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ABSTRACT

This paper conveys the findings of a study of the development of Semarang Metropolitan Region (SMR) over two decades. The developments seen were urbanisation and its impact on Surface Urban Heat Islands (SUHI). This research used remote sensing data satellite imagery of Landsat 5 T M and Landsat 8 OLI to see land cover change from 1998 to 2018. Furthermore, to predict the land cover change, this research used a Stochastic Cellular Automata-Markov Chain (SCA-MC) algorithm. Measurements of the LST and SUHI used Landsat products with Thermal Infra-Red Sensors (TIRS) Band 10 (2018) and TIRS Band 6 (1998). The classification of the results from 1998 to 2018 indicates a widespread change in the built-up area of about 74.62%, revealing urban expansion in the SMR. Moreover, there has been a decline in the vegetation canopy of 36.14%, resulting in an increase in average surface temperature of 2–5 °C. Areas with increased surface temperatures reached more than 30 °C, which is an increase of 245.57 km^2 from 1998 to 2018. Furthermore, the SCA-MC prediction suggests the scenario to mitigate the SUHI through Spatial planning instruments. Thus, control of development is essential to the sustainability of the SMR, through land use planning scenarios.

1. Introduction

The New Urban Agenda highlights the problem of sustainable urban growth, as currently more than 50% of the world's population lives in urban areas, a figure which will grow to 66% by 2050, mostly in Asia and Africa (WHO, 2014). Increasing urban population concentration is a serious problem for all cities in the world because it has a significant impact on increasing surface temperature and linearly influences of urban growth (Mathew, Khandelwal, & Kaul, 2018). Increasing temperatures have a very large impact on ecosystems at local, regional and global Scales that have an impact on the urban environment. The relationship between widespread urban areas and surface temperatures significantly affect temperature differences between urban and suburban, peri-urban, or rural areas. It is known as Surface Urban Heat Island (SUHI) phenomenon. The first case of SUHI that Howard had studied in 1818 (Gartland, 2008; Howard, 2007; Mirzaei & Haghighat, 2010) revealed the fact that urban growth is in line with the emergence of the SUHI, and their results have stimulated the development of similar research in several countries to assess their impact.

Several recent studies have indicated that climate change, SUHI, and urban growth are closely related to urban size (Handayani et al., 2017; Huang & Ye, 2015; Oke, 1973; Pal & Ziaul, 2017; Shwetha & Kumar, 2016). These studies are interesting to examine because the size of an urban area is very dynamic and fast growing, and so SUHI is dynamic. Some urban areas are growing rapidly, resulting in urban growth and land use land cover change (LULCC), it indeed has accelerated the rise in surface temperatures. As stated by the current research that Land Use/Land Cover Change (LULCC) are always synonymous with the emergence of uncontrolled environmental and development issues (Buchori & Sugiri, 2016; Du, 2016; Sugiri, Buchori, & Soetomo, 2011). Hence, explicitly, the increase in SUHI is strongly influenced by the city size and the type of land cover (Bokaie, Kheirkhah, Daneshkar, & Hosseini, 2016; Huang & Ye, 2015). For instance, Ward, Lauf, Kleinschmit, and Endlicher, (2016) has proven that land use patterns and urban forms affect the SUHI in Europe. Other cases, Wang, Huang, Fu, Atkinson, and Zhang, 2016; Wang, Ma, Ding, & Liang, 2016) in China, Adeyeri, Akinsanola, and Ishola, (2017) in Nigeria, and Tran et al. (2017) in Vietnam who have proven the investigation that LULCC affects the SUHI. More details, SUHI also causes an increase in pollutant concentrations in areas that affect local meteorology. Investigation results from Mirzaei and Haghighat (2010) mentioning the fact that SUHI can cause health problems, the

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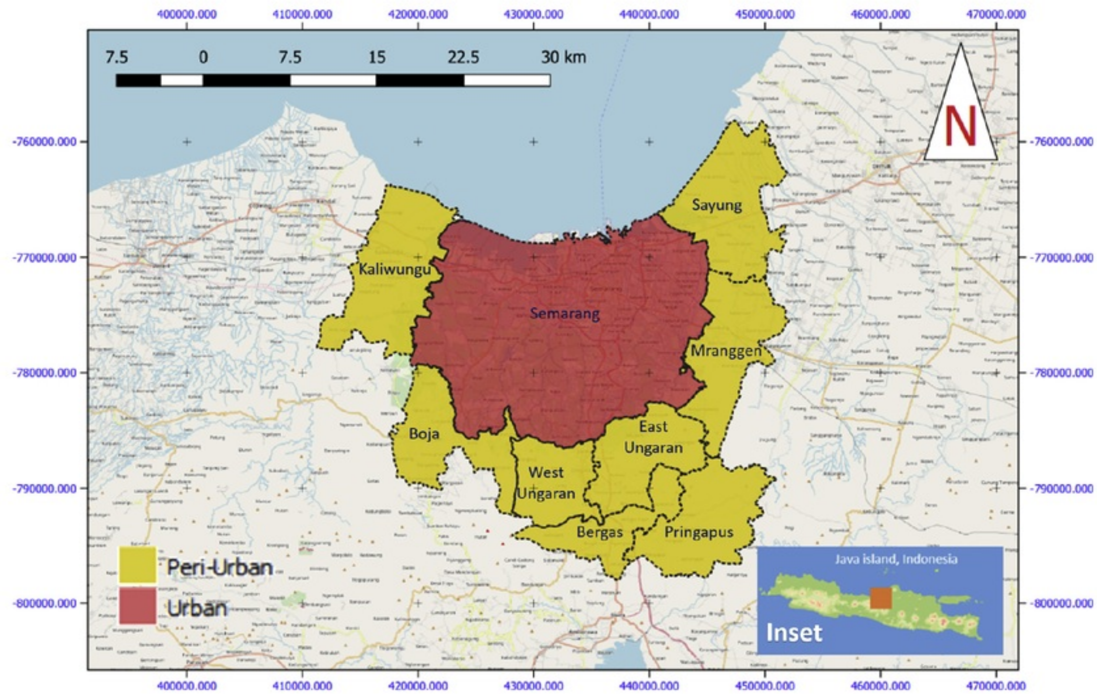

Fig. 1. Map of Semarang Metropolitan Region.

emergence of diseases, and cause death in large numbers every year. It needs special attention because of the fact that the SUHI incident starts from population growth, urban growth, and LULCC.

Rapidly growing populations are projected to accelerate urban growth and show the effects of SUHI in Asian cities, thus affecting the quality of life of urban populations. In the last decade, urban growth and its impact on SUHI have been assessed in several rapid growing cities in Asia (Kotharkar & Bagade, 2018; Li et al., 2011; Mathew, Khandelwal, & Kaul, 2016; Qaid, Bin Lamit, Ossen, & Raja Shahminan, 2016; Sannigrahi, Bhatt, Rahmat, & Uniyal, 2017), but research on this topic in Indonesia is lack. Furthermore, urbanisation in Indonesia not only extends urban size but also changes the structure of land use and population activity because Indonesia has a unique characteristic of urbanisation (Setyono, Yunus, & Giyarsih, 2016). Indonesia is a fast-growing country and has experienced significant increases in urban areas in several regions that affect the quality of life in urban areas, especially in the National Strategic Region of Indonesia, such as the Semarang Metropolitan Region (SMR). Both local and global environmental issues in the SMR should be responded quickly. Since being elected in the list of 100 Resilience Cities in 2014, the SMR has an important role in maintaining urban resilience to global issues, especially climate change. It is now also growing as a metropolitan area that strongly affects the surrounding area (Buchori & Sugiri, 2016; Buchori, Pramitasari et al., 2018; Buchori, Sugiri et al., 2018; Sugiri et al., 2011) and has had a powerful influence on its peri-urban area (Giyarsih & Marfai, 2017) especially on urban climate change.

