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Tracking Land Use Land Cover changes from 2000 to 2018 in a local area of East Java Province, Indonesia

Indarto Indarto[1, CPMR], Farid Lukman Hakim[2, DF]

[1]*Department of Agricultural Engineering–Faculty of Agricultural Technology, University of Jember, Indonesia*, e-mail: indarto.ftp@unej.ac.cd [2]*Jl. Kalimantan No. 37 Kampus Tegalboto Jember, Jawa Timur 68121 – Indonesia* https:// orcid.org/0000-0001-6319-6731

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Abstract. Land Use Land Cover (LULC) changes represent human influences on the natural ecosystem. This study aims to analyse such changes in the eastern part of East Java, a region of ± 3320.3 km^2. The changes are analysed by comparing two editions of maps (the National Digital Map and Landsat-8). Five subsets are explored to understand the LULC changes caused by the development of: transportation infrastructure; industrial sites; the agricultural sector; tourism; urbanisation; and sub-urbanisation. Regional development from 2000 to 2018 has increased built-up areas by 40.55% (122.5 km^2), while paddy fields have increased by 71.08%, and forest plantation areas by 16.03%. Conversely, the development has reduced rural areas by 61.06% (860.1 km^2) and water bodies by 54.02% (44.52 km^2). The LULC has significantly changed the natural landscape to a human-dominated landscape, which is potentially fragile in the face of the disasters to which the region is prone.

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1. Introduction

In this study, the term LULC (Land Use Land Cover) refers to the definition by Parece and Campbell (2015: 3):

> *"... land cover refers to physical features on the surface of the Earth—vegetation, water, the built-up land. Whereas, land use specifically refers to the human (economic) utility of what is on the Earth's Surface. In some instances, terms used to describe land cover can also describe land use ...".*

Researchers usually study LULC changes through the investigation of two or more maps produced at different times. Both a conventional map and a satellite image can be interpreted to study the causal effects of LULC changes and their implication for society and the environment, such as in the studies of Eremiášová and Skokanová (2009) and Ptak and Ławniczak (2012).

The use of Landsat imagery to study LULC changes is a widely known method and has been published in research reports around the world. Pan et al. (2011) used Landsat data archives to study such changes in China, while Fonji and Taff (2014) combined current data (i.e., censuses and statistics) and satellite imagery (Landsat Thematic Mapper) to calculate changes in north-eastern Latvia. Many researchers have employed Landsat images to investigate LULC changes in others cases and locations (for example, the studies of Bayramov, Buchroithner & Bayramov, 2016; Mtibaa & Irie, 2016; Hassen & Assen, 2018). Furthermore, other researchers have studied the relationship between LULC changes and the development of urban areas (Iváncsics & Kovács, 2019; O'Donoghue, 2019; Podawca, Karsznia & Zawrzykraj, 2019).

The term "urban sprawl", defined as an urbanistic phenomenon in urban and suburban areas characterised by widely distributed, low-density housing (Łucka, 2018:3). Urban sprawl has become a popular term used to describe LULC changes and their causal effects, such as the development of transportation networks, industrial sites and tourism (Osman, Arima & Divigalpitiya, 2016; Łucka, 2018; Skadins, Krumins & Berzins, 2019). Sprawl may be caused by sub-urbanisation, industrialisation, transportation or tourism development. Other research has investigated LULC changes related to hydrological processes, and the different impacts caused. For example, Hussein, Alkaabi, Ghebreyesus, Liaqat & Sharif (2020) investigated the spatio-temporal changes in LULC along the eastern coast of the United Arab Emirates (UAE) over 20 years. The impact of these change on potential flooding was also investigated through hydrological model simulations using Landsat images from 1996, 2006 and 2016.

This urban sprawl and the causal effects related to LULC changes may occur in this study area. This paper aims to investigate and quantify how LULC has changed during the last two decades (from 2000 to 2018). It ascertains where significant changes have occurred and asks why specific local changes have taken place. The changes interpreted from the comparison between two editions of maps: the first map clip from a national digital map dated 2000; and the second from Landsat-8 captured in 2018.

2. Research materials and methods

2.1. Study site and input data

The study was conducted in the eastern part of East Java province and comprised two regencies and

