Comparative Assessment of Zenithal and Horizontal Sky Brightness Profiles for Light Pollution Monitoring: Case Study at KUSZA Observatory and Langkawi National Observatory

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https://doi.org/10.5109/7395543

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 11, pp.369-376, 2025-10-30. International Exchange and Innovation Conference on Engineering & Sciences
バージョン：

Comparative Assessment of Zenithal and Horizontal Sky Brightness Profiles for Light Pollution Monitoring: Case Study at KUSZA Observatory and Langkawi National Observatory

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Abstract: *The presence of light pollution affects astronomical observations and astronomy timekeeping, especially crescent moon visibility near the horizon, where twilight effects are most pronounced. Available data for Malaysia regarding real-time horizon sky brightness during Hilal (crescent moon) moon phases is lacking, even with advancements in observational tools. This study aimed to assess and compare the horizon sky brightness at 45° elevation between Langkawi National Observatory (LNO) and KUSZA Observatory (KO), using the Sky Quality Meter (SQM-LU-DL). Findings suggest that both sites showed an average sky brightness of LNO: 13.00 mag/arcsec² and KO: 12.50 mag/arcsec². While the highest recorded zenith sky brightness was 21.34 mag/arcsec² at KO and 21.14 mag/arcsec² LNO for zenithal data, both indicating near-pristine sky conditions suitable for astronomical observations. The thing is, Hilal was still detectable under much brighter conditions, which was significantly easier than expected based on readings of LNO 9.69 mag/arcsec² (19:27) KO 9.89 mag/arcsec² (18:36) in horizon observation SQM type. This supports the assertion that utilizing advanced CCD imaging and total stations allows for crescent detection long before the typical naked-eye threshold is reached. Estimates of the Naked-Eye Limiting Magnitude (NELM) during these observations were under +1.5, which further supports the use of optics in borderline scenarios. This study further refined the framework for Hilal sighting and provides policymakers, religious leaders, and operators with accurate data that enables the integration of SQM monitoring with Islamic astronomy practice.*

Keywords: Astronomy Observation, Sky Brightness, Hilal Visibility, Light Pollution, SQM Monitoring.

1. INTRODUCTION

Modern artificial lighting is crucial for economic and social progress by enabling human activities during the night. While artificial lighting enhances safety and productivity, overuse of light and its inappropriate placement has led to a serious environmental concern, namely light pollution. Light pollution refers to excessive or misdirected illumination that artificially brightens the natural darkness of the night sky, while obscuring the visibility of celestial bodies [1]. This artificial brightening, known as skyglow, is the result of scattering light from atmospheric particles like dust, aerosols and water vapor. The situation is worsened by unshielded and high-output lighting used in urban, coastal and industrial areas [2]. Light pollution is an ever-growing threat to ground-based astronomy and ecological balance, especially with the increase in urban development and tourism in coastal areas.

Like other branches of astronomy, optical astronomy is also plagued with the problem of light pollution. One of the main indicators of sky quality is sky brightness (SB), which is quantified in magnitudes of arcsecond squared (mag/arcsec²). Although SB is measured as a spatially homogeneous quantity, it depends on the angle of view and is often aligned with the zenith (the point directly above an observer) and the horizon (the line where the Earth's surface and the sky appear to meet). The zenith is relatively darker than the horizon, mostly because of the atmospheric path length that light has to travel through (which is minimized). The horizon is always dominated by light from ground sources, such as buildings, streetlamps, and coastal vessels. Research shows that brightness values at the zenith in moderately populated areas can be 1.0-2.0 mag/arcsec² more than zenith values [3]. Nevertheless, most studies on sky quality prefer zenith measurements, thereby ignoring the effect of angular light gradients, which is important for determining the Islamic crescent moon and astronomy observations.