The SMR is experiencing rapid urbanisation and LULCC. The presence of industrial estates in the SMR, particularly in the northern, eastern and southern sectors, has a significant impact on land use shifts and the growth of built-up areas. This growth in the SMR is 8.2% per year, and there has been population growth of 1.4% per year since 2000 (Sejati, Buchori, & Rudiarto, 2018). Efforts to control urban expansion have been undertaken, including analysing patterns of urban land conversion and existing urban expansion conditions in the SMR (Buchori & Sugiri, 2016; Sejati et al., 2018; Sugiri et al., 2011).

However, in the long term, spatial monitoring and prediction of land cover changes and their impact on SUHI have not been implemented. Furthermore, other phenomena of climate change such as *rob* (the Indonesian local term for tidal flood) (Buchori, Sugiri et al., 2018; Marfai & King, 2008; Sejati & Buchori, 2010), alongside the burden of industrial development on the northern coast, causing land subsidence (Marfai & King, 2007), also have an impact on people's survival in the SMR.

Given that the impact is multi-scale and very serious, the SUHI phenomenon has received considerable attention from researchers in various environmental fields, such as climatology, ecosystem ecology, urban planning, and sustainable development (Bokaie et al., 2016; Chen, Zhao, Li, & Yin, 2006; Pal & Ziaul, 2017; Rudiarto, Handayani, & Setyono, 2018; Shwetha & Kumar, 2016). Research on SUHI has observed and compared urban and rural temperatures with instruments based on remote sensing technology (Chen et al., 2006; El-zeiny & Effat, 2017; Wang, Huang et al., 2016; Wang, Ma et al., 2016). Satellite imagery-based observations are capable of measuring SUHI and urban land cover changes and can illustrate variations in the distribution of surface temperatures in larger areas. In addition, this paper also presents the typology of land use change and predictions made with Stochastic Cellular Automata – Markov Chain (SCA-MC) models, so it can predict land use change and the impact of changes on SUHI (Arsanjani, Helbich, Kainz, & Boloorani, 2012; García, Santé, Boullón, & Crecente, 2012; Guan et al., 2011; Moghadam & Helbich, 2013). These predictions provide input to land use planning scenarios in the direction of sustainable development in Indonesia. In this way, this study aims to examine patterns of LULCC in the last two decades in the SMR and its potential impact on SUHI. Furthermore, this study also predicts LULCC scenarios as input of SUHI mitigation in SMR.

Table 1
Landsat Product Information for LST Analysis.

No	Year	Type	Date_acquired	Band	RMB	RAB	K1	K2
1	2018	Landsat 8 OLI	2018-05-05	10	0.00033420	0.1	774.8853	1,321.0789
2	1998	Landsat 5 T M	1998-08-02	6	0.055375	1.18243	607.76	1,260.56

2. Study area and methods

2.1. Study area

The study area is the Semarang Metropolitan Region (SMR) (latitude 6° 58 °S, longitude 110° 25 °E). Administratively, the region in Indonesia is divided into cities and regency. Most urban areas in the city and peri-urban areas are in adjacent regencies. SMR consists of Semarang City (urban area) and three regencies (peri-urban area) that have been affected by urban growth; Kendal (District Kaliwungu and Boja), Demak (District Sayung and Mranggen), and Semarang Regency (District West Ungaran, East Ungaran, Pringapus, and Bergas) (see Fig. 1) (Rudiarto, Handayani, Pigawati, & Pangi, 2013; Sejati et al., 2018).

2.2. Landsat product for spatial image analysis

This study used Landsat satellite imagery from 1998 (Landsat 5 T M) and 2018 (Landsat 8 OLI). These years became the reference for spatio-temporal change over 20 years. Product information (Table 1) provides an overview of the year of acquisition and some information on constants to see changes in the surface temperature of the Earth. Furthermore, to see the link to land cover, the band combination information needs to be presented (Table 2). This provides information on how to view urban and non-urban areas as well as some other uses seen from land cover (Fig. 2).

2.3. Land use and land cover analysis (LULCC)

2.3.1. Gaussian mixture methods

According to the field of land cover classifications, this research used the supervised classification technique with a Gaussian Mixture Methods approach. Sample trainings used were 50 samples representing each land cover in detail. This method is a part of the Machine Learning Algorithm, that used to learn the image character of the colour sample from the sample training with QGIS and dzetsaka tools (Karasiak, 2017).

2.3.2. Markov chain transition and stochastic cellular automata

A Markov Chain is a transitional rule change from one type of pixel to another pixel value (Helbich, Darvishi Boloorani, Jokar Arsanjani, & Kainz, 2012; Moghadam & Helbich, 2013). In image analysis using remote sensing data, the change in pixel value indicates mostly the change of land cover (Moghadam & Helbich, 2013). Changes were seen from pixel values converted into square km, so that the area of change can be calculated; thus, this transition matrix becomes the basis of the cellular automata model (Guan et al., 2011; Mitsova, Shuster, & Wang, 2011; Yang, Zheng, & Lv, 2012). Generally, the winning cells represent the number of cells with one particular dominant land function. This is like a biological metaphorical process in which raster data containing cells can change cell value if there is a dominant agent, such as a black (urban) change in a white (non-urban) area at a given time (t) in a change scenario (Liu, 2009).

Table 2
Landsat Composite Band for Urban Detection.

Type	Band Combination	Detection
Landsat 8 OLI (2018)	R = 7; G = 6; B = 4	Urban and Land Cover
Landsat 5 T M (1998)	R = 5; G = 4; B = 3	Urban area (Special-color)

The modelling scenario used two periods of 20 years from 1998 to 2018 and 2018–2038. The results from the 20 years before and after 2018 can be measured and directed. This study used the year 1998 as a reference because in that year there was an economic crisis in Indonesia. This year was a turning point for the economies of states in Asia, especially Indonesia, because it had to survive the monetary crisis of 1998. By using the period 1998–2018, the picture of urban growth will help evaluate the impact of SUHI. In addition, the images of urban growth as an economic indicator can be evaluated by using environmental sustainability indicators, which in this case is an increase in the surface temperature of the land. SCA-MC-model validation (2038) used Kappa Coefficient (Wang, Hasbani, Wang, & Marceau, 2011). Kappa statistic reflects the difference between actual agreement and the agreement expected by chance. For example, Kappa of 0.85 means there is 85% better agreement. The formula for kappa was illustrated in Eq. (1)

$$Kappa = (P0 - Pe)/(1 - Pe) \quad (1)$$

where P0 is the estimated observation accuracy and Pe is the expected observation accuracy. The Kappa index was devided into five categories with detail information is in the Table 3.

2.4. Surface urban heat island analysis

2.4.1. Conversion of digital number to TOA radiance

Conversion of DN to TOA Radiance was used in accordance with the calculation formula on the Landsat product of USGS. The calculation formula used product information obtained from a metafile from Landsat of each TIRS band, namely band 10 for Landsat OLI and band 6 for Landsat 5 T M. The calculation is shown by Eq. (2).

$$L\lambda = MLQcal + AL \quad (2)$$

where: Lλ is TOA spectral radiance (Watts/(m2 * srad * μm)), ML is a Band-specific multiplicative reSCA-MCling factor from the metadata (RADIANCE_MULT_BAND (**RMB**)_x, where x is the band number), AL is a band-specific additive reSCA-MCling factor from the metadata (RADIANCE_ADD_BAND_(**RAB**)x, where x is the band number), and Qcal is Quantised and calibrated standard product pixel values (DN) (see Table 1).

2.4.2. Land surface temperature

To see the spatial distribution of surface temperature, an LST calculation was performed which also used TIRS band data and the Atmosphere Correction calculation result. TIRS band data can be converted from spectral radiance to the top of the atmosphere by the thermal constants provided in the metadata file, as in Eq. (3).

$$T = \frac{K_2}{\ln\left(\frac{K_1}{L\lambda}\right) + 1} \quad (3)$$

Where: T is the top of the atmosphere brightness temperature (K), Lλ is TOA spectral radiance (Watts/(m2 * srad * μm)), K1 is band-specific thermal conversion constant from the metadata (K1_CONSTANT_BAND_x, where x is the thermal band number), and K2 is band-specific thermal conversion constant from the metadata (K2_CONSTANT_BAND_x, where x is the thermal band number (see Table 1)).

