Measuring urban sprawl on geospatial indices characterized by leap frog development using remote sensing and GIS techniques

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Abstract. Characterizing urban sprawl using spatial measures requires a concise definition of what constitutes sprawling urban spatial patterns. This research attempts to study a measurement of defining sprawl by using leapfrog development index through remote sensing and GIS approach. The IKONOS pan-sharpened and SPOT-5 with 1 and 2.5 meter resolution were used and combined with Geographical information system (GIS) database to analyze the geospatial indicators using the leapfrog development index. Kuantan city has been selected as a study area to examine the leapfrog development based on land use pattern for year 2012. The findings show Kuantan has identified as non-sprawling cities with result from characterization in leapfrog development that has been tested. However, the gap between sprawl and non-sprawling was very low. It is anticipated this research will provide a new direction in sprawl nationally that address finding of sprawl at the atomic level and present a robust analytical approach for characterizing urban development in city scale at once promoting a city via GIS & Remote Sensing technology respectively towards Digital and Green cities.

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. The inability to visualize such growth during planning, policies and decision making process has resulted in sprawl that is both unsustainable and inefficient. A variety of definition of urban sprawl has been derived from different authors as a specific form of urban development with low density, disperse, auto-dependent, environmentally and socially-impacting characteristic [1-8]. The rapid urbanization towards wildlife habitat, watershed land, farm land and open spaces cause many unforeseen consequences including loss of prime farmland, loss of natural resources, increased environmental pollution, traffic congestion and many other physical, social and economy effects [2,3,9]. The sprawl measurement is still in preliminary stage, the basic characteristic of urban sprawl has no explicit expression and the reveal of its internal mechanism has been maintained in the level of empirics.

The previous report stated that the need of a standardized means of objectively quantifying characteristic of sprawl versus smart growth. A higher spatial resolution is needed in order to adequately characterize the nuances of urban sprawl. Many scholars focus on using indicators to
measure urban sprawl by establishing multi-dimensional indicators by Geographical information system (GIS) analysis or descriptive statistical analysis [5,6,10]. Remote sensing and GIS can be separately or in combination for application in studies of urban sprawl. GIS and Remote sensing data can supply physical, social and economic data for simulation [11-13]. There are some researches on how to use remote sensing and GIS to monitor and measure urban sprawl [14-18].

Leapfrog development is a scattered form of urbanization with disjointed patches of urban land uses, interspersed with green areas. If it is “discontinuity”, the developments are considered as leapfrogging from develop land over undeveloped land [6]. The leapfrog development occurs when developers build new residences some distance from an existing urban area, bypassing vacant parcels located closer to the city. In other words, developers choose to build on less expensive land farther away from an urban area rather than on more costly land closer to the city. The impact of leapfrog development does create some extra costs, an infrastructure must be extended farther and a longer distance creates more traffic and longer commutes into the city. Leapfrog development seems to have a similar potential occurring on the land use development in Malaysia. This scenario can be seen in the development of a new housing area outside the city centre especially in Pahang state. Therefore, this research is aimed to examine the problems of urban sprawl with measurement of geospatial indices on Leapfrog development using remote sensing and GIS techniques in identifying an empirical metric for distinguishing urban sprawl from non-sprawl urban development using remote sensing and GIS data with assessing a characteristics and qualities of urban sprawl in Malaysia as well.

2. Research methodology

2.1 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 of 296,000 hectares (figure 1). Majority of the land use patterns consist of built up areas and un-built areas. To achieve better future urban development and infrastructure planning, it is crucial for the municipal authorities to know sprawl phenomenon happening in Kuantan including on how to measures and determined whether that phenomena was sprawl or vice versa.
2.2 Materials and Software
The primary research mainly depended on the data obtained from MACRES, Department of Survey and Mapping Malaysia (JUPEM), and local authority (Kuantan Municipal Council). The satellite data of IKONOS Pan-Sharpened and SPOT-5 are the primary sources while the ancillary consisted of topographic maps, land use maps, road map, contour line, urban map and aerial photograph. The software used to calculate and analyse the raw data, and to generate the results included ERDAS, ArcGIS, MapInfo, E-cognition and SPSS.

2.3 Methods
The image pre-processing and data preparation were carried out; these included image rectification and mosaicking. 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 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 housing 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 housing unit patches. The housing unit leapfrog value was scaled to the municipal leapfrog index ($LF_{mun}$) by summarizing the leapfrog field value of the housing unit point layer by municipality as depicted in Equation 1:(9).

$$LF_{mun} = \frac{\sum Dlf_{unit}}{N_{mun}} \quad (1)$$

Where $LF_{mun}$ is the leapfrog index for new urban patches within a municipality, $Dlf_{unit}$ 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.