To convert sky brightness values to human terms, researchers frequently employ Naked-Eye Limiting Magnitude (NELM), which is defined as the faintest star visible to the unaided eye under certain conditions. NELM has a close relationship with SB, whereby a 21.7 mag/arcsec² sky is capable of providing an NELM of +6.5, thus permitting the observation of the Milky Way and faint stars. Brighter skies, with SB $<$ 20.0 mag/arcsec², restrict visibility of stars with a maximum magnitude of +4.0 [4]. The Bortle Dark-Sky Scale utilizes both SB and NELM to categorize observational settings into nine levels, ranging from Class 1 (pristine rural skies) to Class 9 (heavily light-polluted urban regions). Using SB profiles and NELM calculations provides a more practical and anthropocentric assessment of the site's quality.

Light pollution is now a significant issue in Malaysia, even in areas previously considered suitable for astronomy. The Langkawi National Observatory (LNO) is located on a tourist island and therefore suffers from light pollution from resorts and public lighting. In addition, powerful lamps employed by squid jigging boats that illuminate coastal luminous nocturnal skies also exacerbate hazy horizon brightness [5]. Meanwhile, the KUSZA Observatory (KO) in Terengganu is positioned in a more remote developed coastal region, where there are few buildings to disrupt the natural setting, making it an ideal reference site for dark-sky studies. However, to the study's knowledge, no detailed comparative study focusing on zenithal and horizon SB profiles at these observatories using standardised approaches has been performed.

There is an absence of angular sky brightness data concerning two positions, zenith and horizon, available from Malaysian observatories. In the absence of such measurements, the degree of horizontal light leakage and its impact on observational capability remain inadequately defined. This situation is particularly critical for Islamic astronomical practices, like Hilal (crescent moon) detection, which occurs at low elevations close to the horizon where light pollution is most dense and significantly influences visibility. Moreover, such efforts tend to be grounded in zenith-only datasets that grossly underrepresent variations in angular sky brightness, leading to flawed policy and planning of the observatory.

This gap has prompted this current study to perform a comparative analysis of zenithal and horizontal sky brightness profiles between KUSZA and Langkawi observatories using the Sky Quality Meter (SQM-LU-DL) under the most favourable observational conditions. The impact of sky brightness on human visual astronomy is contextualized by estimating NELM values based on SB readings. The issues encountered are measuring and comparing zenith and horizon SB values, NELM ranges assessed at each location and the causes of angular light pollution are determinable as human-made or natural.

Such research serves the immediate purpose of enabling better informed site management decisions that support dark-sky preservation and sustainable lighting policy in Malaysia, while contributing to astronomy education initiatives and Islamic astronomy in the context of national policy.

As stated earlier, this study combined perceptual thresholds with the assessment of spatial scalar components of angular BB to create an integrated evaluation of sky quality. It advocates for the inclusion of zenith and horizon perspectives in light pollution research and makes regionally relevant contributions for global dark-sky advocacy. It is anticipated that these findings will inform future development of observatories, religious astronomical practices, and environment-friendly initiatives in Southeast Asia [6-9].

2. METHODOLOGY

This part describes how the measurement and comparison of sky brightness were carried out at two observatories in Malaysia, namely KO, located in Terengganu, and LNO in Kedah. The objective was to measure the difference in sky brightness at the zenith (90° upward) and horizon (45° angle) for both locations and estimate the human eye's visibility at night under these values.

Sky brightness readings were taken with the aid of a Sky Quality Meter (SQM-LU-DL) device, which takes light measurements in magnitudes per square arcsecond. Observations were carried out on clear moonless nights to mitigate natural light contamination, and both measurements were taken at the horizon and zenith directions and then averaged for comparison.

Naked-Eye Limiting Magnitude (NELM) values were calculated based on brightness data using a standard formula. This demonstrates the extent of the night sky visibility to the naked eye from each site and each cardinal direction. These methods were chosen to achieve precision and consistency in the results, as well as to understand the impact of light pollution on observation opportunities in Malaysia.

2.1 Site Selection

Site selection is a critical foundation in light pollution research, as local geography, land use and human activity significantly influence sky brightness levels, especially in horizon-facing directions. This study focused on two contrasting observatory sites in Malaysia, namely KO in Terengganu and LNO in Kedah. These locations were strategically selected to represent differing environmental and anthropogenic conditions that enable a robust comparative analysis of zenithal and horizontal sky brightness profiles.