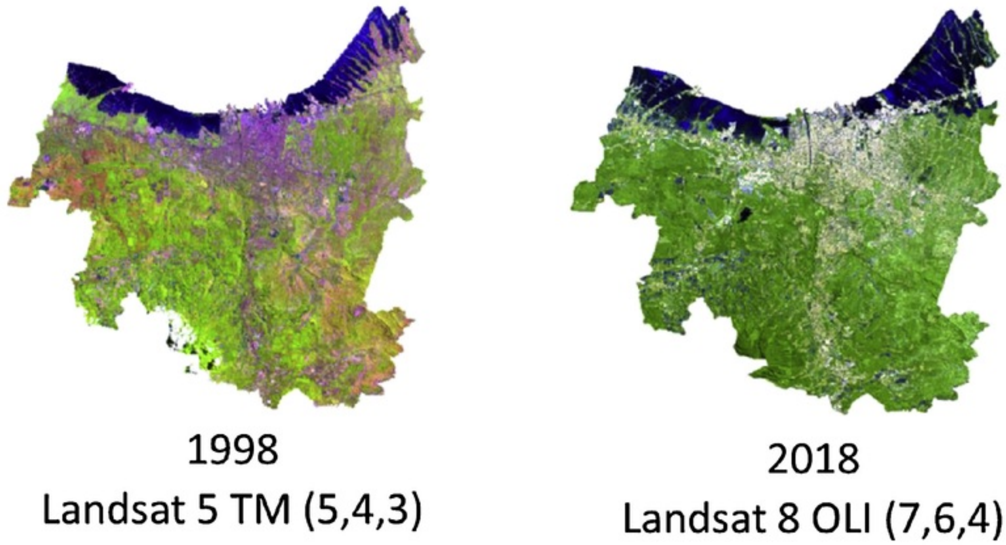

Fig. 2. Landsat Band Combination.

Table 3
Kappa Index for Model Accuracy Assessment.

κ	Strength of Agreement
< 0.2	Poor
0.21–0.4	Fair
0.41–0.6	Moderate
0.61–0.8	Good
0.81–1.00	Very Good

3. Results

3.1. LULCC from 1998 to 2018

The area shift from non-built up to build-up area in urban and peri urban area was based on the satellite image classifications in 1998 and 2018, as shown in Fig. 3. In 1998, the built-up area centred on the Semarang City (urban area) and the main line of transportation. However, its presence in the centre of Semarang City looked more prominent than in the peri-urban (Fig. 3 (a)). In contrast, built-up areas in 2018 are more diffuse and there has been some leapfrog or urban sprawl (Fig. 3 (b)). In 2018, the analysis also shows that urban expansion has spread to the north, east and south peri-urban SMR, such as Sayung and Mranggen sub-districts, West Ungaran and East Ungaran. Only few can be seen separately, in the Kaliwungu (Kendal Regency) section. This shows that in the period 1998–2018, urban expansion has dominated the coastal areas north and east of Semarang City.

However, there was a different situation on the southern side. The existence of urban sprawl was due to the educational centres in the south, such as the existence of the Diponegoro University, Semarang State Polytechnic, and the emergence of new commercial centres in South SMR (Fig. 3(b)). Furthermore, new industrial centres have also developed in the southern SMR, such as in East Ungaran, Bergas, and the Pringapus corridors, where the industry also sprawls. Peri-urban dominates the growth of Buit-up area in 2018, which is up by 115.78% compared to 1998. Meanwhile, the growth of built-up in Urban areas in 2018 is only 36.57% compared to 1998 (Fig. 4 and Table 4). This shows that the growth of development in peri-urban areas runs more rapidly than in urban areas. Urban expansion had also spread to the west part of the SMR in the Kendal Regency. The emergence of industrial areas such as the Special Industrial Zone in Kaliwungu was a trigger for growth in rural-urban SMR transition areas. In the same period, the development of the areas built in the southwest only grew along the main corridors of the Semarang-Boja and Semarang-Kaliwungu lines.

Table 4 depicts the change in land cover area from 1998 to 2018. The total built-up area in SMR in 1998 was 232.36 km^2, with built-up growth in Semarang City dominating SMR. In 2018, the dominance has faded, and growth in the city centre is stagnant, but has started to expand into the peri-urban area, especially to the north, east and south. The total built-up area in 2018 was recorded at 405.74 km^2. This shows the change of land from non-built-up to built-up in two decades is 173.38 km^2 or 74.62%. In contrast, the vegetation canopy and cropland has decreased significantly (Table 4). The vegetation canopy in 1998 was recorded as 250.44 km^2, but this had dropped to 159.92 km^2 in 2018. This shows that vegetation canopy fell 90.52 $km^{2,}$ or by 36.14%. The same condition also occurred for cropland, as in 1998 this covered 336.95 km^2 and in 2018 it had fallen to 302.23 km^2. This shows a decrease in cropland of 34.72 km^2 or 10.3%. Decreasing the area of vegetation canopy and cropland indicates the conversion of land to another form. It is possible that, in the past two decades, land cover changes have shifted to the built-up area, seeing significant change trends. The Typology of land use change as shown in Fig. 5 and Table 5.

Fig. 4 and Table 4 also shows urban growth in the SMR and that not all land has been converted into industries or settlements (Built-up). However, a built-up area of nearly 50% still needs to receive serious attention to maintain environmental sustainability in the SMR. On the other hand, In total, 40% of metropolitan land is still crop land (33%) and vegetation canopy (17%). This means that agricultural and forest activities, especially the protected area, are maintaining pace with urban growth and expansion. One further interesting feature was that peri-urban area like Mranggen and Sayung turned out to have more urban character than the southwestern part of Semarang City.

3.2. Surface urban heat island

Howard's (1818) theory states that urbanisation has an impact on land surface temperatures [illegible] using SUHI. The SUHI transition from 1998 to 2018 is as shown in Fig. 6. Spatially, it can be seen that the number of areas with surface temperatures of 26–30 °C and > 30 °C increased rapidly. The yellow colour, which originally dominated the city of Semarang as the centre of the SMR, has expanded in the year 2018, even to the peri-urban areas of SMR. The red colour indicates

