Towards Climate Change Adaptive Spatial Planning: Urban Heat Islands Distribution in Jakarta Metropolitan Area

Sofi Ulfiasari and Lin Yola

Abstract Climate change rapidly moves due to human activities are concentrated in cities, which causes the increasing excess heat production. In addition, the ongoing development also makes the reduction in green areas that could absorb heat. Concentrated heating in the city causes an urban heat island. This study uses remote sensing analysis to measure the heat in the Jakarta Metropolitan Area using Landsat 5 and 8 imagery results in the distribution of urban heat island for ten years which has increased, both in terms of intensity and the area. To create a sustainable and liveable urban environment, it is necessary to have urban planning responsive to climate change. Government regulations to reduce urban temperatures have not been seriously discussed. On an urban scale, spatial planning policies will significantly affect the development of heat production. The finding of this study suggests scientific contributions to academia, industry, and governments informing policy framework for the UHI and climate change mitigation plan in Jakarta Metropolitan Area.

Keywords Urban Heat Island · Jakarta Metropolitan Area · Remote sensing · Sustainable city

1 Introduction

Jakarta Metropolitan Area was designed in 1950 and structured in 1952. The development center is in Taman Merdeka (Central Jakarta), surrounded by the main road and green area as a development boundary [1]. Cities can provide many socio-economic benefits. On a micro level, urban areas tend to produce more energy than rural areas. Jakarta Metropolitan Area (JMA) has six regions covering 643,789 ha, with Jakarta as the center. The Jakarta Metropolitan Area, connected by ring roads and irregularly

S. Ulfiasari · L. Yola (✉)
Department of Urban Studies, School of Strategic and Global Studies, Universitas Indonesia, Jakarta, Indonesia
e-mail: lin.yola@ui.ac.id

S. Ulfiasari
e-mail: sofi.ulfiasari91@ui.ac.id

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scattered buildings, forms the phenomenon of urban sprawl. Rapid urbanization and anthropogenic warming are increasing symptoms of climate change. The development pathway with rapid urbanization has changed local to global production systems [2]. Urban production of climate risk, cities a key site within which greenhouse gases are produced [3].

Climate change affects all regions of the world, accelerating human activities in urban areas. Cities can become catalysts in global warming if not appropriately managed. Urban heat islands develop when natural land cover in an area is replaced by built surfaces that trap incoming solar radiation during the day and then re-radiate it at night [4, 5]. The configuration of open spaces and buildings in dense urban areas has a significant role in urban microclimate [6]. Walls and road materials such as asphalt are the warmer materials that can accelerate urban heating [7]. Heating in urban areas occurs shortly after sunset, while the temperature drop occurs at 3–6 p.m. The Jakarta Metropolitan Area has a diurnal air temperature variation that started to increase at 6 a.m. and peaked around 3 p.m. on all the observation points (Jakarta/Kramatjati, Bogor, Tangerang, Bekasi) [8]. The scattered observation points have different topographic characteristics but show the same results as if the heating has been evenly distributed. Economic activity is the biggest cause of accelerated temperature rise, changes in land cover make heat storage more widespread. Built-up area increasing 500% in a decade from west to east, the highest density found at North Jakarta, Tangerang and Bekasi [9].

2 Literature Review

2.1 Urban Heat Island

Urban Heat Island (UHI) is defined as the temperature increases in urban areas compared to the surrounding environment after sunset [10–13]. Meteorological, Climatological, and Geophysical Agency (locally known as BMKG) defines an urban heat island as a metropolitan area characterized by a higher ambient temperature compared to the surrounding non-urban regions or suburban areas, the cause of which is the higher absorption of solar energy with building materials in urban areas made of materials such as glass, asbestos, concrete, asphalt [14]. UHI is related to urban energy balance in the form of thermal energy flow; it is composed of solar radiation, heat storage, heat generated by human activities, sensible heat, and latent heat, which can also be converted into other forms of energy to move in the surface flow [15].

2.2 *Urban Sustainability*

Urban sprawl is not the result of explicit government policies but the somewhat inexorable product of mobilization [16]. Urban sprawl is considered an important problem for sustainable living. The sustainable city concept produces urbanization and urban growth direct to environmental problems. Sustainability has spawned much analysis and many different definitions [17]. Contain in SDG's Goal11, because the future will be urban for most people, the solutions to some of the most significant issues facing humans-poverty, climate change, healthcare, and education must be found in city life [18].

