

Research article

Assessment of Urban Mapping Index Accuracy in Relation to Physical Land Characteristics in Humid Tropical Areas

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Abstract.

Settlements and built-up areas can lead to the degradation of ecological systems. Good quality and efficient regional planning is therefore needed for urban areas. Spatial data and satellite imagery can be used for mapping and monitoring urban growth. Unfortunately, mapping urban areas can sometimes be difficult due to local variations, and different algorithms can provide varying results. Urban indices often rely on remote sensing reflectance, the accuracy of which can be influenced by land characteristics. No studies have examined the impact of land characteristics on the accuracy of remote sensing urban indices in the humid tropics. The purpose of this study was to compare urban and built area indices, namely EBBI, NDBI, UI, and IBI, in two climatically and topographically different cities. This study also examined the stability and relationship between these indices with environmental factors such as slope, elevation, and temperature. The results showed that EBBI was the index with the highest accuracy in both study areas: 85% for Batu City and 89.17% for Pasuruan City. Also, EBBI was the most stable index for the temporal studies. Environmental factors, especially slope and elevation, had a strong relationship with the index value applied. Therefore, these findings need to be considered in applying the index in areas that have topographical variations.

Keywords: built-up land, landsat, EBBI, NDBI, UI, IBI, topography

1. Introduction

Indonesia's population growth rate in 2000 to 2015 was 1.49% on average, and the number of people living in urban areas reached 50% in 2010. According to the Central Statistics Agency (2013), it is predicted to reach 67% in 2035. This causes social and health problems, including access to clean water, sanitation, decent housing, congestion, and pollution. Along with the increasing rate of population growth, the need for housing in Batu city and Pasuruan city, food, and jobs have increased. These two cities also serve government services, industry, and entertainment. This can lead to land cover changes in the future. Based on research conducted by [1], it can be seen

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that in the period 2002 to 2017, built up area and open space increased 114 hectares and 1344.9 hectares respectively.

The growing economy area is marked by the change of bare land and agricultural conversion into built-up areas. If it is not managed and regulated properly, changes in land cover can cause many non-residential built-up areas. Urban area planning and mapping need to be done properly and accurately as well as efficiently. Spatial data and satellite imagery can be an alternative for mapping and monitoring urban growth [2]. There are several studies on urban development of residential areas using remote sensing data including [3] which used a combination of remote sensing and population census data in terms of understanding the spatial and temporal characteristics of urban growth patterns and trends. The [4] found that the combined analysis of spectral and morphological spatial patterns can be the right method to make better accuracy.

Mapping of urban areas can be done using urban and built-up land indices such as EBBI, UI, IBI, and NDBI [5] [6] [7] [8]. Each of these indices needs to be compared to determine the most suitable index to be used in mapping of selected urban areas. [5] used an urban index (UI) based on the near infrared channel and the second middle infrared channel (far infrared). [6] used the Normalized Difference Built-up Index (NDBI) which was analogous to the Normalized Difference Vegetation Index (NDVI). Based on [7] research, which used Landsat ETM + data, three indices, SAVI, MNDWI, and NDBI, were applied to distinguish vegetation, water, and built-up area. Meanwhile, for the Enhanced Built-up and Bareness Index (EBBI), the NIR, SWIR, and TIR bands were used [8]. [9] applied EBBI in Denpasar, Bali to distinguish between built and bare land in urban areas. EBBI had 66.24% of an average accuracy rate, which is higher than IBI and NDBI, 54.25% and 51.87% respectively.

Emissivity and albedo of each object are specific and are influenced by the type, character and color of the surface. An object with high emissivity will absorb and radiate lower energy [10]. Topographic differences can affect surface reflections especially in visible and NIR channels [11]. Relatively flat topography area will certainly receive more energy than areas with hilly topography, related to the angle of incidence of sunlight that will reach the earth's surface. Likewise, the earth's surface covered by vegetation will certainly receive less energy when compared to an open area [12]. Studies show the differing ability in terms of accuracy of different indices in varying places. Unfortunately, assessment on how physical land characteristics in humid tropic regions are unavailable. Thus, it is necessary to study the stability of an index when it is applied to areas with different topographical diversity. The objectives of this study are 1) to examine the accuracy of urban and built-up indices applied to Batu City and Pasuruan City, 2)

to examine the stability of urban and built-up area indices applied to Batu City and Pasuruan City 3) to analyse the relationship between environmental factors and urban / built up indices in terms of mapping built-up area.

