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URBAN HEAT HAZARD MODEL BASED ON LOCAL CLIMATE ZONES

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ABSTRACT: Urban heat hazard is the temperature in an urban area of more than 30ºC and impacts humans. The local climate zone (LCZ) is based on the composition of developed and vegetated areas and represents air surface temperature (AST) and Land Surface Temperature (LST). The study aims to develop an urban heat hazard model based on LCZ. The study used high-resolution multi-spectral imagery. The spatial analysis uses the green open area, land cover change, LST, and AST ground through a survey. Those all used to develop LCZ. Based on the thermal band Landsat Imagery, the LCZ developed 1.000 x1.000 meters. The result found that the land cover change affected the temperature rise ± 3ºC. The second was found adequate in the previous study that vegetation-covered is the lowest temperature, both AST and LST, with temperatures>32ºC. The third is due to Vegetation Cover from Land Cover, LST, and AST was generated model spatial of LCZ. The LCZ is divided into five classes based on the percentage of vegetation cover, with the majority of LCZ 4 as vegetation covering only 20%. Based on the Universal Thermal Climate Index and Effective Temperature Index to generate the Urban Heat Hazard (UHH) model spatial based on LCZ. The UHH value with high hazard regarding the temperature> 35ºC. This study concluded that LCZ determines the UHH in the area regarding urban heat signature (AST and LST). The UHH affects the environment with AST >32ºC and will impact a human with head headache, more sweat, and heatstroke.

Keywords: Land surface temperature, Air surface temperature, Urban heat signature, Local Climate Zone, Urban heat hazard

1. INTRODUCTION

The Changes in land cover affect two aspects, natural variations of the earth’s system and human activities [1]. Some examples of land cover changes caused by human activities include bare land surfaces and vegetation converted into impermeable surfaces such as asphalt, concrete, and cement or changing urban morphology such as building areas with varying heights and densities [2]. This change causes temperature changes on the earth's surface [3]. The land cover changes the temperature becomes highest.

Land cover change is a global environmental problem, especially in developing countries [4]. Changes in land cover from vegetation to build-up areas cause a break in the carbon and water cycle and energy fluxes between the soil and the atmosphere [5]. Land Surface Temperature (LST) derived from remote-sensed Thermal Infrared (TIR) satellite imagery is a critical variable in understanding the impact of land use and land cover change (LULC), which has related to urban thermal patterns in various ways [6]. LST is also an important variable related to climate change in urban areas and indicates ground-level energy balance [7]. The Landcover change used to detect LST grew up becomes highest.

Air temperature is essential in explaining the conditions of the terrestrial environment on earth [8]. Land cover types with high vegetation cover are associated with low temperatures, and conversely, land cover types with low vegetation cover are associated with high temperatures [9]. As a consequence of changes in the heat balance and Urban Heat Island (UHI) [10], the air temperature in urban areas with dense buildings/populations is higher than the temperature in the surrounding areas/outskirts of the city [11]. This explanation provides an overview of existing research that has not yet produced a local climate map based on land surface and air temperature changes.

The spatial-temporal analysis of land use and land cover change was carried out with Google Earth Data [12]. Land cover changes related to land surface heat [13] generate a hot temperature area and then will impact the environment [14, 15]. Both arguments explain that the relationship change between land cover and land surface temperature generates hot temperatures.

Climate is the weather conditions in an area over a long period [16, 17]. The current climate classifications were made for macro-scale (> 10,000 km) and mesoscale (100-1000 km) [18]. Microclimate classification is not widely used [19]. The division of climate into smaller scales, such as in urban areas, was not widely applied until the emergence of the theory of Local Climate Zones (LCZ). LCZ is an urban land classification system based on the morphological characteristics of the city, including buildings and types of land cover [20]. The Local Climate Zone describes an area with uniform land cover, structure, building materials, and human activities within 100 meters to several kilometers [21]. Local climate zones are currently widely used as a reference in studies related to UHI because their typology is universal and can classify urban areas worldwide with the same standard [22]. Local Climate Zone is the latest method in climate classification for an urban scale.