The KO is located on the east coast of Peninsular Malaysia (5.54°N, 102.95°E), in a coastal zone characterized by a relatively low population density, minimal commercial development and sparse artificial lighting. Its surrounding terrain consists of vegetation, coastal buffer zones and distant low-rise settlements, contributing to naturally dark sky conditions. According to Faid [7], rural or undeveloped areas such as these are typically associated with lower levels of artificial skyglow, making KUSZA an ideal reference site for studying near-pristine sky brightness values. In addition, the topographical isolation and minimum industrial activity in the region help limit upward-directed light emissions and lateral scattering that would otherwise affect horizon observations [1, 10].

a) b)

Fig. 1. a) Langkawi National Observatory and b) KO

In contrast, the LNO is situated on Langkawi Island (6.31°N, 99.78°E), which is a UNESCO geopark location and a major Malaysian tourism destination. Despite its offshore location, LNO is exposed to substantial artificial lighting from coastal hotels, resorts, commercial complexes and roads. A notable light pollution source is the use of squid jigging vessels along Langkawi's coastal waters, which operate high-intensity LED lights during nighttime fishing activities that significantly contribute to horizon-facing sky brightness [11]. Kyba et al. [2] confirmed that artificial lighting associated with coastal tourism and marine industries can cause light trespass far beyond the immediate vicinity and affect even isolated or natural landscapes.

Both observatories are officially recognized by state and federal agencies and are regularly used for educational programs, public outreach and Islamic astronomy applications, such as Hilal (new crescent moon) observations.

This study ensured a representative sampling of Malaysian coastal observatory environments across a light pollution gradient by selecting KUSZA and Langkawi as the study locations. This enabled a detailed analysis for determining how localized lighting practices, tourism intensity, and geographical shielding contribute to angular differences in sky brightness; hence, providing information that is crucial for future observatory planning, environmental conservation, and the implementation of regional dark-sky policies.

2.2 Instrumentation Setup

The observational setup for this study involved the Sky Quality Meter (SQM-LU-DL) from Unihedron. This device measures light pollution by recording the visibility of the sky in magnitudes per square arcsecond (mag/arcsec²) with a light collection angle of roughly 20° Full Width at Half Maximum (FWHM). The instrument contains a photodiode and filters that transmit infrared light corresponding to the eye's light sensitivity during well-lit conditions [1].

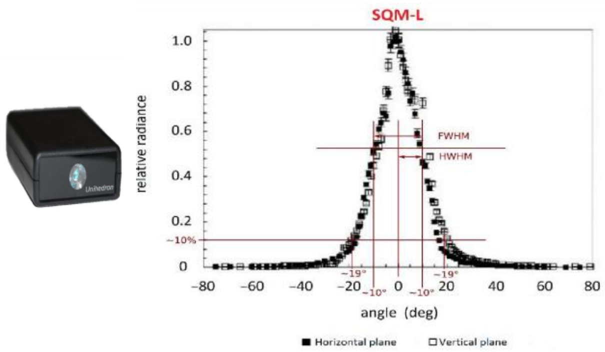


Fig. 2. Image of SQM-L unit (left) and manufacturer's declared calibration curve (right) [1].

The SQM was affixed to a sturdy tripod and focused with a precision digital inclinometer to ensure repeatability of measurement azimuth at both observatory sites. As for zenithal measurements, the SQM sensor was elevated to 90° and positioned vertically. This is the angle used to measure zenith and it normally captures the sky's darkest region free from atmospheric extinction and artificial light [12]. This provides a reference for determining the natural baseline for sky brightness and comparability regardless of the geography.