2. Method

2.1. Study Area

This research was conducted in Batu City and Pasuruan City. The administrative area of Batu City is 199.09 km², surrounded by Malang City, Malang Regency, Mojokerto Regency, and Pasuruan Regency. Batu City lies 600 to 3000 meters above sea level (masl) with a slope ranging from 0 to 40%. Pasuruan City has an area of 35.29 km² which borders the Madura Strait and it is surrounded by Pasuruan Regency. The slope in Pasuruan City ranges from 0 to 12%, located at 0-17 masl. Figure 1 shows the locations of the two cities in a regional setting.

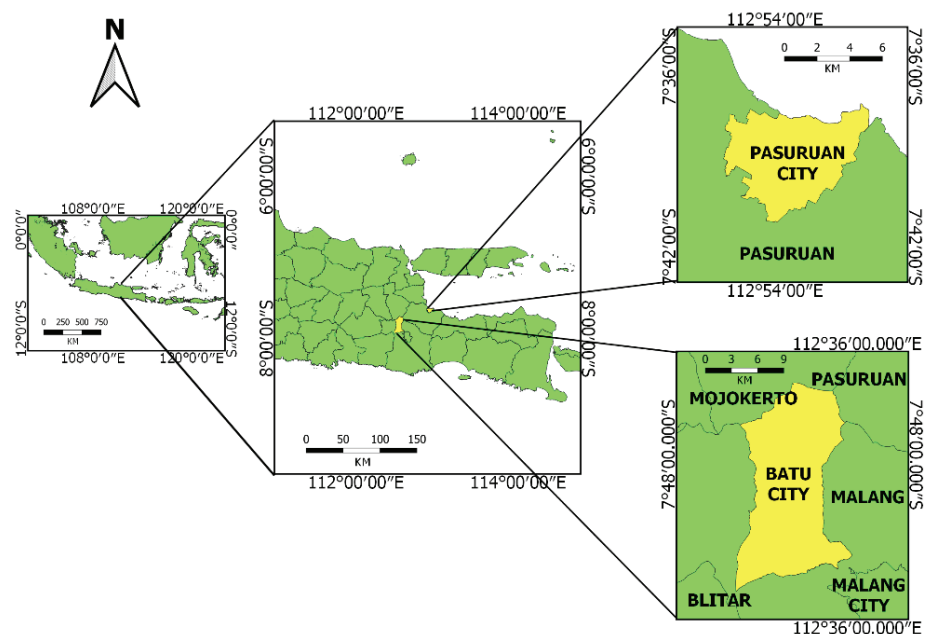


Figure 1: ??????Research Sites.

2.2. Analysis

The built-up area identification was obtained from the visual interpretation of the data in point vector shapefiles, which is then converted into 30 × 30 m pixels in raster form. The points represented the distribution of ground urban locations. The validation process is

carried out by comparing the built-up and vacant land areas determined by the index (EBBI, IBI, NDBI, and UI, table 1) with the results from Landsat 8 OLI/TIRS. Comparative results are based on the difference in the percentage area, which is used to determine the level of accuracy. Percentage of built-up area was determined from Landsat 8 OLI/TIRS imagery analysis. The built-up area percentage refers to the proportion of built-up area in each pixel. Thirty constructed sites were randomly selected for each type of land cover classification, and polygon data sampling was carried out based on the number of Landsat 8 OLI/TIRS pixels (30 × 30 m). Landsat images used in this study were Landsat 8 OLI/TIRS with dates from 28 Juli 2013, 13 Agustus 2013, 4 September 2015, 20 September 2015, and 30 October 2018. The percentage of built area correlates with the results of remote sensing data processing to determine the relationship between the percentage of built area and remote sensing indices.

TABLE 1: Urban and Built Area Indices used in this study.