2. RESEARCH SIGNIFICANCE

The heat effect on an urban area is called an urban heat hazard based on a threshold used by the Universal Temperature Climate Index [14, 15] for assessing the Urban Heat Hazard. It will become an urban heat hazard threat whenever urban heat signatures exceed their threshold [13]. The urban heat hazard could threaten the sustainable urban environmental quality and human well-being. The Significant of this study is to generate a model based on the Local Climate Zone to detect the Heat Hazard form the temperature impact on a human being as a complete analysis of the urban environment.

3. METHODOLOGY

The study uses Landsat 8 OLI-TIRS medium resolution to extract land cover features and generate temporal LST. Remote sensing data processing, including land cover classification and LST processing. The satellite image used in this study is the Landsat 8 OLI/TIRS Satellite Imagery which was taken in the month with the lowest rainfall with more than 20% cloud cover. The nomenclature used is the 2010 National Standardization Agency which is generalized to land cover. The classification is divided into five classes: water bodies, built-up land, open land, non-agricultural vegetation, and agricultural vegetation. The area of each class calculates every year to determine the changing area. The Khat Kappa method is a statistical calculation method used in research to test the accuracy of the data between land cover classification resulting from satellite imagery processing and the results of Google Earth validation and field surveys. The land surface temperature was obtained by calculating the satellite brightness value in identifying the land surface temperature, namely band 10 due to the Landsat 8 OLI/TIRS image, with the formula in Eq. 1.

$$\boldsymbol{L\lambda} = (\boldsymbol{M} \times \boldsymbol{DN}) + \boldsymbol{A} \qquad (1)$$

The first step is to change the image pixel value (DN) to spectral radiance, where $\boldsymbol{L\lambda}$ is the spectral radiance (wm-2SR-1-m-1), M is the multiplicative digital number in band 10, and DN is the digital number in band 10. Moreover, A is the additive value in band 10. After the spectral radiance value is obtained, it is changed to estimate the soil surface temperature value with the formula in Eq. 2.

$$\boldsymbol{T} = \frac{\boldsymbol{K2}}{\boldsymbol{In}\left(\frac{\boldsymbol{K1}}{\boldsymbol{L\lambda}}+\boldsymbol{1}\right)} \qquad (2)$$

Where T is the temperature of the satellite sensor (Kelvin), K1 is the calibration constant 1 for Landsat OLI (774853 K), and K2 is the calibration constant 2 for Landsat OLI (1321.0789 K), and $\boldsymbol{L\lambda}$ is the spectral radiance band 10. Kelvin temperature value converted to Celsius following the algorithm in Eq. 3.

$$\boldsymbol{LST(Celcius)} = \boldsymbol{T} - \boldsymbol{272,15} \qquad (3)$$

Temp-Kelvin is the estimated land surface temperature from satellite sensors and Kelvin units. The air surface temperature modeling to create a surface air temperature map by applying the existing model using a raster calculator on the ArcGISPro device.

The study area is Bogor City, located in the western part of West Java Province, Indonesia, at 106°43'30" - 106°51'00"E and 6°30'30" - 6°41'00" S seen in Fig. 1. The result used to develop LCZ and Land Surface temperatures (LST). Local Climate Zone in the study area with 1.000 x1.000 m^2 generated from 100 x 100 meters based on band thermal Landsat data and Land Cover Type. The LST value uses an algorithm to determine the effect on the environment as air surface temperature and impact on humans based Universal Thermal Climate Index uses 75 sample point LST (land Surface Temperature), Land Cover (LC), and AST (Air Surface Temperature) (Table 1).

Table 1 Air Surface Temperature Sample Point

District	Sample	Type
Center Bogor	16	LST, LC, AST
South Bogor	17	LST, LC, AST
East Bogor	15	LST, LC, AST
North Bogor	16	LST, LC, AST
Tanah Sereal	16	LST, LC, AST
West Bogor	18	LST, LC, AST

Source: Data Sources, 2022

The threshold becomes a hazard whenever the temperature of land cover types is above 32ºC with category strong heat stress [14]. The threshold is based on the Universal Temperature Climate Index [14, 15] for assessing the Urban Heat Hazard (UHH). The UHH uses spatial analysis (spatial pattern) and overlays between landcover types, LST, and Air Surface temperature (AST). Thus, all generated spatial models of Urban Heat Hazards based on the Local Climate Zone in Bogor City in 2022.

