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PATTERNS OF BUILT-UP AREA CHANGE IN SMALL CITIES OF WEST SUMATRA PROVINCE - INDONESIA

*Ahyuni[1] and Hamdi Nur[2]

*[1]Geography Departement, Universitas Negeri Padang, Indonesia
[2]Urban and Regional Planning Departement, Universitas Bung Hatta, Indonesia

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ABSTRACT: West Sumatra Province has many small cities considered by population size as well as their built-up area. In these cities, a vast paddy field landscape still exists as a prominent characteristic. However, there are varied patterns of built-up area change among the cities. This paper examines the patterns of changes over the past 13 years from 2005 to 2018 using spatial metrics method. The measurements consist of the number of patches, patch density, mean patch size, and Urban Sprawl Index. Patterns of built-up area change generated by combining such measurements. It is found that the relationship between spatial geometry measures and growth rate measure is weak. Therefore**,** the study suggests identifying trends and comparisons among cities with the same characteristics to interpret spatial metrics method appropriately. The study also shows three types of built-up area change: (a) infilling with low-density development, (b) edge expansion with low-density development, and (c) edge expansion with scattered/leapfrogging development. The development of cities in the first and second types had a compact pattern, while the third tended to develop fragmented.

Keywords: Built-up area, Pattern, change, West Sumatera

1. INTRODUCTION

West Sumatera is one of the provinces of Indonesia located on the west coast of Sumatera island. It is divided into twelve districts and seven cities. The population is about 5.38 million in 2018. Padang, as the province capital city, has a population of around 945,919, but the other in this province are classified small cities in the range between 62,176 and 134,646 people. The distribution of cities in West Sumatra Province shows in Fig. 1 below.

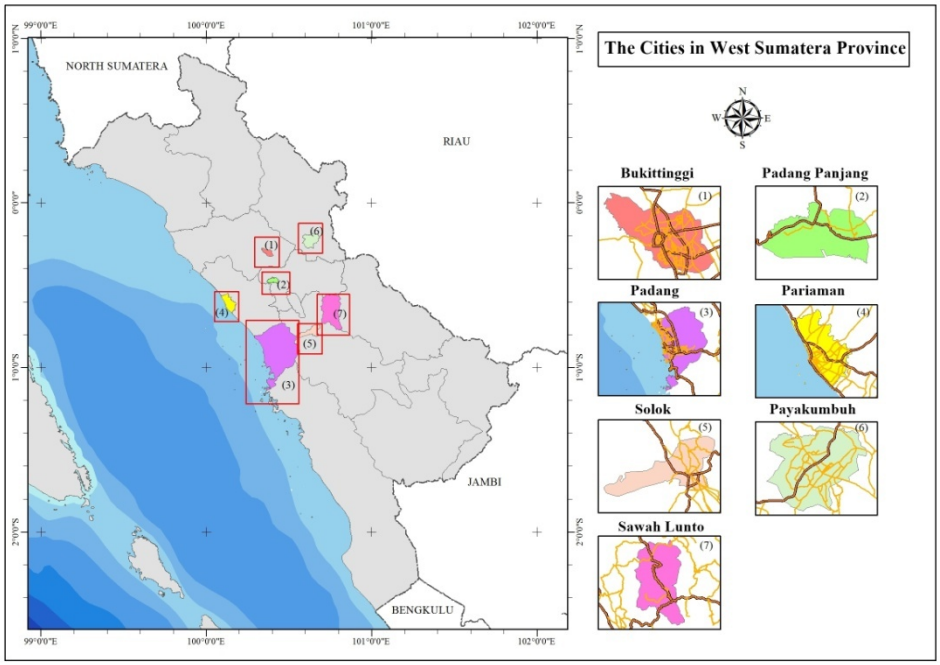

Fig. 1 Cities in West Sumatera Province

Paddy fields are spread out in West Sumatera cities. Based on the spatial plan regulation, this type of land use should not be converted to built-up area. As a result, there are still paddy fields landscape alongside the built-up area. The development of facilities such as new government offices and residential areas in the fringe also made the city development fragmented. It appears that the pattern of urban development varies, at someplace looks continuous or contagious growth and in other parts is fragmented or leapfrogs expansion. Sprawl development of cities caused problems such as the provision of inefficient infrastructure [1] and led to the occupation of unsuitable areas [2]. Sprawl becomes even more important, considering that one of the problems in developing the built-up area in the regencies and cities of West Sumatra is the limited land to be developed [3].

