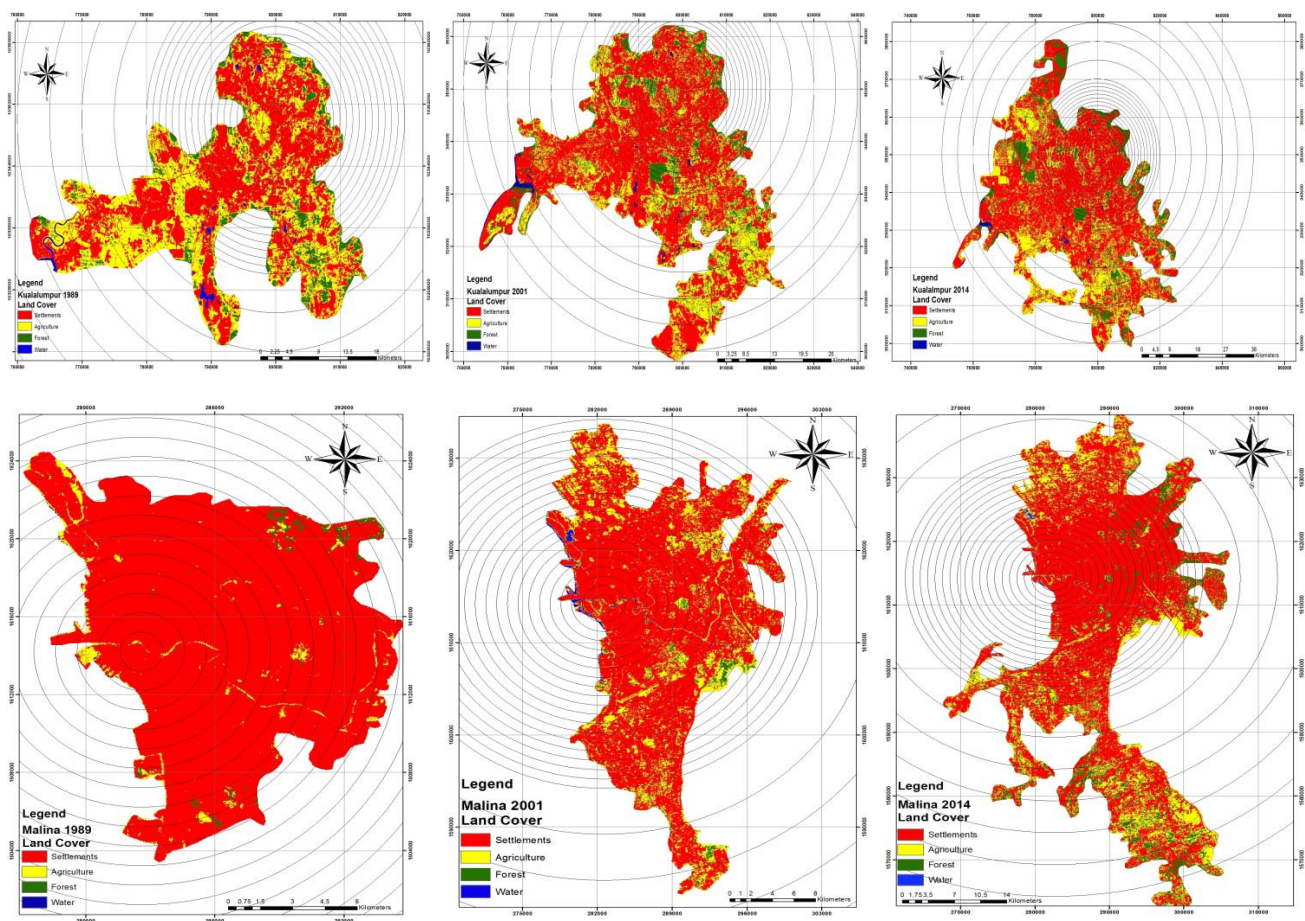
Table 1. Description of Land Use/Cover classes

Land Use/Class	Description
Urban or built-up	Residential, commercial and services, industrial, transportation and roads, mixed urban and other urban
Agriculture and Vegetation	Agriculture field, small vegetation, sand soils, landfill sites, areas of active excavation, dry salt flats
Forest or	Pine, coniferous trees and citrus orchards,

tree/parks	parks, grass belts
Water bodies	River, permanent open water, lakes, ponds and reservoirs, permanent and seasonal wetlands, swamps