No	Indeks	Algorithm	Source
1.	Normalised Difference Built-up Index (NDBI)	$NDBI = \frac{SWIR1 - NIR}{SWIR1 + NIR}$	[6]
2.	Index-based Built-up Index (IBI)	$IBI = \left[\frac{2 * SWIR1}{SWIR1 + NIR} - \left(\frac{NIR}{NIR + RED} + \frac{GREEN}{GREEN + SWIR1} \right) \right]$	[7]
3.	Urban Index (UI)	$UI = \frac{SWIR2 - NIR}{SWIR2 + NIR}$	[5]
4.	Enhanced Built-up and Bareness Index (EBBI)	$EBBI = \frac{SWIR1 - NIR}{10\sqrt{SWIR1 + TIRS1}}$	[9]

To enable comparison of accuracy among differing physical land characteristics, each of study areas (city) was classified based on their topography and climatic variability. For this, an elevation buffer of 500 meter range was established for each city. Similarly, classes of slope with several intervals were created. For differentiating the temperature effect, the cities were classified into two temperature regions. All the classified regions were then used to breakdown the samples and accuracy measurements were recalculated. Overall, the whole approach for this study was presented in Figure 2 below.

3. Result and Discussion

3.1. Extraction of Urban Indices and Threshold Determination

Data presented in the form of built-up land (BU) and non BU. The results of the implementation of the urban index and built area have a range of values -1 to 1. The higher the value owned, the object at the pixel is the built up area. Determination of

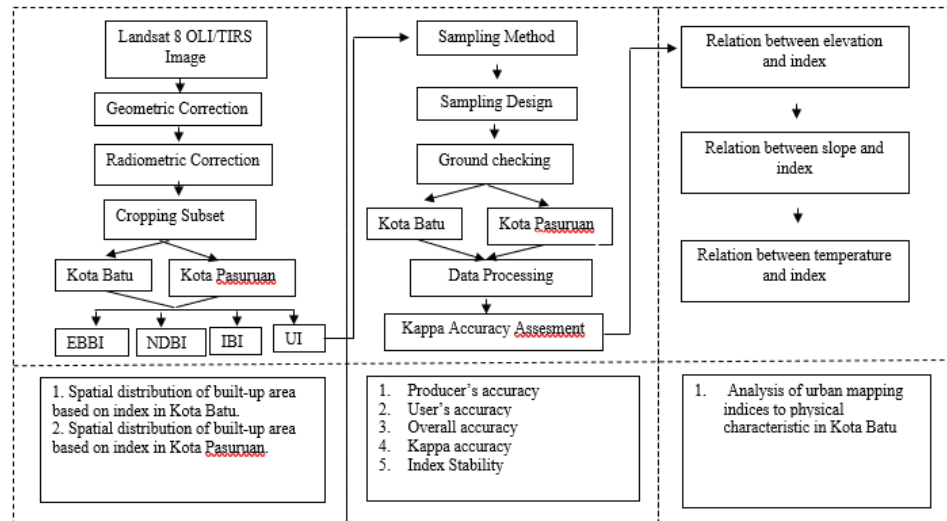


Figure 2: Research Flow Chart.

the threshold (threshold) is one important process in the application of the spectral index. Threshold values segment the image based on certain characteristics of pixels. According to [13], the purpose of determining the threshold value is to produce a binary representation of the image and classify each pixel into one of two categories. In this study the threshold value is based on pixels which have a percentage of land built more than 60%. The purpose of determining the threshold value is to classify pixels into two categories, namely built up land (BU) and not built up land (NBU). However, pixels with a percentage of land built less than 60% are categorized as BLT. The threshold of the developed land for each index is as follows.

TABLE 2: Threshold Value of Built-up areas.

No.	Sites	EBBI	NDBI	UI	IBI
1.	Batu city	-0,011	-0,15	-0,40	-0,12
2.	Pasuruan city	-0,004	-0,15	-0,40	-0,17

The results of the extraction of land built in Batu City and Pasuruan City are presented in Figures 3 and 4. Distribution of built-up land was marked in red.

The following is the result of the extraction of land built by each index in Pasuruan City.

