Infrastructure planning for climate change adaptation based on land development and surface temperature typology

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Abstract. Rapid population growth has led to the development of built-up land in urban agglomeration areas, such as the Surakarta, Boyolali, Sukoharjo, Wonogiri, Sragen, and Klaten (Subosukowonosraten) region. This rapid growth of built-up land is synonymous with the phenomenon of urban sprawl, which contributes to climate change. Consequently, surface temperatures have also increased, indicating the impact of climate change. This research aims to examine the relationship between built-up, surface temperature, and green space to provide a basis for implementing climate change adaptation efforts. Spatial analysis techniques will be employed in this study, utilizing satellite image data from 2000 and 2023 to establish the connection between these variables. The research findings will provide recommendations for infrastructure planning on climate change adaptation.

1 Introduction

Rapid population growth has led to the development of built-up land in urban agglomeration areas, such as the Surakarta, Boyolali, Sukoharjo, Wonogiri, Sragen, and Klaten (Subosukowonosraten) region. Changes in land use resulting from urban sprawl not only change the physical composition of an area but also adversely affect local ecosystems. This rapid growth of built-up land is synonymous with the phenomenon of urban sprawl, which contributes to climate change. One of the most significant challenges in preventing and mitigating the impacts of climate change is the dramatic increase in urban populations [1]. Therefore, research in urban areas is urgently needed because the sources and impacts affect these regions simultaneously. Consequently, surface temperatures have also increased, indicating the impact of climate change.

Urban and regional planners must enhance their collaboration in the retrofitting of existing infrastructure and buildings, as well as in the planning of new developments. By integrating additional 'blue' and 'green' infrastructure, they can address prevalent challenges

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and more effectively anticipate and mitigate the adverse effects associated with current and future climate change.

This research aims to examine the relationship between land development, surface temperature, and green space to provide a basis for implementing climate change adaptation efforts.

2 Methods

The study area for this paper encompasses the urban region and its suburbs in Central Java Province, Indonesia, which are at risk of climate change impacts and require adaptation measures. The focus is on Surakarta City, along with its surrounding suburbs, which include Boyolali, Sukoharjo, Wonogiri, Sragen, Klaten, and Ngawi Regencies. Land development and surface temperature typologies were analyzed using descriptive statistics and geospatial analysis. Land development typologies, land surface temperature (LST), and green open space were measured using satellite imagery data from 2000 and 2023, collectively referred to as Landsat. The LST and green open space data are sourced from the Landsat 5, 7, 8, and 9 satellites. This is a Landsat Spectral Indices products courtesy of the U.S. Geological Survey Earth Resources Observation and Science Center. The built-up area from land development analysis used to measure and understand the distribution of development in an area, particularly in the context of urban expansion. Data on built-up land was obtained from land development typology records for the years 2000 and 2023.

The next stage involves analyzing land surface temperature and green open space using satellite imagery from 2000 and 2023. Google Earth Engine (GEE) was used for data acquisition, where Landsat data is readily available for direct use. Each Landsat dataset utilized is from Collection 2 Level 2 Tier 1, indicating that the data has been corrected for Surface Reflectance (SR) to ensure its suitability for land analysis. Detailed information about each Landsat band can be found in Table 1.

Table 1. Landsat band used.

Landsat 8 and 9	Landsat 5 and 7	Type
Band 2	Band 1	Blue
Band 3	Band 2	Green
Band 4	Band 3	Red
Band 5	Band 4	Near Infrared
Band 6	Band 6	Short wavelength infrared 1
Band 7	Band 7	Short wavelength infrared 2
Band 10	Band 6	Thermal

In data acquisition for each year, a temporal median composite was used to combine several images from one year into one. The goal is to reduce anomalies, minimize cloud cover, and correct errors in Landsat 7. For example, in Landsat for the year 2000, a combination of Landsat 5 and 7 can be used on images taken from 2000-01-01 to 2000-12-31. After we captured the images, we performed cloud removal for each image. Each image affected by clouds was then combined, and the median value was taken to create one median composite image.

LST (Land Surface Temperature) data was acquired from band 10 (Landsat 8 and 9) and band 6 (Landsat 5 and 7). This data has been corrected to Surface Temperature in Collection 2 Level 2 Tier 1, so only a value scale needs to be applied. The data value scale to convert to Celsius units follows the formula [2,3]:

$$LST = Data * 0.00341802 + 149 - 273.15 \quad (1)$$

The green open space is derived utilizing the Enhanced Vegetation Index, which employs mathematical operations based on Landsat spectral bands [4].

$$EVI = 2.5 * ((NIR - Red) / (NIR + 6 * Red - 7.5 * Blue + 1)) \quad (2)$$

NIR refers to the Near Infrared Band, Red refers to the Red band, and Blue here refers to the Blue band in Table 1.

