Zenithal Sky Brightness Measurement at Selangor Observatory

N F Ngadiman¹,²,³, N N M Shariff⁴,²,³ and Z S Hamidi¹,³,⁴
¹ Islamic Astronomy & Solar Astrophysics (IASA) Universiti Teknologi MARA, Shah Alam, Malaysia
² Academy of Contemporary Islamic Studies (ACIS) Universiti Teknologi MARA, Shah Alam, Malaysia
³ Institute of Science (IOS) Universiti Teknologi MARA, Shah Alam, Malaysia
⁴Faculty of Applied Sciences, Universiti Teknologi MARA, Shah Alam, Malaysia

nfn132@gmail.com

Abstract. The first continuous assessment of night sky brightness (NSB) at Selangor Observatory are presented. The brightness at night sky was monitored over 6 months in 2018, using portable light sensor called the Sky Quality Meter-type USB-Data Logging with a fixed position – pointing towards zenith. From the 179 records of night, the study shows that the average NSB readings at Selangor Observatory is 20.04 ± 0.18 magnitude per square arc second (MPSAS), after excluding the moonlight factor. Meanwhile, during the stable night sky conditions, the most recorded NSB value is 21.1 MPSAS with 0.78 MPSAS range and 21.03 MPSAS in average. Therefore, Selangor Observatory is still a relevant location for the implementation of astronomical work since it has a night sky within Bortle scale Class 4 to 5.

1. Introduction

Excessive use of artificial lighting in this unstoppable and rapid development of modern civilization today contributed to a sweeping increase of light pollution issue, thus leading to environmental, health, energy as well as astronomical degradation [1]. In astronomical context, skyglow is commonly perceived as one of light pollution components that deteriorate the night sky brightness (NSB), by reflecting and scattering the light from the ground through clouds and atmospheric particles and producing a luminous background of sky.

The magnitude system was introduced by Hipparchus, usually refers to the apparent visual brightness of celestial object. The brightness also refer to the amount flux of light that coming towards us, in watts per square meter (W/m²) unit. Later astronomers then proposed a logarithmic scale of $\sqrt[5]{100} \approx 2.512$ adopted between each interval of one magnitude. Thus, brightness ratio $B_2/B_1$ equivalent to magnitude difference $m_2-m_1$ as explained by the following formula:

$$m_2 - m_1 = -2.5 \log (B_2/B_1)$$

It implies that magnitude 1 is 2.5 brighter than magnitude 2 while magnitude 2 is $2.5^2$ brighter than magnitude 3, and so on. Additionally, NSB at particular location also can be measured by Bortle scale which has nine level numeric scales, ranging from Class 1 – Excellent dark-sky site to Class 9 – Inner-city sky [2].

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
All the best observatory in the world is subject to the comprehensive NSB studies. To date, there are eight (8) official observatories were built in Malaysia. Nevertheless, previous studies indicate that NSB quantification has been performed only at some observatories such as Langkawi National Observatory [3], [4], [5], KUSZA Observatory [6] and Teluk Kemang Observatory [7] using several sensors such as Sky Quality Meter (SQM) and Charge-Coupled Device (CCD). For the remaining observatories no studies have been found while NSB measurement is crucial to identify and preserve the quality of the night sky at the observatory.

Therefore, the aim of this research is to study the temporal trend of NSB at Selangor Observatory and as a systematic effort for surveying and mapping light pollution in the local night sky. Quantitative information on how pristine the night sky at this observatory is crucial to ensure that astronomers can plan the suitable kind of astronomical observation performed here as well as precise measurements can be obtained.

2. Methodology

2.1 Data Collection

NSB measurement was carried out at the Selangor Observatory (3.8192° N, 100.8143° E), located 20 km away from Sabak Bernam town, with a population of 103, 153 and 7 meters above sea level facing the Straits of Malacca (Figure 1). Sky brightness in magnitude per square arc second (MPSAS) were recorded from 1st March to 26th October 2018 with each minute utilizing Sky Quality Meter Data Logger (SQM-LU-DL) as shown in Figure 2, composed with TAO TSL237S sensor. This photometer’s threshold was set to 10 MPSAS value and oriented towards the zenith due to the least polluted area of the sky (Figure 3), with an angular sensitivity of ~10° at Half Width Half Maximum (HWHM) and ~20° at Full Width Half Maximum (FWHM). A total almost of 120 000 raw numerical data entries were collected from observation site.