3.2. Accuracy and Stability Index

In this study, the accuracy result of image interpretation and field data was tested using an error/contingency matrix, comparing image classification information and the results

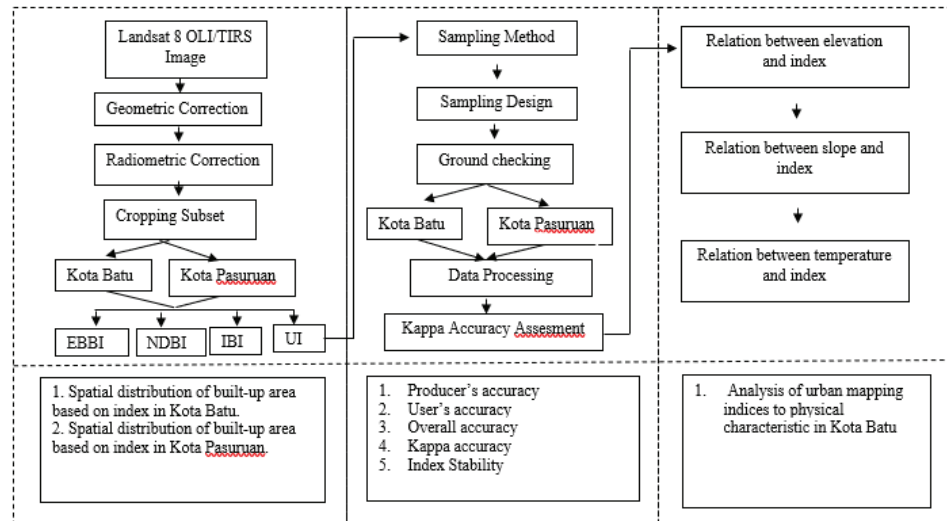


Figure 3: Land Extraction Results Built in Batu City. Red represents the built-up areas/ settlements.

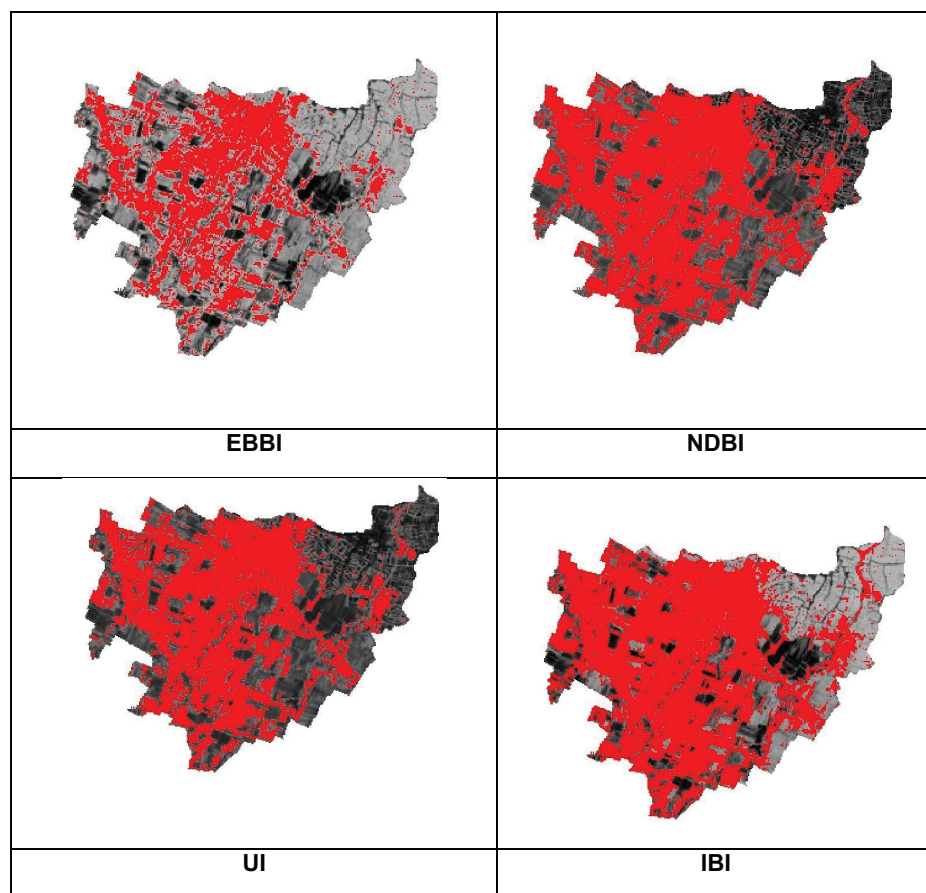


Figure 4: Results of Land Extraction Built in Pasuruan City.

of ground checkings [14]. The ground measurements were carried out on 360 points in Batu City and 120 points in Pasuruan City. Based on this, the level of accuracy in image interpretation (producer accuracy) and mapping (user accuracy) and total

accuracy (overall accuracy) were calculated. The results of the accuracy are presented as follows (Table 2).

