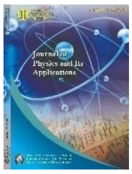
Journal of Physics and Its Applications

Journal homepage : https://ejournal2.undip.ac.id/index.php/jpa/index



Study of Light Pollution Characteristics in Berau with Sky Quality Meter

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A R T I C L E I N F O

Article history:
Received: 1 September 2023
Accepted: 19 March 2024
Available online: 31 May 2024

Keywords:
Light Pollution
Sky Quality Meter
Night Sky Brightness
Moon Phase

A B S T R A C T

The quality of night sky conditions can affect the results of astronomical observations and the survival of wildlife, one of which is sea turtles. One of the causes of the declining quality of the night sky is light pollution. To identify a location's light pollution levels and the quality of the night sky, it is possible to measure the night sky brightness with the Sky Quality Meter (SQM). This research specifically focuses on assessing night sky conditions in Berau, an important sea turtle conservation area, through analysis of SQM. By conducting observation through the period May-July 2022, covering each of the different moon phase, the objectives of this research to quantify the brightness of the night sky in Berau, measured in magnitude per arc square (mag/arcsec^2) to describe the characteristics of light pollution in Berau and interpreted on the Naked Eye Limiting Magnitude (NELM) scale and the Bortle scale. Based on the research results, the highest frequency probability distribution was observed from the value of the sky brightness level measured using SQM in Berau, with the highest value obtained at the new moon phase, 19.60 mag/arcsec^2, the conversion value in NELM being 4.68, and in the Bortle scale, grade 7 with the suburban transition category. And for the lowest value obtained at the time of the full moon phase, 16.66 mag/arcsec^2 with a conversion value in NELM of 2.26, and on the Bortle scale, it is in class 9 with the category of the inner-city sky.

1. Introduction

In a global context, night sky observation and light pollution studies have become a major concern. In America, about 80% of the population can no longer see the Milky Way in the night sky, which shows the importance of research in this area [1]. In Indonesia, especially at Bosscha Observatory, night sky brightness measurements during 2011-2012 recorded mean and maximum night sky magnitudes of 17.75 ± 0.86 mag/arcsec^2 and 19.14 ± 0.79 mag/arcsec^2 [2], far from the ideal value for night sky brightness of 21.40-22.00 mag/arcsec^2 [3]. This indicates a decrease in the quality of astronomical observations due to light pollution.

Research by Strobl et al., showed the negative impact of coastal light pollution on sea turtles in the Caribbean, where there was a significant decrease in the number of turtle nests due to increased nighttime light [4]. A similar study by Dimitriadis et al, on the island of Zakynthos, Greece, found that night light pollution can reduce turtle population recruitment by more than 7% by analyzing the movement patterns of 5.967 hatchlings from 230 nests [5]. This highlights the importance of reducing light pollution.

On Heron Island, a study by Truscott et al, found that terrestrial light pollution affected the swimming behavior of green turtle hatchlings, with higher rates of misorientation on moonless nights and a reduction in hatchling recruitment of 1.0-2.4% [6]. These findings are important because they highlight the impact of light pollution on the life cycle of important species such as sea turtles.

Berau, as one of the regencies in East Kalimantan Province, is a strategic location for this study due to its rich biodiversity and marine potential. As an important habitat for the green turtle species, Berau is important for ecological and conservation studies. According to previous research, green turtles in this area have declined in the number of turtles landing in several protected areas, including Derawan Island. Records show that there was a decrease in the number of turtles from 240 individuals between 2004 and 2005 [7]. This phenomenon highlights the need for more data to understand the status of light pollution, which is one of the factors that negatively affect the life activities of this species.

In this context, this study uses the Sky Quality Meter (SQM) to measure the brightness of the night sky in Berau. The main objective was to measure and analyze the changes in the brightness of the night sky during different moon phases, which is a natural factor related to light pollution. In doing so, the research aims to provide empirical data on light pollution conditions at each phase of the moon. The results of this study are expected to support sea turtle conservation efforts in the Berau region by providing new insights into how the interactions between light pollution and natural cycles, particularly moon phases, affect marine life and astronomical observations. This research is not only important for green turtle conservation, but also opens up opportunities to better understand how environmental impacts, such as light pollution, can affect marine ecosystems as a whole and inform more effective conservation strategies in the future.

