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The Determination of Dawn Time Based Sky Brightness Using Sky Quality Meter (SQM): A Case Study in Medan City

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ABSTRACT

The dawn determination was empirically measured by measuring sky brightness with the Sky Quality Meter from November 1 to November 30, 2024, at the Islamic Astronomical Observatory of UMSU. Observations are made every one minute toward the eastern horizon, and the zenith is observed two hours before the scheduled Fajr hisab. The data are processed using the Moving Average method to reduce noise, allowing the pattern of brightness decline towards dawn to be consistently identified. The results show that the inflection point, a sharp change in the mag/arcsec² value, marks the dawn of the ṣādiq. It indicates that the increase in dawn light was detected at a shallower angle than the hisab criteria of the Indonesian Ministry of Religion, which set the beginning of Fajr at -20°, and the SQM data still show full night conditions without a significant increase in brightness. One of the data shows that the deepest dawn light can still be detected down to –18°, which represents the deepest limit of the local atmospheric response to sunlight in Medan before ṣādiq forms stably. However, the value of 18° does not appear consistently daily, so it cannot be used as the primary reference in determining the time of Fajr. This study confirms that photometric measurements using SQM and Moving Average analysis provide an objective approach to determining the onset of dawn and support the need to re-evaluate the criteria for national depression angles to better match the real dawn phenomenon in urban tropics.

I. Introduction

The transition from night to morning is a fundamental aspect of applied and Islamic astronomy, especially in determining the early time of Fajr. In Islamic normative sources, the dawn of the ṣādiq is described in explicit visual imagery. The Qur'an affirms: "... until it is clear to you that the white thread of the black thread is the dawn..." (QS. Al-Baqarah [2]: 187), which shows that the sign of the entry of Fajr is the horizontal light that is clearly visible on the eastern horizon [1]. The hadith of the Prophet صلى الله عليه وسلم also provides an essential astronomical explanation: "The dawn is not the light that extends upwards, but the one that extends on the horizon." (HR. Abu Dawud no. 2320) [2]. These two sources note that the early determination of Fajr is directly related to the observable physical characteristics of dawn.

In practice, the world's various astronomical authorities use different values of the Sun's depression angles, generally between −14° and −18°, to define the beginning of astronomical twilight and the appearance of dawn [3]. Modern studies show that the appearance of dawn light is influenced by atmospheric conditions, aerosols, and light pollution levels, so the angle of depression cannot be standardized across locations [4]. In Indonesia, the Ministry of Religion has set the angle of −20° for the time of dawn, but some studies report that the sky conditions at that angle remain in a very dark phase and have not shown consistent indications of dawn light [5]. It has led to a growing debate, especially in urban areas such as Medan, which experience increased light pollution and attenuation of atmospheric light.

Most previous studies have relied on visual observation or camera documentation, which, while useful, still have limitations in terms of subjectivity and difficulty distinguishing between very gradual increases in light. Therefore, there is a need to switch to more objective and quantitative methods of observation. The Sky Quality Meter (SQM) is one of the most widely used instruments in atmospheric and light pollution research. SQM can measure the brightness of the sky in real time on a magnitude scale per arcsecond^2 [6], enabling small changes in the intensity of Twilight light to be recorded and analyzed with precision [7]. This method allows researchers to determine the inflection point in changes in sky brightness, which can be scientifically and measurably attributed to the appearance of dawn.

Figure 1. Dawn Visualized Using DSLR

Several recent studies have examined the occurrence of dawn using DSLR cameras, CMOS imagery, and multi-spectral satellite data (VIIRS-DNB) [8]. However, quantitative measurements using simple photometric instruments, such as the Sky Quality Meter (SQM), are increasingly recognized as an efficient means of quantifying sky brightness. The use of SQM in twilight studies can identify inflection points on the sky's magnitude decline curve, which is directly correlated with the appearance of dawn light [9]. This instrument offers advantages, including high sensitivity to variations in sky luminance and the ability to perform continuous data acquisition in dark conditions, making it more effective than visual observation at detecting the beginning of dawn ṣādiq [10].

