Quantifying Urban Growth Pattern and Its Dynamic Changes in Kandy City, Sri Lanka

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***Abstract*— Changing of land use types and formation of the new pattern is a common phenomenon in dynamic urban agglomeration. Studying the spatiotemporal changes of the urban pattern is an important, timely task for the decision-making purpose of city sustainability. The research objective is to capture spatiotemporal variations of the built-up area and how these relationships compare and contrast between spatial and temporal aspects. For this purpose, Kandy City has been selected as a study area,and geospatial analysis was performed using remote sensing data for 1996, 2006, and 2017. The results revealed that the Kandy City had undergone a drastic urban expansion, and it was upgraded by 40% in the last three decades. Proximity calculation shows that the built-up area (BUA) expansion shows the linear development pattern leads by the transportation system.Meanwhile, it illustrated that more than 95% of BUA has accumulated within a kilometer area form road. Results have been discussed by focusing on how to line up urban structures for city sustainability. Some recommendations and possible implicationshave been discussed.The output of the research can be used as proxy indicators, and the proposed methods will be able to apply any city by making necessary calibration on data.**

***Keywords*— Urban structure, urban pattern, linear development, proximity analysis, Kandy City**

I. INTRODUCTION

Rapid urban expansion is essential for developing countries due to the burgeoning economy as well as the rest of urban footprints.Nowadays, more than half of the world's population lives in urban agglomeration [1], and it is expected to reach around 66% by the year 2050 [2]. The urban expansion rate in developing counties is higher than the developed counties[3]. However, unprecedented urban expansion has led to several negative consequences[4], including land-use change,and is now a common phenomenon in developing counties[5]. Due to the development of social services and infrastructure to serve the high growth of population, changing land-use and the urban pattern is common in an urban area.

Generally, urban patterns are formed based on socioeconomic background or physical/topographic attributes in the area. The urban structures or settlement patterns can be roughly defined as "*A settlement is any form of human dwelling, from the smallest house to the largest city*" [6]. There are four types of urban development patterns (dispersed, nucleated, isolated, and linear), which popular among the urban researchers [6–8]. A linear settlement pattern presents the buildings are constructed in lines, often next to a geographical feature like a river or following a road[6].

An urban agglomeration is a much complex and dynamic system that consists of numerous interactive systems. It is influenced by a diversity of variables, such as employment, transportation, infrastructure, market behavior, etc.[9]Among types of major urban systems, land-use changes and transportation are the two most significant to determine both urban form and structure,as numerous researchers demonstrated [9–11]. Further, some sources stated that transportation improvements positively affect the property value of nearby land, not only the city but also the periphery area [12].Additionally, Dissanayake et al. have also stated that the transportation system is a vital factor for assessing life quality [13]. These facts are emphasizing our understanding of the effect of the transportation system to dynamic changes inthe built-up area (BUA). Studying of spatiotemporal changes of BUA and its correlation with other geographical features is essential for planning purposes. However, doing such a kind of study is not an easy task due to several obstacles, including a large geographic area and lacking ground level spatial data. Regarding this context, theoretically roughness, practical oriented, and more sophisticated methods powered by remote sensing (RS) and geospatial application (GA)can be used to overcome the above obstacles.

Researchers have paid comprehensive attention to urban studies from a wide variety of disciplines over the past few decades using RS and GA applications[14,15]. Medium resolution Landsat data sources provide sufficient information for urban patterns and land-use related studies over spatiotemporal changes. Urban changes can be mapped by extracting BUA form RS data. Meanwhile,the urban patterns can also be mapped by incorporating RS data with GA as past researchers demonstrated[16,17].Further, Proximity study (buffer zones) computes the density of BUA by a certain road distance[18].

Several attempts have been made by past researchers to study urban expansion in Kandy City[2,13,19]. However, a compressive study on urban sprawl and its pattern on the spatiotemporal viewpoint is still lacking.The above factors are motivated to select the study area and title in order to examine the urban pattern by BUA in Kandy City. In view of the above aspect, the hypothesis has been made as a linear development pattern is formed by the road system in Kandy City. In this study, Both RS and GA techniques are employed to determine urban patterns and their spatiotemporal changes. The purpose of this study was to capture spatiotemporal variations of the BUA and how these relationships compare between spatial and temporal aspects.