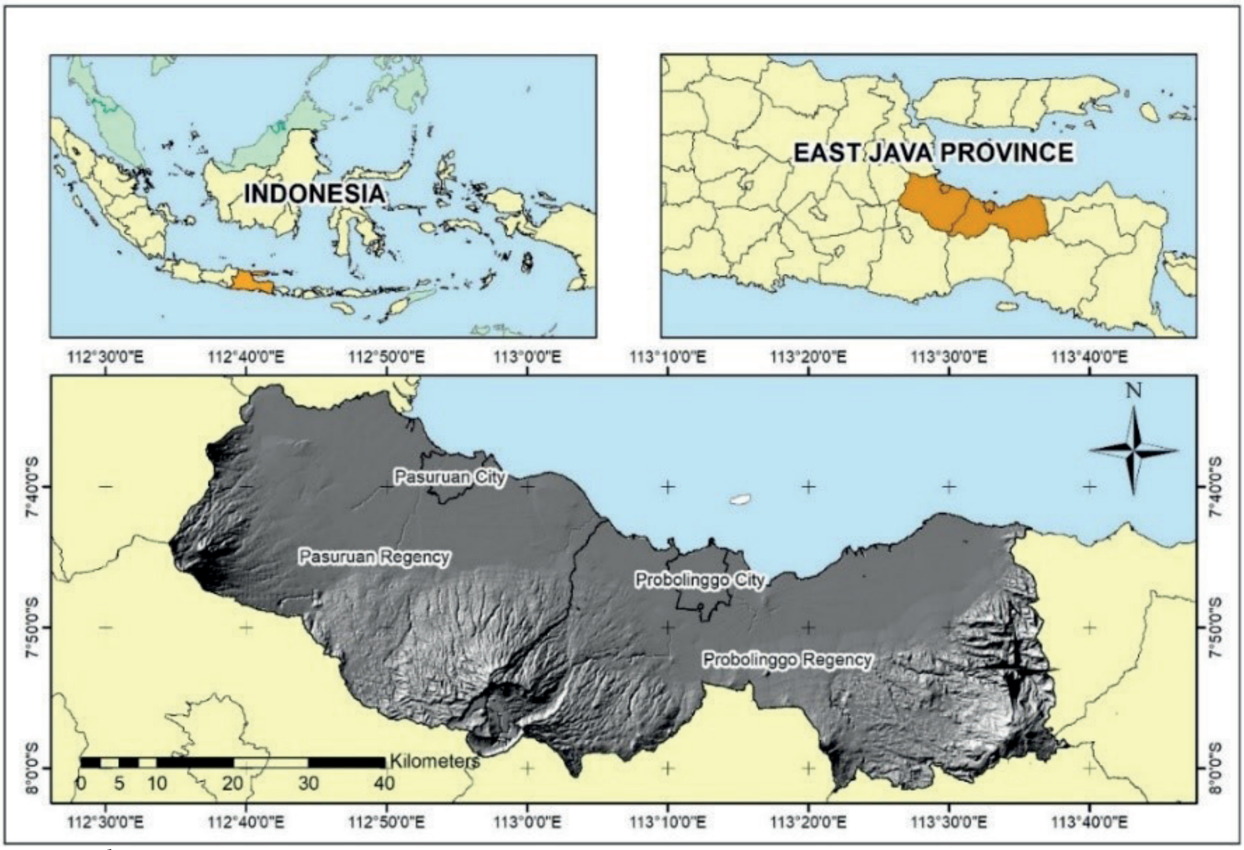

Fig. 1. Study site

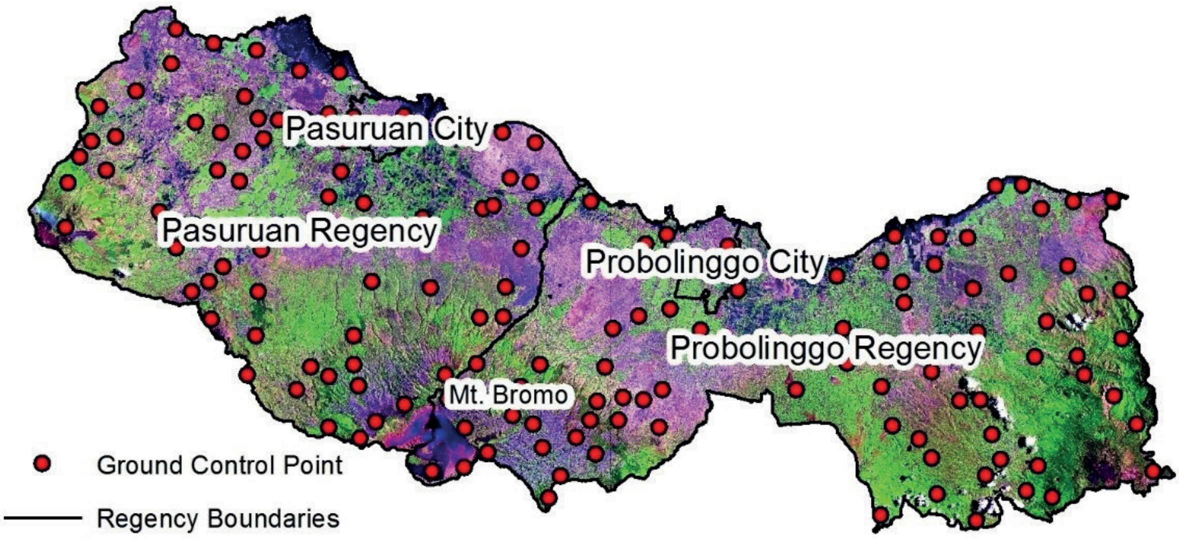

Fig. 2. Raw Landsat-8 imagery and collected training areas

two cities, namely Pasuruan and Probolinggo (Fig. 1) covering an area of 3320.3 km^2. Primary input data were Landsat-8 OLI/TIRS images of the study area, selected on the basis of the presence minimum cloud cover (Fig. 2). The images were downloaded from the USGS website (USGS, 2019).

Table 1 shows the metadata related to the raw images (Fig. 2) used in the study. The images were categorised as TIER 1 and the processing level L1TP. The images were corrected using training areas and a Digital Elevation Model (DEM) (USGS, 2019). In practice, it is challenging to obtain Landsat image-

Table 1. Summary of reasons for participating in street vending in Dire Dawa

Date Acquired	Path / Rows	Cloud Cover (%)	Land Cloud Cover (%)	Data Type	Orbit	Sun Elevation (˚)	Sun Azimuth (˚)	Angle (Nadir/ Off-Nadi r)
28/09/2018	118/65	0.82	0.97	L1TP/T1	Ascending	63.85	79.61	Nadir

ry of this region with little or no cloud cover. Between 2000 and 2018 there is no suitable Landsat imagery (with minimum cloud cover) available for the region, so the study only uses images from 2018.

The other map used was downloaded from the Indonesian Geospatial Agency (Badan Informasi Geospatial, or BIG) through its official web site (BIG, 2018). The national digital map layer known as RBI (Rupa Bumi Indonesia), produced in 2000, was employed to compare the classification results. The RBI map is based on the vector layer and usually used as official reference maps to describe topographic data, land use, land cover, hydrographic and other thematic features. This map covers all areas of the Indonesian archipelago. RBI maps are usually used as a thematic map at a scale of 1:25,000.

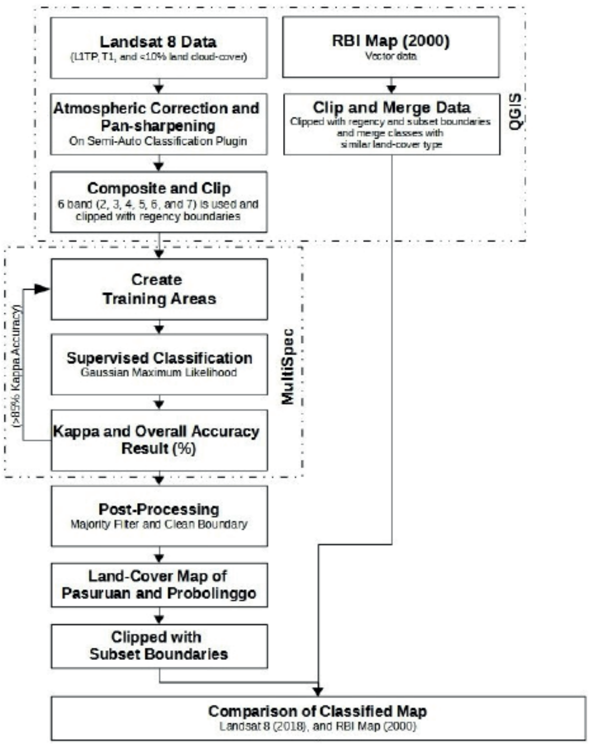

Fig. 3. Flowchart of image treatment

2.2. Method

Image treatment performed with MultiSpec Version 2018.08.30 (Landgrebe & Biehl, 2011), which is open-source software for image-processing tasks. The image treatment procedure consisted of pre-processing, classification and post-processing. The pre-processing consisted in atmospheric correction, pan-sharpening, image-composite and clip. The classification processes included a task for collecting the training areas, supervised classification, and accuracy assessment. The post-processing task used majority filter and clean boundary algorithms (Fig. 3).

Based on the results obtained, it can be argued that the specific proposals in terms of managing the efficiency of trading enterprises presuppose two directions of measures: the first being methodological in nature, and the second, practical in nature (Fig. 11).

The Semi-Automatic Classification Plugin (SCP) (Congedo, 2017), available in QGIS Version 3.8.1 (QGIS Development Team, 2019), was used to process atmospheric correction using the DOS (Dark Object Subtraction) algorithm. Six Landsat-8 bands, bands 2, 3, 4, 5, 6 and 7, were used to make a composite image. The images were then visualised using three bands (6, 5, and 2). The number of LULC classes was created following the national standard, or SNI 7645:2014 (BSN, 2014).

The classification process followed the standard image treatment of Multispec (Landgrebe & Biehl, 2011). In this case, we use Gaussian maximum likelihood algorithms to classify pixels. Supervised classification was processed with the aid of 151 GCPs or training areas (Table 2).

The areal extents on the two maps were compared to interpret the change. Other data were obtained from Google Earth and Global Forest

Table 2. Summary of training areas

Class	Number of TAs	Total surface (km^2)	Minimum (km^2)	Maximum (km^2)	Median (km^2)
Built-up Area	38	66.76	0.17	2.54	1.57
Paddy Field	30	104.98	0.57	3.55	2.17
Rural Area	39	86.18	0.15	2.58	1.93
Forest/Plantation	24	57.62	0.49	4.47	2.27
Water Body	15	2.33	0.02	1.02	0.15
Cloud Cover	5	0.92	0.04	0.57	0.18
Total	151	318.79			

Fig. 4. Location map of subsets A, B, C, D & E (in dotted red rectangles). Captured from Google Earth Engine (http://earthenginepartners.appspot.com/science-2013-global-forest) (Hansen et al., 2013)

Change 2000–18 (Hansen et al., 2013). Five subset areas (i.e. the areas in dotted red rectangles A, B, C, D & E in Fig. 4) were used to demonstrate and discuss the importance of LULC changes on the specific local area.

Figure.4 shows the five subset areas used to track changes, which represent the significant ones that have had a local effect on the region. Subset A represents LULC changes to Pasuruan Regency, with Bangil as its principal city. Subset B covers the administrative area of Pasuruan City, while subset C covers the corresponding area of Probolinggo City. Subset D comprises the specific area in the mountainous region of Bromo Crater, and finally, subset E covers the administrative area of Probolinggo Regency. The two yellow parallel lines that appear relatively close to each other show the national roads. Finally, Fig. 4 also shows primary humid-tropical forests (Turubanova et al., 2018). They are shown in irregular yellow forms, represented by points F, G & H, and are discussed in more detail later in the paper.

3. Results

3.1. LULC changes in the overall area

The classification of Landsat-8 produces overall and kappa accuracies of 91.49% and 88.43%, respectively. It is also noted that those individual accuracies (both reference and reliability) for each class show values of more than 85 % (Table 3).