TABLE 3: Index Accuracy Test Results in Batu City.

No.	Indeks	Producer's Accuracy (%)		User's Accuracy (%)		Overall Accuracy	Kappa
		BU	Non-BU	BU	Non-BU		
1	EBBI	82,50	90,00	94,29	72,00	85,00	0,68
2	NDBI	81,38	92,04	95,71	69,33	84,72	0,67
3	UI	79,77	95,15	97,62	65,33	84,17	0,66
4	IBI	79,84	89,29	94,29	66,67	82,78	0,63

Based on Table 2, EBBI has the highest overall accuracy, which is 85%. It has a Kappa Coefficient value for land use classification, which is 0.68 so that it is included in the substantial agreement category [15].

TABLE 4: Index Accuracy Test Results in Pasuruan City.

No.	Indeks	Producer's Accuracy (%)		User's Accuracy (%)		Overall Accuracy	Kappa
		BU	Non-BU	BU	Non-BU		
1	EBBI	92,31	79,31	93,33	76,67	89,17	0,71
2	NDBI	89,89	67,74	88,89	70,00	84,17	0,61
3	UI	90,11	72,41	91,11	70,00	85,83	0,62
4	IBI	91,21	75,86	92,22	73,33	87,50	0,66

The test was carried out on 120 points spread throughout the Pasuruan City area. The accuracy test results obtained indicate that EBBI has the highest overall accuracy, which is 89.17%. Based on the calculations that have been made, the results show that EBBI has a Kappa coefficient value for land use classification, which is 0.71 so that it is included in the substantial agreement category [15]. Overall, Pasuruan City's accuracy rate is higher than Batu City.

Kappa accuracy test was also carried out in both regions based on environmental classes, the following results were presented (Table 4 and 5).

TABLE 5: Kappa Accuracy based on Environmental Variable classes in Batu City.

Environmental factor	Zone	Index					
		EBBI		NDBI		UI	
Elevation	500 - 1000	0,72	0,64	0,71	0,59	0,65	0,56
	1000 - 1500	0,51		0,51		0,62	0,51
	>1500					0,60	0,51
Slope	0 - 8	0,73	0,73	0,77		0,93	0,94
	8 - 15	0,50		0,69		0,86	0,77
	>15			0,48		0,47	0,39

TABLE 6: Kappa Accuracy based on Environmental Variable classes in Pasuruan City.

Environmental factor	Zone	Index			
		EBBI	NDBI	UI	IBI
Elevation	<500	0,71	0,77	0,63	0,62
Slope Temperature	0 - 8 8 - 15 23	0,71 0,71	0,77	0,93	0,94 0,77
	- 29 29 - 35	0,07	0,69	0,86	0,13 0,21
		0,42	0,26	0,14	
			0,33	0,70	

The relationship between the index accuracy value, the elevation and slope factors shows an inverse relationship, where the higher the elevation and the slope, the lower the accuracy. This infers the role of topography in altering the reflectance and causing reduced accuracy. Meanwhile, the temperature factor shows a linear relationship, as the temperature increases, the accuracy increases. This finding, despite its slight differences in temperature, shows that mapping urban areas in colder temperatures might be subjective to reduced accuracy.

The difference in accuracy values appeared to be influenced by environmental characteristics and atmospheric disturbances. According to [16] the overall acceptable accuracy is 85%. The value obtained can be used as a minimum value for receiving a land cover mapping based on remote sensing imagery. EBBI can map and differentiate between built up and vacant land [9]. Bands used in the EBBI algorithm include SWIR, NIR, and TIRS. SWIR is able to identify the developed land well, it can also show a pattern of reflection and contrast absorption in the developed land and vacant land. Band NIR is able to identify the appearance of vegetation well. TIR is very effective in mapping built up land because it can reduce shadows and water. NDBI and UI have been widely used to map developed or vacant land, but both are less accurate in distinguishing developed and vacant land [6] [17] [18]. [17] noted that the complex spectral response patterns of built-up land, vacant land, and vegetation made it difficult for NDBI to segment the spectral values of objects. NDBI developed by [6] can only map developed land in urban areas such as industrial, commercial and urban settlements. However, NDBI cannot separate developed land from bare land.