This paper identifies the patterns of built-up area change and its types based on land use pattern measures. Built-up urban areas are developed land on which buildings and other urban facilities present. It shows as land cover built-up from satellite imagery. Its changes measured within a specified period. Padang, although not classified as a small city is included as an object of the study because it has similar characteristics to small cities around it.

2. METHODS

This study uses a spatial metrics method to quantify urban forms or patterns of built-up areas using Arch GIS, a Geographic Information System software. This method focuses on spatial properties and spatial distribution of patches and measures as the morphological property of patches [4]. Patches are a concrete area of relatively homogeneous environmental conditions at a specific scale [5]. The pattern measures used in this study are patch density, mean patch size, and patch changed within the built-up area or its parts. The characteristics of changes in the built-up area observed from the measurements from 2005 to 2018. This study uses four temporal series of data (2005, 2010, 2015, and 2018) sourced from various satellite imagery such as Landsat ETM 7, Spot, Quickbird, and Google Earth with cell size as 30 meters. Image classification and land use maps are created by on-screen digitizing. Population data obtained from the Provincial Statistics Bureau.

Land use pattern measures divide into five groups: growth rates, density, spatial-geometry, accessibility, and aesthetic measures [6]. This study uses two of them, growth rate and spatial geometry measures to identify whether land-use change fragmented or in other terms, discontinuous, irregular, or scattered. This pattern of development is also called sprawling [6,7].

Growth rate measures defined as the ratio between built-up areas growth rate and population growth rate. Sprawl Index (SI) commonly used to measure. An index higher than 1 implies urban sprawl [6,8].

Patch density measures the number of patches per unit of the built-up area. The relationship is that the higher patch density, the more fragmented the built-up area.

$$\textit{Patch density (PD)} = N/A$$

Where :
N = total number of patches of built-up area.
A = total of built-up area (km^2)

On the other hand, the mean patch size measures the ratio between the total built-up area and the number of its patches. The larger the mean patches size indicates that urban growth is the more contagious and on the contrary, it means more fragmented.

$$\textit{Mean patches size (MPS)} = \mathbf{A/N}$$

Where :
N = total number of patches of built-up area.
A = total of built-up area (hectare)

The built-up area can be divided into core area, infill development area, and fringe area [2]. The rate of patch change (in the number, size, and density) among areas shows the direction of city development, whether it is more likely to be infill development or edge expansion. The division based on a distance from the city center or the coastline for coastal cities. For small cities, the distanced considered are core area (0-1 km), infill development area (1-3 km), and edge expansion in the fringe area (> 3 km). Specifically for Padang, which is a large city, the distance considered are core area (0-3 km), infill development (3-5 km), and edge expansion (> 5 km). For coastal cities such as Padang and Pariaman, the distance measured from the coastline. Cities expand away from the coastline to reach tsunami safe zone because the west coast of Sumatera is one of the earthquakes and tsunami-prone areas. More than 3 km is considered a safe distance from the tsunami threat.

3. RESULTS AND DISCUSSION

Measurements consist of the number of patches, *patch density* (PD), and *mean patch size*

(MPS) from 2005 to 2018 show the trend of increasing, decreasing, and relatively constant (Table 1). Graph Fig.2 shows different patterns. Solok and Pariaman, respectively, experienced steadily increasing PD/decreasing MPS and increasing PD/decreasing MPS but at a slower rate, as happened in Sawahlunto and Payakumbuh. Decreasing PD and increasing MPS only occurred in Padang and Padang Panjang. Meanwhile, Bukittinggi tends to develop relatively constant.

The urban land use map 2005 and 2018 show that built-up areas exist next to paddy field areas (Fig.2). The development of the built-up area is partly continuous as patches grow bigger and merge, and some others show scattered/leapfrogging to the fringe area.

Based on PD and MPS calculations during 2005-2018, the development of built-up area shows four categories (see Table 1 and Fig. 2-3): (a) Padang and Padang Panjang show decreasing PD and increasing MPS. These mean a contagious development pattern has occurred as the number of patch is reduced because it merges; (b) Cities such as Sawahlunto and Payakumbuh show increasing PD and decreasing MPS but at a slower rate. Despite showing fragmented land development but contagious pattern starting to happen; (c) Solok and Pariaman show more fragmented developments in the period. PD increase and MPS decrease continuously, and (d) Bukittinggi shows relatively constant PD and MPS. This means scattered and contagious development pattern presents together in balanced. The merging of patches accompanies the addition of patches.

