Spatial Analysis of Light Pollution Dynamics Around Bosscha Observatory and Timau National Observatory Based on VIIRS-DNB Satellite Images

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Abstract. Bosscha Observatory is the largest and oldest observatory in Indonesia that has been actively doing astronomical research since 1928. Bosscha Observatory was originally very suitable for observing astronomical objects because of its ideal night sky conditions and covered most of the northern and southern sky areas. However, starting at the end of 1980, the quality of the night sky at Bosscha Observatory has decreased along with the development of cities around the observatory. Therefore, the construction of a new observatory in Indonesia is currently underway, i.e. the Timau National Observatory. One of the main causes of the decreasing quality of the night sky at Bosscha Observatory is light pollution. Light pollution is one form of pollution caused by excessive light outside the room released into the sky, causing an increase in brightness of the night sky. The brightness increasing of the night sky causes relatively faint astronomical object, e.g. Milky Way Galaxy that is difficult to observe. Based on the analysis of the dynamics of light pollution in a radius of 20 km from Bosscha Observatory and at a radius of 90 km from the Timau National Observatory in 2013-2017 using VIIRS-DNB satellite imagery, it is known that there is a wide change in light pollution for the very low, low, medium, high, and very high. The average area of light pollution at a radius of 20 km from Bosscha Observatory for the category of very low, low, medium, high, and very high categories experienced a rate of $41.3 \pm 135.2 \text{ km}^2 / \text{year}$, $5.9 \pm 97.2 \text{ km}^2 / \text{year}$, $15.1 \pm 14.6 \text{ km}^2 / \text{year}$, $18.0 \pm 42.6 \text{ km}^2 / \text{year}$, and $2.1 \pm 10.2 \text{ km}^2 / \text{year}$. The rate of increase in the extent of light pollution for the medium, high, and very high categories occurs south of the Bosscha Observatory, which is towards the city of Bandung. The average area of light pollution in a 90 km radius from the Timau National Observatory for the very low, low, medium, and high categories experienced a rate of $20.8 \pm 43.4 \text{ km}^2 / \text{year}$, $22.1 \pm 40.9 \text{ km}^2 / \text{year}$, $3.0 \pm 7.3 \text{ km}^2 / \text{year}$, and $1.7 \pm 7.3 \text{ km}^2 / \text{year}$. Therefore, the night sky in the 128-268 degrees azimuth direction at Bosscha Observatory is relatively not ideal as a location for observing astronomical objects, and the Timau National Observatory is still relatively ideal as a location for observing astronomical objects, but it is necessary to monitor the dynamics of light pollution in the direction of 207-215 degrees azimuth which leads to Kupang City.

Keywords: Light Pollution Dynamics, Bosscha Observatory, Timau National Observatory, and VIIRS-DNB Satellite Images

1. Introduction

Since the invention of the electric lamp in 1879 by Thomas Alva Edison, the use of artificial light for outdoor lighting at night has increased. Gradually, along with increasing population, an increase in the amount of artificial light as outdoor lighting causes an increase in the brightness of the night sky and
produces light pollution. Light pollution is one form of environmental pollution due to artificial light at night (ALAN), where the artificial light at night is increasingly out of control, both in terms of number and method of installation. Light pollution is defined as artificial light that increases the brightness of the sky by 10% of the brightness of the natural sky above a height of 45° [1]. According to the International Dark Sky Association (IDSA) [2], light pollution has several types, i.e. sky glow - visible light in the urban sky due to artificial light, glare - dazzling artificial light, light trespass - the entry of light that is not desirable and not needed from the outside into a person's home resulting in difficulty sleeping, and light clutter - a group of artificial light sources that causes visual disturbances. Astronomers are the first realizing that the dark sky has been lost due to light pollution [3]. Light pollution is caused by excessive use of artificial outdoor lightings such as street lighting, fluorescent markers, and luminous advertising board lights [4]. Light pollution is increasing along with the development of an area, especially urban areas. The California Energy Commission or the California Energy Commission in 2005 stated that in the United States, about 6% of 4,054 million megawatt hours (MWh) of electricity was used for outdoor lighting and an estimated 30% of outdoor lighting was a source of light pollution [5]. Light pollution prevents astronomers from getting a clear night sky and reducing the visibility of the stars [6]. Based on the four main components classified as light pollution, sky glow is the main cause of the decline in the quality of the night sky around the observatory. Sky glow is formed from the reflection and scattering of light by molecules and aerosols in the atmosphere [7] and many cities that produce sky glows that can be observed as far as 100 miles [5]. This shows that light pollution is the main problem currently faced by observatories around the world, one of which is the Bosscha Observatory in Indonesia.

