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Urban Heat Island Assessment using Remote Sensing Data in West Java, Indonesia: From Literature Review to Experiments and Analyses

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ABSTRACT

Urban heat island (UHI) is a significantly increasing temperature that occurs in the urban region due to urbanization and anthropogenic activities. The UHI represents environmental quality decrease and able to change a microclimate in the long term. It phenomenon can be estimated using multi-temporal remote sensing imagery data. This study aims to analyze the spatial dynamics of UHI in the urban region of West Java from 1998 to 2018. We only used remote sensing data from different datasets. Information of land-surface temperature is extracted from Landsat-5 TM and Landsat-8 OLI images using radiative transfer equation which validated using MODIS data in the same period. This study showed that UHI intensity in the urban region of West Java reach 5.11°C in 2018. For 20 years, the land-surface temperature increased to 4.44°C. The UHI distribution is concentrated in the central business district, industrial area, harbor, terminal, airport, and traffic jam zone. The UHI significantly increased in Depok and Cimahi, which are known as satellite cities for the surrounding megapolitan (Jakarta and Bandung Raya). This model has high validity result with a correlation value of 0.74. The UHI management is important to strengthen urban resilience in the environmental field through green open space, green belts, roof gardens, land use and land cover formal direction, and the use of high albedo materials to build construction.

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1. INTRODUCTION

The negative impact of urban development is a declining trend in environmental quality due to human activities and urbanization (Zarzoso & Maruotti, 2011). The increasing of vehicles, industries, and built-up land causes air temperature in urban areas to warm significantly (Bernales, 2016). The phenomenon is known as urban heat island (UHI). UHI is a location with warmer temperatures than the surrounding environment. This is due to differences in energy use, absorption, and heat exchange between urban and rural areas (Hermawan *et al*., 2021; Warlina & Damayanty, 2021). The highest air temperature has located in the core region and gradually decreases to sub-urban and rural areas (Dede *et al.*, 2019). UHI's existence can change microclimate conditions, in the long term, it changes in temperature, humidity, and air pressure for the surrounding (Husna *et al*., 2018).

The UHI phenomenon causes discomfort for the urban population and is more vulnerable to heatwave threats in the dry season, especially in some areas which have a local dry-wind circulation (Athukorala & Murayama, 2021). It also results to increase energy consumption for air conditioners, exacerbating the effects of warming due to heat transfer mechanism and pollution into the environment, especially if the built-up area in around using materials that can absorb heat with less green vegetation (Rahmat & Mutolib, 2016; Skelhorn *et al.*, 2016; Klok & Kluck, 2018). In developing countries, an increasing air temperature has a linear pattern with urban sprawl phenomenon and change many vegetates land into built-up areas (Widiawaty & Dede, 2018). In West Java, the highest urban sprawl in Indonesia, it happens in the around of megapolitan and metropolitan, such as Jakarta, Bandung, and Cirebon (Nandi & Dewiyanti, 2019; Ismail *et al.*, 2020). The rate of land use and land cover (LULC) change in West Java was reach more than 100 percent for built-up area expansions (Agaton *et al.*, 2016).

However, observation of the UHI phenomenon in urban areas needs a middle-long period along with the urban sprawl rate. The UHI observation is more efficient and effective using multi-temporal remote sensing satellite data to produce land surface temperature (LST) information. This method can measure temperature differences in an area with good precision and is useful for urban analysis and development to strengthen urban resilience. We used only remote sensing data, for information verification, by comparing information from Landsat and MODIS imageries. Therefore, this study aims to analyze the spatial dynamic of UHI in the urban region of West Java from 1998 to 2018.

2. LITERATURE REVIEW

The UHI occurs when the city is much warmer than the surrounding countryside. The temperature difference between urban and undeveloped rural areas is related to the extent to which the surface absorbs and retains heat in each environment. Several parameters must be considered regarding UHI:

(i) Heat island. It influences to the temperature of the land, giving impact especially on the agriculture. Heat island is formed due to several factors: the decline of the urban natural landscape, trees, vegetation, and water bodies. All factors tend to provide shade, evaporating water from leaves, and evaporating surface water to cool the air. Hard and dry urban surfaces, such as roofs, sidewalks, roads, buildings, and parking lots, are warmer because they are less shady and humid than natural landscapes. That is why these types of urban surfaces must be build in standard construction (Sudarjat, 2022; Rahmat, 2021; Rahmat, 2022; Kurniawan, 2022a; Kurniawan, 2022b). The construction

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must also consider physical properties of cities, traditional man-made materials used in urban environments, such as sidewalks and roofs, in which they reflect less solar energy and tend to absorb and release more solar heat than trees and carpets, plants, and other natural surfaces available. Heat island is usually formed during the day and become more pronounced after sunset due to the slow release of heat from urban materials.