Table 3. Accuracy assessment result.

Reference Data	Reference Accuracy (%)	Built-up	Paddy Field	Rural Area	Forest/ Plantation	Water Body	Cloud Cover	Grand Total
Built-up	93.33	42	0	3	0	0	0	45
Rural Area	85.06	3	8	74	2	0	0	87
Paddy Field	94.22	0	163	4	6	0	0	173
Water Body	100.00	0	0	0	0	12	0	12
Forest/Plantation	91.67	0	8	3	121	0	0	132
Cloud Cover	85.71	0	3	0	0	0	18	21
Grand Total		45	182	84	129	12	18	470
Reliability Accuracy (%)		93.33	89.56	88.10	93.80	100.00	100.00	

Note: (1) built-up area, (2) rural area, (3) paddy field, (4) water body, (5) forest-plantation, (6) cloud-cover

Table 4. Change in overall area

Class	RBI km²	LANDSAT km²	Change km²	%
1	302.21	424.75	122.5	40.55
2	1408.66	548.54	-860.1	-61.06
3	944.02	1614.9	670.9	71.08
4	82.41	37.89	-44.52	-54.02
5	582.98	676.41	93.43	16.03
6	-	17.69		
	3320.28	3320.28		

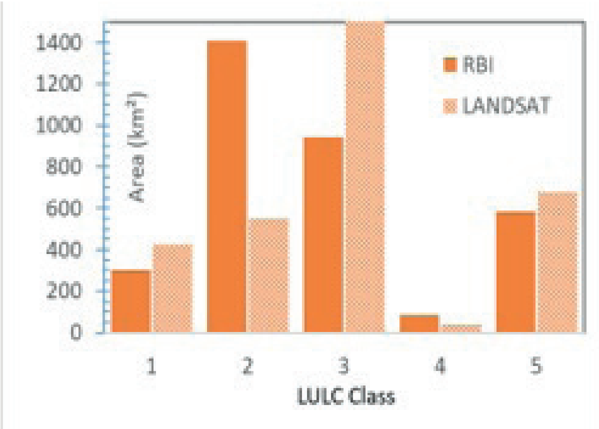

Fig. 5. LULC changes in Table 3

Then, Table 4 and Fig. 5 present the changes from the RBI (2000) to Landsat 8 (2018) in the overall study area. The built-up area increases significantly by 40.55%, or 122.54 km^2, during the 18 years. More specifically, the conversion of agricultural and rural areas into built-up areas has spread around the region, including in the cities of Pasuruan and Probolinggo, and the regencies of Pasuruan and Probolinggo. As the population has increased, the demand for land for housing and urban service areas has also increased. Therefore, agricultural land and rural areas have been converted to fulfil the demand. Figure 5 gives a general view of the LULC changes in the study area.

The rise in the population also increases the demand for food and, subsequently, agricultural land for paddy fields and other commodities. The construction of new irrigation infrastructure has led to the conversion of rural areas to paddy fields. An increasingly large part of the rural area in the region has been converted for agricultural use (paddy fields) and built-up areas. The Landsat imagery can separate the paddy fields, water, annual vegetation, rural areas and urban areas. As shown in the classified Landsat image, the paddy fields extend up to the hilly areas in the region. However, in the RBI map, they are only seen from the middle elevation down to the coastal area. In the Landsat map, both seasonal crops and paddy fields are classified as the same class; in this study, paddy fields represent both irrigated and non-irrigated ones.

Furthermore, in this study, the term "forest-plantation" is used to classify the annual or permanent vegetation, and to distinguish this type of coverage from other types (rural areas, seasonal crops, urban

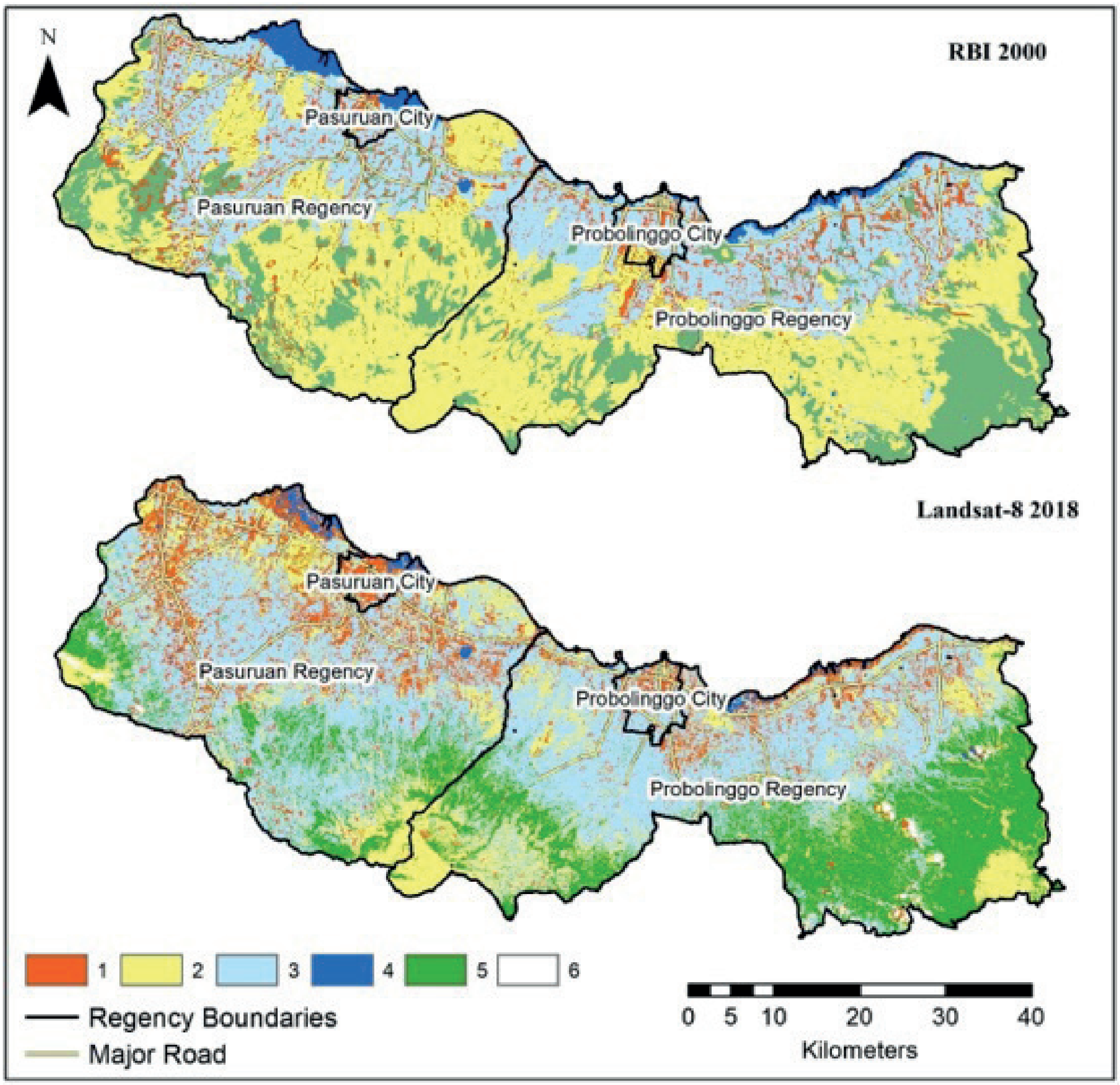

Fig. 6. LULC changes from RBI (2000) to Landsat (2018) Note: (1) built-up area, (2) rural area, (3) paddy field, (4) water body, (5) forest-plantation, (6) cloud-cover

areas and water). The RBI map classifies the area based on land use (i.e., irrigated paddy, non-irrigated paddy, rural areas, urban areas, forests, plantations and water bodies). The Landsat groups and classifies pixels based on digital numeric value and then visualises the land cover in more detail (i.e., seasonal crops, annual or permanent vegetation, rural areas, urban areas, bare soil and water bodies). In general, these slightly different methods of classification will result in blocked or more rigid zones in the RBI map and more fragmented and mixed zones in the Landsat map.