The 1989, 2001 and 2014 images were resampled in post-classification using the nearest neighbor interpolation to match the remaining images of 30m * 30m spatial resolution. Post-classification refinement was used to improve the accuracy of the classification. In addition, because the urban surface is heterogeneous with a complex combination of features (buildings, roads, grass, trees, soil, water), mixed pixels and the salt and pepper effect are common problems when using medium spatial resolution data, such as Landsat [20-22]. In this step a 3*3 majority filter was applied to

all the classified land covers [23]. An accuracy assessment was performed at the metropolitan level. For an unbiased assessment, the stratified random sample strategy [24] was used to select 15 samples for each class totaling 60 points per image. Generally, the accuracy of the classifications is satisfactory, with the lowest values for the 2001 image (an overall accuracy of 85.50% and a Kappa index of 0.867). Except for the 2001 classification, the non-forest vegetation type had lower producer's accuracies than the other land cover types for the remaining eight images, ranging from 72.13% to 79.59%. This class type includes grasslands, brush, and cropland which are mixed with residential and commercial land cover types in many locations, potentially resulting in misclassifications.



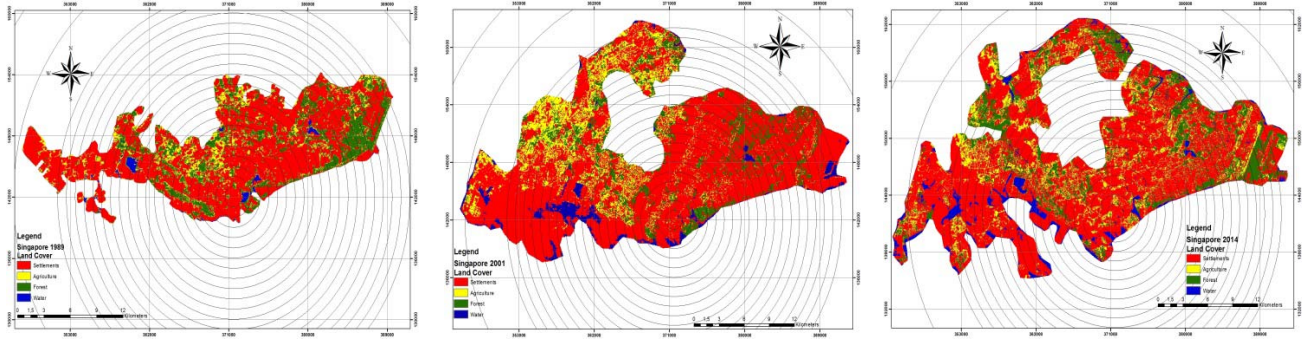


Fig. 2. Multi-buffer ring zones around city center of Kuala Lumpur, Manila and Singapore for 1989, 2001 and 2014 map.

This research was focused on urban built-up and urban vegetation coverage measurement and their interactions. Rangeland was considered to be both non-urban vegetation and forest area. Furthermore water bodies have very limited coverage and along with bare land cover was not discussed further in the results and concluding sections. The maps produced are presented in fig. 2.

After classification multi-buffer rings created for every 1 km distance from 1 to 50 km from city center to outside. Than intersect with classified maps for all three dates. Later on all class area were measured for 1 to 50km distance and derive density according to following formula:

$$\text{Urban density} = \frac{\text{Settlement area/ring}}{\text{Total ring area}}$$

2.4 Urban growth rate

In order to evaluate the spatial distribution of urban expansion intensity, we adapted an indicator called annual urban growth rate (AGR) for evaluating the ‘urbanization’ speed of unit area. AGR is defined as follows:

$$\text{AGR} = \frac{UA_{n+i} - UA_i}{nTA_{n+i}} \times 100\%$$

where TA_{n+i} is the total land area of the target unit to be calculated at the time point of $i+n$; UA_{n+i} and UA_i the urban area or built-up area in the target unit at time $i+n$ and i , respectively and n is the interval of the calculating period (in years). Generally, the target calculating unit is set to the administrative district so as to link with administration or economic statistics. In this research, we preferred the geographical gridding unit since the administrative borders have been changed so frequently in this city. The maps were

therefore gridded as 1 km×1 km units and the annual urban growth rates of each unit were then calculated. Lastly the grid-based annual urban growth rates were clustered by using natural break method and mapped to evaluate the spatial features of the ‘expansion’.

