Analysis of Built-up Land Spatial Patterns Using Multitemporal Satellite Imagery in Pekalongan City

by Nurhadi Bashit

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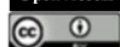*Corresponding author e-mail: nurhadi.bashit@live.undip.ac.id

Abstract

Pekalongan City is one of the cities in Central Java Province which experienced an increase in built-up land. The built-up land can cause negative impacts if the development is done carelessly. Therefore, the monitoring of built-up land is carried out to find out changes in built-up land in Pekalongan City. One method for monitoring built-up land can use the remote sensing method. This study uses the Index-based Built-up Index (IBI) algorithm. Index-based Built-up Index (IBI) is a transformation that combines the Normalized Difference Built-up Index, Soil Adjusted Vegetation Index, and Modified Normalized Difference Water Index algorithm. Research data used Landsat 8 imagery in 2013, 2015, 2017, and 2019. The results showed an increase in the use of built land from 2013 to 2019 amounts to 475.45 ha. The built-up land has experienced the biggest increase from 2017 to 2019 more than 359,088 ha. The results also showed the development of built land in Pekalongan City of 170.544 ha/year. The development of built-up land in Pekalongan City has a spatial pattern to the south due to the construction of toll roads that are connected to the main road. The existence of the toll road causes an increase in built-up land in Pekalongan City.

Keywords: Built-up Land, Index-based Built-up Index (IBI), Spatial Pattern

1. Introduction

Regional growth is characterized by an increase in built-up land. According to Badan Standardisasi Nasional (BSN) (2010), built-up land is land that has undergone substitution of natural or semi-natural land cover with artificial land cover. An increase in built-up land can cause changes in land use such as vacant land turned into built-up land. This causes the vacant land/vegetation land to decrease. Urban areas are dominated by built-up lands with impervious surfaces (Xu et al., 2000).

One of the cities in Central Java that experienced an increase in built-up land was in the City of Pekalongan. Based on Pekalongan City Regulation Number 30 the Year 2011, the National Spatial Planning stipulates that Pekalongan City is the Regional Activity Center. This causes Pekalongan City to have the potential to increase the amount of built-up land.

The built-up land has a negative impact if the city development is done carelessly and does not follow the city's spatial plan. The negative impact of the increase in uncontrolled built-up land such as the reduction of water catchment areas so that the disruption of water resources conditions. Poor absorption of water in the city can cause flooding. Therefore, it is necessary to monitor the increase of

built-up land in Pekalongan City and see its spatial patterns. This was done in order to monitor the increase in built-up land. One method for monitoring a city's built-up land uses the remote sensing method.

The remote sensing method can be used to see the surface conditions of the earth without having direct contact with the object. Therefore, this method can be used to monitor the increase in built-up land and see the spatial pattern of built-up land. This research is to see the built-up land using the Index-based Built-up Index (IBI). The IBI algorithm can detect developed land by utilizing the Soil Adjusted Vegetation Index (SAVI) and Modified Normalized Difference Water Index (MNDWI) from Normalized Difference Built-up Index (NDBI) so that it produces positive pixels only for built-up areas (Xu, 2008). The built-up index is a subset of the spectral indices class, which is one of the most common and used approaches for analyzing data in the optical domain (Azmi et al, 2016). Spectral indices can be used to extract particularly and effective land features if an appropriate threshold is used (Smith, 2000; Zhao and Xiang, 2005)

The purpose of this study was to determine the increase in built-up land in Pekalongan City and to

know the spatial pattern development. This study investigates the distribution of built-up land, area of built-up land, and the spatial pattern of Pekalongan City.

Source : Bappeda of Pekalongan City

Fig 1. Map of Pekalongan city

2. MATERIALS AND METHODS

2.1 Data

Data collection is intended to obtain the data needed in conducting research. This study uses Landsat 8 image acquisition data in 2013, 2015, 2017, 2019, the administrative boundaries of Pekalongan City, and field survey.

