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ANALYSIS OF LAND USE STRUCTURE CHANGE USING GIS BASED SPATIAL MATRICES; REFERENCE TO COLOMBO DISTRICT, SRI LANKA

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Abstract

Urbanisation and urban growth are common phenomena witnessed in both the Western and the Eastern parts of the world. For the record, more than half of the world's population is urbanised. Globally, all regions are responsible for accommodating and adjusting to their urban growth in a sustainable manner. This rapid growth has led to massive urban agglomerations that directly affect the landscape changes in urban areas and this high urban concentration gradually expands outwards in either a haphazardous or a planned manner converting non urban uses to urban uses. As a result, urban land uses are complex and face continuous changes. Analysis of these changes is significant for urban planning and policy making bodies. GIS based landscape mercies the use of land use structure change in urban areas, which most scholars have used. Colombo is the most urbanized district in Sri Lanka and its land use gradually face changes. Hence, this research aims to identify land use structure change pattern in the Colombo district using GIS based landscape matrices. Results contribute to the discovery of significant facts about interpretation of urban land use using selected spatial matrices.

Keywords:

Urban Growth;
Spatial pattern
Land use Structure Change;
LnadscapeMetrics
Land use Pattern.

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1. Introduction

Presently more than half of the world's population lives in densely populated urban areas and it proved higher urban densities in the mega cities of the world, compared to the previous decades. "Close to half of the world's urban dwellers reside in relatively small settlements of less than 500,000 inhabitants, while only around one in eight live in the 28 mega-cities with more than 10 million inhabitants" [1]. These high urban densities occur due to urban growth fuelled by migration and this is the ultimate result of urbanisation. Hence, globally, all regions are responsible for accommodating and adjusting to their urban growth in a sustainable manner. Crookes in 2010 mentioned, "Cities play a critical role in our lives, providing habitats for more than half the world's population [2]." Due to high urban demand, different urban systems create a complexity of land uses in urban areas rapidly. This rapid growth has led to massive urban agglomerations that threaten sustainable development. Ultimately, this high urban concentration gradually expands outwards, in either a haphazardous or a planned manner. The process occurred in a general pattern but the implications were so extensive that continuous changes occurred in urban areas. These spatial changes were happen due to physical processes, which occurred over a long duration showing continuous spatial changes in a temporal manner. Therefore, urban growth can be considered as a spatial-temporal process. In many instances, this growth is uncontrolled and dispersed and this is likely to impede sustainable development [3]. Hence, urban land use structure is so complex and analysis of this landscape structure is significant for urban planning.

A quantitative and qualitative analysis of the landscape structure is needed to understand the patterns of land use change. Landscape metrics or spatial metrics is one of the reliable methods for this purpose. Spatial metrics is based on the geometric properties of the landscape, and it is generally used to measure different aspects of landscape structure, spatial pattern, and their spatio-temporal variances [4]. In the late 1980s landscape metrics was introduced, then blended with information theory and fractal geometry to generate categorical, patch based pictorial representation of a landscape[5]. O'Neill et al., (1988) [6] developed a few sets of different spatial matrices, later modified and tested same [7]. Initially, those quantitative measures had been implemented by using the public domain package FRAGSTATS3[5]. At present, ARC/GIS

10 patch analysis extension has the capability to quantify those matrices and most scholars now use spatial indices to analyse and classify urban form in a systematic manner.

Spatial metrics are based on landscape patches and the patches are defined as homogenous regions indicating a specific landscape property of interest. For example, in Costa et al., (2009) studies the patches are considered as built-up area[7]. Identified patches are grouped into three spatial metrics, namely patch based metrics, class level metrics, and landscape metrics. Patch metrics are used to calculate every patch in the landscape and class based metrics are used to calculate every class in the landscape. Landscape metrics are used to calculate total patches in the entire landscape[9]. In 2012 Ramachandra et.al., have been proposed a variety of landscape metrics to characterise the spatial configuration of the individual landscape class or the whole landscape[4]. He explained

"*Patch size and patch shape metrics have been widely used to assess patch fragmentation both at small and large scales. Patch shape index acts as an indicator, which correlates with the basic parameters of an individual patch, such as its area, perimeter, or perimeter–area ratio. However, these indices fail to reflect the spatial location of patches within the landscape. Heterogeneity based indices proposed subsequently can aid in quantifying the spatial structures within the landscape, which could not be quantified by the patch shape index. Similarly, the proximity indices quantify the spatial context of patches in relation to their neighbors" (p.59)*