3 Results

The high level of accuracy observed in this study could be the result of the coarse classification since only four classes were used. It should also be noted that because of ground resolution differences and different multispectral bands between the images, the generated maps did not have the same classification accuracy. Furthermore, in all buffer rings only urban/built-up area was calculated in place of whole ring. After producing complete land use maps, the total coverage of different classes was determined. Using this information, we calculated the water, forest, vegetation and built-up area per capita for all the study years (Table 2).

3.1 Urban/built-up area

In Kuala Lumpur there are several major trends evident in the changes of land-cover that are consistent over the period 1989 to 2014. The urban/built-up area increased rapidly and there was a marked decrease in other classes. Some interesting patterns in the distribution of dwellings across different buffer zones can be noted in figure 2. As expected, the urban/built-up density in Kuala Lumpur tends to decline outward from the city center. According to the land use/cover maps produced for the urban area of Kuala Lumpur city was expanded from 456.99 km² in 1989 to 1098.48 km² in 2001 and finally reached to 1663.23 km² in 2014 (Fig. 3). This figure represents 46.67% growth in built-up area over a period of three decades. In the first decade urban growth was 35.16% at an

average rate of 3.19 km²/year. In the year of 2001 to 2014 (1663.23 km²) the average rate of expanse was 1.68 km²/year and total 21.85% in second decade. So city expanse rate was reduce just half (1.51 km²/year.) in second decade. The urban/built-up area has grown by factor four over the past 3 decades, increasing from 51.81% of the study area in 1989 to 60.22% in 2001 and finally 64.36% in 2014, while the area of agriculture land decreased from 39.16% in 1989 to 28.53% in 2001 and 27.06% in 2014. The area of forest has first increased from 7.99% to 10.35% from 1989 to 2001 and later on reduced 8.13% in 2014. In contrast, the area of water was 1.04% in 1989, 0.91% in 2001 and 0.45% in 2014 (Table 2).

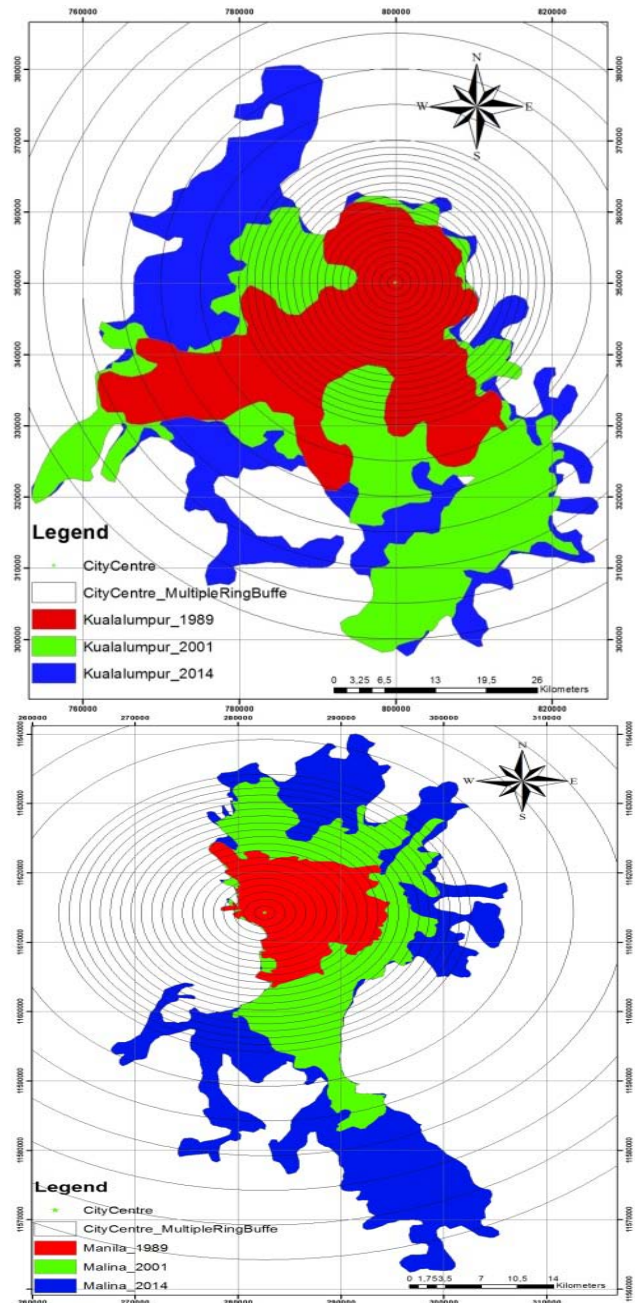
Table 2. Kuala Lumpur land use/cover classes for 2089, 2001 and 2014.