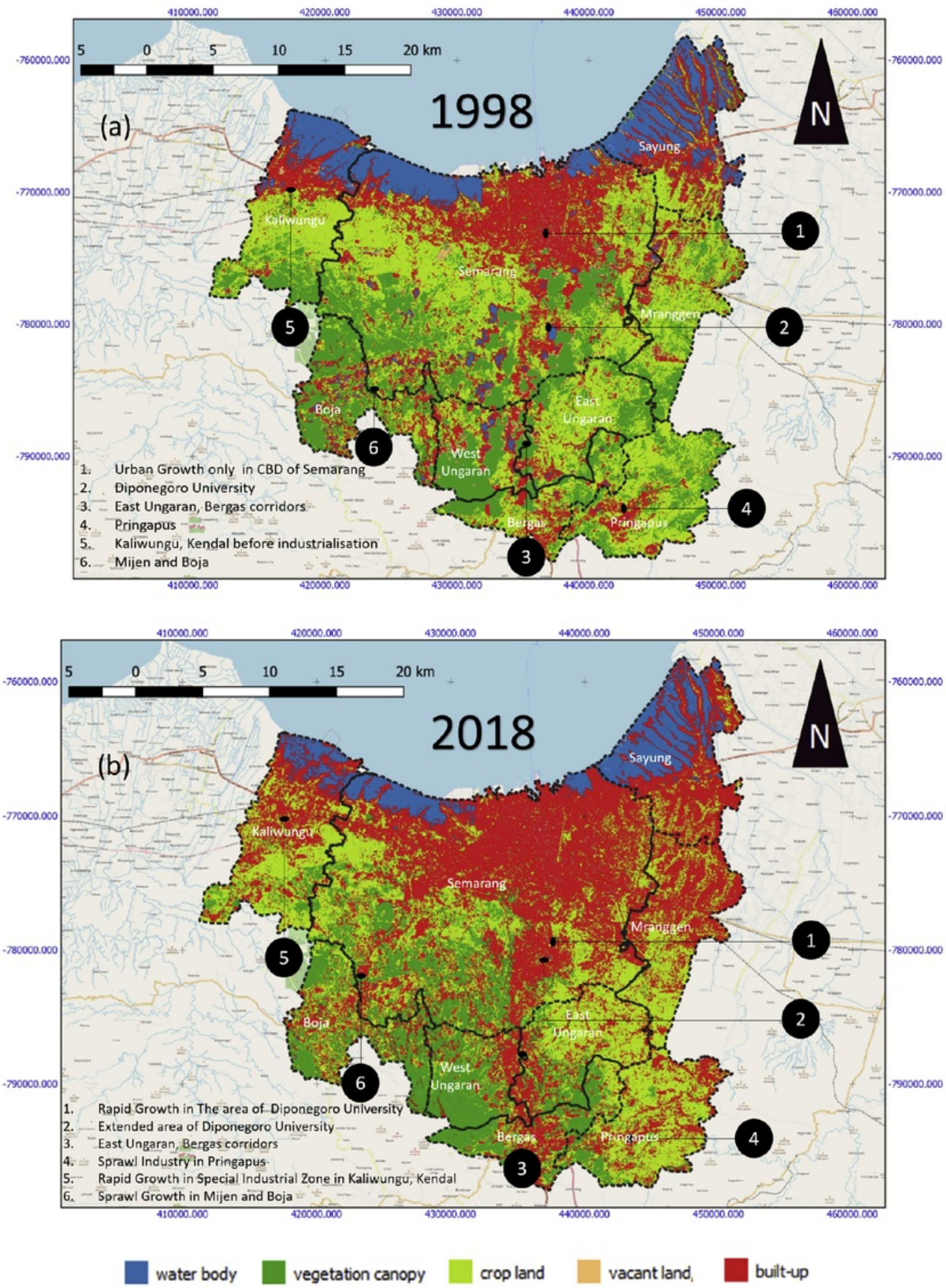

Fig. 3. LULCC 1998–2018 in Semarang Metropolitan Region; (a) LULC 1998; (b) LULC 2018.

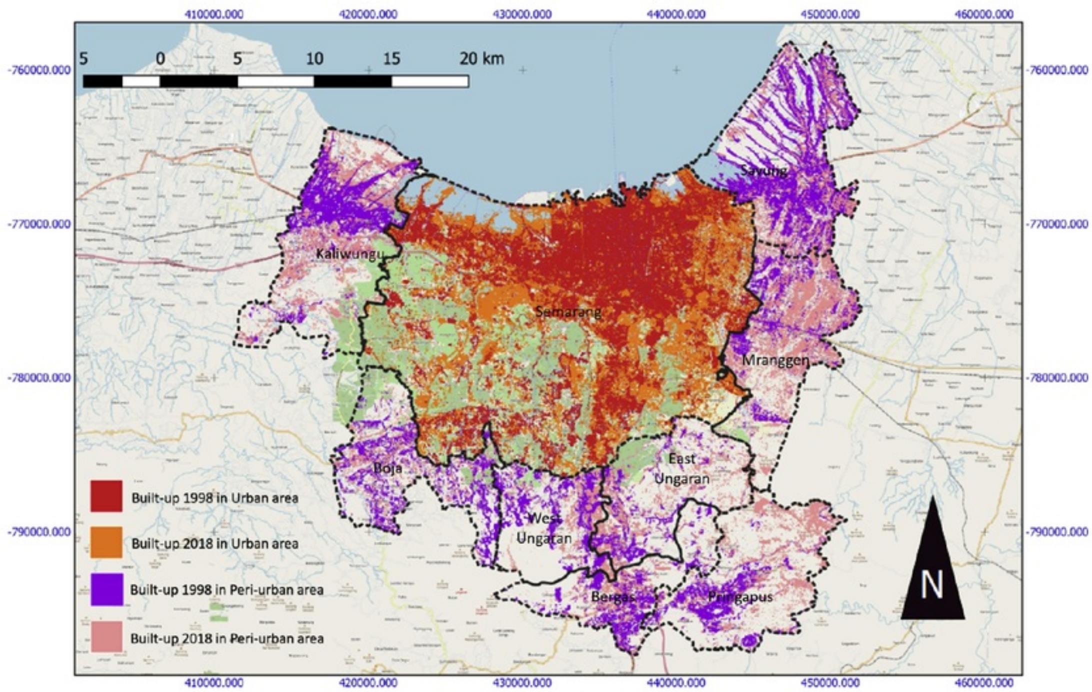

Fig. 4. Built-up Area Growth in Semarang Metropolitan Region.

temperatures > 30 °C and was originally absent in 1998, but in 2018 dominated the main corridors and centres of community activity in SMR.

Table 6 describes the extent of the spatial distribution of SUHI in SMR. Recorded in 1998, the area with a temperature of 15–20 °C has an area of 253.32km^2, but in 2018 there was a significant change to the extent was 1.54 km^2. Once confirmed with the LULCC model, there is a significant change in the built-up area, so that the area with a temperature of 15–20 °C decreases. In other words, the area with a lower surface temperature has decreased by 99.39%. This shows the contribution of urban expansion to changes in surface temperature.

Another important result was that the area with a temperature > 30 °C has increased. In 1998, no area had a surface temperature > 30 °C, meaning that higher temperatures were still within reasonable limits. However, by 2018, land area with a surface temperature > 30 °C had increased to 245.57 km^2. It should be noted that the spatial distribution of regions experiencing a rise in surface temperature is linear with the growth of the built-up area. Thus, in the two decades a change can be seen in average surface temperature, with a rise of 2–5 °C for areas transitioning from not built-up to built-up. The increase in surface temperature is included in the high category, so consideration should be given to control of the land cover so that there is no significant rise in surface temperature.

When compared to LULCC by cross raster data, areas with a temperature rise of 26–30 °C and above 30 °C are caused by two dominant factors, namely the built-up area and the amount of vegetation canopy. These facts show that the rate of urbanisation seen from the widespread built-up area and the decreasing vegetation canopy triggers the rise in surface temperature. Furthermore, if it is compared diagrammatically (Fig. 7), the reduced vegetation canopy area has an impact on the extent of regional distribution of temperatures of 26–30 °C and > 30 °C. Likewise, with built-up areas, the addition of built-up areas is in line with expanding areas with surface temperatures of 26–30 °C and above 30 °C (Table 7). That is, the vegetation canopy factor appears to have a more significant effect. Another fact is the peri-urban (non-urban) area in Pringapus had an average air temperature of 18 °C in 1998 but in 2018 the average temperature increased to 32 °C. Considering the built-up area factor, the diagram shows that not all the built-up areas produce temperatures of > 30 °C, meaning that certain built-up types still have controlled surface temperatures to mitigate the SUHI (See Fig. 7 and 8).

3.3. Stochastic cellular automata- Markov chain model

Any land cover change has a transition probability calculation from one unit land cover to another. Transitions associated with pixel values

Table 4
Land use and land cover change (LULCC) area from supervised classification (Km^2).