The SQM was set to a 45° position above the horizontal plane tilted to true north to make horizon-based measurements and minimize glare from adjacent artificial light sources. This position was selected to portray an actual visual range concerning sky coverage and an observation of low-altitude celestial objects, like new crescent moons (Hilal). While 0° horizontal direct aiming can capture maximum skyglow measurements, it is also be most likely prone to glare from lights at ground level, building light reflections and obstructions on the horizon [3, 10]. A 45° elevation provides balanced capturing of the impact by lateral artificial light sources while shielding the device from glare and terrain effects. This approach has been used in several investigations on sky brightness in sub-horizon sky glow regions and has been shown to provide greater stability and repeatability compared to values taken at very low angles [7].

Each SQM device was programmed to log information at 30-second intervals for 15-30 minutes. Measurements involved all nocturnal conditions with no moon and clear skies (cloud cover <10%). These criteria minimize natural variation of sky brightness due to lunar shading or cloud cover reflection.

This creates a sound approach for assessing the impact of light pollution on sky brightness at different elevation angles, specifically pertaining to coastal observatories with changing environmental conditions.

2.3 Naked Eyes Limiting Magnitude

This study derived estimates of Naked-Eye Limiting Magnitude (NELM) for every observation angle and measurement site in order to convert the instrumental sky brightness measurements into meaningful visual metrics. As an intuitive metric that quantifies the visual quality of the night sky, NELM roughly indicates the faintest stellar magnitude visible to the unaided human eye under prevailing sky conditions. This study sought to interpret light pollution levels, particularly at KO and LNO, by estimating NELM based on measured sky brightness (SB) in magnitudes per square arcsecond (mag/arcsec²).

This estimation was based on a widely accepted empirical approach relating surface brightness (SB) with NELM, and depended on the resolution limit of dark-adapted human eyesight. The formula used is based on guidelines provided by IDA (supported by Cinzano [1] and Walker [3], as follows:

$$NELM = 7.93-5 \text{ x } \log (4.316-(m/5)) + 1$$

This formula makes it possible to transform photometric measurements into limits vertically observable with the naked eye under average observational conditions, little atmospheric turbulence, and no illuminative interference from the moonlight or clouds.

In this model, a sky brightness of 21.7 mag/arcsec² corresponded to an NELM of approximately +6.5, suggesting superb viewing conditions in which the Milky Way and distant stars were visible, typically described as Bortle Class 2 skies. Conversely, SB values of around 21.0 mag/arcsec² give an NELM of about +6.0 and 20.0 mag/arcsec², which translates to an NELM of roughly +5.0 and typical for suburban or semi-urban skies. When the reading is below 19.0 mag/arcsec², the light-polluted urban star limit of +4.0 is obtained, and bourgeois urban light-polluted conditions are encountered.

The average zenith (90°) and horizon (45°) SB readings for each site served as variables for estimating NELM.

These estimates were useful for analysing the sky visual quality vertical gradient, thus accentuating the difference in constraining magnitude between the darkest overhead and the horizontally light-polluted areas. These methods also help answer questions regarding the impact of sky brightness on crescent moon visibility, particularly around the horizon where Hilal observations are made.

Table 1. Naked-Eye Limiting Magnitude Based on Sky Brightness and Corresponding Visual Sky Quality

Sky Brightness	NELM	Bortle Scale	Visual Sky Quality Description
21.7	+6.5	Class 2	Excellent dark sky, Milky Way fully visible
21.0	+6.0	Class 3–4	Rural sky, many stars visible
20.0	+5.0	Class 5–6	Suburban sky, some light dome present
19.0	+4.0	Class 7–8	Urban sky, only bright stars visible
18.0 or lower	+3.0 or less	Class 9	Severely light-polluted sky, very few stars seen

3. RESULTS AND DISCUSSION

This section analyses the results obtained from the sky brightness measurements and naked-eye limiting magnitude (NELM) estimations carried out at two selected observatory sites, namely KUSZA and LNO, during the Hilal observation sessions. The specific objectives focused on evaluating the degree of change in the horizon sky brightness (45° elevation) about the crescent moon's visibility and assessing the overall sky quality at the two locations during actual observational conditions.