Urban Sprawl Index (USI) obtained by comparing the ratio between the built-up area growth rate and population growth rate (Table 2). It is only Sawahlunto has an index number of more than 1 while other cities less than 1. USI indicator does not seem to be strongly related to PD and MPZ. Value of more than 1, which means there is a pattern of sprawl, theoretically should be accompanied with fragmented patterns of land development. However, it did not occur in the cities of West Sumatra. USI correlate with PD and MPZ only on Sawahlunto. The fragmented cities such as Solok, Pariaman, Payakumbuh (with increasing PD and decreasing MPZ) have USI smaller than 1.

It seems necessary to carefully interpret USI. In small cities, the size of patches is small because the actors of land development are mostly individuals or small developers who develop small areas. The map of the built-up area shows there is a lot of fragmented lands but with a small size that causes inconsistent spatial measurements between the growth rate measure and the spatial-geometry measure. Horn and Van Eeden suggested USI method is better to read as a comparative measurement [8]. It is expected that there is a relationship, the higher the value of USI, the more fragmented the land development. This study found that the relationship between growth rate measure and spatial geometry measures is weak. For example, Padang Panjang is the second higher USI (0.9), which assumed has relatively more scattered development than Payakumbuh (USI, 0,2) and Pariaman (USI, 0,8), but on the contrary, by pattern measures (as have discussed earlier) considered growing continuous/contagious, whereas the two cities mentioned later experiencing scattered/ leapfrogging development.

Further analysis of built-up area changes was carried out by dividing the city into three zones: (a) core area, (b) infill development area, and (c) fringe area and then measuring its percentage change of built-up area and patch density (PD). The largest percentage of changes in the built-up area indicate the direction of urban development, whether infilling (1-3 km from the city center or coastline) or edge expansion (more than 3 km from the city center or coastline for a small city and more than 5 km for a bigger city such as Padang). The infill development area is adding patches at the edge or adjacent to the urban core in already urbanized areas [4]. This development type can reduce fragmentation as a consequence of continuous or contagious development. Edge expansion defined as the rapid and continuous expansion of urban land at the edge of existing urban areas [9].

Tabel 1 Pattern measures of built-up area.

Cities	Pattern measures	2005	2010	2015	2018	Built-up area change pattern
Padang	The total area of built-up area (in hectare)	9244.1	9373.0	9669.7	9801.2	
	Built-up area growth rate (2005-2018) (%)				0.45	
	The number of patch	375	328	307	301	decreasing
	Patch density (unit/km^2)	4.06	3.50	3.17	3.07	decreasing
	Mean patch size (in hectare/unit)	24.7	28.6	31.5	32.6	increasing

Table 1 Continues to next page

Table 1 Continued

Cities	Pattern measures	2005	2010	2015	2018	Built-up area change pattern
Solok	The total area of built-up area (in hectare)	705.6	761.6	801.9	858.2	
	Built-up area growth rate (2005-2018) (%)				1.52	
	The number of patch	85	92	103	119	increasing
	Patch density (unit/km^2)	12.05	12.08	12.85	13.87	increasing
	Mean patch size (in hectare/unit)	8.3	8.3	7.8	7.2	decreasing
Sawahlunto	The total area of built-up area (in hectare)	1026.1	1108.7	1189.7	1222.0	
	Built-up area growth rate (2005-2018) (%)				1.35	
	The number of patch	162	251	294	309	increasing but at a slower rate
	Patch density (unit/km^2)	15.79	22.64	24.71	25.29	increasing but at a slower rate
	Mean patch size (in hectare/unit)	6.3	4.4	4.0	4.0	decreasing but tend to constant
Padang Panjang	The total area of built-up area (in hectare)	381.8	394.9	425.8	453.1	
	Built-up area growth rate (2005-2018) (%)				1.33	
	The number of patch	355	342	336	349	decreasing
	Patch density (unit/km^2)	92.98	86.61	78.90	77.02	decreasing
	Mean patch size (in hectare/unit)	1.1	1.2	1.3	1.3	increasing but tend to constant
Bukittinggi	The total area of built-up area (in hectare)	863.2	920.7	959.56	982.6	
	Built-up area growth rate (2005-2018) (%)				1.00	
	The number of patch	300	326	342	344	increasing but at a slower rate
	Patch density (unit/km^2)	34.75	35.41	35.64	35.01	relatively constant
	Mean patch size (in hectare/unit)	2.9	2.8	2.8	2.9	relatively constant
Payakumbuh	The total area of built-up area (in hectare)	1688.6	1708.1	1742.5	1785.5	
	Built-up area growth rate (2005-2018) (%)				0.43	
	The number of patch	288	292	317	327	increasing
	Patch density (unit/km^2)	17.06	17.09	18.19	18.31	increasing
	Mean patch size (in hectare/unit)	5.9	5.8	5.5	5.5	decreasing
Pariaman	The total area of built-up area (in hectare)	1319.2	1351.4	1440.7	1493.1	
	Built-up area growth rate (2005-2018) (%)				0.96	
	The number of patch	131	158	257	277	increasing
	Patch density (unit/km^2)	9.93	11.69	17.84	18.55	increasing
	Mean patch size (in hectare/unit)	10.1	8.6	5.6	5.4	decreasing

