Bogor Botanic Gardens as a nature-based solution for mitigating urban heat island and microclimate regulation

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Abstract. This paper explores the role of Bogor Botanic Gardens (BBG) as a form of Nature-Based Solution (NBS) to mitigate Urban Heat Islands (UHI). Time series analysis of LANDSAT 8 OLI thermal band and Normalized Difference Vegetation Index (NDVI) was done from 2013 to 2020 using Google Earth Engine. Land Surface Temperature (LST) from Bogor and BBG were calculated, compared, and annual UHI areas were derived. The relationship of LST and NDVI were also explored annually to describe the effect of vegetation towards LST with linear regression. Overall, Bogor experiences a decrease of mean LST from 30.67°C and a maximum of 39.14°C in 2013 to 27.07°C and a maximum of 34.35°C in 2020. However, the inside of BBG is cooler with temperature ranging from 28.41°C and a maximum of 35.62°C in 2013 to 24.25°C and a maximum of 29.41°C in 2020. This is an effect of vegetation inside the BBG that regulate microclimate in its surrounding. It can be seen in the negative correlation between NDVI and LST observed with $r^2$ ranging from 0.27 to 0.82. While UHI areas tended to increase from 8220 ha in 2013 to 8926 ha in 2020, BBG consistently acts as an urban cool island in the middle of UHI. Therefore, heat mitigation is proven to be one of the environmental services provided by BBG.

1. Introduction

According to The Economics of Ecosystems and Biodiversity (TEEB) [1], environmental/ecosystem services types relevant to cities including: provisioning services (food, raw materials, freshwater, and medicinal resources), regulating services (local climate and air regulation, carbon sequestration and storage, moderation of extreme events, wastewater treatment, erosion prevention and maintenance of soil fertility, pollination, biological control), habitat or supporting services (maintaining habitat and genetic diversity), and cultural services (recreation, tourism, aesthetic, and spiritual experience). These services also apply to botanic gardens, and Bogor Botanic Gardens (BBG), which was established in 1817, provide a large vegetated area in the middle of Bogor City, West Java, Indonesia.

According to Botanic Gardens Conservation International (BGCI) [2], plant diversity can weather the effect of climate change. Botanic Gardens (BGs) can also play a role in supporting society to adapt to global change [3]. On the other hand, there is a lack of awareness related to the link between botanical gardens and climate mitigation [4]. One of the most studied functions of BGs to weather climate change is their role in providing carbon stock and sequestration [5][6]. BGs can also educate the general public on the impact of climate change and how to mitigate and adapt to it [7]. Recently,
more research has been done on the role of BGs as urban green space to weather climate impact, especially temperature [8].

Bogor Botanic Gardens is situated in the heart of Bogor City, and a lot of research has been done to evaluate the environmental services provided by it. While other environmental services such as conservation value, oxygen production, and carbon sequestration have been thoroughly researched [6], recreation, tourism, and air regulation [9, 10]; BBG environmental services for local climate regulation in urban settings has rarely been studied.

On the other hand, Bogor has been experiencing a lot of development, which increased built-up environment with impervious surface from 8.06% in 2014 to 10.26% in 2015, and 9.75% in 2017 [11]. One of the effects of urban development on the local climate is Urban Heat Island (UHI), where urban areas are warmer than the surrounding areas. This phenomenon can be observed through remote sensing [12][13]. Botanic gardens can also protect to temperature extreme [14]. Therefore, there is a need to evaluate BBG’s potential to regulate land surface temperature to mitigate UHI.

2. Materials and Methods
The study area is the city of Bogor, West Java, Indonesia. Bogor Botanic Gardens (BBG) covers an area of 87 hectares and is situated in the heart of the city at 6°35'32.69" - 6°36'13.39'S and 106°47'39.80" - 106°48'17.56" E, and Bogor development is conveniently encircling BBG [15]. BBG is the oldest botanic garden in Indonesia, with a collection of 12,370 specimens from 3555 identified species and 1255 unidentified, with the most dominant families being Areceaceae, Apocynaceae, and Annonaceae [16].

While it is considered a city, the development of Bogor is not homogenous. Therefore, suburban areas were defined as the less developed areas with less impervious built-up areas. The study area can be seen in Figure 1.

Figure 1. Study area, showing Bogor Botanic Gardens (BBG) situated in the middle of Bogor City.
LANDSAT 8 OLI images from 1st January 2013 to 31st December 2020 were used in Google Earth Engine (GEE) [17][18]. Thermal bands were used to derive Land Surface Temperature (LST) using this formula:

\[ T = \frac{TB}{1 + (\lambda \times \frac{TB}{c^2}) \times \ln(e)} \]  

Where: TB is the digital number of the thermal band, \( \lambda \) is the wavelength, \( c^2 \) is \( \frac{h \times c}{s} = 1.4388 \times 10^{-2} \) m K (h is Planck constant, s is Boltzmann constant, and c is the speed of light), while e is the emissivity. Emissivity is calculated using this formula:

\[ E = 0.017 \times PV + 0.963 \text{ and } PV = \left(\frac{NDVI - NDVImin}{NDVImax-NDVImin}\right)^2 \]  

Land Surface Temperature (LST) from Bogor and BBG were calculated, compared, and annual UHI areas were derived. If BBG is not a part of the UHI, BBG is proven to be an Urban Cool Island (UCI), which is the opposite [23]. The relationship of LST and Normalized Difference Vegetation Index (NDVI) were also explored annually to describe the effect of vegetation towards LST with linear regression. The flowchart of the analysis can be seen in Figure 2.