Bosscha Observatory is one of the observatories in Southeast Asia and is the largest observatory in Indonesia. The Bosscha Observatory was established in 1923 and in 1928, the Zeiss double refractor telescope was installed at the Bosscha Observatory. The existence of the Zeiss double refractor telescope in 1928 became the beginning of the Bosscha Observatory in conducting astronomical observations and research. At the beginning of the establishment of the Bosscha Observatory, Lembang was chosen as an observatory location because, at that time, Lembang was a hilly area surrounded by tea plantations and had a dark night sky, making it ideal for astronomical observations. In addition, the location of the Bosscha Observatory is a strategic location because it covers most of the northern and southern sky areas, considering only a few observatories in the world in the equatorial region.

However, starting in late 1980, the night sky conditions at Bosscha Observatory experienced a decline. This was due to the development of cities around the Bosscha Observatory, i.e. the City of Lembang and the City of Bandung. The development of these cities led to a change in land use around the Bosscha Observatory, i.e. the North Bandung Region from the forest, plantation, and livestock areas to the area of built land (settlements and hospitality). The developed land area is expanding and increasing the use of artificial light for lighting at night. An increase in the amount of artificial light for lighting at night causes light pollution and produces a light dome above the cities around the Bosscha Observatory. Therefore, the construction of a new observatory in Indonesia is currently underway, i.e. the Timau National Observatory. The problem of light pollution around the Bosscha Observatory is a spatial problem, so to overcome it, it is necessary to analyze the dynamics of light pollution spatially, one of them is by using VIIRS-DNB satellite imagery and as a comparison, a similar study was carried out around the national observatory of Timau.

VIIRS-DNB (Visible Infrared Imaging Radiometer Suite-Day / Night Band) satellite imagery is a night-time satellite image managed by the Earth Observation Group, National Oceanic and Atmospheric Administration (NOAA), where this satellite image measures the radiance of night-time lighting on the Earth surface in the new Moon phase [7]. Nightly satellite imagery of VIIRS-DNB has visual and infrared wavelength channels for radiometric measurement of land, atmosphere, cryosphere, and oceans. Nightly satellite imagery data of VIIRS-DNB is used to measure cloud and aerosol objects, ocean color, sea and land surface temperature, ice movement and temperature, hotspots, and earth albedo. Climatologists use the VIIRS-DNB data to increase understanding of climate change globally. VIIRS-DNB satellite imagery provides cloud imagery during the day and some image data in the infrared channel for cloud imaging applications day and night. In addition, VIIRS-DNB
image data is also used to measure weak light radiations for studies of lighting energy estimates [8]. VIIRS-DNB satellite imagery was integrated with sky brightness measurement data using CCD and SQM to make light pollution atlases around the world [9]. Thus, VIIRS-DNB satellite imagery can be used to analyze the dynamics of light pollution at a radius of 20 km from Bosscha Observatory and at a radius of 90 km from the Timau National Observatory.

2. Methodology

The object of this research is light pollution around Bosscha Observatory (107° 37' E; 6° 49' S; altitude 1300 m above sea level) and Timau National Observatory (123° 56,794' E; 9° 35,77' S; altitude 1281 m above sea level) with 20 km radius and 90 km from the observatory. The data used in this study is the VIIRS-DNB nighttime satellite data in 2013-2017. The classification of light pollution levels is divided into 5 classes (very low, low, medium, high, and very high). The classification process from VIIRS-DNB satellite imagery uses two classification methods, the unsupervised classification method for mapping the level of light pollution around Bosscha Observatory and the supervised classification method for mapping the level of light pollution around the Timau National Observatory.