Source: Data analysis, 2019.

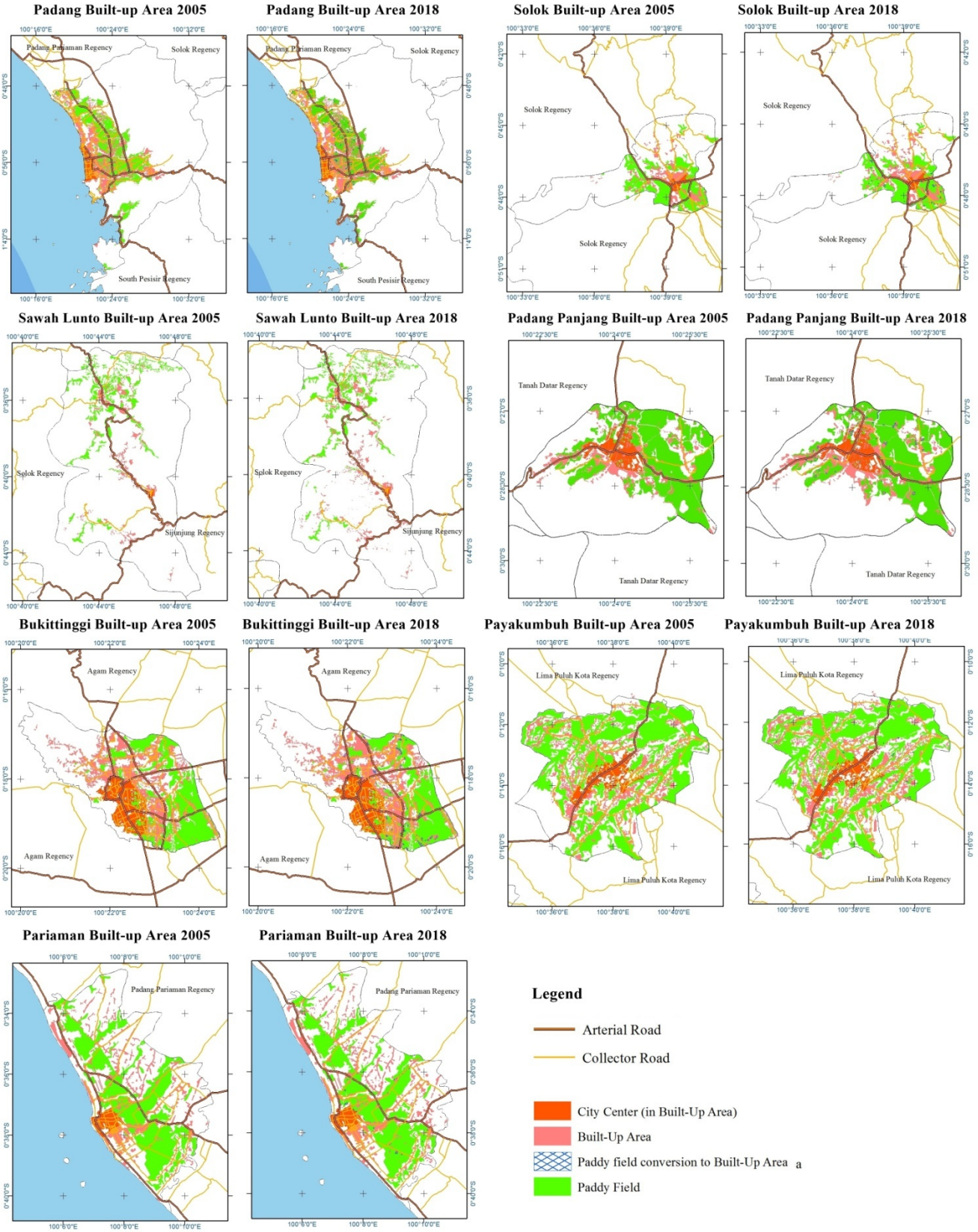

Fig. 2 Built-up area change in 2005-2018.