3. Results and Discussion

Overall, Bogor experiences a decrease of mean LST from 30.67°C and a maximum of 39.14°C in 2013 to 27.07°C and a maximum of 34.35°C in 2020. However, the inside of BBG is cooler with temperature ranging from 28.41°C and a maximum of 35.62°C in 2013 to 24.25°C and a maximum of 29.41°C in 2020. The period from 2016-2017 is the coolest period in this study, mainly due to Indonesia experiencing La Nina in this period, with heavier rain than usual [24]. After the La Nina effect subsided, LST returned to its previous state in 2015 but decreased again in 2019-2020. The probable main cause is the removal of human activities due to the COVID-19 pandemic [25].

Even though thermal fluctuations occurred, BBG consistently has lower temperatures than its surroundings, as explained by Figure 3. The temperature difference ranged from 0.42°C in 2016 to 2.82°C in 2020. The lowest difference happened in 2016, where La Nina occurred, bringing more rain than the normal lowering temperature inside and outside BBG [24]. On the other hand, the temperature inside BBG is still lower than the outside, as seen in Figure 4.
Figure 3. The mean and maximum temperature difference between Bogor City and Bogor Botanic Gardens (BBG).

Figure 4. Distribution of land surface temperature in Bogor city. Note that the middle section is the Bogor Botanic Gardens (BBG), where the temperature tends to be lower than its surroundings.
On the other hand, UHI areas tend to increase from 8220 ha in 2013 to 8926 ha in 2020, as seen in Figure 5, but BBG is consistently acting as an Urban Cool Island (UCI) in the middle of UHI. Unlike UHI, UCI has been rarely reported. The existence of UHI and UCI pairs has also been studied in New York [26], Hongkong [27],[23], and London [28]. However, each of those cities has its own cause. Hongkong is a high-rise city, and the main cause of UCI is reduced radiation because of haze and air pollution [27] and urban morphology [23]. On the other hand, New York has UHI/UCI pair due to the sea breeze and cold fronts [26]. Contrary to those cities, the Bogor UHI/UCI pair is due mainly to BBG since it can maintain lower temperatures than its surroundings. Based on the result of regression analysis, this is an effect of vegetation inside BBG that regulates microclimate in its surrounding, which can be seen by the negative correlation between NDVI and LST observed with annual $r^2$ ranging from 0.27-0.82. This result is consistent with [29] and [30], who reported a negative correlation between NDVI and LST.

![Annual Urban Heat Island Extent](image)

**Figure 5.** The extent of Urban Heat Islands (UHI) in Bogor tends to increase in size even though the area in Bogor Botanic Gardens (BBG) remains an Urban Cool Island (UCI).

Our results show that BBG can weather climate impact, as it is supposed to be one of its environmental services [14],[31]. The latest trend in the development of botanic gardens is that botanic gardens such as BBG should help reforest cities to help regulate oxygen and local climate as a part of urban green space [32], [33]. In the case of Bogor, BBG serves as the hub for ecological connectivity between other urban green spaces [34]. Aside from providing temperature regulation, BBG also provide 1754.84 tons of oxygen per year and sequester 658.06-ton carbon per year [6]. Therefore, botanic gardens, such as BBG, should be integrated with the urban planning framework by the local government [4].

Aside from conservation, the most prominent utilization of BBG is tourism [15]. Since BBG’s vegetation has become the main tool for mitigating urban heat, care must be taken in the operational and development of nature-based tourism in BBG, especially in increasing discipline to conservation and tourism rules within BBG. According to [35], BBG has already implemented sustainable tourism to some degree, but it lacks discipline and participation. Therefore focusing on this aspect is crucial for the sustainability of the environmental service. Furthermore, as seen in Figure 4, some areas in BBG have higher temperatures than the rest due to it being built-up areas [22]. Therefore, the other important aspect is to manage the development of built-up areas inside BBG since it will reduce vegetation cover and increase surface temperature.
4. Conclusion
According to Land Surface Temperature (LST) of Bogor City, Bogor Botanic Gardens (BBG) acts as an Urban Cool Island (UCI). This environmental service is mainly due to the vegetation inside BBG that can regulate microclimate and air quality. Therefore, maintaining BBG as a healthy urban green space is crucial for the well-being of Bogor City itself.

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