Determination of Spatial Factors in Measuring Urban Sprawl in Kuantan Using Remote Sensing and GIS

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Abstract

This research attempts to study the measurement of defining sprawl by using spatial factors indexes through remote sensing and GIS approach. The IKONOS pan-sharpened and SPOT-5 with 1 and 2.5 meters resolution were used and combined with GIS database to analyze the geospatial indicators using spatial factors namely highway strips, leapfrog development and land use segregation these indexes. Kuantan city was selected due to the high growth rate of its population and the rapid establishment of new town area. The finding shows that characterization of these spatial factors has resulted in identifying Kuantan as non-sprawl city.

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Keywords: Urban sprawl measurement; spatial factors; geospatial indices; remote sensing and GIS

1. Introduction

Urban sprawl which has become an issue for many rapidly developing areas refers to the uncontrolled growth of an urban area resulting from poorly or totally unplanned urbanization. Urban sprawl always refers to the outgrowth of urban areas caused by uncontrolled, uncoordinated and unplanned growth. The inability to visualize such growth during planning, policies and decision making process has resulted in sprawl that is both unsustainable and inefficient. The rapid urbanization have impact of wildlife habitat, watershed land, farm land and open spaces cause many unforeseen consequences including loss of prime

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farmland, loss of natural resources, increased environmental pollution, traffic congestion and many other physical, social and economy effect (Burchell and Shad 1999; Hasse and Lathrop 2003; Sierra Club, 2001).

There have been a lot of debates on measuring urban sprawl for more than 20 years shows that meaningful and reliable measures of urban sprawl are still lacked. Based on variety of definitions of urban sprawl has been derived in describing sprawl and as a specific form of urban development with low density, disperse, auto-dependent, environmentally and socially-impacting characteristic (Burchell and Shad 1999; Ewing 2002; Galster et al 2001; Ghate 2005; Majid et al 2005; Torrens et al 2000), it seems there is no general agreement about what defines urban sprawl (Wilson et al., 2003; Sidentop, 2005). In related, it is found also that many scholars focus on using indicators to measure urban sprawl by establishing multi-dimensional indicators by GIS analysis or descriptive statistical analysis (Galster et al 2001; Barnes et al 2001) while the existing understanding of urban sprawl more tend to qualitative instead of quantitative approach. There is also urgent need to provide government officials and planners a scientific method to measure and monitor urban sprawl, especially in rapidly growing cities in developing countries where urban sprawl has caused many environmental problems.

We agree that spatial characteristic somehow effect or are affected by urban sprawl, the relation of these indicator to urban sprawl is often not clear. As consequence, we would argue that small-shot-charge approach to the phenomenon of urban sprawl adds relatively little to clarify the terminology and the concepts, and can lead to inconsistent result and other problems when comparing results from previous studies. Therefore we advocate a more systematic approach to this paper with attempt to measure an existing development in Kuantan area based on suitability criteria through detailing a land use type with characterized the spatial factor of highway strips, land use segregation and leapfrog development using remote sensing and GIS approach.

1.1. Theoretical review on measuring urban sprawl

Characterising urban sprawl using spatial measures requires a concise definition of what exactly constitutes sprawling urban spatial patterns. The study of geospatial indices was started by Hasse and Lathrop(2003) who developed a set of 12 measures to objectively analyze a development tract for the characteristics of sprawl or smart growth. Apart of attempt has been made was to find the best way in measuring urban sprawl by using 12 spatial factors which focuses on development characteristics. Among that, there are three factors have been tested in this study consist of highway strip, land use segregation and leapfrog development.