(ii) City Geometry. The size and spacing of urban buildings affect the wind flow and the ability of urban materials to absorb and release solar energy. In highly developed areas, surfaces and structures are blocked by adjacent buildings become large heat blocks that cannot be dissipated easily. Cities with many narrow streets and tall buildings can become canyons in the city, blocking natural airflow for a cooling effect. City must be designed to get better quality, including temperature, humidity, and water (Amin *et al*., 2022; Khamaia *et al*., 2022).

(iii) The heat is released by human activity. Vehicles, air conditioners, buildings, and industrial plants radiate heat into the urban environment. Residual heat sources of anthropogenic or anthropogenic origin can contribute to the effects of thermal reversal.

(iv) Weather and geography. Quiet and well-ventilated weather conditions lead to larger heat islands, maximizing the amount of solar energy reaching the surface of the city and minimizing the amount of heat that can be transported. However, strong winds and cloud cover prevent heat islands from forming. Geographical features can also influence the heat island effect. For example, nearby mountains can prevent wind from reaching the city or create wind flow patterns through the city.

(v) Temperature. Temperature is the main parameter for measuring energy balance and climate on the earth's surface. Temperature can control longwave energy flux and is strongly influenced by other such as albedo, surface humidity, and vegetation density (Ramadhan & Handayani, 2021). Surface temperature is the thermal state of the earth's surface at particular locations, this is measured at the surface level (Becker & Li, 1990). In general, the highest temperatures are located in the center of cities and decrease gradually from urban fringes to rural areas. Annual average temperature measurement, conventionally, uses daily air temperature data obtained from recording 24 hours per day. These results use to determine the temperatures on average daily, monthly, and yearly. Temperature variations are inseparable from geographical factors, such as vegetation density and terrain elevation – the higher of places, low air temperature (thermometric gradient) (Purwantara, 2015). In geospatial technology advances, the temperature can be obtained by indirect observation via remote sensing satellites that have thermal bands. Temperature measurements can be carried out in a daily or weekly timeframe that is adjusted to the period of recording the region as known as temporal resolutions. The processing of digital number values from satellite images into temperatures, generally, uses the radiative transfer equation algorithm developed by USGS and is suitable for various thermal sensors (Dede *et al*., 2019).

(vi) Greenhouse gas emissions. Currently, greenhouse gas emissions have caused the global average temperature to increase by 1°C over the last 150 years.

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At the local level, objects on the earth's surface also affect surface temperature conditions due to differences in these thermal capacities. One of the impacts of local climate change is UHI and ecosystem shift. The UHI is a condition where the temperature in urban areas is higher than in the surrounding rural areas. The term UHI was first introduced by a British scientist, Luke Howard in 1808. Greenhouse also can be produced by public vehicles and industries, in which these sources give impact on the pollution (Asif *et al*., 2021; Abulude *et al*., 2022; Caraka *et al*., 2021).

There are many studies of UHI in Indonesia that focus on a single area of urban or peri-urban (Zahro *et al*., 2018). Suriana *et al.* (2020) found that UHI tends on built-up land and lower temperatures near water bodies, this information was only obtained from Landsat imagery. A similar method was applied in Banda Aceh, researchers found that UHI was positively and significantly correlated with building density (Achmad et al., 2019).

In the UHI study in the Capital Region of Jakarta, the highest temperature located in the densely-developed areas (city center), data sources come from field measurements and Landsat imagery (Rushayati & Hermawan, 2013). Different from previous studies, our study combines two satellite imagery datasets. Landsat imagery role as the main data, while MODIS are used for verification.

The advantage of this study, we can equalize the data collection period, thus accurate UHI information is better. This method was once common for studies on other subjects, such as land cover, vegetation density, and earth surfaces morphologic, especially on a large scale (Prasetyo, 2016; Nandi, 2018).