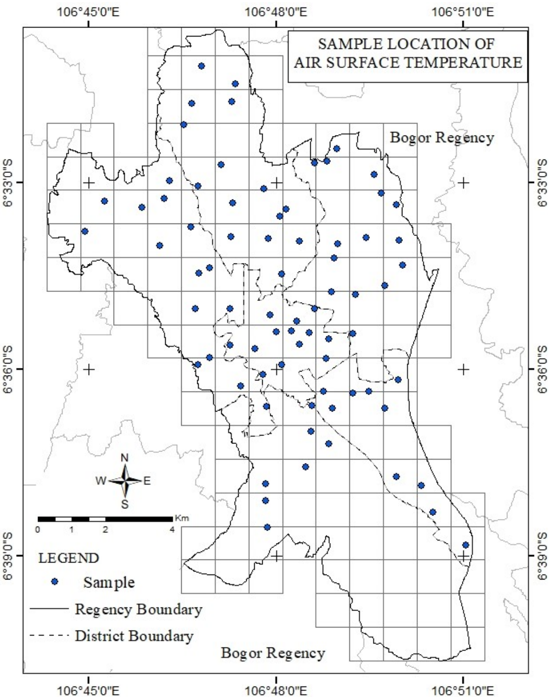

Fig.1 The study area and sample point

4. RESULT AND DISCUSSION

4.1 Green Space

Based on the results of Landsat 8 OLI image processing in 2022 (Fig. 2), it has known that the total green open space area is 4,577 ha or 39% of the area of Bogor City. The area comprises public and private green open spaces (Table 2). If it is reviewed based on Law No. 26 of 2007 concerning spatial planning, which regulates the area of green open space in urban areas, it must be at least 30% of the total city area. The district with the most significant total green open space is the South Bogor District, with 1,745 ha of green open space, whose territory has a hilly area. Meanwhile, the district with the slightest green open space is in Central Bogor District, with an area of 260 ha.

The distribution of green open space in Bogor City is not evenly distributed between regions. Most of the public green open spaces in Bogor City are urban forests and public cemeteries. Meanwhile, the most significant private green open space in Bogor City is in the southern part of the South Bogor District, which includes sub-urban areas in the form of plantations and rice fields. Conversely, the closer to the city center, the less private green open space. This decrease was caused because the downtown area tends to be a commercial area due to the development impact.

Table 2 Green Space in Bogor City, 2022

Green Space	Area (ha)	Percent (%)
Public	373	4.0
Private	4,204	35.0
Total	4,577	39.0

Source: Data Analysis, 2022

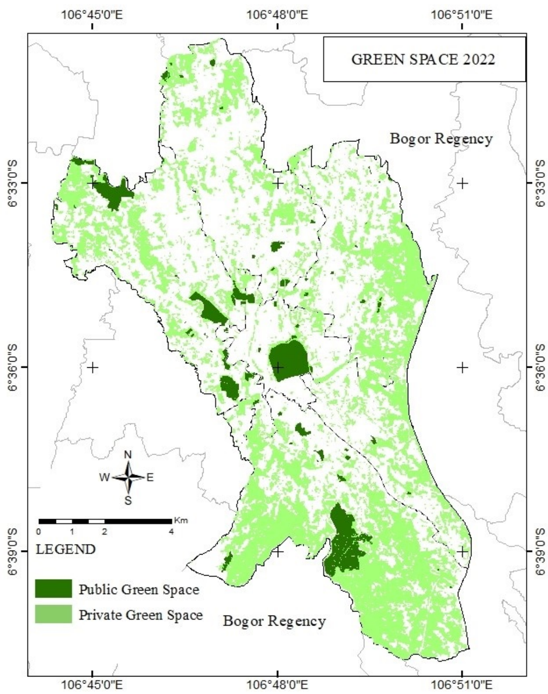

Fig.2 The Green Space in Bogor City, 2022

4.2 Develop a Model of Local Climate Zone

The land cover map was generated by processing Landsat 8 and 9 satellite imagery data recorded on 1st April 2018 and 4th April 2022. Land cover in the form of built-up land occupies about 6,459 hectares or 55% of the area of Bogor City (Fig. 3). Built-up areas are spread throughout the city and are concentrated in the downtown area. Meanwhile, for land cover in the form of open land and water bodies, each occupies an area of 1% and 4% of the total area of Bogor City. In 2022, the built-up land area will dominate Bogor City with 57% or 6,782 Ha (Fig. 4). A change in land cover caused this increase, initially in the form of open land or vegetated built-up land. The area of vegetated land is decreasing over time because various developments in the city area replace it. The area of the land cover of vegetation has decreased from 4,876 Ha to 4,577 Ha. Meanwhile, open land occupies the smallest area, 83 hectares or 1% of the total area. Lastly, the water body has an area of 408 hectares, or 3% of the total area of Bogor City (Table 3).

