Zenithal sky glow measurement in Bandar Lampung as consideration in drafting the regulation of light pollution-free areas around the Lampung Astronomical Observatory (LAO)

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Abstract. Urban development to big cities generally will be accompanied by excessive use of artificial light, such as street lamps, billboards, and building lighting systems. Ineffective and incorrect lighting installation design causes environmental degradation, i.e light pollution. Today, light pollution is one indicator of environmental degradation and energy waste behavior. Study on light pollution has progressed in many fields of science, extending from traditional fields of astronomy to atmospheric physics, environmental science, natural science, and social life. Measurement of sky brightness is also an indicator of the feasibility of an observatory development plan. The location of the observatory is located at coordinates latitude -05° 27' 71" and longitude 105° 09' 39" with a height of 1030 above mean sea level. The construction of an observatory requires a study of the sky's brightness conditions as a matter of consideration to obtain the best observation result. Therefore, to support the Lampung Provincial Government, Institut Teknologi Sumatera (ITERA) and Institut Teknologi Bandung (ITB) in carrying out the construction of observatories in TAHURA WAR, Gunung Betung, Lampung. We did the sky brightness measurements as far as 15 km from the location point of the observatory. We use SQM to measure the brightness of the sky towards the zenith in every crowded area in the city of Bandar Lampung. Then, from the measurement results, we make a map of light pollution. From the mapping results, there are four locations that are indicated to be contaminated by light pollution, namely Tanjung Senang, Teluk Betung, Kemiling, and Gedong Tataan with respective values of 15.8 mpas, 16.6 mpas, 16.8 mpas, and 17.00 mpas..

Keywords: Artificial light at night; Light Pollution; Environment; Sky Brightness; Sky Quality Meter; Urban City; Observatory

1. Introduction
In the year 2016 Institut Teknologi Sumatera (ITERA), Institut Teknologi Bandung (ITB), and Provincial Government of Lampung formed a consortium to initiate construction of a new observatory. Based on topographic and astronomical site surveys, the best position to construct a new
astronomical observatory has been obtained. The location of the observatory is located at coordinates latitude \(-05^\circ 27' 71''\) and longitude \(105^\circ 09' 39''\) with a height of 1030 above mean sea level. In Indonesia, the Ministry of Public Works regulation no. 29/PRT/M/2006 concerning guidelines for technical requirements for building construction, not specifically mentioned about observatories. The observatory is a special building that requires consideration from the results of multi-disciplinary surveys, such as topography surveys, astronomical surveys, and geophysical surveys at construction sites. One of the key parameters to select a site to build an observatory is the night sky brightness because some astronomical research could not be performed with the required quality if the sky is not dark enough. Thus, we can find that astronomical observatories are always in areas far from sources of light pollution. Therefore, to support the Lampung Provincial Government, Institut Teknologi Sumatera (ITERA) and Institut Teknologi Bandung (ITB) in carrying out the construction of observatories in TAHURA WAR, Gunung Betung, Lampung. We did the sky brightness measurements as far as 10-30 km from the location point of the observatory. We use SQM to measure the brightness of the sky towards the zenith in every crowded area in the city of Bandar Lampung. Its result can be used as consideration in drafting the regulation of light pollution-free areas around the Lampung Astronomical Observatory (LAO).

In Section 2, the details of the survey are discussed, including the setup of the measurement devices (SQM) and collecting data. The resulting database forms the backbone for a study of the overall light pollution conditions in Bandar Lampung. Analyses and discussion of the results can be found in Section 3, focusing on the contribution of artificial lighting sources observed in an urban environment and location points that could potentially be disturbing of astronomical observations at the observatory site in the future.

2. Methodology

The Sky Quality Meter (SQM) has been widely used in studies related to light pollution [1,2,3,4]. We have used the SQM-LU model photometer for gathering data in the field. The SQM has installed in the housing it appears as at left in figure 1 (a USB based SQM-LU with only one cable). The SQM housing not only protects the device from the environment but also traps the heat generated by the operation of the device. The methodology was improved to a drive-through approach of integrating the SQM-LU with GPS via a laptop computer to find out the location point during the sky brightness measurement process. We combined with a photographic tripod for mapping a geographical in 10-30 km area from observatory site (see Fig. 1).