3. MATERIALS AND METHODS

This research was located in all administrative of urban regions in West Java, Indonesia, which consists of Bandung, Banjar, Bekasi, Bogor, Cimahi, Cirebon, Depok, Sukabumi, and Tasikmalaya (**Figure 1**). Formally, West Java Province formed several new urban regions (administrative cities) as a growth center after the reformation in 1998 and create suitable cases to observe the UHI phenomenon and regional development pattern (Hariwan & Swaningrum, 2015). Our latest data refer to 2018 and 20 years, in accordance with the long-term regional development plan, also to avoid abnormal temperature data due to COVID-19 lockdown. In addition, COVID-19 condition, including lockdown, change the condition of people and society in all over the world (Sukmawati & Maryanti, 2022; Ammatulloh *et al*., 2022; Al Husaeni & Nandiyanto, 2022; Afifah, 2021; Phanse, 2021; Sangsawang, 2020; Mulyanti *et al*., 2020; Ana, 2020).

UHI observations for twenty years using thermal data on Landsat-5 TM and Landsat-8 OLI satellite imageries (**Table 1**). On Landsat-5 TM thermal data is obtained from band 6, whereas Landsat-8 OLI's thermal data is bands 10 and 11 (Laosuwan *et al*., 2014). The UHI phenomenon was obtained from LST analysis using radiative transfer equation which was validated by MODIS Terra in the same period at dry season between June and September (Dede *et al*., 2019). The radiative transfer formula following Equation [1].

$$L_\lambda = M_L \times Q_{cal} + A_L \qquad (1)$$

where L_λ is the spectral radiance, M_L is the band-specific multiplicative rescaling factor, Q_{cal} is the energy, and A_L is known as the band-specific additive rescaling factor.

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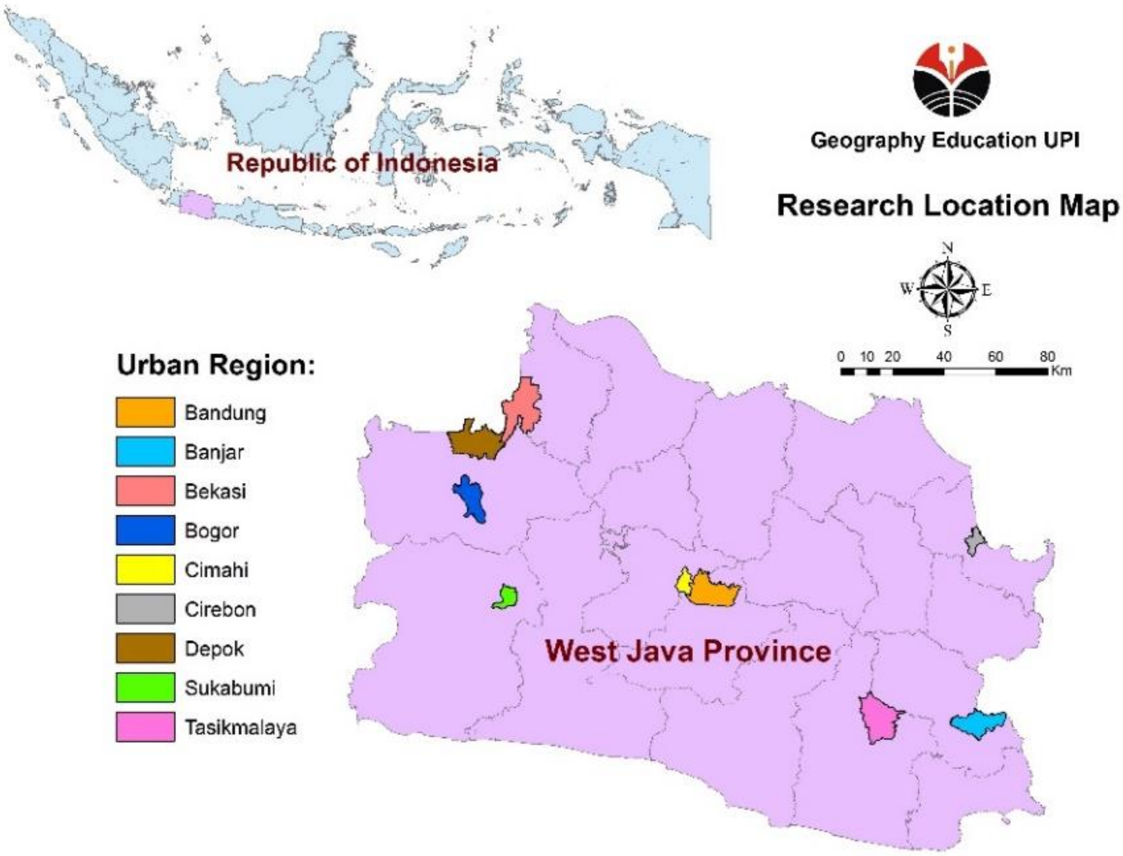

Figure 1. Study area in West Java.