3.2. Example of urban sprawl in subset A

Subset A covers an area of 346.1 km^2. LULC changes within it were observed as increases in the built-up area of up to 65.50%. Paddy fields occupied 43.56 km^2, or 30.87% of the land, during 18 years. As a consequence, rural areas and forest-plantations decreased by 88.69% and 139.10% from 2000 to 2018, as shown in Table 5 and Fig. 7.

The LULC changes in this subset area (see Fig. 8) are characterised by urban sprawl (Łucka, 2018), which is probably caused by the multiple effects of the development of transportation infrastructure, sub-urbanisation, industrialisation and tourism.

Table 5. LULC Changes in subset area A

Class	RBI	LANDSAT	Change	
	km²	km²	km²	%
1	302.21	424.75	122.5	40.55
2	1408.66	548.54	-860.1	-61.06
3	944.02	1614.9	670.9	71.08
4	82.41	37.89	-44.52	-54.02
5	582.98	676.41	93.43	16.03
6	-	17.69		
	3320.28	3320.28		

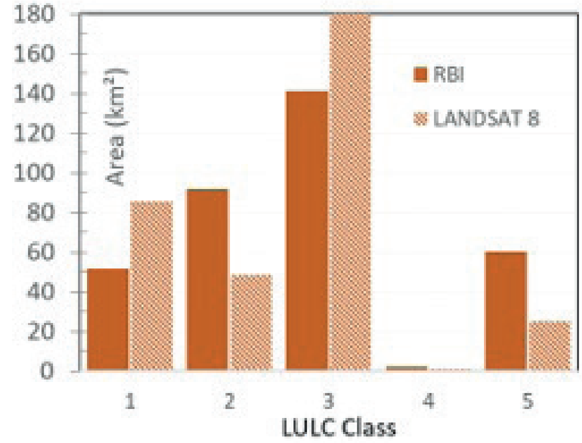

Fig. 7. LULC changes, subset A

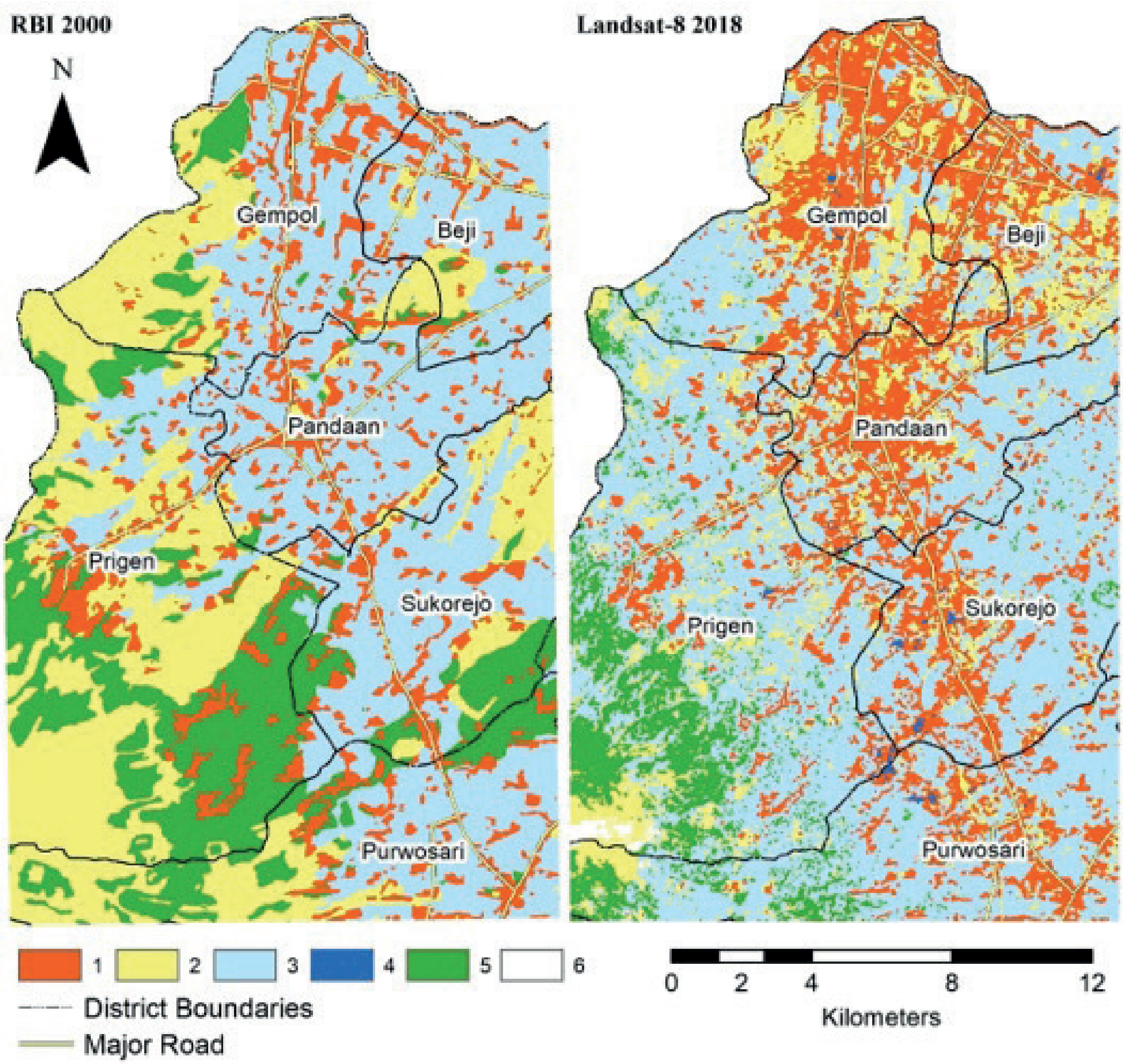

Fig. 8. LULC changes driven by transportation, sub-urbanisation, industrialisation and tourism Note: (1) built-up area, (2) rural area, (3) paddy field, (4) water body, (5) forest-plantation, (6) cloud-cover

First, sprawl as an effect of transportation development is observed in Gempol, Pandaan, and Sukorejo (Fig. 8). The big cities of Surabaya and Sidoarjo are located in the northern part of this subset, with Malang and Batu cities located in the south, Mojokerto and Jombang in the west, and Pasuruan and Probolinggo in the eastern part (Fig. 4). The north (Sidoarjo) and south (Malang) are linked by two motorways (national and highway) which pass through Gempol, Pandaan, Sukorejo, Purwosari and Lawang (Figs 4 and 8). Furthermore, two other motorways (national and highway) run east–west, connecting the western and eastern parts of the East Java region (Fig. 4). Therefore, this region is crossed by major arteries linking East Java, with most transportation activities concentrated in Gempol, Pandaan, Sukorejo and Purwosari (Fig. 8).

Landsat has therefore captured the urban sprawl influence driven by transportation development in the accumulation of built-up areas in Gempol, which stretch out to the north, south and east. This sprawl is linked to the development of major roads. Typically in Java, the distribution of urban areas follows and occurs around national routes. Generally, these cross-city centres continue to the suburban areas, then connect the rural areas with the cities. The Landsat images are capable of capturing this significant change from 2000 to 2018 compared to the RBI map (Fig. 8).

Sub-urbanisation (Leśniak, 2018) also accelerates the rapid sprawl of urban areas in the region. The subset area is considered to be supporting areas for the surrounding cities (i.e., Surabaya, Sidoarjo, Mojokerto, Pasuruan and Malang). Sub-urbanisation has contributeds to the development of urban sprawl, as has the development of industrial sites in Rembang and Beji (Fig. 8).

Finally, the sprawl in the south-westwards direction from Pandaan to Prigen has been caused by mass tourism sites developed in these mountainous areas. Many recreational or tourism sites (for example, Trawas, Pacet and Prigen) are located and accessed in this direction.

All these human activities during the 18 years accelerated the migration of people to the area and changed the LULC significantly. As the number of inhabitants increases, the demand for land for paddy fields also increases. As a result, more and more rural areas and forest-plantations are being converted to paddy fields and built-up areas, the latter being used to service residential areas, industrial sites, tourism sites and other public services areas.