II. MATERIALS AND METHODS

Study Area

Kandy is the capital, main administrative, and economic hub of the central province, Sri Lanka [13]. It is wealth with tropical equatorial climate including comfort weather (Mean daytime temperature: 28 – 32 ℃[2],annual average rainfall around: 2085 mm, and monthly rainfall about: 52–398 mm[19], and relative daytime humidity: 63–83% [20]). Because of the tropical climate, Kandy City performs as a green city and popular tourist destination. Further, its surrounded by a lot of archaeological and historical places, including the home of the temple of the Sacred Tooth Relic (Sri DaladaMaligawa). As a result of these socioeconomic and environmental footprints, Kandy has undergone rapid urban development in the last couple of decades [13].

In this study, 15 × 15 km geographical grid (7.5 km radius from the city center) was selected as the study area, and it is bounded by latitude (7.225320◦ to 7.360850◦) and longitude (80.567086◦ to 80.703099◦), as shown in Fig. 1. It covers 225 km^{2}spatial area, including both socioeconomic and environmental attributes.

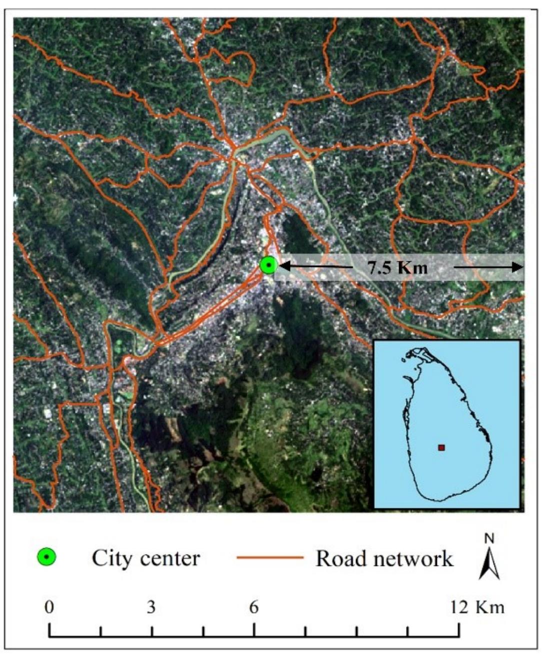

Fig. 1 Study area (Landsat-8 true color composite on March 18, 2017)

Data and Data Processing

Because of the large geographical area, the conventional research method is not convenientand time-consuming task[21]. In order to overcome the above obstacles, theoretically roughness, practical oriented, and more sophisticated methods have been adapted, which previous researchers have also been used [22,23] even in Sri Lanka [2,24]. With this background, data gathering was completed by accomplishing the following steps.

First: Three-time points (1996, 2006, and 2017) were selected as investigated period. Then, radiometrically calibrated and atmospherically corrected Landsat level 2 data sets provided by the United States Geological Survey (USGS) were downloaded [25,26]. In the data download stage, a cloud-free image or minimum cloud cover (less than 10)images were carefully chosen. Pre-georectification wasset toUniversal Transverse Mercator projection (zone 44 north in 1984 world geodetic system). Temporal uniformity over the study period was maintained as much as possible level. However, it was difficult to find the same day and same time image due to the clouddisturbance,a common issue in RS data on the tropical region, even in Sri Lanka [10,11]. Path and row of the Landsat were 141 and 55, respectively. Both 1996 (March 8) and 2006 (April 5) were covered by Landsat-5 thematic mapper (TM), while 2017 (March 18) was covered by Landsat-8 operational land imager (OLI).

Second: Timely updated LULCdatawere not available to cover the investigation period. This obstacle was handled by using LULCclassification techniques that numerous studies have demonstrated [27,28]. Though there is various kind of classification technique, the random forest (RF) classification is still popular among the researchers who attempt to identify the LULC information from medium resolution RS data [29][30]. Hence, the RF method was chosen, and the pixel-oriented supervised classification was employed. Finally, the built-up area was classified and, a misclassification error, which is known as salt-and-pepper noises of the resultant images were removed by applying majority filters and hybrid classification techniques[2].

Third: The correctness of classification results was determined by conducting an accurate assessment (AA). Hundred (100) training points were generated each year by using a stratified random sampling method. Google historical imagery services were chosen as reference data for three-time points, and AA was completed by calculating the kappa coefficient, and overall accuracy.