Spatial matrices were used to quantify the transformation occurring among different land use categories and the major "sources" and "destinations" of new and disappearing land [8]. In addition, they provide more spatially consistent and detailed information about urban structures with the temporal changes, while facilitating improved representation to provide a better understanding of the homogeneous and heterogeneous characteristics of urban areas. These two patterns cannot be shown using a single index and it is necessary to adopt both groups of indices for analysing the spatial patterns of heterogeneous landscapes[4]. Tsai (2005) has classified the spatial metrics into three classes known as density, diversity and spatial-structure patterns[10]. Galster et al. (2001) [11] have identified eight conceptual dimensions of land-use patterns. Most scholars use a number of spatial indices to analyse and classify urban form [4];[12). Those who computed using patch based indices like size, edge length, patch density, and fractal dimension have endorsed the usefulness of spatial metrics for urban modelling [13]. In fact, several scholars have applied spatial metrics with time series data to analyse urban growth [14];[15]. Those studies effectively explored changes of spatial pattern with time. Angel et al. (2007) [16] used spatial metrics to measure the urban extent, urban density, and suburbanisation. Hence, suitable adaptation of appropriate metrics could prove effective for showing complex urban spatial variations using available data. This technique appears capable of yielding significant results. On this assumption, the researcher selected eight spatial metrics to be used to analyse the spatial temporal growth of Colombo district.

Study Area

Sri Lanka is positioned in the Indian Ocean, located very close to the Southern strip of the Indian subcontinent, lying between Northern Latitudes 5°55’ and 9°50’ and Eastern Longitudes 79°42’ and 81°52’. The land area of Sri Lanka is 65,610 sq. km., with an overall length of 432 km, width of 224 km. Sri Lanka is divided into nine regions (or provinces) for administrative purposes, and the Western Region is the most urbanised of them. The geographical area of the Western Region covers a total extent of 369,420 ha, which comprises 5.6% of the total land area of the country. The Western Region consists of 3 districts, namely, Colombo, Kalutara, and Gampaha (Figure 1). Colombo is the most urbanised district in Sri Lanka consist of high urban growth. It contains 77.5% urban population in the country.

Urban agglomeration is high in the Colombo district. Thus, land use pattern of Colombo district is more complex and is continuously changing. Therefore,identification of the land use structure change of Colombo district is significant for future planning and this study endeavoredat that. Most urban scholars considered Colombo land use in different aspects but there is a lack of studies in concern ofland use structure change. Hence, the main objective of this study is to fill this research gap.

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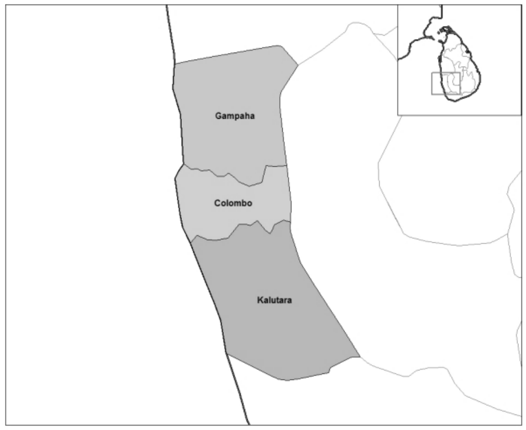
Figure 1



Data and Method

Research expected to review urban growth over a period of three decades, beginning from 1980. However, the land use maps for the specified time spans (10 years each) were not available. Thus, the available maps on 1985, 1996 and 2014 were used. In 1985, the Survey Department prepared a detailed land use map of Colombo District and this was used as the base map. This map was updated for the first time by the Urban Development Authority in 1996. After that in 2014, it was again updated by the land use-planning department. These three maps (1985, 1996 and 2014) were used for analysis. There are 26 standard land use categories listed in these maps. However, land use classification system was not existed in Sri Lanka. The research need to analyse land use structure change based on land cover and density. Hence, the 26 land uses were combined into five simpler categories, and named as urban built-up, low residential, agricultural, green areas, and 'water bodies. Descriptions of specified categories are as follows.

Urban built-up: In Sri Lanka there is no specific land use classification to define urban land use. 'Urban area' as used in this research primarily referred to the urban built-up category. The existing urban administrative boundaries are not the real urban boundaries and the urban built-up area never reflected the actual urban growth [17]. In Sri Lanka, the urban definition also considers the administrative boundaries of MCs and UCs as urban. However, the MC or UC areas do not consist of urban land uses throughout the whole area. Urban land can be described based on its physical and functional aspects. In functional terms 'urban' means activities. In physical terms, it relates to the density of land use [18]. Considering density and functional characteristics of land use in the Colombo district, the urban built-up category is classified as follows.