However, research specifically examining the transition in sky brightness toward dawn in Indonesia remains limited, especially in urban areas with medium levels of light pollution, such as Medan City. Tropical atmospheric variability, local aerosol conditions, and urban light distribution can lead to deviations in sky brightness that require empirical evaluation. Therefore, there is an urgent need to conduct research using SQM measurements combined with visual observations to determine the value of the Sun's depression closest to the dawn of ṣādiq, according to sharia and astronomy [11].

Based on this background, this study was directed to test the hypothesis that the appearance of dawn ṣādiq can be identified through significant changes in the brightness of the sky (mag/arcsec^2) recorded by SQM, and that these values do not appear at a depression angle of −20° as established in the official dawn schedule. This study aims to analyze the curve of sky brightness change, determine the time of the inflection point, and relate it to the angle of the Sun's depression to obtain a more accurate estimate of the beginning of Fajr. Thus, the next part of the methodology describes the design of visual observation and the use of SQM instruments as an integrated approach to identifying early dawn in Medan City.

II. Method

This study uses an observational-quantitative approach and the Sky Quality Meter (SQM LU-DL) to measure sky brightness before dawn. Observations were conducted daily from November 1 to 30, 2024, at the Astronomical Observatory of the University of Muhammadiyah North Sumatra (OIF UMSU) in Medan. Data collection begins 2 hours before local dawn time to cover all phases of astronomical twilight. Measurements were made only in two main directions: the zenith to detect the vertical distribution of light from the atmosphere, and the eastern horizon, the direction of dawn ṣādiq. The instrument is mounted on a ±1.5-meter-tall tripod to minimize local light scattering. Each SQM LU-DL Reading is recorded automatically at one-minute intervals, followed by atmospheric conditions such as clouds, humidity, and skyglow intensity.

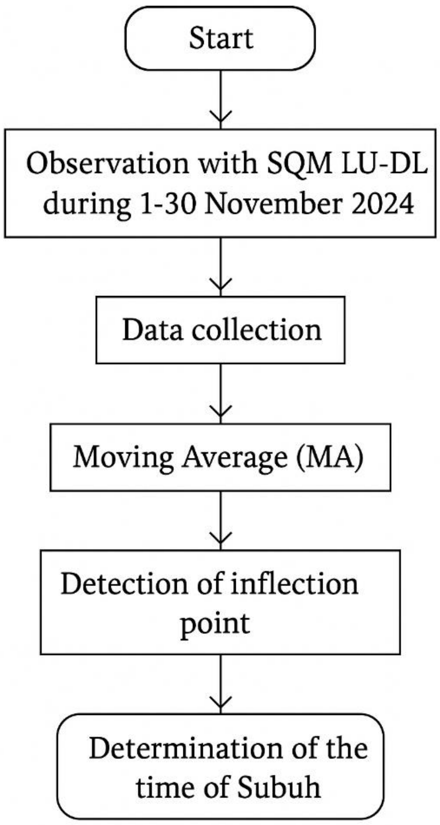

Figure 2. Data Processing Flow Diagram

The data were then processed using the Moving Average (MA) method to smooth noise from atmospheric variability and urban light pollution. The MA technique is used to highlight the main pattern of changes in the brightness of the sky and to make it easier to identify the inflection point, the moment when the curve begins to show an increase in natural light that signals the dawn of ṣādiq. The time of the inflection point is then matched with the Sun's ephemeric data to determine the angle of the Sun's depression at the time the phenomenon appears. The analysis compared zenith and horizon observations to assess the consistency of the eastern direction as the primary indicator of dawn onset. With this approach, the study produced a more accurate empirical picture of the Sun's depression angle and the dynamics of sky brightness before Fajr in Medan City based on SQM LU-DL measurements.