The results are clustered into three main parts. First, Section 3.1 analyses the average horizon sky brightness at both observatories and records specific SB values during the moment of Hilal visibility. Second, Section 3.2 estimates NELM values from the SB data and translates them from instrumental readings to human-visible and Bortle scale terms. Finally, some selected illustrations depict dynamic changes in sky brightness with time, emphasizing critical visibility times and the twilight phases.

The observations comprehensively explain the light pollution phenomenon and its implications for Hilal observations, hence, strengthening the claim for quantitative monitoring tools in Islamic astronomy.

3.1 Sky Brightness Comparison

Sky brightness (SB) was gauged along the horizon at KO and LNO with an SQM-LU-DL Sky Quality Meter during designated Hilal observation periods. SB is measured in magnitudes per square arc second (mag/arcsec²) and provides insight into night sky illumination. This is important for Hilal observations, which are sighted just above the horizon during a very short post-sunset period when lighting from the surroundings and the scattering of light through the atmosphere tend to dominate [13-15].

The average sky brightness, measured through full observation windows, implies that both sites had similar horizons. While KUSZA had an average SB of 12.50 mag/arcsec², Langkawi had an average of 13.00 mag/arcsec², which indicates that Langkawi's horizon was slightly darker during the session. Nevertheless, these averages do not capture the most crucial window for Hilal visibility.

More importantly, this study captured the exact values of sky brightness when the Hilal was sighted visually or captured with instruments simultaneously at both locations. These readings demonstrate the least favourable sky conditions that must exist for the new crescent to be visible, which is a crucial benchmark for scientific verification and also pertaining to matters of faith in Islamic astronomy.

Meanwhile, in Langkawi, the first detection of the crescent moon was at 19:27 through the use of a CCD imaging scope, where the SQM reading was a meagre 9.69 mag/arcsec². Notably, this value indicates a sky that is relatively bright because the measurement was taken shortly after sunset, marking the end of civil twilight. A secondary verification employing a Total Station was completed at 19:51 and it recorded a SQM reading of 16.25 mag/arcsec². This marked an approximately 7 magnitude improvement and illustrates that the sky was much darker after moving into astronomical twilight. The stark difference between the two measurements reveals how atmospheric clarity, background brightness and transparency evolve in mere minutes. It also underscores the need for continuous observation throughout the entire Hilal window.

The crescent at KO was recorded independently earlier at 18:36 with CCD imaging, where the SQM Reading was 9.89 mag/arcsec², which is close to Langkawi's value. As with the detection in Langkawi, this observation also occurred during the civil twilight phase. This reinforces the fact that the Hilal can be detected even before the darkest phases of the sky are reached so long as weather conditions are favourable and instruments as well as the alignment, are proper.

These findings indicate that the upper bound for effective Hilal detection may be between 9.5 – 10.0 mag/arcsec², which is indeed brighter than the traditional viewing thresholds usually required for naked eye techniques, which are above 17 mag/arcsec². This means that the function of imaging instruments (CCDs or other optical imaging devices) is crucial for broadening the timeframe during which observations are possible when the sky is still bright due to twilight scattering or other peripheral light pollution.

The capacity to identify the Hilal even at SB values lower than 10 mag/arcsec² showcases the advancing merits of digital imaging as well as optical systems in contemporary Islamic astronomy. These devices facilitate the observation of the moon even when the conditions are mired in high background light, which is traditionally deemed unfavourable for naked-eye viewing.

Moreover, changes in SB value from 9.69 to 16.25 at the Langkawi observatory over 24 minutes highlight the importance of accurate monitoring and the critical nature of continuous observations for precise sighting. It also underlines the earlier argument that the spatially fixed and temporally defined single SB threshold is insufficient for describing the dynamic or required visibility for observations as they respond to changing levels of sky brightness.

This substantiates the incorporation of SQM monitoring into future Hilal sighting protocols, whereby quantitative criteria pertaining to standardization and reliability, regardless of marginal or borderline conditions, can be developed for different instruments like CCD, telescopes, or even visual observation.