1. The 1985 land use map mentioned a land use category named 'urban built-up', and this was considered as the base of urban built-up.

2. Based on the 1985 map, the Urban Development Authority (UDA) prepared an updated version of the land use map in 1996, and it was used for the study.

3. In 2014, the land use planning department once again updated this land use map and the study referred to it as well. However, in that map too, clear urban built-up category was not included. Presently, the land uses of Colombo District are so complicated that two methods namely, method 'a' for MCs and UCs, and method 'b' for Pradeshiya Sabhas, are used to define urban built-up areas.

a). Godschalk (1988) adapted Anderson's land use (man-made) and land cover (natural or semi-natural) classification system [19] was used to mark out the urban built-up areas within the municipal and urban council areas of the Colombo District.

b). The Pradeshiya Sabha Act of 1987, No 15 defined 'built-up' areas, mainly with the objective of marking them out for property tax purposes. New 'built-up' areas are declared by the Minister of Local Government from time to time. Above mentioned built-up areas are also considered as part of the urban landscape.

iv. Apart from the above mentioned a) and b), population density and building density were also considered as additional factors. While based mainly on the above densities, some field observations and Google images were also used for classification of the urban built-up areas.

Low Residential: In Sri Lanka, land ownership is categorised into private land, crown land and state land, and 100% of the residential lands have private ownership. In the base map prepared by the Survey Department, all residential land uses were labelled as homestead gardens. This category consists of two types of residential lands. Small residential blocks located in highly urbanised areas, and houses with large home gardens located outside of the highly urbanised areas. The extent of these home gardens generally varies from 0.5 to 1 acre of land. In 1985, Wanasingha described homesteads as "land house with site and residing garden" and the extent of these gardens would be 1 or 2 acres of land [20]. Therefore, small land blocks located in the highly urbanised areas were added to the urban built-up category. Large homesteads were named as a separate category, viz. low residential.

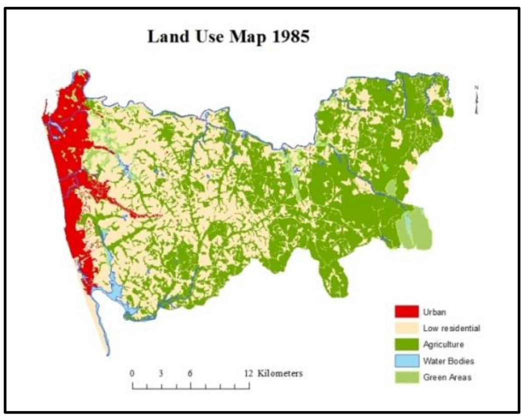
Agriculture: Paddy, coconut, rubber, tea and other crop lands were incorporated in the agriculture category.

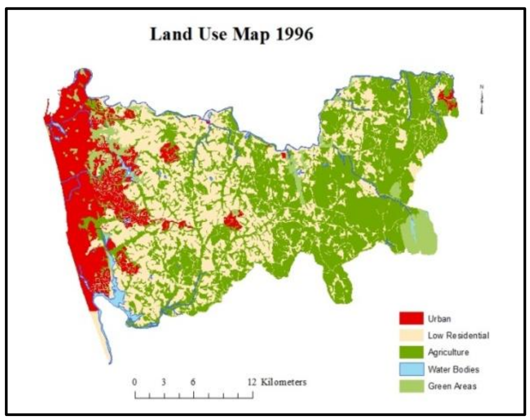
Green Areas: TheColombo District consists of a fair extent of forests, grasslands and marshy lands. In the Western region environmental plan (1995) those areas were designated as environmentally restricted green areas. Therefore, in this research those areas were named as green areas.

Water bodies: Rivers, Tanks, Lakes, and Canals were categorised as water bodies.

The 1985, 1996 and 2014 land use maps classified to above mentioned five categories and Figure 4.4 indicate these three maps.

Figure 1 Shows Classified Colombo District land use maps.