III. Results and Discussion

This session presented empirical findings based on observations of sky brightness using the SQM-LU-DL instrument during the period 1–30 November 2024 at OIF UMSU Medan. All SQM data were analyzed using a moving-average approach to identify patterns of change in sky brightness before dawn [12].

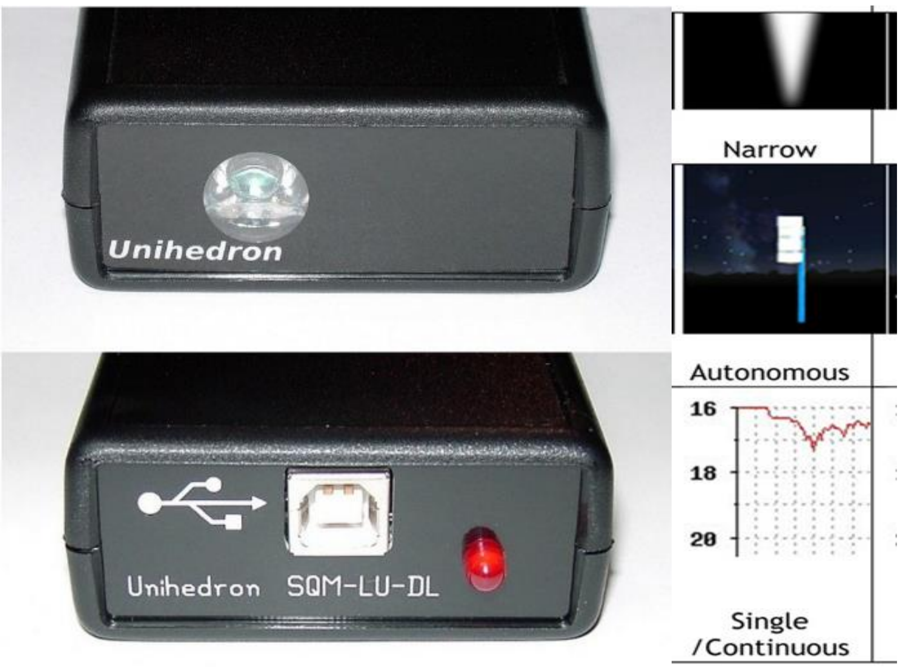

Figure 3. SQM-LU-DL Device

SQM-LU-DL (Sky Quality Meter – Lens USB Data Logging) is a variant of SQM that adds self-contained data logging capabilities for precise measurement of sky brightness [13]. The term Lens indicates that it uses an optical lens with a narrow field of view (~20°), so it captures light from a focused area of the sky and minimizes the influence of side-light sources [14]. Meanwhile, Data Logging (DL) refers to an automatic data logging feature that can operate continuously, even without a computer connection, as this unit can use external power sources such as batteries or power banks. The data is stored directly in the instrument's internal memory, allowing it to be placed outdoors for long-term observation. With its high sensitivity to luminance changes in mag/arcsec^2 units, the SQM-LU-DL is ideal for detecting subtle dawn-light transitions, making it an accurate and stable instrument for studying Dawn time, light pollution, and night-sky quality [15].

This analysis produced a temporal picture of the transition from night to morning, the inflection point in the SQM depreciation decrease, and the angle of the Sun's depression that correlated with the beginning of shadiq. The results displayed in this section are compiled in stages to provide a comprehensive understanding of the dynamics of sky brightness, comparisons between days, and evaluation of the time of Fajr hisab.

3.1 Sky Brightness Data Overview

Sky brightness observation data using SQM-LU-DL during the period 1–30 November 2024 show that the pattern of decreasing SQM values before dawn is reasonably consistent across days. Based on the table of processing results, the majority of inflection points marking the onset of the increase in dawn light are detected from the eastern horizon (0°). At the same time, the direction of the zenith shows a slower, smoother change. The range of SQM values before dawn is in the range of 17.5–18.8 mag/arcsec^2 for the whole night, then decreases slowly when entering the twilight phase until it reaches a value of 8–12 mag/arcsec^2 near dawn time. This pattern corresponds to the twilight characteristics reported in sky photometric studies, which mark the beginning of the dawn of ṣādiq [16].