2. Literature Review

Light pollution, as described by Cinzano and colleagues in 2001, is a global environmental problem that affects approximately two-thirds of the world's population. The effects of light pollution include a reduction in the ability of humans to observe astronomical objects and a loss of visibility of the Milky Way galaxy [8]. The effects of light pollution not only affect astronomy but also ecology, disrupting the behavior of wildlife, including sea turtles, and human health by disrupting circadian rhythms [9-10].

The characteristics of light pollution include different types, such as glare, light trespass, overexposure, and night sky glare. Each has specific adverse effects on the environment and on human and animal health [11-12]. Light pollution particularly affects nocturnal animals, with animals such as sea turtles showing altered natural rhythms due to exposure to excessive artificial light. The importance of reducing light pollution is clear for the well-being of the environment and the conservation of wildlife.

When it comes to natural light pollution, the phase of the moon plays an important role. The phase of the moon, especially during a full moon, affects the brightness of the night sky and therefore the visibility of celestial objects. Throughout the lunar cycle, which lasts approximately 29.5 days, different phases of the moon provide different levels of illumination, which significantly affects the visibility of objects in the night sky [13]. This understanding is useful for planning astronomical observations and assessing the environmental impact of natural light pollution.

In an effort to measure and analyze light pollution, the Sky Quality Meter (SQM) became an important tool in this study. As a photometric tool, the SQM measures the brightness of the night sky with high accuracy and displays results in mag/arcsec^2. The use of the SQM not only indicates the darkness of the sky, but also allows the mapping of light pollution and the assessment of the effectiveness of light pollution reduction policies [14-15]. In this context, studies conducted in different parts of Indonesia using the SQM have shown significant variations in sky brightness, reflecting different light pollution conditions at each location [16].

In 2002, John Bortle developed the Bortle scale, a method for classifying the brightness of the night sky from 1 (best dark sky) to 9 (inner city sky) based on visual observations [17-18]. This scale makes it easy to determine the condition of the night sky and the effect of light pollution on it. The category of light pollution levels can use the Bortle scale. The Bortle scale is used to determine the sky's brightness. The Bortle scale is into nine classes, as shown in Table 1.

Table 1. Naked Eye Limiting Magnitude (NELM) and the Bortle scale.

NELM	Bortle Scale	Category
7.5 – 8.0	1	*Excellent dark-sky site*
7.0 – 7.5	2	*Typical truly dark site*
6.5 – 7.0	3	*Rural sky*
6.0 – 6.5	4	*Rural transition*
5.5 – 6.0	5	*Suburban sky*
5.0 – 5.5	6	*Bright suburban sky*
4.5 – 5.0	7	*Suburban transition*
4.0 – 4.5	8	*City sky*
< 4.0	9	*Inner-city sky*

3. Method

The study was conducted in the Tanjung Redeb subdistrict, Berau regency, East Kalimantan, Indonesia with a coordinate point of 2.143826° N 117.489529° E. Data collection is carried out in the period from May to July 2022. The observation made was to measure the brightness level of the night sky with SQM.

The tools used in this study are as follows: SQM is a simple photometer tool for measuring the brightness level of the night sky. Housing is an SQM protective container made of pipes with a glass cover. Laptop is a device used to obtain and process data generated by SQM. Connector cable is a link between SQM and the laptop. Software is software installed on a laptop used in research, consisting of Unihedron Device Manager and Microsoft Excel 2013 journal web site in both PDF and DOC formats. Furthermore, the data retrieval techniques carried out are as follows: The type of SQM model used in this study is SQM-L as show in Fig. 1 (a). Futhermore, the SQM is protected by a housing made of cylindrical pipe with a diameter of 10.16 cm and a length of 25 cm as shown in Fig. 1 (b). On the upper pipe cover, a gap is given that is covered by a mirror with a size of 9 cm^2. The purpose of placing SQM in pipes is to protect SQM from exposure to sunlight, rainwater and other weather influences.