| Class     | Digital Number Value ($10^9$ nW/cm²/sr) |
|-----------|-----------------------------------------|
| Very Low  | -0.13 – 0.90                            |
| Low       | 0.91 – 3.40                             |
| Medium    | 3.41 – 8.37                             |
| High      | 8.39 – 18.16                            |
| Very High | 18.20 – 86.01                           |

2.1. Unsupervised Classification

The process of making a map of light pollution around the Bosscha Observatory with a radius of 20 km is to classify the level of light pollution based on satellite imagery at night VIIRS-DNB. The method used in the classification process is the unsupervised method with the K-Means algorithm. The unsupervised classification process is carried out without user intervention in selecting a group of data sets that will be used as a reference for classification [10]. The user role is only limited to determine the number of classes or clusters and the number of iterations. K-Means algorithm is implemented by moving a set of clusters (center) recursively using the closest distance to mean approach until the center location of the cluster does not change, or until changes from one iteration to the next iteration are less than some predetermined thresholds [10]. Thus, the classification process with this algorithm produces a relatively accurate classification. The classification process using the K-Means algorithm is iterated 10 times to get a stable classification result.

2.2. Supervised Classification

The process of making a map of light pollution around the National Timau Observatory with a radius of 90 km is to classify the level of light pollution based on satellite imagery at night VIIRS-DNB. The method used in the classification process is a supervised method with a Minimum Distance algorithm. The supervised method was chosen because most of the area around the Timau National Observatory to a radius of 90 km is relatively dark. If the classification process uses the unsupervised method, the classification process is not in accordance with the actual conditions. Therefore, the supervised method is selected and the range of image pixel values for each class of light pollution is adjusted to the range of image pixel DN values around the Bosscha Observatory. Then, the Minimum Distance algorithm is selected because this algorithm performs a classification process similar to the K-Means algorithm. The Minimum Distance Algorithm classifies based on the closest distance of the sample pixels to cluster center points.
3. Result

3.1. Light Pollution Map 20 km From Bosscha Observatory

Figure 1. Light Pollution Map Around Bosscha Observatory in 2013-2017 (left to right from up to down)
3.2. Light Pollution Map 90 km From Timau National Observatory

Figure 2. Light Pollution Map Around Bosscha Timau National Observatory in 2013-2017 (left to right from up to down)

4. Discussion
4.1 Light Pollution Around Bosscha Observatory
Based on the light pollution level map around the Bosscha Observatory (figure 1), it is known that the distribution of the level of light pollution around the Bosscha Observatory is relatively uneven. The level of light pollution for the very low and low class is mostly located in the northern region of Bosscha Observatory, while the level of light pollution for the medium, high, and very high class is mostly in the southern region of Bosscha Observatory or in the 129-268 degrees azimuth.
Agglomeration the level of light pollution around the Bosscha Observatory is strongly influenced by its geographical conditions. The northern region of Bosscha Observatory is a mountainous and hilly area, while the southern region of Bosscha Observatory is a basin area and is an urban area. Based on figure 1, the city of Bandung and Cimahi are areas that have high levels of light pollution. The dynamics of light pollution around the Bosscha Observatory and Timau National Observatory can be analyzed based on the area changes of each class of light pollution levels in 2013-2017. Based on the VIIRS-DNB image data in 2013-2017, it is known that there is area change of each class. The following is a graph of area changes in the extent of each category of light pollution levels around the Bosscha Observatory.

![Figure 3. Extensive Area Changes in Each Class of Light Pollution Level Within Radius 20 km Centered from Bosscha Observatory.](image)