LULC	1998			2018			Δ 1998-2018	% Δ	Δ Urban (%)	Δ peri-urban (%)
	urban	peri-urban	total	urban	peri-urban	Total				
water body	30.55	58.84	89.39	43.08	16.04	59.12	−30.27	−33.86	41.02	−72.75
vegetation canopy	89.62	160.82	250.44	48.61	111.31	159.92	−90.52	−36.14	−45.76	−30.79
cropland	134.90	202.05	336.95	121.66	180.57	302.23	−34.72	−10.30	−9.81	−10.63
vacant land	8.30	9.59	17.89	0.01	0.01	0.02	−17.87	−99.89	−99.86	−99.91
built-up area	120.76	111.60	232.36	164.92	240.82	405.74	173.38	74.62	36.57	115.78
Total area			927.03			927.03				

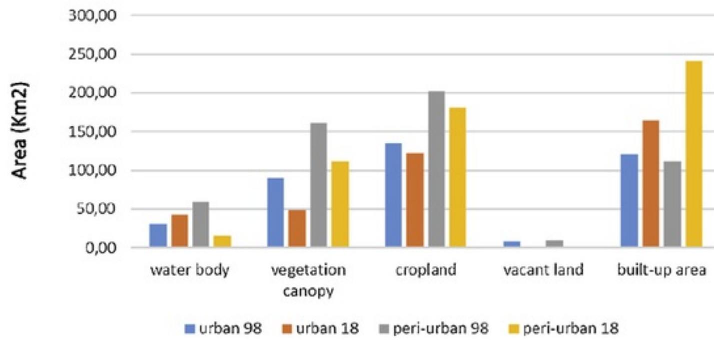

Fig. 5. LULCC in Semarang Metropolitan Region 1998–2018 (Km^2).

Table 5
Typology of Land use Change (1998–2018) in SMR (Km^2).

From | To	Water Body	Vegetation Canopy	Cropland	Vacant Land	Built-up area
Water Body	51.77	1.59	5.62	0.01	30.39
Vegetation Canopy	0.41	84.88	93.69	0.00	71.44
Cropland	0.20	53.39	157.01	0.00	126.33
Vacant Land	0.35	2.21	3.67	0.00	11.64
Built-up area	3.36	17.80	42.23	0.00	165.92

can be modelled by using a Markov Chain. A transition in one of the two types of land use affects the other. Imagine a set of transition probabilities in which there is a conversion of pixel values from non-built-up land to built-up or developed land in the other direction. The matrix for this case can be helpful in establishing the assumption as the basis for showing the pattern of subsequent changes of the probability index value.

The result of the Markov Chain transition model (Table 8) describes the transition pattern from 1998 to 2018. The transition index in each column can explain the possibilities that have occurred in the SMR. We can observe the transition index values for water body, vegetation canopy, crop land, and vacant land into a built-up area. Transition value indicates a number above 0.3, and means that there is a 30% possibility of the total land area or pixel value changing into built-up area. If it is associated with the built-up area dominance in Fig. 5, then the probability of all types of land cover being turned into a built-up area is great. This indicates that it is possible for urbanisation to occur in the next 20 years, and indicates that the growing urban size is very dynamic. The picture for land cover changes to vacant land is similar. The Markov Chain index showed 0.000, meaning that the growth of land cover in the SMR has no tendency to return to vacant land. Furthermore, this change scenario can be carried out with the record of no policy intervention, meaning that if there are policy factors such as deindustrialisation, these occur outside the simulation system.

The simulation of the Stochastic Cellular Automata-Markov Chain (SCA-MC) model used a basic transition matrix built with the concept of a Markov Chain. In the transition matrix describing the transition pattern from the previous 20 years, from 1998 to 2018, the SCA-MC generates against the pattern of change over the next 20 years. This simulation result consists of two scenarios. The first scenario was for "do nothing scenario" and the second one was for "do something scenario". For the second scenario, the model involves the spatial planning

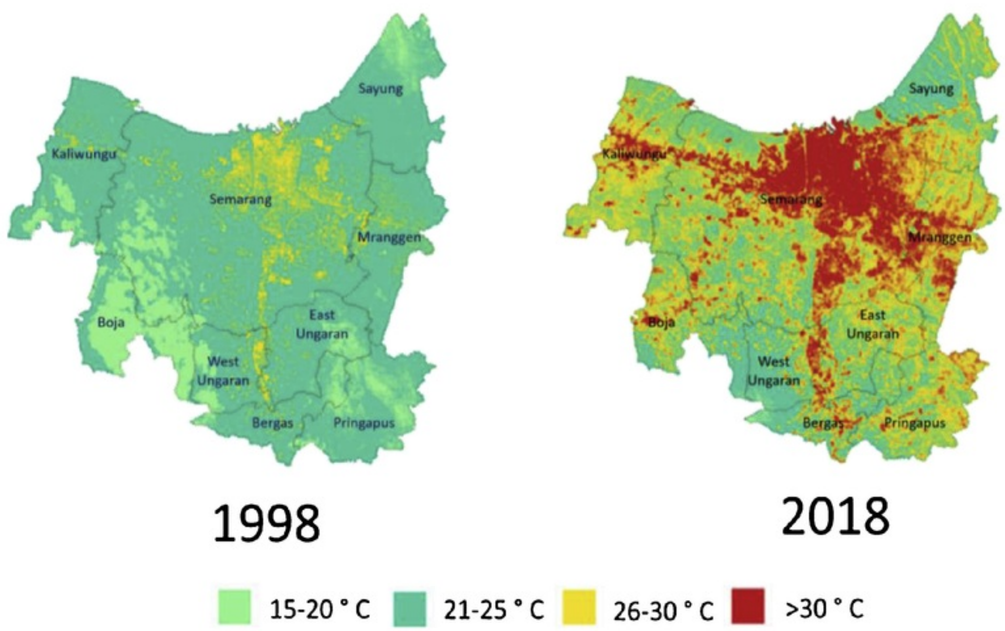

Fig. 6. Land Surface Temperature Transition in SMR.

Table 6
Distribution area of LST 1998–2018 (km^2).

Temperature (°C)	1998			2018			Δ 1998-2018	% Δ	% Δ Urban	% Δ Peri-urban
	Urban	Peri-Urban	Total	urban	peri-urban	total				
15–20	61.92	191.39	253.31	0.10	1.44	1.54	−251.77	−99.39	−99.84	−99.25
21–25	237.12	393.32	630.44	144.35	322.83	467.18	−163.26	−25.90	−39.12	−17.92
26–30	37.30	5.98	43.28	191.19	21.55	212.74	169.46	391.54	412.56	260.45
> 30	0.00	0.00	0.00	127.06	118.51	245.57	245.57	0.00	127.06	118.51
Total Area			927.03			927.03				

instruments like topography, protected area, and the existence of the road network. The running result of the SCA-MC model is as in Fig. 9. When considering the spatial transition results of LULCC from 2018 to 2038, there is a very strong contrast between 1998 and 2018. Table 9 provides an actual picture of the transition results of converted pixels in units of km^2 to know the character of urban growth in the SMR in 2038.

The SCA-MC model produces two scenarios. The first scenario, urban growth naturally without intervention by spatial planning instruments as a constaint factor. The results of the first scenario, the built-up area increased 42.07 Km^2 or 10.36% from 2018. Whereas in the second scenario, the model accommodates spatial planning components, namely topography, protected areas, and the existence of the main transportation lines. The results of the second scenario, increased up to 38.79 km2 or 9.5%. The number of built-up areas in the second scenario is smaller than in the first scenario. However, more important is the existence of an increased canopy vegetation in the second scenario. By utilizing protected areas as areas where there should be no development, built-up growth can be controlled especially in southwestern of SMR.

It is known that the southwestern SMR has not developed as a built-up area since 1998, which means that topographic factors greatly affect the growth of the region. To provide evidence of this, the topography is modelled separately to compare built-up areas, which maintain growth with slower growing areas. Fig. 10 shows that built-up areas do not develop due to topography constraints. With 2D and 3D modelling (Figs. 10 and 11), it can be concluded that the topography changes drastically at distances more than 5 km from downtown. The original altitude of between 0–20 m changes to 50–200 m with slopes of up to 25%. This rise in topographic value means that the southwestern SMR is unattractive as a residential or industrial area.