Fig. 1: (a) SQM-LU (b) Housing SQM

As shown in Fig. 2, the SQM is directed towards the zenith at the highest reachable position and ensures that no other objects hinder SQM observations.

The data collection was carried out every moon phase and one day before and after the moon phase, starting at 05.30 PM to 05.30 AM. The time interval of data retrieval is every 30 seconds. SQM is connected directly to the computer device via a USB cable as a power and data information conductor.

Fig. 2 : Installation of SQM in the zenith direction

The process of collecting and processing data is presented in the flowchart in Fig. 3 below.

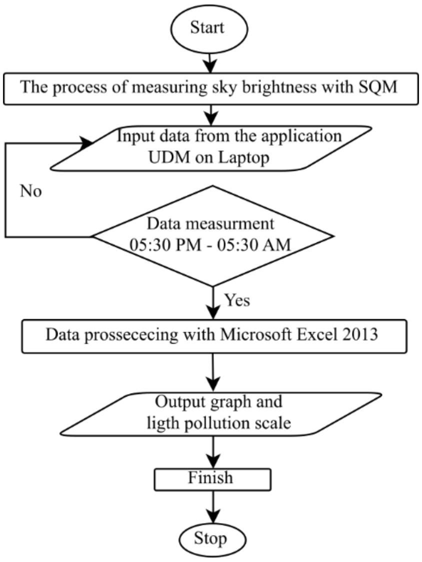

Fig.3: Flowchart of research procedures in data collection and processing

The quantitative research method is a method that will be used in collecting data on the level of sky brightness using SQM in this study. In processing the data that has been obtained, the following statistical analysis is used "Determination of The Brightness of the Sky". To determine the value of the brightness of the sky based on the data collected, Unihedron Device Manager will be analyzed using relative fequency, through the following equation :

$$p_i = \frac{n_1}{N} \quad (1)$$

Where n_i is the number of frequencies sky brightness level occurs at interval i of the moon phase, and N is the number of frequencies the sky brightness level occurs during the entire moon phases. The probability distribution graph can be processed through a collection of data on the brightness level of the sky so that the characteristics of light pollution are known with the value of the sky brightness level as x, h as the class interval area and value of density function $f(x)$ can be written as follows :

$$f(x) = \frac{n_i}{hN} \quad (2)$$

4. Results and Discussion

Observations were made on 4 phases of the moon, namely the new moon, the early crescent, the full moon, and the late crescent moon. Data collection is carried out from May 29 - July 29, 2022, at 5.30 PM - 05.30 AM. Furthermore, the Unihedron Device Manager application collects data by measuring the level of sky brightness obtained by SQM. The following is data on the level of brightness of the sky against time in the new moon phase, June 30, 2022, and July 29, 2022 as shown in Fig. 4.

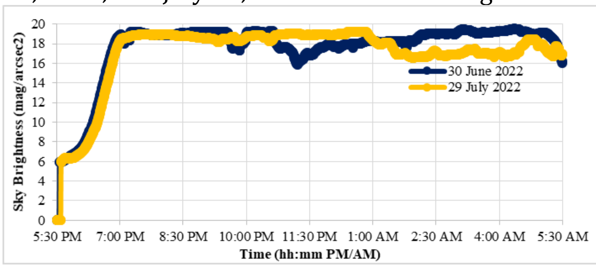

Fig. 4: Visualize the sky's brightness using SQM during the new moon phase.

The graph in Fig. 5 compares the probability of frequency obtained during the new moon phase against the sky brightness level, measured over a range of values. The sky brightness level, measured using SQM during the new moon phase with the highest probability of 44.7%, is shown on the graph to be between 19.46 - 19.86 mag/arcsec^2.

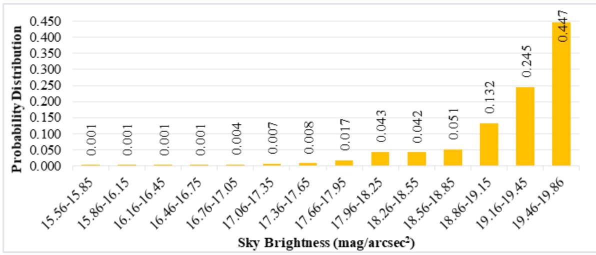

Fig. 5: A probability distribution graph showing the brightness of the night sky during the new moon phases

The graph in Fig. 6 plots the sky brightness level within the same range of values against the frequency probability obtained at first quarter time. The sky brightness level, measured by the SQM during the first-quarter phase with the highest probability of 23.8%, is shown on the graph to be between 18.56 - 18.85 mag/arcsec^2. This probability level is shifted to the left of the graph in Fig. 3, showing a decrease in value based on the highest probability.