Fourth: The road network was digitized by using Google Earth images,and only major roads were selected in order to line up with the objective of the research. Other than this, the newly constructed road can be made obstacles for temporal comparison because these roads were not existing in the past time point. Meanwhile, the developing nodes were also mapped by using Google Earth images.

Spatial Calculation with Proximity Zones

Proximity analysis was employed to assess BUA development pattern on the spatiotemporal viewpoint. Regarding this calculation, a few steps were completed as follows. First, threetypes of buffer zones were created [0.25

km (Z1), 0.5 km (Z2), and 1 km (Z3)]. Meantime, the area left from 1 km (>1) also considered as a separate zone (Z4).Second, the built-up area was extracted by each zone. Finally, results were presented by using maps and graphs, while descriptive statistics were summarized in tables.

III. RESULTS

Built-up Expansion and Its IinearDevelopment Pattern

The derived kappa coefficients were 0.88, 0.80, and 0.80; and the overall accuracies were 95.8%, 97.4%, and 94.5%; respectively, for the classifications of 1996, 2006, and 2017. Accuracy of the classification was accepted range [31]. Thus, resultant images were employed for further analysis.

Spatiotemporal changes inthe built-up area (BUA) and its descriptive statisticsare shownin Fig.1, 2, respectively. The results shown Kandy City has undergone a rapid BUAexpansion in around the last two decades. It has been increased as 528.4 ha (2.3%), 1513.3 ha (6.7%), 5377.5 ha (23.9%) for 1996, 2006, and 2017, correspondingly. In 1996, a higher amount of BUAconcentrated around the city center. Later, it has expanded toward the north and southwest direction along the road,excepting the southern region (Fig.2). Mountains region might be an obstacle for less development in the southern region.Other than this, a linear development pattern was observed over the investigation period. Also, a more mature pattern was presented in 2017.

A Significant influence for the expansion of BUA has been made bythe growth nodes, and they are performed as connecting hubs of the road network. Sixteen growth nodeswere identified (Fig. 2 (a)). They have been matured in 2017 (Fig. 2 (c)), and some of them are reaching their saturation limit. Among them,*Mahaiyawa, Mawilmada, and Katugasthota,* which located along the A9 road (Kandy-Jaffna), were notably highlighted.

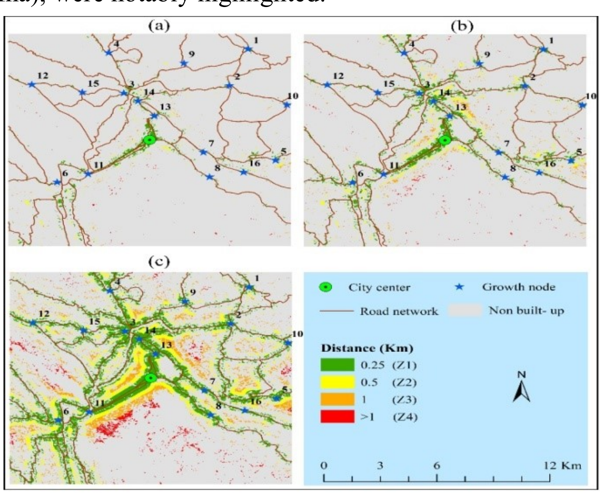

Fig. 2 Spatiotemporal distribution of built-up area by proximity zones. (a) 1996, (b) 2007, and (c) 2017. Note: Name of the growth nodes are Wattegama, Madawala, Katugastoata, Abathenna, Pallekele, Peradeniya, Thennekumbura, Ampitiya, UdaThalawenna, Manikhinna, Getambe, Nugawela, Mahaiyawa, Mawilmada, Haristpattuwa, Gurudeniya for 1-16, respectively.

Spatiotemporal distribution pattern of the BUA shown in Fig.2 with four color ranges. The most proximate BUA area for the road is presented by green color, and its proximity is 0.25 km (Fig. 2). The BUA of the Z1 has gradually improved, and it was 5.4%,14.2%, and 39.9% in 1996, 2009, and 2017, respectively (Fig. 3).Similarly, the rest of the three zones (Z2-Z4) have also shown a similar pattern over the study period.