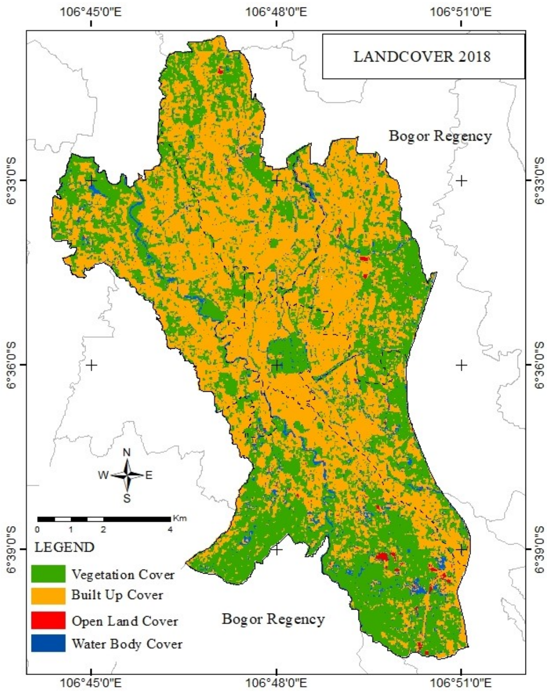

Fig.3 The Land Cover in Bogor City, 2018

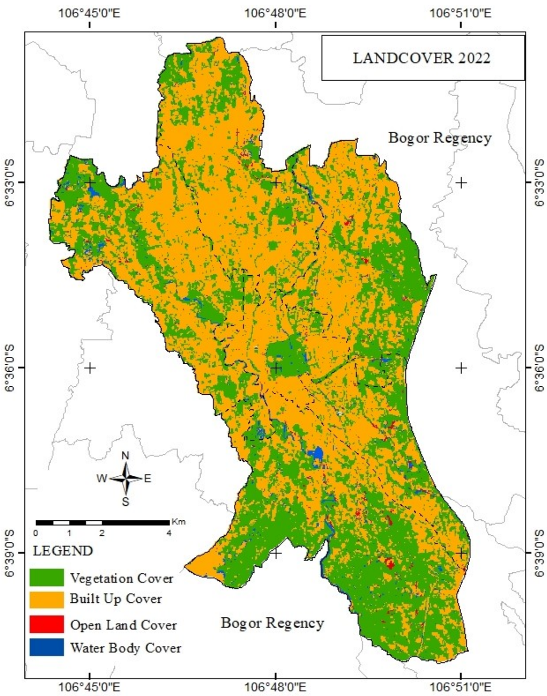

Fig.4 The Land Cover in Bogor City, 2022

Based on the Landsat 8 OLI image analysis, Bogor City's Land Surface Temperature (LST) ranges from 15-35^{o}C (Fig. 5). Bogor City during 2018 dominated LST with 26-30^{o}C an area of 7,646.26 Ha or 64.5% of the area of Bogor City. The LST with 15-20^{o}C with an area of 29.69 or 0.3% based on Bogor City (Table 4).

Table 3 The Land Cover Change (2018-2022) in Bogor City

Land Cover	2018 (Ha)	2022 (Ha)	Change (Ha)
Green Space	4,876	4,577	-299
Build-up Area	6,459	6,782	+323
Open Space	72	83	+11
Water Body	443	408	-35
Total Area	11.850	11.850	

Sources: Data Analysis, 2022

Table 4 The Land Surface Temperatures in 2018 and 2022 in Bogor City

LST (^{o}C)	2018 (ha)	2022 (ha)
15 - 20	29.69	0.00
21 - 25	2,714.15	0.00
26 - 30	7,646.26	2,640.84
31 - 35	1,459.91	8.882.01
> 35	0.00	363.15