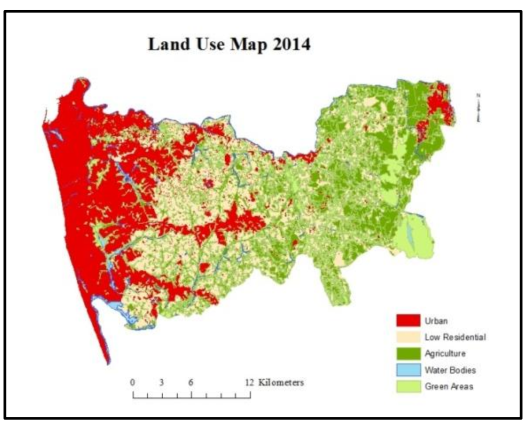


Figure 1 Colombo District Land use 1985, 1996 and 2014

The land use maps that show urban growth in 1985, 1996 and 2014 draw attention to two important phenomena. First, the urban growth spread from the west in an easterly direction; i.e. from the City of Colombo to the countryside. Second, the urban growth pattern spread-out on either side of the main roads and outwards from the town centres. ArcGIS cross tabulation method used to analyze above land use categories. Most scholars use the ArcGIS cross tabulation method for analysing land conversions in the spatio-temporal scale. Xiao et al. (2006) [21]used the cross tabulation method to pinpoint the socio-economic forces behind arable land conversion, while Hung et al. (2008)[22] and Pelorosso et al. (2009)[23] used cross tabulation for analysing spatio-temporal changes in the land use pattern.

Next important point is identify the land use structure change and landscape matrices used for that. Land use structure change of Colombo district analyse in class level and landscape level. To quantify land use structure changes in the class level, 7 matrices MSI (Mean shape index), AWMSI (Area weighted mean shape index), MPFD (Mean patch fractal dimension), AWMPFD (Area weighted MPFD), MPS (Mean patch size), PSCoV (Patch size coefficient of variance), and ED (edge density) were selected. In addition, two matrices, namely SDI (Shannon's diversity index) and SEI (Shannon's evenness index) were selected for landscape level. Table 3 gives the definitions of these selected indices.

Table 3 Selected Landscape matrices and their description

Matric	Abbreviation	Description
Mean patch size	MPS	Average size of all patches in one or all land use
Patch size coefficient of	PSCV	Standard deviation of patch size divided by
Edge density	ED	Total length of one or all land use divided by
Mean shape index	MSI	Average perimeter to area ratio for all patches
Area weighted mean shape	AWMSI	Average perimeter to area ratio weighted by
Mean patch fractal dimension	MPFD	Average fractal dimension of land use patches
Area weighted MPFD	AWMPFD	Average fractal dimension weighted by area
Shannon's diversity index	SDI	Richness of land use types (only landscape
Shannon's evenness index	SEI	Distribution of area among all patches

Adapted from Kevil, 1993

The landscape configuration and fragmentation is measured using the mean patch size (MPS). The fractal dimension describes the complexity and fragmentation of a patch as a perimeter-to-area ratio. Low values of MPFD indicate patch has a compact rectangular form with a relatively small perimeter relative to the area. If the patches are more complex and fragmented, the perimeter increases and yields a higher fractal dimension. The area weighted mean patch fractal dimension (AWMPFD) averages the fractal dimensions of all patches by a higher weighting of larger patches. It is used to measure a different dimension of urban land use structure. Edge density (ED) is a fragmentation index where the effect of spatial extent is concerned. PSCV measures the relative variability about the mean (variability as a percentage of the mean).

Data Analysis

Data is analysed using ArcGIS cross tabulation method. Land use categories of Green areas and water bodies do not show much variation and so those two categories are combined for cross tabulation of land uses and this category is named as ‘other’. Tables 1 and 2 show the cross tabulation figures for land uses from 1985-1996 and from 1996-2014, respectively. Table 1 shows the cross tabulated matrix of land use change from 1985-1996. Land use changes of this period show two significant features.

Table 1 Cross Tabulation of Land use 1985-1996

	Urban	Low Residential	Agriculture	Other	Total 1985
Urban	5722.58	-	-	-	5722.58
Low Residential	5332.84	22148.94	0.00	43.72	27525.50
Agriculture	46.91	1615.36	28625.04	426.19	30713.50
Other	22.07	0.00	0.00	4204.20	4226.27
Total 1996	11124.40	23764.30	28625.04	4674.11	

During this period, urban uses show a prominent feature because low residential, agricultural and other uses were converted to urban uses, but urban uses were not converted to any of the other three uses. Second, agricultural uses have been converted to the other three uses. Low residential category is also prominent because most of the agricultural land was converted to low residential and low residential in turn converted to urban uses. During this period, most of the paddy lands and marshy lands located in these areas were filled to convert them for urban uses. In addition, most paddy fields were not harvested due to low yields and high costs and became converted to abandoned paddy lands. The CMR structure plan Report (1998) [24] noted that 340 hectares of paddy lands were converted to urban and other uses during this period.

Table 2 indicates the cross tabulation matrix of land use changes from 1996 to 2014.