![Figure 2. Flowchart of data processing adopted in the study.](image)

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3. Analysis and Findings

3.1 Analysis on Leapfrog development
The previously settled area was selected at the area which consists of housing unit with more than 50 acres (Time 1). Then, three new housing areas were selected and were buffered with the diameter of 1500 feet (Time 2). The distance from Time 1 and Time 2 was measured by using the MapInfo software to know the urban sprawl pattern in the Kuantan city. If the distance of new housing is higher, the area was considered as sprawling while the converse result was considered as non-sprawl area. The non-housing area was considered as neutral with no value, which consisted of forest, agriculture, and institutional areas.

| New Residential Patches (Time 2) | Distance (Km) from Residential (Time 1) Alor Akar | Index |
|----------------------------------|--------------------------------------------------|-------|
| A (Kota Sultan Ahmad Shah)       | 9                                                | Sprawl|
| B (Taman Kg. Padang Jaya)        | 11                                               | Sprawl|
| C (Astana Golf & Country Club)   | 6                                                | Non-sprawl|
| TOTAL                            | 26                                               |

The new development areas (Time 2) in this research 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 Alor Akar. The result in figure 3 shows that leapfrog development index from Alor Akar (time 1) to three selected new housing development area in Kota Sultan Ahmad Shah, Taman Kampung Padang Jaya and Astana Golf and Country Club (time 2). Time 1 was considered as a development in urban area or previous settlement area and (time 2) was the development away from town centres or a new developments. The result shows that the development of Taman Kg. Padang Jaya was considered as more sprawl with 11km in distance followed by Kota Sultan Ahmad Shah with the distance of 9 km from Alor Akar area. Astana Golf and Country Club was considered as non-sprawl because the distance of this area is only 6km from previously settlement area. Taman Kg. Padang Jaya was more sprawl than other places because the development between the area and Alor Akar mainly consist of industrial and institutional, so the new development area for housing is far from the previous settlement area. The area of Kota Sultan Ahmad Shah was considered far from Alor Akar because this area was proposed nearest to new development of Kuantan Central, which is this development, was in line with the proposed Kuantan Central.

![Figure 3. Measurement of sprawl by using Leapfrog distance from Time 1 to Time 2.](image-url)
4. Result and discussion

The analytical method employed by the geospatial metrics drawn on the discipline of landscape ecology in order to characterized land use pattern of landscape. Geospatial indices were based on remote sensing delineations of new urban growth which it is impossible to distinguish individual tracts when they are contagious. The leapfrog development index was part of this and it provides a measure of how far a patch of new development is from the edge of previous existing settlement. While various approaches to measuring dispersion can be taken, this analysis calculated the leapfrog index by a straight line distance measurement from the new development patch to the perimeter of the nearest previously settled area. Patches with large leapfrog distance are considered sprawling whereas patches in close proximity of contiguous to previous settlement (i.e. infill or concentric growth) are considered non-sprawl or smart growth. Even though this study adopt and revised a method from Hasse and Lathrop (2003), it is different by sample of calculation where the previous research was calculate the distance from new development area from previously settled area an comparing among few district instead of this research detailing and focusing in a one district. In our case study, Kuantan city was considered will encounter a sprawl in a few years. The analysis of leapfrog index shows that a distance of two areas were considered sprawl among a three area of new development are tested. Kuantan city was an area that considers undergone rapid changes when it replaced the agriculture to the build-up development mostly to residential, commercial and industrial. Time 1 which has been tested was the one of the old urban area and existed during an early Kuantan urban reformed. While the time 2 were the new development that patches away from the urban centre and develop over the agriculture area. Distance decay function of land development can be observed in result between time 1 to time 2 A and B with a distance 9-11km. This pattern of land development away from a city centres and was part of local authority policy to expand their future development.

5. Conclusion

The complex nature of land use pattern in urban sprawl requires indicators to employ a multiple geospatial indicators. In this paper, we examine the most significant indicators related to leapfrog development city scale using remote sensing imagery data and GIS approaches. We realize the application of technology in city management is crucially needed since development of cities is moving rapidly in most developing countries. However, there are other possible indicators that have the potential for spatial analysis of urbanization in general and urban sprawl in particular. Leapfrog development index provides 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, which are reflected in changing sprawl index value and its technological tools, they may give insights into the long term patterns, underlying process, and likely the consequences of spreading development compared to their smart growth analysis.

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