![Figure 1. (a) SQM installed in the housing (b) image when during the sky brightness measurement process.](image)
The system is composed of a silicon photodiode as detector (ams-TAOS TSL237S). The spectral sensitivity of the photodiode, combined with the transmission of the HOYA CM-500 near-infrared cut-off filter, provides a final spectral response overlapping the Johnson B and V bands used in astronomical photometry. The SQM photometers have a quoted systematic uncertainty of 10 percent (0.1 mag arcsec−2) [5,6]. We moved to selected locations of a grid, taking the measurements one by one. As for the selected locations, namely Pahoman – A, Teluk Betung – B, Teluk Betung 2 – C, Gruntang – D, Kantor Gubernur – E, Lembah Hijau – F, Tahura – G, Kemiling – H, Bukit Kemiling Permai – I, Mesjid Agung Pesawaran – J, Gedong Tataan – K, Gading Rejo – L, Kedaton – N, Bukit Randu – O, Panjang – P, Panjang2 – Q, Gunung Betung – R, UBL – S, Rajabasa – T, and Alfurqon – U (see Fig. 2). All locations permitting access and reachable by motorized vehicles were surveyed. In this study, we have adopted from several measurement techniques to make a map of light pollution [7, 8, 9, 10, 11, 12, 13]. We measured at zenith angles and build a map of the all-sky brightness from the result the measurements selected locations. Many locations of target areas were covered on the same night to maximize the comparability of data obtained under similar conditions.

\[ \log R = -4.7 - 2.5 \log D \log F \]  

(1)

The expected values of light energy loss from Bandar Lampung can be estimated by using Walker’s relation [14]:

\[ F = 10^{(4.7+2.5\log D+\log R)} \]  

(2)

\[ E = \frac{F}{L} \]  

(3)

Figure 2. Map of measurement locations marked with red dots and observatory site marked with a red star shape.
where $L$ is the average lighting efficiency (in lumen/Watt). From relations (2) and (3) we can put $E$ in the following form:

$$E = \frac{10^{(4.7 + 2.5\log D + \log R)}}{L}$$  \hspace{1cm} (4)

If we know the average lighting efficiency ($L$) and assumed the average time for lighting at night is 10 hours per night during the year, then the average electric energy loss per year ($T_y$) can be calculated as follows:

$$T_y = E(W) \times 10\text{hour} \times 365\text{day} \quad (\text{Wh})$$ \hspace{1cm} (5)

Or

$$T_y = \frac{C\left[10^{(4.7 + 2.5\log D + \log R)}\right]}{L} \quad (\text{kWh})$$ \hspace{1cm} (6)

where $C = 3.65$.

3. Results and Discussions

Lampung Province is the region with the highest population density on the Sumatra Island reaching 234 people / km$^2$, for comparison of other provinces such as North Sumatra reaching 191 people / km$^2$, and West Sumatra reaching 124 people / km$^2$ (adopted in The BPS-Statistic Indonesia, 2013). Urbanization is driving the rapid growth of cities. With the increasing number of population living in urban areas, the demand for new residential areas will also increase too. In addition, the need for lighting will also gradually increase too. The fact is that much outdoor lighting used at night is inefficient. Many sources of light contribute to sky glow such as street light, advertisements and signage, and Several stars like Wezen, Adhara, and Sirius become hard to see because of the effects of the bright sky due to light pollution (see Figure 3). This light and the electricity used to create it is being wasted by spilling it into the sky, rather than focusing it on to the actual objects and areas that people want to be illuminated. The process of developing an area cannot be avoided. However, to minimize the occurrence of light pollution can be prevented through local regulations that control the type of lights and the technical installation in their respective places.

![Figure 3](image-url)  

**Figure 3.** (a) Several stars like Wezen, Adhara, and Sirius become hard to see because of the effects of the bright sky due to light pollution  
(b) Many sources of light contribute to sky glow such as street light, advertisements, and signage.
We did the sky brightness measurements as far as 15 km from the location point of the observatory to be used as a light pollution free area. We use SQM to measure the brightness of the sky towards the zenith in every crowded area in the city of Bandar Lampung. Then, from the measurement results, we make a map of light pollution (see Figure 4). The result from this research there is four locations that are indicated to be contaminated by light pollution, namely Tanjung Senang, Teluk Betung, Kemiling, and Gedong Tataan with respective values of 15.8 mpas, 16.6 mpas, 16.8 mpas, and 17.00 mpas.

![Light Pollution Map](image)

**Figure 4.** Map of measurement locations marked with red dots, and observatory site marked with a red star shape

In this study, we also determined the amount of loss cost due to light pollution. Based on the effective installation of lights to minimize glare, which is less than 70°. The energy used effectively is assumed to be 30%, while the energy loss is 70%. Hereafter, according to the regulation of Minister of Energy and Mineral Resources Regulation No. 28 of 2016 concerning electricity tariffs for the purposes of public street lighting at low voltage (P-3/TR) of Rp 1352, - / kWh. Therefore, it can be determined the amount of the loss of energy and cost due to the poor installation and lighting system (see Table 1). Overall, the average loss cost for lighting at night in Bandar Lampung is 0.793 Billion IDR per year.
Table 1. Electric energy loss from Bandar Lampung City per hour and year.