The use of remote sensing and GIS techniques can be separately or in combination for application in studies of urban sprawl. Geographical information system (GIS) and Remote sensing data can supply physical, social and economic data for simulation Mohd Noor et al, 2012). There are some researches on how to use remote sensing and GIS to monitor and measure urban sprawl (Ibrahim et al 2009; Yeh and Xia 2001; Li 2009; Sudhira et al 2003; Jain 2008; Weng 2002). There is a strong need to better define the term “sprawl” in order to focus specifically on the undesirable and problematic characteristics of development that many stakeholders are arguing about. Remote sensing has the capability to provide spatially consistent datasets that cover large areas with both high spatial detail and high temporal frequency. Remote sensing is a “unique view” of the spatial and temporal dynamics of the processes in urban growth and land use change (Herold et al 2003). Satellite remote sensing techniques have, therefore, been widely used in detecting and monitoring land cover change at various scales with useful result (Wilson et al 2003; Stefanov et al 2001). Recently, remote sensing has been used in combination with Geographical Information System (GIS) and Global Positioning System (GPS) to assess land cover change more effectively than remote sensing data alone (Muller and Zeller 2002; Weng 2002). It has been
proved to be useful in mapping urban areas, and as data source for the analysis and modelling urban growth, and land use/land cover change (Wilson et al 2003; Herold et al 2003; Asmat et al, 2012).

1.2. Study Area

The study area is located in Kuantan district (03°52N, 103°17E and 03°45N, 103°23E), Malaysia, which covers an administrative area spread over an area about 296,000 hectares (figure 1). Majority of the land use patterns consist of built up areas and un-built areas. Population of Kuantan was 607,778 in 2012 and it is projected to be 642,555 in 2015, as per the present growth rate (Kuantan Local Plan, 2010-2015).

2. Materials and method

The primary research mainly depended on the data obtained from ARSM (Malaysian Remote Sensing Agency), Department of Survey and Mapping Malaysia (JUPEM), and local authority (Kuantan Municipal Council). The satellite data were the primary sources while the ancillary data were the secondary data (Table 1).
2.1. Methods

The image pre-processing and data preparation were carried out; these included image rectification and mosaicking. The image-to-map procedures were applied to the IKONOS Pan sharpened images using set of ground control point’s area that appeared in the same place, both in the imagery and known locations in corresponding map and urban plan used as ancillary information in the rectification process. The rectified datasets were then mosaicked thus producing the entire study area from 1 set of the raw IKONOS data and 20 sets of Spot-5 images as supported data (Figure 2). Image classification was then applied to the pre-processed image and the land use classes map of the entire study area was produced. Supervised classifications techniques were chosen for this study, which was performed using object-based classifier in e-Cognition software system. The system enabled all fine details of the land cover to be classified and later merged accordingly to form the classes in accordance to urban land use classes used in urban planning practice.

The analysis of urban sprawl growth in Kuantan city was carried out by using Highway Strip, Leapfrog development and Land use Segregation spatial factors. As developed, the highway strip index is a binary measure. Residential units are designated highway strip if they occur along rural highways outside of town centres and the surrounding urban growth boundaries. New residential units within the delineated rural highway buffer are considered sprawling for this measure. For this study, the road was buffered by using GIS software. The existing land use data were set with Pahang Cassini-soldner projection system in order to get the precise width of the buffer area. Then, the buffer was set as 300 feet or 100 meter in the actual area, a common depth for a 1-acre (0.4-ha) residential lot. Residential units that fell within the buffer were coded to 1 and units outside the buffer were coded to zero. The municipal-level highway strip index (\(H_{S\text{mun}}\)) was calculated by summing the number of residential units that occurred within the highway buffer and then normalizing by the total number of units that were developed within the area as depicted in Equation 1 (modified from Hasse and Lathrop, 2003):

\[
H_{S\text{mun}} = (\sum H_B\text{unit})/N_{\text{mun}}
\]
Where $H_{Smun}$ is the highway strip indicator by area, $HB$ unit is the residential unit within highway buffer, and $N_{mun}$ is the number of residential units in the study area. This provided, in essence, a probability measure of highway strip occurrence for each area. The area that experienced a higher ratio of residential highway strip development was considered more sprawling for this measure than the area with lower ratios.