Sources: Data Analysis, 2022

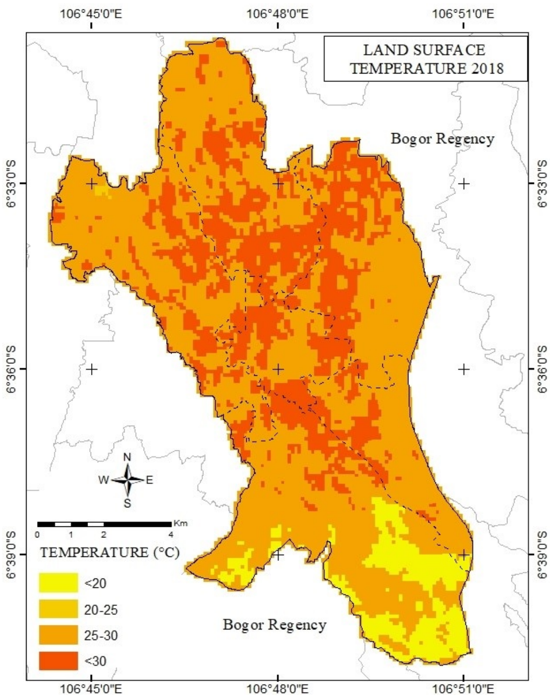

Fig.5 The Land Surface Temperature in Bogor City, 2018

Areas with high-class LST in 2018 in Bogor City spread over land cover areas with the built-up area. Areas with high-temperature LST spread in the northern part of Tanah Sareal District, the southern part of North Bogor District, southeast and north of North Bogor District, the northern part of South Bogor, the northeastern part of Central Bogor, and West Bogor District (Fig. 5).

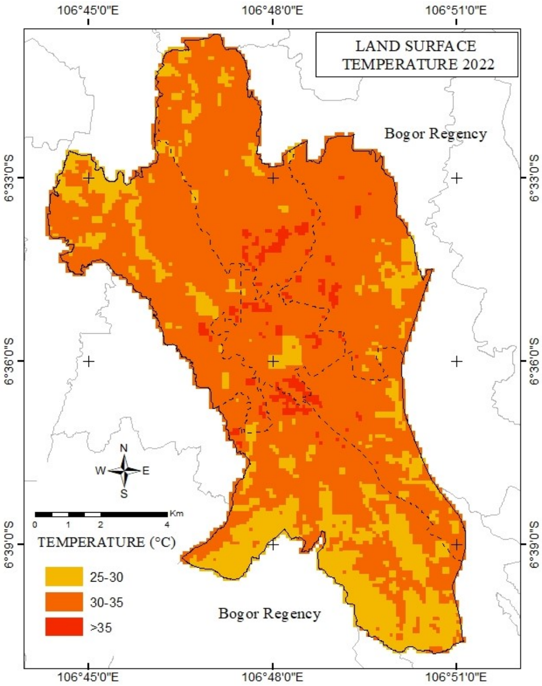

Fig.6 The Land Surface Temperature in Bogor City, 2022

Based on the results of the Landsat 9 image conversion recorded in 2022, the Land Surface Temperature (LST) of Bogor City is between 25ºC-more than 35ºC, including in the medium – very high class (Fig. 6). LST Bogor City in 2022 domination by high temperature, with an area of 8,882.01 ha or 74.4%, LST with a medium temperature laid on 2,640.84 ha or 22.6%, and very high temperature is 363.15 ha or 3% (Table 5).

Table 5 The Land Surface Temperature Change in Bogor City

LST (ºC)	2018 (%)	2022 (%)
15 - 20	0.3	0.0
21 - 25	22.9	0.0
26 - 30	64.5	22.6
31 - 35	12.3	74.4
> 35	0.0	3.0

Sources: Data Analysis, 2022

Areas with high-class LST in 2022 in Bogor City are spread over various land covers, including vegetated land, built-up land, and open land, except for water bodies. Areas with very high-class LST are spread out in the center of Bogor City with land cover, namely built-up land. Areas with moderate LST in 2022 in Bogor City spread over areas with land cover, namely vegetated land spread across the south and northwest of Bogor City (Fig. 6).