Kualalumpur	Area_1989	%	Area_2001	%	Area_2014	%
Settlements	456.99	51.81	1098.48	60.22	1663.23	64.36
Agriculture	345.46	39.16	520.40	28.53	699.21	27.06
Forest	70.50	7.99	188.74	10.35	209.99	8.13
Water	9.18	1.04	16.54	0.91	11.68	0.45
Total	882.13	100.00	1824.16	100.00	2584.11	100.00
Manila						
Settlements	189.61	96.70	416.87	77.08	776.65	69.12
Agriculture	6.37	3.24	110.14	20.37	243.89	21.71
Forest	2.19	1.11	9.44	1.75	98.59	8.77
Water	0.1	0.05	4.36	0.81	4.42	0.39
Total	196.08	100.00	540.81	100.00	1123.55	100.00
Singapore						
Settlements	196.88	66.25	383.23	69.71	464.69	70.19
Agriculture	34.67	11.67	80.26	14.60	80.84	12.21
Forest	60.74	20.44	62.58	11.38	89.65	13.54
Water	4.89	1.65	23.64	4.30	26.87	4.06
Total	297.18	100.00	549.71	100.00	662.05	100.00

In Manila in 1989 urban/built-up area was 189.61 km², in 2001 it was 416.87 km² and in 2014 it was 776.65 km². Urban growth rate from 1989 to 2001 was 42.02% with the rate of 2.82 km²/year and from 2001 to 2014 was 12.30% (0.95 km²/year). So total urban growth of manila from 1989 to 2014 was 40.45% (1.61 km²/year). In Singapore urban/built-up area was 196.88 km² in 1989 and 383.23 km² in 2001 and finally reaches 464.69 km² in 2014. Urban growth rate from 1989 to 2001 was 33.89% with the rate of 3.50 km²/year and from 2001 to 2014 was 32.02% (2.46 km²/year). So total urban growth of manila from 1989 to 2014 was 52.24% (2.08 km²/year).

General trends in land cover change were identified in all three cities. The results of satellite image classification (Fig. 2) suggest that the metropolitan area has experienced significant land conversions mainly due to urban expansion. At the metropolitan scale, the built-up land cover increased over the past three decades at an average rate of

1.86, 2.08 and 1.61 km²/year in Kuala Lumpur, Manila and Singapore respectively and the non-forest vegetation cover bore the major burden of urbanization. The forestland cover remained relatively unchanged at the metropolitan level. The water body class, which was the smallest land cover among the three detected classes, stable due to man-made reservoirs was created over the study period.



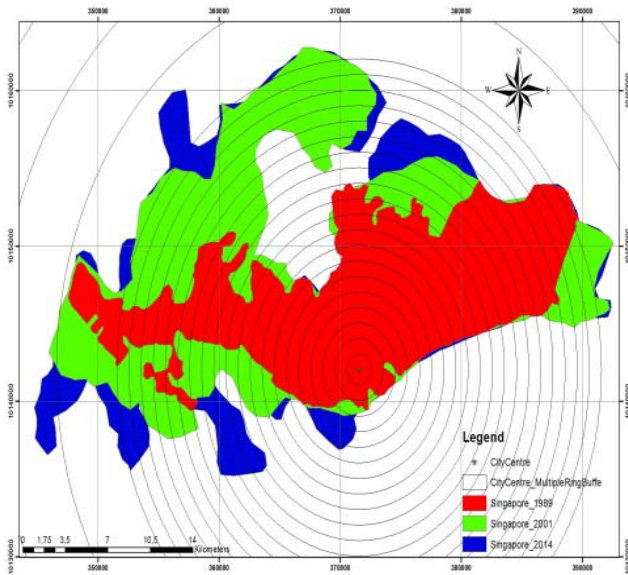


Figure 3. Kuala Lumpur, Manila and Singapore city growth in 1989, 2001 and 2014 map.

3.1 City density

City density patterns around the city center were also examined to ascertain whether different zones have represented different densities. Figure 4 shows 50 buffering zones from 1 to 50 km distance. It has been argued that the first 5 zones represent the areas that are within walking distance from city center. High-density development has been supported by the government to encourage people to walk to train stations or other destinations such as shopping centers. This policy has in part been pursued to encourage active transport as part of a healthy lifestyle.