![Flowchart of data processing adopted in the study for highway strip measurement](image)

While for the leapfrog development, the previous settlements were delineated as patches of urban land use existing in Time 1 that corresponded to designated place names on a USGS quadrangle map or existing patches larger than 50 acres (20 hectares). This filtered out smaller non-named patches of Time 1 urban areas that had already leapfrogged from settled areas. Three new residential areas was recognized
and buffered as 1500 feet in diameter and categorized as patch A, B and C. A straight-line distance grid was generated from the “previously settled” patch and the value was assigned to each new residential unit patches. The residential unit leapfrog value was scaled to the municipal leapfrog index ($LF_{mun}$) by summarizing the leapfrog field value of the residential unit point layer by municipality as depicted in Equation 1: (Modified from Hasse and Lathrop, 2003).

$$LF_{mun} = \left(\sum D_{lf}\right)/N_{mun}$$ (2)

Where $LF_{mun}$ is the leapfrog index for new urban patches within a municipality, $D_{lf}$ is the leapfrog distance for each new unit, and $N_{mun}$ is the number of new residential units in a given municipality. New growth that occurs at large leapfrog distances is considered sprawling. The measurement using Land Use Segregation index, the land use map has been gridding by using GIS software. The existing land use data need to be set with Pahang Cassini Soldner projection system in order to get the precise length and width of the grid. Then the grid will be set as 450m x 450m or 1500 feet x 1500 feet in the actual area.

The municipal-level segregated land-use index ($SL_{mun}$) was calculated by averaging the segregated land-use value of each new residential unit by municipality as depicted in Equation below. New urban growth that exhibits a higher proportion of segregated land use is considered more sprawling than a mixed land-use pattern for this measure as per equation 1(Modified from Hasse& Lathrop, 2003):

$$SL_{mun} = \left(\sum Seg_{unit}\right)/N_{mun}$$ (3)

Where $SL_{mun}$ is the segregated land-use indicator by municipality; Seg unit is X minus the number of different developed land uses within 1,500 ft (450 m) of a given residential unit, in which X is one plus the maximum land-use mix in a given dataset.

3. Analysis and finding

3 sets of IKONOS images and 20 sets of Spot-5 images were successfully geometrically corrected with transformed RSO coordinate with RMSE ± 0.5 pixels to ensure accuracy of the sprawl. In fact, this RMSE has been widely used as a good practice to ensure good geometric output apart from ensuring sound configuration of ground control point that is evenly distributed in the study area. Fill this imagery is also subject to image enhancement. The image classification was carried out in two steps process to produce first level classes of built and un-build areas, and further detailed land use classes within the built-up areas.

3.1. Highway strip

This research was determined a sprawl character using the calculation of the primary and secondary collector road instead of highway due to its location was outside from Kuantan area. The residential area in Kuantan covers 75.5% of the total land use percentages which cover 33 653 of residential units from the total of 44 563 lots. The result in this study shows that the development in Kuantan city was considered as non-sprawl. The highway strip sprawl in Kuantan city is considered as likely not to occur in the near future due to the higher gap of the highway strip percentages between sprawl which is only 5.89% and non-sprawl area which is 94.10% (Table 2).
Table 2. Percentages of highway strip development in Kuantan city

| Residential Unit | Units  | Percentages (%) |
|------------------|--------|-----------------|
| Sprawl (1)       | 1984   | 5.89            |
| Non-Sprawl (0)   | 31,669 | 94.1            |
| TOTAL            | 33,653 | 100             |

The result of highway strip index obtained for Kuantan city is 0.063 and it shows as very low indexes \([HSmun = 1984/31669]\) for urban sprawl development. The number of residential lot within the buffer area (highway strip index = 1) is only 1984 lots compared to numbers outside the buffered area (Highway strip index = 0) which is 31,669 lots. This study was focuses on investigating a highway strip occurrence in one district with different road categories and different types of residential area instead of comparing of its application in more than one district. The result shows that a study by Hasse and Lathrop (2003) and Mesev (2007) for highway strip development index was 0-value or low sprawl because of the limited highway area in their study area.

3.2. Leapfrog development

The new development areas (Time 2) in this research identified are Kota Sultan Ahmad Shah, Taman Kg. Padang Jaya and Astana Golf and Country Club while the previous settlement area (Time 1) was located in AlorAkar. Each distance from Time 1 to Time 2 was measured in Kilometres (km) was recorded.