1-30 November 2024

Masehi	Hijriah	Arah SQM				
		0	30	45	90	Barat
01/11/2024	28/04/1446	10° 23'	-	-	10° 27'	-
02/11/2024	29/04/1446	10° 11'	-	-	10° 08'	-
03/11/2024	01/05/1446	13° 52'	-	-	13° 58'	-
04/11/2024	02/05/1446	13° 46'	-	-	13° 52'	-
05/11/2024	03/05/1446	09° 53'	-	-	13° 13'	-
06/11/2024	04/05/1446	08° 44'	-	-	08° 42'	-
07/11/2024	05/05/1446	12° 39'	-	-	12° 14'	-
08/11/2024	06/05/1446	17° 23'	-	-	18° 00'	-
09/11/2024	07/05/1446	08° 52'	-	-	08° 47'	-
10/11/2024	08/05/1446	12° 15'	-	-	12° 12'	-
11/11/2024	09/05/1446	08° 35'	-	-	08° 35'	-
12/11/2024	10/05/1446					
13/11/2024	11/05/1446					
14/11/2024	12/05/1446					
15/11/2024	13/05/1446					
16/11/2024	14/05/1446				14° 16'	
17/11/2024	15/05/1446	08° 41'	-	-	08° 41'	-
18/11/2024	16/05/1446	11° 02'	-	-	11° 00'	-
19/11/2024	17/05/1446	07° 10'	-	-	07° 08'	-
20/11/2024	18/05/1446	10° 26'	-	-	10° 23'	-
21/11/2024	19/05/1446	10° 39'	-	-	10° 40'	-
22/11/2024	20/05/1446	10° 12'	-	-	10° 09'	-
23/11/2024	21/05/1446	11° 04'	-	-	11° 09'	-
24/11/2024	22/05/1446	13° 35'	-	-	13° 41'	-
25/11/2024	23/05/1446	10° 10'	-	-	10° 07'	-
26/11/2024	24/05/1446	10° 34'	-	-	10° 30'	-
27/11/2024	25/05/1446	12° 08'	-	-	12° 03'	-

Figure 4. Fajr Time in November from SQM

The data in the table, shown in figure 4, indicate that the onset of a significant decline toward the eastern horizon occurs at a Sun's depression of 08°–14°, with most sunny days showing consistency at 10°–12°. It was evident on November 1–9, 2024, when the row of SQM values at 0° (green highlight) showed a gradual downward trend before entering the sharp inflection phase. In contrast, the direction of the zenith often indicates a value that is still relatively stable at the same time, so the decline is only visible a few minutes later. This finding reinforces the understanding that the dawn of ṣādiq was first seen on the eastern horizon, not at the zenith, in accordance with the atmospheric optical principle [17].

Variations between days are seen especially on days with humid or cloudy atmospheric conditions. On days such as November 10–14, the data showed a lower (brighter) SQM value even before dawn, due to light pollution from Medan. This phenomenon aligns with the findings of Rakhmadi et al., who reported that the area around OIF UMSU experienced a strong skyglow contribution from urban LED lights [18]. These conditions cause a decrease in SQM similar to the dawn pattern, although there has been no increase in the Sun's natural light.

When the overall data is analysed using the moving average method, the gradual decline leading to a sharp inflection becomes clearer. The average point of inflection lies between –12° and –14°, with slight variation due to daily atmospheric conditions. This result is much shallower than the official criteria of the Indonesian Ministry of Religion, which set the Fajr angle at -20°. At an angle of –20°, the SQM data still shows a full dark value (±18 mag/arcsec^2), with no indication of increased dawnlight. This empirical consistency supports the findings of Magevira [19] and Raisal et al. [15], who concluded that the –20° angle does not yet reflect the dawn conditions of ṣādiq in tropical-urban regions.