2.2 Data Selection

The SQM-LU-DL started to collect data when the sky brightness reached 10 MPSAS readings due to its threshold was set to 10 MPSAS as explained in section 2.1. For the NSB data analysis phase, only
data from 9pm to 5am were selected. This is to eliminate the scattering factor of the remaining sunlight during the astronomical twilight phenomena, which in turn affects and disrupts the accuracy of NSB readings. The data in several parts of the discussion were converted to candela per square meter (cd/m²) unit which inverted the measurement scale thus it more intuitively represented brighter skies attain higher values, especially in correlation explanation. The relation between MPSAS and cd/m² unit can be defined as \[ \text{cd/m}^2 = 10.8 \times 10^4 \times (\text{mag/arcsec}^2)^{-0.4}. \]

3. Result and Discussion

Figure 4 shows the trend of NSB changes throughout the measurement whereby the pattern of average sky brightness indicates that the NSB monthly evolutions at Selangor Observatory were rather similar, gradually falls, then almost remains constant for a certain period and rises again with each month. Monthly variations of NSB readings were within \(2.74 \times 10^{-2} \text{cd/m}^2\) to \(4.18 \times 10^{-4} \text{cd/m}^2\) equivalent to 16.49 to 21.03 MPSAS.

Apart from the illumination of the Sun, moonlight remained the single biggest natural factor that influenced the NSB readings. The observations of sky brightness on night by the Moon’s presence above the horizon over the sampling period were significantly correlated as shown in Table 1. We used Pearson correlation to explain the effects of moonlight on the observed NSB. Generally, the relationship between variables in Pearson correlation was define by \(r\) (correlation coefficient) value, which the closer \(r\) value to 1 or -1, the more closely the variables correlated. If \(r\) value close to 0, it means there is no relationship between the two variables. From the observations, the range of \(r\) value was 0.65 to 0.73, with average 0.68 and \(p < 0.0001\) indicate the strength of this correlation was markedly moderate. This indicates night sky at Selangor Observatory displayed a clear linear increase of sky brightness as moonlight increased. Therefore, NSB at Selangor Observatory resulting from moon rhythms from its lowest when the moon is new, to its highest when the moon is full and above the horizon.

Due to this effect, the NSB data were classified into two categories: 1) All data, and 2) Moonless data (NSB readings measured on moonless night). This is to establish more accurate NSB quantification in order to determine the exact status of the night sky in this observatory. The statistics of NSB measurement over six months were presented in Table 2. As expected, moonless data led to an
increase in the average NSB, which 20.04 ± 0.18 MPSAS while 19.08 ± 0.12 MPSAS if all NSB data were included. The observed NSB during the Moon’s presence spanned a quite large range, about 4 MPSAS brighter. If the value of 20.04 ± 0.18 MPSAS is compared to zenith NSB value suggested by the International Astronomical Union (IAU) which is 21.6 MPSAS for good astronomical site, the night sky at Selangor Observatory is 1.56 brighter than the standard, even the moonlight effect has been removed from the NSB data. Thus, based on this average value, we can conclude that Selangor Observatory has a suburban night sky equivalent to Bortle scale Class 5 where usually light pollution is obvious to casual observer and ground objects are partly lit for this kind of night sky.

| Month   | Type of data | Mean   | σ     | Range | Minimum | Maximum |
|---------|--------------|--------|-------|-------|---------|---------|
| May 2018| All Data     | 18.88  | 1.38  | 4.1   | 16.49   | 20.59   |
|         | Moonless data| 19.95  | 0.44  | 1.44  | 19.15   | 20.59   |
| June 2018| All Data    | 19.17  | 1.25  | 4.18  | 16.54   | 20.72   |
|         | Moonless data| 20.15  | 0.38  | 1.37  | 19.35   | 20.72   |
| July 2018| All Data    | 19.13  | 1.33  | 4.19  | 16.49   | 20.68   |
|         | Moonless data| 20.26  | 0.39  | 1.46  | 19.22   | 20.68   |
| Aug 2018| All Data     | 19.18  | 1.25  | 4.34  | 16.69   | 21.03   |
|         | Moonless data| 20.22  | 0.38  | 1.5   | 19.53   | 21.03   |
| Sept 2018| All Data    | 18.99  | 1.18  | 4.26  | 16.41   | 20.67   |
|         | Moonless data| 19.86  | 0.45  | 1.92  | 18.75   | 20.67   |
| Oct 2018| All Data     | 19.15  | 1.12  | 3.82  | 16.62   | 20.44   |
|         | Moonless data| 19.84  | 0.32  | 1.2   | 19.24   | 20.44   |

In addition, the night sky status of this observatory is further strengthened by observing the mode of NSB values. The histogram in Figure 5 indicates the relative frequency distribution of overall average NSB during moonless nights throughout measurement. The most commonly occurring MPSAS values is within 20.05 to 20.15 MPSAS, with frequency of 13. Meanwhile, the frequency of NSB values >20.05 MPSAS indicates 48 equivalent to 53% compared to frequency of 43, which 47% for readings <20.05 MPSAS. This pattern portrayed that night sky at Selangor Observatory was exposed to the light pollution in several directions with clouds sometimes were noticeably illuminated in the direction of light sources.