In between 1996-2017, 2624.2 ha or 34.6% new BUA has been added to Z1, while 261.2 ha (5.4%) has only been added to the Z4. This result enhances our understanding of the urbanization process has still driven by road networks. Because the higher level of development has observed form most proximity zone, other areas vice versa. Further, this trend is also proved by Z3. It has only improved by 15.7% in the last two decades in Kandy City.

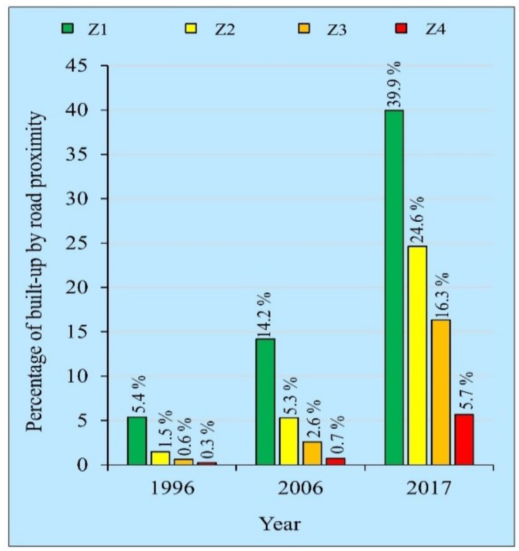

Fig. 3 Percentage of the built-up area by road proximity between 1996-2017.

New Trends of BUAExpansion

The results revealed that BUA has mainly expanded along the road by occupying the closest land portion. This pattern can be seen throughout all investigation time points; it was 408.2 ha in 1996, 1076.3 ha in 2006, and 3032.4in 2017.

Table 1 descriptive statistics of BUA by road proximity between 1996-2017

Proximity zones	Built-up area (ha)		
	1996	2006	2017
Z1	408.2	1076.3	3032.4
Z2	76.1	272.5	1264.3
Z3	31.5	128.6	807.0
Z4	12.6	35.9	273.8
Total	528.4	1513.3	5377.5

When compared to the other two years, there is a trend to expand BUA away fromZ1 in around 2017 (Table 1). BUA on Z2 was 76.1 ha in 1996, 272.5 ha in 2006, and 1264.3 ha in 2017. Meanwhile, it was in Z2 as 31.5 ha, 128.6 ha, and 807 ha for 1996,2006, and 2017, respectively. The facts in Table 1 and Fig.3 illustrated that BUA was expanded regardless of road proximity. This pattern was quite interesting to answer the questions on how it is happing and what are the driving forces behind this pattern. The cost of land has been made a vital impact on this trend. The cost of land which closes to the road has dramatically increased,whicha common phenomenonin an urban area, as numerous previous researchers have demonstrated [12]. Hence, Kandy City is not an exceptional case.It can be seenon the ground level. When we conducted the interview, the residents were stated that buying land close to the road is quite difficult because of the high price. As an alternative solution, they attempt to select second and third zones (Z2,Z3). This trend could be the reason for expanding BUA to other zones. Further, Z1 is reaching its saturate level in some areas, especially around the city center. Then, the alternative solution is moving to the other zones. These facts are realized that land price has been made a significant influence on BUA expansion. It is emphasized that this trend continues, and it will be caused for expanding of BUA in the future also.

Based on the results of the research, three urban flows were determined in Kandy City, as shown in Fig.4. The urban flowspresentlinear centric distribution witha higher concentration of BUA towards the Kandy City centerfrom three different arteries (F1-F3) along the main transportation line. F1: Kandy-Jaffna road, F2: Kandy-Colombo road, and F3: Kandy-Mahiyangana road. The urban flow pattern emphasizes our understanding of the linear distribution of BUA and its inspiration on the Kandy urbanization process. It is observed that a major urban form was originated around the *Katugasthota*growthnode, as shown in the circled area (D1) in Fig.4. The high density of BUA expansion (Both Z1 and Z2) can be seen from the city center to D1 at present, and it might be more improved in the future. There is a possibility to transfer single-core Kandy City as a multi-core city in the future, or it may be expanded Kandy City by connecting D1 and the city center.