2.2 Stage of Research
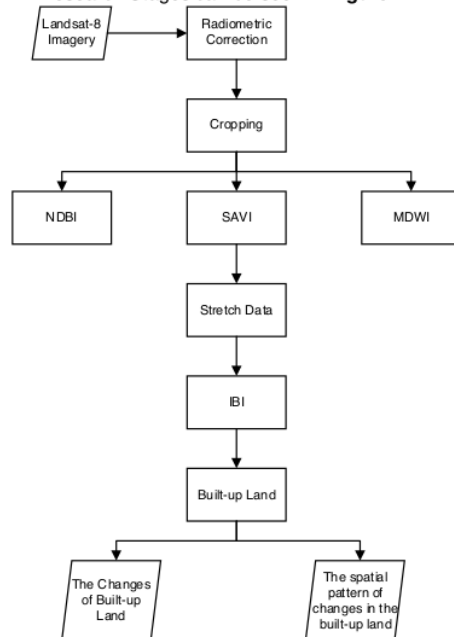Research Stages can be seen in **Figure 2**.

Fig 2. Research Stages

2.3 Built-up Land

The built-up land is land that has undergone a process of development such as buildings, buildings, roads, and others. The built-up land is often referred to as the built environment. According to T. Bartuska and G. Young (1994) explains the definition of the built environment is something that is created, arranged and maintained by humans to meet human needs and mediate the environment as a whole with results that affect the environmental context such as buildings, roads, facilities, and other facilities.

The identification of built-up land consists of several types of objects including buildings, offices, settlements, and others. Settlements are objects that increase the amount of built-up land in an area due to human needs for shelter. An increase in built-up land can cause a decrease in environmental quality due to the density of settlements so that the proportion of open space and parks becomes small.

2.4 Index-based Built-up Index (IBI)

The building index is a transformation model that is used to manage built-up land. The increase in population causes development in the Impervious Surface Area (ISA) area or an increase in artificial airtight structures, one of which is in the area of built-up land (Alhawiti, 2017). Index-based Built-up Index (IBI) is an algorithm formed by a combination of several indexes to produce built-up land classifications. IBI uses several algorithms including Normalized Difference Built-up Index (NDBI) for developed land, Soil Adjusted Vegetation Index (SAVI) for vegetation, and Modified Normalized Difference Water Index (MNDWI) for water bodies (Xu, 2008). The equation for determining IBI, as follows.

$$NDBI = \left(\frac{SWIR\,I - NIR}{SWIR\,I + NIR}\right) \dots\dots\dots\dots\dots\dots\dots (1)$$

$$SAVI = \left(\frac{(NIR - RED)(1+l)}{NIR + RED + l}\right) \dots\dots\dots\dots\dots (2)$$

$$MNDWI = \left(\frac{GREEN - SWIR1}{GREEN + SWIR1}\right) \dots\dots\dots\dots\dots (3)$$

$$IBI = \left(\frac{[NDBI] - \left(\frac{[SAVI] + [MNDWI]}{2}\right)}{[NDBI] + \left(\frac{[SAVI] + [MNDWI]}{2}\right)}\right) \dots\dots\dots\dots (4)$$

Where:
IBI   = Index-based Built-up Index
NDBI = Normalized Difference Built-up Index
SAVI   = Soil Adjusted Vegetation Index
MNDWI = Modified Normalized Difference Water Index
NDWI = Normalized Difference Water Index
NIR   = Near Infrared Band
SWIR I = Short-Wave Infrared I Band
GREEN = Green Band
NDVI   = Normalized Difference Vegetation Index
SAVI   = Soil Adjusted Vegetation Index
NIR   = Near Infrared Band
RED   = Red Band
l   = 0 if vegetation cover is high, 1 if low

In the footsteps of NDVI, (Zha et al. 2003) developed a multispectral index using moderate resolution image of Landsat 5 Thematic Mapper

(TM), it called Normalized Difference Built-Up Index (NDBI), the multispectral index is established on the ratio between the infrared band with low reflectance on the built surfaces and mean-infrared band with a high reflectance. The SAVI can work in the area with plant cover as low as 15%, while the NDVI can only work effectively in the area with plant cover above 30% (Ray 2006).

The IBI algorithm has the ability to increase the ability to detect built areas because of the reduction of the SAVI and MNDWI index from the NDBI index which will produce positive pixels only for the built-up land and values from 0 to negative are detected as not built-up land (Xu, 2008). This combination can remove the noise of the vegetation and water and thus improve the extraction accuracy by adding other distinguishing characteristics, such as spatial enhancement of the input data and the thermal bands in the calculation of modified index (Azmi et al, 2016).