We find that in Kuala Lumpur city centre urban density was more than 90% for last three decade. In 1989 it was reduced dramatically on distances of 5km from city centre around 55% and on 15km less than 10% and after 40km it's 0%. If comparing 1989 and 2014 on distances of 5, 8, 15, 20 and 30km the city density has increased very high. If we compare only 1989 and 2001 than on the distance of 8, 15 and 19km, the city density was highly increased. From 2001 to 2014 on the distance of 4 and 30km density was increased. On distance of 50km the city density was 0% in last 3 decade. For whole 3 decade city density was dramatically reduced on distance of 20km and later on stable (fig. 4).

Manila city density was more than 80% in 1989 and 2001 but in 2014 it was more than 95% in center. Then it's continuously reduce till 5km distance from city center and later on stable till 8km. in 1989 it was dramatically reduced from 8 to 13km distance about 55% to 0%. Maximum urban/built-up

city density difference from 1989 to 2001 was on 13-15km distance around 40%. Analysis shows that urbanization was increased in between 11 to 25km distance and later on its 0% (fig. 4).

In Singapore at city center urban/built-up density was 90% in 1989 and 2001 but in 2014 its little bit reduce (85%). Its continuously reduce in all three decades till 7km, later on stable from 7 to 20km for 2001 and 2014. In 1989 urban density reduce continuously from city center to till 30km and it was 0% on 30km. The maximum variation was on 12 to 20km distance, where density was in increase from 1989 to rest years from 10% to around 30%. In all three decades city density was 0% from 30km distance to later on (fig. 4).

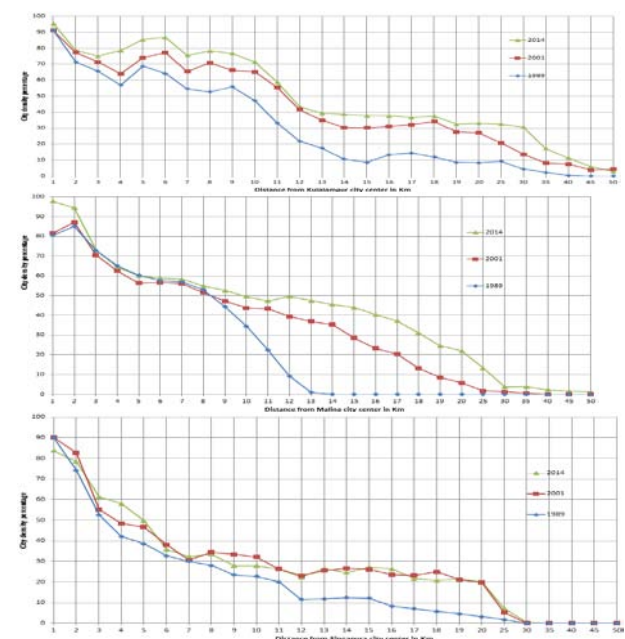


Figure 4. Kuala Lumpur, Manila and Singapore city density from 1 to 50km distance for 1989, 2001 and 2014.

In **Kuala Lumpur** in 1989 the city center urban density was more than 90%, the share of agriculture was 10%, forest and water was 0% (fig. 5). Till 4km distance from center the urban/built-up area continuously reduces (55%) and agriculture has continuously increased till 45%. Latter on both have small variation and from 8 to 15km distance both classes reduce. In the last both classes were stable or variant little bit and after 40km distance both classes have 0% density. Forest class has 0% density from 1 to 4km and from 30 to 50km distance. It has less than 10% density from 5 to 30km distance. The water class has almost close to 0% density in all distance. In 2001 density of urban/built-up and agriculture is same like 1989 till distance of 8km. Later on urbanization reduces continuously. In 2001

agriculture has 10% density from 8 to 50km distance. Forest has 0% density on 1 and 50km distance. Forest has highest 15% density on 9km and 10% density on 7, 8, 10, 11, 16 and 17km distance. Water class was very less on maximum distance and has 0% density (fig. 5). In 2014 in city center urban density was more than 95% and other classes (agriculture, forest and water) was less than 5%. From 1 to 3km distance, urban/built-up areas reduce till 75% but agriculture increase and reach up to 22%, later on reduce or varies around 10 to 15% in all distances. Urban/built-up density again increases after 3 to 6km and later on reduces continuously and reaches on 0% density on 50km distance. Forest was variant on 10% and vise-versa with agriculture class. In all distances water was close to 0% density (fig. 5).