Finally, the forest and plantation areas that were initially located within a certain perimeter (as shown on the RBI map) have now decreased and become more spread out. In the Landsat map, the forest-plantation areas are mixed with paddy fields and rural areas, the mixture appearing as green, yellow, red and light blue areas in the bottom left-hand corner. This means that natural forest-plantations have been partly converted to paddy fields, rural areas and built-up areas.

3.3. Urban sprawl in cities

The LULC changes in Pasuruan and Probolinggo cities are used in the study to illustrate the development of built-up areas needed for urban inhabitant services as a result of the increased population. Table 6 shows an increase in population numbers of 17% in Pasuruan and 22% in Probolinggo between 2000 and 2017. The increase in population demands

Table 6. Population changes from 2000 to 2017

City/Regency	Population					Change	
	2000	2004	2010	2014	2017	No. of people	%
Probolinggo City	191,670	202,251	217,679	226,777	233,123	41,453	22
Pasuruan City	168,630	178,766	186,805	193,329	197,696	29,066	17
Probolinggo Regency	1,005,000	1,045,071	1,099,011	1,132,690	1,155,214	150,214	15
Pasuruan Regency	1,366,950	1,436,699	1,516,492	1,569,507	1,605,307	238,357	17

(BPS Jawa Timur, 2002, 2010, 2015, 2017)

Table 7. LULC of the two cities

	RBI		LANDSAT 8		Change	
	Pas.	Prob.	Pas.	Prob.	Pas.	Prob.
Class	km²	km²	km²	km²	%	%
1	11.33	18.92	20.17	20.43	78.10	7.99
2	0.66	7.32	3.99	2.22	503.51	-69.73
3	18.22	28.11	10.31	32.03	-43.42	13.98
4	6.67	1.31	3.87	0.95	-41.94	-27.47
5	1.49	0.05	0.02	0.06	-98.50	35.38
6	-	-	0.00	0.01		
	38.36	55.7	38.36	55.70		

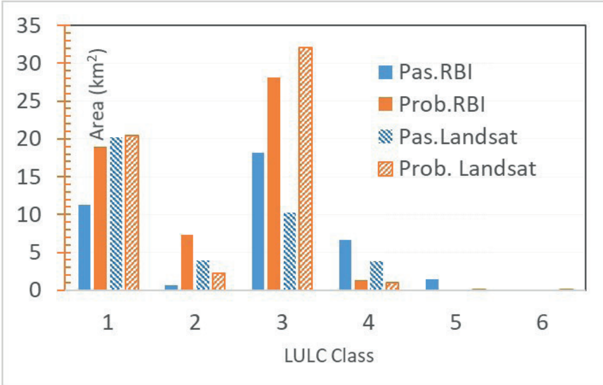

Fig. 9. LULC change in the city areas

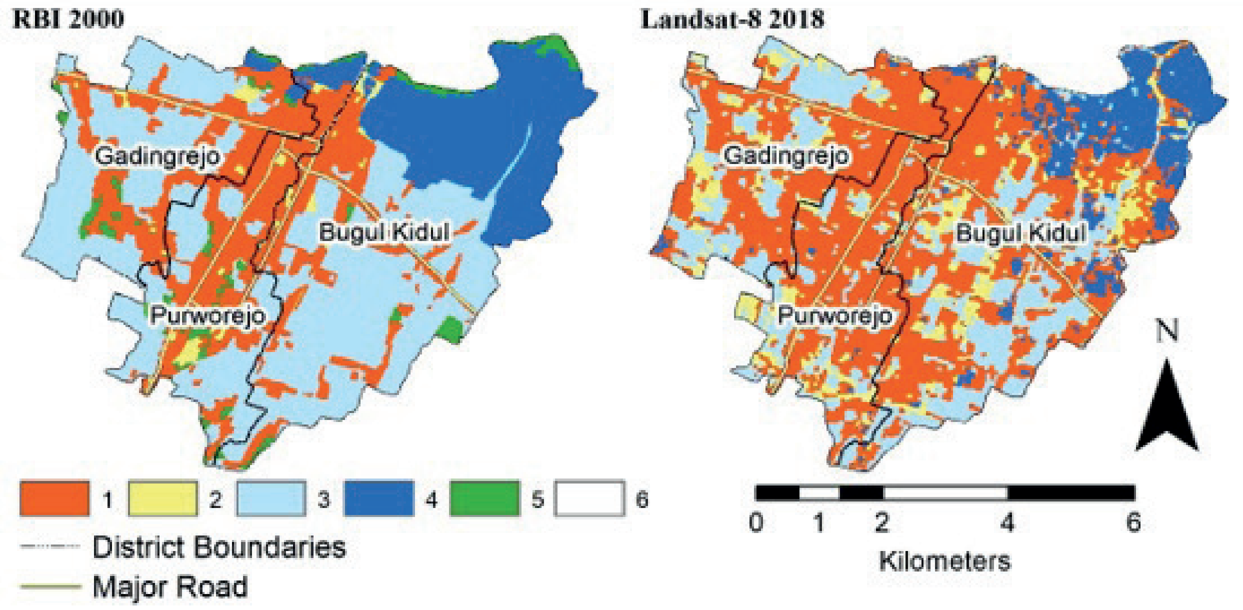

Fig. 10. Subset B: Pasuruan City

more built-up areas for residences, public facilities and city services.

Table 7 and Fig. 9 show the total area covered by Pasuruan City as 38.36 km^2, and that of Probolinggo city as 55.7 km^2. From 2000 to 2018, the built-up area increased by 78.1% (around 9.0 km^2) in Pasuruan City, and in Probolinggo by 7.99% (4.7 km^2). Therefore, the ratio of population to built-up area is denser in Probolinggo than in Pasuruan. Landsat visualised this phenomenon as an increase in built-up areas in the two cities.

Figure 10 shows the LULC changes in Pasuruan, while Fig. 11 shows those in Probolinggo. As seen in Fig. 10, the 78.1% increase in built-up areas in Pasuruan City was mainly caused by the need for space to service the increased population. Also, the development of infrastructure for fishery facilities in the upper right-hand zone is classified as a built-up area.

As a result, another land-use for paddy fields, annual vegetation (forest-plantation) and water bodies has decreased to compensate for the change. Moreover, land that was previously occupied by paddy fields or annual vegetation has been converted for residential use. The residual area of paddy fields or annual vegetation will become rural areas. Therefore, more areas have been converted from rural areas, water bodies and paddy fields into built-up areas.

The sprawling urban landscape also shows in Probolinggo City (Fig. 11). The built-up area is spreading out in all directions. The built-up areas