2.5 Standard Deviational Ellipse

The Standard Deviational Ellipse is used to determine the direction of the distribution of changes in the built-up land. Standard Deviational Ellipse is a method for analyzing the spatial characteristics of geographical features such as the inclination center, distribution, and direction of the pattern. Standard Deviational Ellipse calculates the standard distance in the x and y directions to determine the direction of the elliptical axis on the feature distribution (Sa'diyah, 2016). Standard Deviational Ellipse will produce new features in the form of ellipse polygons. The ellipse polygon attribute data are the average x and y coordinates, two standard distances (long axis and short axis), and ellipse orientation. The ellipse polygon shows the direction of change.

2.6 The Change of Built-up Land

The built-up land has increased every year depending on the economy of a region. This increase can have positive or negative impacts. Monitoring the rate at which built-up land is needed to be anticipated by doing calculations so that it can minimize negative impacts. According to Yunus (2000), the speed of change in built-up land can be formulated based on the average value of built-up land growth as in Equation 5.

$$Plt = \frac{St\,(T2) - St\,(T1)}{T} \qquad (5)$$

Where:

Plt = mean growth of built-up land
St = settlement (ha)
T2 = year of end of observation
T1 = year of initial observation
T = difference in observation time (T2-T1)

2.7 Classification Accuracy Test

The results of the classification of built-up land need to be tested for accuracy to show the accuracy of the classification results. The accuracy test in this study uses the Confusion Matrix Calculation table. The confusion matrix calculation table is a derivation of the sum of the omission, commission, and overall accuracy of the mapping (Short, 1982). The confusion matrix is the relationship between known reference data and the results of the classification based on interpretation. Accuracy assessment is obtained from this relationship so that the reference is used as a reference to see the accuracy of the classification results. Accuracy is determined empirically by selecting samples at each pixel from the classification results and checking labels against classes determined from reference data (collected during field surveys).

Reference data is the actual object information, while the object chosen to assess accuracy is called object testing. An assessment of the percentage of objects from each class on each object drawn in the image can be estimated together with the proportion of objects from each class that does not match the actual object in giving a label to each other class. The results of labeling inappropriate objects are presented in tabular form, often referred to as matrix errors. The values listed in the table represent the number of actual objects in the field on each true and false object (Richards, 2006).

3. RESULTS AND DISCUSSION

3.1 Built-up Classification

The built-up land classification using the IBI algorithm by reducing the results of the NDBI algorithm to the results of the SAVI and MNDWI algorithms. The IBI algorithm results in a better classification of built-up land because it utilizes 3 formation algorithms. The IBI algorithm has the advantage of classifying built-up land because pixels that are positive are only for built-up land.
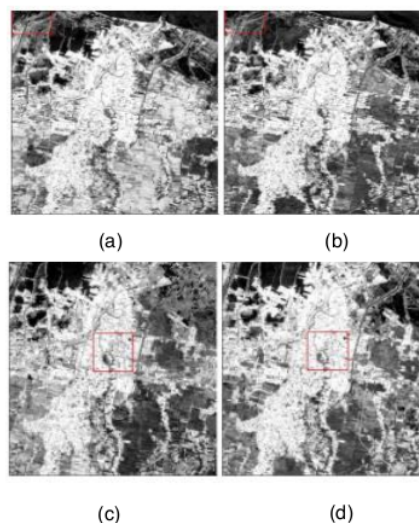
Fig 3. The Results of IBI Algorithm in (a) 2013, (b) 2015, (c) 2017, (d) 2019

The results of the IBI algorithm produce pixel values -1 to 1. The built-up land can be identified based on pixel values in the form of positive values.