Multilevel governance plays a vital role in taking a step toward climate change and urban sustainability [3]. According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), three categories of adaptation options can be identified, namely structural/physical, social, and institutional [19]. Control of land use change refers to spatial planning, the need for land protection from a climate adaptation perspective, which is enabled by all types of plans for the wider area [20]. However, the urban spatial studies has been associated to range of variables to investigate the best strategies and solutions for planning a more sustainable cities [21, 22].

3 Methods

This study was conducted in Jakarta metropolitan area (locally known as Jabodetabek). Using remote sensing technology as a research method, a whole scene Landsat 5 and 8 (path 122 rows 64 and 65) of 2009/07/29, 2014/9/13, and 2019/8/1 was acquired with less cloud cover. The formula for calculating the urban heat island intensity was reviewed from the following reference [23]: The threshold value of urban heat intensity expressed in μ as average surface temperature and α as standard deviation and heat island intensity formula [24, 25]. T_{rad} represents the surface temperature.

$$\Delta T = \left(\mu + \frac{\alpha}{2}\right) \underline{\text{and}}\, I_{HI} = T_{rad} - \Delta T$$

4 Results

Rapid development has occurred in the last few decades. In 2009, the distribution of urban heat islands in Jakarta was centered in DKI Jakarta to surrounding areas like District of Bogor, Kota Bogor, Tangerang Selatan, and Tangerang. The UHI intensity that dominates Jabodetabek ranges from 1 to 4 °C; areas with high intensity are seen in the center of Jakarta. Parts of the Bekasi Regency show the urban heat island even though the site is a suburb. This condition indicates that the development of the city towards the sub-urban is enormous so that it affects a significant modification of the atmosphere. The growth in 2009 had a substantial effect on the urban climate; warming occurred not only in DKI Jakarta but almost all areas of Bekasi and Tangerang also have the same characteristics.

In 2014, the distribution of heat islands in Jabodetabek showed that the condition of heat islands at 5 °C occurred a lot. A road network connected DKI Jakarta to Depok City, Bekasi City, was spread unevenly, and parts of Bekasi Regency showed heat island intensity up to 8 °C. The increase in area in the Bogor City area is located at a higher altitude than Jakarta but has the exact characteristics of the urban heat island. UHI spreads in the outermost region of Greater Jakarta with a value of 1 °C. Indications of UHI are also closely related to the physical development in that location.

The distribution of UHI in 2019 is shown in Fig. 1, which emphasizes the increasing damage to the atmosphere and the environment. The UHI value in the center starts at 5 °C, which is very high in contrast to the surrounding area. These areas form a pattern connected, covering the face of the city of Jakarta to the city of Bekasi. A small area with a UHI value of 1 °C in 2014 merged to form a large area with a heat island value reaching 4 °C in 2019. Spatially, the increase in size, more even distribution, and the growth of the new urban heat island make Jabodetabek a dangerous metropolitan area. The heating that occurs continuously until it penetrates mountainous areas makes it necessary to evaluate development to reduce the rate of urban warming.

Spatially, the increase in the distribution and value of UHI that has occurred in Greater Jakarta for a decade is evenly distributed, especially in areas directly adjacent to DKI Jakarta. During the first five years, the size of the UHI of heat decreased by 11,399 ha and increased considerably in the next five years by 54,796 ha. Over a

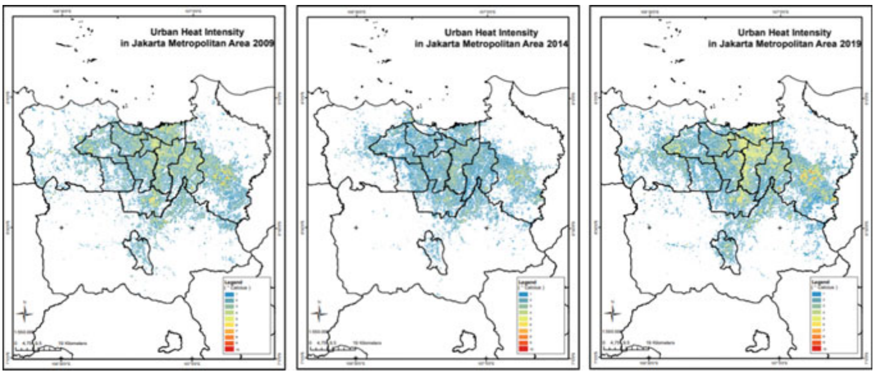

Fig. 1 Urban heat intensity in Jabodetabek on year of 2009, 2014 and 2019

Table 1 Urban heat Island intensity and comparison of area among 2009, 2014 and 2019