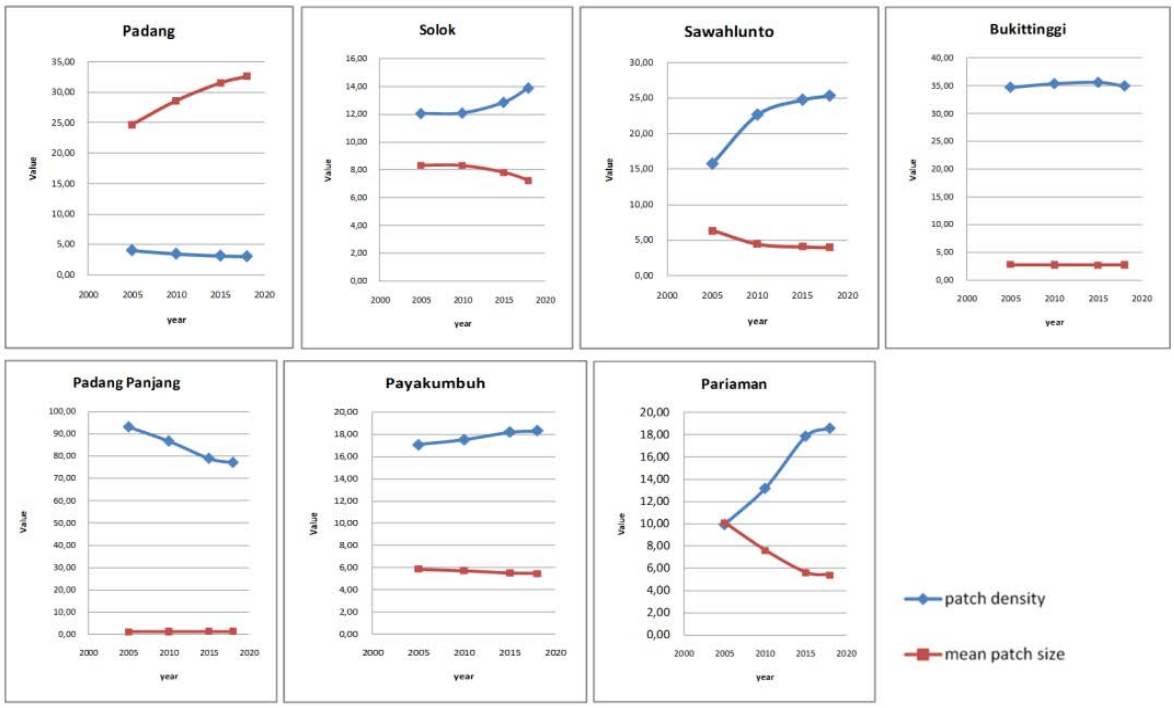

Fig. 3 The graphic pattern of built-up area patch measures changes in 2005-2018.

Table 2 Urban sprawl index measures by a growth index.

Municipalities	Population in 2018	The compound annual built-up population growth rate 2005-2018 (%)	The compound annual built-up area growth rate 2005-2018 (%)	Urban Sprawl Index (USI)
Padang	944,919	1.31	0.45	0.3
Kota Solok	70,299	1.85	1.52	0.8
Sawahlunto	62,176	1.14	1.35	1.2
Padang Panjang	53,367	1.52	1.33	0.9
Bukittinggi	129,670	2.07	1.00	0.5
Payakumbuh	134,646	1.91	0.43	0.2
Pariaman	88,119	1.20	0.96	0.8

Source: Data analysis, 2019.

Table 3 Pattern measures of urban built-up areas change in 2005-2018 at a certain distance from the city center or coastline.