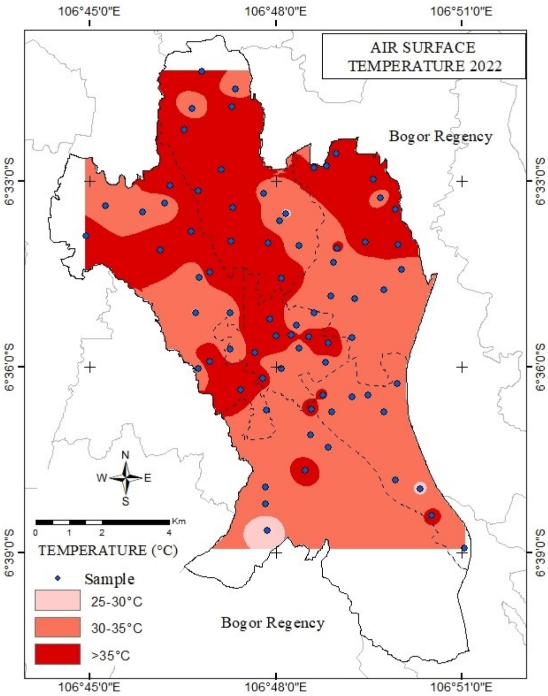

Fig.7 Air Surface Temperature in Bogor City, 2022

Based on Fig. 7 and Table 6, the AST 2022, and LST 2022-2018, saw that every landcover type had its temperature. Vegetation Covered had a temperature for AST is 29.25, with LST in 2022 being 31.77 and LST in 2018 28.52. The result saw that the landcover change would affect the LST rise between ± 3ºC. This temperature risen was the information in the study area. Secondly, the result addressed that the vegetation-covered or green area had the lowest temperature compared with other landcover types.

Table 6 Average AST 2022, LST 2018-2022 in Bogor City

Land Cover	AST (ºC)	LST 2022 (ºC)	LST 2018 (ºC)
Green Open Space	29.25	31.77	28.52
Build-up Area	36.84	33.18	30.84
Open Space	33.81	32.47	29.33

Sources: Data Analysis

Based on Land Cover, Air Surface, and Land

Surface Temperature, this research development models spatial Local Climate Zones. The model generated LCZ within 1.000 x 1.000 meters or downscaling from 100 x 100 meters. The model spatial divided become five classes (Fig. 8). LCZ 1 is a type of land cover with 100 % vegetation, LCZ 2 with 80 % is vegetation-covered, LCZ 3 covers with 60 %, LCZ 4 covers with 40 % vegetation covered and LCZ 5 covers similar or less than 20 % covered by vegetation (Table 7).

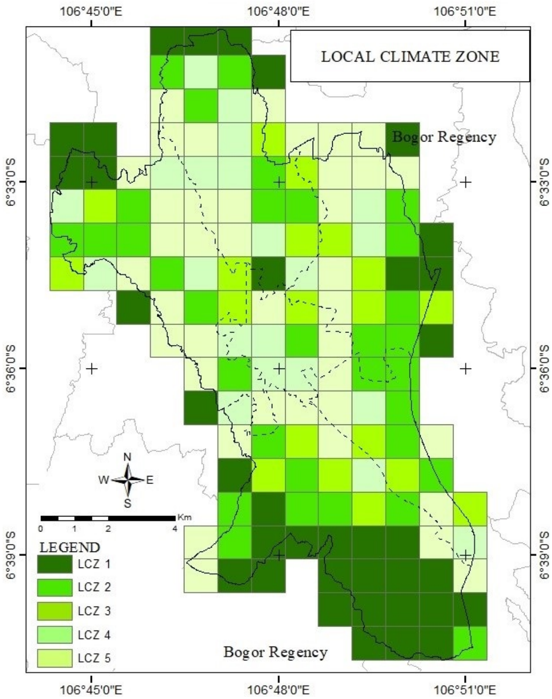

Fig.8 Model Spatial Local Climate Zone, 2022

Table 7 Local Climate Zone in Bogor City, 2022

LCZ	Total Grid	Area (m^2)	Percentage (%)
LCZ 1	25	25.000	20
LCZ 2	31	31.000	24
LCZ 3	21	21.000	16
LCZ 4	35	35.000	25
LCZ 5	20	20.000	15