In line with the SCA-MC modelling results, the northern and eastern regions of the SMR become an area that continues to grow as a built-up area. This growth is supported by a relatively flat topography condition with a height of between 0–25 m and 0–8% slope (Fig. 11), making it easy for the development of built-up areas. The built-up area development is different in each part of the SMR region because the relationship between topography and development financing is very strong. Areas with flat topography minimise costs, especially in maturation and land engineering, and vice versa, the higher the slope and topography, the greater the cost for development. When compared diagrammatically (Fig. 12), it appears that built-up areas will continue to grow in 2038, but slowed in relation to changes between 1998 and 2018. The growth chart of 2018–2038 is gentler than the shifts in 1998–2038, as the availability of ready-to-build land becomes limited due to topographic characteristics. Validation of this model uses Kappa from the 2018 projection map with existing 2018 maps with the result as illustrated in Fig. 13. The Kappa Index is 0.5217 (accuracy is Moderate).

4. Discussion

4.1. Impact of LULCC to SUHI

This study reveals the presence of a dominant type of LULCC factor on the changing spatial distribution of SUHI in two decades. The SMR urban growth trend in the last 20 years represents a positive spike but there is a strong, observable environmental context, which is the reduction of canopy vegetation. This finding confirms four facts. Firstly, The investigation of LULCC and SUHI in SMR proof the Howard's theory (1818) and studies in several countries (Adeyeri et al., 2017; Tran et al., 2017; Wang, Huang et al., 2016; Wang, Ma et al., 2016; Ward et al., 2016), urban expansion has expanded the size of the city, and thus regions with rising surface temperatures have become more widespread. Urban growth has an impact on peri-urban development so that the growth of SMR from 1998 to 2018 (see Fig. 3) is more dynamic in peri-urban areas. Secondly, the results are contrary to the findings of some previous studies on urban growth in Pringapus areas. In this area, it was found that urban dynamics do not always expand to the nearest area because in real conditions there is also a sprawl growth pattern. This is in line with the ideas of Buchori, Sugiri, Maryono, Pramitasari, and Pamungkas, (2017) which state that the leap-frog growth trend will be a challenge in the SMR, mainly because of special towing factors

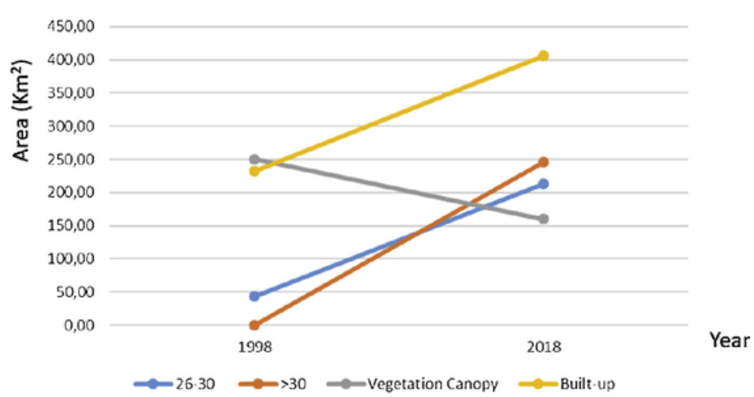

Fig. 7. Comparison of area with vegetation canopy and Built-up with area by temperature 26–30 °C and > 30 °C.

Table 7
Cross Raster data-Contribution of LULC to LST 1998–2018 (km^2).

LULC	Temperature (°C) 1998					Temperature (°C) 2018				
	15–20	21–25	26–30	> 30	Total	15–20	21–25	26–30	> 30	Total
waterbody	16.72	72.57	0.09	0.00	89.39	0.01	27.80	30.26	1.06	59.12
vegetation canopy	126.28	122.41	1.75	0.00	250.44	1.30	58.28	98.77	1.57	159.92
cropland	72.07	264.16	0.72	0.00	336.95	0.21	249.03	50.23	2.76	302.23
vacant land	2.44	13.92	1.53	0.00	17.89	0.00	0.01	0.00	0.00	0.02
Built-up area	35.81	157.37	39.18	0.00	232.36	0.03	132.07	33.47	240.17	405.74
Total	253.31	630.44	43.28	0.00	927.03	1.54	467.18	212.73	245.57	927.03

such as industrial and settlement land requirements. The land requirements for industry and labour make Pringapus grow as an urban area from industrial development. Despite its status as a non-urban, Pringapus has had a very high surface temperature shift, caused by the expansion of areas with a surface temperature of > 30 °C. Hence, urban and non-urban status can be ignored when surface temperature shifts remain influenced by the type of land cover or land use. This is slightly different from some studies showing that urban area greatly influences SUHI (Mathew et al., 2018; Meng et al., 2018)

The third fact is the constraint factor of topography, which in some research has become an obstacle in the construction of built-up areas, but which in this research has been invaluable. The results of the LULCC model with SCA-MC prove that between 2018 and 2038 built-up growth slows due to the topography factor. In contrast to urban growth and SUHI research in Europe, which generally has flat topography, this research found that, topography is a limiting factor in the growth of built-up areas. It is important to maintain environmental sustainability, especially to limit the built-up area and keep the surface temperature down. Thus, the southwestern SMR areas such as West Ungaran and Boja can be maximised to support the city of Semarang. Furthermore, areas with high topography can be utilised as a protected area by concentrating and adding vegetation canopy so that the rise in surface temperature can be slowed. This is consistent with Sejati et al. (2018), who found that the NDVI and NDBI correlation value for SMR is -0.99, meaning that the relationship between vegetation canopy and built-up is negative.

The fourth fact is that the rapidly growing process in the northern, eastern, and southern SMR has significantly triggered the development of the surrounding area, which in turn expanded the functional area of the SMR. According to the shift in the built-up area, the growth of the northern and eastern parts of the SMR is faster than other parts. This phenomenon appears to be affected by the ease of access and infrastructure in the northern and eastern regions of the SMR. The existence of national ports and international airports is proof that this area is very crowded. Among all centres of growth, the middle and northern SMR (Semarang City and Sayung) are the most influential, followed by Mrangen, Ungaran, Bergas, and Pringapus with slightly lower intensity. This fact should be immediately addressed as the northern regions are vulnerable to natural disasters such as flood and *rob* (Buchori, Sugiri et al., 2018; Buchori & Tanjung, 2013; Marfai & King, 2008; Sejati & Buchori, 2010) and land subsidence (Marfai & King, 2007). If it is not controlled by initiating an alternative space to divert the burden of industrial growth in the north, then the northern part of the SMR will sink, as predicted in previous research.

From these facts, SUHI can be controlled through spatial planning instruments that regulate the spatial distribution of LULC, so that it can reduce the expansion of areas experiencing a rise in surface temperature. Furthermore, based on the second fact, the peri-urban areas should also remain under control, especially in the face of the phenomenon of urban expansion. If Semarang continues to expand Bergas and Pringapus, industrialisation will be concentrated in the south of the SMR, whereas some areas of agriculture and forest can be used to increase the amount of vegetation canopy in reducing the impact of SUHI. Other interesting findings in Kaliwungu and Boja, where up to 2038 LULCC predictions are still limited in the area of Kendal Industry, the southern part of Kaliwungu and Boja remain under control but still functioning as cropland and vegetation canopy to support the city of Semarang.

4.2. Urban sprawl trend and SUHI

The results of LULCC's analysis from 1998 to 2018, built-up areas in peri-urban areas grew 115% so this growth was greater than the growth of built-up areas in urban areas. This is due to sprawl growth in housing and industry in peri-urban areas (see Fig. 3 (b)). It shows another trend found in this study especially in peri-urban of SMR. As Weber (1907) and Losch (1954) pointed out, industrial site determination considers several areas of land and appropriate land prices, proximity to sources of raw materials, and proximity to labour sources. Especially for labour, the current industry in Jakarta Metropolitan Region (JMR) diverted

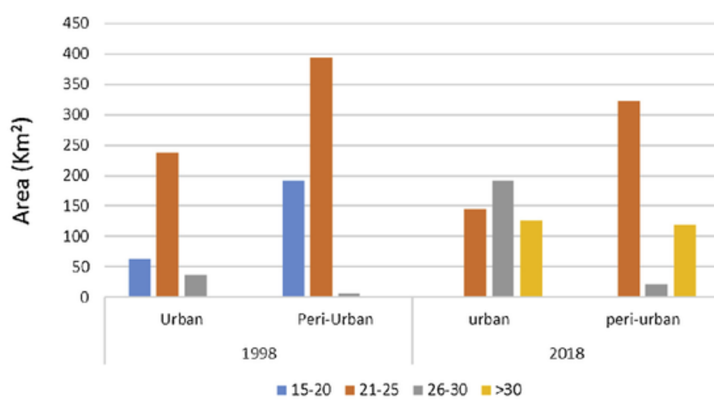

Fig. 8. Comparison of SUHI in SMR.