City	Distance from the city center or coastline (km)	Percentage increase in built-up area zone during 2005-2018 (%)	The extent of patch density (PD) change in 2005-2018 (unit/km^2)	Types of built-up area change
Padang	0 - 3	26	-0.7	Edge expansion with
	3 - 5	31	-2.0	low-density
	> 5	43	-0.9	development
Kota Solok	0 - 1	4	0.15	infilling with low-
	1 - 3	58	1.19	density development
	> 3	38	-2.35	
Sawahlunto	0 - 1	11	-1.71	edge expansion with
	1 - 3	12	7.65	scattered/leapfrogging
	> 3	77	9.10	development
Padang	0 - 1	20	-0.7	infilling with low-

City	Distance from the city center or coastline (km)	Percentage increase in built-up area zone during 2005-2018 (%)	The extent of patch density (PD) change in 2005-2018 (unit/km^2)	Types of built-up area change
Panjang	1 - 3	77	-39.3	density development
	> 3	3	-8.9	
Bukittinggi	0 - 1	3	1.3	infilling with low-
	1 - 3	82	-1.6	density development
	> 3	15	-10.8	
Payakumbuh	0 - 1	3	0.0	edge expansion with
	1 - 3	50	1.5	scattered/leapfrogging
	> 3	47	1.0	development
Pariaman	0 - 1	20	1.8	edge expansion with
	1 - 3	34	9.2	scattered/leapfrogging development
	> 3	46	8.6	

Source: Data analysis, 2019.

Cities that have developed in a large portion in infilling areas (1-3 km for small cities and more than 3-5 km for large cities such as Padang) characterized by low-density development because this area tends to changes continuous or contagious. However, development in the fringe area or edge expansion type (more than 3 km for small cities and 5 km for large cities), on the first stage will cause scattered/leapfrogging development, but when the cities develop further, edge expansion in the fringe area can be followed by low-density development.

The largest change in certain zones of built-up area as measured by percentage increase can be used as an indicator to see whether urban development is infilling or edge expansion.

A positive value of PD indicates fragmented development with scattered/leapfrogging form, and a negative value of PD shows that there is a contagious development with low-density development.

In more detail, by combining two indicators, the percentage increase in a built-up area in the distance from the city center or coastline and PD value change, then the types of city development could be found out, as shown in Table 3.

Generally, development in the city center is the lowest proportion except for Pariaman, where many built-up areas have been developed in this zone, as shown by the proportion of the built-up area in the city center that increases by 20% and a positive value of PD.

Padang and Padang Panjang in aggregate have a decreasing in number and density of patches; their PD change in all three built-up zones are negative. These cities' patterns of growth tend to be compact.

On the other hand, Pariaman, Payakumbuh, and Sawahlunto, which have an increase in the number of patches and density, have a positive value of PD on each part of their zone and tend to grow toward the fringe area. These cities' patterns of growth tend to be fragmented.

Three types of built-up area change are identified:

Type I: edge expansion with low-density development. This type is found in Padang. This type characterized by an increase in the percentage of the built-up area at a fringe area further from the coastline (42% increase at a distance more than 5 km). As the largest city in the province, growth occurs in the fringe area, however, with a negative value of PD. It means that although the fringe area develops but the city's land use changes have tended to compact.

Type II: infilling with low-density development. This type found in Solok, Padang Panjang, Bukittinggi. This type characterized by the largest percentage increase in the built-up area at a distance of 1-3 km. The process that occurs in these cities is infilling development with low-density. An interesting finding, as shown in Table 3, is that development in the fringe area in this type has a negative PD value. It means that it already tends to develop continuous or contagious.

Type III: edge expansion with scattered/leapfrogging development. This type found in cities that develop towards fringes area with positive PD change, which means fragmented development occurs. This type found in Sawahlunto, Payakumbuh, and Pariaman. Though note needs to be given to Payakumbuh, where edge expansion tendencies have accompanied by infilling development almost in the same amount, nonetheless, in the future, development towards the fringe area will be more rapid. This prediction considers that there is a vast paddy field in the infilling area, and most of them may not be allowed to convert to the built-up area because urban spatial planning regulation in Indonesia

stipulated that a vast paddy field should be conserved.

4. CONCLUSION

The extent, distribution, and characteristics of built-up changes can be easily quantified using spatial metric measurements using Geographic Information System tools. Patterns of urban development generated by combining measurements. Applied to cities in West Sumatra, three types of built-up area change have been identified.

However, interpreting patterns needs to be done cautiously because it is difficult to define the threshold of what is called the sprawling or fragmented pattern in a city, as found in this study in applying USI method. Therefore it needed to identify trends and comparisons relatively among cities with the same characteristics to carry out appropriate measurements interpretation.

5. ACKNOWLEDGMENTS

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