Urban Heat Island Intensity (°C)	2009 (ha)	2014 (ha)	2019 (ha)
1	51,671	69,517	54,860
2	40,494	48,546	64,007
3	36,404	157,2	39,380
4	14,963	2451	22,498
5	4220	520	1657
6	492	148	8874
7	114	48	351
8	58	12	132
9	12	5	50
10	2	1	17
Total	148,430	137,031	191,827
UHI of Jakarta Metropolitan Area	23,05%	21,28%	29.80%

decade, the increase in the area and the rise in temperature values. This can lead to changes in local climatic conditions.

The urban heat island reached 14,843 ha in 2009 with the largest area of 1 °C. The higher temperature difference with the lower area. The urban heat island was found in an industrial location, precisely in a factory in Bekasi Regency, dominated by concrete and buildings with heat-absorbing materials and the absence of green areas. In 2014, UHI intensity range four and 5 °C, while at a discount of 1 °C, the area increased to 18,146 ha. This increase in the area indicates a new site experiencing a growth in excess heat. During the 2009–2019 period, the largest area of 1 °C heat island value was seen in 2014, 69,517 ha or about 10.9% of the Jabodetabek area. In 2019 being the warmer year for ten years, the urban heat island experienced an increase in temperature and area. Even the difference in temperature between urban and sub-urban areas of 6 °C has an area of 1.3% of the Jabodetabek area. The difference in temperature above 6 °C spreads in Bekasi Regency and Depok City. The development of industrial and residential areas is the main trigger for increasing heat islands.

Presidential Decree No. 54 of 2008, Article 32 paragraph 4 states that the proportion of urban/urban public green open spaces is at least 20% of the area of each Jabodetabek city. Completing Presidential Decree No. 54 of 2008 to become Presidential Decree No. 60 of 2020 is the first step to emphasize regional integration. In line with Presidential Decree No. 60 of 2020, Bodetabek is designed as a residence/settlement. There is a buffer and protective area expected to support the burden of Jakarta's conurbation, as is the case in providing green space to reduce the impact of warming in the city. In 2014 the intensity of the heat island above 5 °C began to spread evenly and from the west–east direction through Jakarta. Steps that can be taken to reduce the island of heat are adapting Presidential Regulation No. 61 of 2011 concerning the national action plan for reducing greenhouse gas emissions, setting out mitigation steps that can be taken by each region, including the implementation of environmentally friendly transportation development, especially in the DKI Jakarta, Banten Province, and Banten Provinces. West Java so that all three are connected without producing high exhaust emissions.

The action to reduce the intensity of the heat island in Indonesia has not been regulated in legislation; no regulation governs the intensity limit of the island of heat that is not harmful to the community. The integration of the Jabodetabek area arrangement is not in line with the plans that have been made; the phenomenon of the heat island, which cannot be denied, is in the zone of the designated area to be built so that efforts to reduce the heat island by providing green open space in the site are not accessible. In addition, the Presidential Regulation does not contain a single paragraph that discusses the impact of environmental damage caused by air damage. The results of this study are expected to be helpful and contribute to the formation of new regulations.

5 Conclusions

The distribution of the heat island in Jabodetabek is strongly related to the road network infrastructure development. The heat stress developed along the densely built areas in 2009 was seen in the DKI Jakarta area and some others buffer zones such as parts of Depok City and Bekasi Regency with an area of 148,430 ha of the heat island. In 2014 the pattern of heat islands developed from the city center to buffer zone with an area of 137,031 ha. Meanwhile, in 2019, the heat island covering an area of 191,827 ha was distributed evenly from the upstream, middle, and downstream regions; conditions seemed un-control considering that the heat island that occurred covered up to 30% of the entire Jabodetabek area.The implication of the island of heat on the direction of development is the cycle of increasing urban heat that continues to increase due to the rapid city development. In response to this, the authority suppresses the heat island mitigation through the regulation of PP No. 60 of 2020 and PP No. 61 of 2011 to be implemented by all administrative area.

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