![Figure 5. Relative frequency of average NSB on moonless night](image-url)
Figure 6 shows the highest and lowest average of NSB each month on moonless night. This can be seen clearly in the graphs where the brightness fluctuates in certain period, especially during the lowest average night every month, probably due to cloud coverage that reflected and scattered any artificial light throughout the sky thus causing the brightening of the sky. Besides, the factor of observatory location which near to coastal area also contribute to the NSB readings inconsistency. Therefore, the deterioration of sky brightness was discernible during the lowest NSB average, which the magnitudes varied irregularly, until the readings reached 16 MPSAS, even without the influence from moonlight. For the highest NSB average each month, we can see patently that the magnitudes were laid be between 20 to 21 MPSAS. However, the sky condition at Selangor Observatory seems to fluctuate quite fast within an hour, even on the night with highest NSB readings. It is perceptible that August has the most stable and consistent night sky readings, with 0.78 MPSAS range. Followed by July and June with a range of 0.91 and 1.46 MPSAS respectively. Meanwhile, for May, September and October the NSB dispersed >2 MPSAS range.

Figure 6. The highest (blue) and lowest (red) NSB throughout measurement.

Hence, NSB histogram plots for the consistent nights with range <2 MPSAS are presented in Figure 7. This figure was obtained from the entire data points of each night, which approximately 1443 in total, start from 9 pm to 5 am. The most recorded NSB values throughout good and stable night sky condition at Selangor Observatory are 21.1 MPSAS on August, 20.88 MPSAS on July, 20.99 MPSAS on June with frequency of 45, 72 and 36 respectively. This proves that with good meteorological and cloud coverage factors, the sky at this observatory can reach the level of rural/suburban transition sky. In fact, the maximum NSB reading was recorded at 21.17 MPSAS.

Figure 7. Relative frequency for the best and consistent night sky condition.
4. Conclusion
A ground-based measurement of zenithal night sky brightness at Selangor Observatory based on SQM-LU-DL detector was performed. Our results to date show that Selangor Observatory is still a suitable and relevant location for the implementation of astronomical work since it has a night sky within Bortle scale Class 4 to 5 based on average value of $20.04 \pm 0.18$ MPSAS. According to the NSB pattern at this observatory, the good night sky conditions can be identified around the new moon phase. During this period, the most recorded NSB value is 21.1 MPSAS with 0.78 MPSAS range and 21.03 MPSAS in average. Therefore, NSB monitoring must be continued in order to observe long-term NSB trend. Besides to ensure that the function of this observatory as an astronomical research centre can be maintained despite the artificial light threat spreading in line with the modern unstoppable development of human civilization.

Acknowledgments
We are grateful to Selangor Observatory and SQM network. This work was partially supported by the Ministry of Higher Education (MOHE) and REI grant 600-IRMI/REI 5/3 (014/2018).

References
[1] Faid, M. S., Shariff, N. N. M., Hamidi, Z. S. Sabri, S. N. U., "Monitoring the Level of Light Pollution and Its Impact on Astronomical Bodies Naked-Eye Visibility Range in Selected Areas in Malaysia Using Sky Quality Meter," Journal of Industrial Engineering and Management Science, vol. 2016, no. 1, pp. 1-18, 2019.
[2] J. E. Bortle, "Introducing the Bortle Dark-Sky Scale," Sky and Telescope, vol. 101, no. 2, p. 126, 2001.
[3] Zainuddin, M. Z., Chin, W. L., Harun, S., "Astronomical Limiting Magnitude at Langkawi Observatory," in AIP Conference Proceedings, 2010.
[4] Tahar, M. R. et al., "Spatial Model of Sky Brightness Magnitude in Langkawi Island, Malaysia," Research in Astronomy and Astrophysics, vol. 17, no. 4, p. 1–10, 2017.
[5] Ngadiman, N. F., Ahmad, N., Wahab, R. A., "Pemupusan Atmosfera dan Kecerahan Langit Malam.,” Jurnal Falak, vol. 4, pp. 163-176, 2018.
[6] Umar, R., Jannah Awang, W., Nadhirah Berzanji, S., Farhana Abd Majed, N., Khairul Amri Kamarudin, M., & Garba Abdullahi, M., "Spatial Model of Sky Brightness Magnitude in KUSZA Observatory, UniSZA.,” International Journal of Engineering & Technol, vol. 7, no. 12, 2018.
[7] Tahar, M. R., Ahmad, N., "Characterizing Light Pollution Spectra to Identify Light Pollution Contributors at Balai Cerap Teluk Kemang," in Ilmu Falak dan Masyarakat di Nusantara, Institut Tanah dan Ukur Negara, 2018, pp. 197-204.