Based on Figure 3, it is known that the area for very low classes did not experience very significant changes. In 2015, the area for very low classes decreased from 859.1 km$^2$ to 705.8 km$^2$. But in 2015 it increased to 836.7 km$^2$, and then in 2017, it decreased to 691.8 km. The area in 2017 is the lowest area for very low classes. Then, the area for the low class fluctuated. In 2014 and 2016 the area was decreased, i.e. 168.6 km$^2$ and 190.7 km$^2$. The area for the class is showing an increase from 2013-2017. Average changes in area per year for each class start from very low to very high classes of -41.3 ± 135.2 km$^2$/year, 5.9 ± 97.2 km$^2$/year, 15.1 ± 14.6 km$^2$/year, 18.0 ± 42.6 km$^2$/year, and 2.1 ± 10.2 km$^2$/year. The average area change of light pollution for the high class has the highest value compared to the other classes. This shows that there is an increase in light pollution in the area around the Bosscha Observatory within a radius of 20 km. The average change in light pollution for the high category will certainly continue to increase along with the development of urban areas in the south and north of the Bosscha Observatory.
Based on Figure 1, the direction of the development of light pollution levels for the medium, high, and very high class in the south of the Bosscha Observatory tends to move eastward. This shows that the development of industrial areas in the eastern city of Bandung contributes to an increase in light pollution in the city of Bandung. Then, the development of the level of light pollution for the high category in the north of the Bosscha Observatory shows a relatively insignificant change in the area. However, because of its proximity to the Bosscha Observatory (<1 km), light pollution in the City of Lembang also affects the observation of astronomical objects in the northern sky even though it is not as severe as in the southern sky. This is because the City of Lembang has a much smaller administrative area compared to the cities of Bandung and Cimahi. Nevertheless, it is necessary to periodically monitor the dynamics of light pollution in the northern region of Bosscha Observatory.

4.2 Light Pollution Around Timau National Observatory

Based on the light pollution level map around the observatory (figure 2), it is known that within a 90 km radius, the Timau National Observatory area is mostly in very low class. Low, medium and high classes can only be found around Kupang City. This shows that the Timau National Observatory area is still relatively ideal as an observatory location. The following picture is a chart of changes in the extent of each category of light pollution levels around the Timau National Observatory.

Figure 4. Extensive Area Changes in Each Class of Light Pollution Level Within Radius 90 km Centered from Timau National Observatory.

Based on Figure 4, it is known that very low classes area dominates the area around the Timau National Observatory. The very low classes area is also relatively unchanged which is indicated by a flat graphical form. Then, the low classes area experienced a decline from 2013-2016, from 170.7 km² in 2013 to 47.6 km² in 2016, but experienced an increase in 2017, which was 82.4 km². The middle and high classes area has a relatively similar value in 2014-2016, but in 2017 the class area is
experiencing an increase to 32.5 km² from the previous in 2016 amounted to 20.4 km², while the high classes area has decreased to 8.4 km² from before in 2016 amounted to 19.0 km². The average change in area for each class is from very low to high at 20.8 ± 43.4 km²/year, -22.1 ± 40.9 km²/year, 3.0 ± 7.3 km²/year, and -1.7 ± 7.3 km²/year. The average change in the area of each class shows that the very low class does not experience an extensive decline, while the low class has a decrease of 22.1 ± 40.9 km²/year. This shows that the Timau National Observatory area is still relatively ideal as an observatory location. However, the development of the area south of the Timau National Observatory needs to be monitored periodically, especially in the 207-215 degrees azimuth range. This is because the development of the area in the south of the Timau National Observatory is predicted to grow further with the development of road access. If the development of the region in the south is not controlled, then the possibility of the condition of the southern sky at the Timau National Observatory will experience a very significant increase in light pollution.

5. Conclusion
The conclusion that can be obtained based on the analysis of the dynamics of light pollution around the Bosscha Observatory and Timau National Observatory is as follows:

a) The level of light pollution for the very low and low class is mostly located in the northern region of Bosscha Observatory, while the level of light pollution for the medium, high, and very high class is mostly in the southern region of Bosscha Observatory or in the 129-268 degrees azimuth. Grouping the level of light pollution around the Bosscha Observatory is strongly influenced by its geographical conditions. The northern region of Bosscha Observatory is a mountainous and hilly area, while the southern region of Bosscha Observatory is a basin area and is an urban area. Based on figure 1-5, the city of Bandung and Cimahi are areas that have high levels of light pollution.

b) The average area change of each class shows that the very low class does not experience an extensive decline. This shows that the Timau National Observatory area is still relatively ideal as an observatory location. However, the development of the area south of the Timau National Observatory needs to be monitored periodically, especially in the 207-215 degrees azimuth range. This is because the development of the area in the south of the Timau National Observatory is predicted to grow further with the development of road access. If the development of the region in the south is not controlled, then the possibility of the condition of the southern sky at the Timau National Observatory will experience a very significant increase in light pollution.

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