Table 8
Markov Chain Transition Matrix of LULCC in SMR.

From 1998 | to 2018	water body	vegetation canopy	cropland	vacant land	built-up	Total index
water body	0.4924	0.0215	0.0760	0.0000	0.4101	1
vegetation canopy	0.0018	0.2881	0.4029	0.0000	0.3072	1
cropland	0.0007	0.1792	0.3961	0.0000	0.4240	1
vacant land	0.0197	0.1239	0.2056	0.0000	0.6508	1
built-up	0.0376	0.1055	0.2499	0.0000	0.6070	1

investment in SMR especially in Bergas and Pringapus. The first factor is the availability of labour and the minimum wage. In the JMR, the minimum wage is very high at over 3 million IDR per month, while the minimum wage in the SMR is still below 2.5 million IDR per month (Central Bureau of Statistics in the JMR and SMR, 2017). In addition, the price of land is also greatly different in the JMR and is very high compared to the price of land in Pringapus (SMR), so some industries in the JMR have chosen to relocate to the SMR (Sugiri, Buchori, & Ma'rif, 2015).

The result of the SCA-MC model for SMR growth shows that urban sprawl has wide potential to become a trend considering SMR as a

Table 9
SCA-MC simulation up to 2038.

LULC	1998	2018	2038 (s1)	2038 (s2)
water body	89.39	59.12	44.82	38.42
vegetation canopy	250.44	159.92	144.32	213.38
cropland	336.95	302.23	290.04	230.57
vacant land	17.89	0.02	0.03	0.12
built-up area	232.36	405.74	447.81	444.53
total area	927.03	927.03	927.03	927.03

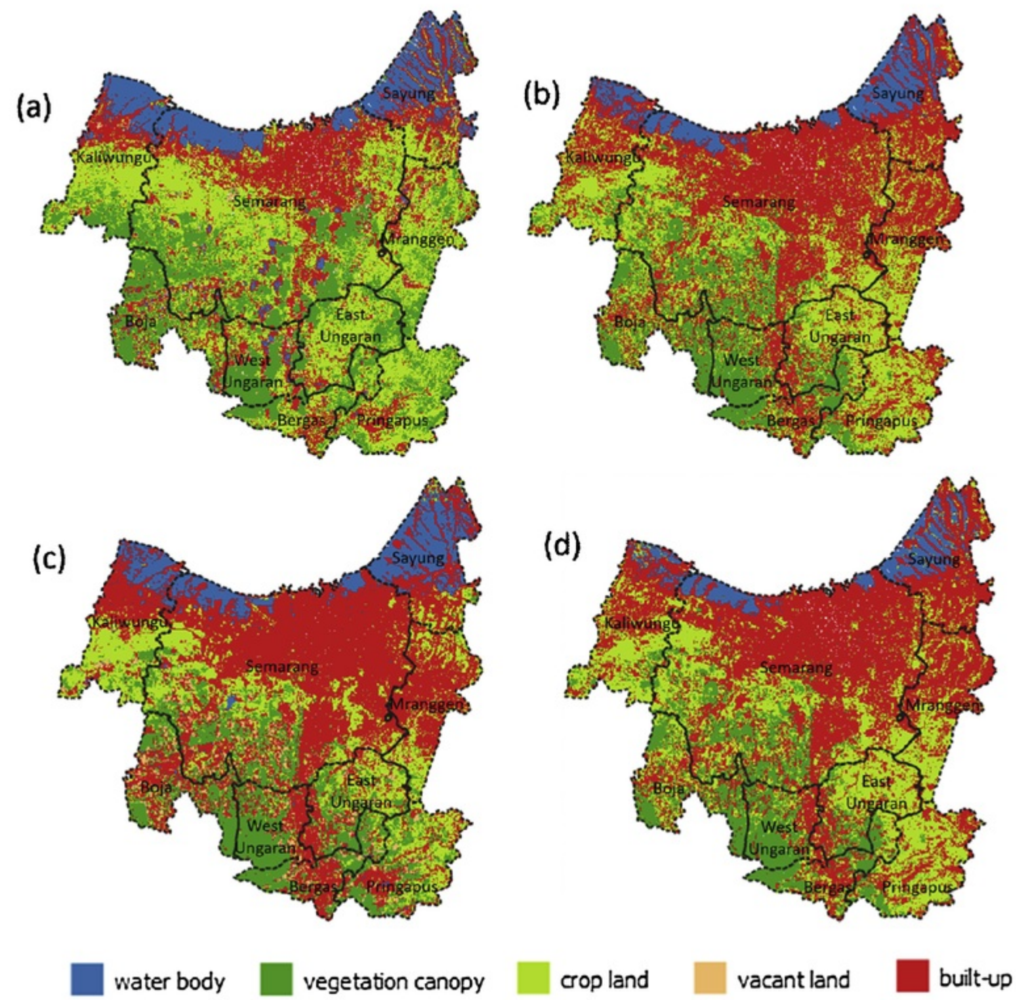

Fig. 9. (a) LULC 1998; (b) LULC 2008; (c) LULC prediction for 2038 scenario 1 (s1); (d) LULC prediction for 2038 scenario 2 (s2).

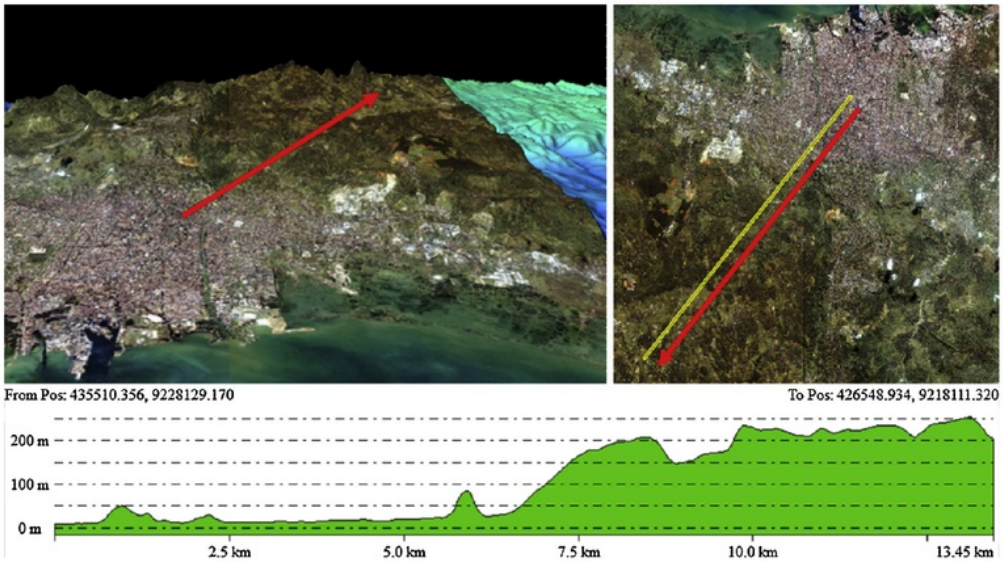

Fig. 10. Topography model of the southwestern SMR.

national strategic area with complete access and transportation. The proportion of built-up deployment in peri-urban areas is higher after 2018. This fact confirms indications of unsustainable trends, especially when associated with studies from Buchori and Sugiri (2016); Buchori et al. (2017), and Sugiri et al. (2011). Furthermore, the growth of industry in peri-urban and rural-urban transition areas resulted in reduced vegetation canopy, which affected SUHI in the SMR. This issue is of particular concern because poor location planning has an impact on the distribution of natural or human resources, and these clearly disturb environmental sustainability. However, this sprawl fact corresponds to a statement from Buchori et al. (2017); Lagarias (2012); Mehmood, Mehmood, Butt, Younas, and Adrees, (2016), and Raza et al. (2016), as urban sprawl is usually located in the suburbs and rural areas, which sequentially implies an increased inefficiency regarding urban development. Furthermore, the higher intensity of sprawl urban spread may indicate potential threats to the environment, and thus it requires controlled measurements through the SMR growth policy instrument. Another impact is the wasting of land resources if the sprawl phenomenon is uncontrolled, and so policy makers should be encouraged to pay more attention to environmental sustainability rather than just pursuing local revenue.