In **Manila** in 1989 urban/built-up was 80% and other classes were close to 0% on city center. Later on urbanization was reducing continuously and on 13km distance all classes was 0% so final city boundary was till 13km. In 2001 agriculture was around 15% and little bit water class but forest density 0% and urbanization was more than 80% on city center. Agriculture was reducing till 3km distance later on increase and highest on 13-14km around 18% and after 25km its 0%. In all distance forest and water variant near to 0%. In 2014 urbanization is more than 95% and agriculture was more than 15%. Urban was reducing continuously and reach 0 on 30km distance. Other classes were also close to 0 but from 13 to 25km distance agriculture was around 10%.

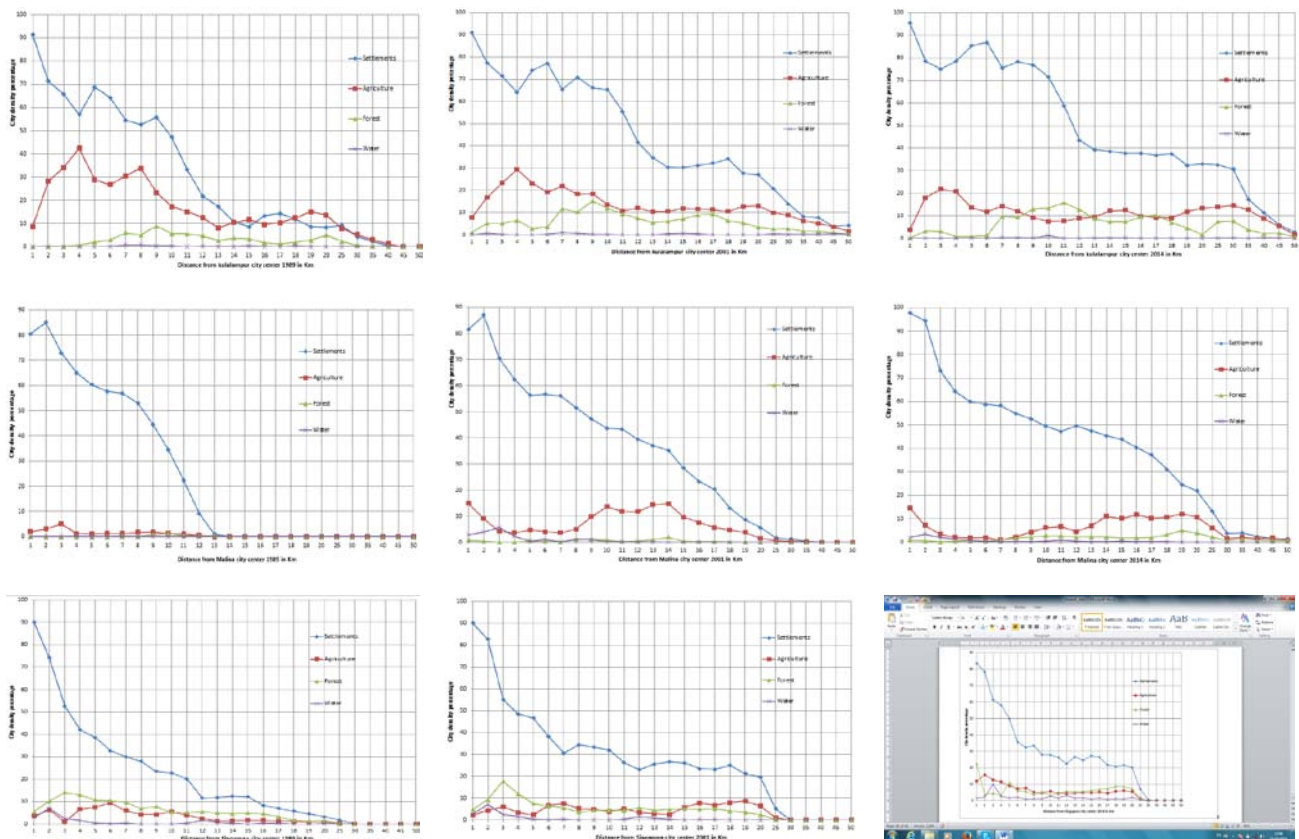


Fig. 5. Kuala Lumpur, Manila and Singapore land cover class density from 1 to 50km distance for 1989, 2001 and 2014.