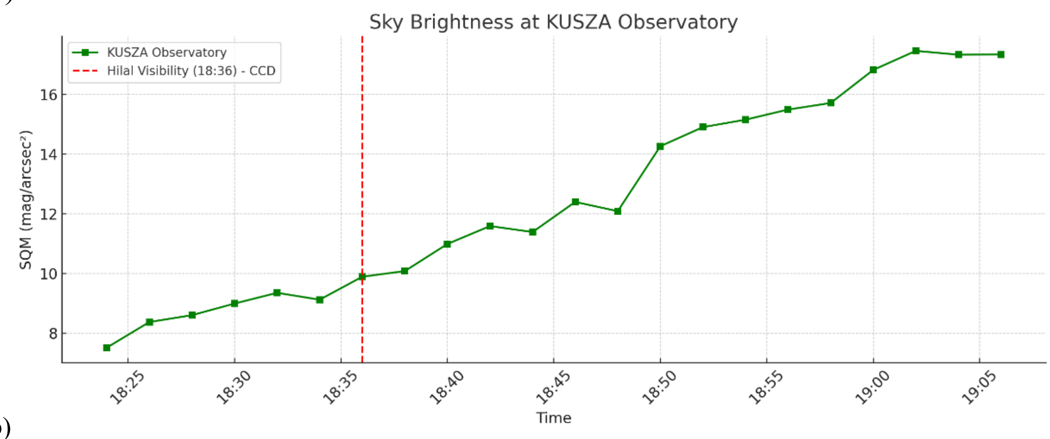
Table 2. Sky Brightness at KUSZA Observatory and Langkawi National Observatory

Observatory	Angle	Sky Brightness (mag/arcsec²)
KUSZA	Horizon (45°)	12.50 (Average)
	Zenithal (90°)	21.34
Langkawi	Horizon (45°)	13.00 (Average)
	Zenithal (90°)	21.14

Table 3. Sky Brightness During Hilal Visibility at Each Site

Observatory	Hilal Detected At	SQM at Hilal Time (mag/arcsec²)	Instrument Used
Langkawi	19:27	9.69	CCD Imaging
Langkawi	19:51	16.25	Total Station
KUSZA	18:36	9.89	CCD Imaging

(a)



(b)

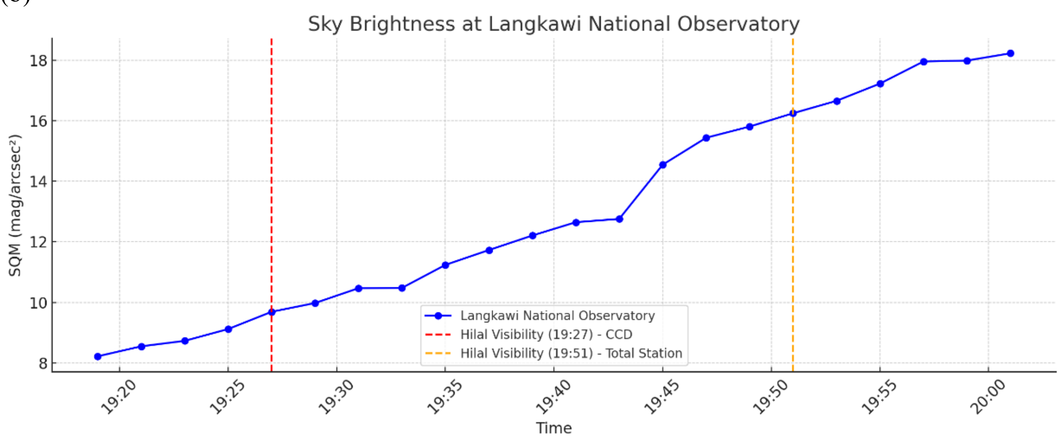


Fig. 3. Sky Brightness During Hilal Observation at Langkawi National Observatory and KUSZA Observatory.