This can facilitate the classification of built-up land. In this case, the built-up land is all objects on the surface of the earth that are man-made structures such as roads, buildings, settlements, industries, offices, hospitals, schools, etc.
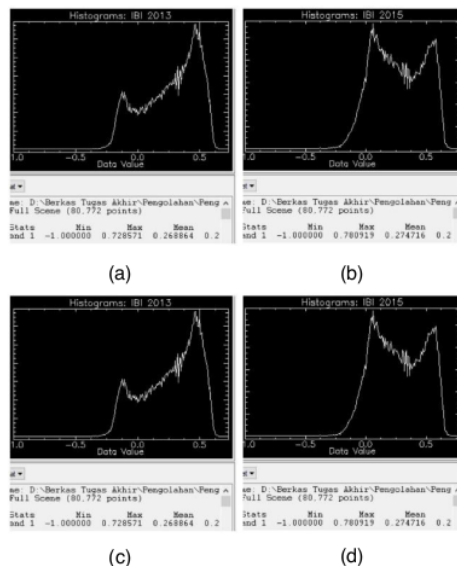
Fig 4. The Results of Histogram of IBI in (a) 2013, (b) 2015, (c) 2017, (d) 2019

This study uses a threshold range of pixel values of ≤ 0.2 to obtain the results of the classification of built-up land and for non-built-up land has a pixel value of <0.2. The highest pixel value identifies the built-up land with high density and the lower the pixel value the less density in the area. The results of IBI processing can be concluded that the high level of built-up land density is in the city center and the smaller the pixel value the further away from the city center.
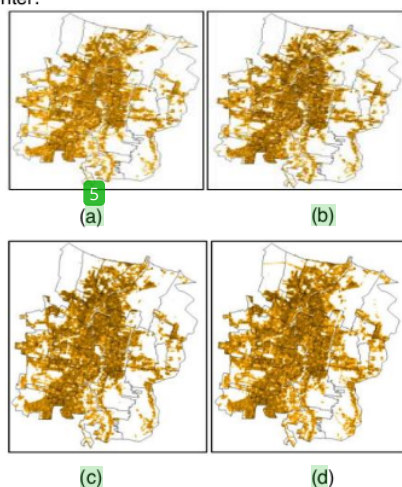
Fig 5. The Result of Built-up Land Classification in (a) 2013, (b) 2015, (c) 2017, (d) 2019

3.2 The Changes in Built-up Land

The results of the classification of built-up land can be seen an increase in the area of built-up land in 2013 to 2019 experiencing an increase. During the period of 6 years from 2013 to 2019, built-up land in Pekalongan City has increased by 475.453 ha. In 2013, North Pekalongan District was the highest built-up land with a total area of 652.352 ha and South Pekalongan District had the most extensive area with an area of 466.181 ha. This happens because North Pekalongan District is the largest district in Pekalongan City which has an area of 1,716.687 ha which is dominated by non-built-up land. South Pekalongan District has an area of 1,147.384 ha which is dominated by non-built-up land.

Table 1. Areas of Built-up Land

No	District	Areas of Built-up Land (ha)			
		2013	2015	2017	2019
1	West Pekalongan	585.821	595.669	614.467	660.268
2	South Pekalongan	466.181	478.924	499.702	688.029
3	East Pekalongan	494.048	499.837	508.891	606.276
4	North Pekalongan	652.352	658.176	691.707	819.282
	Total	2,198.402	2,232.606	2,314.767	2,673.855

In 2015, North Pekalongan District had an area of 658,176 ha so that the district experienced an increase from 2013 of 5.824 ha. The Districts of West Pekalongan and East Pekalongan experienced an increase in the built-up land area of 28.646 ha and 5.789 ha. The area built-up land with the lowest area is South Pekalongan District where the area of 478.924 ha has increased by 12.743 ha. West Pekalongan District experienced the biggest increase in 2 years between 2013 and 2015 with an area of 28.646 ha. In 2019, North Pekalongan District had a high increase of built-up land with an area of 33.531 ha. The Districts of West Pekalongan and East Pekalongan have an increase in the area of built-up land by 18.798 and 9.054 ha. South Pekalongan District has a total built-up land area of 499.709 ha, which can be said to have increased by 20.778 ha.

In 2019, North Pekalongan District has an area of built-up land amounting to 819.282 ha and an increase from 2017 of 127.575 ha. The Districts of West Pekalongan and East Pekalongan have an area of built-up land amounting to 660.268 ha and 606.276 ha with an increase in built-up land amounting to 46.401 ha and 91.385 ha. South Pekalongan District has a built-up land area of 588.029 ha and an increase of 88.327 ha. Based on the calculation of the area of built-up land in the City of Pekalongan it can be concluded that the city has experienced an increase in built-up land that varies every time so that it is always necessary to carry out monitoring so that development is in accordance with city planning.