4.3. Land use/Land cover scenario and SUHI mitigation

The modeling results show that entering the spatial planning instruments in the LULCC scenario shows different results. If the SUHI is identical to the growth of the built-up area, the second scenario can be an alternative in mitigating the SUHI. Predictions from the SCA-MC model that growth in the SMR slowed after 2018 became the basis of the scenario of land use planning as a mitigation effort against SUHI. If

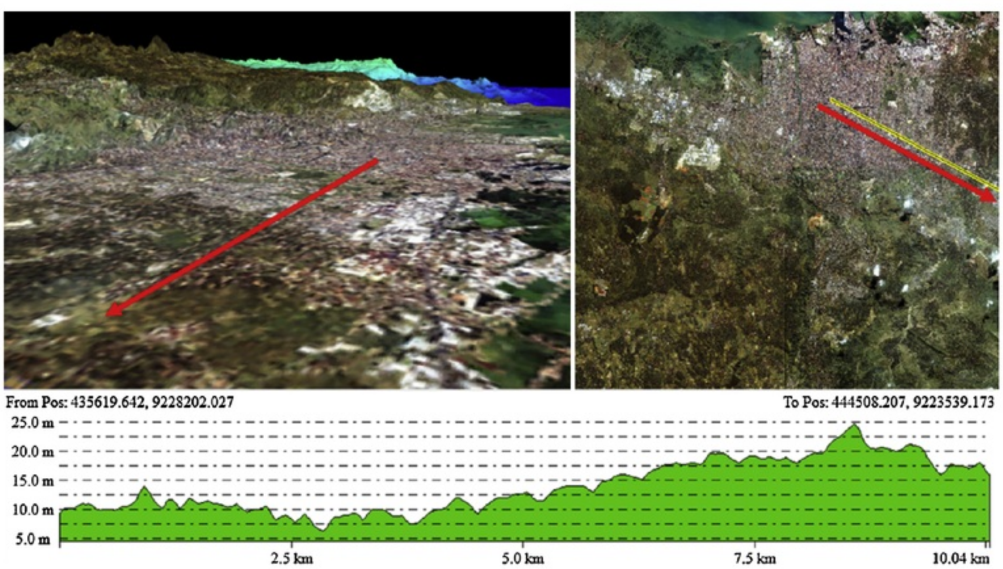

Fig. 11. Topography model of the northern and eastern SMR.

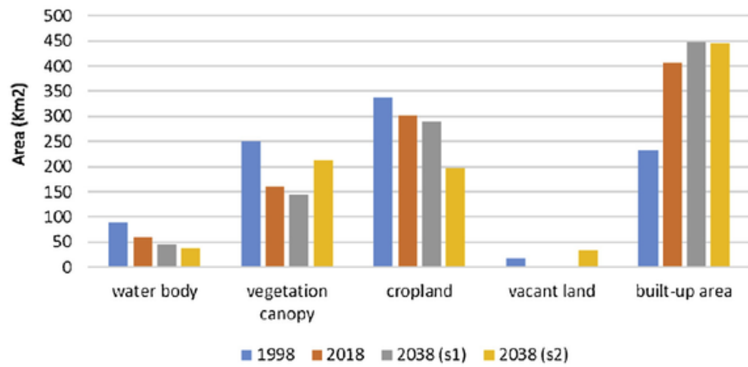

Fig. 12. Prediction of LULC in SMR 2038.

Category	KIA
1	0.9807
2	0.5730
3	0.4650
4	0.0081
5	0.4508

2018 PROJECTED

Category	KIA
1	0.7506
2	0.3659
3	0.4332
4	0.0000
5	0.7768

Overall Kappa = 0.5217

Fig. 13. Kappa Coefficient for Projected Map.

SUHI is identical to built-up growth, then scenarios that might be implemented by policy makers include: (1) designating high topographic areas as protected and buffer areas, namely the southwest of Semarang City and its peri-urban like West Ungaran, Boja, and some parts of Kaliwungu. The function of these areas is as worth keeping of the balance of canopy vegetation, so it is not changed or used as a built-up area. It can control the expanding area with high surface temperatures; (2) the built-up area of the northern SMR should be limited, as the possibility of sea level increases, such as robs, compounded by land subsidence, may threaten public safety despite adaptation efforts (see Buchori, Pramitasari et al. (2018), Buchori, Sugiri et al., 2018)). Another impact in the northern part of the SMR is the built-up areas, most of which have industries and surface temperatures above 30 °C; if no controls are set, then surface temperature can increase and impact on public health in the SMR; (3) areas with surface temperatures between 26–30 °C and above 30 °C are required to plant, in particular to plant canopy vegetation in their settlement environment; (4) the southern part of the SMR such as Pringapus and Bergas must have immediate planned control and restrictions on the growth of rural industries.

SUHI mitigation is closely related to efforts to control the increase in surface temperature of the Earth. As Mathew et al. (2016) and 2018); Mirzaei and Haghighat (2010) stated, the impact of SUHI is not only on air quality but also on habitats and ecosystems. The emergence of new disease vectors, changes in cropping, and human body resistance are a major concern of mitigation efforts. Furthermore, mitigation through land use scenarios can assist governments in adopting spatial policies. Mainly within the SMR, Semarang City's government should start to think collaboratively by involving the surrounding districts that are part of the SMR to arrange the layout together. By doing so, SUHI mitigation efforts are more quickly realised towards the sustainability of the SMR.

5. Conclusion

This study has succeeded in revealing the empirical facts of urban growth and SUHI dynamics in the Semarang Metropolitan Region over two decades. The northern, eastern and southern SMR is tending to grow intensively, triggered by industrial parks and central Java gateways, such as ports and airports centred in the SMR, and so the SUHI in this region is very high and may increase if uncontrolled. The much lower growth intensity occurred in the western and southwestern regions, as indicated by the slowing of built-up growth due to the physical factors of space in the region. This has become a potentially beneficial mitigation scenario of SUHI in the SMR.

The occurrence of sprawls randomly filled some peri-urban areas in the southern part of the SMR. This phenomenon is very likely to occur in urban growth, which is usually followed by the emergence of the spread of built-up areas between the core city and surrounding peri-urban. However, if not carefully managed, it may endanger environmental sustainability, as productive land for food agriculture and vegetation canopy as part of the mitigation of SUHI will be reduced. Furthermore, the successful SCA-MC model illustrates the transition and prediction of LULCC in the SMR, potentially as a direction for local government in regulating the spatial layout. This evidence shows the development of the SMR after 2018 slows and stagnates. Based on these trends, the government can develop appropriate policies to lead to sustainable development. If left unchecked, the future of the SMR can continue into environmental degradation, as it is vital to ensure the equality and sustainability of the SMR's development.

GIS, remote sensing, and modelling using Cellular Automata - Markov Chain as the main support tools have proven appropriate in providing spatial information and illustrating predictions of the spatial dynamics of a region. In this study, the data units obtained from satellite imagery with some algorithms and processing techniques are able to describe the phenomenon of two decades of urbanisation in the SMR. Well-managed data and information provided in this format is certainly useful as a decision support system for the government. However, to obtain a more detailed typology, future work in this area is required. One possibility is to use satellite imagery with more detailed resolution to see the utilisation of each land plot and measure its impact on SUHI.

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