Table 1. Research dataset.

Dataset	Description and criteria	Source
Landsat-5 TM (1998)	Thermal band with 120 m spatial resolution and cloud cover less than five percent.	Earth Explorer USGS
Landsat-8 OLI (2018)	Thermal band with 100 m spatial resolution and cloud cover less than five percent.	Earth Explorer USGS
MODIS Terra (2018)	MOD11 data as validator. The imagery has a 1000-m spatial resolution.	GSFC NASA

The spectral radiation must be converted to LST values. The conversion is based on the dataset's metadata of each satellite imageries which shows in text format file. The conversion value of spectral radians can use Equation [2].

For the LST of each dataset, we use the spatial histogram to get the average temperature value and its standard deviation to measure UHI after converting the value from Kelvin to Celsius degree unit (Husna *et al.,* 2018). The UHI analysis considers surrounding pixels using Equation [3].

$$T = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda}+1\right)} \quad (2)$$

where T is the effectiveness temperature on Kelvin from satellite imagery, K_2 and K_1 are the calibration constant values from metadata.

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$$T_{UHI} = T_p - (\mu + 0.5\ SD) \quad (3)$$

where T_{UHI} is UHI temperature, Tp shows the value temperature for each pixel, µ and SD are the temperature average of the image and its standard deviation.

4. RESULTS AND DISCUSSION

The average temperature for 20 years in urban areas in West Java increased by 4.44°C (**Table 2**). The highest temperature has occurred in Bekasi, Depok, and Bogor who known as satellite cities for megapolitan Jakarta, while reduction of vegetation areas due to the construction of industrial estates, settlements, and other built-up lands to the periphery area massively happens. In the same period, a different condition occurred in Tasikmalaya where the average temperature decreased by 0.14 °C.

In a round of the city, upper-area reforestation programs from the government and community were held since 2011, it is indirectly able to reduce air temperature even though urban sprawl continue to occur. Vegetation greenness has a significant role in microclimate (Rahmat *et al*., 2018).

In 2018, UHI in West Java has more widespread distribution than in 1998 except for Tasikmalaya and Cirebon. The highest UHI occurred in Bekasi which reach 8.88 °C and the value is higher than the average UHI of West Java with the value of 5.11 °C. In terms of area ratio, Cimahi has the most widespread distribution of UHI.Development direction of Bandung Raya towards Cimahi as satellite city and new core region, especially since Cimahi got new administrative status (Budiyantini & Pratiwi, 2016; Nandi, 2018; Marlyono & Nandi, 2018). Similar conditions also occur in Depok where the UHI pattern connects the city center and outskirt of megapolitan Jakarta. In detail, the dynamics of UHI in West Java shows in **Figure 2**.

Based on its categories, very high UHI (VHUI) with temperatures of more than 4°C concentrated in the central business district, industrial area, harbor, terminal, airport, and traffic jam zone. Many locations as human activities centers contribute to greenhouse gas emissions such as CO_2, SO_2, and NO_x. Continuously, decreasing air temperature towards the suburbs makes the area classified as non-UHI (Liu, 2015). The reduced UHI in several cities in West Java in 2018 was generated by the prevalence of high temperatures throughout the region, so the value is close to the average. In addition, the placement of green open spaces, green belts, reforestation, the influence of cold air, traffic engineering, and managing of industrial estate development also change the UHI distribution (Leal-Filho *et al*., 2021). Besides the modeling also shows the existence of other anthropogenic phenomena.

Table 2. Temperature dynamics in urban region.

Urban Region	1998				2018			
	Min	Max	Average	SD	Min	Max	Average	SD
Bandung	14.40	30.98	22.74	1.48	11.10	33.84	28.14	1.83
Bogor	18.08	27.25	23.41	1.30	23.24	35.43	29.90	1.79
Banjar	18.08	28.92	23.94	1.03	16.90	33.05	26.23	1.64
Bekasi	20.32	28.08	23.67	1.09	22.24	41.52	31.87	1.55
Cimahi	12.03	26.04	22.03	1.66	17.23	33.13	27.75	1.98
Cirebon	20.32	35.01	29.19	1.77	22.31	34.94	30.37	1.28
Depok	20.77	28.08	23.69	1.07	22.87	37.65	31.12	1.87
Sukabumi	20.77	30.16	24.4	1.58	22.80	33.33	27.77	2.07
Tasikmalaya	15.58	28.71	22.84	1.53	19.67	26.56	22.70	1.25
Average	17.82	29.29	23.99	1.39	19.82	34.38	28.43	1.70