Fig. 3. Measurement of sprawl by using Leapfrog development from time 1 to time 2
The result shows that by using geospatial indices on Leapfrog development spatial factors in measuring sprawl from AlorAkar (time 1) to three selected new residential development area in Kota Sultan Ahmad Shah, Taman Kampung Padang Jaya and Astana Golf and Country Club (time 2), the sprawl new development area can be detected and measured. The calculation method to determine either sprawl or non-sprawl was based on residential area as the starting point between new development area and previously settled area.

The result for leapfrog analysis shows that the development of Taman Kg. Padang Jaya was considered as more sprawl with 11km in distance (42%) followed by Kota Sultan Ahmad Shah with the distance of 9 km (35%) from AlorAkar area (refer Table 3). Astana Golf and Country Club was considered as less sprawl development because the area is only 6km (23%) from previously settled area which is AlorAkar. Taman Kg. Padang Jaya was more sprawl than other places because the development between the area and AlorAkar mainly consist of industrial and institutional, it shows the new development area for residential is far from the previous settlement area. This place also was far from the AlorAkar because the area was proposed as Kuantan Central which is new development, so Kota Sultan Ahmad Shah was developed in line with this proposed Kuantan Central.

| New Residential Patches | Distance (Km) | Percentages (%) |
|-------------------------|---------------|-----------------|
| A (Kota Sultan Ahmad Shah) | 9 | 35 |
| B (Taman Kg. Padang Jaya) | 11 | 42 |
| C(Astana Golf & Country Club) | 6 | 23 |
| TOTAL | 26 | 100 |

3.3. Land use segregation

The sprawl analysis on land use segregation factor is based on residential units. The result for land use segregation shows that the distribution of land use sprawl based on the residential shows that the sprawl area (< 3 types of land use) mainly focus in the Proposed Kuantan Sentral, Kota Sultan Ahmad Shah and Taman Gelora. The area with more than three types of land use is concentrated at Bandar Kuantan, Bandar Indera Mahkota, Bukit Setongkol, Bukit Pelindung and Taman Kampung Padang (Fig. 4).
Table 4. Measurement of urban sprawl based on land use segregation

| Measurement | Percentages (%) |
|-------------|-----------------|
| Sprawl      | 14.3            |
| Non-sprawl  | 85.7            |
| TOTAL       | 100             |

The analysis of land use segregation also shows that 85.7% of study area is non-sprawl and only 14.3% is considered as sprawl.

4. Discussion

The case study demonstrates that the sprawl indicator measures provide a robust set of tools for analysing spatial patterns of urbanization. This study was adopted a calculation of three types of geospatial characters namely highway strip, leapfrog development and land use segregation are based on residential area as the reference point. The result shows that the development in Kuantan city was considered as non-sprawl. However, in some area, a pattern of sprawl has started to develop and need to be resolved for the future especially in suburban. The calculation on the area which being re-calculated by using built-up area as a reference point, the result shows a level of increasing for both sprawl and non-sprawl area, it is because a majority of institutional area contain less than two of land uses. The factor of increasing on non-sprawl area was the implementation of mix development which consists of more than 3 types of land uses including industrial and commercial area. Because sprawl is a function of the spatial pattern of individual residential units, our approach moderate in that it matches the scale of the index with
the scale of the phenomenon. Measuring sprawl at the residential unit level also facilitates investigations into other political and geographical factors that result in different manifestations of growth at the any levels or any geographical unit of interest. One drawback of our sprawl measurement is their limitation of study area and the number of factors tested. The need of improvement on extending to a varies study area and number of factor will make this research much more practicable.

5. Conclusion

The complex nature of land use pattern in urban sprawl requires indicators measures to employ a multiple geospatial indicators. In this paper we examine for the most significant indicators related to land use segregation city scale using remote sensing imagery data and GIS approach. We realize the application of technology in city management is crucial needed since cities were moving rapidly in the most developing countries. However, there are other possible measures or variation to the measures employed here that hold potential for spatial analysis of urbanization in general & urban sprawl in specific. Land use segregation index provide a significant approach for identifying, comparing, and contrasting sprawl development in a more detailed manner for further investigation of the underlying process at play. As urban patterns for given region change with time, that reflected in changing sprawl index value and its technological tools may itself provide insight into the long term patterns, underlying process, and likely consequences of spreading development compared to its smart growth analysis.

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