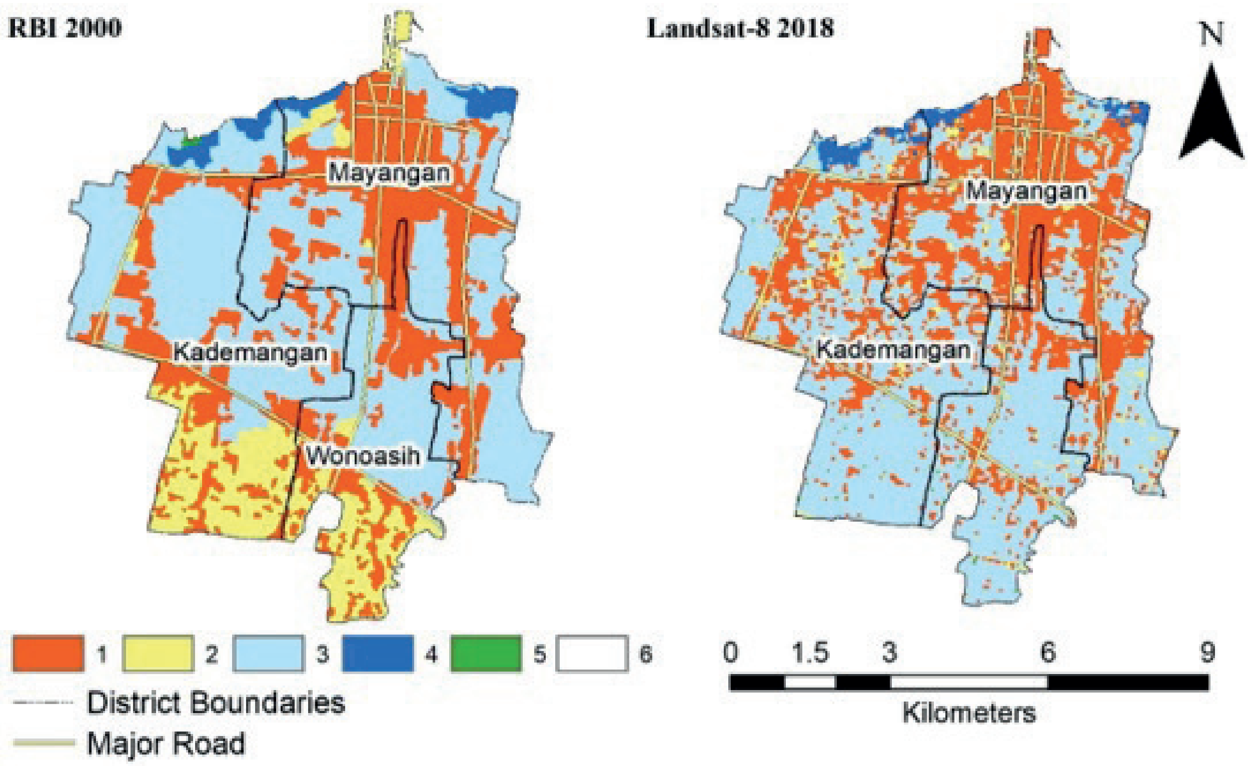

Fig. 11. Subset C: Probolinggo City

in the city initially follow the line of the major roads from west to east. The urban areas are located to the right- and left-hand side of the roads. These urban areas act as a buffer zone for the road and continue to penetrate the paddy field areas. Therefore, more and more paddy fields are being converted into built-up areas.

However, the extent of the paddy field area in Probolinggo city is relatively constant. The development of irrigation infrastructure has successfully converted rural areas into paddy fields in the south-eastern part of the city. The built-up areas then sprawled out and fragmented in all directions to form new suburban areas, as classified by Landsat. This sprawl was probably caused by the rapid development of real estate in the city to meet the demand for housing.

Green areas on the maps represent annual vegetation or trees, but not precisely in the form of forests or plantations. Landsat 8 can easily distinguish between paddy fields, rural areas, pavement, water bodies and annual vegetation. Annual vegetation in

Table 8. LULC changes in subset D

Class	RBI	LANDSAT 8	Change	
	km²	km²	km²	%
1	10.46	10.83	0.38	3.61
2	280.7	92.65	-188.10	-67.00
3	23.16	157.32	134.17	579.35
4	0.02	0.00	-0.02	-100.00
5	64.56	118.13	53.57	82.98
6	-	0.00		
	378.94	378.94		

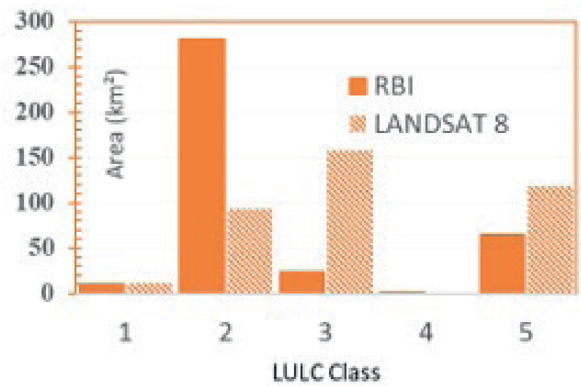

Fig. 12. LULC changes in subset D

this study represents trees with permanent coverage in all seasons (dry and wet). In rural areas, this may indicate the presence of forests or plantations. In contrast, in the city areas, it represents permanent trees in people's backyards, neighbourhood yards, gardens, city parks and green vegetation.

3.4. LULC changes driven by agriculture practices and tourism activities

Other LULC change examples were observed in the mountainous region of Bromo Crater and its surrounding areas. The total area of subset D is 378.94 km^2. On the RBI map, the region is composed of rural areas (74.1%, or 280.7 km^2), forest-plantations (17.05%, or 64.6 km^2), paddy fields, at 6.12% (23.16 km^2) and built-up areas, at 2.77% (10.46 km^2). The