| Date     | Locations | Average MPSAS (in mps) | Ratio (R) | Distance (D in km) | Electric power loss (E in kWh) | The average electric energy loss per year (Ty in kWh) | Ineffective 70% Energy loss per year (Ty in kWh) | Loss of Cost (in Billion IDR) |
|----------|-----------|------------------------|-----------|-------------------|-------------------------------|-----------------------------------------------------|----------------------------------------------------|-----------------------------|
| 3/16/2018 | G. Rejo - L | 19.17                  | 0.92      | 15.24             | 379.56                        | 1385386.62                                         | 969770.60                                         | 1.311                       |
| 4/7/2018  | Pahoman - A | 18.11                  | 0.87      | 12.25             | 207.93                        | 758924.78                                          | 531247.30                                         | 0.718                       |
| 4/7/2018  | Alfurqon - U | 16.97                  | 0.81      | 11.44             | 163.98                        | 598528.10                                          | 418969.70                                         | 0.566                       |
| 4/7/2018  | T. Betung - B | 16.29                  | 0.78      | 11.56             | 161.60                        | 589839.75                                          | 412887.80                                         | 0.558                       |
| 4/7/2018  | T. Betung2 - C | 17.59                  | 0.84      | 11.92             | 188.61                        | 688413.45                                          | 481889.40                                         | 0.651                       |
| 4/15/2018 | Rajabasa - T | 17.63                  | 0.85      | 12.69             | 220.86                        | 806132.02                                          | 564292.40                                         | 0.763                       |
| 4/15/2018 | UBL - S      | 15.86                  | 0.76      | 13.22             | 220.39                        | 804409.18                                          | 563086.40                                         | 0.761                       |
| 4/15/2018 | Kedaton - N  | 17.99                  | 0.86      | 12.32             | 209.40                        | 764300.11                                          | 535010.10                                         | 0.723                       |
| 4/28/2018 | G. Tataan - K | 17.05                  | 0.82      | 10.51             | 133.34                        | 486678.59                                          | 340675                                           | 0.461                       |
| 4/28/2018 | Pesawaran - J | 16.56                  | 0.79      | 9.89              | 111.31                        | 406293.88                                          | 284405.70                                         | 0.385                       |
| 4/28/2018 | BKP - I      | 17.06                  | 0.82      | 9.01              | 909.35                        | 331911.99                                          | 232338.40                                         | 0.314                       |
| 4/28/2018 | Kemiling - H | 16.29                  | 0.78      | 8.21              | 688.06                        | 251140.32                                          | 175798.20                                         | 0.238                       |
| 4/29/2018 | Tahura - G   | 16.87                  | 0.81      | 4.64              | 170.76                        | 62328.20                                           | 43629.74                                          | 0.059                       |
| 4/29/2018 | L. Hijau - F | 17.04                  | 0.82      | 8.96              | 894.49                        | 326488.44                                          | 228541.90                                         | 0.309                       |
| 4/29/2018 | K. Gub. - E  | 16.20                  | 0.78      | 11.23             | 149.42                        | 545374.18                                          | 381761.90                                         | 0.516                       |
| 4/29/2018 | Gruntang - D | 16.82                  | 0.81      | 14.88             | 314.01                        | 1146121.63                                         | 802285.10                                         | 1.085                       |
| 5/5/2018  | B. Randu - O | 17.30                  | 0.83      | 12.48             | 207.90                        | 758843.93                                          | 531190.80                                         | 0.718                       |
| 5/6/2018  | Panjang - P  | 18.44                  | 0.88      | 21.98             | 912.24                        | 3329666.96                                         | 233076.7                                         | 3.151                       |
| 5/6/2018  | Panjang2 - Q | 18.19                  | 0.87      | 17.61             | 517.04                        | 1887193.16                                         | 1321035                                          | 1.786                       |
| 9/9/2017  | Betung - R   | 20.85                  | 1         | 0                 | -                             | -                                                   | -                                                 | -                           |

4. Conclusions and Recommendations
In Bandar Lampung region their many sources of light contribute to sky glow such as street light, spotlight, advertisements and signage. There are four locations that are indicated to be contaminated by light pollution, namely Tanjung Senang, Teluk Betung, Kemiling, and Gedong Tataan with respective values of 15.8 mps, 16.6 mps, 16.8 mps, and 17.00 mps. The average loss cost for lighting at night in Bandar Lampung is 0.793 Billion IDR per year. So, the following recommendations should be done to overcome the light pollution problem in the future especially the observatory site in the Mount Betung. Set restrictions and laws that require correct light systems by the government of Lampung Province and replace all bad lighting systems with new systems that consume less energy and give adequate lighting as needed of each place.

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