Table 2 Cross Tabulation of Land Use 1996 - 2014

	Urban	Low Residential	Agriculture	Other	Total 1996
Urban	11054.05	-	-	70.35	11124.40
Low Residential	7407.82	11202.73	4466.76	686.98	23764.30
Agriculture	2144.57	6963.35	16735.96	2781.16	28625.04
Other	540.76	140.71	176.57	3816.07	4674.11
Total 2014	21147.20	18306.79	21379.30	7354.57	-

According to the Table 2, urban category remained the same as it did previously with only slight differences. However, 70.35 hectares of the urban category converted to other uses; most urban green spaces were expanded in the previous decade and that is the main reason for that. Urban conversion was high in this period and 75% of the urban areas were converted from low residential areas and 20% were converted from agricultural land. Further, 95% of the low residential areas were converted from agricultural uses. During the same period, agriculture lands decreased from 28625 to 21379 hectares. 'Other' land was also converted to all three main uses in small amounts.For quantification of landscape matrices, the patch analyst extension of ArcMap version 5.1 was used. Calculation was done by class level and overall landscape level. Seven indicators were calculated at the class level and nine indicators at the landscape level.For both levels MSI, AWMSI, MPFD, AWMPFD, ED, MPS, PSCoV were calculated. In addition to that, at the landscape level SDI and SEI were calculated (Table 4).

Table 4 Landscape matrices of the three land uses at 1985 - 2014 Colombo District

Class	MSI	AWMSI	MPFD	AWMPFD	ED	MPS	PSCoV	SDI	SEI
Urban Built-up (1985)	1.57	3.85	1.30	1.34	18.31	8.43	195.66		
Low Residential (1985)	1.61	2.12	1.31	1.31	60.86	12.57	136.11		
Agriculture (1985)	1.72	2.69	1.32	1.32	68.13	18.80	343.04		
Landscape (1985)	1.65	2.57	1.31	1.32	147.30	14.55	299.14	0.91	0.83
Urban Built-up (2014)	2.16 +	6.45 +	1.58	1.42	280.69-	0.37 -	792.18+		
Low Residential (2014)	3.56 +	2.90 +	1.62+	1.41	230.63-	0.58 -	373.37+		
Agriculture (2014)	2.83 +	2.49 -	1.45	1.35	91.09 +	2.62 -	532.30+		
Landscape (2014)	2.67 +	4.00 +	1.58	1.39	602.42 +	0.62 -	772.39+	1.1	1

Calculated using ArcGIS patch analyst

At first, in the landscape level the Shannon Diversity Index (SDI) and the Shannon Evenness Index (SEI) are important; compared with 1985, the SDI and SEI of 2014 show a 2% increase. This suggests that there were a diversity of changes in the spatial structure during the 1985-2014 period, due to expansion of social and economic activities. The cross tabulation tables depict the extent of land use changes from other categories to urban. This is proved by land use level indices ED, MPS and a few other indices in Table 4, which show that agriculture and other uses had reduced by 2014. Most agricultural activities were replaced by residential activities. Much of this was brought about by land subdivisions focusing on the middle income population looking for housing, and that was the reason for the increase in the low residential category. However, the areas coming under the low residential category did not increase as much as expected because a substantial acreage of the low residential category was being converted to the urban category at the same time. MPS at landscape level showed a 95% decrease. This shows that spatial agglomerations are high at present, although it happened on a small scale before 1985. This decrease is primarily indicated in the MPS of all three land uses. PSCoV at landscape level increased by 61.2% and it indicates a significant difference in the variability of land uses. After 1985, urban development occurred at a faster pace and change of PSCov at land use level was dominated by urban built-up which increased by 60%. This resulted in the infill land development pattern of most residential and other developments. ED, MSI and AWMSI had increased at both landscape level and the two land use levels, but in agriculture it had decreased. MPFD and WMPFD show slight changes between these two periods. Those identified urban changes need to compare with spatial expansion and intensity.

Conclusion

Land use variations were evaluated using cross tabulation and the results showed significant variations. In addition, landscape matrices were used to measure the land use structure change. Some of the landscape matrices were measured and the results pinpointed two land use dynamics; one was that land development activities were becoming more diverse and the other was that the land development process caused fragmentation and splitting up of land. The land use pattern presents a different picture and it shows the urban area gradually expanding by spreading out through peripheral areas with the urban fringe functioning as a transition zone. As a result, fringe land keeps getting converted to urban uses on a massive scale. It is important to measure this conversion pattern as well as the conversion type. An advanced transport network, good road infrastructure, low land values and less pollution are some of the reasons why developers were able to attract people from the core area to the edge of the district and outer regions.

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