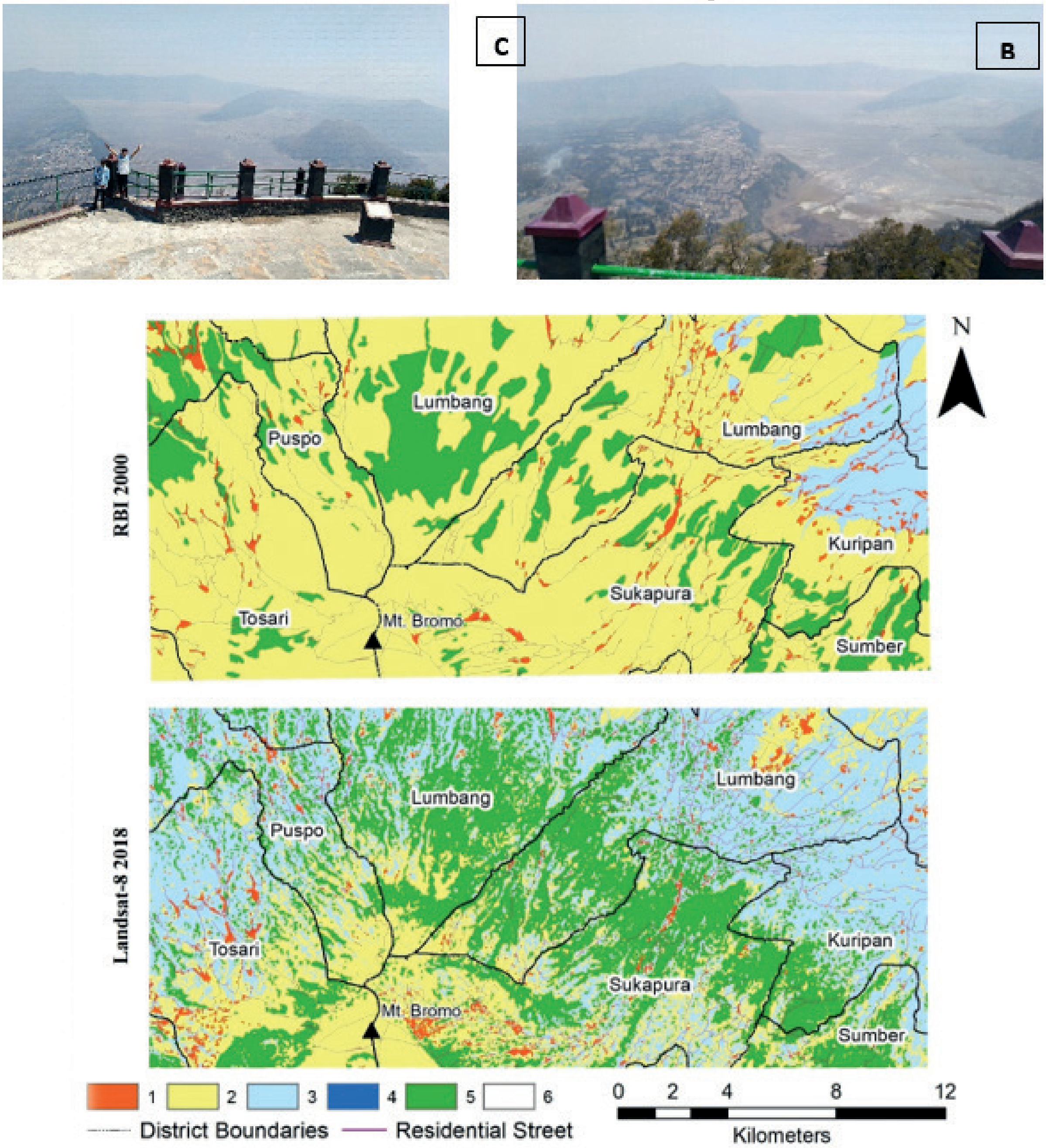

Fig. 13. LULC changes in subset D

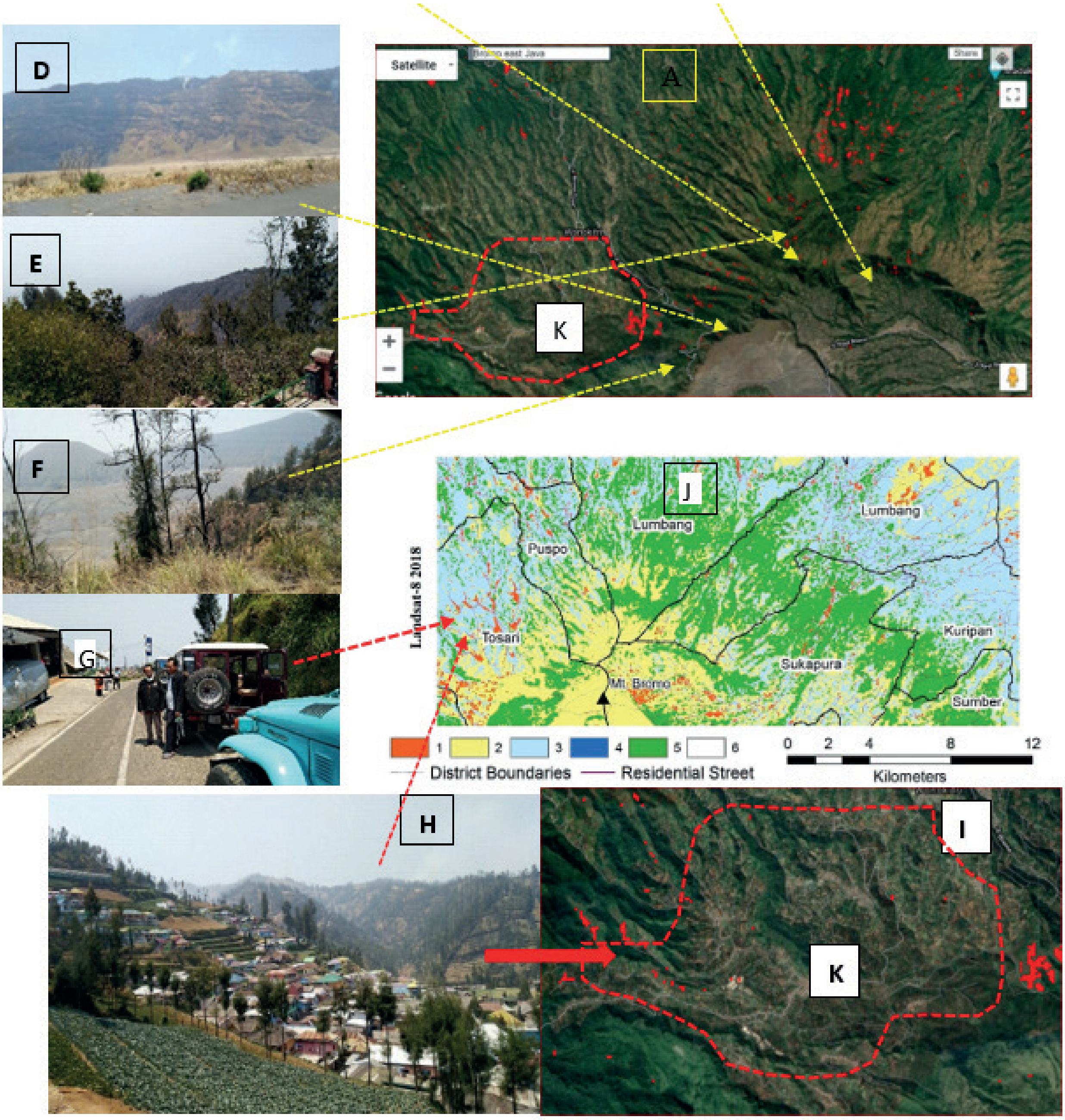

Fig. 14. LULC change caused by tourism and agricultural activities

changes observed included an increase in built-up areas to 3.61% during the 18 years. The land occupied by paddy- fields also increases by up to 579%. Conversely, in the same period, rural areas decreased by 67% or 188.1 km^2 from the total area of subset D (see Table 8 and Fig. 12).

The changes show a fragmented landscape sprawling irregularly around the subset areas, which consist of mixed land use (i.e., built-up areas, agriculture land and annual vegetation) to form a beautiful but fragile landscape (Fig. 13)

Subset D covers part of Bromo Crater and its surrounding villages (Fig. 14). Tourists from around the world visit the crater, which comprises the active crater of Bromo and the surrounding natural exotic tropical landscape. The region is located at an altitude of between 2,000 and 3,000 m above sea level. The government agency manages the site for natural conservation called Taman Nasional Bromo-Tengger-Semeru (TNBTS). The agency conserves the primary humid-tropical forest ecosystem and the supporting ecosystem around the region of Mount Bromo, Tengger highland and Mount Semeru. In the area, the primary tropical forest can still be found, as shown in Fig. 4G (Turubanova et al., 2018). Today, such humid tropical forest areas can only be found in and around the active craters in East Java, for example in Mount Bromo and Semeru (Fig. 4G), Mount Kelud (Fig. 4H) and Mount Wilis and Arjuna (Fig. 4F). However, most of these humid tropical forests areas are located out of the subset D areas, as shown in Fig. 4..

Furthermore, Fig. 14 illustrates the actual field conditions of subset D. Firstly, a field survey was taken on October 22 2019. Then, Fig. 14J shows the areas classified by Landsat. Also, Fig. 14A shows the Google Earth terrain view downloaded on April 15 2020. The sporadic red points show the locations of forest losses, as reported by Hansen et al. (2013), which are overlaid on top of the Google Earth image layer.

Secondly, the photos in Figs 14B and 14C show the mixed landscape, composed of agricultural fields, housing and rural areas. This flat area is located closely surrounding the primary sand-desert of the active crater. The flat-rural area was formed from the previous Bromo eruption. Local people now occupy this area for their activities. The area is part of Probilonggo regency. The two photos were taken from the border of Pasuruan Regency at an altitude of ±2,800 m. The four regencies, i.e., Malang, Pasuruan, Probolinggo and Lumajang, share their border on the radius of Bromo; therefore, each Regency has access to these international tourist sites.

Moreover, Figs 14D and 14E show the location of burnt areas at the time of the visit (October 22 2019). Figure. 14D shows the area on the western side of the crater, while Fig. 14E shows the areas in a region of hilly steppes in subset D. In 2019, all areas in East Java experienced dry weather, which led to forest fires, mostly around the hilly areas of the province (Cendana, 2019; Detik.com, 2019; Jatim Pos, 2019; Walhi, 2019), one of which occurred at Bromo (Figs 14D & 14E). The fires were mostly caused by human activities (Cendana, 2019; Detik.com, 2019).

In extreme dry seasons, after fires have taken place, people occupy burnt areas and plant seasonal crops. As burning activities are repeated annually for prolonged periods, this results in the loss of forest areas in the region. The phenomenon, as described in the previous paragraph is shown by Hansen et al. (2013) as forest loss (as shown in Figs 14A and 14I).

The built-up areas in this mixed landscape (Fig. 14H) represent the residential cluster used to serve as local housing, villas or hotels to serve tourism, and other villages facilities. Figure 14G shows the residential road and other public facilities that were serving the village and tourism. The mountainous agricultural area, as shown in Fig. 14H, is used to plant seasonal commodities, including fruit and vegetables (such as carrots, cabbages and potatoes).

More and more natural landscapes are being converted into agricultural fields (Fig. 14I). The irregular area marked with the label K shows an example of land located between Tosari and Wonokitri that has been converted from natural to agricultural areas. This conversion is found in most of the hilly areas of this region, both in Pasuruan and Probolinggo Regencies. In the Landsat image (Fig. 14J), this mixed landscape may be classified as paddy fields or rural areas, and sprawls irregularly around the subset area.