4 Discussion

All three cities examined in this study have grown on coastal area. Due to the marked difference in socio-economic conditions, the urbanization of **Kuala Lumpur** is considerably different from that observed in Manila and Singapore. The urban growth under the Kuala Lumpur Land Use Master

Plan has been influenced by economic development. Once the economy of the city has undergone remarkable changes, including an increase in the population of the city as well as expansion of urban land use, over all the urbanization of Kuala Lumpur was increase. Moreover, the majority of new immigrants lived in densely populated informal settlements adjacent to industrial zones, transport hubs and major markets along the city fringes.

Within the context of official housing policy, these areas were considered to be illegal urban centers over time, the 1989 and 2014 maps show that urban expansion has occurred in two directions, one to the east and a linear branch-type to the north and south. At that time, the urbanization of Kuala Lumpur was also characterized by the development of urban areas along newly constructed roads and highways. That's why area of the inner city transportation infrastructure increased.

The rate of urbanization increased continuously after 1989 due to the economic boom in *Manila*. Even so, despite the economic boom, immigrants moved to the city at this time. In order to promote decentralization of the city center, numerous apartment buildings were constructed in the suburbs. Taken together, agricultural land and forest areas were converted to urban use and the urban areas continued to expand along highways to the north and south of the city. Despite the observed increase in the rate of urbanization since 1989, the urban core coalesced with the various fragmented urban patches to form a homogenous urban patch in 2001.

The adoption of the economic growth reforms marked a remarkable change in the progress of urbanization in *Singapore*. However, compared to the cities of Kuala Lumpur and Manila, the urbanization of Singapore has also produced several problems. In the newly urbanized areas, the new transportation routes (the development zones around the city) and apartment buildings were planned very close to existing urban areas and are an average of 10km away from the city center. The development of new urban areas far from the main city center not only attracts people to the suburbs, but also increases the long-term development potential. In Singapore, the new urban areas were quickly assimilated into the old urban center by the rapid and unexpected economic growth that followed the economic reforms. In addition, urban growth in Singapore has primarily occurred along the major transportation routes on the eastern and western side of the center, which has resulted in an increase in the price of land. The resettling of inhabitants and extension of transportation routes inside the existing urban areas has also been difficult. Its increase the high rate of construction cost inside the city. Taken together, these problems illustrate the importance of developing adequate land use plans for Singapore to cope with rapid urban development.

The census data indicate that the main phase of population growth in all three cities occurred between 1989 and 2001. The main causes of this growth were a high birth rate in the early years of

the Islamic revolution, rural to city migration and the merging of nearby villages with the city as it developed. Urban expansion and subsequent landscape changes are governed by geographical and socio-economic factors such as population growth, policy and economic development. In most cases, urban expansion and associated land use/cover changes resulted from a combination of these factors. For example, socioeconomic policy can strongly affect urban expansion and under the changes driven by urban expansion the land use patterns of the urban outskirts were altered or adjusted in pursuit of high economic returns (orchards or croplands changing to vegetable land). Even though it was difficult to clarify the influence of these factors in these changes their influence was examined by analyzing the relationships between developed area (including urban and residential area) and socioeconomic factors such as population, industrialization, traffic conditions and infrastructure.

Urbanization may be linked with details of topography, transportation, land use, social structure and economic type, but in generally related to demography and economy in a city [25]. In the following, we analyze consequences of the plurality of these influencing factors on spatial urbanization. We analyze spatiotemporal processes of urbanization by urban form and its changes over time. The methodology to analyze spatiotemporal urban growth was two-fold: At first the analysis aims to identify types of spatiotemporal urban patterns at the city level. Therefore, we analyze parameters like absolute areal growth or built-up densities (sealed areas per spatial entity), as well as landscape metrics. In general, spatial metrics can be defined as quantitative and aggregate measurements derived from digital analysis of thematic-categorical maps showing spatial heterogeneity at a specific scale and resolution [26, 27]. The second step provides insight into detailed spatial gradients, like the change of built-up density with respect to increasing distance to the urban center. Thus, location-based analysis of urban structure satisfies this requirement. The main idea was to learn mechanisms of the complex process of spatial urban growth by finding similarities and differences between cities development.