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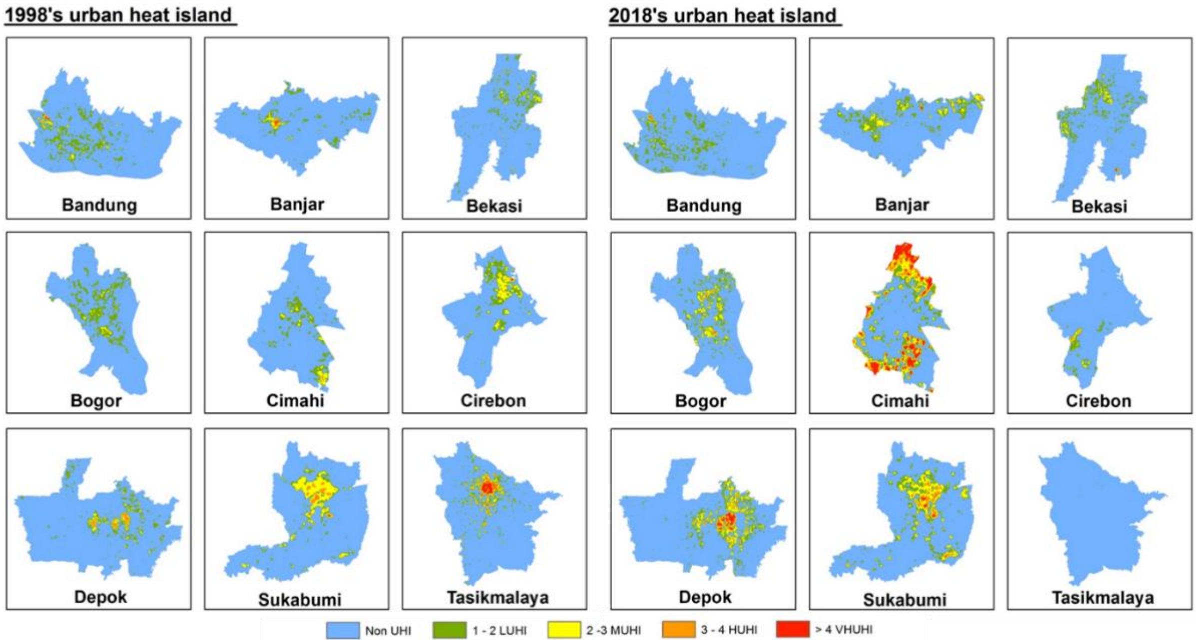

Figure 2. UHI in 1998 and 2018.

UHI modeling in West Java has high validation. The LST modeling results of Landsat imagery with MODIS Terra in the same period have correlation values reaching 0.74. However, observing the dynamics of UHI using remote sensing data is more effective and efficient if comparable datasets from other satellite imagery, weather observation data, and ground survey are available (Zhou *et al.*, 2011; Ismail *et al.*, 2020; Dede & Widiawaty, 2020).

The increasing trend of LST and UHI in urban areas can be managed through vegetative and non-vegetative mechanisms to strengthen urban resilience and mitigate hydro-meteorologically disaster risk such as green open space, green belts, roof gardens, LULC formal-direction and using high albedo materials to build urban construction (Aflaki *et al.*, 2017; Somantri & Nandi, 2018). We need regional planning which adapted this issue in mid-long-term development (RPJM or RPJP) for cities and peri-urban areas as strategic issues.

5. CONCLUSION

UHI dynamic related to the LST distribution in each urban region. For 20 years UHI in West Java grew rapidly in Cimahi and Depok. The distribution pattern of UHI is clustered on the central business district, industrial area, harbor, terminal, airport, and traffic zone. This phenomenon has linear decreasing toward the peri-urban area. The UHI modeling using satellite imagery requires a comparable dataset that comes from a ground survey, weather observation data, and other satellite imageries which can assess the temperature dynamics at the specified time. This research can be a reference for urban and regional policies amidst the threat of climate change.

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7. AUTHORS' NOTE

The author(s) declare(s) that there is no conflict of interest regarding the publication of this article. The authors confirmed that the data and the paper are free of plagiarism issues.

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