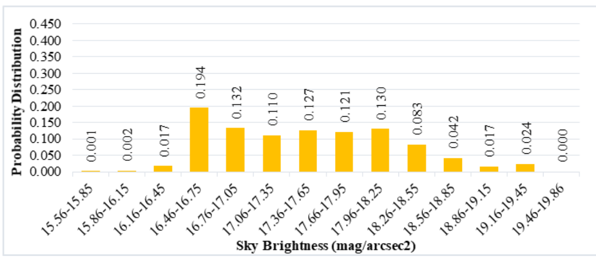

Fig. 6: A probability distribution graph showing the brightness of the night sky during the first quarter phases

Figure 7 is a graph depicting the sky brightness level and probability of each range during the full moon phase. It shows that the sky brightness level in the full moon phase, with the highest probability of 19.4%, is between 16.46 - 16.75 mag/arcsec^2. This probability level is shifted to the left of the graph in Fig. 4, showing a decrease in value based on the highest probability.

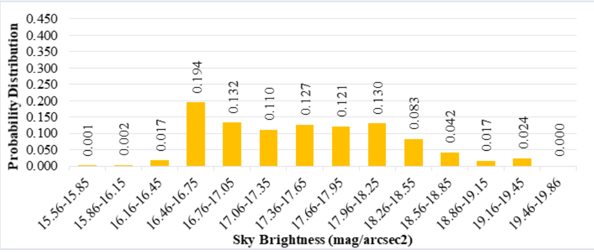

Fig. 7: A probability distribution graph showing the brightness of the night sky during the full moon phases

The graph in Fig. 8 shows the sky brightness level and probability of each range in the last crescent phase. It shows that the sky brightness level in the third quarter phase, with the highest probability of 21.4%, falls within the range of 18.56-18.85 mag/arcsec^2. The probability level in this phase once again increased, indicating a higher likelihood of encountering this specific range of sky brightness during the third quarter phase. This increment is noteworthy, as it contrasts with the probability trends observed in other moon phases. Unlike the previous phases where a decrease in sky brightness level was noted, the third quarter phase demonstrates a reversal in this trend, with an upward shift in the probability curve.

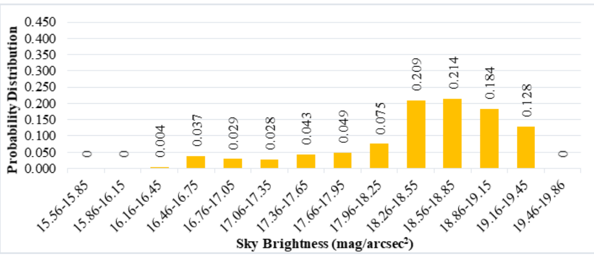

Fig. 8: A probability distribution graph showing the brightness of the night sky during the third quarter phases

Based on Fig. 9, it is known that the tendency of the sky brightness value will vary in each phase of the moon. This can be shown by analyzing the maximum probability shift in the range of sky brightness values during each moon phase. Thus, the moon phase affects the sky brightness value. Based on the largest probability, the highest range of values occurs during the new moon phase, which is 19.46-19.86 mag/arcsec^2, while the lowest range of values occurs during the full moon phase, which is 16.46-16.75 mag/arcsec^2. In addition, the same range of values is obtained in the first and third quarter phases, which is 18.56-18.85 mag/arcsec^2. During the new moon phase, natural light will be minimized due to the absence of lunar activity in the sky brightness measurement, resulting in high values. Meanwhile, during the full moon, the contribution of moonlight as one of the sources of natural light pollution is very significant, resulting in low sky brightness values.