Table 2. The Changes in Built-up Land Area

No	Years	Built-up Land (ha)	%	Non-Built-up Land (%)	%
1	2013	2,198.402	47.5	2,431.252	52.5
2	2015	2,232.606	48.2	2,397.048	51.8
3	2017	2,314.767	50	2,314.886	50
4	2019	2.673.855	57.7	1,955.799	42.3

The built-up land Pekalongan City in 2013 has an area of 2,198.402 hectares (ha) of which 47.48% of the total area of Pekalongan City. In 2015 and 2017 experienced an increase in the area of built-up land to 2,232.606 ha and 234.767 ha. In 2019 the area has reached 2,673.855 ha, which is 5.75% of the total area of Pekalongan City. The results of the processing of the built-up land using the IBI method resulted in changes in the built-up land that continued to increase from the period of 2013 to 2019. This increase was due to the construction of urban buildings in the form of shopping centers, settlements, road networks both in the form of main roads and toll roads.

3.3 Spatial Patterns of Built-up Land

The result of the classification of built-up land using the IBI algorithm can be seen in its spatial patterns. Determination of the spatial pattern of built-up land using standard deviational ellipse. This method is one of the methods to analyze the spatial characteristics of geographical phenomena such as the direction, distribution, and distribution patterns. The development of the built-up land of Pekalongan City in 2013-2015 can be seen in Figure 5. The pattern of development of the built land can show the direction of the development of Pekalongan City in the span of every 2 years in this study.
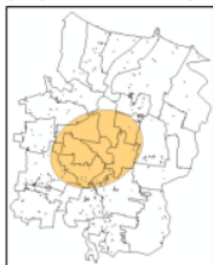

Fig 6. Spatial Patterns of Built-up Land in 2013-2015

In 2013-2015 the direction of the ellipse showed the center of change was in the area near the main street of Pekalongan City, the road that connects between Batang Regency and Pekalongan Regency. Changes in built-up land have occurred along the main road in Pekalongan City. The development of Built-up land by Pekalongan City in 2015-2017 can be seen in Figure 6.
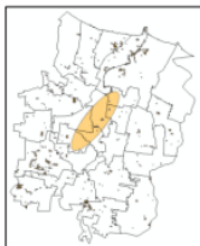

Fig 7. Spatial Patterns of Built-up Land in 2015-2017

In 2015-2017 the direction of ellips showed that the center of change was in the area near the main road of Pekalongan City, the road that connects the center of Pekalongan City and the south of Pekalongan Regency. Changes in built-up land occur in many urban areas that are along the main street of Pekalongan City. The development of the built-up land consists of improving road infrastructure and building urban settlements for housing.
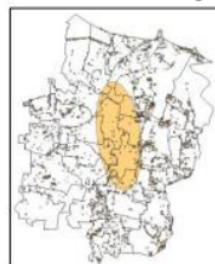

Fig 8. Spatial Patterns of Built-up Land in 2017-2019

In 2017-2019, the direction of ellips indicates the center of change is in the area near the main road of Pekalongan City, the road that connects the center of Pekalongan City and the South Pekalongan Sub-District. The conversion of land into built-up land exists along the main road in Pekalongan City. The built-up land experiences developments in objects such as road infrastructure and urban settlements. South Pekalongan District has a new toll exit that connects the main road with the toll road. North Pekalongan District is under construction of a ring road connecting Batang Regency to Pekalongan Regency to Pemalang Regency which does not pass through the center of Pekalongan City.
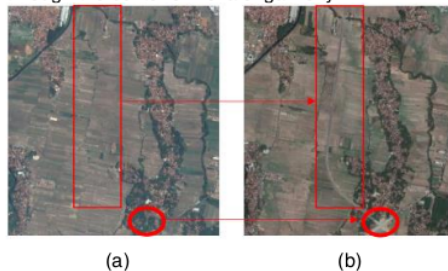

(a)   (b)