As shown in Figure 3a, the Hilal was first seen using CCD imaging techniques at Langkawi National Observatory at 19:27 with a SQM reading of 9.69 mag/arcsec² (which is considered bright and indicates that the civil twilight phase was still ongoing). The first sighting was confirmed at 19:51 when the second observation was carried out using a Total Station, which provided a sky brightness measurement of 16.25 mag/arcsec². This represents the significant darkening of the sky and marks the beginning of astronomical twilight.

The line chart depicting SQM values over time demonstrates clear and aggressive increases between these two times highlighted in the text, denoting intense enhancement in sky conditions during the crucial Hilal window.

Based on Figure 3b, the KO data captures a comparable pattern but with an earlier detection time of 18:36 via CCD imaging, alongside a brightness measurement of 9.89 mag/arcsec². After this observation, the SQM value steadily increased, surpassing 17 mag/arcsec² towards the close of the observation period. This seems to indicate that even if the Hilal was observed earlier in brighter conditions, the site was gradually darkening and extending the duration available for Hilal observations, whether using the naked eye or aided by instruments.

Overall, both graphs verify that Hilal can be seen at approximately 9.7 to 9.9 mag/arcsec², with Langkawi exhibiting a stark difference between earlier and later SQM readings due to the timing of the observations. The visibility lines also highlight the necessity for continuous observation during the twilight phases, where sky conditions can shift quite swiftly [16], thus impacting the opportunity window as well as the actual visibility of the Hilal.

In addition to horizon observations, Zenithal sky brightness measurements provide a valuable benchmark for assessing the overall darkness of an observatory site, especially when free from direct horizon-based light interference. At KO, the zenith brightness reached 21.34 mag/arcsec², slightly darker than the value recorded at LNO, which was 21.14 mag/arcsec². These readings fall within the internationally recognized threshold for pristine or near-pristine sky quality, indicating that both sites offer excellent overhead observing conditions suitable for deep-sky astronomy and crescent moon visibility. The slightly higher zenith brightness at KUSZA may be attributed to its geographic positioning on the less developed east coast, where coastal settlements are sparse and light pollution sources are minimal. In contrast, Langkawi, although also achieving dark zenith conditions, is more exposed to tourism-related lighting and coastal maritime activity, which may affect overall darkness, especially during weekends or peak seasons. Despite this, both observatories demonstrate that quality zenithal observations are possible, reinforcing their importance as reference sites for national crescent moon observation programs.

These findings also suggest that while horizon conditions may vary significantly between sites due to local topography and development, zenithal measurements remain a reliable indicator of baseline atmospheric clarity and sky quality, especially for high-elevation celestial observations.

3.2 NELM and Sky Quality Classification

The Naked-Eye Limiting Magnitude (NELM) was estimated based on recorded sky brightness (SB) values to assess the photometric quality of the night sky at both observatories. NELM describes the quantitative measurement of how much night sky is available to the human eye in specific atmospheric conditions and this provides a more practical approach to the measurement. It becomes particularly critical when attempting to correlate SQM data with the visual or instrumental detectability of faint celestial bodies, like the crescent moon (Hilal).

Based on the empirical formulation, the following equation was applied to calculate NELM from SB values of regimes in mag/arcsec²:

$$NELM = 7.93\text{-}5 \times \log (104.316\text{-}(m/5)) + 1$$

This formula represents the minimum contrast detection threshold for human observers in dark-adapted states and assumes visually average conditions without telescopic aids. NELM was calculated from average horizon SB and specific SB during Hilal visibility periods for greater resolution of observational limitations.

The average horizontal sky brightness recorded for Langkawi translates into 13.00 mag/arcsec², which indicates an estimated NELM of around +3.2. KUSZA's average of 12.50 mag/arcsec² yielded a NELM of about +2.9. These values indicate moderately light-polluted skies in which only extremely bright stars and planets are observable at the horizon. Based on the Bortle Dark-Sky Scale, this would be approximately Class 7-8, which describes urban/suburban transitioning areas with extremely low horizon visibility for celestial objects [17]. However, while observing the crescent Hilal, sky brightness was notably lower for Langkawi using the CCD imaging at 19:27, while the sky brightness was recorded at 9.69 mag/arcsec², which suggests an NELM of around +1.1. Meanwhile, during the Total Station observation at 19:51 the sky brightness improved to 16.25 mag/arcsec² with an NELM around +5.6, indicating much better visual conditions relevant to NELM value.