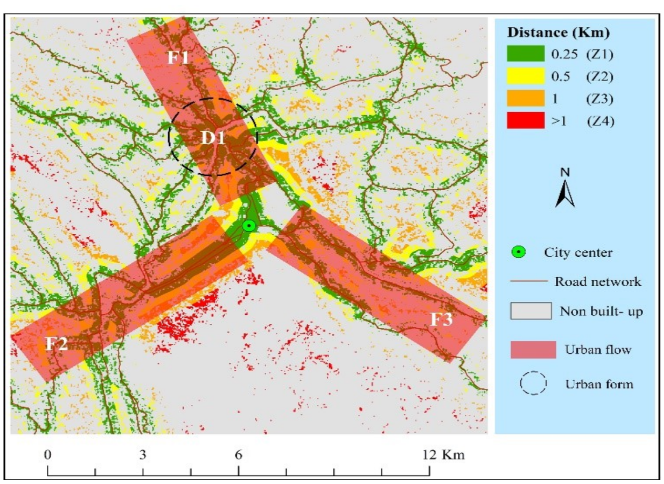

Fig. 4 Spatial distribution of the urban flows and urban form

IV. DISCUSSION

Kandy is an essential administrative capital of the Central Province, Sri Lanka. It provides manyservices, including administrative, education, tourist industry, transportation, and economic activities, etc. As a result of these services, a massive urban expansion has been taken place in Kandy City in the last two decades. Additionally, the built-up area has expanded asa linear development pattern along the transportation line. Examining such a kind of urban pattern is important for decision making and future urban planning. Though there is various kind of research includingLULC changes and urban development, study related to the quantifying the type of urban patternsand its trends are still lacking in Kandy City. These aresome of the motivation factors that have inspirited to select this research title. In the process, pixel-oriented supervised classification wascompleted using Landsat data. Linear development pattern and its road proximity were calculated, and the formation of urban form and flows were also identified. Finally, field investigation, Google Maps, and Google street view were used to ground-truth the results.

As stated by Wegener 2004 [32], land-use changes and road systems are the two most significant factors for determining the urban form and structure in the long term basis. Dissanayake et al.[13] stated that the transportation system is a crucial factor for assessing life quality in Kandy City. Economic hub, coupled with the tropical equatorial green environment, has been made liveable city environment in Kandy.Hence, the city has undergone rapid urban expansion with high growth of population in the last couple of decades.

Proximity analysis shows that morethan 95% of the BUA has expanded within a kilometer area from the road. Also, it presentsa linear development pattern. Similarly, the high-density area has also concentratedinto Z1, but it wasexpanded into Z2 and Z3 in around 2017. This urban pattern indicates that linear development is becoming more mature, and it goes beyond the conventional development outline, as shown in Fig.2, 4. The reason could be nearby road land becoming its saturate level or increasing of land price. Huang (1994)[33] found that transportation positively affects the value of adjacent land. While the same source has stated that land prices can be increased by over 10 percent on the region-wide sale prices.

Regarding the implications of the research results, urban development authority and other respective administrative bodies can use the results of the research for future urban planning in Kandy City. Regarding this context, the spatial development pattern of BUA provides information about which region is to be developed. In contrast, temporal changes in BUA provide facts for future forecasting of BUA expansion. The number of commuters in Kandy Citywill be able to reduceby decentralizing city center services to the growth nodes. As another approach,new industries can focus on the growth nodes. This mechanism will support to diminish the urban pressure and traffic conjected generates by commuters. The results of the research can be used as proxy indicators to enact policies regarding urban planning, and future development scenarios should line up with "goal 11" of the sustainable development goals (SDGs)[34].

V. CONCLUSIONS

This study investigated the spatiotemporal distribution of urban patternsby using remote sensing data in the Kandy city from 1996 to 2017. BUA has only selected, and its development patterns were mainly observed usinggeospatial techniques. The results of the research revealed that Kandy City had undergone drastic urban development, and primarily it shows a linear pattern. It has been matured in the last decades, andmore than 95% of BUA fraction has been concentrated within the one-kilometer area from roads, while a new urban form has been originated around growth nodes. New urban flows have also been identified from three different arteries in Kandy City. Indeed, the transportation system has made a significant influence onurban linear development, and it has been observed as a triggering factor in Kandy City. Finally, we conclude that the results of this can be used as a reference for urban planning and land use development for making an environmentally friendly, socially acceptable, and economically accountable Kandy City.

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