Fig 9. Display TOL Roads in Google Earth (a) 2017 (b) 2019

The built-up land has increased from previously vacant land or vegetation to road and settlement infrastructure as shown in Figure 9. South Pekalongan District there is a new toll exit that connects the main road with the toll road which was built in 2018. The existence of the exit toll can cause an increase in the area used for trade and services in the surrounding area.
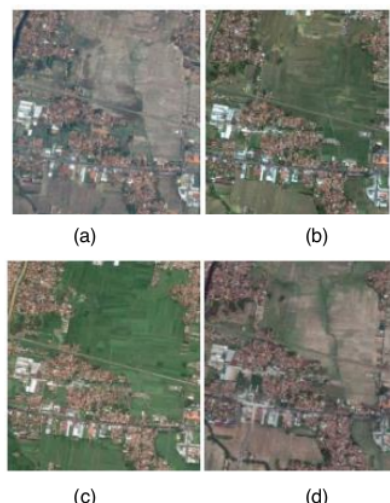
Fig 10. Appearance of Built-up Land on Google Earth (a) 2013 (b) 2015 (c) 2017 (d) 2019

Residential buildings experienced a significant increase from 2013 to 2019. West Pekalongan District has increased the area of built-up land that is used for settlements. The built-up land has increased in areas along the main road Pekalongan - Batang. Easy access to the main road is one of the factors that drive the community to build a residence in the area. The main road of Batang - Pekalongan - Pemalang has good economic prospects to become a trading area such as shops and services.

3.4 The Built-up Land Improvement

The distribution of built-up land in Pekalongan city has increased from 2013 to 2019. The largest increase in built-up land was found in 2017 to 2019 because South Pekalongan District was built with public facilities such as a exit toll that connects the main road with a toll road that was built in 2018. This has led to an increase in built-up land in Pekalongan City. The built-up land was built in 2013 has an area of 2,198.402 ha and in 2015 it has an area of 2,232.606 ha so it can be concluded that from 2013 to 2015 there was an increase in the area of built-up land at a speed of 17.101 ha/year.

In 2015 until 2017, the speed of development reaches by 41.080 ha/year. Developments from 2017 to 2019 have a speed of 170,544 ha/year. This shows that 2017 to 2019 experienced the highest speed compared to previous years. The built-up land experienced an increase between 2013 and 2019 due to the existence of public facilities such as toll roads. West Pekalongan District experienced an increase in the number of built-up land areas that became settlements. Whereas the increase in built-up land occurred in many sub-district along the main Pekalongan-Batang road. Access to the main road is one of the factors driving the increase in built-up land.

3.5 Classification Accuracy Test

The results of the classification of built-up land using the IBI method need to be tested for accuracy in order to know the level of accuracy of the results obtained. The accuracy test of built-up land is done by calculating the confusion matrix. Reference data use field survey data in 2019. The accuracy test aims to see the accuracy of the results of the classification of built-up land so that the classification results can be used. The accuracy test is done by making a confusion matrix table like Table 3.

Table 3. Confusion Matrix

	Built-up Land	Non-Built-up Land	Total
Built-up Land	25	4	29
Non-Built-up Land	3	34	37
Total	28	38	66
Overall Accuracy		89.39%	
Kappa Accuracy		80.46%	

Based on Table 2, the results of the classification of built-up land produce an over accuracy of 89.39%. The accuracy of the results of the classification of built-up land using the IBI method can be said to be good. There are some misclassification due to the similarity in the value of the processing results so that the results become misclassified. The cause of misclassification is Landsat 8 imagery which has a large spatial resolution that is 30 m is not enough to detect non-built-up land such as vacant land and small vegetation cover in urban areas, thus affecting accuracy in detecting non-built-up land in a dense built environment.

4. CONCLUSION

Based on the results of this study, it can be included that the City of Pekalongan increased the increase of built-up land between 2013 and 2019. The largest increase of built-up land in 2017 to 2019 with an area of increase of 359.088 ha could be used to increase the availability of land area of 170.544 ha/year.

The spatial pattern of built-up land in 2017 to 2019 shows towards the south because South Pekalongan District is built a exit toll connecting the main road with the toll road. Road access is one of the supporting factors that drive the increase of built land. Good economic growth potential makes this area a trading location.

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