3 Results and Discussions

It's important for urban planners, environmental scientists, and policymakers to explore the typology of land development, surface temperature, and green open space. This understanding will be instrumental in determining effective climate change adaptation strategies, especially in infrastructure planning.

3.1 The land development

The land development in the study area shows that there has been a significant change. As depicted in Figure 1, the built-up area in 2023 increased compared to 2000. This land use change is primarily focused on the urban areascentered on the urban area, which is the core of the Subosukowonosraten area, including Ngawi. Starting from the city of Surakarta and extending into the surrounding suburbs, with primary roads serving as channels for the transformation of developed land.

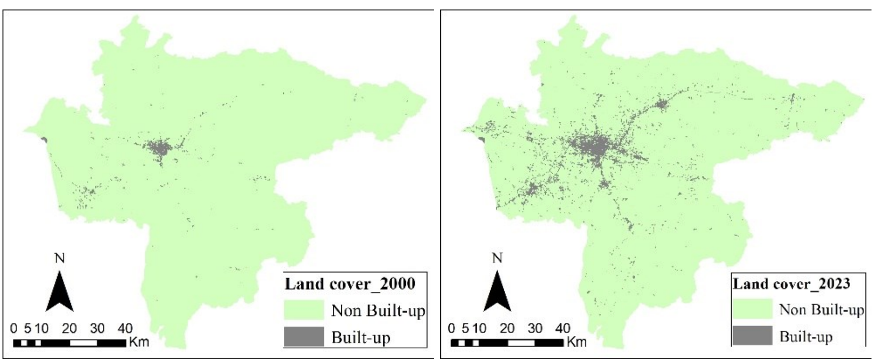

Fig. 1. The development of built-up and non built-up land from 2000 to 2023 at study area.

Some research has also investigated the relationship between changes in land use and land cover (LULC) and the intensity of the urban heat island (UHI) effect, which subsequently contributes to climate change impacts. Zhang [5] predicted that there would be significant expansions in built-up areas, which would lead to corresponding increases in land surface temperature (LST). Based on the results of spatial analysis of land development, it can be seen that the built-up area has grown from 2000 to 2023. The built-up area on 2023 has grown 26,932 hectares or 374% from built-up area on 2000. This increase in built-up area can have an impact on reducing green space and increasing surface temperatures.

3.2 The land surface temperature

Between 2000 and 2023, land surface temperatures in the study area predominantly increased by 1 degree Celsius (Table 2). This rise in temperature is likely associated with the previously described land changes. Nonetheless, an anomaly is observed in Surakarta City, where temperatures have decreased. This requires further study to obtain more reliable data and to comprehend the conditions prevailing in the area.

Table 2. Land surface temperature difference between 2023 and 2000.

City	Boyolali	Sukoharjo	Surakarta	Karanganyar	Klaten	Ngawi	Sragen	Wonogiri
^{0}C	1.57	1.38	-1.18	1.12	1.26	0.96	0.43	1.95

Figure 2 presents the outcomes of the land surface temperature analysis conducted in Surakarta City and its surrounding suburbs. Despite a decline in the average temperature within Surakarta City from 2000 to 2023, it remains categorized within the highest temperature group. Conversely, in other regencies, there has been an increase in temperature, resulting in an elevation to a higher classification group.

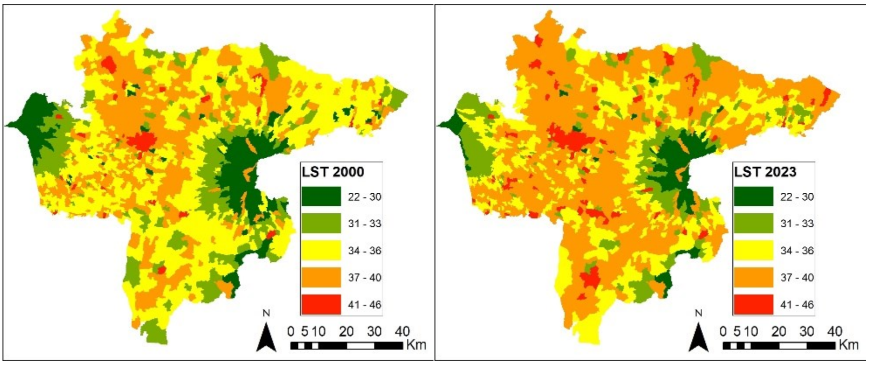

Fig. 2. The land surface temperature (in Celsius) from 2000 to 2023 at study area.