The time and conditions of crescent Hilal observation at KUSZA were an SB of 9.89 mag/arcsec² translated to NELM +1.3 at 18:36. This supports the idea that, despite brighter skies earlier in the evening, instrumental observation was beneficial for crescent detection under conditions unfit for the naked eye.

Based on the analysis using NELM, instrument-aided detection [18] is possible at levels far more illuminated than what the eye can see, with most occurrences at stratospheric skies with SQM values below 10 mag/arcsec². However, the Langkawi timing of 19:51 indicates that when SB levels reach or surpass 16 to 17 mag/arcsec², Hilal is visible to the naked eye. This observation supports the argument that the NELM-SQM correlation should be adopted in contemporary stark light guidelines, especially when optical tools are used in settings with high levels of light pollution.

While both observatories exhibited similar limitations near the horizon, the reinforcement of time-sampled observations in the Langkawi region suggests that precise bounding conditions, such as twilight, might help discern differing trends speculated for twilight-dominated semi-urban regions.

Table 4. NELM using the Sky Brightness Metrix

Observatory	Condition	SB (mag/arcsec²)	Estimated NELM	Bortle Class (Approx.)	Visibility Notes
Langkawi	Avg. Horizon	13.00	+3.2	Class 7–8	Bright sky; only major stars visible
Langkawi	Hilal @ 19:27 (CCD)	9.69	+1.1	Class 9	Very bright sky; only crescent detectable via CCD

Observatory	Condition	SB (mag/arcsec²)	Estimated NELM	Bortle Class (Approx.)	Visibility Notes
Langkawi	Hilal @ 19:51 (Total Station)	16.25	+5.6	Class 4–5	Darker sky; improved low-altitude visibility
KUSZA	Avg. Horizon	12.50	+2.9	Class 7–8	Moderately bright; limited visual depth
KUSZA	Hilal @ 18:36 (CCD)	9.89	+1.3	Class 9	Very bright sky; visibility via CCD only

4. CONCLUSION

This study explored and compared the zenithal and horizontal sky brightness conditions at two prominent observatory sites in Malaysia, namely KO (KO) and LNO, with particular emphasis on the visibility of the Hilal crescent moon. Sky brightness measurements were conducted using the Sky Quality Meter (SQM-LU-DL) at a 45° elevation during the official crescent moon sighting sessions. These measurements were used to compute average sky brightness, estimate sky quality in terms of Naked Eye Limiting Magnitude (NELM), as well as classify the sky quality according to the Bortle scale.

The results indicated that both locations had roughly the same average horizontal sky brightness values but differed in the time of Hilal detection. Langkawi recorded the first Hilal at 19:27 with a sky brightness of 9.69 mag/arcsec² and later at 19:51 under much darker conditions of 16.25 mag/arcsec². KUSZA recorded Hilal much earlier at 18:36 with a brightness of 9.89 mag/arcsec². These measurements suggest that the crescent can be captured with instruments well before visual detection, as twilight illuminates the sky far brighter than where the eye can see.

The NELM confirmed this hypothesis since during the first crescent detection at both sites, the NELM was less than +1.5, which is far lower than what is required for human sight. However, with time, the NELM improved to over +5.5 and this marked the condition shift into favourable observations. These results justify the use of instrumental limits combined with SQM climate metrics for Hilal sighting criteria, primarily in areas influenced by ambient light pollution and twilight diffused illumination.

5. ACKNOWLEDGEMENTS

This study was supported by the Majlis Agama Islam Dan Adat Melayu Terengganu through the Industry Grant RM015/UniSZA/2023/PPL/MAIDAM(074). Special thanks is dedicated to Electromagnetic Research Group and East Coast Environmental Research Institute for their assistance in this study.

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