4 Conclusions

Remote sensing and spatial metrics provides an innovative method for analyzing urban growth patterns. In this study, a detailed analysis of urban growth in Kuala Lumpur, Manila and Singapore

over a three decade period was performed and the results were presented using urban change maps. Using these results, we were able to examine the changes in the urban land use of three cities over time. Over the past three decades, urbanization has significantly modified the land cover of metropolitan Kuala Lumpur, Manila and Singapore city. The built-up land markedly increased, mostly at the expense of the non-forest land, for all the study cities as well as for the metropolitan area as a whole, while forestland remained relatively unchanged at the metropolitan level. City based analyses identified fast and slow sprawling spots of the metropolitan area. This research work identified the landscape effects and spatial patterns of built-up land expansion. As a general trend at the metropolitan level, non-forest vegetation and forestland patches became more fragmented as a result of the increase of built-up area over the period of study. These types of studies can provide complementary information on urban land conversion when solely using population based indices may skew the interpretation.

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References:

- [1] Waibel, M., Drawn and quartered—Hanoi's ancient centre is feeling the pressure from outside and in, So what can architects and officials do to stop the rot? *Vietnam Econ. Times*. 1995, 24–25.
- [2] Johnson, M. P., Environmental Impacts of urban sprawl: a survey of the literature and proposed research agenda. *Environment and Planning A*, 2001, 33(4), 717–735.
- [3] Peiser, R., Decomposing urban sprawl. *Town Planning Review*, 2001, 72(3), 275–298.
- [4] Weber, C., Remote sensing data used for urban agglomeration delimitation. *Remote Sens. Urban Anal.*, 2001, 155–167.
- [5] Pendall, R. Do land-use controls cause sprawl? *Environment and Planning B: Planning and Design*, 1999, 26(4), 555–571.
- [6] Lucy, W. H., & Phillips, D. L., Suburbs and the Census: Patterns of Growth and Decline. *Washington, DC: The Brookings Institute*. 2001.
- [7] Boori M.S., Amaro V.E., Land use change detection for environmental management: using multi-temporal, satellite data in Apodi Valley of northeastern Brazil. *Applied GIS International Journal*, 2010, Vol. 6(2): 1-15.
- [8] Boori M.S., Vozenilek V., Burian J., Land-cover disturbances due to tourism in Czech Republic. *Advances in Intelligent Systems and Computing, Springer International Publishing Switzerland*. 2014, Vol. 303: 63-72, [Doi: 10.1007/978-3-319-08156-4-7](https://doi.org/10.1007/978-3-319-08156-4-7)
- [9] Boori M.S., Amaro V.E., A remote sensing approach for vulnerability and environmental change in Apodi valley region, Northeast Brazil. *International journal of Environmental, Earth Science and Engineering*, 2011, Vol. 5(2): 01-11.
- [10] Taubenböck, H., Pengler, I., Schwaiger, B., Cypra, S., Hiete, M., & Roth, A., A multi-scale urban analysis of the Hyderabad Metropolitan area using remote sensing and GIS (p. 6). Urban remote sensing joint event, Paris, France. 2007.
- [11] Boori M.S., Amaro V.E., Vital H., Coastal ecological sensitivity and risk assessment: A case study of sea level change in Apodi River (Atlantic Ocean), Northeast Brazil. *International journal of Environmental, Earth Science and Engineering*, 2010, Vol. 4(11): 44-53.
- [12] Van Ginkel, H., Urban future. The cities of the developing world are spectacularly ill-prepared for the explosion in urban living. *Nature*, 456, 32e33. 2008.
- [13] United Nations. World urbanization prospects. The 2011 Revision. New York. 2012.
- [14] Gamba, P., Dell'Acqua, F., & Dasarathy, B. V., Urban remote sensing using multiple data sets: Past, present, and future. *Information Fusion*, 2005, 6, 319–326.
- [15] Jensen, J. R., & Im, J., Remote sensing change detection in urban environments. In R. R. Jensen, J. D. Gatrell, & D. McLean (Eds.), *Geo-spatial technologies in urban environments: Policy, practice and pixels* (2nd ed., pp. 7–30). Springer-Verlag: Heidelberg. 2007.
- [16] Anderson, J. R., Hardey, E., Roach, J., Witmer, R.E., A land use and land cover classification system for use with remote sensor data. US geological survey professional paper, Washington, DC, 1976, 964, 28 pp.
- [17] Feizizadeh, B., & Helali, H., Comparison pixel-based, object based image analysis and effective parameters in classification land cover

e land use of west province Azerbaijan. Journal
of Geographic Research, 2010, 47, 73e84.