Overall, the data patterns from the eastern horizon and the zenith in November 2024 show the typical dawn character of tropical urban regions: the sky begins to dim in the solar depression range of –10° to –14°, with the earliest response from the eastern horizon. Atmospheric conditions and light pollution remain the determining factors, but the general pattern can still be clearly identified, providing an accurate basis for determining the inflection point as the empirical appearance of the early dawn in Medan City.

3.2 Inflection Point and Early Dawn Determination

The application of the Moving Average method to the SQM-LU-DL data series has proven effective in smoothing noise fluctuations and clarifying the pattern of sky brightness transition before dawn [12]. With this smoothing technique, gradual changes in the twilight curve can be identified more stably, making it easier to detect breakpoints that mark inflection points. The inflection point is interpreted as a sharp change in the mag/arcsec^2 value, which is the strongest photometric indicator of the dawn of ṣādiq. Based on overall observation data toward the eastern horizon throughout November 2024, the inflection point consistently occurs in the solar depression range of –12° to –14°, while the zenith direction shows a similar pattern but with lower sensitivity and a response lag of 5–15 minutes. The difference in response between these two directions is in line with the theory of atmospheric scattering, in which the early light of dawn first appears on the horizon before reaching the zenith area [20].

As a representative example, the data on November 8, 2024, show a very clear twilight pattern. The SQM value in the direction of the eastern horizon was stable in the range of 17.0–17.4 mag/arcsec^2 before 05:00 WIB, indicating full night conditions without the disturbance of dawn light. However, over a very short time (a few minutes), the value drops steeply to ≈12 mag/arcsec^2, indicating a significant increase in the intensity of twilight light. When this value is matched with the ephemeric data, the decrease corresponds to the position of the Sun at a depression of about –13°, so it strongly indicates the onset of dawn ṣādiq. SQM-based twilight analysis showed that photometric inflection points consistently occurred in the range of –12° to –15°, not at –20° as determined by the official hisab of the Ministry of Religion of the Republic of Indonesia.

A similar pattern was also observed on several other days, such as November 4, 7, 14, and 20, where the inflection points remained consistent despite varying atmospheric conditions. It confirms that the Moving Average approach not only reduces noise but also improves the detection ability of subtle twilight phenomena in urban areas with high light pollution. This determination of dawn angles based on inflection points shows a high level of reliability, as also recommended in an international study on the use of SQM for twilight mapping in light-polluted environments [21].

Overall, the findings in this section confirm that the analysis of inflection points using the Moving Average method is a robust, empirical approach for determining the beginning of dawn ṣādiq based on sky brightness [22]. The results of this study indicate that the onset of dawn in Medan City is better described by a depression angle of around –12° to –14°, which is significantly different from the –20° standard used so far.

3.3 Evaluation of Hisab Criteria –20°

The results of observations during November 2024 show that the depression angle of –20°, as used in the official hisab criteria of the Ministry of Religion of the Republic of Indonesia (Kemenag RI), does not indicate the appearance of dawn ṣādiq [23]. At a time when the Sun is in a depression of –20°, the SQM-LU-DL value is still in the range of 17–18 mag/arcsec^2, which is the same brightness level as the full night conditions and does not show a significant decline pattern as found before true dawn. No breakpoint values or brightness gradient changes typical of twilight transitions were found in depressions this deep. This condition indicates that the -20° standard is too dark and does not reflect the characteristics of the local urban atmosphere, especially in Medan, where light pollution and humidity are high.

The evaluation of the –20° criterion is in line with the findings of Magevira [19], who stated that the angle does not represent the time of dawn appearance based on empirical observations across various locations in Indonesia. The study showed that the shallower dawn angle, around –14° to –15°, is more consistent with the pattern of sky brightness measured by photometric instruments. The findings of this study are further strengthened by the observations of Ritonga et al. in Medan [24], who reported that the dawn of ṣādiq was visually and photometrically observed in the depression range of –11° to –14°, very close to the range reported in this study.