3.3 The green open space

In addition to identifying trends in land surface temperature change, it is crucial to examine trends in vegetation availability. A study conducted in Algeria, North Africa, indicated that LST can be utilized to assess soil water conditions, including the availability of water essential for the sustainability of vegetation [6]. Consequently, a significant relationship exists between LST and vegetation availability. Based on the analysis of satellite imagery from the years 2000 and 2023, there has been an overall decrease of 19% in green space within the study area. This reduction corresponds to an increase in the average LST of 1.2 degrees Celsius during the same period. The analysis results indicate that the expansion of built-up areas significantly affects the availability of green space in the study area.

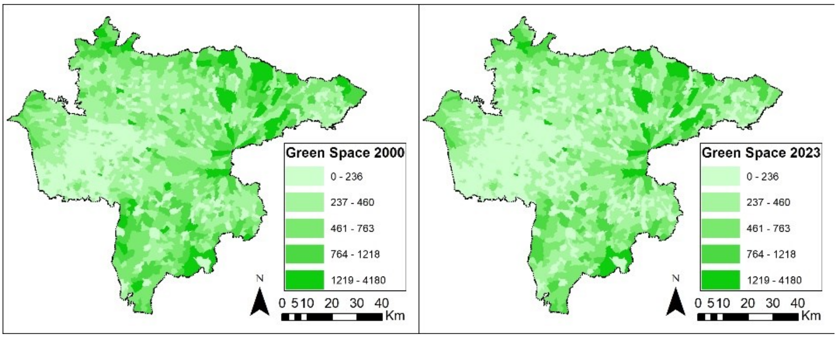

Fig. 3. The green space from 2000 to 2023 at study area.

3.4 The infrastructure planning for climate adaptation

By overlaying LST data with the changes in built-up areas from 2000 to 2023, we can identify the priority areas for infrastructure planning as seen on Figure 4. Cities primarily promote greenery through parks, forests, open spaces, and gardens. Increasing evidence indicates that these initiatives can enhance the quality of life in urban areas. Around the world, cities are implementing these green actions to mitigate the impacts of climate change [1,7,8].

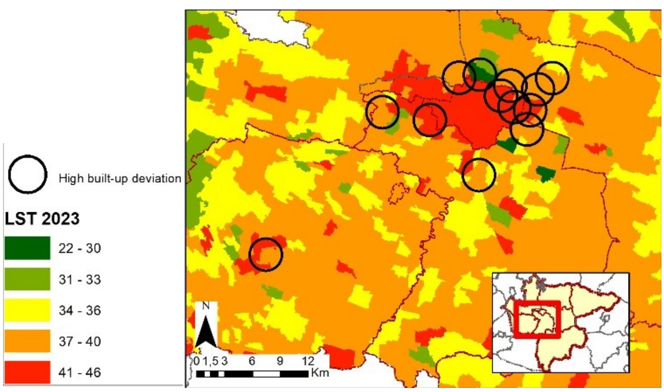

Fig. 4. The priority areas for infrastructure planning.

Numerous studies illustrate that green infrastructure can significantly contribute to climate change adaptation. Elmqvist et al. [9] identified that a 10% increase in tree canopy cover resulted in a reduction of urban temperatures by 3–4 °C in the cities under investigation. In a similar vein, research conducted by Moreno-García [10] demonstrated that urban parks characterized by mixed tree cover and open spaces mitigated night time temperatures by 3.0 °C to 4.5 °C in comparison to surrounding built environments. Furthermore, Almeida et al. [11] revealed that green spaces and parks exceeding 250,000 m² exert a positive influence on the urban climate. Nevertheless, given the limited availability of contiguous large open spaces in numerous urban regions globally, it remains feasible to attain urban heat island (UHI) mitigation benefits through the development of multiple smaller urban parks.

4 Conclusion

Research results have shown that from 2000 to 2023, there were changes in land use, green space, and surface temperature. Land development has led to an increasingly large built-up

area, which corresponds to the expansion of urban areas. This development has also impacted the decreasing area of green space, as it seeks to accommodate the needs for residential space and built infrastructure for the community. As a result, land surface temperature has increased, indicating the impact of climate change. The rising surface temperature highlights the need for infrastructure planning to adapt to climate change. Therefore, green and blue infrastructure should be prioritized in spatial planning as an effort to address climate change.

This research was supported by Universitas Sebelas Maret Indonesia grant (grant number 194.2/UN27.22/PT.01.03/2024) for International Collaboration research scheme.

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