On average, Batu City has an overall accuracy lower than Kota Pasuruan. This can be influenced by the variability of elevation, slope, and temperature. The higher the elevation and slope of the Kappa accuracy rate decreases. Misclassification is often found on pixels of built-up area at elevation and steep slope. So that in the application of indices in the mapping of built land it is necessary to consider variations in the slope and elevation of the area.

The index stability is assessed by comparing the temporally 16 days time series index with the assumption that during that period there is not much change in the built-up land. The stability should infer the degree of change of extracted urban areas. The less fluctuation of the areas, the more stable the indices. The results were presented below.

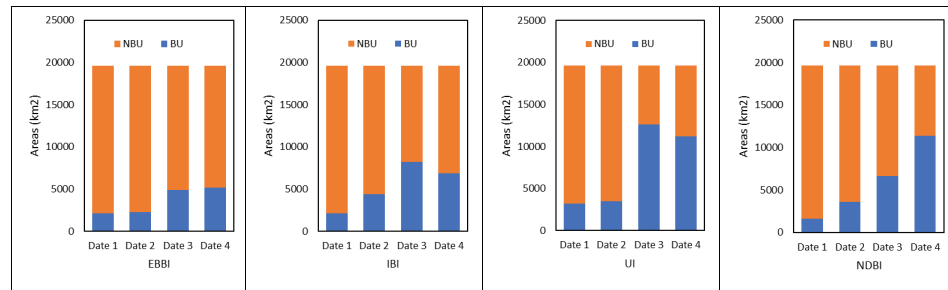


Figure 5: Stability of Urban Indices.

In July – August 2013, EBBI, NDBI, and UI indexes were relatively stable, only the IBI index showed a double value from the previous 2 weeks. Meanwhile, in September 2015, EBBI and NDBI experienced an overestimation. UI and IBI show below-estimated results. But visually, EBBI is an index that shows the most stable mapping results and it is in accordance with the appearance of Batu City on Google Earth. Overall, EBBI outperformed the stability as there is no difference between Date 1-2 and Date 3-4.

3.3 Correlation of Index Values With Environmental Factors

The correlation used in this study is the Karl Pearson correlation. Pearson correlation was performed using SPSS, where the value ranges from -1 to 1. If the correlation value obtained is 0 then there is no relationship between the variables tested. The strength of the correlation indicates the degree of influence of a variable to reflectance. It is expected that a lower correlation infers a weaker association and thus a less influence of this variable to alter the reflectance. Determination of correlation analysis was carried out using 360 points in Batu City and 120 points in Pasuruan City which were taken randomly based on elevation class, slope, and temperature. The following is the result of calculating the correlation between environmental factors and the applied urban indices (Table 6).

Overall, the EBBI shows the lowest association to varying ecological variables in both cities. This suggests that EBBI is least influenced by variations of biophysical conditions. In other words, EBBI can be better applied for mapping complex urban areas.

TABLE 7: Correlation of Urban Index with Environmental Factors.

No.	City	Index	Correlation		
			Elevation	Slope	Temperature
1.	Batu	EBBI	-0,54	-0,51	0,75
		NDBI	-0,52	-0,52	0,78
		UI	-0,52	-0,56	0,78
		IBI	-0,52	-0,53	0,80
2.	Pasuruan	EBBI	0,12	0,04	0,70
		NDBI	0,25	0,04	0,81
		UI	0,24	0,02	0,82
		IBI	0,26	0,04	0,81

4. Conclusion

Based on the research results obtained, overall accuracy in a row EBBI, NDBI, UI, and IBI for Kota Batu by 85%, 84.72%, 84.17%, and 82.78%. Accuracy tests for Kota Pasuruan were 89.17%, 84.17%, 85.85% and 87.50%, respectively. EBBI is the index that has the highest accuracy in the two study areas, namely 85% for Kota Batu and 89.17% for Kota Pasuruan. The Kappa EBBI, NDBI, UI, and IBI indices are as follows: 0.68; 0.67; 0.66; and 0.63 for Batu, for Kota Pasuruan 0.71; 0.61; 0.62; and 0.66. Kota Batu has a lower level of accuracy compared to Kota Pasuruan, so the application of urban indexes and built-up areas in the mapping of built land needs to examine the variations in slope and elevation of the study area. EBBI is also the most stable index and least influenced by varying ecological conditions.

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