Sources; Data Analysis

4.3 Spatial Model of Urban Heat Hazard

Based on Land Surface Temperature on the Universal temperature Index, Urban Heat Hazard in 2018 only maximum Moderate Hazard, and the other hand in 2022, Urban Heat Hazard getting High Heat Hazard caused the temperature upper than 35ºC (Table 8). UTCI stated that a temperature > 32ºC is critical to a human being. The ETI stated that temperature>32ºC impacts humans like low impact as getting sweet until heat stroke. Based on UTCI and ETI, the impact of high heat hazards on the human body is getting sweat and head headaches until heat stroke. Moreover, the distribution of Urban Heat Hazards spreads around Bogor City (Fig. 9).

Table 8 The Urban Heat Hazard Between 2018 and 2022 in Bogor City

LST (ºC)	2018	2022
15 - 20	No Hazard	0
21 - 25	Low	0
26 - 30	Moderate	Moderate
31 - 35	High	High
> 35	0	Very High

Sources: Data Analysis

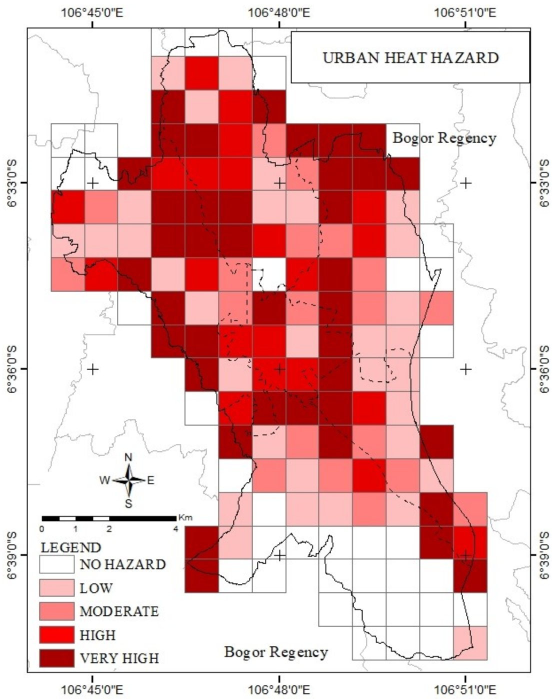

Fig.9 Model Spatial of Urban Heat Hazard in Bogor City, 2022

A previous study by Ali and Patnaik concluded that residents in summer could improve the urban climatic condition through shading and transpiration [23]. In contrast, plants release water vapor into the surroundings, increasing relative humidity and decreasing air temperature [24]. Urban Heat will not impact humans if the temperature is lowest, caused by vegetation-covered (plants) dominant in those areas. This result had similar to [23], where the dense vegetation covered the lowest temperature due to urban heat hazards. Threatening the natural ecosystem creates vulnerability to an environmental hazard [24]. The research agrees with Bekele et al., which explained the land cover changes in Bogor City. These changes will generate the heat hazard in Bogor City as Urban Heat Hazard Threat.

Generally, cities face specific urban events due to the urban setting that can alter the local microclimate with higher impacts [25]. Urbanization increases the risk of extreme heat episodes in Europe's cities due to the loss of urban green space [26]. That spatial-temporal detecting land cover changed much importance [27]. This research agrees with [28] in detecting the land cover change. The research detecting land cover changed the effect on urban heat and impact on air surface temperature as thermal comfort.

Finally, the novelty of the result is that the research improved the Local Climate Zone and could detect urban heat hazards based on a combination of vegetation-covered, build-up areas, the Air Surface Temperature, and Land Surface Temperature.

5. CONCLUSION

Based on the Universal Thermal Climate Index, the LST value uses an algorithm to determine the effect on the environment as air surface temperature and the impact on humans. This study concluded that a local climate zone determines the urban heat hazard in the city regarding urban heat signature. The urban heat hazard affects the environment, with air surface temperature getting more than 32ºC, then impacts a human with head headache, more sweat, and heatstroke. This study concluded that a local climate zone determines the urban heat hazard in the city regarding urban heat signature (AST and LST). The urban heat hazard affects the environment, with air surface temperature getting more than 32ºC, then impacts a human with head headache, more sweat, and heatstroke.

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