However, the beautiful landscape, as seen in Fig. 14H, is fragile in the face of environment-related disaster. In the rainy season, this dominant landscape located on the stepped terrain will propagate more runoff. As a consequence, landslides and floods frequently occur in the locations that have previously been burned. This phenomenon was evident at the end of 2019 and the beginning of 2020; in October 2019, such areas caused significant landslides and flash flooding in the hilly areas of East Java (Berita, 2020).

3.5. LULC changes driven by industrial development and sub-urbanisation

Subset E (Fig. 15) represents the flat area of Probolinggo Regency, which is located from the west to the east of the regency, parallel to the coastline. The terrain elevation range from 0 and 200 m above

Table 9. LULC changes in subset E

Class	RBI	LANDSAT 8	Change	
	km²	km²	km²	%
1	27.11	38.32	11.21	41.36
3	4.23	21.06	16.83	397.38
2	107.87	103.36	-4.51	-4.18
5	16.05	6.83	-9.22	-57.45
4	15.12	0.75	-14.37	-95.03
6	-	0.06		
	170.39	170.39		

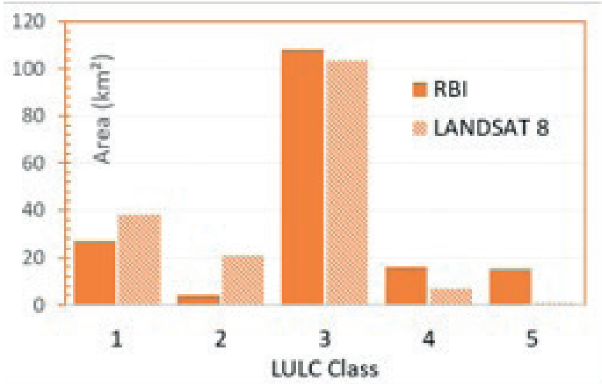

Fig. 14. LULC changes in subset E

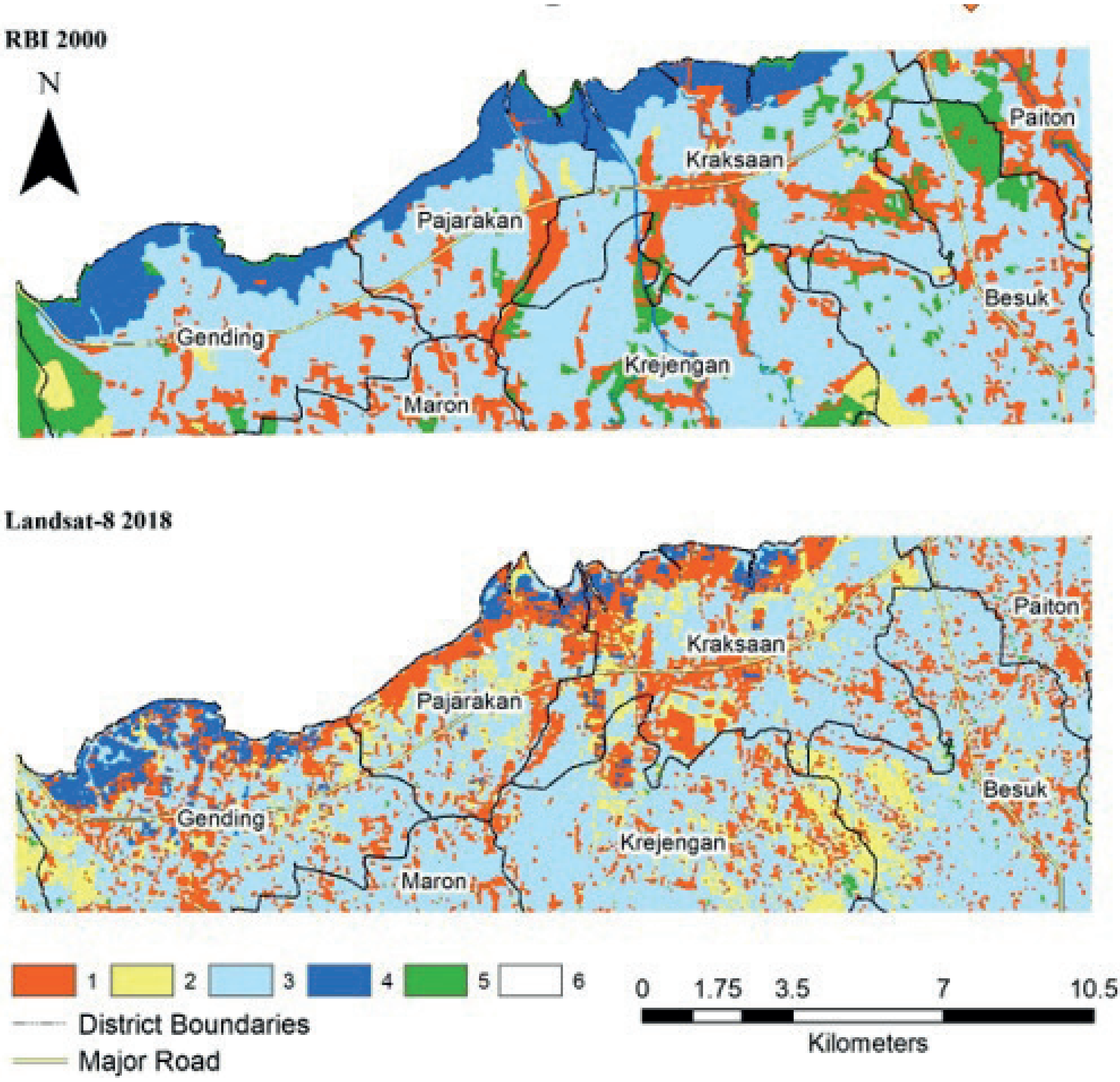

Fig. 15. Subset E: changes driven by industrial services and sub-urbanisation. Note: (1) built-up area, (2) rural area, (3) paddy field, (4) water body, (5) forest-plantation, (6) cloud-cover

sea-level. The LULC changes in this sub-area are driven by industrialisation and sub-urbanisation.

Table 8 and Fig. 16 show that from 2000 to 2018 the built-up areas increased by 41.36% (from 27.1 km^2 to 38.32 km^2), while rural areas increased by 16.83 km^2 (397%). This increase is compensated by the decrease in paddy fields (4.18%), forest-plantations (57.45%) and water bodies (95.03 %).

In Paiton, a massive power station known as the Paiton Power Station (PPS) was installed for electrical energy production. PPS produces energy equivalent to 800 Megawatts (MW). The power station started in approximately 1995. The installation supplies electricity to the areas of Java and Bali Island, covering the demand of at least five provincial areas, namely West Java, Central Java, Special Authority of Yogyakarta, East Java and Bali (PJB, 2020). The industry and its derivates have made a significant contribution to the development of built-up areas in the region (Fig. 15).

Landsat shows the related change very clearly. The wide-block area of irrigated paddy fields on the RBI map (Fig. 15) has been converted into mixed and fragmented landscapes, with an increasing number of paddy fields converted into built-up and rural areas.

The development of the energy industry has resulted in young and more educated local people from Probolinggo and other cities moving to this eastern part area of the regency to work in the industry itself or supporting ones. The centre of Probolinggo Regency is located in Kraksan, and more built-up areas have appeared around it. Finally, this sub-urbanisation also contributes to the urban sprawl in this subset area, in all directions and irregularly.

4. Conclusions

The LULC changes in the specific local area of East Java have been analysed. During the two decades (from 2000 to 2018), LULC has changed significantly in the region. A more detailed view using five subset areas shows the primary driving forces of LULC changes: the development in transportation infrastructure; sub-urbanisation; the development of and changes in agricultural practices; the development of industrial sites; and tourism activities. The changes tend to manifest themselves as urban sprawl, which is typically distributed irregularly, probably as a result of development planning. The increases in regional development and population that have occurred in the region during the last two decade have changed LULC significantly. The changes are seen in the increase in urban built-up areas of 40.55%, in paddy fields of 71%, and forests and plantations of 16.03%. Conversely, the development has also significantly reduced rural areas by 61.06% and water bodies by 54.02%. The study has also shown the capability of Landsat imagery to track the significant LULC changes in the region.

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