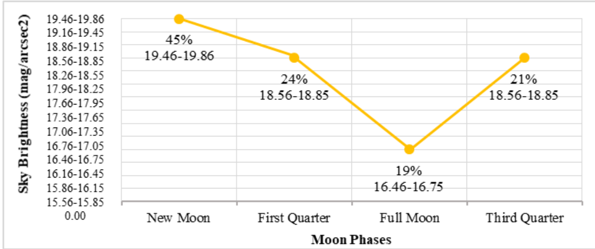

Fig. 9: Graph of the relationship between the brightness levels of the sky at each phase of the moon

Overall, the highest-frequency night sky brightness values obtained by SQM in the Berau region during each moon phase are presented in the following table 2.

Table 2. Sky brightness and light pollution values in Berau

Moon Phases	Sky Brightness (mag/arcsec²)	NELM	Bortle Scale
New Moon	19.60	4.68	7
First Quarter	18.80	4.08	8
Full Moon	16.66	2.26	9
Third Quarter	18.63	3.94	9

Table 2 shows the sky brightness values in three different units: mag/arcsec^2, NELM, and the Bortle scale, which measures the amount of light pollution. Mag/arcsec^2 is the SQM unit of measurement data. NELM is the range of visibility of astronomical objects in observations made with the naked eye. And the Bortle scale is a measure of the level of light pollution.

The highest night sky conditions from the observations occurred during the new moon phase, which was 19.60 mag/arcsec^2 with a NELM value of 4.68 and a Bortle scale at level 7 with the Suburban Transition category. Areas with these conditions describe night sky conditions that are no longer able to see the Milky Way galaxy directly with the naked eye. The results also show that the sky area in the Berau region is able to see celestial objects with faint magnitudes at a value of 19.60 magnitudes within an area of every one arcsec^2.

During the partial moon phase, namely the first and third quarters, the sky brightness level in Berau was recorded at 18.80 mag/arcsec^2 and 18.63 mag/arcsec^2, respectively. During the full moon phase, the sky brightness level reached 16.66 mag/arcsec^2, with a NELM value of 2.26, and was categorized as deep city sky with a Bortle scale level of 9. Based on the standard sky brightness level required for nocturnal animals such as sea turtles, a minimum sky brightness of 17.58 mag/arcsec^2 is required. In Berau, the sky brightness in the partial moon phase reached 18.80 mag/arcsec^2 and 18.63 mag/arcsec^2, while in the full moon phase it was 16.66 mag/arcsec^2 [19]. This comparison shows that the sky brightness levels in Berau are in line with the criteria that are favorable for the survival of nocturnal animals, such as sea turtles, making this region ideal as a sea turtle conservation area.

Nurhalizza et al. stated that there is a significant relationship between sky quality and moon phase, as well as its correlation with light pollution levels. The study confirmed that during the new moon phase, sky quality tends to be higher compared to the full moon phase [20]. This result is consistent with the findings obtained in Berau, where the highest sky brightness levels were recorded during the new moon phase, while the lowest sky brightness levels were recorded during the full moon phase.

Understanding the empirical data on light pollution conditions in each moon phase allows for an improved understanding of how this natural phenomenon impacts the environment. Furthermore, the results of this study emphasize the importance of maintaining and improving the quality of the night sky. This research also demonstrates the potential of the Berau region as a conservation area for nocturnal animals and as an ideal location for sky observation.

4. Conclusions

Based on observations, it shows the influence of the moon's phase on the night sky's brightness in Berau. It is evident from the shift in the frequency probability of the sky brightness level measured by SQM throughout each moon phase. The brightness level characteristics of the Berau sky, the new moon phase is 19.60 mag/arcsec2, the first and third quarter phases are 18.80 mag/arcsec2 and 18.63 mag/arcsec^2, and the full moon phase is 16.66 mag/arcsec^2. The highest value of the night sky brightness level in NELM is 4.68, and the Bortle scale is at level 7 with the Suburban Transition category. Furthermore, based on the criteria for the brightness level of the night sky for nocturnal animals such as sea turtles, the Berau region meets the limits of suitable criteria.

Acknowledgments

This research was supported by the Institute for Research and Service and the Master of Physics Education at Ahmad Dahlan University.

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