In addition, international twilight studies show that urban environments with high skyglow levels experience an acceleration of twilight light response in shallower depressions than natural dark locations [25]. It confirms that the angle of dawn is location-dependent and is greatly influenced by atmospheric conditions and local light pollution. Thus, applying a single standard of 20° across Indonesia, including major cities such as Medan, is no longer in line with modern empirical evidence, especially as instrument-based measurements, such as SQM, are increasingly used.

The findings in this subchapter strengthen the argument that the criteria for subh–20 ° hisab need to be re-evaluated, taking into account actual observational data and modern photometric approaches. The depression range of -12 ° to -14 ° offers more realistic estimates, is adaptive to humid tropical atmospheric conditions, and is consistent with various contemporary observational studies. These findings provide an important basis for developing more accurate, context-specific hisab parameters for urban areas in Indonesia.

3.4 Scientific and Practical Implications

Scientifically, this study's results confirm that the use of the SQM-LU-DL instrument, combined with the Moving Average analysis, provides a consistent quantitative approach for detecting the onset of the dawn ṣādiq. This technique effectively reduces the influence of atmospheric noise and light pollution while objectively displaying the brightness pattern of twilight, a pattern that cannot be observed visually alone. This photometric-based approach is also in line with the global trend in twilight studies, which prioritize light-intensity measurement instruments as a physical indicator of the onset of dawn [26]. Thus, this method has great potential to become a new scientific standard for dawn-time research in urban environments with high levels of skyglow.

Practically, the findings of this study indicate the need to re-evaluate the Fajr depression angle standard used by astronomical and religious authorities in Indonesia, especially the Ministry of Religion of the Republic of Indonesia. The -20° angle showed no photometric correlation with the occurrence of dawn light in field data from Medan, and empirical results indicated a range of –12° to –14° as a more representative candidate. The use of this more appropriate angle has the potential to harmonize the results of classical hisab with those of modern observational indicators, resulting in a more accurate Fajr schedule in terms of astronomy and in conformity with natural phenomena.

The findings also offer significant opportunities for collaboration among astronomy academics, religious institutions, and observatories. The implementation of the SQM-based method can be used as a national model for regional astronomy observatories to conduct data-based local validation [27]. In addition, this approach strengthens efforts to standardise dawn observations in humid tropical regions such as Indonesia, where atmospheric conditions and light pollution differ significantly from those in subtropical regions on which much classical research is based [28]. Thus, this study provides a strong scientific foundation for updating the Fajr time criteria to be more adaptive, realistic, and in line with field observation conditions.

IV. Conclusion

This study shows that observations of sky brightness using SQM-LU-DL during the period 1–30 November 2024 provide a strong empirical basis for understanding twilight dynamics and for determining the beginning of dawn ṣādiq in Medan City. The analysis of the data smoothed using the Moving Average method identified a consistent inflection point on the SQM depreciation curve before dawn. The inflection point generally appears when the Sun is at a depression angle of -12 ° to -14 °, which marks the beginning of an increase in natural light from the eastern horizon. These results show a significant misalignment between the measurable astronomical phenomenon and the official hisab criteria of the Indonesian Ministry of Religion, which sets the beginning of Fajr at an angle of –20°. At that angle, no indication of an increase in brightness was found that could be attributed to the dawn of ṣādiq, so the -20° angle could be judged to be too dark and irrelevant to the conditions of an urban tropical atmosphere such as Medan. This finding aligns with previous studies that recommend a shallower depression angle for early Fajr determination.

Overall, this study demonstrates that the SQM-based photometric approach provides a more objective, replicable, and subjectivity-free observation method than naked-eye observation. These findings can serve as a basis for re-evaluating the national Fajr time standard and provide opportunities for collaboration between astronomical institutions and religious authorities to formulate Fajr time criteria more in line with field observations. For further research, it is recommended to conduct multi-location observations, extend the inter-seasonal observation period, and integrate additional instruments, such as controlled-exposure DSLR cameras or radiometric sensors, to enrich photometric data and improve accuracy in determining the onset of dawn.

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